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EDITORIALS

Scrap Iron

TWO or three years ago a committee of which Senator Nye was chairman spent months investigating the subject of munitions and took occasion to accuse directly or by inference a number of reputable chemical manufacturers of being leaders in propaganda and similar activities in stirring up strife abroad or at home for the sake of maintaining munition plants on a highly profitable basis. Some misinformation was distributed at the time and neither the committee nor the members generally seemed willing to recognize what must be obvious—namely, that every resource of a nation at war, with the possible exception of money and men, may be properly classified as munitions.

All this came back to us the other day when we read of peaceful efforts made on the part of those who object to the export of scrap iron from this country to nations that have not declared war but which in one instance intimidate and threaten to gain their objectives and in the other utilize every weapon of modern warfare, including poison gas, to overcome an enemy.

We find it difficult to understand why those who were so outspoken in the hearings of yesteryear cannot do something practical about the munitions problem which is actually with us.

The Profession of Chemistry

WE ARE among those to whom it has never occurred to question the professional status of chemistry. The dictionary, so often our guide, defines a profession as "that of which one professes knowledge; the occupation, if not purely commercial, mechanical, agricultural, or the like, to which one devotes oneself; a calling in which one professes to have acquired some special knowledge used by way of instructing, guiding, or advising others or of serving them in some art; calling; vocation; employment; as the profession of arms; the profession of chemist."

Apparently that is not sufficiently authoritative for some, because, as noted in our NEWS EDITION for April 20 on page 288, the question of whether or not the chemist belongs to a recognized profession was a point argued before the Supreme Court in United States *vs.* Harry L. Laws, 163 U. S. 256–269. The court held that a chemist belongs to a recognized profession, and we quote:

> Although the study of chemistry is the study of a science, yet a chemist who occupies himself in the practical use of his knowledge of chemistry as his services may be demanded may certainly at this time be fairly regarded as in the practice of a profession.

The Court further went on to say:

> Formerly, theology, law, and medicine were specifically known as *the professions;* but as the applications of science and learning are extended to other departments of affairs, other vocations also receive the name. The word implies professed attainments in special knowledge as distinguished from mere skill. A practical dealing with affairs as distinguished from mere study or investigation; and an application of such knowledge to uses for others as a vocation, as distinguished from its pursuit for its own purposes. There are professors of chemistry in all the chief colleges of the country. It is a science the knowledge of which is to be acquired only after patient study and application. The chemist who places his knowledge acquired from a study of the science to the use of others as he may be employed by them, and as a vocation for the purpose of his own maintenance, must certainly be regarded as one engaged in the practice of a profession which is generally recognized in this country.

In concluding its opinion, the Court said:

> The fact that the individual in question, by this contract had agreed to sell his time, labor, and skill to one employer, and in one prescribed branch of the science, does not in the least militate against his being a professional chemist, nor does it operate as a bar to the claim that, while so employed, he is nevertheless practicing a recognized profession. It is not necessary that he should offer his services to the public at large nor that he should hold himself ready to apply his scientific knowledge and skill to the business of all persons who applied for them before he would be entitled to claim that he belonged to and was actually practicing a recognized profession. As well might it be said that the lawyer who enters into the service of a corporation and limits his practice to cases in which the corporation is interested thereby ceases to belong to the profession. The chemist may confine his services to one employer so long as the services which he performs are of a professional nature. It is not the fact that the chemist keeps his service open for employment by the public generally which is the criterion by which to determine whether or not he still belongs to or is practicing a recognized profession. So long as he is engaged in the practical application of his knowledge of the science, as a vocation, it is not important whether he holds himself out as ready to make that application in behalf of all persons who desire it, or that he contracts to do it for some particular employer and at some named place.

Vannevar Bush in his address, "The Qualities of a Profession", says that in every one of the professional groups there will be found the initial central theme intact—they minister to the people—otherwise they no longer endure as professional groups. "A true profession exists only as the people allow it to maintain its prerogatives by reason of confidence in its integrity and belief in its general beneficence." It is difficult to imagine any group that renders a more basic or diversified service to society than does the chemist in his practice. Not only does he minister to the public directly, but his service is augmented by his contributions to all the arts and sciences, because with mathematics and physics, chemistry shares a truly fundamental position.

The chemist, therefore, by definition, by legal decision, and by service in its best sense is a professional man. As such he may often be called upon to make some sacrifice, must conduct his work with dignity and devotion to the highest professional ideals, and is entitled to the respect and honor of the public which he faithfully serves.

Complimented

VERY rarely have we printed anything in self-praise. We are sufficiently complimented by the extraordinarily high voluntary renewal rate which Industrial and Engineering Chemistry enjoys. Recently a subscriber was asked whether his failure to renew indicated any dissatisfaction. At the same time he was told something of the plans for the current year, made with a view to increasing the serviceability of Industrial and Engineering Chemistry. His return letter not only brought payment for renewal but contained the following information:

> This is the first time in five months that I have earned any money, and believe me, that $25 looks like a fortune to me. So if I do not find another thing in 1939, at least I will have Industrial and Engineering Chemistry's numbers for the year.

This is praise, indeed, and we appreciate it, though we realize that the other thousands who voluntarily subscribe year after year likewise express their opinion that our pages are of real value to them.

Reviewers' Identity

ON SEVERAL occasions we have considered suggestions that our system of reviewing papers submitted for Industrial and Engineering Chemistry be changed so that authors will know who reviewed their papers. Each time we have concluded that anonymity enables the critic to speak more freely than would otherwise be the case, and we have continued a practice which has meant much in achieving and maintaining the high standard characteristic of our publication.

Lately several reviewers have volunteered, when submitting their suggestions, to have their identity disclosed to authors. Still others have made it a practice to send authors signed copies of their reviews at the same time the manuscripts have been returned to us. We have yet to hear of any unpleasant experiences arising from such procedures and, in fact, believe that generally the result has been beneficial to the author and mutually satisfactory to author and critic. While we have no intention of revealing to authors the names of reviewers without the reviewers' consent, we intend to do what we can to encourage practices which, when feasible, obviously present an improvement over our usual methods. Reviewers are invited to consider its advantages.

America

IN THIS issue there are presented, for your information and the record, points of view with respect to what has come to be known as the American Way. Here it is our privilege to reprint, with the written permission of the copyright owners, the Jaqua Company of Grand Rapids, Mich., a declaration by Wilferd A. Peterson. It is one of those statements to "paste in your hat."

I Believe in America

In a topsy-turvy world where dictators glare at us from the pages of magazines and shout at us over the radio;
In a world sick with isms and propaganda from pink to scarlet,
I, as a plain citizen of these United States, wish to reaffirm my faith in democracy.
I believe in America.

America where a humble immigrant boy from Scotland could become a Steel Master;
America where a plain mechanic could become an Industrial Giant;
America where a telegraph operator could become the Genius Who Lighted the World;
America where a lanky, homely lad, born in a log cabin, could become the Leader of a Free People;
America where a man can stretch himself and grow;
America where life is an adventure and the sky is the limit;
America where the sun of inspiration and encouragement shines on men;
America where the individual counts most and human personality is supreme.
I believe in America!

America where a man need defer to no tyrants, be servile to none, and can look the world courageously in the eye;
America where a man can stand on a soap box and say his say without facing a firing squad at dawn;
America where we can laugh out loud at our leaders without being led away to a prison cell;
America where we can sleep in peace without fear of awakening to the cannon roar and marching feet of an invading army!
America where a man can freely worship the God of his fathers or find God in his own way amid the singing streams and whispering trees of the great outdoors.
I believe in America!

America where we progress through evolution, not revolution;
America where creative thinkers and earnest workers are building a brave new world in which to live;
America where achievement is written in steel and stone and growing things; towering skyscrapers, inspiring cathedrals, gigantic bridges, modern hospitals, beautiful parks, research laboratories and halls of learning;
America where new horizons of opportunity beckon men who possess the pioneering spirit;
America where men may dream great dreams and make those dreams come true;
America where the upward march of man has but begun!
I believe in America!

CHEMICAL INDUSTRY DEVELOPS IN THE AMERICAN WAY

AMERICA'S basic philosophy of life and government which has come to be called the "American Way" has lately been attacked from many directions. Zealots of the different ideologies now loose in the world have developed offensives. Some of the most subtle of these have been by those who have profited under the American system and reside within our borders. World economic conditions have favored the attackers; and although the defense of the American institutions until lately has been complacency and inertia, the weak armor which a contented people sets against change, the defenders have become sufficiently nettled to launch a campaign of education to remind our people of much they seem to have forgotten.

Several of the articles to follow (pages 501–595) are designed to contribute to that purpose as it relates in part at least to a single industry—that of chemical processes and production. Here it is our purpose to show how the American Way has promoted growth in industry, how that growth has taken a variety of forms, and how the manner of growth has been primarily influenced by freedom of operation of the law of supply and demand. The American Way has developed through the pioneering of courageous and resourceful individuals on a continent singularly blessed with raw materials. Individual initiative, under a system of free competition, has given a growing population a high standard of living. The tools employed have been research and invention, elaborated by engineering skill, supported by courageous capital, and protected by tariffs and a helpful patent system. In terms of benefits for the man in the street, the American Way represents a philosophy of life and a method of government that deserves preservation—in short, something for which we should be willing to fight.

Obviously industry, as well as individuals, is interested in every phase of the freedom ensured to America by those fundamental charters, the Declaration of Independence, the Constitution, and the Bill of Rights. The freedoms of special importance to industry are, first, the choice of materials or objects which it may produce and secondly, the choice of persons to spend the recompense for their labors in a way to satisfy their desires. Under our system those who manufacture or otherwise produce articles of commerce are guaranteed freedom to make what people desire; on the other hand, those who purchase are guaranteed freedom to spend what they earn as may please them, purchasing what they desire and investing as they see fit. These basic American philosophies have shown themselves as guiding motifs in the growth of industry.

If these two aspects of freedom vital to industry are followed through their various implications, the basic reasons for a great many peculiarities in industry's growth in the United States become apparent. The diversification of industry as a result of specialization and the division of labor, the growth of companies by meeting specific phases of demand and by fully utilizing their own resources, mergers of groups in related lines to effect economy of labor both in production and distribution, some peculiar advantage of location or a unique skill in a particular type of activity—all of these result directly from the freedom of individuals to spend their labors as they choose and to convert their recompense therefrom into a form satisfying to themselves.

One significant aspect of these two freedoms is the multiplicity of products resulting from their exercise. Each attains variety through the freedom of individuals to engage in any productive enterprise that appeals. Thus, monopoly in production may be prevented by the attraction which high profits offer possible competitors. Generally this is effective in the chemical industry in curbing monopolistic tendencies and in bringing about a downward trend of prices for the output. This freedom of competition among producers is a vital spur to research in the chemical industry and its allied lines.

Research has become as vital in a corporation's assets as business acumen, good will, and plant equipment. Upon research depends the survival of whole industries, as well as of the corporate units which constitute them. Freedom to pursue research extends equally to the primary question of whether to invest in this asset or not, and to the direction which research will take.

The challenging systems all have dictation and planned economy in common, and the more prominent among them seek to abolish the profit motive. We hear much, even in this country, about the base profit motive, and yet there is much to show that from five to seven years of persistent and expensive work generally elapse between an idea and its profitable exploitation. Such work can be sustained only out of profits—ultimately some individual's profits. A distinctive feature of the American Way is the frequency with which brilliant investigators are supported by grants or bequests from private individuals, as well as from industry, all such sums being fruits of the profit motive.

The rejoinder is that research and development should be carried out by the state. Yet it is obvious that this activity is much too complex for effective accomplishment under governmental auspices. Only general policies can be laid down by such governments, and under the challenging systems a brilliant young man who might have definite ideas about a pressing problem might be too little known and certainly could not have reached a state of authority to be useful; he might even have been regimented to some other task. A Carothers, a Nieuwland, or a Steenbock would never have a chance, before the event. Even under our own system there is too much regimentation in some places, but fortunately a man with a dynamic personality or with ideas and some voltage behind him can always discover a more progressive employer. Our university men are absolutely free to develop their own ideas.

It remains to be seen what the ultimate effect will be of present attempts by totalitarian states to bring university research men directly into the service of the state. Success would seem to involve a greater wisdom as to the ultimate outcome of a quest in pure science than anyone has so far possessed.

Necessarily the development of the results of research requires engineering skill and knowledge, executive ability, and patient money. All of these have been developed in the American Way to an extent equal to the need for them. Above all, cooperation among all the groups contributing to industrial success has been traditional, and scientist, engineer, workman, and capital have learned how to cooperate for the common good.

The primary motives involved in industrial development are the creation of profitable employment for capital and for labor, and the meeting of a demand, latent or active, for products which capital and labor can by their combined efforts create. To these primary motives and their direct accomplishment must be added innumerable secondary purposes which are served simultaneously. The variety of demand is equally a question of the freedom of purchasers to spend their earnings as they please. Upon producers rests the necessity to please purchasers with the output of their factories. Improvements in all types of manufactured products necessarily follow the free selection by consumers from among competitive wares. The consumer looks for products to satisfy his vital needs. The producer, having provided them, seeks to stimulate desires which create new demands to be met by his goods.

This concept of industry is essentially different from that of dictator-governed countries and of traditional monarchies. These survive through control of wealth, army, industry, and labor. The earnings of the people must be controlled by the state for its own purposes. Only such parts of the common capital and income as may be decided by the ruler go into industry. Industry is thus controlled by the state to ensure the strength of the army and with little regard to other considerations. Labor, too, must contribute to the army, whose prime object is to maintain the *status quo* in the state. Indeed, the more intimately totalitarian states and autocracies are examined, the more obvious it becomes that defense of the autocrat or dictator, maintenance of the state against internal and external change, and control of a capable standing army are the state's first considerations. Manifestly, a people whose strength, productivity, and wealth are being utilized primarily by a ruler has negligible opportunity for influencing the state, for developing ingenuity, and for working out its own salvation.

The democracies are essentially different. Primarily such states emphasize the welfare of the people, for they have no dominant individual whose *status quo* must be maintained. Armed forces achieve only secondary importance in democracies, and the collective good of all their people becomes their foremost care.

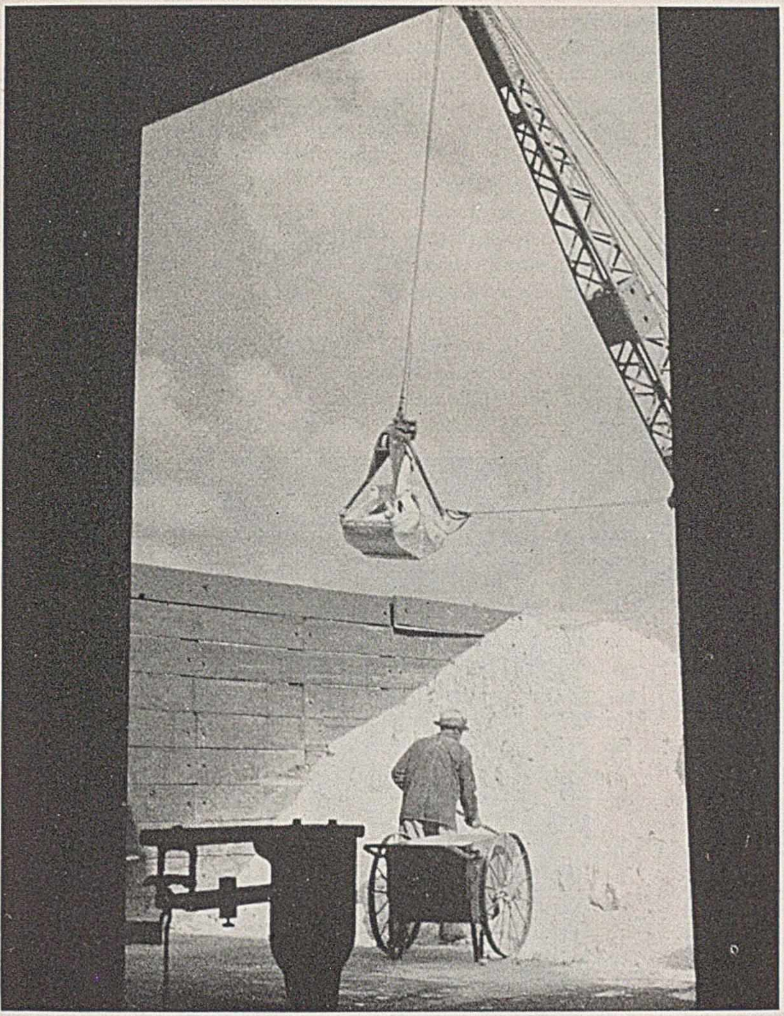
In these broad, basic considerations, democracy differs from autocracy. The purest examples of democracy are to be found in the governments of the United States, of Great Britain, and of France. In its geographical isolation from the chicanery and intrigue of Europe's politics, the United States has developed an independence impossible elsewhere. Its government and its philosophy of life have undergone characteristic development. They are intimately and inseparably interwoven. Together they constitute the American Way.

By proper selection of one's examples, many of the advantages accruing to all the people through industrial developments can be illustrated. The efficacy of certain important government measures, undertaken as encouragement rather than as fiat, in the development process is vital to the whole. These measures are typified by the protection of our patent system and of our selective tariff. Neither is in itself a mandate to industry to develop in this direction or that. Rather they are permissive in protecting industry in its development in directions desired by the people. The result is salutary and even more effective in getting things done than the ukases and fiats of dictators and autocrats.

One finds numerous lines of endeavor nurtured and fostered by this protection. The automotive industry is encouraged to cooperate with petroleum refiners in measures to conserve liquid fuel reserves through the simultaneous development of better fuel and more efficient engines to utilize it, developments which greatly prolong the benefits of automotive transportation to the people. Similarly, one finds petroleum refineries diligently converting their wastes through chemical synthesis into new and valuable products, and building thereby an entire new industry to employ labor and to produce values. The development on the one hand of industries of a strictly consumer aspect, like that of pharmaceutical manufacture, is fostered along with such strictly producers' programs as the industrial utilization of farm crops. None of these vital developments has needed from government more than permissive support and protection. Each has grown lusty without dictatorial intervention and for that very reason possesses innate vitality, which can exist only through the will of the people who have created it from their labor, capital, and desire for its products.

In almost endless ways companies have grown through their abilities to serve the people well. The merging of related company units to secure greater efficiency in marketing of ultimate products, the complete elaboration of specialized techniques to raise efficiency in manufacture, and the utilization of a unique raw material in as many ways and for as many purposes as possible—each of these has characterized certain companies in their particular fields of chemical industry and has provided their reasons for existence and growth.

Finally, too, industry has faced the problems of developing integrated supplies of a vast number of raw materials and of creating tools and equipment in which to process them. These have been solved with remarkable success by Americans working in and under the American system without the need of dictatorial compulsion.



Sulfur Pile at the Monsanto, Ill., Plant

GROWTH OF AMERICAN INDUSTRY

Through Research, Development, and Merger

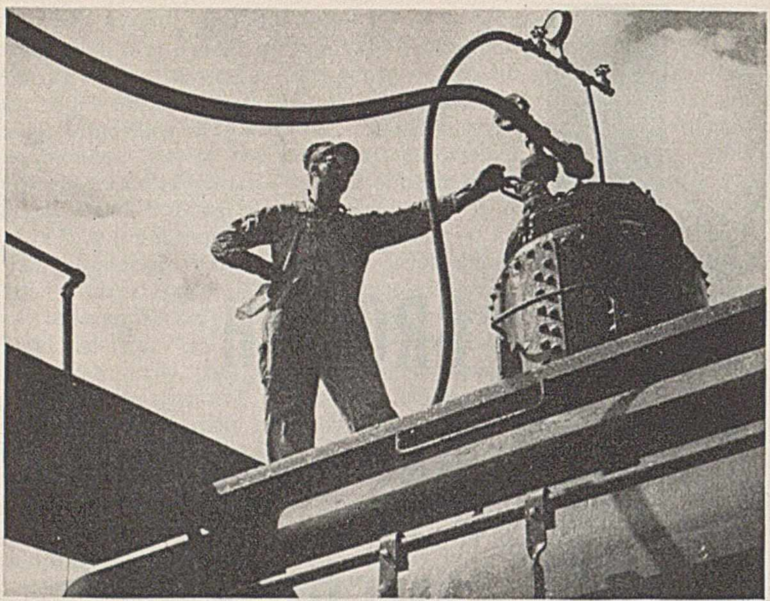
CHARLES BELKNAP
Monsanto Chemical Company, St. Louis, Mo.

THERE can be but one criterion of progress in industry, and that is the degree to which industry has gone forward in serving the needs of people. Dictatorships are built on the creed that industry best serves the people by serving the state. In America we believe that the people are best served through a system of free competition. Which will prove itself in the long run is a matter for history and time to decide. But let us review the situation as it has affected the chemical industry in this country, citing pertinent instances from the development of Monsanto Chemical Company.

Under the democratic or American Way, any individual with courage, backing, and an idea can start a legitimate business. It is not necessary to get the blessing of a government or any individual, and if the new business can supply materials that people do not have or supply existing materials that are better or cost less, the chances are that it will succeed.

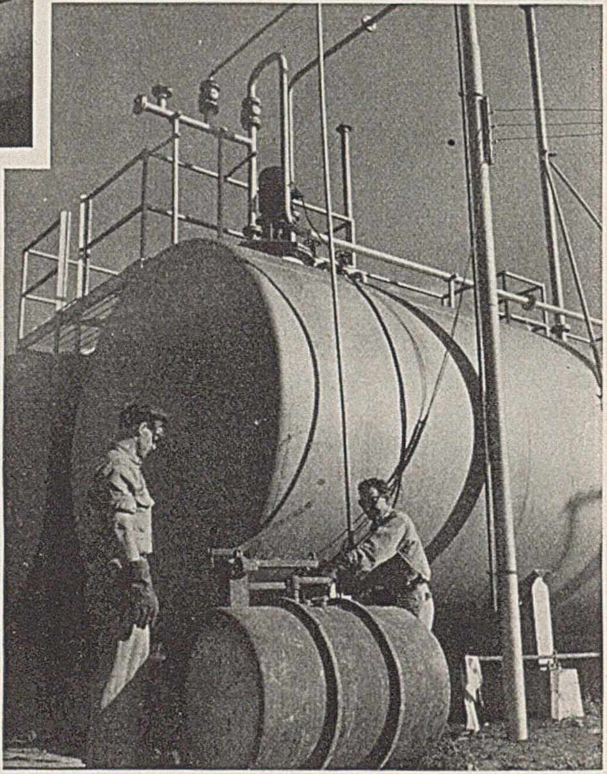
Without this assurance of a fair chance, it is probable that John Francis Queeny would never have founded the Monsanto Chemical Company in 1901 to make saccharin. On the other hand, if he had been favored by a paternalistic government with every assurance of success without worry, as might well have happened since at that time America was almost entirely dependent on foreign sources for her chemical requirements, the chances are that the American people might still be paying for saccharin several times what they are paying today.

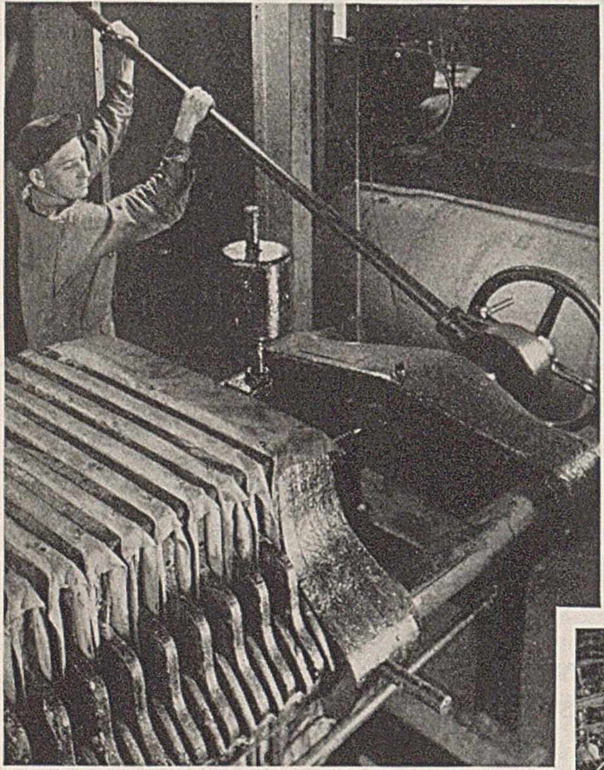
As it was, the Monsanto Chemical Company in 1901, with its 5000-dollar capital, made saccharin in competition with firms which were in virtual control of the world market, not only of the product itself but of the intermediates, raw materials sources, and patents covering the process. Times were extremely difficult and Monsanto lost money for four years, despite the addition of several other synthetic products. But eventually the prices of these chemicals began to fall. Germany and Switzer-



(*Left*) Filling a Tank Car at the Monsanto, Ill., Plant of the Monsanto Chemical Company

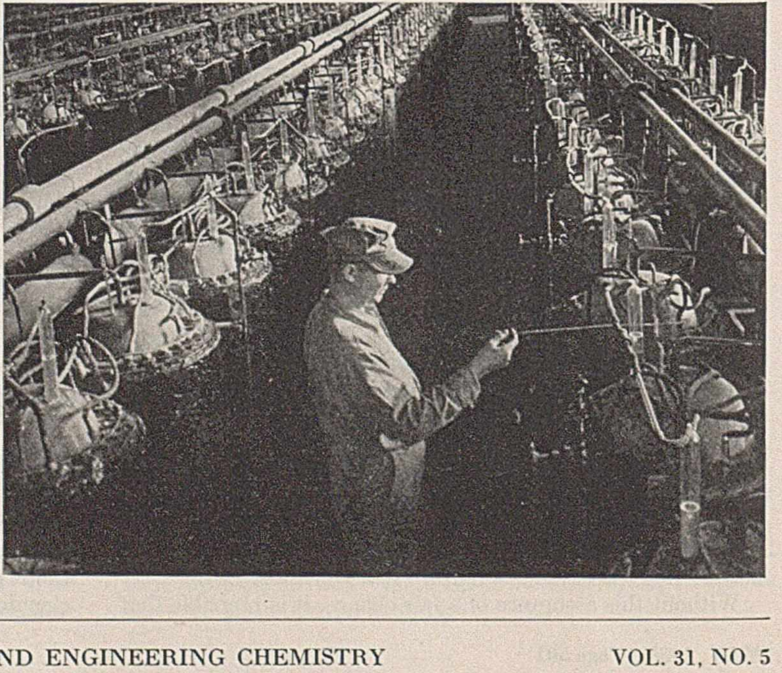
(*Below*) Storage Facilities at Monsanto's St. Louis Plant





(*Above*) Pilot Plant at the St. Louis Works of Monsanto

(*Right*) Tapping the Valves on Chlorine Cells to Ensure Proper Functioning



land, the chief foreign suppliers, began to feel the competition, and prices were lowered further, but Monsanto and other small American producers hung on and were already showing progress when the war broke in Europe in 1914.

This, of course, was the stimulus that led to a great expansion of the American chemical industry. But because that same industry had been fighting the rigorous foreign competition all during the years before the war, it had learned how to make many of its products much more cheaply than they had been made fifteen years before. It is doubtful if the same progress would have been achieved under government protection.

ADVOCATES of totalitarianism will point out that because of the keen competition and lack of incentive for the American chemical industry to develop during the early 1900's, our country was at a serious disadvantage when the war did break and German chemical supplies were cut off. This is quite true. One branch of the American industry which was almost entirely undeveloped at that time was dyestuffs. Almost every one of our important dye intermediates had been imported from Germany. During the early years of the war it was necessary to start styles for black and white in women's clothing because of the inability of our chemical industry to produce good colors. But while this was an inconvenience, though only temporary since American chemists did learn to make good dyes, it had meant that people in this country prior to the war paid less for their color by buying dyes from Germany than if the United States had attempted to go into the dye business. By means of trade and competition for markets, both of which are foundation stones of the American Way, our people were able to enjoy a far higher standard of living than if they had reverted to the old principle of self-sufficiency.

During the war the chemical industry prospered but at the expense of a depression and a period of loss on operations for several years following. When the industry got on its feet again and was free to delve into new research problems, growth took place rapidly, wages increased, and prices of chemicals were lower than they had ever been in the history of the industry.

Companies had full opportunity to throw themselves into the spirit of free enterprise during the period of the twenties. They were free to study the needs of the American people and turn their research staffs to the solving of problems and development of new products to meet these needs. There was no government interference, no ordering of what to make and what not to make. There was no earmarking of profits for government use or dictation as to what lines of research should be pursued. Managements were free to plow profits back into business for private research and improved plants, and, what is more important, they held full confidence in the laws of their government that made this freedom possible.

As a result, wages in all American industry reached a new high level, and American people were able to buy many more of the necessities and conveniences of life with a day's pay than were people in any of the totalitarian states. And that same wage advantage holds true today in spite of the fact that the rise to power of dictators has been the most spectacular during the past ten years. According to a recent study by the National Association of Manufacturers, the real wages of workmen in the three major democracies, the United States, Great Britain, and France, are higher than the real wages in the dictator countries of Germany, Italy, and Russia.

A CHARACTERISTIC of the planned economies of totalitarian states is to have a central government agency for directing the efforts of industries along lines deemed to be of greatest importance to the state. And since self-preservation is the paramount concern of the state, efforts are often bent toward defense preparations at the expense of progress in peaceful living.

One step forward in the peacetime chemical progress of this country, which probably would not have come about had all effort been government-directed, is the development of synthetic ethyl alcohol on a commercial basis. Ethyl alcohol had always been made from grain satisfactorily, and since the country had a plentiful and dependable grain supply, there was no pressing need for synthetic alcohol. But an American chemical company felt that it could sell more alcohol by making the product synthetically and at a lower cost, so it went to work and developed a synthetic process. The result has been a benefiting of the American public through lower prices for alcohol and products in which it is used. Like instances could be cited in the histories of acetic acid and synthetic methanol in this country.

Another example of progress through private and unregulated research is the development of the life-giving medicinal, sulfanilamide. Under a regulated system of industry, this product would have been assigned to a specific company for further research and commercial development. But suppose that company was not especially interested in sulfanilamide and had no one on its staff who could look into the future and see the tremendous benefit to the human race that lay locked up in the new substance? Research is something that is initiated and moved by intense belief in the possibilities of an idea. Without freedom of scientific investigation, much of the true spirit of research is lost. And only through research can the chemical industry develop and progress in the sense of doing a better job of serving people.

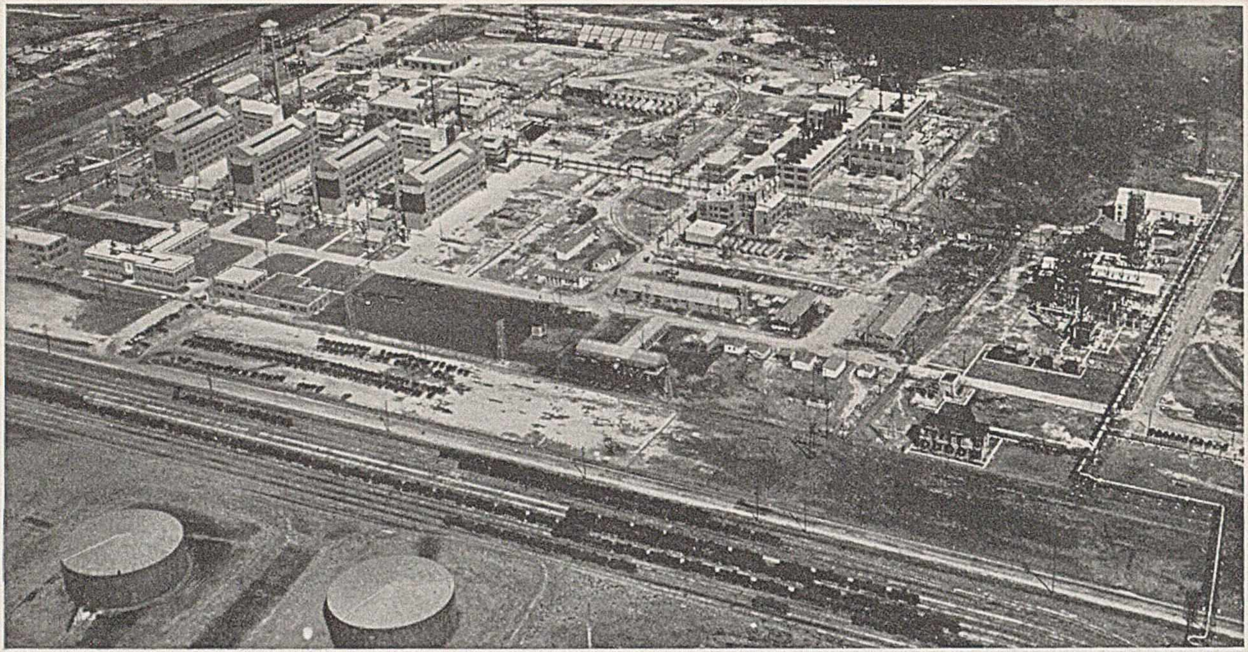
Under the American Way we have no checking of company records or files by government agents. The private life of business is respected. There are no political appointees on boards of directors. Stockholders can be reasonably sure that their money is secure, provided the company is properly managed. Under a dictatorial government, an entire company, regardless of how it has been functioning, can be dissolved with but a wave of the hand of the person in command.

Cartels are a favorite method of European countries for the regulation of manufacturing and distribution activities. Since these destroy the last semblance of competition among countries, there is a tendency among participating countries to slow down, to soldier on the job, in the knowledge that their market is simply waiting to be sold.

Restriction of trade is naturally a characteristic of totalitarian states whose chief concern is self-sufficiency. Government permission is required to purchase anything outside of the country. The mere fact that there is so much government red tape involved in outside purchases makes buyers hesitant.

IN THE development of the chemical industry under the American Way, an outstanding element in addition to research and the adaptation of research has been mergers and consolidations of companies. In mergers we have a combining of talents and facilities of two or more companies with a view toward better and more efficient customer service at a lower cost.

When we view the American chemical industry today we see an industry that has progressed through the intelligent application of research and development and the combining of interests and services through mergers, to a point of favorable comparison with chemical industry anywhere in the world. Americans today are able to enjoy more conveniences of living made possible through chemistry than are people in any other country. Without the American Way, with its right to buy and sell freely, right to use profits in any way seen fit, right to choose what shall be made, and right to protection of property, it is doubtful whether this progress could have been achieved.



Manufacturing Plants for Tetraethyllead and Intermediates on the Mississippi River North of Baton Rouge, La. Tetraethyllead is manufactured and blended with other components of antiknock fluid; sodium and chlorine are made from salt brine piped from a near-by well; and ethyl chloride is manufactured from chlorine and gases from an adjacent refinery.

PROBLEM + RESEARCH + CAPITAL = PROGRESS

THOMAS MIDGLEY, Jr.

Ethyl Gasoline Corporation, Detroit, Mich.

THE story of the research problem that resulted in the discovery of tetraethyllead as an antiknock material, and the development of manufacturing and distributing facilities which today allow its use in three fourths of all gasoline sold in the United States and Canada, is an example of the American Way in practice. It is, of course, only a small part of the larger story—the great story of the development of the automobile.

All Americans over forty years of age know from personal experience the great difference between the automobiles of today and those of their childhood. Younger people should read the story of that change carefully and prayerfully. For in the dreams, the speculation, the science, the endless labors that have made the automobile, and the entire automotive and oil industries what they are, we find living illustrations of nearly all that is right and wrong with the American way of business. And we find that the "wrongs" disturb us very slightly in contrast to the magnitude of "rights" that have swallowed and digested them.

That story of the automobile isn't one story. It is a multitude of stories. Tetraethyllead has only the role of a contributing factor to the main story; yet of this detail alone the following things may be truthfully said:

Tetraethyllead broke down one of the barriers that was blocking the road to automotive progress—the barrier of knock.

It has thus added to the power and performance of over fifty million automobiles.

It has contributed to the constant improvements in quality and the steadily decreasing price of billions of gallons of gasoline annually.

It has made possible the present peaks in performance of airplanes.

It has strengthened our national defense.

It has lowered costs in power farming and truck transport.

It has caused the construction of millions of dollars worth of factories, laboratories, transportation, and blending facilities, for its manufacture, distribution, and use.

It has given temporary and permanent employment to many.

It has uncovered fresh sources of mineral wealth by "mining" the waters of the ocean successfully.

It has aided oil companies in the conservation of petroleum in their gasoline refining processes.

It has paid taxes towards the support of government.

It has made a profit for those corporations that had the courage to go through a long and difficult "shirt-losing period" because they believed that antiknock gasoline would eventually succeed.

Those are large and valuable rewards to claim for one research project, for the development of one of industry's many discoveries. But they have been carefully weighed and worded in the spirit of conservatism. They are not stated here to boast of the importance of work with which the writer was personally concerned, nor to boost the fortunes of the corporation which is now manufacturing and selling products arising from the original discovery. They are stated to show the rewards to a nation that come from freedom of research, freedom of capital, protection by patents, and opportunity for ultimate profit; to point to the necessity for these freedoms if America is to continue to benefit from other such discoveries.

DISCOVERY OF TETRAETHYLLEAD

The popular notion of chemical and engineering developments is still that of the long-haired inventor in an attic who makes a great discovery and is swindled out of a million-dollar fortune by a slick promoter. The truth more often is like the story of Ethyl, which was over three million dollars in the red before it began to earn a profit for those who had backed it.

We did not stumble on tetraethyllead by accident. We did not go into the laboratory on Tuesday and come out on Friday with our product. We did not even know what we were looking for, until a lot of time and money had been spent.

The research started because General Motors began having trouble with knock in motors. Charles F. Kettering fathered the program and took responsibility for the thousands of dollars that were needed through months and years of discouraging work. We started in a little room, in a little way; and as the problem appeared more and more difficult, more money was poured into it and T. A. Boyd and Carroll Hochwalt were assigned to work with me. We combed the shelves of chemical supply houses, the volumes of reference libraries, and the possibilities of the periodic table of elements. And when, after years of research which might have seemed fruitless to many people, we came to tetraethyllead; it was no accident. We knew before we ever manufactured the first test sample of this difficult compound that it was probably what we were looking for.

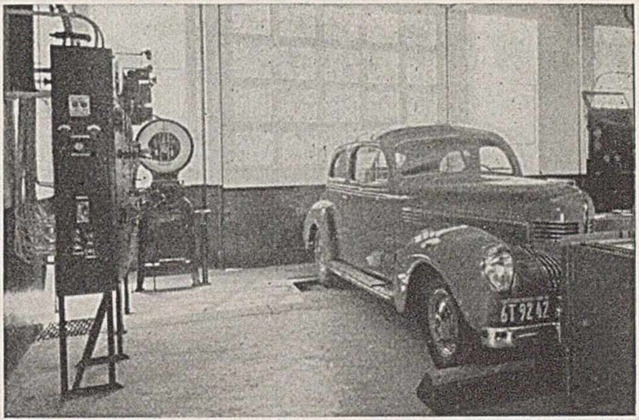
The popular idea might be that when we found tetraethyllead we shouted hosannas for it, and all marched in to ask the boss for a raise. Actually, there wasn't a pause in the program. We started spending more money, doing more research, and looking for other ingredients to go with tetraethyllead, to make up a commercially practical compound that could transfer the antiknock qualities of tetraethyllead to a gallon of gasoline. Thousands of miles were run in various types of automobile tests, hundreds of hours of operation were put in by engines on dynamometer blocks, running day and night. We thought we knew what we had, but we knew we knew very little about it. We had to find the answers, the right answers, to many questions.

For example, we found that we needed ethylene dibromide to mix with the tetraethyllead. And if we were ever to sell enough of the compound to make the discovery a real commercial success, we would need a lot of it. Bromine was then an expensive chemical used primarily for making photographic plates and headache powders. The principal known reservoir of bromine is the sea. But there are only approximately 67 parts of bromine in a million parts of sea water. Could it be extracted commercially? In the course of what Mr. Kettering calls the typical "shirt-losing era" of a new industry, the Ethyl Gasoline Corporation spent $500,000 for a boat called the *S. S. Ethyl*, to "mine" the waters of the ocean for bromine. It didn't work very well; but it proved a point that ultimately resulted in the formation of a joint subsidiary company with Dow Chemical. Today the Ethyl-Dow Chemical Company takes over a million and a half pounds of bromine a month from sea water, at a plant built among the sand dunes of the North Carolina coast.

We also had manufacturing problems. The laboratory method for making a few pounds of tetraethyllead was just a starter. Three plants in succession were built, used awhile, and then abandoned before we learned to make tetraethyllead in substantially the way it is manufactured today.

Research work for a project such as Ethyl is never over. It does not stop with a discovery. The corporation which developed and markets tetraethyllead antiknock compounds today has an annual payroll of $370,000 for 112 people engaged in research work. They are trying to improve both the product and the manner of use: (1) by finding more efficient methods of manufacture; (2) by cooperating with oil companies on research projects to find better ways of using antiknock compounds in motor fuel; (3) by working with automotive companies on cooperative programs to squeeze greater value from the high-quality gasolines now available; (4) by working with manufacturers of aviation engines on similar problems; (5) by conducting cooperative research with automotive accessory companies.

Perhaps one reason why popular notions of inventions and discoveries—and their commercialization—is so far from the truth, is that after the work is done, we are all inclined to abbreviate our troubles and skip over the mistakes and blind alleys that cost money and got us nowhere. The story of any research project is usually presented in brief and sounds simple. Ethyl has been presented that way before. It is, therefore, probably wise to discuss it in more detail as the tough, uncompromising problem which it really was. It should be evident to anyone who knows all the facts, that the discovery of Ethyl and the benefactions it has brought were possible only because of the American way of business, only because courageous corporate executives had the foresight to invest large sums of money and continue backing an idea through periods when less astute minds might have dropped it. They would not have done this had they not believed in the end they would make a profit from it for their stockholders. They would not have been able to do it had they not previously made large sums of money for their corporations from other ventures, which allowed them to finance this one. They would not have been able to do it had there been any law against their taking the chance of losing the money put into it. For it must be remembered, that with only slightly different circumstances the whole project of Ethyl might have been written off at one time as a $3,000,000 flop.

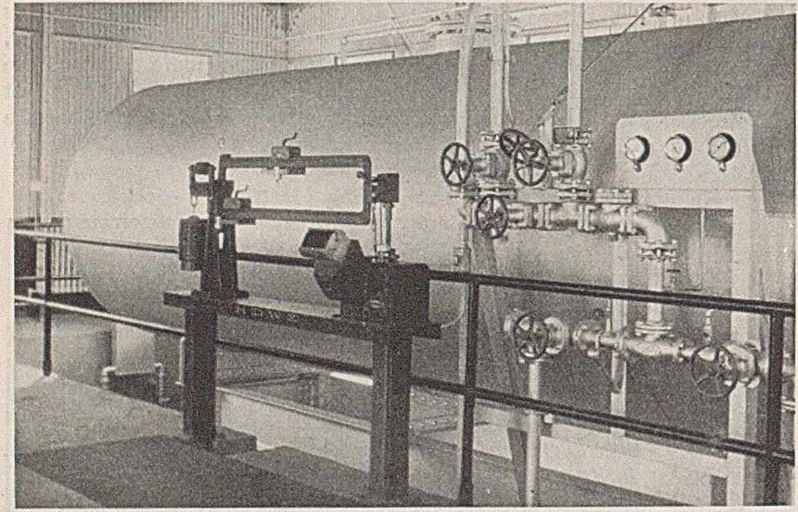


Passenger Car on Chassis Dynamometer (Rollers under Rear Wheels) for Power Test in Laboratories at San Bernardino, Calif.

SALES PROBLEMS

So far we have discussed only the research part of this project. We have looked at it from the point of view of the chemist. There is also the role of the salesman to be considered in the traditional shirt-losing period of every large development.

We had analyzed our problem, solved it by research, and developed the first methods for manufacture. Now the product had to be marketed. Ethyl gasoline was first offered to the public in February, 1923. A service station in Ohio attached a contraption to one of its pumps. If a motorist wanted regular gasoline, the attendant simply pumped. If he wanted antiknock gasoline, the attendant would turn a pet cock and drops of fluid were ejected into the gasoline as it was being pumped through the hose into the automobile. Car owners noticed the difference and told each other about it. "Stops knocks"; "more power on hills"; "cooler engine", they said. Other service stations installed the contraptions, and finally our salesmen were able to persuade a few oil companies to blend the drops with their gasoline. Manufacturing costs were such that we could not offer the oil companies a profit on the fluid. It cost them 3 cents for 3 cc. of tetraethyllead, and they charged only 3 cents to the motorists for putting it into a gallon.



Interior of a Refinery "Blending Plant", Where Ethyl Fluid Is Mixed with Gasoline

Gasoline is pumped through the horizontal pipe (lower right corner) creating a vacuum in the adjoining line, which draws fluid from tank for blending. The entire tank is cradled on a scale, so that amounts of fluid withdrawn can be measured by weight.

Specifications were drawn regulating the quality of gasoline with which Ethyl fluid could be blended. Procedures were established which restricted the blending of fluid with gasoline to fully equipped blending plants in oil refineries or in large terminals of oil companies. A double-check inspection of quality was set up, with laboratories spotted about the country constantly checking gasoline samples to determine their octane rating, gum or sulfur content, and other characteristics. This inspection, of course, was devised primarily to protect the business health of the Ethyl Corporation. It also has been of service to the motorist, although the typical large refiner today maintains standards of quality more exacting than our requirements.

The sale of tetraethyllead to a number of large oil companies made possible higher compression pressures in engines, with correspondingly better fuel efficiency and engine performance. The gradual appearance of these high-compression automobile engines is interwoven with a number of other advances, such as higher engine speeds, better metals, and the sum total of hundreds of minor changes, each adding its increment of improvement. It is therefore hard to measure the independent effect of leaded gasoline on automobile engines, but we can say confidently that the existence of leaded gasoline has added annually to American automobiles approximately fifty times the 1,800,000 potential horsepower of Boulder Dam. The final outcome has been better cars and fuels for the public at lower prices (much lower if you deduct the increased taxes on gasoline); the result has been more cars sold, more gasoline bought, and more jobs created.

COOPERATION WITH OTHER INDUSTRIES

Of course, progress—which always means changes—in engine design kept turning up new problems. To cooperate with the oil and automotive industries in their attempts to solve these problems the Ethyl Gasoline Corporation established laboratories at Detroit and in California. These later research workers have studied the effect of increased compression ratios on power and economy, metallurgy, ignition systems, heat losses to the cooling water, and exhaust gases. They have studied the distribution of fuels in intake manifolds as this problem has concerned both oil and automotive companies in recent years. With an eye to the future, they are studying the problems of supercharging.

Working in close cooperation with these industries, as well as the aviation industry, truck and bus industries, and many accessory companies, Ethyl engineers have attacked problems connected with the use of antiknock fuels.

Another field in which the continuing efforts of research have led to tangible results is power farming. Five years ago, all tractors were designed with low-compression motors to burn kerosene, distillate, or gasoline. But farmers who burned gasoline in those tractors got only part of the power that was inherent in their fuel. Why not build tractors with high-compression automobile-type engines capable of using gasoline efficiently? This would obviously increase the market for leaded gasolines. It would also, we knew, give the farmer something he wanted—a tractor more powerful, more flexible, less balky, in which the old bugaboo of oil dilution would be removed. Tractor engineers who had this belief found ready and able assistance in Ethyl engineering laboratories. Salesmen sold the idea of high-compression tractors, explaining their merits to the farmer and the tractor dealers.

Today, most tractor manufacturers make high-compression tractors, and in a recent survey of Master Farmers, five of every six who mentioned what type their next machine would be, specified a high-compression model. There's the American way for you, in miniature. We helped the farmer and the tractor business with research, capital, and salesman ship, and in doing so we increased our own business.

In the course of its work Ethyl has grown into a considerable organization. Division offices are located in ten key cities across the continent. A chemical research laboratory is located in Detroit, as well as the engineering laboratories there and in San Bernardino, Calif. Six smaller laboratories at convenient points through the country are maintained for testing fuels. Large manufacturing plants are located at Baton Rouge, La., Kure Beach, N. C., and Deepwater, N. J. The total investment and the total number of people employed either directly or indirectly made it a big business.

All its originators were trying to do was to make an engine run better, but in this research, as in most others, the significant benefits came as unpredictable offshoots to the main investigation. This is entirely appropriate, however, for in my opinion progress is the usual by-product of the American way of business.

GROWTH OF AN AMERICAN INDUSTRY AROUND A MAJOR PRODUCT

WALTER CLARK
Eastman Kodak Company
Rochester, N. Y.

Eastman Kodak Company

George Eastman in 1921

THE story of the Eastman Kodak Company is essentially that of one man with one purpose. The man—George Eastman. The purpose—simplifying photography and making it available to all people for their pleasure, their education, their health, and the scientific and technical ends which make life easier and safer for them. George Eastman died in 1932, but the tradition which he founded lives on. The industry has become far greater and more widespread than even his prophetic dreams could have conjured, but the men who followed him are inspired with his purpose. It is no exaggeration to say that the present importance of photography in the world is primarily due to his genius and to the school of followers who started with him.

When Eastman was a youth, photography had been practiced for forty years. The popular daguerreotype had come and gone, the calotype was seen only in the museums, and the wet collodion process was at its zenith and producing extremely fine results. But something was wrong. Photography involved a love of labor. It required effort and time, both of which were deterrents to those who had to earn their living at other work. It could be indulged in only by a select few; it involved expensive and bulky equipment. The photographer of the out-of-doors had to carry a dark tent which he could erect in the field, a bulky camera and stand, heavy glass plates which he could sensitize on the spot, bottles of solution for preparing them, and means for developing them immediately they had been exposed in the wet state. This equipment was called "portable" because, by employing an assistant and exercising sufficient effort, the photographer could carry it from one spot to another.

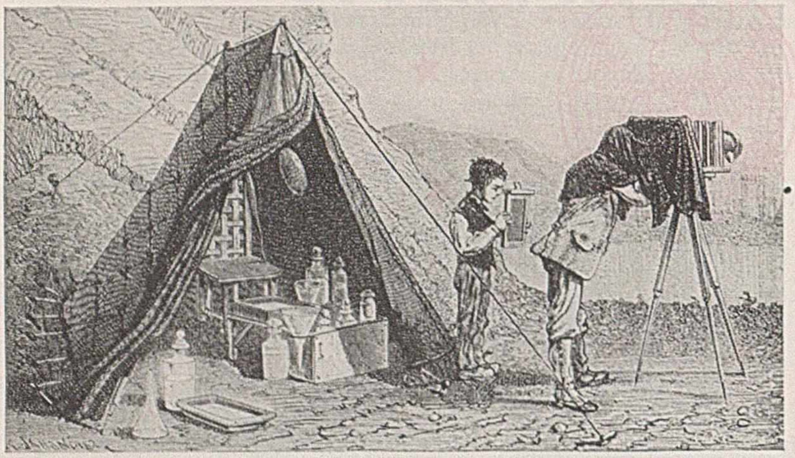
George Eastman learned photography by this method when he was a young bank clerk in Rochester, N. Y. He paid five dollars to a photographer to initiate him into the mysteries and then spent a vacation in a dark tent on Mackinac Island, applying himself to the practice. This was in 1877 when he was 23 years old. He developed an intense interest in the process. He began to study it thoroughly, reading all the available books and subscribing to the leading magazines on the subject. He read textbooks of chemistry, for photography was a chemical subject and a knowledge of chemistry was essential to a proper understanding of it. His mother's kitchen, and later a small room in a downtown office building, became the first Eastman research laboratories, but the work had to be done at night, for the job at the bank occupied the daylight hours. His father had died and he had to support his mother.

SIMPLIFICATION OF EQUIPMENT

Eastman believed that the term "portable" applied to the photographic apparatus of the time was, to say the least, a misnomer, and he made his goal the simplification of photography so that pictures could be taken without a burdensome mass of equipment. Shortly before this time, a new process of making dry plates by precipitating silver bromide in gelatin, coating it on glass, and drying, had been worked out in England. The plates were much more sensitive than the wet plates which Eastman and others were using, and it was no longer necessary for the photographer to prepare his plates and develop them at the site of the photograph. Eastman immediately realized the advantages, read all the publications from England, and started experiments on his own. In 1878 he decided to go into the business of plate making. Early in 1879 he made dry plates of good quality and had devised the first machine to coat plates mechanically. In 1880 he went into the business of manufacturing plates for others. He hired an assistant to help with the plate production in the first Eastman factory, a room over a music store in Rochester near the site of the present Kodak Office. The demand for plates soon exceeded the capacity of the factory, and in January, 1881, he formed a partnership with Henry A. Strong, under the name of the Eastman Dry Plate Company.

Eastman's inventive and business genius had already made itself obvious. He had obtained a British patent for his coating machine on July 22, 1879, during his first visit to England, and applied for a United States patent on September 8 of the same year. He was then twenty-five years old. By December, 1879, he had sold the English rights and in the middle of the next year applied for a patent for an improved coating machine. In August of that year he started his first merchandising effort outside of his own city, and a few months later he had left the bank and was in business for himself. He announced his intention to advertise extensively and to put competent demonstrators on the road. His fame had already spread to Europe.

Eastman had remarkable foresight as to the possibilities of photography and was fascinated by its business potentialities.



An Amateur Photographer of 1875, with "Portable" Photographic Equipment

When he was twenty-six years old, he had established four fundamental business principles on which he was to build his organization: He envisioned mass-production methods by means of machinery, low prices to increase the use of photography, world-wide distribution, and extensive advertising and selling by demonstration.

This young man established and started to apply the principles which are followed by the big industries of the present time. In addition, he had started his industry on the basis of his research, and research was to be one of the principles which should guide its development. All the principles governing research, production, and selling were clearly demonstrated by Eastman from his early days as a photographic manufacturer, and have guided the Eastman Kodak Company in its development to its present position in the industrial world.

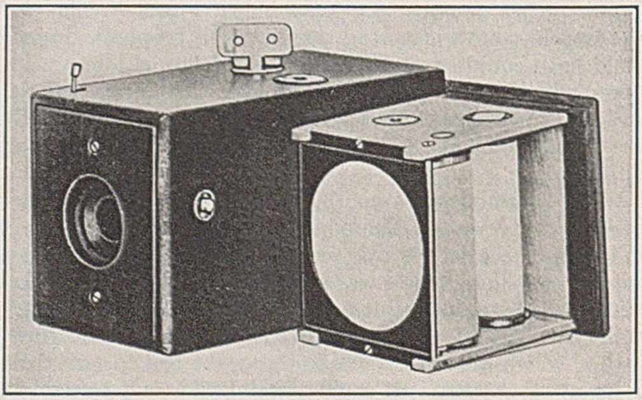
It was not to be expected that the business would progress without setback. By the beginning of 1881 the output of plates was considerable, but during that year came the first real catastrophe; the plates would not keep, and thousands of dollars worth of useless goods were on the shelves of his biggest customer. Eastman met the situation in a manner typical and worthy of note. He recalled the whole stock and undertook to replace all plates which had not measured up to his promises. From the outset Eastman thus recognized his responsibility to the customer and to his industry. All through his career this was one of his outstanding characteristics, and this sense of responsibility became an inherent principle of the growing organization.

ROLL FILMS

Although the practice of photography was much simplified by the commercial introduction of the dry plate, the photographer still had to carry a burdensome camera and tripod and sheets of sensitized glass which were heavy and breakable. The customers were primarily professional photographers. Further simplification permitting the general use of photography by the amateur was in Eastman's mind, and in 1883 or 1884 he conceived the idea of a popular system of photography which has developed into the present roll-film method. In conjunction with William H. Walker, a holder was devised which could be attached to the back of a camera in the position normally occupied by the plate holder. The new holder was loaded with a roll of paper coated with a sensitive layer similar to that which had been used for coating the dry plates. After exposure and development, the roll of paper was greased to make it more transparent and printed by contact onto another piece of paper similarly coated. It was necessary to make these papers in long continuous strips, coated evenly, and for this Eastman invented and patented in 1884 the first continuous coating machine for photographic films and papers. A new company, the Eastman Dry Plate and Film Company, was founded in 1884 to replace the original Eastman Dry Plate Company.

The paper roll film did not satisfy Eastman, however, because the grain of the paper was liable to be reproduced in the print. This led him to devise what he called a "stripping film", which consisted of a roll of paper coated with a layer of soluble gelatin, in turn coated with a collodion layer; over this was applied the gelatin-silver bromide layer. After development the film could be laid down on a sheet of glass; after the gelatin layer was softened, the paper support could be stripped from the film negative, and a transparent negative obtained for printing. This stripping film, patented in 1884, was put on the market in 1885.

The invention of this new type of roll film naturally led Eastman to turn his attention to the simplification of the camera and resulted in the introduction of the first Kodak in 1888. This was a small box camera which could readily be held in the hand, and which was supplied with a roll of stripping film on which one hundred exposures, circular in shape and 2.5 inches in diameter, could be made. After each exposure the roll was turned forward so that the succeeding picture could be made on the adjacent piece of film. This was simplicity itself, but there was still the problem of what to do with the exposed roll. At this time there were no photofinishing establishments to carry out the developing and printing; so the Eastman Dry Plate and Film Company undertook to do the work for the users of the cameras. The camera containing the exposed roll was sent to the factory, where the roll was developed, prints were made, and the camera was reloaded with a fresh roll of film, all for $10.00. At this time the phrase,



The First Kodak of 1888 Used a 100-Exposure Roll of Stripping Film

"You press the button, and we do the rest", was coined as one of the earliest business slogans. The new camera and roll film opened up photography to thousands who had previously shown no interest in it.

Even at this time Eastman's ingenuity and versatility were evident. He had studied the properties of emulsions, collodion layers, paper, and gelatin, invented machines for coating glass plates, rolls of paper, and stripping film, and had overcome the optical and mechanical problems of camera design, in addition to solving the problems of marketing the products. But still he was not satisfied, and his thoughts were constantly set on a means for making the film base itself transparent without the need for stripping. He had made many experiments with materials which might be applied to paper to render it transparent, translucent, or waterproof, in the event that the ideal substitute could not be found; and he had had much experience with cellulose nitrate, particularly with a view to using it to prepare long flexible transparent sheets. When he started work with this material, the only solvents known were ethyl alcohol and ether; although sheets of cellulose nitrate could be coated from such a solvent mixture, they were not of any value as a support for film.

In 1886 Eastman employed a young chemist to study the problem. This is one of the earliest records of an American manufacturer engaging a trained chemist to devote his whole time to research. After three years a material satisfactory for use as a transparent film support was found. The secret consisted in dissolving nitrocellulose in wood alcohol and adding camphor together with fusel oil and amyl acetate. In 1889 the first transparent, flexible roll film was marketed. The film support was made by spreading the cellulose nitrate solution on a long glass table made up of lengths of plate glass joined together at their ends. The material was allowed to dry on the table. It was coated with a substratum of sodium silicate, and later of gelatin, to make the emulsion adhere to it, and then with the gelatin-silver bromide emulsion itself. After the emulsion had been coated and dried in a darkroom, the film was slit into desired widths and wound on spools.

MOTION PICTURE FILM

During the first year that the new film was marketed, Thomas Edison obtained a short length and used it in the first motion picture camera. The pictures obtained were used in the Edison Kinetoscope, forerunner of the modern motion picture projector. Eastman's invention of flexible film thus made possible the motion picture, in addition to laying the foundations of modern amateur and professional photography, and the many other branches of photography which use film.

In 1891 the roll film for Kodaks was made daylight-loading. This was effected by winding it on a wooden core inside a light-tight box and attaching black strips of cloth to the ends of the film. It was later improved by winding the film on the core inside a protective layer of black paper which had sufficient extra length to permit several turns of paper to be made outside the film to protect it from light, as in the modern roll film camera.

During the period from 1886 to 1889 the business increased so rapidly that a change in the capital structure was made in order to finance new factory buildings and distributing agencies. In 1889 the Eastman Photographic Materials Company, Ltd., was incorporated in London to take over the business in countries outside the Western Hemisphere, and the Eastman Company was incorporated in this country. Buildings were erected on the site of the present Rochester factory at Kodak Park. In 1892 the name of the company was changed to the Eastman Kodak Company.

The Kodak was soon followed by other models of camera. The first pocket Kodak was designed in 1895 and was followed in 1898 by the first of the collapsible cameras, known as the folding pocket Kodak. In 1900 the Brownie camera, originally intended for children, was placed on the market at a price of one dollar.

By 1895 the motion picture industry had developed to a point where the need for a special positive film was evident; this was worked out by the Eastman Kodak Company and put on the market in that year.

By the turn of the century, therefore, Eastman's genius had produced the small amateur cameras and the roll films and motion picture films which have not changed in basic principle. He had made amateur photography and inaugurated the practice of photofinishing, and had made possible the motion picture. In addition, he had done much work on photographic printing papers. The earliest to be marketed was Eastman's standard bromide paper, which was coated with an emulsion similar to that used for the dry plates. He abandoned this until he had invented a paper-coating machine in 1895. In 1892, he marketed a gelatin printing-out paper known as Solio, and this had an instantaneous success. Printing-out papers using collodion instead of gelatin were very popular. Therefore, in 1889 the American Aristotype Company was purchased, and in the same year Velox paper, invented by Leo H. Baekeland, was purchased from the Nepera Chemical Company. Eastman recognized fully the merits of good photographic products which had been invented by others, and in some cases he acquired rights to them if he was not able to equal them in quality after a reasonable amount of work. His ambition was to ensure that the Kodak Company was in a position to supply the complete line of products necessary to cover all photographic needs. He paid well for patents offered by inventors if he felt they had merit for his business.

AMATEUR MOTION PICTURE PHOTOGRAPHER OF 1939

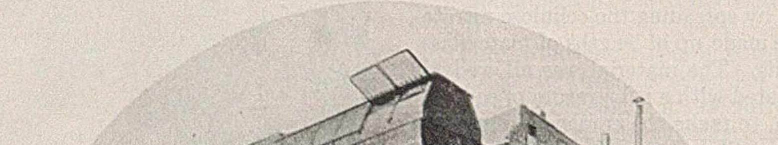
EMPLOYMENT OF TRAINED CHEMISTS

From the beginning Eastman recognized the advantages of employing trained chemists to assist in his research and control his manufactures, and in 1886 employed his first qualified research man. In 1891 Eastman turned to the Massachusetts Institute of Technology to select a young chemist who should devote himself to photographic chemistry until graduation, after which he should be made assistant manufacturing chemist of the company. He also turned to other universities for a graduate chemist and retained a qualified man to continue research for the company in New York. In 1897 he employed another young chemical engineering graduate from M. I. T., and at the turn of the century other technical graduates joined the staff. Many of them now occupy leading positions in the administrative and manufacturing branches.

We mention these facts to emphasize Eastman's early insistence on the value of trained chemists and experienced technicians in his industry. He selected his men carefully, so that they could carry on the affairs of the company in his tradition in the event of his death; it is significant that technical men who have been responsible for the company's manufactures have always figured prominently in the management and on the Board.

At the turn of the century Kodak Park was growing rapidly, and the company's employees were increasing in numbers. The original land purchased for the factory was 7 acres; now there are 400 acres. The employees numbered 15 in 1885, five years after Eastman started to produce dry plates commercially. After Kodak Park had been placed in operation in 1895, there were 120, of whom 76 were in Rochester and 44 in England. Even at that time the European operations were an important part of the business. In 1903 there were 3000 employees; in 1922 they numbered 14,600; in 1930, 25,000; and at the present time there are over 38,000, in all branches of the business.

Under the catalytic influence of Eastman and his band of competent employees, the photographic industry continued its rapid development after the beginning of the century. Whenever a new use for photography became apparent, work was done to supply materials for it, and men were trained to present its advantages to possible users.



EASTMAN DRY PLATE AND FILM COMPANY'S PLANT IN ROCHESTER, N. Y., PHOTOGRAPHED IN 1889 ON THE NO. 1 KODAK

MATERIALS FOR AMATEURS

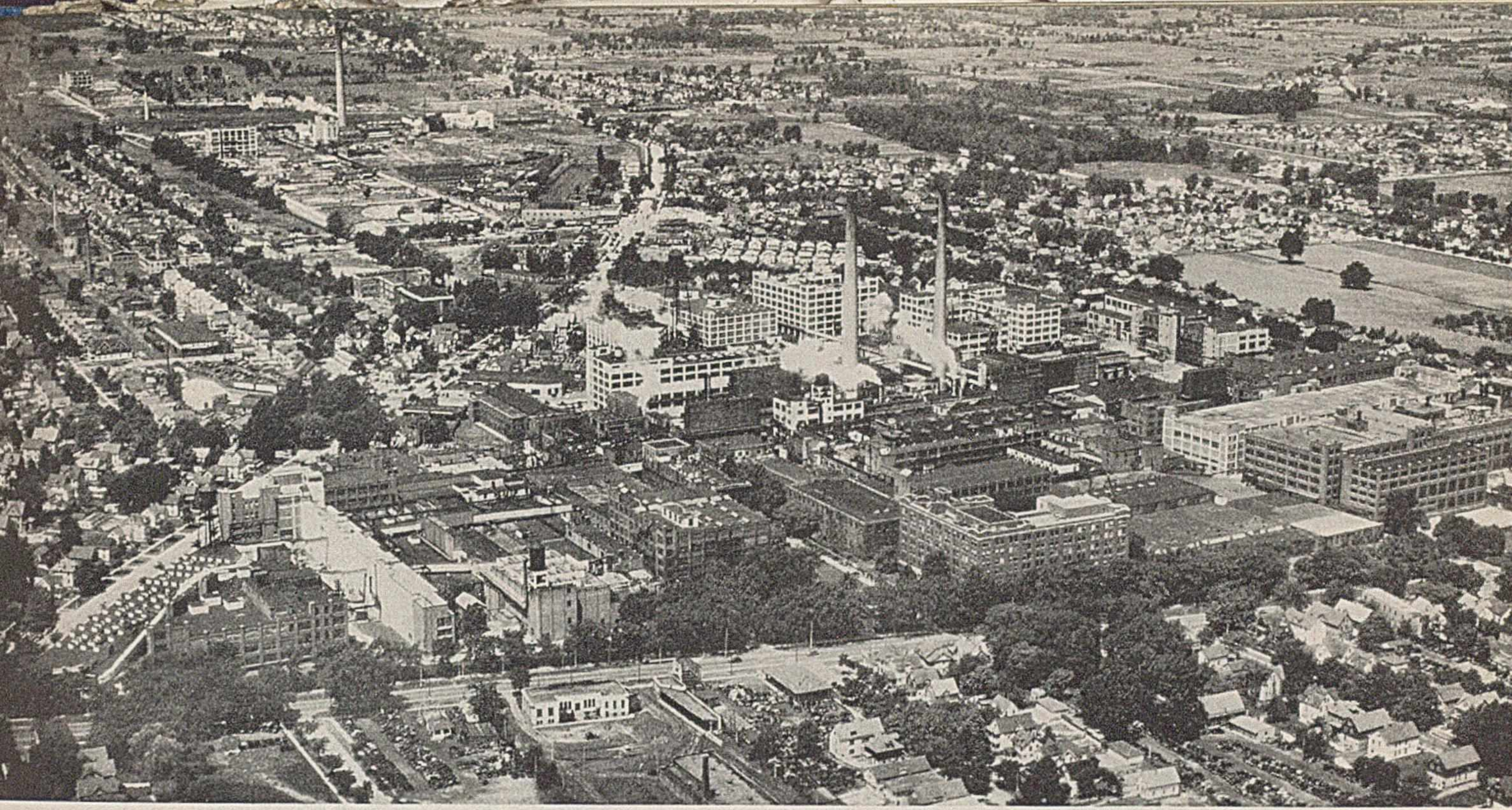
Progress in materials for amateur photography has been rapid right up to the present. One of the early difficulties with roll film lay in its tendency to curl because of the contraction of the gelatin. This was overcome in 1903 by applying a plain gelatin coating on the back of the film to give the present type of noncurling or N. C. film. In 1905 the black paper used for the daylight-loading roll film cartridges was replaced by the so-called duplex paper, which was red on one side and black on the other. This prevented the possibility that the numbers printed on the paper might offset on the film when kept a long time.

Because the amateur himself might want to develop his films without the need for installing a darkroom, a daylight developing machine was introduced in 1902, and in an improved form in 1904. In 1905 the company placed on the market a new apparatus for developing films, employing the so-called tank developer method.

FILM BASE

The first nitrocellulose film base was coated on long glass tables. This method was employed for ten years, but was not readily adaptable to continuous production and was relatively expensive. The engineers at Kodak Park, therefore, sought new methods of casting the material, and in 1899 they had devised a method of casting the film base on continuously rotating drums. This permitted operation 24 hours a day, resulted in a great increase in output, and gave a product of uniform thickness. The huge wheel machines employed for the manufacture of film support at the Kodak plants at the present time are derived from these early machines.

Eastman realized that cellulose nitrate was not the perfect material for making film support because it presented a fire hazard. From the beginning of the century, therefore, he had encouraged work on a safety type of film. Cellulose acetate was known, but it did not possess the mechanical properties of nitrate. It was brittle and not suitable for the strains imposed in repeated projection in motion picture machines. By 1909, however, Eastman's men had produced a cellulose acetate sheet which was commercially practical, and it was made available for some photographic purposes. Continued research made it satisfactory for educational and home motion pictures, x-ray film, and other uses, although it was not the equal of nitrate film for projection in the motion picture theaters. In the meantime, however, through cooperative work between the Motion Picture Producers and Distributors of America, Inc., state and national authorities, and organizations interested in fire protection, laws, regulations, and practices were instituted to govern the use of nitrate



Aerial Photograph of Kodak Park in 1938

film. The motion picture industry adapted its practices in accordance with these and as a result has an enviable record of freedom from fires.

PHOTOGRAPHIC PLATES

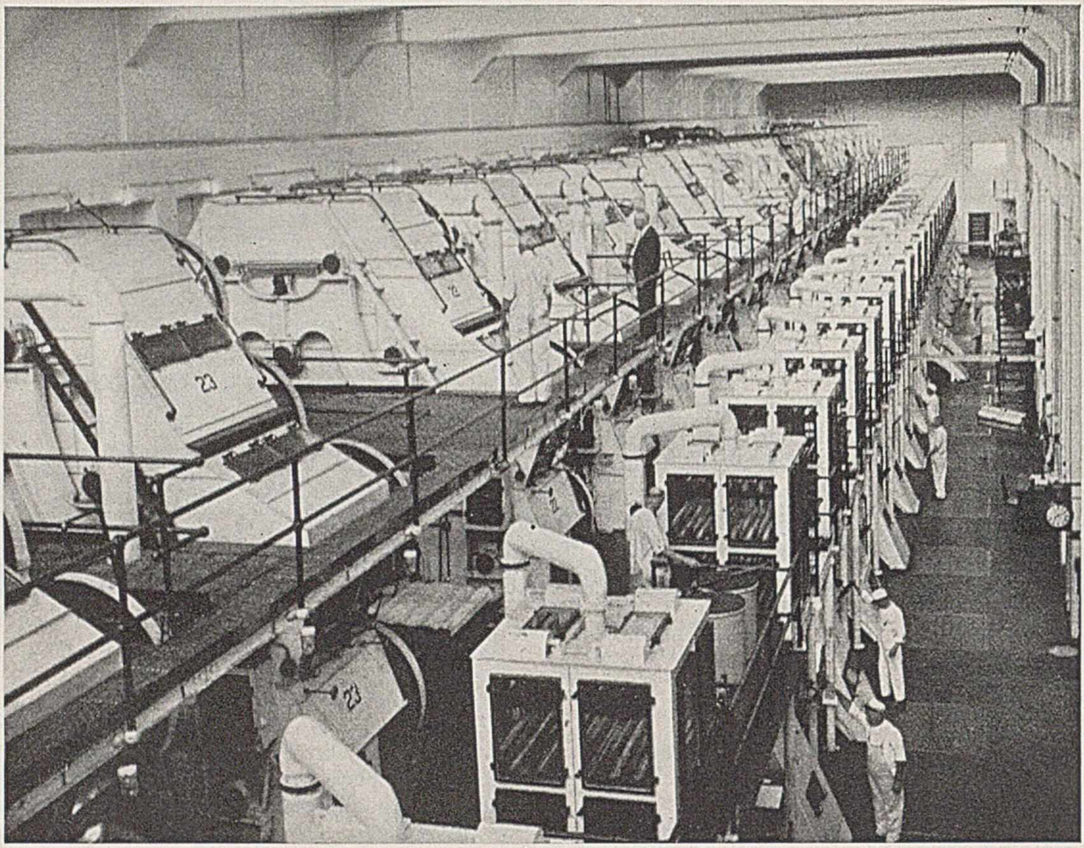
Progress in the manufacture of photographic plates was not impeded through the success of the flexible film. In 1902 the Seed and Standard dry plate companies were purchased, the Stanley company was acquired in 1904, and in 1911 these concerns were consolidated in a new plate factory with over five acres of floor space at Kodak Park. For more than two decades after amateur photographers had begun taking photographs on film, portrait and commercial photographers continued to use glass plates. The reason was primarily that film, in sheets as large as the plates these photographers used, would not present a flat surface in the camera. If this difficulty could be overcome, it was clear that films would offer definite advantages over plates, notably in their light weight and freedom from breakage. Much effort was spent on the problem, and in 1913 the company introduced the first practical cut sheet films. For many years these materials have been used in preference to plates by the majority of portrait and commercial photographers, although large numbers of plates are still made for other purposes.

Between 1902 and 1906 the Hoechst Dye Works discovered new dyes by which the sensitivity of plates could be extended to the green and red. During this period plates sensitized to these colors by bathing were placed on the market in Europe. In 1906, however, the firm of Wratten and Wainwright in England produced superior plates by incorporating the dyes during the manufacture of the emulsion instead of by bathing and the first Wratten panchromatic plates were put on the market in 1906. In addition, they worked out an extensive series of light filters of dyed gelatin and safelights for lighting photographic darkrooms, and had become internationally known for researches on photographic processes and for investigations in color photography. In 1912 Eastman wished to found a new research laboratory at Kodak Park. He purchased the Wratten and Wainwright Company, and appointed its technical director as head of the new laboratory. In 1913 the production of panchromatic plates and colored light filters was started at Rochester, and in the same year the company placed panchromatic motion picture film on the market for the first time. This met with great success. At present it is used almost exclusively for motion pictures and in other forms for amateur and commercial photography.

In 1918 a special x-ray film was coated on both sides with emulsion and marketed under the name of "Dupli-Tized" film. The use of this film is now general throughout the world, and it has entirely replaced plates and single-coated film for radiographic work.

AMATEUR MOTION PICTURE FILM

Through the first manufacture of film, Eastman was instrumental in starting the motion picture industry, and the manufacture of motion picture film is still one of the Eastman Kodak Company's main activities. The annual production of 35-mm. motion picture film alone would reach over eight times round the world. With the public's interest in the movies and in amateur photography, it was natural that the company should turn its attention to motion picture photography for the amateur. The principles which guided Eastman in the development of the first film and camera for the amateur were behind the study of amateur motion picture photography. In this case the amateur had the pictures seen in the theaters as a standard of quality; it was necessary to provide him with a simple camera and projector, and to be able to develop the films for him in all parts of the world so that the results would satisfy him on the score of quality, with the minimum of expense and effort. This was accomplished in 1923, when a new system of amateur motion picture photography was made available to the public. The apparatus comprised a camera, the Ciné-Kodak, and a projector, the Kodascope, with necessary accessories, together with a film so packed that it could be loaded into the camera in daylight. The film was of the so-called reversal type, the film exposed in the camera being converted into a positive for projection. Owing to the small size of the picture (the film was 16 mm. wide) and the use of the reversal process, the taking of motion pictures by the public at a practical price was made possible and is now a large industry. Fifty-two processing stations,



Some of the Present Machines at Kodak Park for Coating Film Support

staffed with technically trained people, are scattered all over the world for handling the film. The original camera was hand-cranked, but in 1925, a spring motor-driven model was introduced. In 1932 a system employing 16-mm. film, which could be split after processing to give 8-mm. film, was put on the market with its appropriate apparatus; in 1937 the company marketed a projector for the high-quality projection of 16-mm. sound films.

COLOR PHOTOGRAPHY

In one respect the amateur motion picture has surpassed the professional film from which it was derived—the use of color. A far higher percentage of amateur movies is made in natural color at present than are professional films.

From the first, Eastman had given thought to the problem of reproducing objects in their natural colors instead of in black and white, and work was started on this subject early in the present century. When the research laboratory was founded in 1912, the problem was taken up in earnest, and a color process called Kodachrome was actually developed to a commercial state in 1915. It was made available for portraiture and medical photography, but the demands made on the staff during the war did not permit its full exploitation. As soon as circumstances permitted, work was actively renewed on methods for making color photography available to the professional and commercial photographers, the motion picture industry, and the amateur. The earlier Kodachrome process was worked out for motion pictures and was actually used in production by one of the motion picture companies. It was realized that this was not the ideal system of color photography, however, and work was pursued along other lines. This first resulted in 1928 in the Kodacolor process, the first system of amateur motion pictures in color. This proved popular although it was not as simple as desired. In 1935 a new process, using the old name of Kodachrome, was put out for amateur movies and soon replaced the earlier process. Steady improvement was made and the process was extended. At present it is widely used, not only for amateur motion pictures but also for still photography in miniature cameras, in cut sheet form by commercial photographers, and for lantern slides, photomicrography, etc.

The enormous progress made by the company in the color field is due not only to the improved knowledge of the principles of color photography itself, but also to great improvement in emulsions and sensitizing dyes and the technique of film manufacture.

One of the great problems tackled by the research laboratories after the war was that of improving the dyes used for sensitizing emulsions to the colors to which silver bromide itself would not respond. The company was already the first to manufacture panchromatic film in 1913, and at the end of the war made the first panchromatic aerial film. By 1931 entirely new classes of sensitizing dyes had been worked out, and new types of panchromatic, orthochromatic, and infrared films and plates were made available. In that year, an immense step forward was made by the introduction of supersensitive panchromatic materials, mainly as a result of the work on dyes. Advances have since been made which have permitted the company to put out the new types of photographic film which have practically revolutionized motion picture, amateur, press, and commercial photography, and have made possible the enormous development of color photography. The culmination of Eastman's early entry into the photographic field is the modern high-speed fine-grain film and color film, made possible by years of research and experience in the manufacture of emulsions, film support, and sensitizing dyes. This experience has been applied to the introduction and improvement of photographic materials for special purposes: x-ray photography, aerial photography, sound recording, duplicating film, infrared film, documentary photography, spectrography, astronomy, and innumerable other scientific uses. Experience in camera design and lens manufacture has resulted in the modern camera with wide-aperture, color-corrected lens, precision shutter, coupled range finder, and other attachments and accessories which have made the camera a flexible precision instrument without losing the original idea of the first Kodak.

RAW MATERIALS

The policy of the Eastman Kodak Company has always been to make sure of its source of supply of raw material, and the company manufactures many of its own. At Kodak Park there are plants for making sulfuric and nitric acids, essential for the nitration of cotton to make cellulose nitrate. Cotton is purchased in the open market but is nitrated at Kodak Park. At the plant at Kingsport, Tenn., acetic acid, acetic anhydride, and wood alcohol are produced from the distillation of wood, and cellulose acetate is made from cotton obtained in the South. Gelatin for emulsions is made at Rochester and at a gelatin plant at Peabody, Mass. Bullion silver in large quantities is converted to silver nitrate at Rochester, and in this city is manufactured a large share of the company's raw paper for photographic purposes. It is the only plant making high-grade photographic paper in the United States. As a result of development work extending over a period of twenty years, an entirely new and very stable photographic paper has been produced. Photographic base paper must be of such physical strength that it can withstand alternate immersion in alkali and acid and prolonged handling while wet. In addition, it must be of such a high degree of chemical purity that it will produce no effect on the emulsion coated on it; moreover, it must not undergo deterioration on prolonged storage. Using highly purified spruce fibers as the raw material and a new type of sizing, Kodak Park has evolved a new type of basic paper which has now been in use for several years and which satisfies all rigid requirements.

Hydroquinone, elon, pyrogallol, and other organic chemicals required as developers, dyes, sensitizers, and many other photographic agents are manufactured at Kodak Park and Kingsport. A large Synthetic Organic Chemicals Department manufactures over three thousand special organic chemicals for sale for research and industrial purposes. This department was started, like several others, during the war, when supplies were cut off from Europe.

The Eastman Kodak Company manufactures its own cameras and lenses in enormous quantities. The Camera Works at Rochester employs some three thousand people and is being considerably enlarged to accommodate the machinery and people necessary to make the new types of precision instrument which are the cameras of today and tomorrow. There are also large camera works in England, Canada, and Germany.

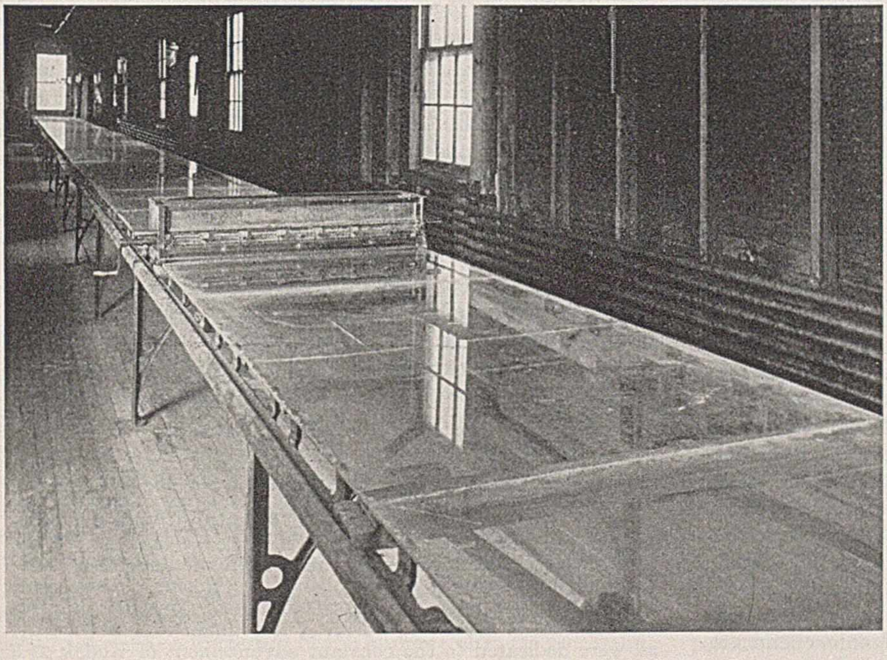
Lenses, thousands a week, of all grades from simple lenses for cheap cameras to the high-aperture color-corrected anastigmats, are made in the company's Hawk-Eye Works in Rochester and in the English plant. At the Hawk-Eye Works are also made the precision instruments used for research, testing, and development, as well as other high-class optical instruments for the photographic trade.

NONPHOTOGRAPHIC ACTIVITY

For many years the company's policy was to devote its attention exclusively to the single field of photography, and to manufacturing only the apparatus and sensitive goods required. As a result it found itself in the position of possessing unexcelled knowledge of the properties and production of materials useful in other fields. In recent years it has utilized this knowledge in some nonphotographic branches. For instance, it had a great knowledge of cellulose acetate, derived from years of research on safety film. This permitted the company to start the manufacture of cellulose acetate rayon, primarily to allow large production of cellulose acetate so that its cost for photographic purposes could be lowered. Eastman is now the world's second largest manufacturer of acetate rayon. It is also the largest manufacturer of cellulose acetate plastic molding compositions in the United States. It supplies large quantities of cellulose acetate to provide the plastic interliner for safety glass and in the form of thin sheets as Kodapak for transparent wrapping material. Its experience in the field of high-vacuum technology, originally studied in connection with photographic problems, has enabled it to start a plant in cooperation with General Mills for the concentration of vitamins by vacuum distillation of natural oils. It also manufactures cellulose esters which are used in the production of lacquers. Its experience in the molding of glass has resulted in the establishment of a department devoted to the manufacture of millions of lenses for roadside signs. These are some of the "extra-curriculum" activities of the company, leading naturally from its researches in the field which is still its primary interest —photography.

LABORATORIES

The progress of photography, as represented by the development of the Eastman Kodak Company, from Eastman's earliest efforts to the present time, has involved an immense amount of research and experiment. Mr. Eastman himself was a born experimenter, and the


Early Glass Table Used at Kodak Park for Coating Film Support

application of scientific and technical study to the solution of problems has been the backbone of the company's policy. A laboratory was established in the earliest days. This was the start of a scientific organization which has played a major part in the development of the company. It was a separate research department, not concerned with production or business problems, and clearly established the recognition of the need for research. When Kodak Park was founded later, one of the original buildings was designed for use as a chemical laboratory, and the direction of the manufactures of the company has always been in the hands of technical men.

The original laboratory at Kodak Park was soon paralleled by other laboratories working specifically for various divisions of the factory. Each department establishes a section which can supply it with the scientific information it may need for its direct control and operation. A research laboratory was established in 1912 to deal especially with the fundamentals of the science of photography and to carry on pure scientific research along lines of interest to the company. It has built up a staff of experts on the various aspects of the theory and practice of photography. The original laboratory rapidly outgrew its first quarters, and extensions were made from time to time. After two years of construction, an entirely new laboratory was completed in 1931, and provision was made for further extension in the future. It was not long before the new building was over crowded, and in order to permit adequate handling of the ever-increasing new problems, the building was almost doubled in size in 1937. In 1913 the research staff numbered 17; in 1939 it is about 500.

The laboratory has three main divisions, devoted to photography, chemistry, and physics. The industrial field served is very wide; it covers the products which the company manufactures, raw materials and their applications, new projects initiated in the laboratory, and fundamental scientific problems directly or indirectly related to the company's present or future interests. Each of the divisions of the research laboratory performs work falling into three functions: fundamental research; development work on new materials, processes, and apparatus; and plant and service problems arising in connection with the manufacture and use of existing products.

The research laboratory works in close cooperation and harmony with the laboratories in the plant, and with the manufacturing and sales departments. The great strides which have been made in new products and the improvement of existing ones in recent years are the result of this cooperation. There are thirty-four laboratories in Kodak Park other than the research laboratory, and many laboratories in other plants, including a large research department at the English plant.

From the original department over the store in Rochester, where plates were first made for sale in the home city, Eastman's vision and concentration on making his organization photographically all-embracing and world wide in scope, has resulted in the present prominent position of the company in the industrial and business worlds. Thirteen manufacturing units are located in all parts of the world. There are two hundred and fifty other Eastman Kodak establishments distributed over the globe. The first product was the dry plate. At the present time, Kodak Park alone manufactures 75 kinds of plates, not counting more than 100 kinds which are made on special request for scientific purposes, 190 kinds of films, 450 kinds of photographic papers, 100 kinds of cellulose acetate and nitrate sheeting. These figures do not include the multitudes of different sizes and types of packaging. Of photographic chemicals, there are made 140 kinds in 633 packages, over 3000 kinds of synthetic organic chemicals, 225 kinds of other miscellaneous chemicals, and 125 miscellaneous photographic supplies. In addition, many materials are manufactured to be used by other Kodak Park departments and other Kodak plants. Add to these the special products made at the other twelve manufacturing plants, the enormous variety of cameras, lenses, projectors, and other photographic appliances, and some idea will be obtained of the extent and ramifications of the single industry which has resulted from Eastman's ambition and skill.

Kodak Park, the largest of the factories, is 400 acres in area and 2 miles from east to west; it has 5,750,000 square feet of building floor space, 250,000 square feet of shed floor space, 9 miles of streets, 9 miles of railroads, and 25 miles of water mains. The refrigeration plant for cooling and air conditioning is the largest single interconnected refrigeration compressor plant in the world; it has 14,000 tons of total compressor capacity, sufficient to supply 28 pounds of ice a day to a million ice boxes. Kodak Park has its own water works and filtration plant, with a maximum capacity of 24,000,000 gallons in 24 hours, sufficient to supply a city of 250,000.

EASTMAN'S RELATIONS WITH EMPLOYEES

The successful functioning of a large industry is in the hands of every employee. George Eastman realized from the outset the value of proper selection of men. He also clearly realized his responsibility to his employees, and in its efforts to promote their well-being, the Eastman Kodak Company is unsurpassed among the world's great industrial organizations. The company maintains a program of production control designed to stabilize employment. It pays equal to or higher than the prevailing rate of wages in the community. Since 1912, with the exception of one year, the company has given its employees an annual wage dividend, representing a share in the earnings. The total amount paid so far in this way is $43,000,000. After the war Eastman personally contributed a hundred thousand shares of Eastman Kodak stock and the company provided an equal amount, to be divided among the personnel on a basis of length of service. The stock was sold to employees at a nominal price, which was paid for by the dividends while the shares were held in trust before delivery to their new owners. The company accords extensive benefits to its employees in the form of life insurance, disability insurance, and retirement-annuity payments. A savings and loan association makes home ownership easily possible for Eastman workers by means of mortgages and group-building projects. There are large medical departments with dispensaries in all the plants. There are sickness and unemployment benefits, varying with the length of service, and emergency loans and legal advice are provided through the Kodak Employees Association.

Mr. Eastman's philosophy was founded on a sense of responsibility to his public, to his employees, to his stockholders, and for his products. He never evaded an issue and was ready to accept responsibility in the broadest sense of the word. We could not close this brief survey of his accomplishments in a more fitting way than by quoting the words uttered by the late Rush Rhees, president emeritus of the University of Rochester, at the dedication of the Eastman Memorial at the entrance to Kodak Park:

> This memorial will be a lasting symbol of the abiding influence and inspiration which the memory of George Eastman will exert . . . on the thousands who in the future years may contribute by thought and labor to the future realization of the vision which Kodak's founder cherished for it and for a world increasingly worthy of man's loyalty . . . Nothing less massive than this marble pillar can fitly remind us of the strength of his combination of technical, business, and financial ability. And all were dedicated to the constant advancement of Kodak as a service to science, art, and human pleasure.

SYNTHETIC ORGANIC CHEMICALS FROM PETROLEUM

An American Development

BENJAMIN T. BROOKS
114 East 42nd Street, New York, N. Y.

MANY accomplishments have served to arouse interest in the manufacture of synthetic organic chemicals from petroleum and natural gas. The recent statistical reports of the U. S. Tariff Commission whose findings for 1938 are summarized in Figure 1, the two volumes on "The Chemistry of Petroleum Derivatives" by Ellis (*10*), and the industrial accomplishments of the Carbide and Carbon Chemicals Corporation as recognized by the award of the Perkin Medal in 1936 to George Curme point particularly to this interest.

Synthetic organic products from petroleum or natural gas are now being manufactured by two major oil companies—the Standard Oil Company of New Jersey and the Shell Petroleum Corporation—and by the following chemical companies—Carbide and Carbon Chemicals Corporation, Dow Chemical Company, Monsanto Chemical Company, Air Reduction Company (or its subsidiary U. S. Industrial Alcohol Company), and the Sharples Solvents Corporation. Important patents in this field have also been issued to E. I. du Pont de Nemours & Company, Inc., Socony Vacuum Oil Company, Inc., Standard Oil Company of California, Purdue University Research Foundation, and Standard Oil Company of Indiana.

This industrial and scientific development has been peculiarly American. Although the scientific spirit is without national bias, a great deal in these achievements seems to be characteristically American. America has been producing about 65 per cent of the world's petroleum, but other countries have had petroleum in quantities and at price levels more than adequate to have supported such chemical developments. The three largest refineries in the world are outside of the United States. The largest is located in the great Iranian fields and is owned and operated by British interests. In the main, the results can be traced to iconoclastic individuals, supported sooner or later by progressive American companies. Many products new to commerce have been introduced, the commercial success of which was originally unpredictable. Petrified plans handed down by higher authority have not been the rule. There has been no mass research, no Five-Year Plan. In a real planned economy there are few planners; under the American system there are thousands of planners, but each must sell his ideas to someone who has a pay roll to meet. American companies, appreciating the risks but free to choose, have not been backward or niggardly in the support of these new ventures. The facts speak for themselves.

One of the most successful ventures in this field was not originally planned that way at all. It originated outside of the petroleum industry, in an attempt to find a cheaper process for producing acetylene than from calcium carbide. George Curme, working for The Prest-O-Lite Company, Inc., at Mellon Institute, discovered that acetylene could be produced from gas oil by cracking under certain conditions, but found that a considerable proportion of ethylene was also formed. This led to attempts to utilize ethylene. The effort eventually was concentrated upon cracking under optimum conditions for ethylene and to manufacture a product never before marketed, ethylene glycol.

GLYCOLS AND SYNTHETIC GLYCEROL

Earlier attempts to make ethylene glycol started with ethylene dichloride—for example, heating it under pressure with aqueous sodium carbonate. In this country the first suggestion of using ethylene chlorohydrin for this purpose appears to be found in the patents of K. P. McElroy, which were later acquired by Carbide and Carbon Chemicals Corporation. At the same time, during the World War the Germans made the chlorohydrin as an intermediate for mustard gas by passing ethylene (from alcohol) into a solution of bleaching powder along with carbon dioxide. I used a solution of hypochlorous acid made by passing chlorine into cold alkali carbonate solution, but Moses Gomberg, working for the United States Chemical Warfare Service, found that excellent yields of the chlorohydrin were obtained merely by passing ethylene into cold chlorine water.

In the meantime it was known from work done here and abroad that nitrated glycols were useful in lowering the freezing point of nitroglycerin as in dynamite. The first attempt to manufacture glycol in this country was based upon this fact, and during the war the development was financed by an explosives company. But with the end of the World War, glycerol returned to low price levels, and the decision of this company to abandon the project appeared to be orthodox. Another explosives company at the same time abandoned a project to make synthetic glycerol from propylene. Government superplanners surrounded by advisory boards would undoubtedly have made the same decisions, if indeed such projects could have been considered by such important people.

When a few years later Curme and his associates persuaded the Union Carbide and Carbon Corporation to manufacture ethylene glycol, it was

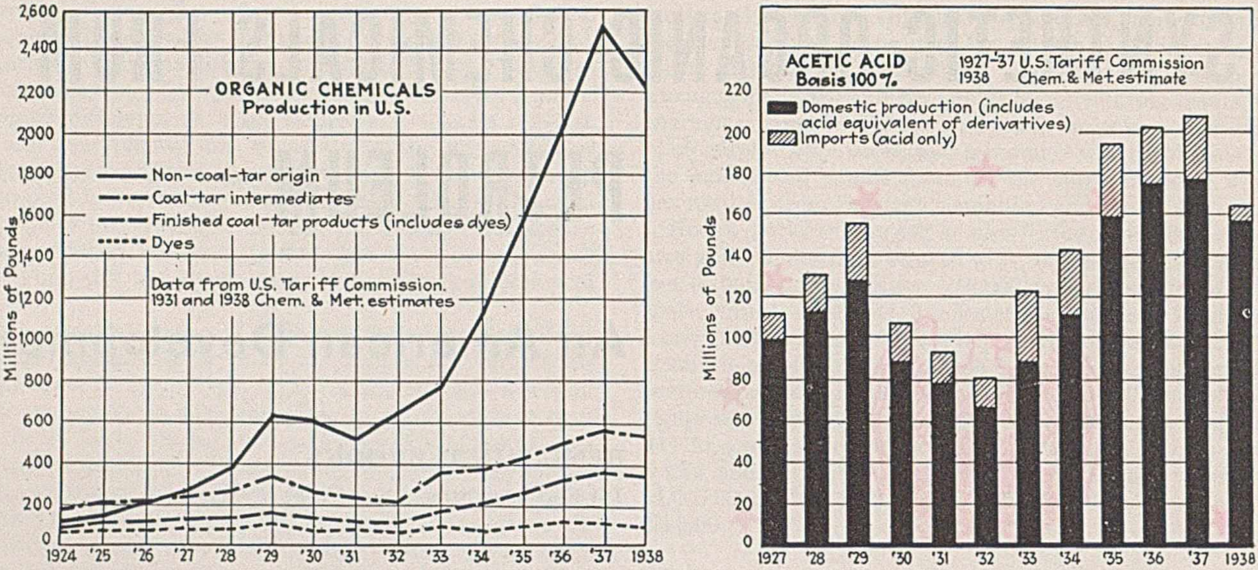


FIGURE 1

sold, not as a substitute for glycerol, but on its merits as a new commercial article at a price substantially above that of glycerol. This was an unpredictable venture of salesmanship. And one might ask, what price salesmen in a totalitarian state or in a fully planned economy?

In addition to the glycol consumed in explosives, the main commercial use quickly became antifreeze material for automobile radiators. In producing ethylene glycol through ethylene chlorohydrin and ethylene oxide, a by-product, diethylene glycol, was formed which proved to be more satisfactory for certain uses than pure ethylene glycol. When ethylene glycol was first manufactured by Carbide and Carbon about 1924, no commercial demand existed for such other products as ethylene oxide, ethanolamines, or the various glycol ethers. The company then set up a list of secondary products which could be manufactured but whose commercial future no one could confidently predict. Today the list of major products of the glycol series include the following: ethylene glycol, propylene glycol, diethylene glycol, ethylene glycol ethyl ether (methyl Cellosolve), ethylene glycol butyl ether (butyl Cellosolve), diethylene glycol methyl ether (methyl Carbitol), diethylene glycol ethyl ether (Carbitol), diethylene glycol butyl ether (butyl Carbitol), dioxane, dichloroethyl ether (Chlorex), ethylene oxide, Cellosolve and Carbitol acetates, ethylene dichloride, ethylene chlorohydrin, propylene chlorohydrin, propylene oxide, ethanolamines (mono-, di-, and tri-), and ethylene diamine.

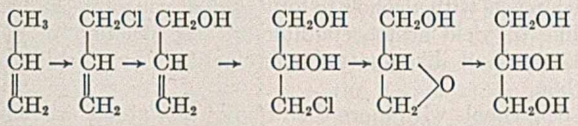
GEORGE O. CURME

There is a certain symbiotic relation in the manufacture of most chemical products. To manufacture pure ethylene glycol and related products from cracked hydrocarbon gases containing propylene and other hydrocarbons required the substantially complete separation of ethylene from propylene. Such a separation process was worked out by Curme and his associates. More recently Van Nuys (*28*) and Wilkinson (*30*) of the Air Reduction Company have shown that it is possible to separate ethylene from cracked gas mixtures by low-temperature fractionation in a purity of 98 to 99 per cent. Also for several years this company operated three Gyro cracking furnaces; this process was well known as a so-called vapor-phase cracking process for gasoline. The success of glycol manufacture was soon accompanied by processes for utilizing propylene, which led directly to the manufacture of isopropyl alcohol and the catalytic dehydrogenation of this alcohol to acetone. The manufacture of acetone at new low cost levels led to the manufacture of ketene and acetic anhydride by the same company.

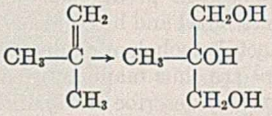
It has long been evident to organic chemists that synthetic glycerol could be made at a price. During the World War, Essex and Ward of the du Pont company showed that the pyrolysis of propylene dichloride yielded allyl chloride ($CH_2=CHCH_2Cl$) instead of the isomer $CH_3CH=CHCl$ which results on treating with caustic alkali. The addition of hypochlorous acid to allyl chloride or to allyl alcohol followed by hydrolysis yields glycerol. Recently E. C. Williams, of Shell Development Company, announced the manufacture of synthetic glycerol, and recent patents assigned to that company show also the synthesis of β-methylglycerol. Engs and Redmond (*11*) and Groll and Hearn

E. C. WILLIAMS

(*13*, *17*) have shown that, when propylene is chlorinated at temperatures above 200° C., allyl chloride is formed direct, with yields of 85 to 90 per cent. The Shell chemists have made frequent use of the conversion of chlorohydrins to oxides by treatment with lime or caustic alkali; this reaction usually gives very high yields. Also they find that unsaturated chlorides of the allyl type give good yields of alcohols on hydrolysis with alkalies (*26*). Thus allyl chloride may be hydrolyzed to allyl alcohol, which by treatment with hypochlorous acid yields the chlorohydrin. Treatment of the chlorohydrin with lime yields the epoxide, and oxides of this type are readily hydrolyzed with nearly quantitative yields to the glycol, in this case glycerol (*14*, *15*):

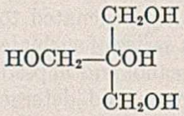


Similar reactions (*9*, *14*, *16*) starting with isobutene yield β-methylglycerol:



$$CH_2{=}C(CH_3){-}CH_3 \rightarrow CH_3{-}C(OH)(CH_2OH){-}CH_2OH$$

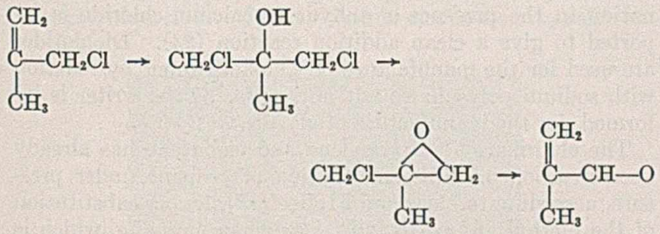
Further chlorination in the first stages yields the new tetrahydroxyl derivative:



$$HOCH_2{-}C(OH)(CH_2OH){-}CH_2OH$$

Levine and Cass (*20*), of the du Pont company, recently showed that, when propylene dichloride is chlorinated at low temperatures in the presence of iron catalyst and ultraviolet light, a 90 per cent yield of 1,2,3-trichloropropane can be obtained, which should yield glycerol on hydrolysis. However, the chlorohydrins and epoxides react much more readily and smoothly than the chlorides.

In exploring the chemistry of isobutene the chemists of the Shell laboratory have discovered many new compounds and have found several ways of producing methylacrolein. For example, isobutenyl chloride adds hypochlorous acid to dichloro-*tert*-butyl alcohol which, on treatment with lime, yields the epoxide; the latter yields methylacrolein when treated with hot dilute acids (*13*, *16*):



The synthetic chemical products manufactured by the Shell company include the following: acetone, diacetone alcohol, isopropyl ether, mesityl oxide, methyl ethyl ketone, methyl isobutyl ketone, *tert*-butyl alcohol, allyl alcohol, allyl chloride, isocrotyl chloride, methallyl alcohol (isobutenol), methallyl chloride, dimethallyl ether, acrolein, β-methyl epichlorohydrin, isobutene glycol, isobutene oxide.

Mention should be made of the recently developed process of catalytic oxidation of ethylene by air in the presence of silver catalysts. Good yields of ethylene oxide are reported, the lean reaction mixture being scrubbed by very dilute aqueous sulfuric acid, according to a recent patent to Balcar (*2*), which absorbs the oxide and hydrolyzes it to glycol. Although this process did not originate in the United States, Air Reduction Company, Carbide and Carbon Chemicals Corporation, and Shell Petroleum Corporation have recent patents in this field.

ALCOHOLS AND KETONES

The first synthetic alcohol to be manufactured in commercial quantities was isopropyl alcohol. It was apparently first manufactured for sale by the Standard Oil Company of New Jersey, which acquired the original process from Carleton Ellis. The Standard Alcohol Company, which manufactures alcohols and other synthetic products, is a subsidiary of the Standard Oil Company of New Jersey. M. B. Hopkins is vice president of the Standard Alcohol Company, and research relating to these products is under the direction of Per K. Frolich, director of research, Standard Oil Development Company. Here again this important commercial synthesis was not planned and ordered by a large, highly organized industry but was the suggestion of an inventive individual. The source of the propylene used by Standard Oil of New Jersey has been the pressure-cracking stills at the Bayway refinery, and the propylene-propane fraction from the gasoline stabilizers has been employed. More recently Buc, of the New Jersey company, discovered that isopropyl ether is a valuable antiknock motor fuel, in unexpected and striking contrast with ethyl ether which knocks badly. Most textbooks still represent the formation of ether from alcohol as the removal of one mole of water from two moles of alcohol by the dehydrating action of concentrated sulfuric acid. Even ethyl alcohol yields mainly ethylene, carbon, and sulfur dioxide under these conditions, but in the case of isopropyl alcohol the conventional ether preparation method is worthless. Schneider, also of the New Jersey company, has worked out methods which utilize dilute acid; he circulates propylene in such a way that the process continuously produces either all ether or all alcohol, and since concentrated acid is not used, there is no acid concentration problem. The first of Schneider's patents are beginning to appear and should correct our common conception of this comparatively elementary organic reaction. In view of Buc's discovery, Schneider's work and the fact that propylene is available in large quantities, blended motor fuels of 100 octane number, containing up to 40 per cent isopropyl ether, constitute one of the few sources of aviation fuel of the octane value now sought for military aviation.

M. B. Hopkins

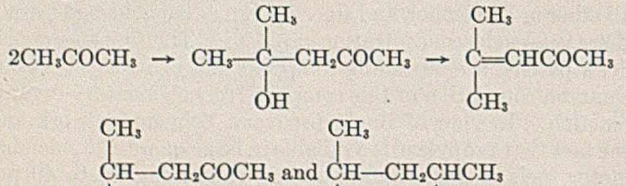
Synthetic ethyl alcohol has had a long history which need not be reviewed here. The account of Fritsche's failure in his attempt to manufacture ethyl ether from the ethylene of oil gas at Richmond, Va., and Brooklyn, N. Y., many years ago is well known. The latest edition of Ullmann (*27*) condemns synthetic ethyl alcohol made by treating ethylene with sulfuric acid as uneconomic. However, some American chemists do not have the proper respect for the voice of authority. Evidently a little critical thinking, taking into account the benefits of other dovetailing processes, and a little intelligent audacity were required to set up this process for the manufacture of synthetic ethyl alcohol, diethyl sulfate, and ethyl ether on a large industrial scale. Synthetic ethyl alcohol has been manufactured by Carbide and Carbon at Charleston, W. Va., since 1931 and at Whiting, Ind., since 1936.

Up to the present time the process favored for the manufacture of both ethyl and isopropyl alcohols has employed concentrated sulfuric acid. Under these conditions the formation of substantial proportions of diethyl and diisopropyl sulfates is possible, which reduces acid cost but requires reconcentration of the diluted acid. Recently patents have been issued to Lewis (*21*) and to Archibald and Schneider (*1*) of Standard Oil Company of New Jersey, to Shiffler and Holm (*25*) of Standard Oil Company of California, to Metzger (*23*) of Air Reduction Company, to Davis and Francis (*7*) of Socony-Vacuum Oil Company, and to Bent (*4*) of Shell Petroleum Corporation, based upon the use of dilute sulfuric acid at relatively high temperatures and pressures; operation is continuous so that reconcentration of the acid is avoided. These dilute acid processes are recent developments and are not yet in commercial operation.

Up to 1918 it was not known that the so-called acid oils formed on refining cracked gasoline with sulfuric acid and diluting with water consisted of alcohols together with polymers (*6*). Soon after Standard Oil of New Jersey started the manufacture of isopropyl alcohol, the operation was applied to light cracked naphtha and secondary butyl, amyl, and hexyl alcohols were produced. These were soon followed by the corresponding ketones, made by catalytic dehydrogenation. Of these *sec*-butyl alcohol and the corresponding ketone (methyl ethyl ketone, or "M. E. K.") are the most important. The latter products are also made by the Shell company at Los Angeles.

During the World War the supply of acetone from wood distillation was inadequate, and the fermentation process, then started industrially, brought with it the production of *n*-butyl alcohol. Shell Petroleum Corporation and Carbide and Carbon Chemicals Corporation now manufacture large quantities of acetone by the catalytic dehydrogenation of isopropyl alcohol, and the price of acetone is at an unprecedented low level.

The new low cost levels of acetone have stimulated interest in its condensation products. The condensation of acetone to diacetone alcohol (cf. particularly McAllister & Bullard, *22*), dehydration of the latter to mesityl oxide (cf. particularly Fairbairn and Engs, *12*), and hydrogenation to methyl isobutyl ketone and to the hexyl alcohol, 4-methyl-2-pentanol, has long been known:



$$2CH_3COCH_3 \rightarrow CH_3\text{—}\underset{OH}{\overset{CH_3}{C}}\text{—}CH_2COCH_3 \rightarrow \underset{CH_3}{\overset{CH_3}{C}}{=}CHCOCH_3$$

$$\underset{CH_3}{\overset{CH_3}{CH}}\text{—}CH_2COCH_3 \text{ and } \underset{CH_3}{\overset{CH_3}{CH}}\text{—}CH_2\underset{OH}{CH}CH_3$$

These products are now manufactured by Carbide and Carbon and Shell Petroleum.

The pyrolysis of acetone to ketene,

$$CH_3COCH_3 \rightarrow CH_2{=}CO + CH_4$$

was discovered by Wilsmore in 1907 and remained only of academic interest for many years. The yields reported commonly ranged from 10 to 20 per cent. However, by applying the principle of low conversion per pass and recycling the acetone, yields of 70 to 80 per cent are obtained. Special patents for the production of ketene have been issued to Eastman Kodak Company, E. I. du Pont de Nemours & Company, Inc., Carbide and Carbon Chemicals Corporation, Shell Petroleum Corporation, and Standard Oil Company of New Jersey.

The reaction of ketene with acetic acid to form acetic anhydride has long been known, but the recent production of ketene on a large scale is evidently one of the three processes for manufacturing this anhydride which has brought its price down to unprecedentedly low levels. Although the consumption of acetic anhydride in the United States is estimated at 177,000,000 pounds in 1937, sales have been reported as low as 7.5 cents per pound as compared with about 30 cents a few years ago. Very few synthetic organic chemicals are produced in greater quantities than is acetic anhydride.

Ketene in acetone solution readily polymerizes to diketene which reacts with alcohols to form acetoacetic esters, and with aniline to yield acetoacetanilide. These reaction products of ketene and diketene are manufactured by Carbide and Carbon.

The alcohols with more than five carbon atoms are manufactured by condensation reactions of simple aldehydes and ketones such as acetaldehyde, butyraldehyde, and acetone. Some of the condensation products of acetone have been mentioned. Normal butyl and hexyl alcohols, two secondary hexyl alcohols, an octyl alcohol, an undecanol, a tetradecanol, and a heptadecanol are thus manufactured. Several recent patents to Wickert (*29*) describe thirty-three new condensation products starting with butyraldehyde or its two eight-carbon condensation products, with various ketones such as methyl ethyl, methyl isobutyl, methyl amyl, etc. The condensation products are hydrogenated to secondary alcohols. Wickert shows that in a series of such alcohols the neutralized alkyl sulfates of hexadecanol and heptadecanol are extremely effective as wetting agents and detergents; these products are sold as "Tergitol."

ALKYL HALIDES

The most important alkyl halide is ethyl chloride. About 65,000,000 pounds are manufactured in the United States annually. It is used mostly for the manufacture of tetraethyllead and ethylcellulose. This chloride was formerly made from ethyl alcohol, but excellent processes for its production from ethylene and hydrogen chloride are now known. Ethylene dichloride is a by-product of the chlorine water method of making ethylene chlorohydrin and may be produced direct by the chlorination of ethylene. It is difficult to chlorinate olefins without simultaneous substitution; Deanesly (*8*) showed that even in the dark the addition of chlorine to the double bond induces substitution, but chlorination in the presence of anhydrous calcium chloride is reported to give a clean addition reaction (*24*). Dichlorides are used for the manufacture of Thiokol rubber by reaction with sodium polysulfides but not, so far as the writer is informed, for the manufacture of glycols.

The chlorination of propylene and isobutene has already been mentioned. The chlorination of propane under pressure, according to Hass and McBee (*18*), favors substitution of the methyl groups to form 1,3-dichloropropane, which is the material used by Hass for making cyclopropane (advocated as an anesthetic). The chlorination of isobutane is carried out for the production of *tert*-butyl chloride (*5*) which hydrolyzes readily to *tert*-butyl alcohol. The chloride, alcohol, or isobutene may be employed for the manufacture of *tert*-butylphenol which finds its way into some of the newer oil-soluble phenol-formaldehyde resins. The Dow Chemical Company produces *tert*-butyl-phenol, ethyl chloride, and ethylene dichloride. Chlorinated pentane has for many years been the basis of the manufacture of amyl alcohols and acetates by the Sharples Solvents Corporation. Tertiary amyl alcohol or the corresponding amylene also readily alkylates phenol; the resulting *tert*-amylphenol is used also for oil-soluble phenol-formaldehyde resins. These alkylated phenols find some industrial application as antioxidants.

RESINS AND POLYMERS

Synthetic organic chemicals from petroleum find their way into synthetic resins and plastics through a variety of channels, which can only be briefly mentioned here. The polymerization of dienes, or more correctly the copolymerization of dienes and simple olefins, made by cracking at high temperatures to produce light oils rich in dienes, has been described by Thomas of Monsanto Chemical Company. These resins, produced by the action of anhydrous aluminum chloride, are hydrocarbons of high molecular weight and complex structure. Pure isobutene yields a series of highly polymerized materials, including viscous oils which are of value in improving the viscosity index of lubricating oils; the most highly polymerized product resembles colorless rubber and is sold under the name of "Vistanex." The alkylation of phenols by isobutene has already been noted. Ethyl chloride (from ethylene) is used in the manufacture of ethylbenzene, which is evidently the raw material for the production of styrene and styrene resin by one process. Acrylic acid ester resins are made by one process from ethylene chlorohydrin (*3*), and methyl methacrylate is made from acetone via the cyanohydrin and its reaction with methyl hydrogen sulfate (*19*). The polysulfones formed by the reaction of sulfur dioxide and olefins are hard white products of promise.

Photo by Blackstone Studios

CHARLES ALLEN THOMAS

RESEARCH

Coincident with outstanding technical advances in the American petroleum industry, particularly in the last twenty years, there has been a great deal of chemical research both in the laboratories of petroleum refining companies and in university laboratories. These researches in the industry itself have generally been required to have some particular industrial objective. However, much of this work in refinery laboratories has been of the highest scientific value, and a great deal of it has been published in our chemical journals. Ellis (*10*) gives an exhaustive review of this work and of the patent literature.

CARLETON ELLIS

The work in various American universities in the field of chemical engineering applied to petroleum and in the field of organic chemical research relating to what I prefer to term "nonbenzenoid hydrocarbons" reflects more clearly the free play of complete freedom in research that we enjoy under the American system. It is impossible to review fairly the vast amount of chemical research that has been done in industrial and university laboratories on these hydrocarbons.

More valuable research of permanent value, at least in the field of hydrocarbon chemistry, was done in Russian universities which enjoyed a large degree of academic freedom under the Czar than has been the case in the last twenty years under the plan of mass researches ordered by a dictatorial government.

Under the American capitalist system successful individuals or companies frequently give substantial sums to defray the costs of research; for example, $500,000 was donated a few years ago by John D. Rockefeller, Sr., and the Universal Oil Products Company for petroleum research. One of the outstanding results of research subsidized in this way was a most exhaustive research on the chemical composition of petroleum carried out by several chemists in the National Bureau of Standards.

It would be difficult to appraise at this time the real value of the investigations of F. C. Whitmore, H. B. Hass, Charles D. Hurd, E. B. Spence, H. J. Lucas, and others; and of the work in chemical engineering of M. R. Fenske, W. K. Lewis, W. N. Lacey, and others.

This review is necessarily inadequate, since so much outstanding work has been done, but the examples selected should serve to show the primary importance of individual initiative and the happy freedom of choice which surrounds most of our scientific and industrial work.

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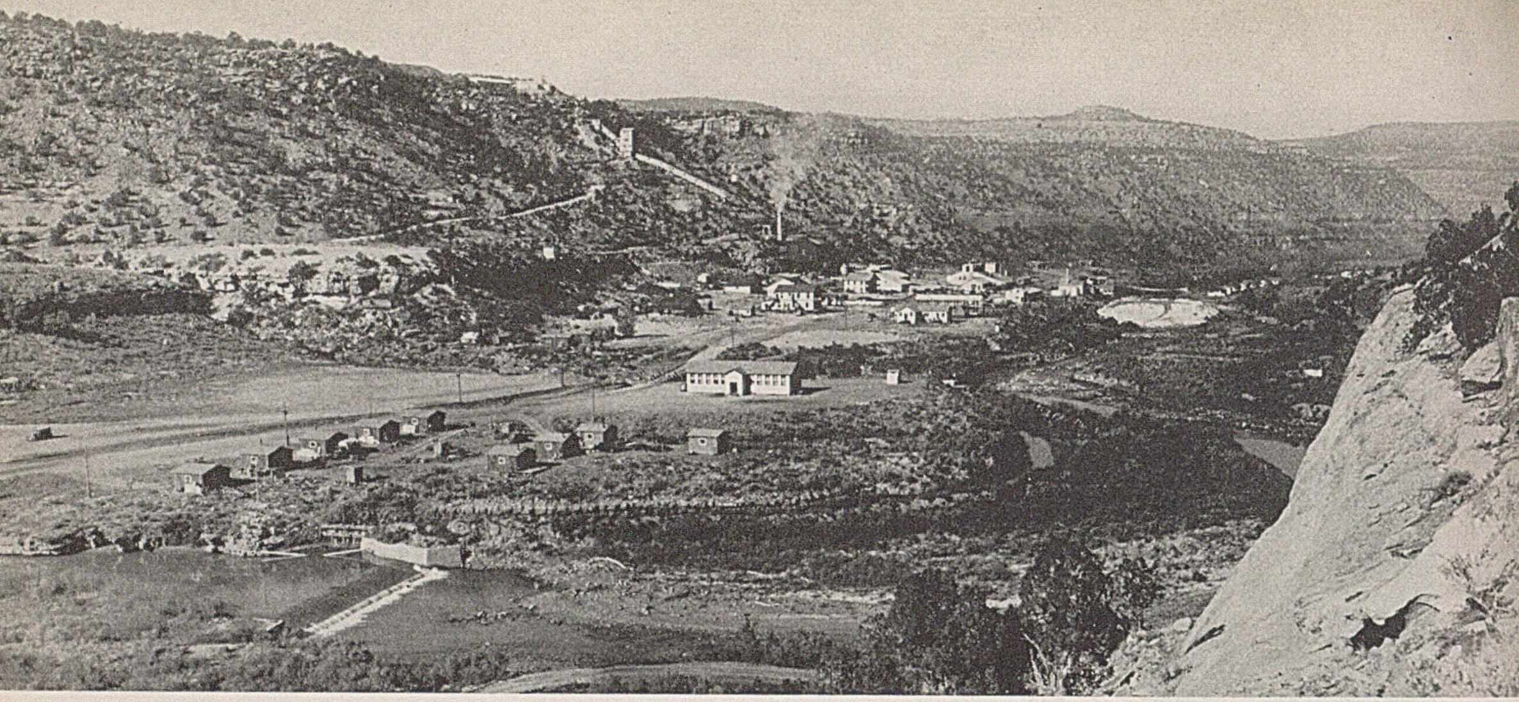


VANADIUM MINE AND PLANT AT URAVAN, COLO.

Courtesy, U. S. Vanadium Corporation

STRATEGIC RAW MATERIALS

F. J. VAN ANTWERPEN
60 East 42nd Street, New York, N. Y.

UNEQUAL geographical distribution of raw materials has created national monopolies. Monopolies cause international irritations, and irritations long continued lead to war. Those nations which become involved in war have double need for raw materials to maintain efficient military and industrial machines. Nations at peace also suffer from lack of industrial raw materials because trade with the belligerents becomes impossible. The purpose of this article is to examine the raw materials imported into the United States, both as to need and quantity, and to point out what is yet to be done toward attaining independence of foreign suppliers. Those nations with great quantities of necessary raw materials have the greatest possible chance of protecting these possessions, unless some vitally strategic imports are shut off. If this happens to any nation, human resourcefulness in developing and adapting substitutes may often assure continuance of supplies.

In this study imports will be examined to see whether the United States is dependent for any material which, if the foreign supply were stopped, would cripple industry. Industrial rather than military requirements are stressed in this analysis since armed forces depend to a great extent upon normal commercial developments. By comparing the years 1926 and 1937 (Table I) the change over twelve years may be analyzed, and an attempt is made to explain the varying dependence.

Tables II, III, and IV show the three classifications of important raw materials. Table II lists those principally imported, and each is given a separate analysis. The Army and Navy munitions boards list several other materials which have not been included here but are considered by them to be strategic. They are coconut shells, coffee, hides, manila fiber, mica, optical glass, quartz crystal, silk, and wool. These have been developed as short paragraphs in the body of the article and no statistics are quoted, for normally statistics of these materials are either too small to be significant, or are misleading unless broken down into special cases.

ANTIMONY

Industrially, antimony is important through its use in many alloys—type metal, britannia metal, Babbitt metal, battery plates, hard lead, and white metal alloys. Military importance comes from its use in shrapnel, primers, lead shot, and tracer bullets. As a sulfide, antimony is used as a range finder in gunnery, for upon the explosion of shells containing it, dense clouds of white smoke are formed.

Table II indicates that our dependence for antimony is almost complete and is increasing slightly. This is not so alarming in 1937 as it was in 1926, for in the latter year our main supplier was China; in 1937 it proved to be Mexico. China still ships us more regulus or metal than any other country, but the antimony content of the ore we receive from Mexico for smelting here is about 60 per cent of our total consumption. The total amount of antimony from ore and metal received from China is only 5 per cent of our consumption. Latin American countries are becoming important producers, and in 1937 the antimony content of ores shipped to us from Latin America was: Mexico, 18,220,000 pounds; Chile, 3,414,000; Bolivia, 2,094,000; Argentina,

Table I. Imports, Exports, and Production for 1926 and 1937 (in Thousands of Pounds) (*19–25*)

	1926						1937					
Name	Imports	Exports	U. S. production	U. S. consumption[1]	Production, % of consumption	Dependence on imports, % of consumption	Imports	Exports	U. S. production	U. S. consumption	Production, % of consumption	Dependence on imports, % of consumption
Antimony	43,638	...	4,766[2]	48,404	10	90	29,724	874	2,532[3]	31,382	8	92
Asbestos	516,000	2,210	2,716	516,506	...	100	614,376	6,008	27,792	636,160	4	96
Asphalt	284,000	76,500	...	8,656,000	...	...	1,920,002[p]	417,514[p]	5,608,242[p]	7,110,730[p]	98	2
							57,326[n]	37,012[n]	970,768[n]	991,082[n]	98	2
Bauxite	630,000	196,000	880,000	1,324,000	67	33	1,110,000	271,000	926,000	1,765,000	53	47
Camphor	2,018[c]	...	...	6,132	...	100	1,912[c]	0	0	1,912	...	100
	1,170[r]						1,016[r]	0	0	1,016	...	100
	2,944[s]						1,828[s]	...	...	...	...	...
Cement	1,210,000	366,000	62,000,000	62,844,000	98	2	680,000	142,000	44,500,000	45,038,000	99	1
Chrome ore	481,178	...	316	481,404	...	100	1,215,000	0	5,140	1,220,140	0	100
Cinchona bark	3,906	...	...	3,906	...	100	84	0	0	84	0	100
Cobalt	875	...	...	875	...	100	1,661	0	0	1,661	0	100
Copper	779,441	965,685	1,750,000	1,563,756	112	...	574,724	691,168	1,675,540	1,559,096	108	0
Cryolite	17,000	7,834	...	9,166	...	100	36,600	0	0	36,600	0	100
Fluorspar	152,000	...	257,314	409,314	63	37	74,126	916	362,460	435,670	83	17
Graphite	32,387	810[4]	10,939[5]	39,042	28	82	59,186	2,028	...	...	...	...
Iodine	711	...	...	711	...	100	1,785	0	299	2,084	14	86
Iron ore (million lb.)	5,700	1,940	151,500	155,200	97	3	5,330	2,760	160,000	162,570	98	2
Lead	310,722	142,481	1,391,660	1,559,901	89	11	71,806	40,182	886,284	917,908	97	3
Magnesite	185,092	...	267,000	452,092	59	41	107,638	0	406,874	514,512	80	20
Manganese	800,000[1]	...	456,000[1]	1,263,600	36	64	982,000[1]	0	338,000	1,320,000	26	74
Mercury	2,146	9	572	2,709	21	79	1,438	35	1,250	2,653	47	53
Molybdenum	...	...	1,371	1,371	100	...	7	14,709	29,419	14,717	200	0
Nickel	45,500	3,138	615[2]	42,977	1	99	108,871	8,947	438[3]	100,362	0	100
Opium	144	...	...	144	...	100	183	0	0	183	0	100
Phosphate rock	38,900	1,671,000	7,200,000	5,567,900	129	...	29,500	2,330,000	9,400,000	7,099,500	134	..
Platinum (troy oz.)	114,968	13,471	286[2,6]	103,661	0	100	148,809	62,441	9,997[3,6]	96,365	10	90
Potash	532,560	...	46,732	579,292	8	92	702,234	65,742	567,000	1,201,492	48	52
Quinine sulfate	97	...	...	97	...	100	83	...	...	83	0	100
Rubber	980,000	50,000	...	930,000	...	100	1,287,105	106,316	...	1,180,789	0	100
Salt	121,455	317,816	14,800,000	14,360,729	104	...	102,082	140,222	18,483,128	18,444,988	100	0
Sulfur	...	1,302,000	4,250,000	3,948,000	108	...	875	1,470,000	6,030,000	4,560,000	132	0
Tin	173,516	4,320	16[2]	169,180	0	100	194,000	690	[3]	193,310	...	100
Tungsten ore	6,190	29	2,766	8,927	31	69	10,190	...	7,000	17,190	41	59
Vanadium	1,940	...	661	2,601	25	75	1,259	...	1,086	2,345	46	54
Vanadium ore	16,800	...	43,200	60,000	72	28	14,806	...	262,160	276,966	94	6
Zinc	29,295	304,238	1,223,982	939,039	130	...	76,372	17,042	1,102,330	1,161,660	95	5

[1] Estimated.
[2] Does not include secondary recovery: antimony, 37,400,000 pounds; nickel, 6,100,000; tin, 64,000,000; platinum, 38,795 troy ounces.
[3] Does not include secondary recovery: antimony, 24,680,000 pounds; nickel, 4,800,000; tin, 59,718,000; platinum, 55,926 troy ounces.
[4] Exported 3,474,000 pounds of synthetic graphite.
[5] Manufactured 21,164,000 pounds of synthetic graphite.
[6] Includes Alaska.
[c] Crude. [n] Natural. [p] Petroleum. [r] Refined. [s] Synthetic.

Table II. Materials Normally Imported to a Major Extent

Material	% Dependence on Imports 1926	1937	Material	% Dependence on Imports 1926	1937
Antimony	90	92	Mercury	79	53
Asbestos	100	96	Nickel	99	100
Bauxite	33	47	Opium	100	100
Camphor	100	..	Platinum	100	90
Chrome ore	100	100	Potash	92	52
Cinchona bark	100	100	Quinine	100	100
Cobalt	100	100	Rubber	100	100
Cryolite, natural	100	100	Tin	100	100
Graphite, natural	82	..	Tungsten ore	72	59
Iodine	100	86	Vanadium	75	54
Manganese	64	74	Vanadium ore	28	6

Table III. Materials Normally Imported to a Minor Degree

Material	% Dependence on Imports 1926	1937	Material	% Dependence on Imports 1926	1937
Asphalt, natural	..	2	Iron ore	3	2
Asphalt, petroleum	..	2	Lead	11	3
Cement	2	1	Magnesite	41	20
Fluorspar	37	17	Zinc	0	5

Table IV. Materials Normally Exportable

Material	Production, % of Consumption 1926	1937	Material	Production, % of Consumption 1926	1937
Copper	112	108	Salt	104	100
Molybdenum	...	200	Sulfur	108	132
Phosphate Rock	129	134	Zinc	130	95

1,962,000; Peru and Panama, minor amounts. The output of Bolivia is capable of greater expansion which makes our situation more comfortable from an economic and military standpoint.

The extent of reserves in the United States is not certain, and the quantity produced domestically, mostly from crude lead, is too small to satisfy our requirements. Recovery of secondary antimony is large and almost equals the consumption of virgin metal.

Experiments are now in progress for the utilization of complex antimony ores containing precious metals, but there is still a question as to whether the natural reserves are extensive enough to guarantee independence, even under favorable economic conditions.

ASBESTOS

No change in our dependence upon imports of asbestos has occurred in the past decade. In 1926 we produced 0.5 per cent of our consumption and in 1937 we supplied only 4 per cent. Our reliance upon outside sources is a matter of economics; it is cheaper to import from Quebec than to ship from our principal deposits which are in the Southwest. These reserves are probably large (*12*), and there are a number of potential mines. But they are not being operated because the material is not as clean or desirable as that obtained from the Canadian deposits, and the long haul to market adds to the cost. The Quebec belt of asbestos, mainly chrysotile, extends into Vermont, and most of the asbestos produced in the United States comes from there. The utilization of this deposit is becoming increasingly important, for the material is of the same quality as that in Canada. Proved resources which from time to time have produced asbestos for domestic use exist in Arizona, California, Maryland, Montana, Idaho, Washington, and Georgia.

The principal uses of this material are in asbestos-cement products, asbestos paper, millboard, brake linings, high-temperature insulation, and to a smaller extent, in woven materials. The past decade has seen a change from the woven brake linings to the molded type. Total consumption of asbestos has not altered through this practice, for it is used in both types of brakes. The molded types utilize a shorter fiber, and in this manner our dependence on long-fiber asbestos, which is imported from British Africa, may be reduced.

Mineral substitutes such as rock wools, slag wools, and rock corks have been on the market for a number of years and are used in low-temperature insulation. Glass wool cloth is being developed to replace asbestos in electrical appliances but has not found extended use. No substitute has yet appreciably altered our consumption of asbestos.

Replacements for brake linings are not known, but reserves of asbestos for production of the molded type are available in the United States; reserves of spinning fibers, our smallest item of consumption, are located in Arizona and Maryland. There is no great hope for future development of the large southwestern deposits, for prices, freight costs, and requirements of evenness of quality form an economic burden too heavy to shoulder in the present market.

BAUXITE

Our dependence upon extraterritorial deposits of bauxite for about 40 per cent of our consumption has changed little over the past twelve years and only the comparative richness of the foreign ores leads us to import at all. Like many of the materials imported into our nation a slight price increase would make our many marginal and submarginal deposits workable without necessitating major technological changes in manufacturing operations (*12*).

Packing Synthetic Camphor after Flaking

Courtesy, E. I. du Pont de Nemours & Company, Inc.

The aluminum industry is the largest single consumer of bauxite, using about 50 per cent of our yearly supply. The manufacture of chemicals, abrasives, cements, and refractories accounts for the other 50 per cent (*32*).

Strategically our only concerns are the supply of cryolite and the present production capacity of aluminum plants. Aluminum consumption has increased rapidly, and despite the recession in 1937 more aluminum was used in the United States during that year than ever before. Totals for 1937 rose above those of 1929 in primary and secondary production, almost a fourfold increase in consumption over the low of 1934. Only by increasing output through additional production units could we meet emergency demands, and because aluminum manufacture requires an immense amount of electrical energy, the time necessary for the completion of power plants becomes the critical factor (*36*). At present, expansion programs are under way in the aluminum industry which will probably eliminate plant capacity as a vital strategic problem.

CAMPHOR

The most important and certainly the most strategic essential oil is camphor. Japan has a monopoly on the natural product "obtained by distilling the wood of an evergreen tree of the laurel family found in Formosa, Japan proper, and southern China." The price and production are controlled by the Japanese Government (*35*), and only the success of Germany early in the twentieth century in producing synthetic camphor relieved the world of sole dependence upon Japan and attendant high prices. The price of natural camphor has steadily dropped in an unsuccessful attempt to discourage synthetic producers.

In 1932, with the price of natural camphor about 29 cents a pound, and with tariffs of 1 cent per pound for crude and 5 cents for refined and synthetic, production of the synthetic material began in the United States (*7*). This industry, which owes its life to the efficiency of modern chemical engineering, has to date successfully kept pace with the lowering price of natural and imported synthetic camphor.

The Tariff Act of 1930 (page 51) states: "If at the end of three years after the enactment of this Act, the President finds that during the preceding six months the domestic production by quantity of synthetic camphor did not exceed 25 per centum of the domestic consumption thereof by quantity, or, at the end of four years .... that during the preceding six months such domestic production did not exceed 30 per centum of such consumption, or, at the end of five years..... that during the preceding six months such domestic production did not exceed 50 per centum of such consumption, he shall by proclamation so declare, and, after six months thereafter, the rate on synthetic camphor shall be 1 cent per pound."

A committee reported to the President on each occasion and for each period when domestic industry, working under a duty of 5 cents a pound to offset high American labor costs, met the requirements. Production figures for synthetic camphor are not available, but annual output is believed to be well above 1,500,000 pounds.

Camphor's most important use is as a plasticizer in the manufacture of nitrocellulose plastics, at one time utilized in laminated glass as well as in molded articles and films. The present trend is toward plastics which do not require camphor; although the production of nitrocellulose products is not decreasing, other raw materials—notably cellulose acetate, cellulose ethers, and synthetic resins—are being used in most of the recent plastic applications. Strategically camphor can no longer be considered important.

COBALT

All American requirements of cobalt, a cartel-protected material, are imported. Ordinarily this would be serious, but our total consumption for 1937 was less than 2,000,000 pounds, so this metal, on a tonnage basis, is relatively unimportant. Leading sources are Canada, Union of South Africa, Belgian Congo, and Australia. Future consumption may grow if the price falls, for the steel industries are making valuable industrial cobalt alloys and the decrease in cost would encourage use. The principal outlets of cobalt-iron combinations are for metal cutting tool steels and permanent magnets, although nickel aluminum magnets are replacing cobalt types to some extent.

The chief use of this material is the production of color in pottery and glass. Depending on the amount added, light blue to deep blue tones are obtained, and in flint glass, small amounts act as decolorizers (*30*). This element is relatively new to industry and experiments now in progress with plating, glazing, and mordanting may increase its fields of application.

CRYOLITE

The Danish State owns and controls the one known commercial supply of natural cryolite (*32*). Only at Ivigtut, Greenland, is it mined (*8*), and shipments are made to two distributors, one in Copenhagen and the other, the Pennsylvania Salt Manufacturing Company, in the United States. The latter used cryolite to manufacture soda and alum as early as 1865, and although cryolite is no longer used for this purpose, the company has maintained its contract.

The principal consumers are the aluminum industry, which uses cryolite as a solvent for bauxite in its electrolytic process, and the ceramic industry, in which cryolite is the base of an opaque glass resembling porcelain, for use in ceramic ware and vitreous enamels on steel. The 100 per cent dependence of the United States for its supply of this natural material is not critical or important, for the aluminum industry is now using artificial cryolite satisfactorily (*9*, *26*), and synthetic resins are being used to produce porcelainlike effects on metallic surfaces.

FERROUS ALLOYS

The importance of chromium, manganese, molybdenum, nickel, tungsten, and vanadium is due primarily to their use in ferrous alloys. Our dependence upon external producers for these metals is critical, for only tungsten and molybdenum are produced to any extent in the United States; the other alloying elements, silicon, zirconium, titanium, and copper, are either used in small amounts or are not strategic since they are produced in the United States.

The present tendency has been toward an increased use of alloying materials, nor is there any indication of a change in this trend. Therefore, in this section emphasis will be placed on the military nature of such materials.

Chromium. We are practically 100 per cent dependent for chromium. A small amount is produced in the United States, but relatively low-grade ores make it impossible for domestic producers to compete with foreign suppliers who have the advantage of richer deposits.

Iron-chromium alloys are necessary for production of such equipment as bearings, cutlery, crusher parts, valve steels, armor plate, and in applications where resistance to corrosion, especially at high temperatures, is necessary. The steel industry, which uses the greatest amount of chromium, requires a product containing 50 per cent or more chromic oxide (*12*), and it is unlikely that the mines of the United States could produce enough material of such quality to care for our normal requirements. The alloy-type ores come from Africa and New Caledonia; of our 1937 imports, Africa supplied 52 per cent, Cuba 12 per cent, and New Caledonia 11 per cent. The Cuban ore ought to be important strategically, but because its chromium content is low it cannot be used for alloying. Such ores are used in the manufacture of refractories and, next to steel, this industry is our largest consumer of chromium. Chemical manufacturing accounts for 13 per cent of our consumption, the compounds produced being used in electroplating, dyeing, and tanning (*27*).

From a military standpoint an accumulated supply of high-grade ore is a necessity. Recently the Navy commissioned a domestic producer to supply 2000 short tons of metallurgical-grade ore. This stock will be held in reserve for emergency use.

Partial substitutes for chromium are known, and molybdenum alloys are being used for high-temperature and high-pressure applications. However, substitutes (for many purposes there are none) will not make us independent of foreign chromium.

Manganese. The steel industry uses manganese as an aid in removing undesirable impurities from the molten steel and as an alloying element. It helps to desulfurize and deoxidize the furnace charge, and few pounds of steel are produced which have not been processed with manganese. In view of our great production of steel products, this metal is important. It would be desirable to have the major part of our consumption produced in this country, but the domestic sources are unable to produce manganese concentrates from our low-grade ores which will compete economically with the imported material. In an attempt to encourage domestic production, Congress imposed a tariff of 1 cent per pound of manganese in 1922. This was later reduced in the Brazilian trade agreement of 1935 to 0.5 cent per pound. The tariff aid was not successful because from 1922 to 1935 domestic industry produced only 5 per cent of American requirements for metallurgical-grade ore (*6*). In 1926 domestic production was 36 per cent of consumption and by 1937 this had dropped to 26 per cent.

There is an intense interest in the manganese problem of the United States, and many surveys have been made by individuals and societies. The American Institute of Mining and Metallurgical Engineers acknowledged the importance of the problem in 1925 and suggested a program designed to relieve the shortage an emergency could create (*1*).

Reserves of low-grade ore in the United States are large, and economical methods of extraction would eliminate manganese from the list of strategic materials. Leith and Liddell (*12*) estimated that the reserves of Spiegel in the Cuyuna Range of Minnesota alone are equivalent to the amount of ore which industry would consume in 36 years. From a military standpoint our domestic sources of high-grade ore are probably great enough to ensure a five-year supply.

Most of our manganese comes from Russia, the African Gold Coast, Brazil, and India. In 1937 Russia supplied about 41 per cent of our consumption, Africa 29 per cent, and Brazil and India each about 8 per cent. Cuba sent 13 per cent, an increase over the 4 per cent supplied in 1936 which was made possible through technological improvements.

MOUNTAINS OF MOLYBDENUM

Industry has been busy on the problem of developing an independent manganese supply, and processes of leaching manganiferous iron ores are now on the border line of being economical.

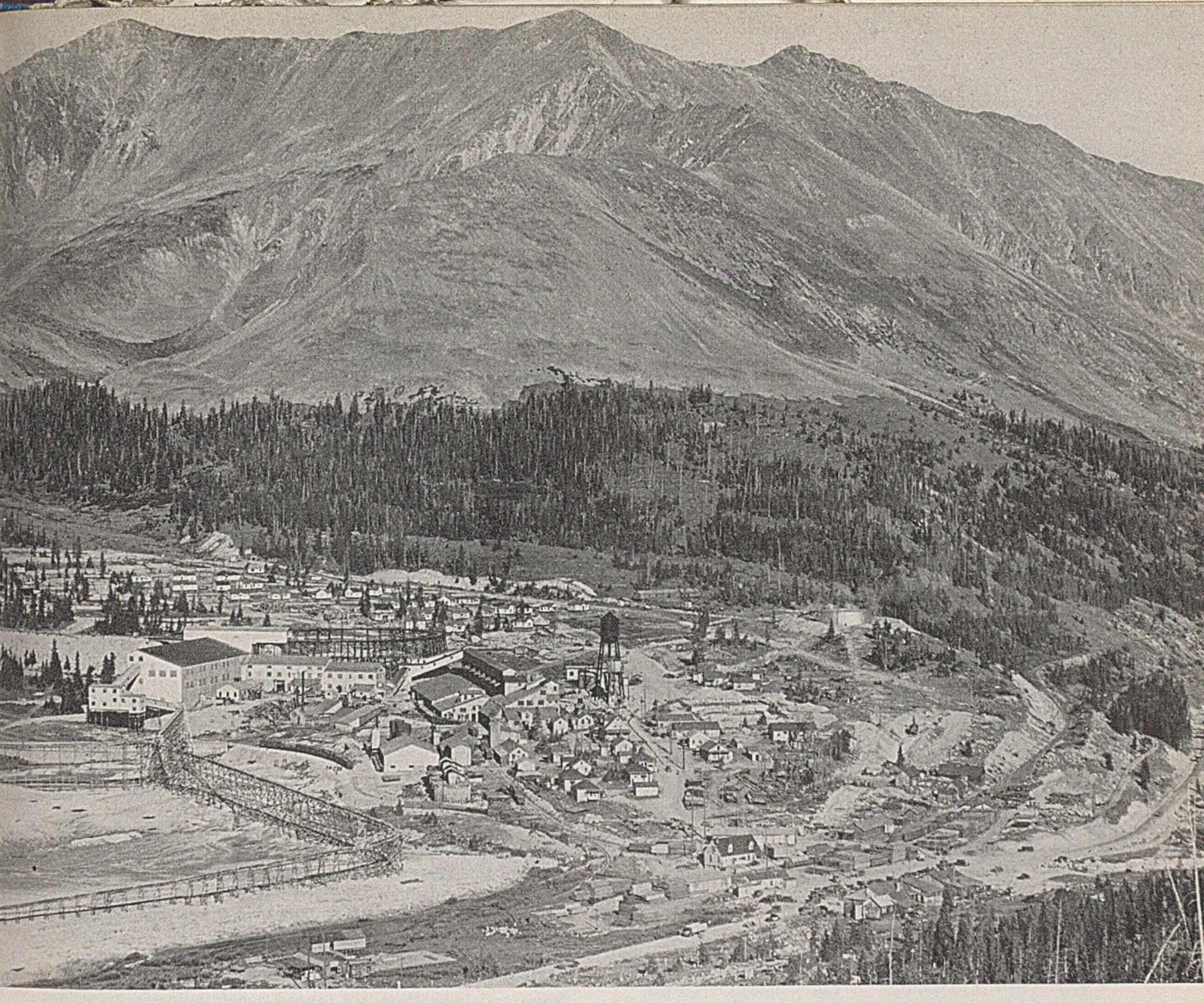
The United States Bureau of Mines has experimented with and developed an electrolytic process of recovering manganese in metallic form (*12*). This may prove to be economically sound, but until such processes are commercially feasible the United States will continue to be dependent upon foreign sources.

A continuing supply of manganese during an emergency is quite necessary with present steel-treating techniques, but variations are possible and they would undoubtedly be practiced. Increased costs due to war conditions would force manufacturers to substitute spiegel (*10*), silicon-manganese, and other manganese alloys for ferromanganese as they did during the World War. The committee of the A. I. M. M. E. (*1*) estimated that perhaps 15 per cent of our metallurgical needs could be supplied by low-manganese pig iron, and that from 15 to 50 per cent of our needs could be supplied by spiegel.

Steel manufacturers know how to use slag piles for the recovery of manganese, and this technique only awaits an emergency to become a source of supply (*28*). The use of low-manganese pig iron as the original charge in the furnace will provide another method of saving; it has even been suggested (*28*) that increasing the basicity of the slag by the inclusion of additional quantities of fluorspar would reduce the manganese compounds in the slag to metal. Germany and England have been using soda ash to desulfurize steel batches, and aluminum compounds have been employed as deoxidizers.

In an emergency the supplies of manganese from Cuba and Brazil may acquire vital importance; but before domestic production, plus that of Brazil and Cuba, could equal the amount of ore necessary for a wartime steel industry, a stringent shortage would occur. In view of this, a bill was introduced in the Senate recently to encourage storage of quantities of high-grade foreign ore within our borders. In this way our wartime steel industry could draw upon such reserve supplies while other sources were increasing their output.

NICKEL. The only large supply of nickel the United States ever had was a mine at Lancaster Gap, Pa., which in 1891 became uneconomical to operate in competition with the high-grade ores produced at the Sudbury Mine in Canada and the mines in New Caledonia. Since 1909 (*12*) no nickel has been mined in the United States. Although some is



Courtesy, Climax Molybdenum Company

produced every year as a by-product of copper refining, the United States is entirely dependent on imports.

In 1937, 108,871,000 pounds of nickel were imported; exports in the form of Monel metal, bars, sheets, rods, etc., were 8,947,000 pounds, and world production was probably not greater than 250,000,000 pounds. Therefore in 1937 the United States consumed about 40 per cent of the world's nickel; in 1926 this figure was 59 per cent. In these same years we produced about 0.5 per cent of the amount we consumed.

Our chief source of nickel is Canada, a friendly country, and it is difficult to imagine conditions which would shut off our supplies. However, in its surveys the Army considers only the United States as a source of material; for strictly military uses, consideration of normal stocks, secondary recovery, and domestic production has led Emney (*5*) to conclude that we could last through a state of seige of at least two years without imports.

The percentages of nickel used in various industries are as follows (*17*):

Nickel steels	55	Heat and electrical resistance	3
Monel, Inconel	12	Nickel, brass, bronze, and castings	3
Nickel-copper alloys	10	Nickel-iron alloys	1
Electrodeposition	10	Miscellaneous	1
Nickel cast iron	5		

It has been reliably estimated that over a period of time most of our nickel steels could be replaced by other materials. There is no known substitute for nickel in stainless alloys, but distinct savings of the metal could be effected by nickel plating.

The relative nearness of nickel deposits makes this metal less critically strategic than substances shipped from long distances, such as tin, manganese, and chromium; and it is possible to substitute nickel in several applications now consuming tin and chromium.

TUNGSTEN. Production of tungsten in the United States is apparently increasing, for in 1926 domestic sources supplied 31 per cent of our needs, and by 1937 this had increased to 41 per cent. American mines are aided by a tariff of 50 cents a pound and, as the table on the following page shows, price affects the amount produced (*11*, *29*, *30*, *32*).

Reserves of high-grade ore are estimated as equivalent to an eight-year supply, and although low-grade deposits are extensive no economical process of recovering the tungsten content is available.

Most of the tungsten imported into the United States comes from China, where the ore is plentiful, from the Malay Peninsula, and from Australia. China leads by far in the amount shipped to

Pine Creek Tungsten Mine near Bishop, Calif.

Courtesy, U. S. Vanadium Corporation

us, sending 68 per cent of the total imported; the Malay states and Australia account for only 18 and 6 per cent, respectively. Tungsten is used in the manufacture of steel for high-speed tools as the alloy is able to keep its cutting edge when heated, in electric light filaments, in magneto steel, in radio tube filaments, and in a few chemical applications. By far the largest use is in alloys, estimated at 90 per cent.

Year	U. S. Production, 1000 Lb.	Av. Price per Unit	Year	U. S. Production, 1000 Lb.	Av. Price per Unit
1926	2766	$11.10	1932	792	$ 9.20
1927	2328	10.37	1933	1790	9.58
1928	2416	10.40	1934	4098	14.57
1929	1660	13.13	1935	4790	13.37
1930	1404	12.09	1936	5224	14.83
1931	2808	11.02	1937	7000	19.50

An important substitute, or rather alternative, that is being used as an alloying element is molybdenum. Domestic reserves of this element are large. If necessary it could replace most of the tungsten used in steels. For example, Germany has limited the use of tungsten by edict and with apparently no difficulty has substituted molybdenum. In 1925 the subcommittee on tungsten of the A. I. M. M. E. (*1*) reported that "molybdenum steel, once made, has very desirable qualities. The difficulty is in making the steel. Molybdenum volatilizes, does not mix uniformly with steel; the steel is red-short, making an enormous scale loss." However, the decarburization of the steel was at that time overcome by the use of borax. The modern method utilizes heat treatment, and today molybdenum is being used successfully in considerable quantities.

From a military standpoint our tungsten resources should be conserved, and yet the mines must be kept operating so that war supplies will be available. A possible solution is the creation of huge military stock piles of foreign ore and tariffs favoring producers in Bolivia and Mexico. In this way South American mines will be available in case the Pacific Ocean shipping lanes to Asia are closed.

Vanadium. Although we imported only 6 per cent of the vanadium ore we consumed in 1937, we were dependent for 54 per cent of our supply of this metal. In other words, 94 per cent of the ore used was produced domestically and supplied only 46 per cent of the metal, and the 6 per cent of ore imported produced 54 per cent of the metal. In 1937 imported concentrates contained about 9 per cent vanadium; United States carnotite ores contained on an average about 2 per cent vanadium, and lower grade ores brought the percentage of contained vanadium even lower. Dependence upon foreign ores is apparently economic, for in 1936 we imported 71 per cent of the metal consumed. Activity of domestic producers reduced this amount to its present figure and indications are toward a continuing increase in production. Chief external sources are Peru and Africa. Peru has produced most of the world's supply for many years.

Vanadium is used principally to increase the elastic limit, yield point (*31*), and impact strength of steels. The effects produced by small amounts of vanadium are out of all proportion to the amount added, compared to other alloying materials. Vanadium oxide is a catalyst of increasing usefulness, particularly in the manufacture of sulfuric acid.

Amounts of vanadium consumed are small, but it is an important metal since no substitutes for it in alloys are known. Strategically the deposits of Peru are readily accessible, and domestic deposits are now greatly increasing their production.

The position of the United States in regard to ferrous alloys may be summed up in the following quotation (*2*): "While it would not be entirely proper to say in these days of resourcefulness that anything is indispensable, it is nevertheless true that without ferro alloys certain of our major industries would be set back at least a generation in their development."

IODINE

Prior to 1932 the world's supply of iodine came from Chile and Japan. The Chilean industry, which had a virtual world monopoly, derived its iodine from the nitrate deposits; Japan's source was the iodine contained in seaweed. There was no production of iodine in the United States, and consumers were forced to pay the pegged price of about $4.50 a pound. A monopoly-controlled production is always a shining mark for the chemist, and the discovery of a high content of iodine in certain petroleum well waters of the West Coast provided the opportunity for an American iodine industry. Production started in 1932, and for about a year the Chilean price stayed the same. Domestic producers would soon have captured the entire market of the United States, but prices were drastically lowered and by 1936 were less than $1.00 a pound. Even with this low price domestic producers supplied 30 per cent of our needs. We produced 65,000 pounds more in 1937 than in 1936, though this amounted to only 14 per cent of our consumption. Imports increased more than threefold which accounts for our lower percentage of production. The savings to consumers, due solely to the resourcefulness of this particular American chemical industry, is enormous, and prices are unlikely to rise again to their once exorbitant levels. If competition and low prices cause domestic producers to cease operations (a fear which led Army officials to keep iodine on their strategic list), a proved source of iodine will still exist in this country to ensure against foreign control.

MERCURY

The ratio of imports to consumption of mercury has decreased during the past decade. In 1926, 70 per cent of our mercury was imported, and by 1937 this had been reduced to 53 per cent. In order to compete with the foreign product, mercury production in the United States requires a protective tariff and relatively high prices. The duty amounts to $19.15 per flask which, using the average 1936 price, is equivalent to 25 per cent ad valorem.

Mercury comes from Spain, Italy, and Mexico, and the chief producing states are California, Oregon, Arizona, and Texas. Spain and Italy have a virtual monopoly on mercury production, and in 1936 a cartel agreement between the two countries was abolished. The price, however, is independent of the cartel, for production of both countries is sold through one source.

Domestic ores are not rich (*12*), and production is a matter of price. Our problem consists of ensuring a native supply for emergencies without unduly penalizing consumers during normal periods.

Mercury's chief uses are in drugs (*34*), chemicals, fulminates used in detonators and ammunition, electrical apparatus, thermometers, the manufacture of vermilion and felt, and to a minor extent in mechanical devices.

In equipment applications the use of mercury is increasing, but this cannot be said of other fields. Vermilion is being replaced by other pigments. Synthetic organic compounds are replacing mercury compounds as detonators, the use of felt is decreasing in men's wear, and organic synthetics are making great inroads into the amount of mercury used in drugs.

OPIUM AND QUININE

Opium and quinine are not produced in the United States, and we are solely dependent upon outside sources for these medicinal substances.

Quinine production is a matter of absolute advantage to certain countries, climatic conditions being favorable to the cinchona tree in limited areas only. Ninety per cent of the world's cinchona bark comes from the Netherland Indies where production and manufacture are controlled by bureaus of both planters and manufacturers (*36*). Quinine is used in the treatment of malaria and, until the recent advent of two synthetic substitutes, was the only drug known which had desirable inhibitory effects upon this disease. The synthetic compounds are atabrine and plasmochine. The latter has been reported as being more potent than quinine (*33*). Although the essential chemicals necessary for the manufacture of the substitutes are imported from Germany (*36*), there is no reason why American chemical manufacturers could not produce them, during an emergency, in quantities sufficient to supply our needs.

The poppy plant, from which opium is derived, depends on a national comparative advantage of cheap labor and localized demand, legal and illegal, in the Far East. The cheapness of labor is amply illustrated by the fact that the financial reward to a poppy grower in India is estimated at 25 shillings (about $6.00) for six months of labor (*4*).

The League of Nations has continuously made ineffective gestures toward control of this drug but as yet with little effect. It is possible that the only solution to this great social problem lies in synthesizing morphine, opium's most important constituent. Most of the alkaloids have already been synthesized, notably nicotine and papaverine. Codeine, which is prepared by the methylation of morphine, awaits only the synthesis of that compound.

The chief sources of opium are Great Britain and the Netherlands, who between them supply 89 per cent of our consumption.

PLATINUM

In 1917 the United States Government, with the help of the War Department and the Russian Embassy, smuggled 21,000 ounces of platinum out of Russia. This incident illustrates the need for platinum during a war period when a potential shortage for commercial use made this action necessary. Seemingly unimportant in commercial applications, platinum's many uses in chemical industry as a catalytic agent, in crucibles, rayon spinnerets, sulfuric acid spraying jets, and electrical instruments such as thermocouples, contact breakers, and switches, make it an important raw material.

However, the picture has changed considerably since 1917 when the main source of platinum was Russia. Today Canada, Colombia, and the United Kingdom supply us with most of our platinum. Canada ships platinum ore to England, and she, in turn, ships us the refined metal.

Other substances are being used in place of platinum (*3, 15*): vanadium catalysts in chemical industry, alloys of cobalt and silver in the electrical field, and alloys of nickel and of palladium for dental work. It has even been suggested that glass may replace platinum in rayon spinnerets. Platinum's use continues as one of convenience or necessity, for its high price has made it a metal for which substitutes are actively being sought. The speculative nature of the price of platinum has been important in recent years because the metal has been hoarded, instead of gold, as a hedge against inflation.

Strategically we are comparatively safe, for the platinum from the ores of Canada could, in an emergency, be extracted by our own refiners.

POTASH

Since 1926, when we produced only 8 per cent of our consumption, newly discovered potash deposits have increased this figure to 48 per cent. The discovery of these deposits is the result of a patient search conducted by the Geological Survey, the Bureau of Mines, and several private groups (*18, 31, 32*). Indicated reserves are large, and future developments are expected to add substantial amounts.

The most important consumer of potash is the American farmer, for it is vital to plant life. He uses about 95 per cent of our supply (*24*). The other 5 per cent is utilized by our chemical industries for such materials as caustic potash, potassium chloride, potassium carbonate, etc.; in these and other forms, potassium is used for the manufacture of soft soap, glass, and explosives.

Of the amount imported, Germany accounted for 66 per cent and the Netherlands shipped us 14 per cent. Material sent from the Netherlands probably originated in either France or Germany, so that the major amount of our imports are of German origin. However, American industry is capable of expansion to supply all of our needs in an emergency, and American farmers will never again face a shortage of potash through embargoes on imports.

RUBBER

The United States will probably never produce natural rubber, and its dependence upon importation will continue as long as it is economical to use Nature's product. Largest imports come from the Malay States and the Dutch East Indies, and minor amounts are supplied by Ceylon and Brazil. The major production of rubber is therefore under British and Dutch protectorate.

In the depression year of 1932 rubber sold for an average price of 3 cents a pound. Producers claimed this was below production cost and sought a method of protection. On July 1, 1934, the English, Dutch, French, Siamese, and Borneans entered into a five-year protective agreement, with options for renewal at the end of the period. The plan is evidently working, for prices have risen, and the average prices for three years were: 1934, 13 cents; 1937, 19.4 cents; 1938, 16 cents (approximately). The agreement has recently been extended for another five years (*16*).

The search for synthetic rubber has evolved several useful materials, Neoprene, Thiokol, Buna, and Soyprene among them. It would be too costly to replace the plantation product with that of the factory, but should an emergency arise which would cause the price to rise and remain at an exorbitant level, synthetic rubber would capture a large part of the market.

Courtesy, Intercontinental Rubber Company

HARVESTING 4-YEAR-OLD CULTIVATED GUAYULE SHRUBS, A SOURCE OF DOMESTIC RUBBER

Another source of rubber is the guayule shrub which grows wild in Central Mexico and has been cultivated to a limited extent in California. Results of the domestic venture are said to be technically successful but not commercially attractive at present. The wild plant requires about seven years to reach its rubber-producing stage, though this can be reduced to four under cultivation. The rubber produced contains about 20 per cent of resin, and although methods of extraction are known, uses today do not require its removal. Consumption of guayule rubber in the United States now amounts to about 6,000,000 pounds from uncultivated Mexican shrubs, and about 800,000 from domestic sources.

The principal use of rubber is in the manufacture of automobile tires, and attempts are being made to adapt the synthetic material to this use. The man-made product is already supplanting natural rubber for gaskets, laboratory equipment, and various other applications where its stability is useful.

Strategically America is in a critical condition because a leaf disease, which ultimately kills the tree, prevents the creation of South American plantations. As a natural material, adapted to the temperate zone, we have only the guayule shrub, and this, together with synthetic rubber and secondary recovery, must answer our emergency needs.

TIN

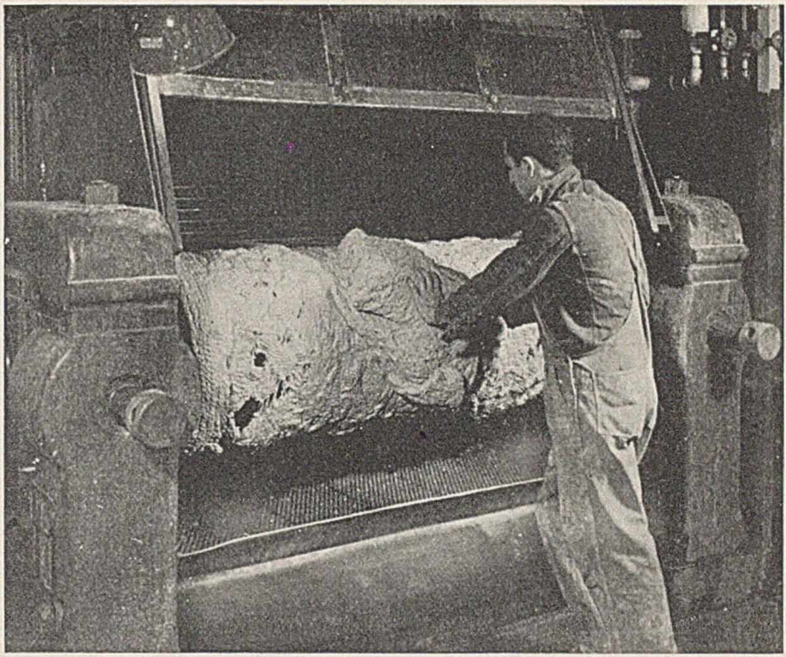
The production of tin in the United States (Table I) is almost entirely secondary and is recovered from metals, alloys, and chemicals. During 1937 Alaska produced about 380,000 pounds, the United States about 5760 pounds. In thirty-six years the United States has produced 291 long tons; in the past decade the minimum yearly consumption of primary tin was 35,478 long tons (*24*). The United States has no known suitable deposits or reserves. The British Straits Settlements are our largest suppliers, and in 1937 we received 86 per cent of the amount they produced, which was 76 per cent of our imports. Bolivia sent to us about one thousandth of our consumption, yet they produced about 38 per cent as much as did the Straits Settlements. However, Bolivia exports ore because she does not have the fuel for conversion, while most of our importation is tin that has already been refined. The United States smelts very little tin, and if our supplies of metal were shut off, necessity would require the building of an American tin-smelting industry. Strategically, though probably not economically, a tin-refining industry should be a part of the industrial structure of our United States.

The uses of tin are varied. The ubiquitous tin can uses almost half of our consumption, and solder, Babbitt and other alloys, foil, tubes, and chemicals make up most of the other 50 per cent. Military uses include tin metal in shrapnel and compounds of tin in flares and smoke producers (*5*).

Substitutes for tin are growing in importance. In bearing metals and bronzes, nickel may sometimes be used in place of tin. Recently bearings of synthetic resins, lubricated with water instead of oil, have shown promise abroad. For foil, cellophane is used, and tubes are now being made of aluminum. In the tin-plating industry possible substitutes are nickel and aluminum. We need only to examine the list of substances which are not suitable for packing in tin-lined cans to wonder why tin substitutes have not already come into more general use. Mantell (*13*) listed forty-eight foodstuffs which were packed in tin cans, and for twenty of them the container proved unsuitable. Resin linings are now used in beer cans, but because resins are injured by the high heat required for sterilization, they cannot be generally used for foodstuffs. However, this application is too new for its possibilities to have been exhausted. Enamel-lined cans have been in use many years for canning substances which cannot be packed in tin, and glass will continue to be an important, satisfactory food container.

Tin's importance rests upon the fact that it protects iron and that the technology of making cans has reached its high efficiency upon tin-coated ferrous sheets. A switch to substitutes would require a definite change in technology which might involve higher costs and a decreased use efficiency.

Tin is one of the great problems and weaknesses in our military strategy, and a serious effort should be made to perfect the use of substitutes and actively to import and smelt Bolivian ores.



Courtesy, E. I. du Pont de Nemours & Company, Inc

Rubber Mill for Washing a Domestic Synthetic Rubberlike Substitute

STRATEGIC MILITARY MATERIALS

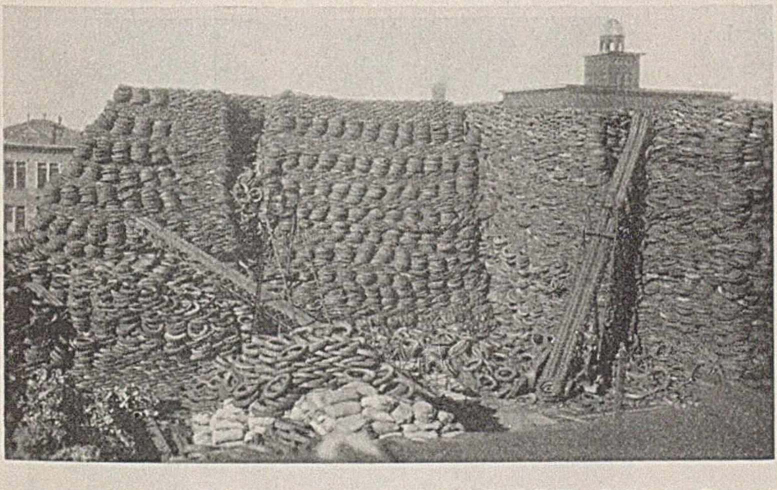
The strategic materials listed by the Army and Navy munitions boards must be considered in a military sense. Coconut shells are considered strategic because they produce a superior charcoal for gas mask use. Sources are the tropical countries indicative of a lengthy water transportation.

Coffee is a strategic material though it can hardly be classified as important or critical. Brazil is the world's largest producer. The only two reasons we would have to fear a shortage is war with Brazil, which is most unlikely, or a war which successfully throttles our Caribbean ocean transport. Any war which could shut off our supply of coffee would certainly bring with it a spirit of sacrifice capable of foregoing the pleasure derived from such a luxury.

About one third of the hides consumed in the United States are imported, so that this item is not seriously strategic. Substitutes for leather are finding greater use, and if necessity dictated the change, our present consumption could be reduced.

The commercial source of Manila fiber is the Philippine Islands, so that its availability during emergencies depends on the United States defense system. Cotton is an acceptable substitute; like all of our imported fibers, the most strategic item is the time necessary to introduce the substitute successfully.

Mica is an important insulation material and the United States has an ample supply of every form used except sheet mica. Imports of the other forms are great but only because of the cheap labor available in producing countries.



Courtesy, U. S. Rubber Reclaiming Company

Reclaimed Rubber Is a Domestic Source of This Raw Material

Optical glass and quartz crystal find outlets in scientific equipment, cameras, radios, etc. The United States manufactures about 50 per cent of its optical glass requirements and imports quartz crystal from Brazil.

Military uses of silk are in parachutes, insulation, and powder bags. Industrially it is a luxury which could be eliminated in extreme emergencies.

Wool is necessary for clothing, and the United States produces about two thirds of its consumption. It has few substitutes, but by curtailment of nonessential uses we could maintain our self-sufficiency.

In our analysis we have noted that certain of our strategic materials could be produced in the United States if price warranted. Such materials could be described as economically strategic to differentiate them from others which are not contained within our borders. As mentioned before, the munitions boards consider only the United States as a source of material during wartime. There is no consideration of possible imports or using sea lanes that are not at the mercy of the enemy. If during a war this were actually the case, economy would have no meaning, and many of the materials we now view as important strategically would be produced in sufficient quantities in the United States. In this category are the many processes, which are even now on the border line of being economical, for producing manganese from low-grade ores, the tendency of tungsten production to increase as price rises, and the recent drastic expansions in vanadium production.

Ferrous alloys are necessary for steel manufacturing, but it does not follow that a shortage of alloying material would bring a cessation of steel making. There are other methods and techniques which would be perfected and used as economic conditions warranted, though steel manufacture would become more complicated and costly. Strategically such practices ought to be perfected during normal periods, for in this manner changes brought on by emergencies can be made with a minimum of errors. The German program of *Ersatz* may not be economically sound but it is good military strategy.

Mercury is another substance which could be produced in much greater quantities in the United States if price warranted such expansion. Natural cryolite could be supplanted by the artificial product; and although it would mean an immense expansion of present domestic production capacity, asbestos could be produced in sufficient quantities.

Iodine is an economic strategic material to every country with access to the sea. If price warranted, iodine could be produced from kelp. Domestic production from petroleum brines is a matter of price. Bauxite and potash are also raw materials which a rising price would remove from our strategic list.

Three items now considered strategic may be removed by the combination of chemistry and efficiency. They are rubber, silk, and mica. At present it would take strained and unusual economic conditions to replace natural rubber with our chemical substitutes, but it is possible. Silk may be replaced by recently announced polymerization products for insulation and parachute uses, though there is no reason to believe that they are being considered for such applications, and by cotton and rayon for powder bags. Mica has an untried and new substitute in "Alsifilm", a coherent self-supporting film made from bentonite clays. Sheets may be produced in any size, and it is thought to use this material in place of sheet mica, the only mica product in which we are deficient.

The substances in which we are deficient or totally lacking are tin, nickel, chromium, antimony, platinum, rubber, silk, opium, quinine, Manila fiber, coffee, coconut shells, and sheet mica. It has already been noted how synthetic resins are being used for tin; domestic alloying materials for chromium and platinum, and organic substances for rubber, silk, opium, quinine, and Manila fiber. These substitutes, however, cannot totally replace the original materials, and to the problem of developing and perfecting such substitutes, American chemistry must devote unceasing attention.

The chemist and chemical engineer have in times past relieved the pressure created by lack of essential materials. In the last war, dyestuffs, coal-tar medicinals, potash, and nitrates were the critical materials. The United States now lacks none of these materials. Since the World War, America, with the help of chemical industry, has developed sources for the production of iodine and potassium. The chemical engineer has helped the chemist in the production of camphor and bromine.

The United States also has a program of *Ersatz*, but only because industry is free to challenge any economic setup it may choose, only because industry has not been standardized. If war should come it will find us a nation of immense resources both mental and physical. If war does not come the continuing process of change due to natural economic forces will steadily alter our dependence upon imported raw materials, creating thereby a strengthened industry.

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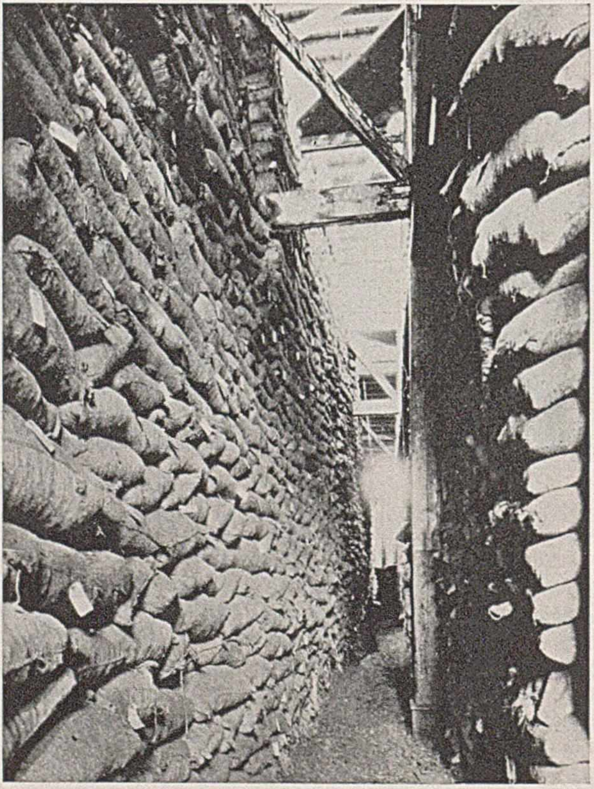
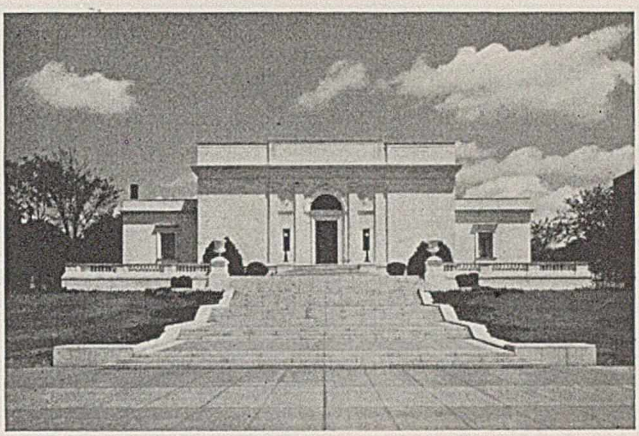
(22) *Ibid.*, 1928.
(23) *Ibid.*, 1936.
(24) *Ibid.*, 1937.
(25) U. S. Bur. Foreign and Domestic Commerce, Summary of Monthly Bulletins of Exports and Imports, 1926, 1937.
(26) U. S. Bur. Mines, *Information Circ.* 244 (1927).
(27) *Ibid.*, 6556 (1932).
(28) *Ibid.*, 6768–6772 (1934).
(29) U. S. Bur. Mines, Minerals Yearbook, 1927.
(30) *Ibid.*, 1935.
(31) *Ibid.*, 1936.
(32) *Ibid.*, 1937.
(33) U. S. Dispensatory, 22nd ed., p. 1526, Philadelphia, J. P. Lippincott Co., (1937).
(34) U. S. Tariff Commission, *Information Series* 21 (1920).
(35) U. S. Tariff Commission, *Rept.* 104 (1935).
(36) War Dept., Commodities Div., Planning Branch, Strategic and Important Critical Materials, Jan. 5, 1938.

Crude-Drug Warehouse for Storage of Cascara Bark from the Pacific Coast (see Following Article on "The American Way in Pharmacy")



THE AMERICAN WAY IN PHARMACY



In the American Institute of Pharmacy, Home of the American Pharmaceutical Association, Is Located a Laboratory for the Development of Drug Standards

GEORGE D. BEAL
Mellon Institute, Pittsburgh, Pa.

THE origin of many manufacturing industries of today may be found in earlier retail establishments. The operations of manufacturing pharmacy are duplicated in miniature in the prescription pharmacy, and on a large scale they serve the manufacturing chemist. They are evolved from the ancient art of the apothecary, who produced medicines, perfumes, and chemicals for domestic and industrial use.

Pharmacy in America is fortunate because it grew at a time when medicine was in the mood for becoming more scientific. Much of therapeutics was influenced by discoveries by the pharmaceutical profession of the character and constitution of drugs and of the manner of dispensing them. Scientific pharmacy outmoded the shotgun prescription by disclosing incompatibilities that invalidated its activity and by providing specifics that went direct to the seat of the trouble.

PROGRESS IN PHARMACEUTICAL TECHNOLOGY

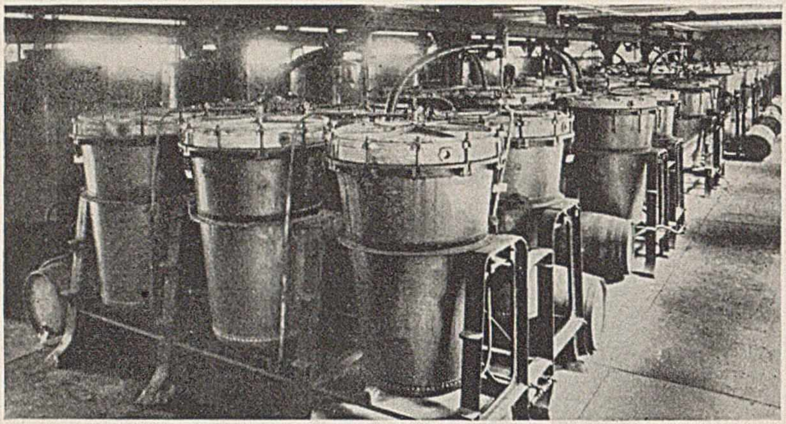
The progress of the pharmaceutical industry in America may be divided into five sections which greatly overlap. When this industry came into being, its dealings were with inorganic and vegetable drugs, and botanical explorations were extending the latter field. Hence we speak first of botanical exploration as active in nineteenth century pharmacy to about 1880. The development of mechanization, when machines began to replace hand operations, commenced about 1840 and grew most rapidly between 1880 and 1910. The demand for uniformity in strength of preparations, representing the inception of scientific control, began when people started to migrate from one part of the country to another. It agrees interestingly with the rapid growth of steam transportation after 1860. The trend to biological products, introducing bacteriological and glandular products and the vitamins, appeared about 1890. The replacement of natural products with those of the laboratory by actual chemical reconstruction parallels the progress of chemical science. The very active use of the laboratory in this way, however, comes so late in the last century that we may say that the role of chemical synthesis assumed importance in 1900.

INTRODUCTION OF DRUGS—BOTANICAL EXPLORATION

Pharmacy in America derived from the old world much of its fundamental science, a respectable part of the materia medica, and many of its traditions. It has grown independently because its pioneering spirit promptly scattered the citizenry over a continent where they had to depend in every way upon local resources. The aboriginal inhabitants through centuries of trial and error had discovered the medicinal value of various "teas" and poultices. How this knowledge was originally obtained no one knows. Perhaps there existed a "doctrine of signatures" similar to that of the old world, based on some crudely organized knowledge of anatomy. An old herbal states, for example:

> Walnuts have the perfect signature of the head; the outer husk or green covering represents the pericranium or outward skin of the skull, whereon the hair groweth, and, therefore, salt made of those husks or barks is exceedingly good for wounds in the head. The inner woody shell hath the signature of the skull, and the little yellow skin or peel that covereth the kernell is like the skin scarf that envelopes the brain and therefore it is very profitable for the brain and resists poisons, for if the kernell be bruised and moystened with the quintessence of wine and laid upon the crown of the head it comforts the brain and head mightily.

A number of vegetable drugs indigenous to North America have found an apparently permanent place in present-day medicine. Some of them have their counterparts in other portions of the globe as members of world-wide botanical families; others are merely alike in that each contains some member of a chemical family of active principles. There is a close similarity in the constituents and therapeutic activity of the American cascara,



Classical Form of Percolator, as Used in the Production of Fluid and Solid Extracts of Vegetable Drugs

The percolate may be concentrated in vacuum pans, or, as in the illustration, the percolators may be arranged in series, the extracting liquid, or menstruum, passing from the weaker to the stronger drug. As the drug in one percolator becomes exhausted, it is replaced with fresh drug.

Courtesy, Parke, Davis & Company

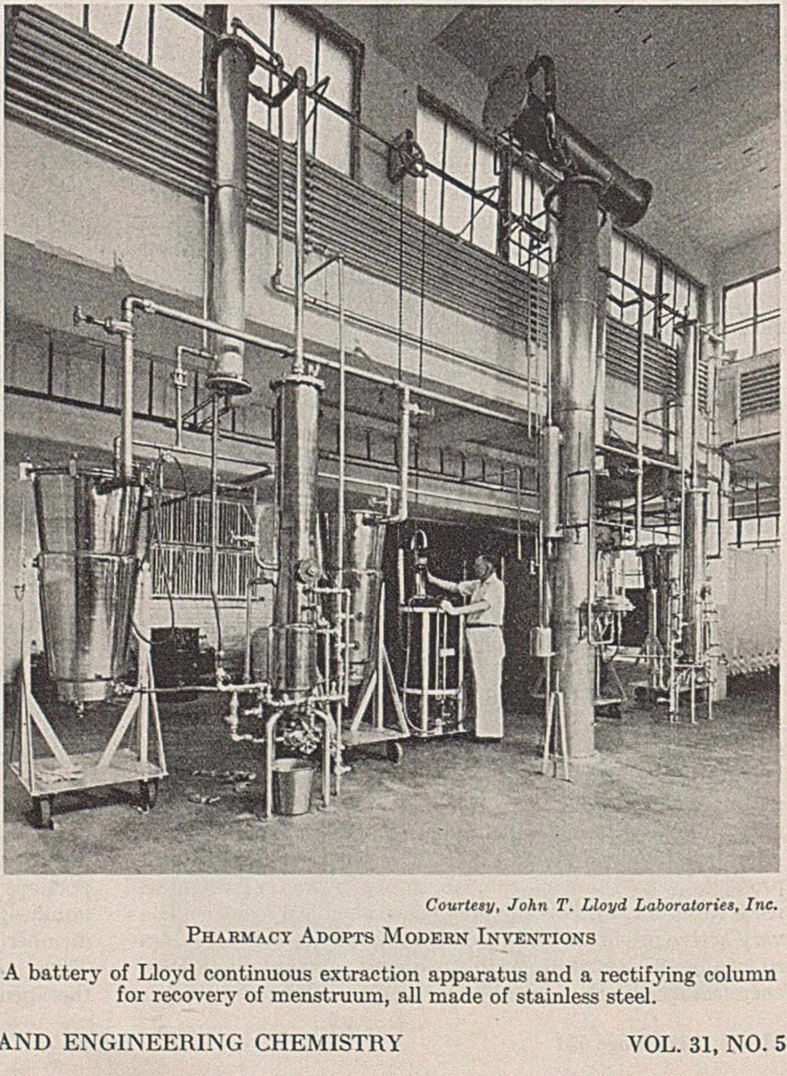
European buckthorn, Asiatic rhubarb, African senna, and tropical aloe; the five represent four botanical families, yet all depend upon derivatives of anthraquinone. The nineteenth century pharmacists were the first to give serious recognition to new drugs from the western hemisphere, other than coca, tobacco, and cinchona; and they could use botanical descriptions prepared by a brilliant group of taxonomists who, in the first half of that century, had settled in every part of the country to be civilized. A wealth of new material was described scientifically, and its uses in the primitive medicine of the interior were related. Pharmacists acted as agents for collectors of these crude drugs and experimented in the manufacture of medicinal preparations therefrom.

DEVELOPMENT OF MECHANIZATION

Centralized chemical manufacturing operations were fairly well known at the beginning of the nineteenth century, but one venture in particular should be mentioned here as being especially significant in pharmacy. In 1812 was founded the firm of Farr and Kunzi; later it was known as Powers and Weightman. Then through merger it became the Powers-Weightman-Rosengarten Company, the Rosengartens having begun operations in 1829. Now by final consolidation it appears in the form of Merck & Company, Inc. It was well toward the middle of the century before drugs and chemicals were powdered other than in a mortar. At that time Charles Hagner, a paint grinder of Philadelphia, used a stone paint mill to pulverize cream of tartar.

Percolation apparatus was used in France in 1813 for the clarification of sugar solutions by bone black. In 1815 it was applied to the extraction of drugs by Count Real, but European pharmacists preferred to make their tinctures by maceration and America held to the tradition. Within a few decades it was taken up by some of the earlier pharmaceutical educators and researchers, notably Procter and Squibb; the efficiency and the permanency of such preparations were established, and the groundwork was thus laid for the beginning of modern pharmaceutical manufacturing.

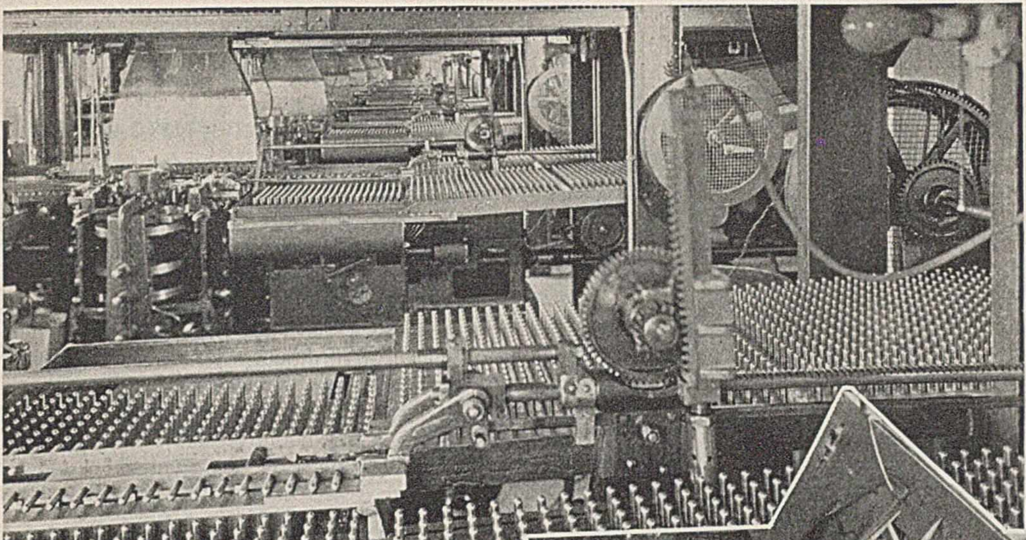
Even with this impetus, percolation was not accepted quickly, owing to a fear of destruction of active principles by heat during concentration. (Parke, Davis & Company during the '70s produced their fluid preparations of drugs by maceration and expression, advertising "we neither percolate nor use heat in any form.") With the improvement of grinders and evaporators the process became popular, however, and resulted in the development of some of the first large-scale manufacturing apparatus used in pharmacy. Squibb's "fractional percolation" was an early modification, emphasizing countercurrent flow, to obtain a fluid extract of high concentration without evaporation. Later develop-



Courtesy, John T. Lloyd Laboratories, Inc.

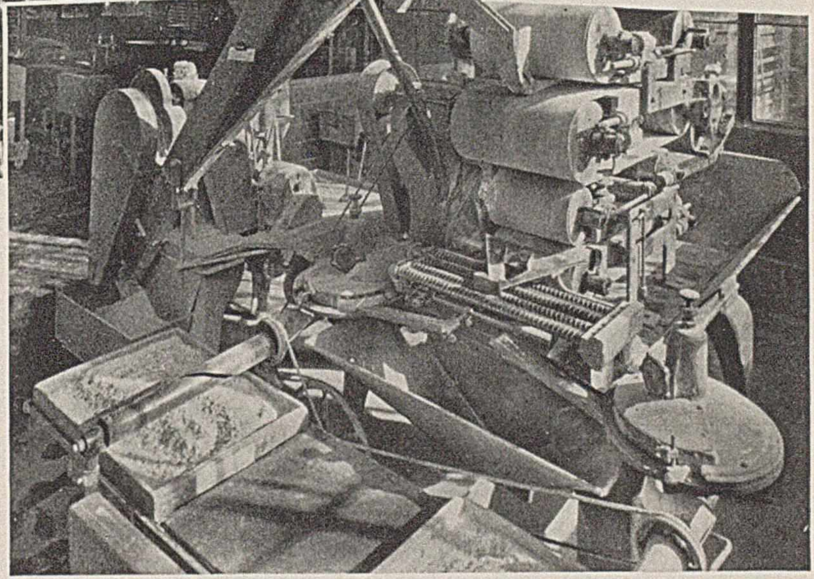
Pharmacy Adopts Modern Inventions

A battery of Lloyd continuous extraction apparatus and a rectifying column for recovery of menstruum, all made of stainless steel.



(*Left*) MANY HANDS WOULD BE REQUIRED TO FILL THE GELATIN CAPSULES PRODUCED BY THESE EIGHT UNITS IN THE PLANT OF A LEADING PHARMACEUTICAL MANUFACTURER

Each unit has an average daily capacity of 250,000 empty capsules.



(*Right*) PILLS OF ABSOLUTE UNIFORMITY ARE ROLLED BY THE MILLION IN THIS AUTOMATIC PILL MACHINE

The pill mass is fed from a hopper. It is cut into the required size and rolled into balls which pass between the upper belts, where they are rolled into long narrow cylinders. These are cut into segments of the required length and passed between the lower belts, where they are formed into small round pellets. The corrugated rolls in front discard those of incorrect size. The attachment in the right foreground converts the soft round pills to ovals when desired.

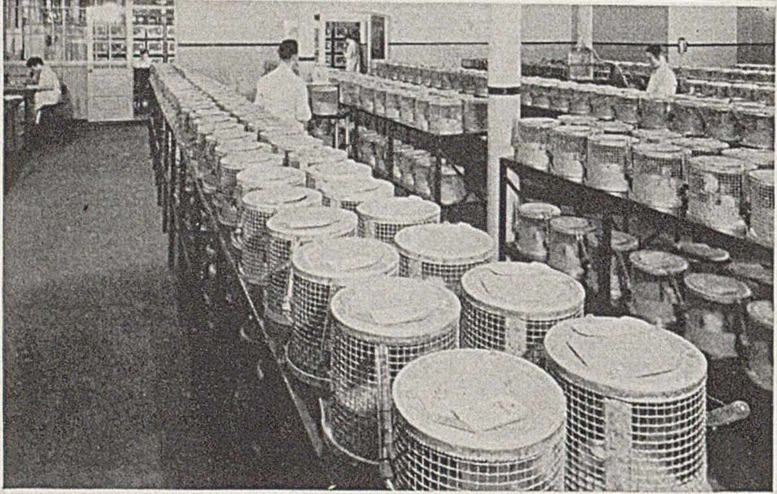
Courtesy, Parke, Davis & Company

ments have included recirculation of the percolate, pressure percolation, vacuum percolation, and continuous percolation after the manner of Soxhlet. One of the most useful developments based on the continuous system was made by John Uri Lloyd who combined, in one sealed system, percolation, concentration of the percolate by surface evaporation, and recovery of menstruum from the exhausted drug by steam distillation.

The preparation of concentrated extracts of vegetable drugs has passed out of the hands of the retail pharmacist almost entirely, although he uses them extensively in compounding prescriptions. Because they lend themselves very well to the use of large-sized equipment, even the average manufacturing establishment is turning its production over to a few specialists in crude drugs and drug extraction as a matter of economy. Although we have gone a long way in the production of plant educts of high purity, such as alkaloids and glucosides, a great opportunity still remains for improvement of methods for the preparation of the common drug extracts, which are often more useful therapeutically than the purified active principles. The extracts as they are known today contain in general far too much inert material. Substances that have been separated in living tissue by cell walls may be antagonistic chemically when brought together by a common solvent. The selection of a menstruum for an extraction must be based upon other than mere total solvent power. Nineteenth century pharmacy knew only alcohol, glycerol, and water as neutral solvents. Research in the use of solvents in pharmacy is being stimulated by the large number now being introduced into other industries.

In mechanizing pharmaceutical operations, the profession has developed, adapted, and borrowed in most ingenious fashion, and its equipment has frequently been adopted by others. Some of its mechanical hands work to the greatest advantage in the bulk production of pills, compressed tablets, and gelatin capsules. Not only do these mechanisms approach perfection in the smoothness and speed with which they operate, but their precision is such that they can work to a much closer tolerance of weight and composition than can the hand of the dispensing pharmacist. Yet they contribute to the progress of pharmacy rather than to unemployment. The weighing of raw materials, and the inspection and control of the finished product still remain in the hands of the skilled pharmacist. The precision of the machine is such that the quantity of batch can be computed almost to a single pill, but the weighing of a potent alkaloid or the standardization of a solid extract cannot be done mechanically.

The mixing equipment for a pill batch is like the dough mixer of the bakery, the revolving



(*Above*) Preparation of Culture Media in a Biological Kitchen; in the Left Background Is a Specially Designed Autoclave for the Sterilization of Media, Cultures, and Utensils

(*Below*) The House of a Thousand Cages

In the test rooms for the assay of vitamin preparations, each rat is of known history and is fed according to the requirements of the individual assay procedure. Vitamins A, B_1, B_2 (G), and D are routinely tested by this method.

kettles for sugar or chocolate coating came from the candy maker, but the machines that transform the doughy mass first into "pipes" of carefully controlled diameter and finally reduce them into slugs that, rolled between eccentrically moving belts, produce the pills, are inventions of the pharmaceutical industry. At one time the prescriptionist impaled pills one by one on a needle and dipped them into gelatin solution, then carefully sealed the pinhole; today by an interesting arrangement of suction bars, hundreds of pills are hemispherically coated at one dip and transferred to a second similar bar, where the coating is completed. The production of rolled pills requires the use of a plasticized binder, and the latter when dehydrated may confer upon the pill the physical properties, including resistance to disintegration, of a bullet. This development has led to the extensive substitution of compressed tablets, in which dry binders may be used. Automatic machines evolved for the purpose stamp out compressed tablets at extremely high speeds, and the utility of these machines is such that they have been introduced into many other industries. A specific example is the stamping of tablets of molding powders for use in the plastics industry.

INCEPTION OF SCIENTIFIC CONTROL

Progress in extraction led to the desire for adequate standardization of extracts, for the establishment of drug strength, or for the control of potency. The first standard could be purely arbitrary—for example, the ratio of 1 cc. of preparation to 1 gram of drug, which generally represents the most concentrated liquid extract manufactured, the fluidextract. The concentration of percolates may lead to decomposition, the aging to oxidation or hydrolysis; different lots of a crude drug may vary in potency and require the assay and adjustment of strength of many preparations.

Standardization is one of the greatest contributions of the manufacturers who became active during the last half of the nineteenth century. Since the majority of their operations were initiated, supervised, and carried out by pharmacists, they were done as far as possible in accordance with the art of the apothecary. Standardization of procedure thus preceded standardization of product. The private journal of Edward R. Squibb, the founder of E. R. Squibb and Sons, shows that at that time his interests were largely in process standardization (Volume 9, begun in 1869; earlier volumes were lost in a fire). He records, among many others, data on ether and the density of alcohol (the Squibb pycnometer is widely used today); menstrua for drug extractions and data on thirty or more vegetable drugs, including such important ones as cinchona, senna, aconite, hyoscyamus, jalap, nux vomica, gentian, cascara, and belladonna; the assay of opium; and data on chloral, cocaine, chloroform, bismuth salts, amyl nitrite, ethyl iodide, and atropine. This firm was also known as an early producer of standardized ergot preparations.

Organized as Parke, Duffield & Company, in 1867, the name was changed to Parke, Jennings & Company in 1869, and the firm was reorganized as Parke, Davis & Company in 1875. According to early price lists, this firm began the manufacture of standardized extracts in 1879 with "Liquor Ergotae Purificatus", a "purified" solution of ergot. At that time the active principle of this drug was thought to be sclerotic acid, and the rubric for the preparation read "10 cc. of the normal liquid require, for complete precipitation, 100 cc. of a solution containing 1 per cent of crystallized lead acetate." In 1883 their price list contained some twenty "normal liquids", which were really standardized fluidextracts; most of them represented alkaloidal drugs, such as belladonna, hyoscyamus, stramonium, nux vomica, and ipecac. Some of these early alkaloidal assays were empirical and were merely the determination of nitrogenous bases by titration with potassium-mercuric iodide, the well-known Mayer's reagent. Under the leadership of A. B. Lyons, however, the use of immiscible solvents in the "shaking-out" assay for alkaloids was developed nearly to the point it has reached today.

Eli Lilly & Company began the production of pharmaceuticals in 1876, and in 1884 Josiah K. Lilly initiated the standardization of tinctures and fluidextracts with reference to their alkaloidal content. This advance led to the establishment of a control laboratory in 1886, and to its analytical program was soon added research on new products and extraction methods. Among their important contributions to pharmacy has been their pioneer work on the commercial production of the active principles of ductless glands and on the cultivation of important vegetable drugs.

Alpheus P. Sharp, the first graduate of the Maryland College of Pharmacy, began the practice of pharmacy in Baltimore in 1845. In 1852 he accepted Louis Dohme as an apprentice and, after Dohme's graduation in pharmacy from Maryland in 1860, took him into partnership. A younger brother, Charles E. Dohme, became a member of the firm later. They believed implicitly in the importance of chemistry as one of the fundamental sciences supporting pharmacy. A program for research and scientific control was established in 1891, and the services of Charles Caspari, Jr., Alfred R. L. Dohme, and Herman Engelhardt were secured. During the same time a retail pharmacy which had operated in Philadelphia from about 1800, always in the same location, came into the hands of H. K. Mulford and expanded into pharmaceutical manufacturing. The Mulford Biological Laboratories became an important factor in the production of pharmaceuticals of biological origin. They were the first to offer diphtheria antitoxin commercially, pioneered in the production of smallpox vaccine, and have contributed many other important biological products. In 1929 the two companies merged as Sharp & Dohme, Incorporated.

Abbott Laboratories began in 1888 to manufacture a few standardized pills and tablets of alkaloidal salts and developed several specialties for the use of physicians. The interest of this company has always been with organic chemicals; hence it has been very active in the development of synthetic medicinal agents and with the production of vitamin concentrates and hormones. Other names of great importance in scientifically controlled manufacturing pharmacy are Merrell, Upjohn, Patch, Warner, Wyeth, Norwich, and Smith, Kline and French, in addition to others who have contributed greatly to progress. A large volume would be required to list all of their accomplishments.

These paragraphs by no means tell the history of chemical control as applied to industrial pharmacy, but they do emphasize the importance attached to this subject at a time when the larger part of American industry looked upon it as an expensive luxury or a silly fad. But chemical control did not satisfy the entire needs of the profession. There were drugs with constituents of unknown character that did not lend themselves to chemical assay, and others whose chemical characteristics were not well related to therapeutic usefulness. With more precise knowledge of physiologic reactions and methods for their measurement came the biological assay of drugs. Probably the first biologically assayed preparation put on the market was an extract of ergot in 1894, the same drug that introduced the chemically standardized line fifteen years before, and bioassayed digitalis preparations quickly followed, because the chemical standardization of either in a significant way was apparently hopeless. Forty-five years of experience with these particular drugs still leaves their assay a subject for almost acrimonious debate at any scientific meeting.

THE TREND TO BIOLOGICAL PRODUCTS

Biological products began to be spoken of in the closing years of the last century, although the manufacture of digestive ferments and smallpox vaccine in earlier years was an indication of what was to come. Diphtheria antitoxin was first made commercially during this period and has been followed by many others, notably that for tetanus. These products carried the industry over into the field of animal husbandry in which living animals replaced vegetable drugs. The bacterial vaccines, in which cultivation *in vitro* rather than *in vivo* was developed, were a natural sequence. The first twenty years of this century were especially rich in these discoveries; greater strides in preventive medicine were made possible by adding prophylaxis against such devastating diseases as typhoid fever and diphtheria to the accomplishment of practically controlling smallpox. In addition to the therapeutic and prophylactic use of serums and vaccines, they have extended farther into preventive medicine in diagnostic tests for the identification of disease and the determination of immunity.

Specialists in another division of biological research were then giving attention to the ductless glands. The first significant step was the almost simultaneous discovery and isolation by Abel and Takamine of the active principle elaborated by the adrenal gland, known both as epinephrine and adrenaline. Entirely new techniques had to be evolved for the production of such substances, and it is doubtful if these glandular products would be available today, except at prohibitive costs, if we did not have a well-organized meat packing industry. Pituitrin, thyroxin, insulin, and the sex hormones are later products of this same line of research and development, which is continuing with unabated energy.

Courtesy, Eli Lilly and Company

LIVER, ONCE THE CHEAPEST OF MEAT PRODUCTS, IS NOW THE THERAPEUTIC AGENT FOR THE CONTROL OF PERNICIOUS ANEMIA; THIS VIEW SHOWS A STEP IN THE PRODUCTION OF LIVER EXTRACT

The production of insulin upon a commercial scale has been possible only because of the careful studies that have been made of the physical chemistry of proteins. In every step from extraction from the glandular tissue through all of the stages of purification to its final separation in solid form, control of its en-

(*Top*) CONTAMINATION MAY BE PREVENTED BY ISOLATION

This room for the handling of iodine is provided with an outside entrance only. Free flames used in this room cannot cause explosions in other parts of the building.

Courtesy, Parke, Davis & Company

(*Center*) CHEMICAL MANUFACTURING IS AN EVER-INCREASING ACTIVITY IN PHARMACEUTICAL INDUSTRY

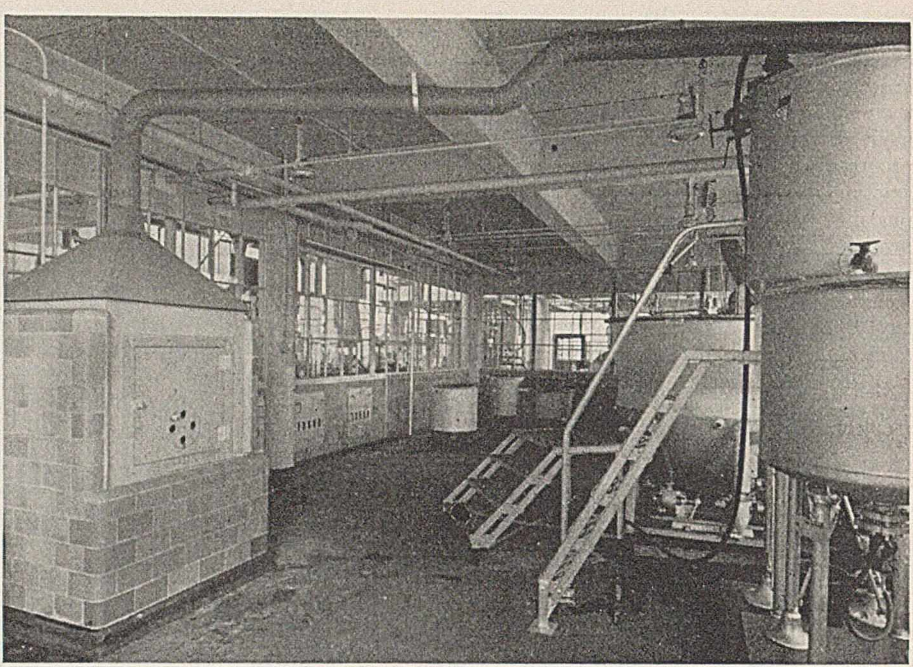
Thousand-gallon vessels for chemical reactions and a battery of filter presses in the left background.

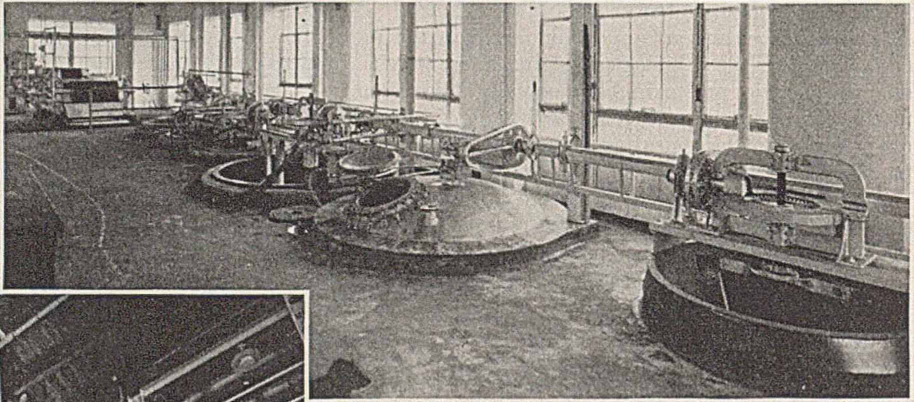
Courtesy, Parke, Davis & Company

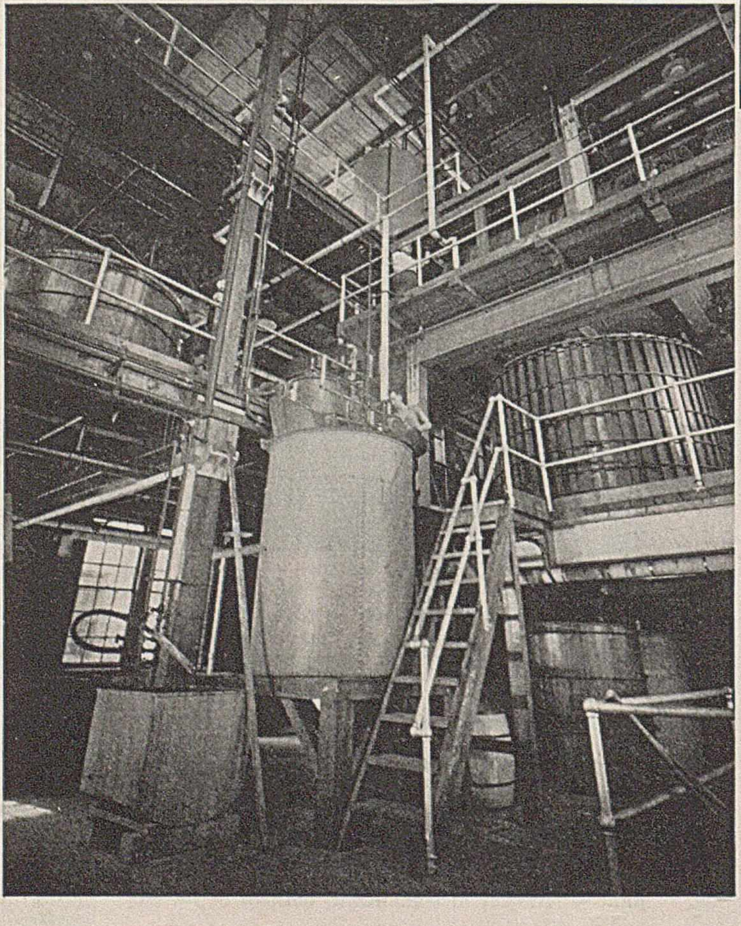
(*Bottom*) THE PILOT PLANT PREVENTS MISTAKES IN THE TRANSITION FROM TEST-TUBE REACTIONS TO COMMERCIAL MANUFACTURING OPERATIONS

Many important organic chemicals have been developed in this plant.

Courtesy, Merck & Company, Inc.







vironment brings about the desired fractionation. Here is one of the best illustrations of what can happen when pure science and industry combine forces for the solution of a baffling problem. All the theoretical knowledge and test tube experience of the university could not in this case complete the solution without the practical experience and the elaborate equipment of the manufacturer for process and control.

Praised, condemned, and finally lauded, is the history of cod liver oil. First thought to have curative value in wasting diseases, then pronounced as no more nutritious than vegetable oils while much less pleasant, it is now recognized as the principal source of our two most important vitamins. Pharmaceutical industry has improved methods of production, preserved the oils against deterioration in potency and flavor, discovered other natural sources of its vitamins, and produced concentrates of high potency and great utility. The discovery of each new vitamin has been followed promptly by the pharmaceutical development of its natural source (a commercial concentrate) or of the synthetic form. Probably the largest percentage of all expenditures for control is made on behalf of the standardization of these products. Thus pharmacy cooperates with nutrition and food chemistry.

THE ROLE OF CHEMICAL SYNTHESIS

From the study of the influence of drugs on body function came the guidance that led to the introduction of chemical synthesis into the pharmaceutical industry; it is largely a development of this century and one in which America has taken a commanding place. The synthetic study of drugs began with attempts to reproduce alkaloids that came from foreign sources or existed as complex mixtures in their parent drugs, such as the mixture of cinchona alkaloids from which quinine is obtained. Some go back to the very beginning of organic chemistry, and many have not been successful in reaching the original goal, although their by-products have been of great importance. For example, Perkin's attempts at the synthesis of quinine laid the foundation for our entire dyestuff industry.

Synthesists have had at least three aims: the reproduction of natural derivatives, the manufacture of compounds of equivalent or superior activity from which certain faults should be absent, and the discovery of new drugs of unusual properties. The first class includes salicylic acid, thymol, menthol, camphor, epinephrine, ephedrine, ascorbic acid, and thiamin chloride. The second has such useful drugs as procaine, homatropine, benzedrine, and the synthetic sex hormones; and the third includes the barbiturates and the many important organometallic compounds, especially the arsenicals and mercurials. The biological division of pharmacy continues to grow of its own initiative; the synthetic method progresses in part from its own momentum and partly as a successor to the botanical period. Vegetable materia medica is not without its specifics. The white man's conquest of the tropics was made possible only by the use of quinine to combat malaria, and quinine is still obtained from cinchona. Digitalis is essential to the treatment of cardiac disorders. Ergot is perhaps the most valuable therapeutic aid that the obstetrician possesses. Cocaine and morphine, in spite of their habit-forming properties, are still the standard of performance, respectively, for local anesthetics and hypnotics. With the exception of phenolphthalein and the saline laxatives, all the useful cathartics are of vegetable origin.

Pharmaceutical research has been successful in developing agents that lack some of the faults of their natural predecessors. Synthetic procaine is a local anesthetic that is free from two serious objections to cocaine: It is nonhabit forming and is not so toxic as the original drug. Homatropine is more specifically mydriatic than atropine. Benzedrine, in addition to other useful physiological properties, has a degree of volatility that makes it a convenient topical vasoconstrictor by inhalation. In addition to the fact that synthetic production of naturally occurring sex hormones overcomes the difficulty arising from their low natural concentrations, it is possible that some of them may be modified to therapeutic advantage.

The third field to be entered by synthetic chemistry is that of entirely new means of obtaining desirable therapeutic effects. The use of inhalation anesthetics is a century old and owes much to American investigators. The production of ether of uniformly satisfactory quality was an accomplishment of an American manufacturer, Edward R. Squibb. The development of the use of newer anesthetics, ethylene and cyclopropane, is attributable largely to the energy of American laboratories. Barbital, the first of the malonylurea hypnotics, was introduced from Europe, but the improved derivatives are almost without exception the products of our own laboratories. Many advances have been made in the field of organometallic compounds which are useful as general antiseptics or as specifics for the control of certain infections. Some of the most brilliant organic chemists are employed today in the research departments of pharmaceutical manufacturers and are contributing notably to American progress in chemotherapy as well as organic chemistry. I often wonder if our leaders in organic chemistry realize that papers dealing with research developments of great value to them appear in pharmaceutical periodicals such as the *Journal of the American Pharmaceutical Association.*

PHARMACEUTICAL EDUCATION

The key to the growth of pharmacy as a profession, business, and industry lies in the strength of the organization work of the past century. The early colleges were almost as much professional associations as educational institutions. The first of these schools was the Philadelphia College of Pharmacy, organized in 1821; it was followed within the next two decades by colleges in Boston, New York, and Baltimore, and then in such western cities as Cincinnati and St. Louis. In their faculties were found the authors of the textbooks and other compendia that established the profession independently in this country. The same colleges staffed both the drugstores and the factories, and from their ranks came the inspiration for the later state-supported schools.

Education in pharmacy has been shared by state and private interests; state support has been rendered chiefly through land-grant colleges. State support, however, has not been as extensive as in other fields of endeavor, so that the creation, guidance, and control of the method of education has come largely from within the profession. There have been few important endowments, so that the spirit of professional service has been responsible for practically all the support received by pharmaceutical education. But there is one fact to which we in American pharmacy can point with pride: Pharmaceutical education in our country is not only sound through systematic development but is uniquely supreme in world pharmacy. I am so convinced of the accuracy of this statement that I regard it as easy to defend.

ORGANIZATION OF THE PROFESSION

As might be expected, professional organization followed rather closely upon education. The associations or corporations promoting the schools and the alumni of the schools developed a professional teamwork that led to the formation of national associations, beginning with the American Pharmaceutical Association in 1852. Its purpose, as expressed in its constitution is:

> 1. To improve and regulate the drug market by preventing the importation of inferior, adulterated, or deteriorated drugs and by detecting and exposing home adulterations.
> 2. To encourage such proper relations among pharmacists, druggists, physicians, and the people at large as may promote the public welfare and tend to mutual strength and advantage.
> 3. To improve the science and art of pharmacy by diffusing scientific knowledge among pharmacists and druggists, fostering pharmaceutical literature, developing talent, stimulating discovery and invention, encouraging home production and manufacture in the several departments of the drug business.
> 4. To regulate the system of apprenticeship and employment so as to prevent, as far as practicable, the evils flowing from deficient training in the responsible duties of preparing, dispensing, and selling medicines.
> 5. To suppress empiricism and to restrict the dispensing and sale of medicines to regularly educated pharmacists and druggists.
> 6. To uphold standards of authority in the education, theory, and practice of pharmacy.
> 7. To create and maintain a standard of professional honesty equal to the amount of our professional knowledge with a view to the highest good and greatest protection to the public.

This association served as a meeting place for all the interests of pharmacy, which it took care to sponsor, and it encouraged the formation of conferences and committees that have become strong associations in their own right. It brought together in one section those interested in education and legislation and encouraged the eventual organization of the American Association of Colleges of Pharmacy and the National Association of Boards of Pharmacy. It saw and encouraged the drawing away of its great commercial interests into the National Association of Retail Druggists. Those pharmacists who became manufacturers or jobbers came together in their own special groups as the National Wholesale Druggists Association, the Federal Wholesale Druggists Association, the American Drug Manufacturer's Association, the American Pharmaceutical Manufacturer's Association, and the Proprietary Association of America. Then, because so many of the problems of the profession are common in some essential to every branch, all of the associations come together again most informally as the National Drug Trade Conference and are thus enabled to agree on matters of such great importance as legislative policy.

It also encouraged and fostered state associations, recognizing that practical means for the elevation of the profession included an intimacy and a community of interest that go with geographic nearness. State associations have played an important part in the government of the profession because they are usually called upon to nominate the members of the state regulatory boards.

No other country has organized so strongly and so well. It is not too much to say that this American way of administering the professional and industrial aspects of pharmacy is also a strikingly unique characteristic of our pharmaceutical life.

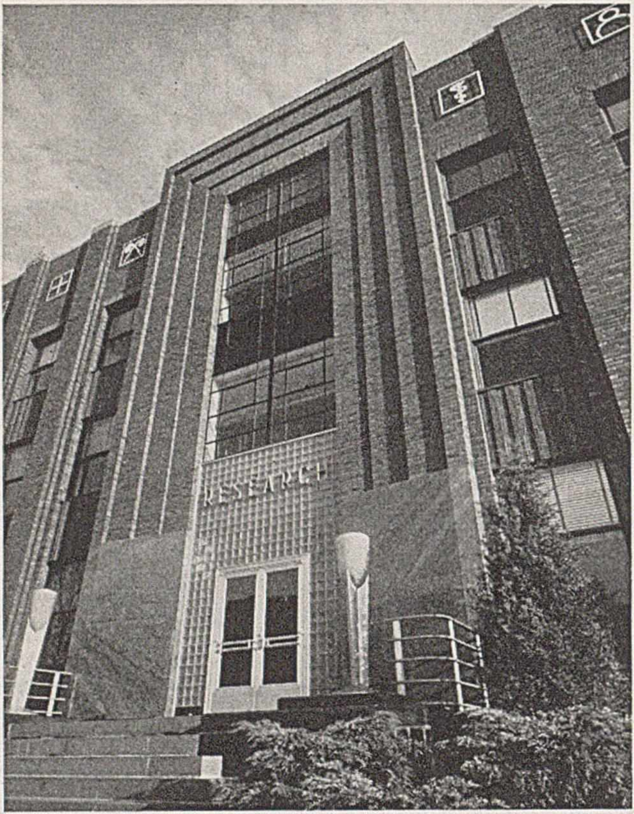
PROFESSIONAL ACTIVITIES

The legal regulation of the practice of pharmacy is, in general, a function of state control and practically all the control principles have countrywide acceptances.

Legislative control of the profession falls into three general classes:

1. Establishment and examination of qualifications to practice pharmacy.
2. Regulation of practices that may affect the common good, as the control of the distribution of poisons and narcotics.
3. Establishment of trade-practice standards by promulgation of standards of strength, quality, and purity, and of regulations for labeling and advertising of drugs and medicines.

The state regulations, in general, cover entrance and graduation requirements for the schools and provide for the certification of practicing pharmacists. They also regulate intrastate traffic in poisons and control the quality of drugs sold within the state. Federal laws govern drug merchandising almost entirely as a form of interstate commerce through the medium of legislation forbidding adulteration and misbranding, but regulate traffic in alcohol and narcotics by using the taxing power of the central government. Although it is said that "the power to tax is the power to destroy", the manner in which the commercial handling of drugs is controlled through legislation is thoroughly appreciated by the profession. A great part of the regulatory legislation of pharmacy has either been initiated by specialists within the profession or amended until it is in full accord with their thoughts. The cooperative drafting and securing of both beneficial and corrective legislation are distinctive parts of the American Way in pharmacy and constitute strengthening links among the branches of the profession.



Research Emblemizes Progress

A pharmaceutical researchist's laboratory—a dream of the founders realized on a firm foundation.

Courtesy, Abbott Laboratories

The democracy that exists in pharmacy is no better illustrated than in the establishment of standards of strength, quality, and purity for medicinal substances. Attempts at the standardization of pharmaceutical formulas have been increasingly successful since the sixteenth century; these compilations of formulas are known as formularies or, more specifically, pharmacopoeias. The majority of the earlier works were of local origin, but certain treatises deriving from well-known medical centers, such as the Edinburgh Pharmacopoeia, had more than local reputation. The first American pharmacopoeia was published for the use of the military hospital of the Continental Army at Lititz, Pa., in 1776. The Massachusetts Medical Society published one in 1808, based upon the last preceding edition of the Edinburgh Pharmacopoeia, and the New York Hospital issued a similar publication in 1816.

When planning the Massachusetts Pharmacopoeia, it was the intention of the originators to make it national in scope but no such cooperation could be obtained. After the appearance of the New York Hospital Pharmacopoeia, however, Lyman Spalding was able to promote a convention which authorized the first United States Pharmacopoeia in 1820. The conventions of 1830 and 1840 and the committees that issued the first and second revisions were composed of physicians exclusively, but the valuable cooperation given by the then existing colleges of pharmacy in preparing the second revision led to the inclusion of these colleges as constituent members of the convention of 1850.

Since 1850, except for the determination of the scope of the United States Pharmacopoeia, the establishing of dosages, and the setting of standards of a pharmacodynamic character, the problems of pharmacopoeial revision have been in charge of pharmaceutical workers to an extent not approached in any other country. Furthermore, with the exception of the French Codex of 1818, our pharmacopoeia was the first to become national in scope and was the first to invite the participation of pharmacists. The Food and Drugs Act of 1906 made the inclusion of a substance in the U. S. P. one definition of a drug and provided that the standards there set forth should be official for those drugs. Prior to that time the U. S. P. had been made official in various state drug laws, and a court decision affirming such an inclusion in Ohio was one of the bases on which particular sections of the federal act were framed. Thirty-two years of successful operation under such standards led to the inclusion of the U. S. P. as a compendium of standards under the Food, Drug and Cosmetic Act of 1938.

The convention by whose authority the pharmacopoeia is revised and issued is a representative body composed of delegates from national and state pharmaceutical and medical associations and all the recognized colleges preparing for the two professions, the branches of the Federal Government responsible in any way for maintaining the public health, and numerous other scientific societies, including the American Chemical Society. Here we have an unusual application of the principles of democracy well justified in view of the efforts put forth by the professions in its revision and the respect accorded the pharmacopoeia as an example of professional self-government seen nowhere else in the world.

The U. S. P. is devoted primarily to the standardization of simples and a few of their more important preparations. There are many useful preparations extensively prescribed by physicians that are somewhat less than universal in their application, and a number of drugs whose usefulness in the compounding of prescriptions is a matter of pharmaceutical rather than therapeutic necessity. For their standardization there has existed for over fifty years the National Formulary, revised and published by the American Pharmaceutical Association. This work is accorded exactly the same legal status as the United States Pharmacopoeia. Unofficially, New and Nonofficial Remedies, published under the auspices of the Council on Pharmacy and Chemistry of the American Medical Association, provides precise standards for new drugs conforming to certain scientific and ethical standards, and showing sufficient promise of therapeutic merit to justify their use by physicians. Many drugs reach the U. S. P. after their period of probation in N. N. R.

The United States Pharmacopoeia and the National Formulary, despite their legal status, are purely voluntary enterprises. The only fixed honoraria are those paid to the chairmen of the Revision Committees. The only salaries, except those of a purely clerical nature, are those paid to research assistants assigned to a few subcommittee chairmen for the study of specific revision problems. These volumes are made possible only by a great pride of profession on the part of those specialists charged with the preparation of standards, who deem it an honor to be called to place their professional ability at the service of their colleagues. As another instance of the esteem in which these volumes are held, there exists the Spanish Edition of the U. S. P. for use in Spanish-speaking countries of Central and South America. Translations of the eighth, ninth, and tenth revisions were prepared by pharmaceutical specialists of the University of Havana. The Spanish edition of the eleventh revision emanating from the Pan-American Sanitary Bureau of the Pan-American Union, is official in our Spanish-speaking possessions and several Spanish-American republics.

The voluntary production of compendia of standards requires unlimited cooperation by those skilled in the art. Naturally a great mass of experience and statistical data regarding drugs is to be found in the laboratories of pharmaceutical manufacturers. It is typical of the American Way that this experience has been placed freely at the disposal of the revisers and that it is always possible to call upon pharmaceutical manufacturers and their technical aides for collaboration. An especially valuable agency in all problems regarding drug standardization is the Joint Contact Committee of the American Drug Manufacturer's Association and the American Pharmaceutical Manufacturer's Association, which is a scientific committee, created to represent collectively the interests of the memberships before governmental and other standardization agencies. Through the medium of this committee one can probably obtain more quickly a cross section of experience with an analytical method than in any other industry or interest.

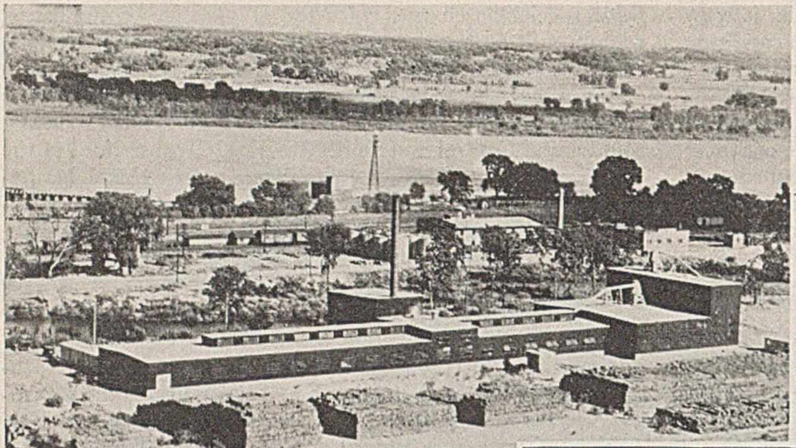
CONCLUSIONS

The American Way in pharmacy has made for a well-balanced organization. It began as a self-contained and self-sufficient profession because of the needs and limitations of pioneer life. It took what was best of old-world science and added thereto a new materia medica from a country of great botanical richness. It pioneered in the application and adaptation of engineering methods to its manufacturing industries, and led the world in developing new automatic machinery for its special uses. Chemical engineering, which all of us hold in admiration for its rapid development as a profession, owes not a little in groundwork to the older subject of physical pharmaceutical technology, which really gave birth to the fundamentals of process and product engineering and demonstrated the high utility of these specialties at a time when science had not been infused in other sections of American industry.

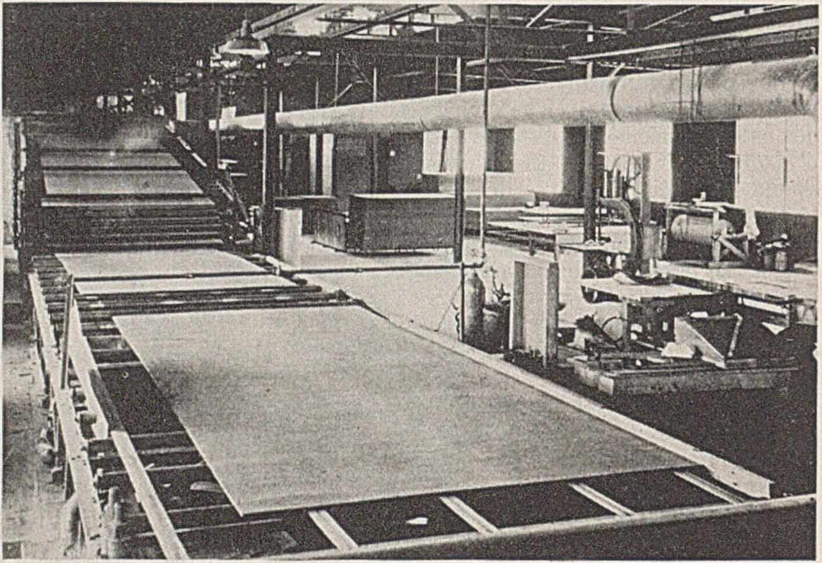
Pharmacy established a nationwide system of strong professional education and raised its own standards as necessary. It has cooperated in, even initiated, the passage of regulatory legislation. It has to a very large extent made its own standards of conduct, particularly with reference to standards of strength, quality, and purity for drugs and medicinal preparations. It has successfully combined scientific and commercial interests in one profession, and its advancement has been so dynamic that it may be likened to the lifting of a man by his own bootstraps.

ACKNOWLEDGMENT

The author takes pleasure in mentioning with deep appreciation the helpful information received from F. O. Taylor of Parke, Davis & Company, F. W. Nitardy of E. R. Squibb & Sons, J. P. Scott of Eli Lilly & Company, Joseph Rosin of Merck & Company, Inc., H. E. Ditzel of Sharp & Dohme, and J. T. Lloyd of the John T. Lloyd Laboratories.



(*Left*) Cornstalk Insulation Board Plant of Maizewood Insulation Company, Dubuque, Iowa



(*Below*) Cornstalk Insulating Board Coming from the Dryer

CHEMURGY

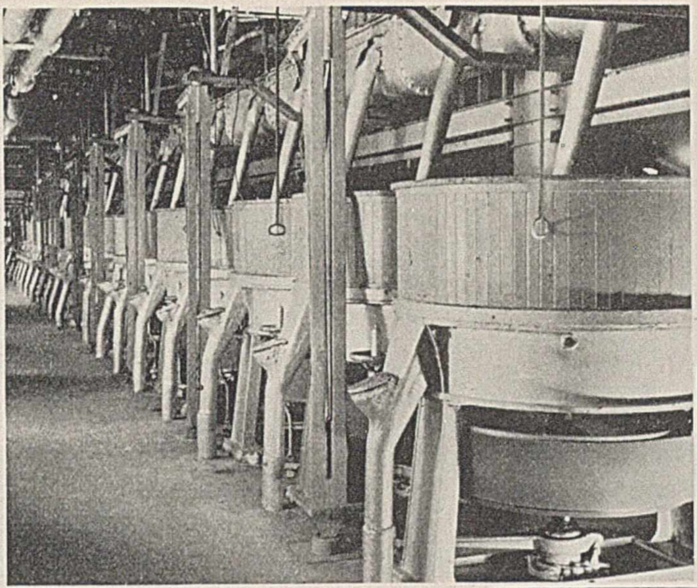
Utilization of Farm Products in the American Way

WHEELER McMILLEN

Farm Journal, Washington Square, Philadelphia, Penna.

FARM chemurgy is defined as putting chemistry to work for the farm. The movement fostered by the National Farm Chemurgic Council, Inc., seeks "to advance the industrial use of farm products through applied science." In the broader sense, chemurgy is a program seeking to raise agricultural income and thereby create employment by freeing the farm market from the inelastic stomach market. Naturally most of this effort comes within the general field of chemistry, although the movement may concern itself with such matters as more fur-bearing animals, riding horses, or flowers, to the extent that such nonfood products of the farm may invite additional advantage.

The chemurgic concept was initiated about 1926 as an outgrowth of the postwar agricultural situation. Numerous political programs for farm relief were being advanced. Consideration of the various proposals led to the belief that most of them would have approximately the effect of efforts to stuff oversized pillows into undersized suitcases; whenever one end was tucked in, another appeared certain to pop out. At that time, agricultural technology had advanced far ahead of prewar standards. The mechanization of agriculture, along with the new knowledge of genetics and other sciences, indicated that production could steadily increase in quantity and probably would. Since agriculture was primarily concerned with food production, the prospect was apparent that human stomachs would have to be expanded considerably or a great many more stomachs would have to come into the market for American farm products. Since birthrates were showing evi-



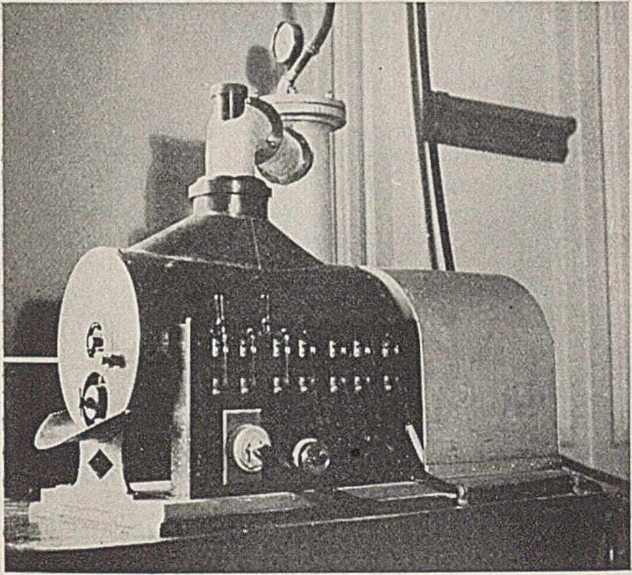
(*Left*) AFTER THE GERM HAS BEEN REMOVED FROM THE CORN, THE REMAINDER OF THE KERNEL IS FINELY GROUND IN THESE BUHR MILLS PREPARATORY TO THE SEPARATION OF FIBER AND GLUTEN FROM THE STARCH

(*Below*) REFACING A BUHR MILL STONE FOR MAXIMUM GRINDING EFFICIENCY

Courtesy, Corn Industries Research Foundation

(*Below*) EXPERIMENTAL DEXTRIN CONVERTER

Courtesy Stein Hall Company



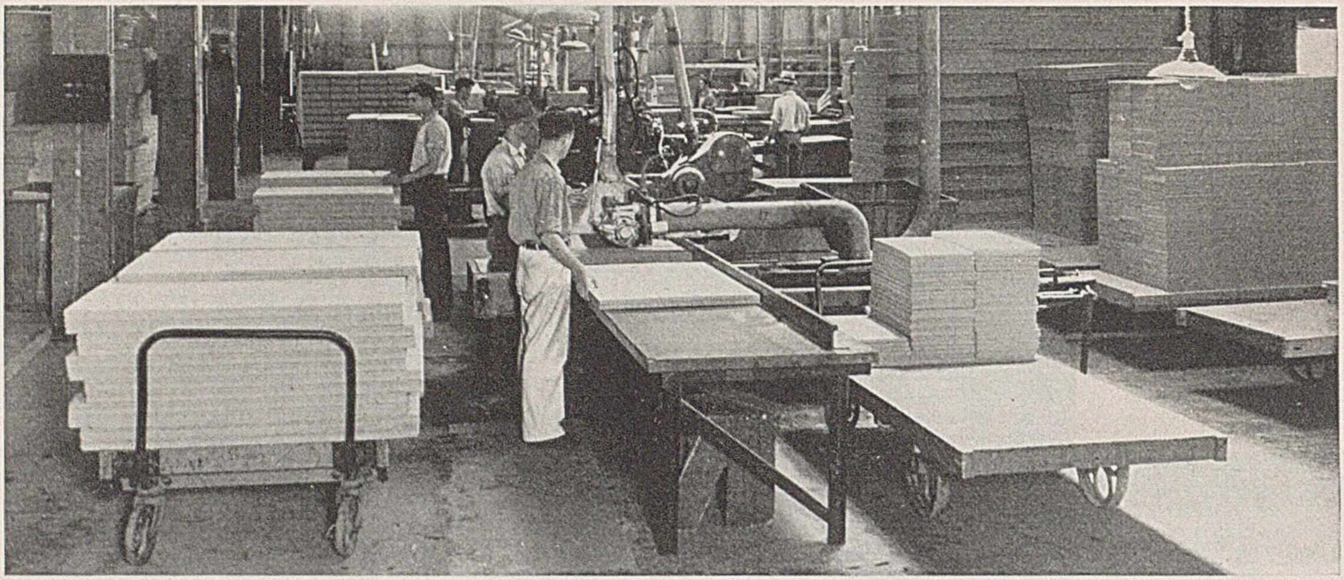
dences of decline, and foreign buyers of foodstuffs beginning for various reasons to demand less from American farmers, little hope could be discerned. Even at that time it appeared fairly clear that agriculture in the United States faced a clouded outlook if it were to be restricted to the existing markets.

Inquiries by men interested in the problem revealed that considerable quantities of farm-grown raw materials were being utilized for nonfood purposes, while inventors and researchers were here and there concerning themselves with further efforts. Corn was being converted into butyl alcohol, starch, and several other industrial products. Oat hulls were beginning to be made into furfural. Soybean oil was trickling into industrial markets where cottenseed oil had long been used. Linseed oil, of course, had long been a paint material. Wastes, such as straw and cornstalks, were attracting attention. Organic chemistry was becoming a conspicuous science. Therefore, it seemed possible that if research effort could be directed into the field of farm materials, eventually enough of them might be siphoned off into nonfood markets so that producers no longer would be burdened with the mighty surpluses. The idea was that if political approaches were depended upon, the problem would be a recurrent one; but if the scientific and industrial approach could be applied, some degree of permanent solution might be expected.

Advocates of the idea gained very limited acceptance. Politicians saw few votes in research funds and appropriated none. Industries were under little pressure to seek new sources of raw materials or felt that most of the farm materials under discussion were too costly to assemble. The depression years saw little encouragement for new industries. Agricultural scientists were mainly concerned with established efforts to increase production or reduce the costs.

Meantime the agricultural situation steadily grew worse. Farm income dropped from 12 billion dollars to less than 6. In consequence of that and of mounting private debts, business collapsed and urban prosperity disappeared. Beginning with a few hundred millions for the Farm Board experiment in 1930, 8 billion dollars have been expended in one way or another to raise farm income. The result, lowest prices in history, in terms of gold.

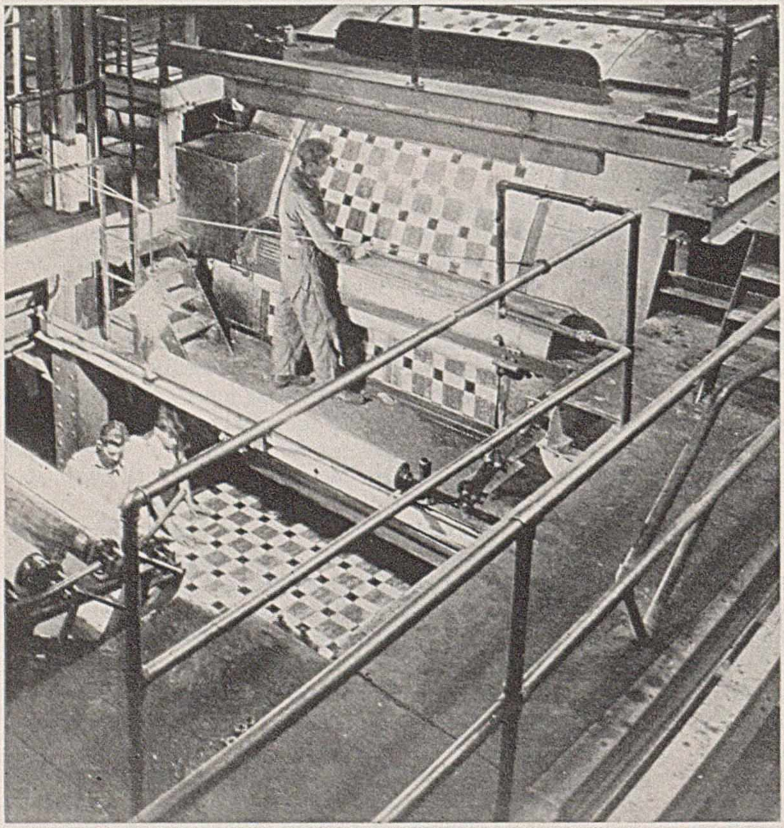
IN THE spring of 1934 an attempt was made to organize the chemurgic idea when a conference of agriculture, industry, and science was called at Dearborn, Mich. Before 1934, however, there were important indications that raw materials from the soil had a future. Ford was already well advanced with soybean utilization,



Courtesy, Celotex Corporation

Machines for Trimming Celotex to Size; Setting and Rules Are Used Which Take into Account the Exact Expansion of the Board from Bone-Dry to the Moisture Condition under Which It Will Be Used

and soybean products were going into several industries. Tung oil production was getting a foothold on the Gulf Coast. Herty's researches pointed definitely to larger scale marketing of southern woods. Substantial evidence was piling up. In the minds of the men who came to Dearborn that May, even of many who came with skepticism, grew a strong presumption that here was an American Way of meeting the agricultural problem. The result was the organization of the Farm Chemurgic Council. More than the agricultural problem, however, is involved. Looking at the American scene now that 1939 is under way, we see that ten million people are listed as without employment. One fourth of the population may be characterized as being on half pay, since the agricultural income is seldom more than 12.5 per cent of the national income, and 25 per cent of the population is directly engaged in agriculture.

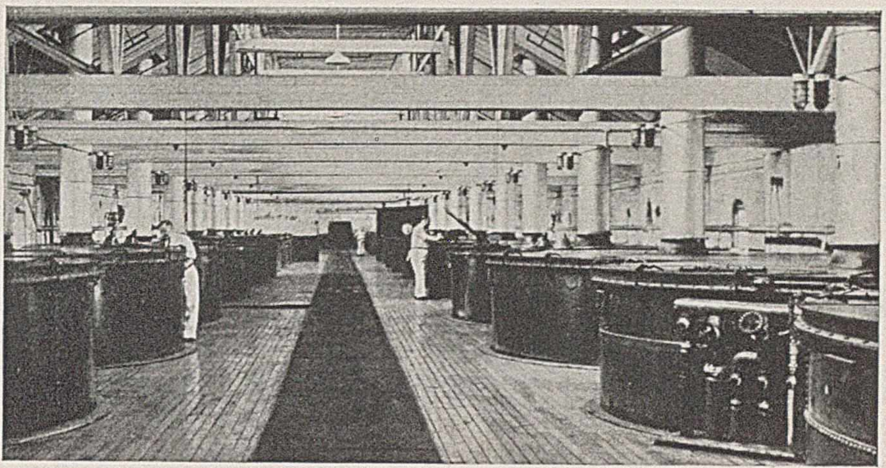


Giant Rotary Machine for the Manufacture of Straight-Line Inlaid Linoleum at the Plant of the Armstrong Cork Company; the Entire Operation, Largest of Its Kind in the World, Is Seven Stories High

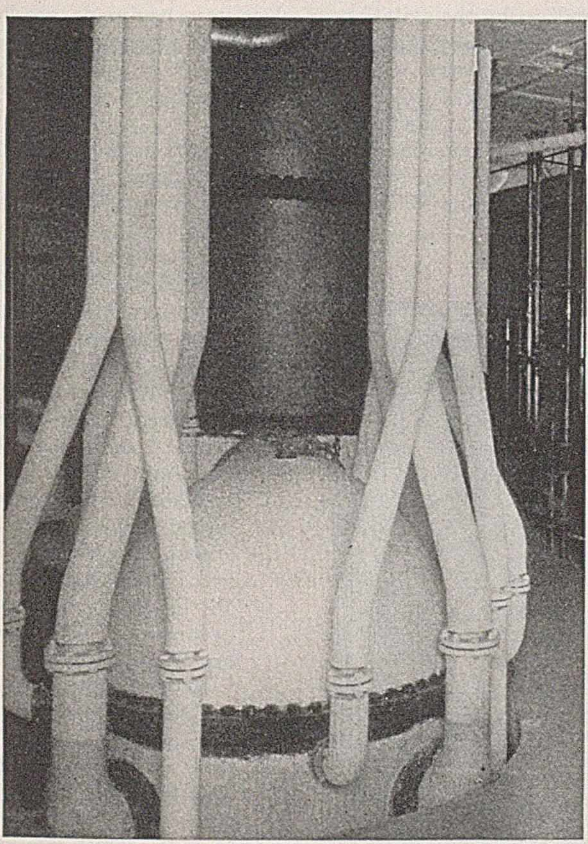
Statisticians point to the extraordinary similarity of their chart lines depicting farm income and factory pay rolls. The two rise and fall together. Whoever studies these parallel lines finds difficulty in escaping the conclusion that if one is lifted, the other will respond also. There may be some question as to which has to rise first, but none as to the historic experience that prosperous agriculture has always been accompanied by prosperity in the nation.

Notwithstanding ten million unemployed and a depressed agriculture, forty-two million people are listed as gainfully employed. These are people with jobs or businesses, able to buy their food, shelter, and various luxuries. An American solution to the paradox, chemurgy argues, will be to enable the fortunate forty-two million to buy a larger share of their goods from the agricultural groups. Then the increased earning power in agriculture will in turn operate to restore employment.

The technique of accomplishing this diversion of existing purchasing power into farm income is not without complication. A first principle is that efforts shall be made to enable American farmers profitably to produce for needs now supplied by imported materials. A conspicuous example is the field of vegetable oils, where it seems certain that without great new research or expense, means can be devised for the farmers of this country to supply a portion, perhaps a very large portion, of the existing American market. A second principle is that research shall undertake to develop new products from farm-grown raw materials that will be in demand when offered in the stores. Examples of this may be found in the field of plastics.



The Actual Soap-Making Reaction Takes Place in These Kettles Which Are Three Stories High; Only the Tops Appear Here



Courtesy, Quaker Oats Company

Furfural Column

As a concomitant of all progress, doubtless some substitution of farm raw materials may develop for other American materials, such as minerals. Optimists may hope that such displacement will be accompanied by sufficient new needs to prevent serious injury to any part of the present national economy.

At the risk of repeating a well-understood fact, it may not be amiss to emphasize the point that increased agricultural income appears automatically to reflect itself in expanded national income. A raw material dollar becomes from 7 to 10 dollars of national income, by one process or another. The agricultural dollar is promptly sent into the channels of trade and manufacture. Farmers are consumers both of production and consumption goods. For nearly two decades they have been restricting their purchases by necessity. A recent calculation indicated that present farm needs for telephones, electrical service and equipment, water systems, tractors, combines, automobiles and trucks, excluding all other items, approaches a total of seventeen billion dollars. Now that the farm debt structure is less oppressive than it was a few years ago, new agricultural income will certainly go into channels creating employment. Upon this concept, a considerable measure of the validity of the chemurgic idea rests.

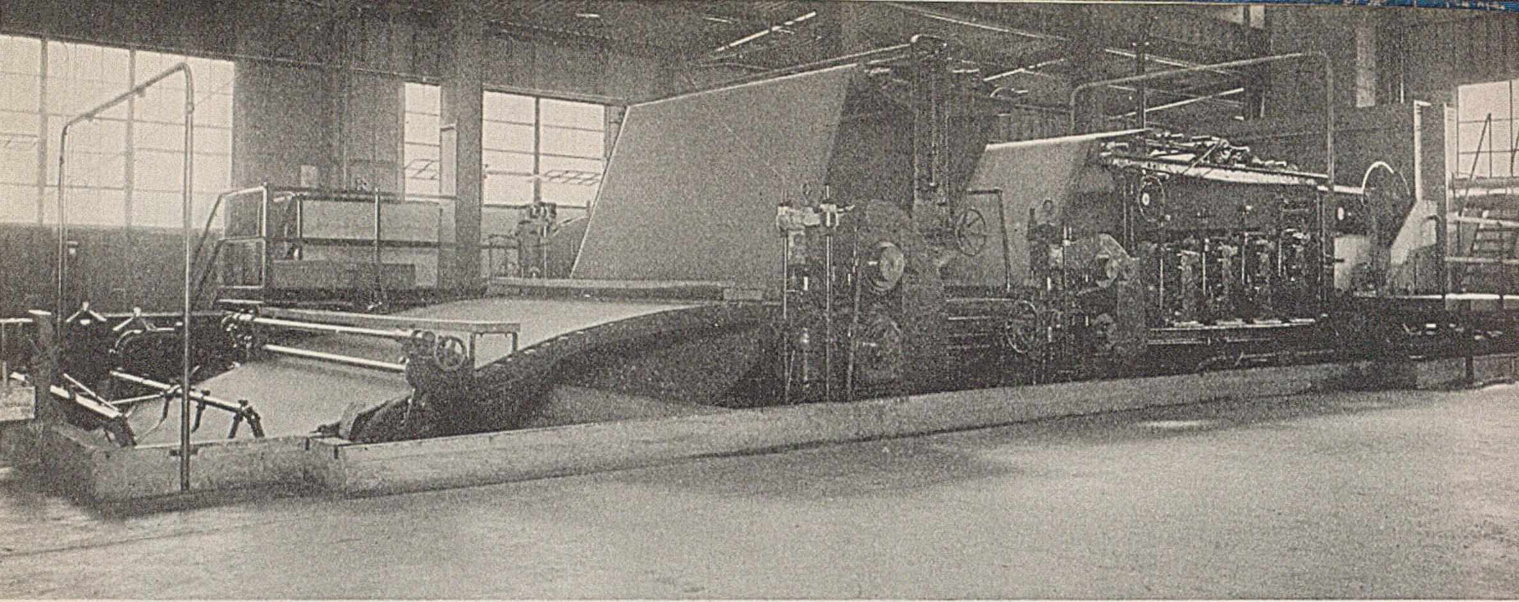
The direct chemurgic objectives are new uses for present crops, new crops for existing or new uses, and profitable markets for farm by-products and wastes.

POSSIBLY the most spectacular result of the educational work done in recent years are the four new regional laboratories, authorized last year by Congress and provided with annual appropriations of one million dollars each. Although the Department of Agriculture has almost from its beginning recognized occasional industrial possibilities from agricultural materials, the creation of these laboratories marks the first substantial recognition by government of the necessity for more vigorous chemurgic research.

Much of the research in this field must be done by government on the broad ground that new knowledge will eventually benefit all the people. Industries cannot be expected to conduct random research into farm products. Farmers cannot be organized to supply such large funds, nor should they be expected to do so since they are not the sole beneficiaries.

However, the four laboratories, dramatic as they may appear, will touch only a small part of the research need. A glance at their restricted programs is sufficient. The law creating them contemplates that they shall work upon surplus crops. In accordance with that limitation, the plan is that the studies shall be as follows: New Orleans—cotton, sweet potatoes, and peanuts; Peoria—corn, wheat, and farm wastes; Philadelphia—apples, potatoes and truck, tobacco, and milk products; San Francisco—fruits and vegetables, wheat, potatoes, and alfalfa.

In other words, the four laboratories will undertake to find new uses for the present surpluses only. They will do nothing towards finding new uses for less abundant crops or for finding



Courtesy, Celotex Corporation

In These Board Machines, Cane Fibers Are Felted into Board and Given a Ferox Treatment Which Is a Chemical Complex Toxic to Fungi, Termites, and Other Cellulose-Destroying Organisms

new crops, either of which might tend to prevent rather than cure the surpluses.

Included therefore in the present chemurgic program are suggestions for a further appropriation to provide each state with 25 thousand dollars to be used exclusively for studying new crop possibilities, and for another appropriation to be used to study expanded uses for the crops which at present produce no troublesome surpluses but which might be extended on acreage now devoted to the surplus crops. The four-laboratory program has no provision for studying grain sorghums, flax, hemp, pyrethrum, perilla, tung nuts, or any of perhaps a hundred subjects which lend hopeful promise.

CHEMURGY may be justified in making some claim to concrete results even now, although its leaders and their organization are not concerned about credits. One of the earliest and most active leaders, the late Charles H. Herty, by his dramatization of the values of the southern forests, stimulated in part the recent large investment in new paper mills in the coastal plain areas. The newsprint mill at Lufkin, Texas, now in process of erection, is clearly attributable to his efforts. Also in process is the new plant of the Champagne Paper Company, in western North Carolina.

Courtesy, Commercial Solvents Corp. *Photo, Margaret Bourke-White*

Tail Boxes on Anhydrous Alcohol Still

The agricultural demand for soybean paint, stirred up by the agitations of chemurgy, has made possible the marketing of considerable quantities of soybean oil through the paint industry. Other soybean uses have made possible the absorption of the record 57,000,000 bushel crop of 1938 without shock to the farm price.

Tung oil production has been stimulated on a sound basis and perhaps to some extent on an unsound basis. There seems to be no formula for guaranteeing that every effort inspired by a worthy movement will be equally worthy. One of the conspicuous concerns of the National Farm Chemurgic Council has been to discourage improper promotions from which success cannot be expected. At the same time, it is recognized that some honest failures must be expected, as occur in the best of businesses, where all the elements cannot be foreseen. The American Way is to try.

However the definite achievement to date may be measured, the greater part of chemurgic history is still to be made. The acceptance of an idea is deliberate and properly so. When an idea involves scientific research as a tool essential to its realization, years may be required for conspicuous gains to appear. When the ailments from which the nation suffers have been so long in the making, it is not to be expected that they will yield to overnight treatment. Chemurgy would like to hurry but realizes that the provision of markets adequate to absorb enough production to give the farming fourth of the population their fourth of the national income will require considerable time.

Nevertheless, here is clearly an American approach to the problem. For a century the great gains in national wealth have come largely from new inventions, new scientific discoveries, and the utilization of neglected materials. Chemurgy proposes to follow that course with reference to agriculture.

In their evangelistic moments, chemurgic leaders like to portray the possibilities as "illimitable, except for the limitations of human knowledge." And perhaps they are. Plant growth is, except for about 2 to 5 per cent of its substance, the product of air, moisture, and sunshine. The quantities of air, moisture, and sunshine are presumably without end. Their products reappear upon the earth each year. Consequently, as knowledge of plant materials advances, in theory at least the industrial utilization of farm materials faces an inexhaustible supply of annually renewable wealth. Ample demonstration is available that knowledge can be obtained, and that, whenever it is worth commercializing, a business will follow.

We believe this is in accord with the American Way of doing things and, like Americans, believing it desirable and perhaps even imperative, we want to hurry it along.

★ ★ ★ ★ ★

Nonfood Uses of American Agricultural Products[1]

SOURCE	RAW MATERIAL	MANUFACTURED PRODUCT	PRINCIPAL USES
Almonds	Kernels	Sweet-almond oil	Pharmaceutical
Apricots	Seed kernels	Volatile oil	Pharmaceutical
Bay (*Pimenta acris*)	Leaves	Volatile oil	Preparation of bay rum
Bayberry (wax myrtle)	Berries	Wax	Candles, polishes
		Volatile oil	Pharmaceutical
Bees, honey	Comb honey	Beeswax	Lutes, polishes, candles, cosmetics, lithographing
Broomcorn	Panicles (brush)	Brooms and whisk brooms	Floor cleaning, brushing
Candelilla weed	Stems	Wax	Polishes
Cascara tree (*Rhamnus purshiana*)	Bark	Extract	Medicinal
Cattle	Hides and skins	Leather	Footwear, luggage, harnesses
		Glue	Adhesive, paper size, composition for inking rolls
		Gelatin	Photographic emulsions
	Tallow and grease	Soap	Detergent
		Stearic acid	Candles, stearates
		Glycerol	Dynamite, pharmaceutical, plastics, antifreeze
	Bones	Bone fat	Soaps
		Bone meal	Fertilizer
		Bone char	Decolorizer, absorbent
		Bone black	Pigment
		Bone glue	Adhesive
		Phosphorus	Source of pure phosphoric acid and phosphates
		Bone oil	Source of pyrrole, insectifuge
	Blood	Dried blood	Fertilizer, feed
		Blood albumin	Leather finishing, clarifying agent, textile printing
	Hoofs and horns	Glue	Adhesive
		Plastic	Buttons, combs, knife handles
	Glands, selected	Hormone preparations	Medicinal
	Entrails, miscellaneous	Tankage	Fertilizer
	Hair	Hair felt	Rug liners, insulation
	Feet and shin bones	Neat's-foot oil	Leather dressing, lubricant
	Milk	Condensed whey	Feed
		Whey powder	Feed
		Condensed buttermilk	Feed
		Buttermilk powder	Feed
		Casein	Paper coating, plastics, adhesives, binder in water paints
		Lactic acid	Tanning, source of lactates
Citrus fruit	Cull and surplus lemons	Citric acid and citrates	Medicinal
	Grapefruit seed	Fixed oil	Sulfonated oil
Corn	Kernels	Starch	Sizing yarns and paper, laundering, explosives
		Dextrins	Adhesives, binders, sizing backs of carpets

(*Continued on page 546*)

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[1] Compiled by the Bureau of Chemistry and Soils, U. S. Department of Agriculture. Information on the industrial uses of woods and other forest products was kindly furnished by H. S. Betts, U. S. Forest Service. Mechanical uses of wood in the form of lumber, etc., are omitted.

Nonfood Uses of American Agricultural Products

(*Continued from page 545*)

SOURCE	RAW MATERIAL	MANUFACTURED PRODUCT	PRINCIPAL USES
Corn (*Continued*)		Mixed sugars	Spinning rayon
		Corn sirups	Filling leather, tobacco products
		Lactic acid	Tanning, source of lactates
		Corn gluten	Feed
		Corn oil cake	Feed
		Corn bran	Feed
		Corn sugar molasses	Fermentation
		Ethyl alcohol	Pharmaceutical, perfume
		Fusel oil	Solvent, source of chemicals
		Butyl alcohol	Solvent, source of chemicals
		Acetone	Solvent, absorbent for acetylene
	Cobs	Mechanical products	Absorbents, packing, polishing, feed diluent, smoking pipes
	Stalks	Fiberboard	Structural insulation, wallboard
Cotton	Lint	Yarns, fabrics, thread	Clothing, household fabrics, cordage, bags, reinforcing rubber tires, awnings, paulins
		Cotton felt and batting	Mattresses, padding, rosin straining
		Absorbent cotton	Dressing wounds
	Linters and hull fiber	Absorbent cotton	Dressing wounds
		Cotton felt and batting	Mattresses, padding
		Nitrocellulose	Explosives, lacquers, plastics
		Cellulose acetate	Acetate rayon, plastics, flame-resistant film
		Paper pulp	Blotting paper
	Seed kernels	Cottonseed oil	Soap
		Cottonseed meal	Feed, fertilizer
		Cottonseed hulls	Feed, packing, stuffing
Elm, slippery	Inner bark	Mucilage	Medicinal
Flax	Seed	Linseed oil	Paints, varnishes, linoleum, printing ink
		Linseed cake and meal	Feed
	Straw from seed	Tow	Upholstering
		Rugs	Floor covering
		Pulp	Insulating board and "quilts", cigaret paper
	Stems	Textile fiber	Thread and twine
Fleabane, Canada	Flowering herb	Volatile oil (erigeron)	Medicinal
Foxglove	Dried leaves	Extracts, tincture	Medicinal
Ginseng	Root	Dried root	Medicinal in China
Goats, Angora	Hair	Mohair yarns	Clothing and upholstery fabrics
Goldenseal (*Hydrastis*)	Roots	Extracts and tincture	Medicinal
Grape	Seed (dried)	Grape (or raisin-seed) oil	Lubricant, soap
Grass, marsh	Dried stems	Rugs	Floor coverings
Hemp (*Cannabis sativa*)	Stalks	Textile fiber	Cordage, bagging, canvas
	Immature flowering tops	Extracts	Medicinal
Hogs	Carcass and selected viscera	Lard oil	Lubricant, illuminant, metal cutting, oiling wool
		Oleic acid (red oil)	Soap, oleates, ointment
	Skin (side strips)	Leather	Insoles, razor strops
	Bones	Bone meal	Fertilizer
		Bone black	Pigment, absorbent
		Bone fat	Soap
		Bone glue	Adhesive
	Blood	Dried blood	Fertilizer
	Glands (selected)	Hormone preparations	Medicinal
	Intestines	.....	Sausage casings
	Entrails, miscellaneous	Tankage	Fertilizer
	Hair	Fertilizer	Fertilizer
Horses:			
Butchered	Carcass	Canned meat	Dog food
Not butchered	Carcass	Tankage	Fertilizer
Butchered and not butchered	Fat	Greases	Soap, lubricants
	Hide	Leather	Shoe uppers, razor strops
	Bones	Bone glue	Adhesive
		Bone meal	Fertilizer
	Entrails	Tankage	Fertilizer
Jimson weed	Dried leaves	Stramonium extracts	Medicinal
Magnolia (cucumber tree)	Flowers	Extract	Medicinal
Moss, Spanish	Entire plant	Decorticated Spanish moss	Upholstery stuffing
Moss, sphagnum	Entire plant	Dried sphagnum moss	Absorbent for retaining moisture in floral pieces and in plants during shipment
Nettle	Leaves	Chlorophyll extract	Coloring food and food wrappers, soap, toilet preparations
		Carotene	Medicinal, source of vitamin A
Nightshade (*Atropa belladonna*)	Leaves	Extracts	Medicinal

(*Continued on page 547*)

Nonfood Uses of American Agricultural Products

(*Continued from page 546*)

Source	Raw Material	Manufactured Product	Principal Uses
Oats	Hulls	Furfural	Refining lubricating oils and wood rosin, plastics, source of furan chemicals
Olives	Fruit	Expressed oil	Ointments, liniments
		Extracted oil	Soaps, lubricant, wool oil
		Oil foots	Soap
Pennyroyal	Green tops	Volatile oil (hedeoma oil)	Insectifuge, medicinal
Peppermint and spearmint	Green tops	Volatile oils	Medicinal
Pineapples	Waste juice	Ethyl alcohol	Pharmaceutical, perfume
Potato	Tubers	Starch	Textile sizing
Rice	Grain	Starch (from broken rice)	Face powder
		Rice polishings	Dietetics, source of vitamin B complex
		Rice bran	Feed
	Straw	Paper pulp	Paper and fiberboard
	Hulls	.....	Fuel, packing
Rye	Straw	Straw paper	Wrapping, egg-case filler, corrugated strawboard
		Fiberboard	Insulating
		Straw braid	Hats
Safflower	Seed	Drying oil	Paint, varnish
Sassafras	Root bark	Volatile oil	Perfuming soap, medicinal
Sheep and lambs	Carcass	Tallow	Soap, lubricant, source of stearic acid and glycerol
	Intestines	Catgut	Strings for musical instruments and tennis racquets
		Sausage casings	Frankfurters
	Glands, selected	Hormone preparations	Medicinal
	Entrails, miscellaneous	Tankage	Fertilizer
	Bones	Bone products (similar to those from hog bones)	
	Blood	Dried blood	Fertilizer
	Skins	Pulled wool	Textiles
		Leather	Bookbinding, gloves
		Imitation chamois skin	Dusting, washing glass
	Fleece	Scoured wool	Textiles
		Wool grease	Stuffing leather, belt dressing, treating cordage, lubricant in wire drawing, source of lanolin
Soybean	Seed	Soybean oil	Paint, varnish, soap
		Soybean protein	Plastic, adhesive
		Soybean meal	Feed, adhesive
Stillingia	Seed	Fixed oil	Candles, soap, textile dressing
Sugar cane	Stalk juice	Molasses, inedible	Industrial alcohol
	Extracted stalks (bagasse)	Fiberboard	Wallboard, insulation
		Acoustical board	Improving acoustics
		Mulching paper	On pineapple plantations
Sweet potatoes	Roots	Starch	Textile size, dextrin
		Sweet potato pulp	Feed
Tansy	Leaves, tops	Volatile oil	Medicinal
Tobacco	Wastes	Nicotine	Insecticide
		Tobacco dust	Insecticide
Trees, forest:			
Aspen	Wood	Paper pulp	Book paper
Basswood (linden)	Wood	Paper pulp	Book paper
Beech	Wood	Paper pulp	Book paper
		Charcoal	Fuel, absorbent
		Methanol	Solvent, source of formaldehyde
		Acetate of lime	Source of acetone and acetic acid
		Wood tar	Source of medicinal creosote
Birch	Wood	Charcoal	Fuel, absorbent
		Methanol	Solvent, source of formaldehyde
		Acetate of lime	Source of acetone and acetic acid
		Birch tar oil	Leather dressing
Cedar, eastern red	Leaves	Cedar-leaf oil	Medicinal
	Wood	Cedar-wood oil	Moth repellent, perfuming soap, medicinal
Cedar, northern white	Leaves	Volatile oil	Medicinal
Chestnut	Wood	Extract	Tanning
		Paper pulp	Roofing paper, fiberboard
Cottonwood	Wood	Paper pulp	Book paper
Fir (*Abies* species)	Wood	Chemical wood pulp	Paper manufacture
		Mechanical wood pulp	Newsprint paper
Fir, balsam (*Abies balsamica*)	Wood	Mechanical wood pulp	Newsprint paper
	Oleoresin	Canada balsam	Adhesive for lenses, lacquer, mounting microscopic specimens
	Leaves	Volatile oil	Perfuming soap
Fir, Douglas (*Pseudotsuga taxifolia*)	Wood	Chemical wood pulp	Paper, fiberboard

(*Continued on page 548*)

Nonfood Uses of American Agricultural Products

(Continued from page 547)

SOURCE	RAW MATERIAL	MANUFACTURED PRODUCT	PRINCIPAL USES
Hemlock, eastern (hemlock spruce)	Wood	Mechanical wood pulp	Newsprint paper
		Chemical wood pulp	Book paper
	Bark	Extract	Tanning sole leather
	Leaves	Volatile oil	Medicinal
Hemlock, western	Wood	Mechanical wood pulp	Newsprint paper
		Chemical wood pulp	Paper
		Alpha-cellulose	Rayon, transparent wrapping
Hickory	Greenwood and sawdust	.....	Smoking meats
Maple, sugar (hard maple)	Wood	Charcoal	Fuel, absorbent, metallurgy
		Wood alcohol	Solvent, making formaldehyde-alcohol denaturant, antifreeze
		Acetate of lime	Source of acetone and acetic acid
		Hardwood tar	Ore flotation
		Wood creosote oil	Disinfectant, ore flotation
		Pyrolignite of iron	Dyeing, calico printing
Miscellaneous trees	Hardwood waste	Wood ashes	Fertilizer
		Charcoal	Fuel, metallurgy
		Acetate of lime	Source of acetic acid and acetone
		Wood alcohol	Solvent, denaturant, source of formaldehyde
		Pyrolignite of iron	Dyeing, calco printing
		Hardwood tar	Composition roofing, ore flotation
	Softwood waste	Chemical wood pulp	Fiberboard; wrapping, sheathing, and roofing papers
		Wood flour	Filler in molded plastics
	Sawdust	Oxalic acid	Chemical processes, bleaching straw and wood, ink and rust removers
		Floor sweeping compounds	Cleaning floors
		Gypsum plaster board	Walls
Oak	Wood	Acetate of lime	Source of acetic acid and acetone
		Pyrolignite of iron	Dyeing, calico printing
		Wood alcohol	Solvent, denaturant for alcohol, source of formaldehyde
		Charcoal	Fuel, metallurgy, absorbent
Oak, chestnut and black	Bark	Extracts	Tanning sole leather
Osage orange	Wood	Extract	Dyeing leather and textiles
Pines, southern	Oleoresin (from longleaf and slash pines)	Gum spirits of turpentine	Paint thinner, solvent, source of pinene for synthetic camphor
		Gum rosin	Varnishes, soaps, paper size
	Stumps and "lightwood"	Destructively distilled wood turpentine	Paint thinner
		Destructively distilled pine oil	Ore flotation, disinfectants
		Pine tar	Roofing compositions, ore flotation, paint, tar soap, on cordage
		Pine tar oil	Medicinal
		Pine pitch	Shoemaker's wax, caulking decks
		Charcoal	Fuel
		Steam-distilled wood turpentine	Paint thinner, solvent
		Steam-distilled pine oil	Disinfectant, deodorant, detergent, ore flotation
		Wood rosin	Varnish, soap, paper size
	Wood	Chemical wood pulp	Wrapping and bag paper, fiberboard
	Wood, waste	Lignin-containing wood fiber	Pressed-wood paneling, wallboard, insulating board
Poplar, balsam	Wood	Chemical wood pulp	Book paper
Poplar, yellow (tulip tree)	Wood	Chemical wood pulp	Book and blotting paper
Redwood	Bark	Fiberboard	Insulation
Spruce, eastern	Wood	Mechanical wood pulp	Newsprint paper
		Chemical wood pulp	Book and writing papers
		Alpha-cellulose	Rayon, transparent wrappers
		Absorbent wood cellulose	Absorbent pads
Spruce, Sitka (western)	Wood	Mechanical wood pulp	Newsprint paper
		Chemical wood pulp	Book and writing papers
Tupelo	Wood	Chemical wood pulp	Wrapping and book paper
Willow	Wood	Charcoal	Absorbent, black gunpowder
Tung tree	Nut kernels	Drying oil	Varnish, paint
Wheat	Straw	Strawboard	Insulation, egg-case fillers
		Strawpaper	Wrapping, corrugated board
Wintergreen (*Gaultheria procumbens*)	Leaves	Volatile oil	Medicinal, perfume
Witch hazel	Dried leaves and twigs	Alcoholic extract	Toilet preparations, pharmaceutical
Wormseed, American (*Chenopodium anthelminticum*)	Seeds and leaves	Volatile oil	Medicinal
Wormseed, Levant (*Artemisia maritima*)	Unexpanded flower heads	Volatile oil	Medicinal
Wormwood (*Artemisia absinthium*)	Leaves	Volatile oil	Medicinal

THE AMERICAN WAY IN INDUSTRIAL RESEARCH

Mellon Institute and Other Institutions

E. O. RHODES
Koppers Company, Pittsburgh, Penna.

"IT IS science, not governments nor wars of conquest, that opens to us new horizons." These words, spoken by the late Andrew W. Mellon, will bear repeating in these troubled times when individuals and groups of individuals are striving through changes in government or wars of conquest to open new horizons. They are the words of an American industrialist and statesman who realized that "improvement in the standard of living of the human race can come about in the future only by reason of new discoveries and inventions, just as in the past the steam engine and other inventions have been responsible for many improvements in the standard of living enjoyed by the average man today. It is these things and not governmental or political action that have increased production, lowered costs, raised wages, elevated the standard of living, and so have brought about a greater participation of the human race in these benefits."

Because of this profound belief in the ability of science to open new horizons, intelligent assistance and financial support were furnished by Andrew W. Mellon and his brother, Richard B. Mellon, to a plan of industrial chemical research which, conceived in 1906 by Robert Kennedy Duncan, is operating today in Mellon Institute in accordance with Duncan's original precepts.

The purpose of this narrative is to trace the growth of Duncan's plan, to indicate how its application has opened new horizons to countless industries and individuals, to show how it has grown in a way that is typically American and, in growing, has contributed largely to the establishment of methods of doing and modes of living which now constitute the American Way.

Our forefathers came to America from across the sea. Hardships and disappointments attended their efforts to establish themselves in this land of abundant opportunities. Trails had to be blazed into uncharted areas. Opposition to their coming had to be overcome. But success rewarded their efforts and they succeeded in establishing for themselves and for us the democratic institution which is America.

The history of Mellon Institute resembles that of our country to a remarkable degree. The idea from which it sprang came from abroad. Its establishment was attended by hardships and disappointments, but steadily it forged ahead, blazing a trail for American industries and for all Americans along scientific lines, building for itself a reputation for dealing with American problems in a democratic way.

ROBERT KENNEDY DUNCAN

Robert Kennedy Duncan, the father of the idea, was born in Brantford, Ontario, Canada, in 1868. Following his preparatory school days he attended the University of Toronto, graduating from that institution with honors in 1892. For one year he was the incumbent of a fellowship at Clark University (1892–93). Then began that period in his life which was to acquaint him with American ways and American institutions, an acquaintanceship which later enabled him to visualize how the plan which he conceived could be applied to advantage in America. He became an instructor in physics and chemistry in an academic high school at Auburn, N. Y. (1893–95), and then held the same position in Dr. Julius Sach's Collegiate Institute in New York (1895–98) and in the Hill School, Pottstown, Penna. (1898–1901). While teaching in New York he took a postgraduate course in chemistry at Columbia University. From 1901 to 1906 he was professor of chemistry in Washington and Jefferson College. During this phase of his career he found time to devise new processes for manufacturing phosphorus and glass. He also contributed articles to New York periodicals, went abroad to study and report on radioactivity for *McClure's Magazine*, and in 1905 and 1906 studied the relation of modern chemistry to industry in various European countries for *Harper's Magazine*. This was a momentous investigation. From it came the idea which was to have such tremendous influence on Americans and American institutions.

In his travels through Europe Duncan had made the following observations:

> The new Germany is a Germany of workshops; and workshops, too, in which, in the intelligent application of means to ends, which constitute the scientific method, in the eagerness to harness new knowledge to their service, and in a willingness to spend money in intelligent experimentation, there is demonstrated a condition of almost perfect functioning. In France also, although not with the same method, but in a spirit as eager and intelligent, there is the same turning over into sensible scientific conduct of the traditional industries and the same activity in the establishment of new ones. In Italy, too, long deemed a land

> of languorous ineptitude, the scientific spirit has stirred into active being a multitude of new industries. Even in England there is abroad in the land the spirit of applied science.

When Duncan compared these conditions in Europe with those which he had observed in America he found America wanting and stated:

> It is no mistake to say that American manufacture is a chaos of confusion and waste. It is no mistake either to say that the American manufacturer now knows it. The confusion and waste, it should be said, are chemical, not mechanical. Along the lines of mechanical contrivances America need acknowledge no peer. But mechanical contrivances are but a small part of the operations of modern industry. Since every manufacturer deals with the modification of substance, and substance is the business of chemistry, every manufacturer is just exactly to that extent chemical.

Robert Kennedy Duncan

Such comparisons as these were running through his mind when the idea which was to help make America industrial-research-conscious came to Duncan. He was in Rome at the time, attending the Sixth International Congress of Applied Chemistry. Suddenly it occurred to him that the way to bring order out of the research chaos in America was to enlist the aid of the universities with their laboratories, libraries, and consultative facilities in the solving of the problems of industry. He had seen perfect coordination of universities with industries in Germany and knew of many cases in which the universities had rendered services to the industries which could not be furnished by their own technical men who were too occupied by factory routine or lacked adequate training or facilities.

INDUSTRIAL FELLOWSHIP SYSTEM

Why not bring the university to the aid of industry in America, reasoned Duncan:

> The consistency and propriety of this aid are seen in the accepted dictum that the university stands for the whole good of man—for the uplift of man. The absolute function of the university is not only the increase and diffusion of knowledge among men but of useful knowledge. It must be remembered that it is only through useful knowledge that the people have gained the material blessings of our new civilization. Furthermore, it must be remembered that every useful agent in our new civilization is the product of an industry, and that it is only through the industries that these new products of civilization can go to the people...
>
> Everywhere throughout America, wherever there is the smoke of a factory chimney, there are unsolved, exasperating, vitally important manufacturing problems—problems in glass, porcelain, starch, tanning, paints, drugs, meats, iron, oil, metallurgical products—problems wherever man deals with substance. It seems clear that these problems can best be answered by combining the practical knowledge and the large facilities of the factory with the new and special knowledge of the universities, and by making this combination through young men who will find therein success and opportunity.

The opportunity to test these theories was near at hand for Duncan. Following his return from Rome in 1906 he was called to the University of Kansas as professor of industrial chemistry and in 1907 initiated a definite system of industrial fellowships. The beginning was modest and unpretentious. A company that was engaged in the manufacture of launderer's materials believed that a study of the chemical problems involved in laundering would benefit that business. Duncan decided the University of Kansas could furnish the assistance which the company desired, so a fellowship was established and an agreement was drawn up which contained the following provisions:

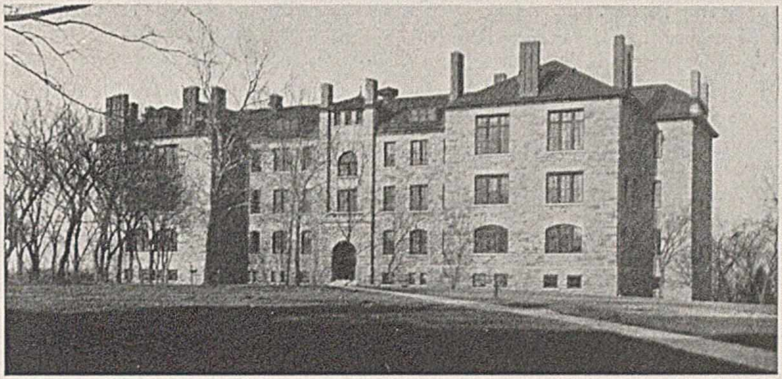
> The purpose of the fellowship was the discovery of improvements in the chemistry of laundering.
>
> A fellow who was to receive five hundred dollars per year was to be appointed by the chancellor of the university, the director of the chemical department, and the professor of industrial chemistry. He was to be a member of the university, pay all regular fees, including laboratory fees, work under the direction of the professor of industrial chemistry and forward periodically, through the professor of industrial chemistry, reports of the progress of his fellowship work.
>
> All discoveries were to belong to the donor company, but the fellow was to receive one tenth of the net proceeds from such discoveries. At the expiration of the fellowship the services of the fellow were obtainable for three years, provided the terms of such services were satisfactory to both parties.
>
> On the expiration of the fellowship, the fellow should prepare a monograph containing what he and others had been able to discover about the chemistry of laundering. The university reserved the right to publish this monograph three years after the expiration of the fellowship.

The fellow selected for this first industrial fellowship was W. F. Faragher. For his services he received five hundred dollars per year for two years. His fellowship was then extended for an additional six months with the salary doubled, and in recognition of his researches he was awarded the degree of doctor of philosophy by the University of Kansas. He next entered the factory of his donor company, where he continued along the lines which he had started as a fellow. Later he was to hold other fellowships, notably those dealing with petroleum technology; today he holds a responsible position in that field and is intimately associated with the latest developments in petroleum refining.

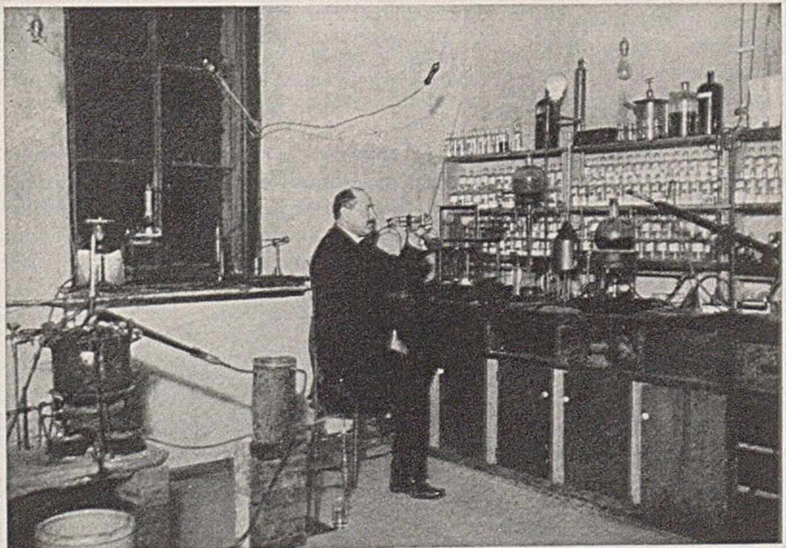
The success of Fellowship No. 1 convinced Duncan that his plan was sound. He was encouraged to advocate fellowships to other companies and associations; he was able to convince the university that space in the basement of the chemistry building should be alloted to him, and he persuaded the legislature of the state of Kansas that some financial support should be furnished to assist in the establishment of this industrial fellowship system. These objectives were not accomplished easily, but Duncan was blessed with a magnetic personality and with the ability to convince others by words, both written and spoken, that he could be of assistance to them. Above all he was fired with enthusiasm for his plan and with a determination to make it succeed. In rapid succession he started fellowship No. 2 to conserve the diastatic content of dried alfalfa; No. 3 to standardize the large-scale manufacture of salt-rising bread; No. 4 to extract casein from buttermilk; No. 5 to separate utilizable constituents from crude petroleum; No. 6 to develop an enamel lining for steel tanks; No. 7 to correlate the physical properties of glass and its chemical constituents; No. 8 to improve the manufacture of portland cement; No. 9 to extract adrenalin from the glands of the whale; and No. 10 to develop an improved finish for wood.

INDUSTRIAL RESEARCH AT THE UNIVERSITY OF KANSAS

The mere enumeration of these first ten fellowships is unimpressive, but each contributed valuable knowledge and assistance to the donor company or association, won additional support and assistance for the industrial fellowship system, and aided one or more young men to become established in his chosen field of chemistry. The latter was a source of great satisfaction to Duncan, for the welfare of "his boys", as he termed his fellows, was always uppermost in his mind. Were he alive today he would derive complete satisfaction from the fact that R. C. Shuey, fellow No. 2, and F. P. Brock, of fellowship No. 6, hold important positions in the Bakelite Corporation; that A. J. Weith of Fellowship No. 6 is director of research, and L. V. Redman, inventor of "Redmanol" on Fellowship No. 10, is vice president of the Bakelite Corporation; that H. A. Kohman, Fellow No. 3, has been successful in each of his succeeding researches on bread; that F. W. Bushong, until his recent death, held a position of trust in the Gulf Refining Company; that E. W. Tillotson is an assistant director in Mellon Institute; and that E. R. Weidlein is the director of that institution. Duncan once said: "No one who has met the young men constituting the staff of these industrial fellowships would doubt for an instant but that they will grow into men of power and influence for good." How well those early fellows and many others who followed them have fulfilled his prophecy!



Chemistry Building at the University of Kansas, Home of the Industrial Fellowship System, Wholly 1907–11, in Part 1911–13



F. W. Bushong, Industrial Fellow at the University of Kansas, 1908–13

In the early days at Kansas, principles and practices were established which to a large extent were responsible for the success of the industrial fellowship system as a whole and of individual fellowships in particular. Duncan was never a dictator. He gave to each fellow the opportunity to conduct his studies and researches in accordance with his own ideas. He likened his group of fellows to a fraternity and held frequent meetings in order that "his boys" might discuss their separate problems with him and among themselves. Here was cooperation among scientific workers to an unusual degree, each representing different industries with different interests but each contributing helpful advice whenever possible to the others.

The industrial fellowship system at Kansas continued to grow. Fellowships on borax, vegetable ivory, soap, and gilsonite were added, and the University of Kansas "recognized the progress and demonstrated value of the work as a whole" by constituting the system a department by itself, assigning to it the name "Department of Industrial Chemical Research of the University of Kansas." But this was not all. Still greater achievements were ahead. The fellowship plan had attracted the attention of Andrew W. Mellon in a curious manner which he has described as follows:

> The manner in which it came about was quite unpremeditated, as those things often are. Strange as it may seem, it all goes back to a school of languages and a quite innocent desire on my part to speak French fluently enough to travel abroad in comfort—a desire, I may add, which remains unsatisfied to this day. At any rate, I called on the school for help and they sent a young Frenchman to my house in the evenings during the summer of 1909. He was a very enthusiastic young man and one night he brought a letter from his father in France who had made a chemical discovery, as he thought, and wanted it tested by some in-

dustry in a position to utilize the discovery commercially. I gave the letter to the general manager of the Gulf Oil Company, who reported a few days later that the supposed discovery was not of practical value and, to prove it, gave me a book called the "Chemistry of Commerce" by Robert Kennedy Duncan, professor of chemistry at the University of Kansas. I read the book with interest, but the part which particularly enlisted my attention was the last chapter, in which Dr. Duncan described his plan for industrial fellowships, by means of which industry could utilize the services of qualified scientists to solve its problems in much the same way as is being done here (in Mellon Institute) today.

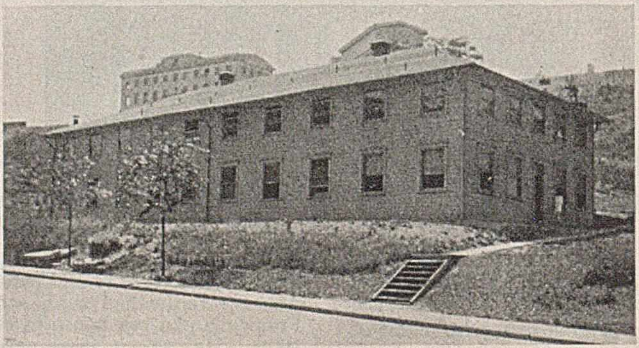
INDUSTRIAL RESEARCH AT THE UNIVERSITY OF PITTSBURGH

So impressed was Andrew W. Mellon with the possibilities of Duncan's scheme that he and his brother persuaded Duncan to organize a department of industrial research in the University of Pittsburgh. They provided him with a two-story frame building (costing ten thousand dollars) on the university campus, and funds for its maintenance and for a multiple fellowship which was to study ways and means for the "abatement of the smoke nuisance in Pittsburgh." Duncan stated that this fellowship was "many times larger than any heretofore established for any purpose whatever or in any university." Here too was a fellowship established, not for the benefit of an industry but for the good of humanity. It was the first of a series of fellowships of like nature which were to follow.

On September 1, 1911, the Department of Industrial Research of the University of Pittsburgh was started in the little frame laboratory with eleven fellowships which Duncan had received even before the building was ready, concrete proof that his plan was gaining recognition and support. The subjects were baking, bread, smoke, glass, glue, soap, fruit waste, petroleum, flooring, natural gas, and cement. Each, in the years to come, was to achieve some measure of success in its particular field. Improvements were made in glass manufacturing methods. A yeast food was developed which enabled the baking industry to decrease the quantity of yeast required for bread by 50 per cent. Later, during the World War, this yeast food was to be used by all the allied armies. The groundwork was laid for many technological developments in the utilization and processing of petroleum, and this work later was to expand greatly in scope and importance. These are only a few of the important results of the early work in Pittsburgh. Space does not permit the recounting of others.

Richard B. Mellon

Meanwhile, work in the industrial chemical department in Kansas continued. Other fellowships were added, and by frequent visits from Pittsburgh Duncan continued to keep in touch with its problems and successes. Each visit increased the respect of his fellows for their leader and fired them with new enthusiasm.



Home of the Industrial Fellowship System in Pittsburgh, 1911–15

MELLON INSTITUTE OF INDUSTRIAL RESEARCH

But this enthusiasm for Duncan and for his plan was not confined to his fellows. The brothers Mellon, impressed by the evident practical value of this system both to learning and to industry (in March, 1913), established it on a permanent basis and consented to allow their family name to be placed upon it as the Mellon Institute of Industrial Research and School of Specific Industries at the University of Pittsburgh. Funds were provided for a new and permanent building, apparatus, and a library.

Greatly encouraged by this generous support, Duncan redoubled his efforts, transferred his fellows from Kansas to Pittsburgh, and added still more fellowships until in May, 1914, the total number was thirty-two. The amount of money which had been contributed by industrialists for expenditure in the little frame building was $183,800 and the total fellowship list was running at the rate of $97,400 per year—irrefutable evidence that the plan was working. Duncan voiced his own satisfaction with the progress made in the following words:

Andrew W. Mellon

> It may be said that this system of cooperation between industry and learning, between the factory and the university, has positively passed the tentative and experimental stage and that it now stands as a valuable and permanent relation to both. Any anxieties I may have are not now connected with this example of the system, but with my desire that it should be extended into other educational institutions. We believe that this can be accomplished by handing over to the universities for this service some of our own men inducted into a full knowledge of the working of this system through years of connection with it.

This appraisal of the past and hope for the future was written by Duncan shortly before his death. When he was about to see his fellows in the better building and provided with the better facilities which he had planned for them, he succumbed on February 18, 1914, to a stomach ailment from which he had suffered for many years. The basement of the chemistry building at the University of Kansas and the simple frame building at the University of Pittsburgh had been his workshops. In them he had demonstrated to America that the university "can take the best brains and training of the whole country and form them through notable and useful achievements into the highly specialized service which modern manufacture and the human needs of modern men require." He had shown a doubting world that industrial fellows working in the atmosphere of the university on totally unrelated subjects can help one another and in so doing can aid the industries for which they work.

With the dedication of the new building in 1915, Mellon Institute of Industrial Research was able to add more fellowships and thereby aid more industries. The use of pilot plants to test procedures developed in the laboratory, on a semicommercial scale, was continued. (It had originated during the earlier days at Pittsburgh.) More emphasis was placed on pure science researches and more opportunities were provided for the fellows to obtain additional training in the university and for university students working for graduate degrees to obtain useful industrial chemical experience in Mellon Institute.

Headquarters of Mellon Institute, 1915–37

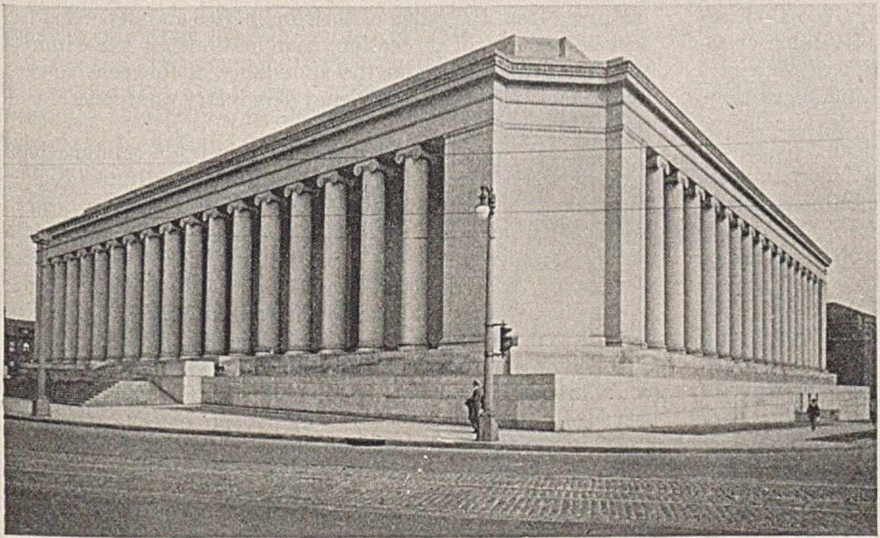
So thoroughly had Duncan trained his successors, Raymond F. Bacon, director until 1921, and Edward R. Weidlein, director thereafter, that the work of the institute went forward exactly in accordance with his plans. More fellowships were added, and new products and processes were developed; some of them were of such importance that novel and important industries resulted from them. The "Redmanol" industry, originating from the work at Kansas, grew in importance and merged with the Bakelite Corporation. From researches at Mellon Institute dealing with the manufacture of synthetic products from ethylene grew the mighty Carbide & Carbon Chemicals Corporation. The Niacet Chemicals Corporation developed the synthesis of new products from acetylene and from cane sugar. The Visking Corporation of Chicago was founded to manufacture sausage casings from viscose by a method developed at Mellon Institute. The Koppers Company recovered important quantities of much needed toluene from carbureted water gas and developed new methods of purifying gas with the aid of industrial fellowships at Mellon Institute; and the Gulf Oil Company found industrial research to be so productive that its fellowships were expanded to the limit of the space available in Mellon Institute, and then a separate research department was formed to supplement the fellowship. These are only a few of the outstanding achievements of the institute in the period between 1915 and 1937. Many others could be mentioned if space allowed.

Edward R. Weidlein, Director of Mellon Institute since 1921

The Department of Research in Pure Chemistry, headed by Leonard H. Cretcher, enlarged the scope of its activities and started to investigate and develop drugs for the treatment of pneumonia. Regarding the institute's pure science activities, Richard K. Mellon, a trustee, has well said:

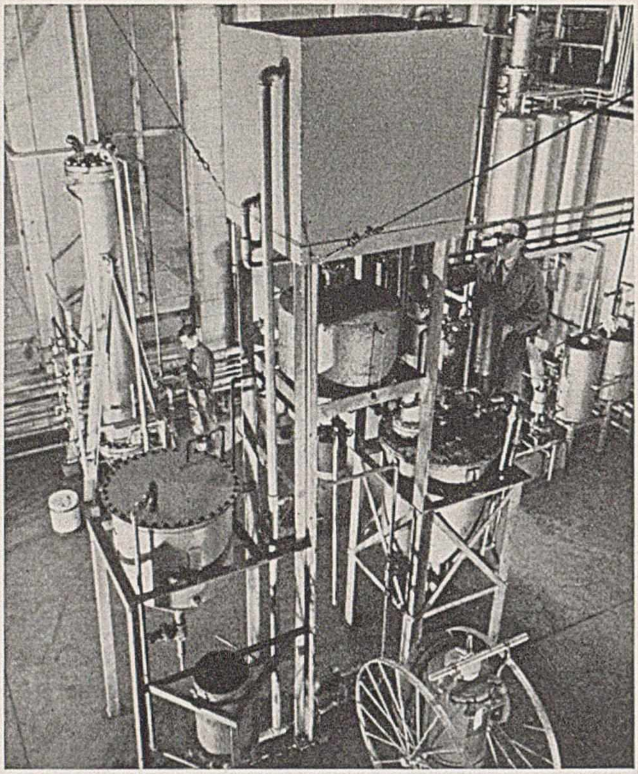
> A general feeling seems to prevail that the institute is a scientific chemical laboratory, aiding only industry. This is not entirely true, and we can well realize the reason for the misunderstanding. Scientists are so shy about their work that little is ever published regarding their efforts. Fellows of Mellon Institute are constantly at work doing pure research in the fields of chemistry and biology and have been quite successful in their discoveries. Many lives have been saved as the result of the individual effort of these fellows, and it is the hope of the founders that they will continue their research in the biological and related fields.

Present Home of Mellon Institute



Too much praise cannot be given them, and I know they regard success as their chief reward.

So well satisfied were Andrew W. Mellon and Richard B. Mellon with the accomplishments of the institute which bears their name and with the efficient manner in which its affairs were being conducted by Edward R. Weidlein and his associates, that they decided to provide the magnificent building which is now the home of Mellon Institute. In this building, dedicated in May, 1937, every facility for the convenient and efficient working of Duncan's system of industrial research has been provided. A new era of the industrial fellowship system is under way in more beautiful quarters and with more efficient tools, but in inward essence it is still the same as it was in the beginning.



Unit Experimental Plant in the Mellon Institute of Today

OPERATING PRINCIPLES OF MELLON INSTITUTE

A problem requiring investigation is proposed by an individual, a company, or an association of manufacturers. If the problem is of such scope as to require the services of at least one man for a period of not less than one year, a contract covering the establishment of a fellowship is arranged between the donor and Mellon Institute, provided that no other research is already in progress on the same problem and provided that the institute can give the necessary accommodations for the satisfactory conduct of the investigation.

On acceptance of the problem by Mellon Institute, a suitably trained worker is engaged by the institute and given a laboratory. Immediately available to him are the library, machine shop, advisory, consultative, and secretarial assistance, and the many facilities which the institute can furnish.

Before starting actual experimental work the fellow reviews thoroughly all literature and patents pertaining or related to his problem to preclude the duplication of work previously performed and to obtain such ideas and suggestions as may be obtainable from these sources. He also learns everything the donor knows about the problem.

As the work of the fellowship proceeds, the fellow submits weekly reports to the executive staff of the institute and confidential reports are transmitted monthly to the donor. Nothing about the work of the fellowship is published without the consent of the donor, and the latter decides whether patent protection shall be sought for new processes or products developed by the fellowship. All the results of the fellowship belong to the donor. The institute derives no financial benefit from any fellowship. A donor defrays, by contributing the foundation sum of a fellowship, the fellow's salary and other actual operating expenses of the fellowship. The institute's reward is the fulfillment of Duncan's plan, so generously supported by the Mellon family, to demonstrate to American industry the benefits obtainable from industrial research and to train young men for service in American industries.

Today two hundred and sixty scientists on eighty-five industrial fellowships in Mellon Institute are attacking problems that will have far-reaching effects, not only for their donor companies or associations but for human beings in every walk of life. The spirit of cooperation which characterized the first group of fellows, Duncan's fraternity, at Kansas still prevails, but now the fraternity is called the Robert Kennedy Duncan Club. Fellowships for seemingly unrelated industries still find, just as they did at Kansas, that they have common interests, and cooperative effort often leads to mutual benefits. A fellowship working on organic synthesis cooperates with a fellowship on textiles and jointly they develop a new process for the finishing of fabrics.

EXPANSION OF INDUSTRIAL RESEARCH

Many of the problems assigned to present fellowships in Mellon Institute are more fundamental in nature or more complex than the majority of those of earlier days. This fact is indicative of vast changes which have been taking place in America since the inception of Duncan's industrial fellowship plan, changes brought about to a large extent by recognition and adoption of that plan and the principles for which it stands.

Prior to the conception of Duncan's idea in 1906, American industries were faced with serious problems. With few exceptions they were staffed by men who knew little, and frequently cared less, about applied science. Many of them had risen from the ranks of their industries and depended for success upon tariff protection, combinations for the elimination of competition, and the abundance of inexpensive raw materials. Waste and inefficiency in industry were general and not exceptional.

With the passage of laws which made trade combinations illegal, increased costs of living which necessitated higher wages, and increased instability of tariffs designed to protect inefficiently made domestic goods against foreign materials produced under conditions of scientific efficiency, a crisis was developing which had to be solved if American industry was to survive. Many industrialists realized, at least to some extent, that they needed the aid of chemists, but where could they obtain such chemists and, if they did secure them, where could they work and what could they do? For the industrialist usually thought of chemists as analysts or control laboratorians. True they knew that chemists were at work in universities and colleges, but they knew too that those chemists usually were concerned with studies and researches in the realm of the pure science and were wont to consider the application of science to industry as impure. Into this breach stepped Duncan with his plan to bring together the learning and the facilities of the universities and the problems of the industries. They watched with skepticism but increasing interest the successes achieved at Kansas. They visited the institute in Pittsburgh and considered the advantages to be gained by adopting its methods of applied research. Soon it was no longer necessary to "sell" industrial fellowships to prospective donors; requests for fellowships came to the institute without solicitation. The spirit of applied scientific research was abroad in the land. Laboratories of corporations increased their staffs and facilities. Laboratories organized originally for analytical and testing work added research service, and several government bureaus broadened the scope of their activities to include problems of immediate interest to industries.

These increased activities created a demand for properly trained and researchful chemists and chemical engineers. Universities and colleges added courses to their curricula or increased their facilities for providing adequate instruction where they were already established. Graduate study in chemistry received its first weighty impetus in America. To be a chemist took on a new dignity and a new importance.

The substitution of efficiency for the waste and inefficiency which prevailed in industry in 1906 took place slowly at first and then with increasing momentum until today it can be said that a golden age of applied chemistry in America has arrived.

The contributory part played by the fellows of Mellon Institute in this march of chemical progress cannot be overemphasized. From time to time, fellows experienced in applied scientific research leave the institute to take responsible positions in industry and thus spread the gospel of scientific endeavor. Many of these fellows, for "once a fellow always a fellow", have induced their companies to organize departments for research, or to obtain the benefits of research through fellowships at Mellon Institute or through similar institutions organized for industrial research since the first application of Duncan's idea. The fact that there are such similar institutions here and abroad marks the attainment of Duncan's final wish, that the Mellon Institute system "should be extended into other educational institutions."

OTHER INDUSTRIAL RESEARCH INSTITUTIONS

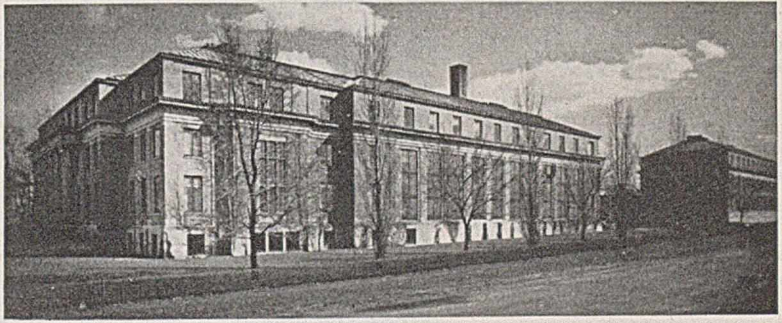
Following the transfer of the industrial fellowship system from Kansas to Pittsburgh, the Department of Chemistry of the University of Kansas operated a division of state industrial research for a time. Then the research spirit, thus demonstrated as fruitful, diffused gradually into other states as well as into other educational institutions. The simultaneous development of scientific management with its research precepts helped this cause. Industrial research, sporadic, occasional, unsystematized, and unappreciated in general, had been conducted in the United States since colonial days. It required such a procedure as Duncan's, however, to lead the way to a clear recognition of the realizable value of properly planned, systematically conducted industrial research. In the subsequent sections of this article will be presented brief descriptions of several industrial research organizations that have been established to meet some of the investigational needs of technology. These specific illustrations of institutional industrial research are intended solely as examples of what has been accomplished in an American Way.

Battelle Memorial Institute. About ten years ago an institute was founded in Columbus, Ohio, whose basic operating principles are analogous to those of Mellon Institute. Original plans for the institute were formulated by Gordon Battelle, whose family had long been prominent in the industrial development of the state. On his death in 1923 his will provided funds to endow an institute to serve as a memorial to the Battelle family. The purpose of the institute, as stated by Gordon Battelle, is to be of service to industry through original scientific research and the dissemination of scientific information.

The usual procedure for conducting research for industry is under an industrial sponsorship plan. A research problem is carefully defined in consultation with the sponsor, and, if no prior commitment exists, the problem is assigned to the proper operating division and is taken up as a group project. One or more men are assigned to full-time work on the job with any necessary assistance from the other technical men in the division and the service departments.

The institute is made up of research divisions which specialize in the following fields: metallurgy, ceramics, beneficiation of raw materials, chemistry, and physics. Each of these divisions is under the direction of a technical supervisor who has assistance in a staff of trained men. The work of all divisions is headed through an executive department which correlates and directs the work to take advantage of the abilities of the entire staff. The object is to make research entirely practical and to secure useful commercial results as quickly as possible.

Under this sponsorship plan all the results of the work, including inventions or discoveries made by staff men assigned to the work, become the property of the sponsor. Ordinarily, sponsored research projects are set up for periods of one year. Written reports are submitted at regular intervals so that the sponsor is kept in constant touch with the project. Work for private sponsors is confined to actual research problems, and thus the functions of the consulting firm and the commercial testing laboratory are avoided except when such work is a necessary part of a research program.

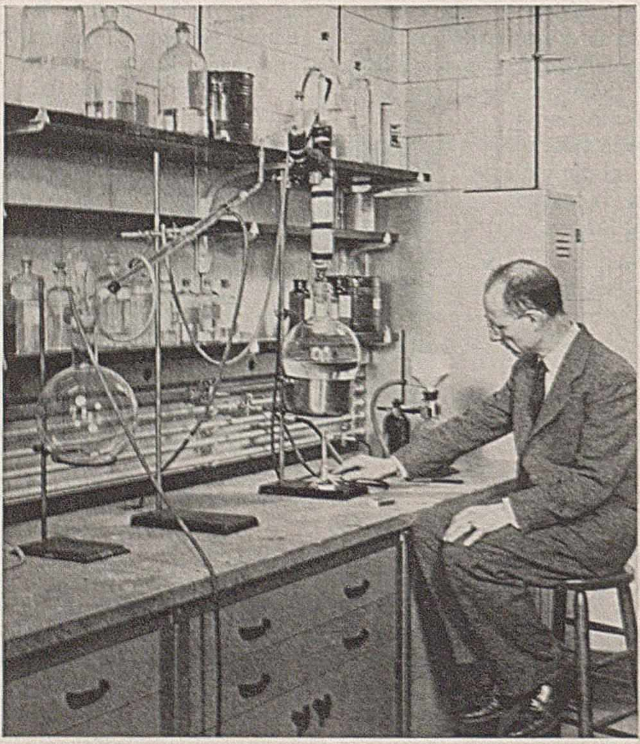

Battelle Memorial Institute, Columbus, Ohio

The staff now numbers one hundred and seventy-five, and the laboratories are housed in three buildings occupying 135,000 square feet of floor space.

The Purdue Research Foundation, at Purdue University, West Lafayette, Ind., was incorporated in 1930 with the primary purpose "to cooperate with industry in the solution of pure and applied research problems which are adequately subsidized, to the end that the foundation, the university staff members, the graduate research student, and industry itself shall be mutually and substantially benefited." It is also the purpose of the foundation "to provide funds and encouragement to members of the university staff to continue research for the purpose of creating new and useful fundamental knowledge."

The Ohio State University Research Foundation was established at Columbus, Ohio, in 1936. "Exploratory work and the notable pioneering of Purdue University in the establishment and conspicuous success of its own research foundation showed the type of organization needed." The purpose of the O. S. U. foundation is well described in a leaflet entitled "Men and Methods in Research Work", as follows: "The Ohio State University Research Foundation has been established to further advantageous relations between industry and the Ohio State University, particularly in arrangements for cooperative research." The smaller industry, one without a fully equipped laboratory and staff, finds at the university a diversity of personnel and equipment which can be placed at his disposal. The larger industry finds that problems of a scientific nature can be handled here to advantage, apart from distractions of production, control, and marketing.

Armour Research Foundation. Another educational institution which has seen the desirability of establishing a separate research organization is the Armour Institute of Technology at Chicago which in 1936 incorporated the Armour Research Foundation. Its purpose is to conduct scientific research and development in various branches of pure and applied science. It has a staff of thirty-six members, trained in various branches of chemistry, physics, and engineering. Each staff member has at his disposal the facilities and personnel both of the foundation and of the institute. The foundation is designed to provide an industry, or a group of industries, with the physical plant and scientific aid needed in the solution of research projects. These facilities are being used both by industries having no laboratories of their own and by industries maintaining extensive research organizations that wish to have special problems worked out, especially long-time projects. To permit the broadest possible use of its facilities by both large and small organizations, the activities of the foundation have been separated into two divisions, an experimental engineering division which enables the use of the general laboratories and facilities for short-term studies and special tests, and an industrial research division in which the major activities of the foundation are centered. In the experimental engineering division the fees for services are determined in advance and depend upon the time, facilities, and personnel involved. In the industrial research division the standard fee for a research project is five hundred dollars per month and, except in special cases, is underwritten for a period of six months. This charge covers a suitable laboratory, all available required equipment, the full-time services of one research worker or the equivalent, and the necessary supervisory services as may be needed.


Corner in a Research Laboratory of the New Mellon Institute Building

Projects are under way in the fields of metallurgy, fuel technology, mechanical engineering, ceramics, and the utilization of agricultural products. Projects are announced only if permission to do so is granted by the sponsor.

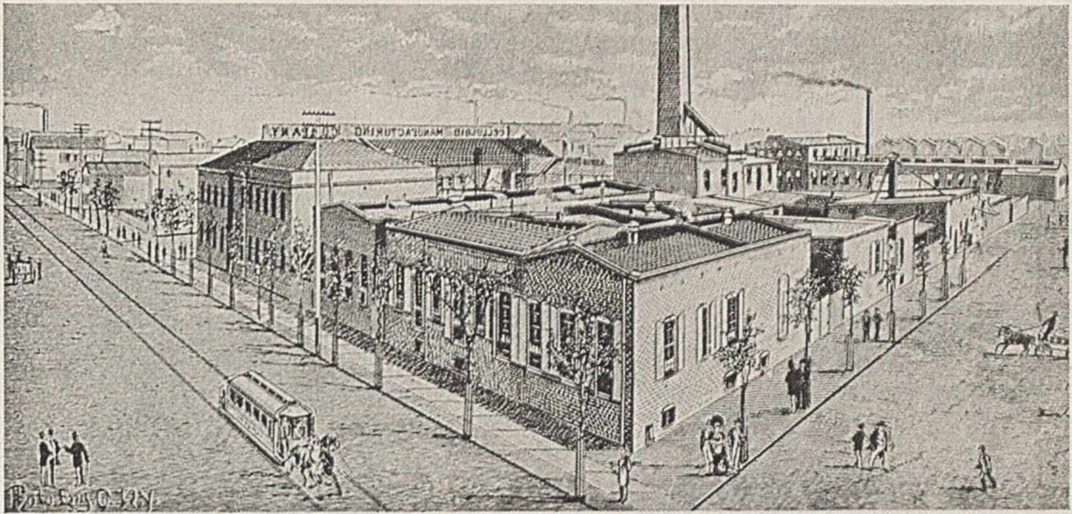
Armour Foundation publishes *The Frontier*, a journal of general scientific research interest, five times a year. From time to time it issues technical bulletins covering results from partially or nonsubsidized investigations. In special cases the results from wholly subsidized projects are published when permission is granted by the sponsor because of the general scientific value of the findings.

The Institute of Paper Chemistry shows the trend which industrial research may take in the future in that it devotes all its time and work to problems of one branch of technology, the pulp and paper industry, rather than to miscellaneous problems of a wide group of industries.

The institute, located at Appleton, Wis., was founded in 1929. Although, first of all, an educational institution, research is a major objective. The research work can be placed under four headings: work done by students in fulfillment of their thesis requirements; work of staff on problems of a broad nature, mostly fundamental in character; problems brought up by the membership; and research pursued for concerns that are not eligible for membership. The studies are confidential and the results belong entirely to the cooperator.

The institute is organized as a nonprofit organization. Membership is limited to manufacturers of pulp and paper who pay annual fees based upon their rate of production. The institute prefers to work on a project basis rather than on a fellowship basis. In general, the charges are based upon cost plus 15 per cent for overhead. The membership includes sixty pulp and paper concerns, representing about three hundred mills located in every important papermaking state. The institute staff consists of eighty-three members. They are located in three buildings which with equipment facilities are valued at approximately a million dollars.

These and other institutions are cooperating with industry in the prosecution of scientific research along lines similar to those pioneered by Duncan thirty-two years ago at the University of Kansas. Collectively they represent an American Way of conducting industrial chemical research which has contributed richly to the fund of scientific knowledge in America. This research has aided established industries and has founded new ones. It has provided opportunities for young men in the fields of science, and above all it has helped the well-being and prosperity of mankind and the professions concerned, especially our own field of chemistry.



First Buildings of Celluloid Corporation, Built in Newark in 1875

PLASTICS

In a single generation, developments in a chemical specialty have left imprints on all industry

ARCHIE J. WEITH

The Bakelite Corporation,
Bloomfield, N. J.

John Wesley Hyatt as a Young Man

IN ITS growth the plastics industry has followed two paths of endeavor: that toward the improvement and creation of new thermoplastic materials, as typified by Hyatt's celluloid; and that toward the improvement and creation of thermosetting materials, as typified by Baekeland's phenolic plastics.

The story of plastics is like a modern version of "Cinderella and the Glass Slipper." However, it isn't a search for a fairy princess but a search for a new kind of glass to make the slipper. Nor does this story concern itself with fantasy, but with Americans pioneering in a chemical world, applying man's own resourceful imagination toward the founding of a new industry. It is the story of the efforts of man to draw upon the materials of nature—greatest chemist of all—and to improve upon them by chemical synthesis.

JOHN WESLEY HYATT

Inspired by a prize—not a beautiful princess' hand in marriage but a reward of $10,000 for a material which would be a substitute for ivory—John Wesley Hyatt, a journeyman printer, set to work. Blessed with resourcefulness and imagination, he found his goal in 1868 when he saw in a drop of dried collodion the possibility of producing a plastic mass.

Thus did an industry begin by employing the tool of invention, for Hyatt had discovered that nitrocellulose, combined with camphor, gave him a desirable substitute for ivory. The manufacture of this first synthetic plastic, celluloid, was beset with many difficulties, but with his engineering skill Hyatt devised a means of making an ideal mechanical mixture of nitrocellulose and camphor, a means for completing the solution under heat and pressure, and finally a means of forming the plastic into molds and in the shape of sheets, rods, and tubes.

This much accomplished, Hyatt searched for the third tool of American industry—namely, courageous capital. Capital had need to be courageous to sponsor a process for the manufacture of a highly explosive material reported as being made of guncotton and camphor. Even a fire, which occurred shortly after the company began operations and which utterly destroyed all stock and machinery, did not dampen the confidence of the inventor's backers, nor did the long and expensive litigation in defense of the inventor's right granted him by a helpful patent system. With all this, the need and desire for a new material resulted in the growth of a new industry which, in 1880, had a total sales value of little more than one million dollars and had already begun to foreshadow the growth of a greater plastics industry.

LEO HENDRIK BAEKELAND

More than three decades passed before the search was renewed for a better plastic material. This time no reward stimulated the search, but again invention and research were the first tools to be used, supported by the courageous capital of the inventor himself who had already experienced that an industry can grow in the American Way. Having invented Velox photographic paper about 1893, Leo Hendrik Baekeland had been fortunate enough to find a financial sponsor. Success was not his immediately, but through perseverance the values of the Velox process became clearly recognized; in 1899 he disposed of his rights to this process and received a very liberal reward. Thus financially independent, Baekeland found himself free to devote his life to the solution of other problems that had baffled chemistry. By 1909 he was able to announce the principle for the practical production of heat-hardenable phenolic resins, the first man-made thermosetting plastics.

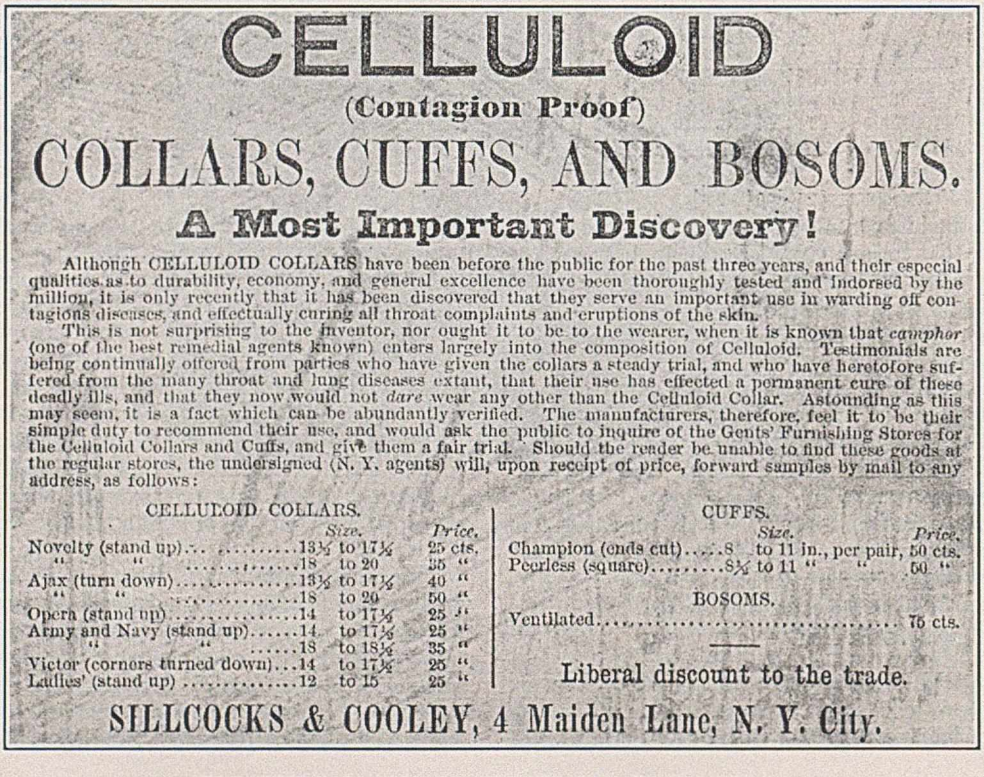
Almost overnight the plastics industry, which had been peacefully plodding along, was stimulated into action. The next thirty years were to witness the introduction of a score of new plastic materials and the development of an industry valued five hundred times as great as that ten years after Hyatt's discovery of celluloid.

It is not difficult to understand why Baekeland's discovery gave such an impetus to industry. He had produced the first dimensionally stable plastic material, the first plastic which could be shaped exactly to form and, once shaped, would stay put. The significance of dimensional stability is best appreciated when it is realized that today standardization makes mass production possible and that the word "interchangeability" is the sum and substance of all standardization. Now, for the first time it was possible to mold a plastic material to exacting tolerances, to repeat it time and time again, and to have the molded product retain its dimensional stability. Is it any wonder that the plastics industry was in a sense reborn, and that production has increased 2000 per cent in the thirty years that have passed since Baekeland's invention! His discovery stimulated the search for new plastics so that today their varieties have increased twenty fold and their uses a million fold. But more than that, it has stimulated research and invention far beyond the environs of plastics. In the words of Baekeland a few years ago: "The phenomenon of polymerization which plays so important a part in synthetic plastics is now being studied in relation to the obscure phenomenon of life and other fields. Able scientists and chemists throughout the world are devoting their untiring efforts in many branches of scientific chemical research. Where their research will lead, one can only conjecture. One thing is certain, that they will give to the world many new and vital discoveries."

Leo Hendrik Baekeland

Where only the most courageous and patient capital would back Hyatt, and where Baekeland risked his own private

Advertisement from *Harper's Weekly*, June 4, 1881



CELLULOID

(Contagion Proof)

COLLARS, CUFFS, AND BOSOMS.

A Most Important Discovery!

Although CELLULOID COLLARS have been before the public for the past three years, and their especial qualities as to durability, economy, and general excellence have been thoroughly tested and indorsed by the million, it is only recently that it has been discovered that they serve an important use in warding off contagious diseases, and effectually curing all throat complaints and eruptions of the skin.

This is not surprising to the inventor, nor ought it to be to the wearer, when it is known that *camphor* (one of the best remedial agents known) enters largely into the composition of Celluloid. Testimonials are being continually offered from parties who have given the collars a steady trial, and who have heretofore suffered from the many throat and lung diseases extant, that their use has effected a permanent cure of these deadly ills, and that they now would not *dare* wear any other than the Celluloid Collar. Astounding as this may seem, it is a fact which can be abundantly verified. The manufacturers, therefore, feel it to be their simple duty to recommend their use, and would ask the public to inquire of the Gents' Furnishing Stores for the Celluloid Collars and Cuffs, and give them a fair trial. Should the reader be unable to find these goods at the regular stores, the undersigned (N. Y. agents) will, upon receipt of price, forward samples by mail to any address, as follows:

CELLULOID COLLARS.

	Size.	*Price.*
Novelty (stand up)	13½ to 17½	25 cts.
" "	18 to 20	35 "
Ajax (turn down)	13½ to 17½	40 "
" "	18 to 20	50 "
Opera (stand up)	14 to 17½	25 "
Army and Navy (stand up)	14 to 17½	25 "
" "	18 to 18½	35 "
Victor (corners turned down)	14 to 17½	25 "
Ladies' (stand up)	12 to 15	25 "

CUFFS.

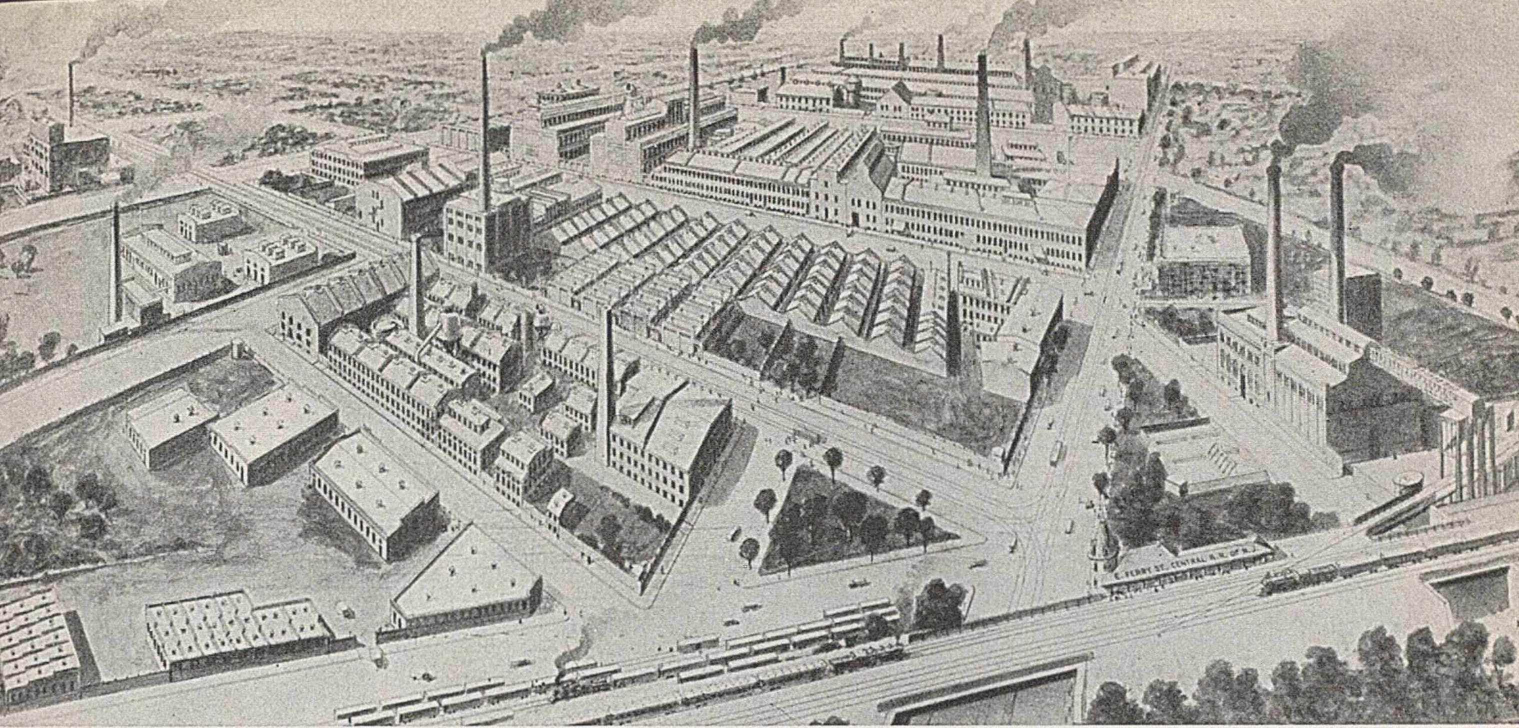
	Size.	*Price.*
Champion (ends cut)	8 to 11 in., per pair,	50 cts.
Peerless (square)	8½ to 11 " "	50 "

BOSOMS.

Ventilated.......................... 75 cts.

Liberal discount to the trade.

SILLCOCKS & COOLEY, 4 Maiden Lane, N. Y. City.



Present Home of Celluloid Corporation at Newark

fortune, today research in plastics is backed by capital willing to undertake the risks and hazards involved that the industry may continue to thrive and grow. This branch of the chemical industry has set up large research organizations which are dedicated solely to the improvement of existing materials and the creation of new synthetic resinous products. Millions of dollars are spent annually for this type of research alone. Other groups of engineers and scientists devoted their lives toward the improvement of fabricating technics—more efficient molding processes, faster production machines. The impetus given by the discovery of thermoplastic and thermosetting materials drives on. Types of plastics that heretofore have been useless commercially have come into their own.

CELLULOSE ACETATE PLASTICS

Search for an ester of cellulose, more stable and less flammable than the nitrate, led to the development of the acetate. Here again, an early invention by an American, G. W. Miles, in 1906 disclosed that triacetate could be "ripened" into a product of increased stability and ready solubility in acetone. This plus the pioneering work of the Celluloid, Fiberloid, and Eastman Kodak companies led eventually to the present successful commercial use of cellulose acetate plastics. Great impetus was given to the use of these materials (and all thermoplastic materials) by the engineering skill displayed in the recent development of injection molding technique. Improved methods of manufacture have also resulted in an acetate of increased clarity. Thus, we find acetate being widely used in the manufacture of shatterproof glass. In fact, in 1937 the sale of acetate plastics was about three fourths as great as the sale of nitrocellulose plastics.

Still other thermoplastic derivatives of cellulose have achieved merit as constituents of lacquers, films, and wire coating materials. Notable among these is ethylcellulose, introduced and now being supplied by the Dow Chemical and Hercules Powder companies.

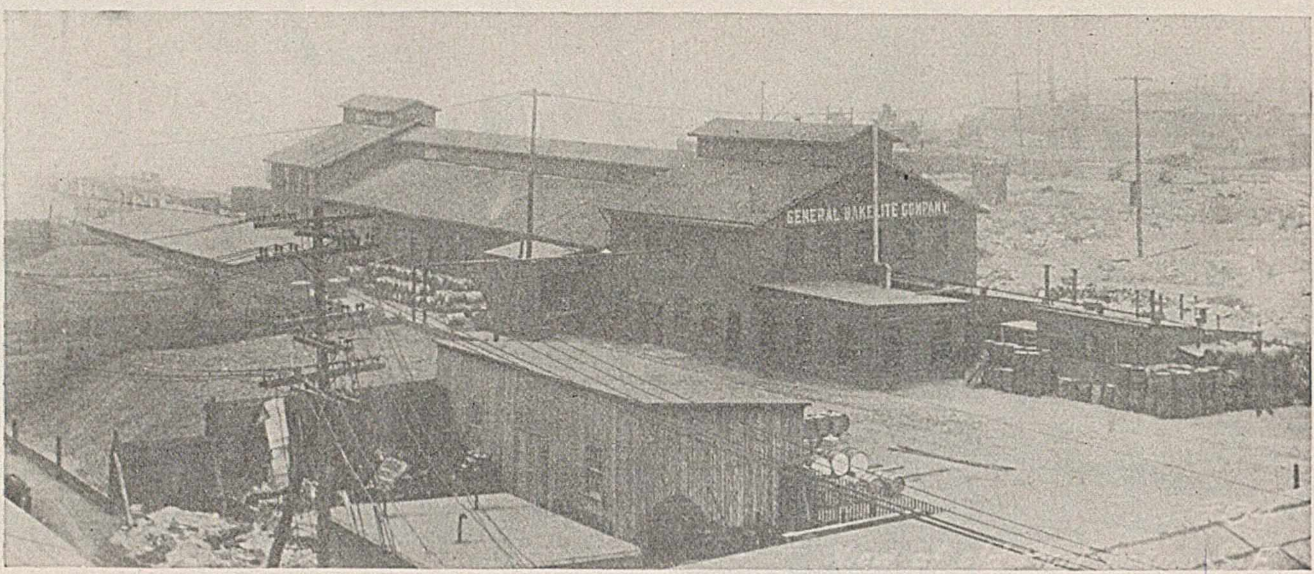
VINYL PLASTICS

Research has turned from cellulose as a raw material for thermoplastics and created a new group, the vinyl plastics. First to become of importance were the esters of vinyl alcohol, namely, vinyl acetate and vinyl chloride. These have been developed into articles of commercial value mainly through the efforts of the research staff of the Carbide and Carbon Chemicals Corporation. A notable advance has been the commercialization of these polyvinyl resins as synthetic textile fibers. They possess unique elasticity, fatigue, and water resistance. Their knitting properties and washability are exceptionally good. Because of their excellent electrical and chemical properties, these esters are also becoming increasingly important as wire coating materials.

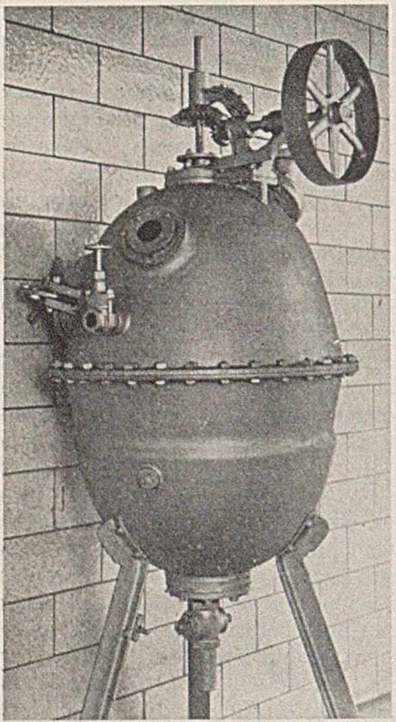
Other derivatives of vinyl alcohol, the acetals, formed by the interaction with various aldehydes, are also useful thermoplastics. One in particular, the butyraldehyde derivative, has improved the qualities of shatterproof glass.

Polyvinyl benzene or polystyrene is probably the oldest of all plastics; it was known as early as 1839 and more recently has been made commercially available through the cooperative efforts of the Dow Chemical Company and the Bakelite Corporation. Its transparency, absence of color, and excellent electrical- and water-resisting properties have long held the interests of chemists. Improved methods for the synthesis of the monomer and for its polymerization have made it one of the outstanding thermoplastic materials. It is also unique in that it requires no plastification for molding by injection. This important characteristic imparts to the molded object a dimensional stability superior to other thermoplastics and has led to its adoption as watch crystals and lenses. Its excellent chemical resistance is indicated by its use as closure materials on mineral acid containers by leading chemical manufacturers. With its exceptional electrical properties, which are equal to fused quartz at any frequency, polystyrene has found particular favor in the radio industry.

The acrylic plastics also belong to the vinyl plastics family. They, too, have been known for a long time but have entered the plastics field only in the last year or two, chiefly through the research work of Röhm & Haas and the du Pont company. The acrylates, like polystyrene, are beautifully transparent and tough. They may be compression-molded and also, when plasticized, injection-molded. Their clarity and beauty give them a high decorative value which craftsmen and designers have utilized in the creation of many *objets d'art*. Their practicability is demonstrated in their use as aeroplane cockpit enclosures.



Original Factory of the General Bakelite Company, Leased October 1, 1910, Abandoned December 1, 1917



"Old Faithful" Still, Dr. Baekeland's First Semicommercial Unit in His Yonkers Laboratory

It was later shipped to Perth Amboy and used for making small batches; now, retired from active duty, it occupies a place of honor in the Bound Brook Plant

AMINO, CASEIN, ALKYD PLASTICS

Of the thermosetting plastic materials, the amino plastics made from formaldehyde and urea are second in importance. The development of these plastics in this country has been largely due to the American Cyanamid and Plaskon companies and to the researches of Carleton Ellis. These resins have achieved their greatest importance when mixed with cellulose fillers and used as molding and laminating materials. Urea resins are useful as wood-bonding adhesives and as lacquer and enamel components. Their lack of color and stability toward light have made them particularly suitable for the molding of decorative articles and laminated paneling for the building industry.

The casein plastics were produced commercially in the United States about 1919. They have had an up-and-down existence. But lately, as a result of improved methods of manufacture and molding technique and of greater cooperation throughout the industry, their future looks far more promising. They are used chiefly for buttons, buckles, and similar ornaments. The volume of business in buttons alone is stated to be some eight million gross annually.

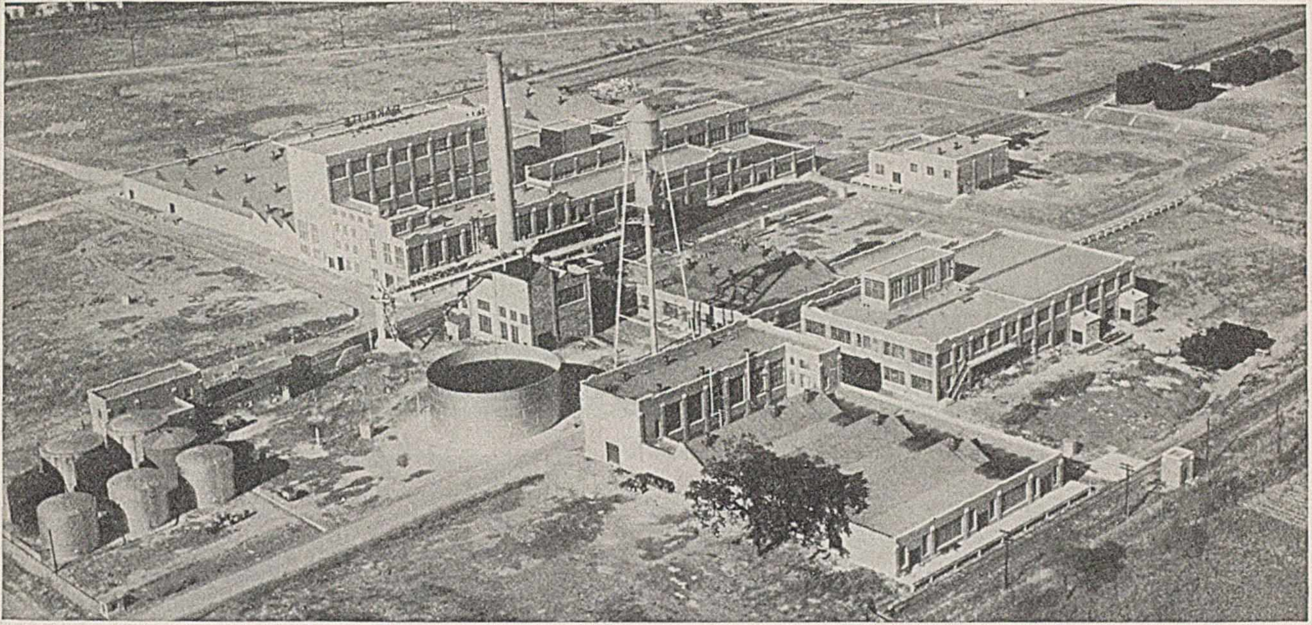
The alkyd plastics, those resins formed from polyhydric alcohols and polybasic acids, were first developed industrially in this country by the research laboratories of the General Electric Company. Although for a time they were employed as casting materials, their principal uses today are as paints, varnishes, lacquers, and industrial cements and bonds.

SEARCH FOR THE IDEAL PLASTIC

Recently other plastics closely related to the alkyds, namely, plastics made from polyamines and polybasic acids, have been developed by the research laboratories of the du Pont company. Here is another good example of the fruits of modern organized industrial research. The company set out with a definite objective—to synthesize from readily available native raw materials a wholly new group of chemical compounds to meet definite deficiencies of many industrial materials that in the main are now imported. Research opened the way for the discovery of the sought-for chemically made substance. These new materials, first introduced commercially as synthetic bristles for tooth brushes to replace natural hog's hair bristles, can now be spun into fibers which have all the feel, luster, and strength of silk.

Scientists continue to search for the ideal plastic material. From this search has already grown an industry with a total annual production value of some half billion dollars, an industry in which the annual output in pounds in the past ten years alone has increased almost sixteen times—and this during years of depression and business hesitation. Furthermore, where but one type of synthetic plastic was known at the beginning of the twentieth century, we have today almost a score, each with varying characteristics, properties, and advantages, which make them useful to man in a million different ways.

What reasons have made it possible for the plastics industry to expand so rapidly? It is human nature to be dis-



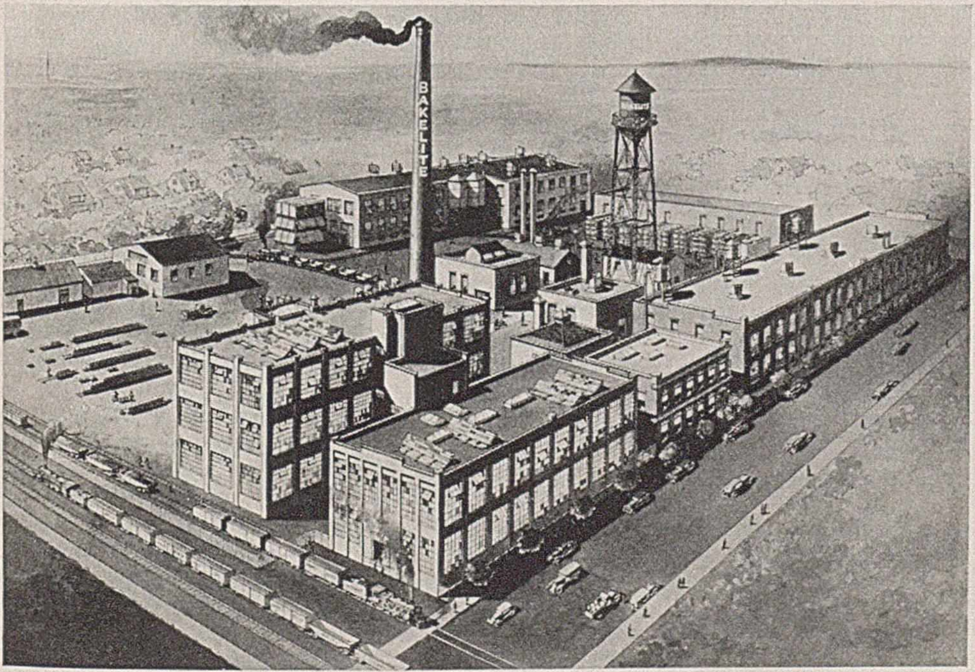
Present Plant of the Bakelite Corporation at Bound Brook, N. J.

satisfied, to strive for better and better ways of living. When nature's products are found to have shortcomings, industry turns to research for better materials.

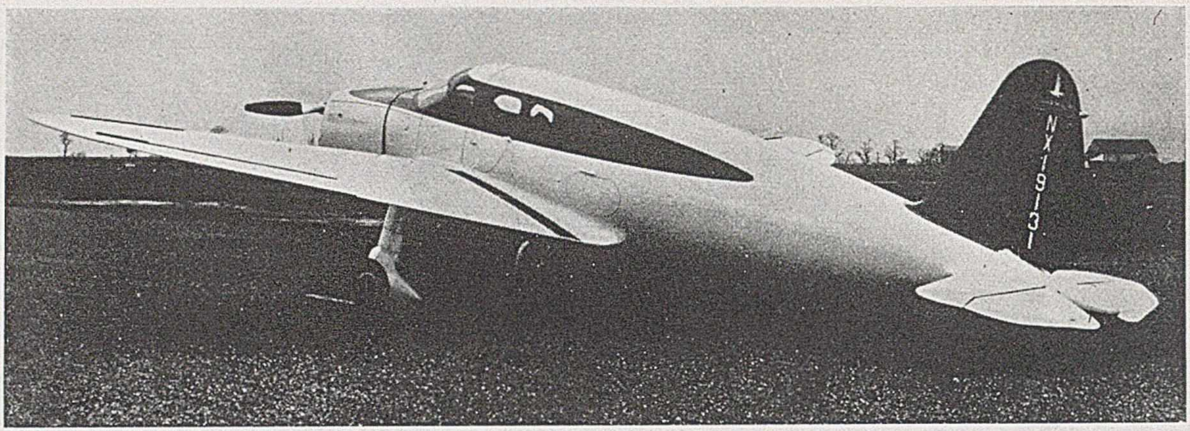
PLASTICS IN THE AUTOMOBILE

Hence the growth in the variety and amount of plastics is decidedly the result of consumer demand. This is best illustrated by the way in which plastics serve the automotive industry. Today, the modern automobile runs smoothly because its ignition system is protected with a molded phenolic distributor head and other parts. It runs quietly because of silent phenolic laminated timing gears, safely because it is equipped with phenol resin–bonded brake linings and safety glass which is laminated with a vinyl acetal. Electrical wiring is insulated with a vinyl plastic. Colorful, decorative fitments, handles, and other accessories of cast phenolic resin or molded acetate or urea adorn the modern car. The steering wheel and horn button are molded of tough, flexible acetate in a variety of pleasing colors. Instrument panels and clock case faces are of polystyrene, while the windshield may be of acrylate. In fact, there are some two hundred parts of the automobile which are made in whole or in part of plastics. Yet designers and automotive engineers have only just started to take advantage of the many properties inherent in plastics. Today the metal body is protected with a priming coat of phenol resin varnish and a finishing coat of an alkyd or cellulose lacquer. This development alone reduced car finishing time from seventeen days to less than eight hours. Tomorrow we may witness an all-plastic automobile body produced complete in less than eight minutes.

Plastics benefit the automotive industry in still other ways. Synthetic phenol resin–bonded abrasive wheels, which can be operated safely at high speeds, and abrasive papers make possible the fabrication of metal parts to those exacting tolerances which are so necessary for interchangeability in mass production. Again, plas-



Bakelite Corporation's Research and Development Laboratories, Bloomfield, N. J.



Experimental Plane with Fuselage Molded in Two Sections from Sheets of Hardwood Veneer Bonded Together with Phenolic Resinoid

tics in the form of phenolic or urea resin adhesives serve to bond laminated wood for truck bodies and trailer construction.

The automobile is only one example of many that could be cited to show how plastics serve industry in its efforts to make a better world in which to live. Such major factors in modern life as the central station, the telephone and radio, the textile industry, building and electrical appliances, could also be mentioned.

RAW MATERIALS UTILIZED

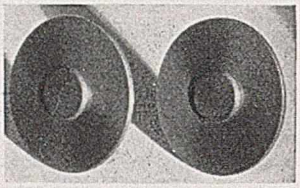
As it serves industry by creating better materials through science and research, so other industries profit through the purchase of raw materials by the plastics industry. Plastic material manufacturers draw upon the resources of the nation for the raw products which must be used in the manufacture of synthetic plastics. A listing of all of the natural sources of chemicals and materials would take us on a surprising journey that encompasses the whole country—coal mine, natural gas fields, quarries, the lumber regions, cotton plantations, paper and textile mills, farms. From the coal mines come important basic materials from which we get phenol and formaldehyde. These mines also supply dyes and solvents. Natural gas fields provide an abundant source of raw materials for plastics, particularly the vinyl compounds.

Table I. Number of Manufacturers Associated with the Plastics Industry, and Capitalization per Group

Capitalization	Plastics Manufacturers	Plastics Fabricators				Plastic Equipment and Supplies
		Cast resins	Laminated	Pyroxylin	Molded	
Over $1,000,000	24	2	14	13	43	35
500,000	5	..	1	6	6	16
300,000	2	2	2	5	14	11
100,000	3	6	3	10	27	27
50,000	3	7	..	2	19	11
25,000	1	8	1	4	16	8
10,000	..	3	1	4	7	4
5,000	..	2	..	2	6	2
No estimate	6	23	2	4	43	4
Total	44	53	24	50	181	118

Other mines and quarries furnish fillers, such as asbestos for heat-resistant plastics. From the forests of the north, reaching from Maine to Oregon, come wood-flour fillers. Southern cotton plantations with their endless rows of white capped plants supply cotton linters for making acetates. Cotton flock and coatings from textile mills are used for fabric base phenolic molding materials. Bolts of fabric and rolls of paper are utilized in laminated products. Continuing the journey, we find that the sources of plastics include many farm products. The chemist has allied himself with the farmer who hardly realizes how many of his materials find their way into the home, into the office, and into the factory as plastic products. Livestock furnishes glycerol for the alkyd resins. Linseed oil from flaxseed, lactic acid from milk, China wood oil from tung trees, bean meal from soy plants, alcohol from sugar cane—all play a vital role in the modern plastics industry.

Consumption of these and many other products used by plastics manufacturers continues to increase, enabling the suppliers of these products to effect lower prices. For example, responsive to the demand made by phenolic plastics, the production of phenol has increased from 6,000,000 to some 60,000,000 pounds; the price has decreased to one fifth what it was twenty years ago. In the same period the production of formaldehyde has increased from 25,000,000 to over 50,000,000 pounds, and the price has been reduced to one half. Likewise the increased demand for plastic materials, with consequent lower cost of raw materials, has enabled the plastics industry to reduce prices. For instance, plastics derived from coal-tar resins alone sell for one fourth of the price they did less than twenty years ago.



Weston Insulating Coil Supports

These were the first pieces of Bakelite molded ever used in the electrical industry and are made within the close limits of 0.001 inch

Thousands of workers in molding, laminating, and fabricating plants, in paint and varnish plants, and in plants of plastic material manufacturers depend upon the plastics industry for their livelihood.

Thus a new industry has been born under the system of American democracy, which encourages rather than curbs individual initiative. It is an industry made possible by the magic wand of chemistry through the pioneering and untiring efforts of resourceful individuals supported by courageous and patient capital. Looking confidently toward the future, the plastics industry has already indicated how it may serve one of the newest of industries—aviation—by announcing pioneering research on a plastics plane. Once more it is clearly demonstrated that industry under a democracy can better meet a nation's needs in peace or war, if war must come.

PROGRESS THROUGH COOPERATION

History and Development of Laminated Safety Glass

EDWARD R. WEIDLEIN
Mellon Institute, Pittsburgh, Penna.

The Franklin Institute, on March 31, honored the Carbide & Carbon Chemicals Corporation, E. I. du Pont de Nemours & Company, Inc., the Libbey-Owens-Ford Glass Company, the Pittsburgh Plate Glass Company, and the Monsanto Chemical Company for their progressive attitude in carrying on the Benjamin Franklin ideal of the application of science to industry for the benefit of mankind.

The work of these companies has made available an improved and high-test safety glass. The results reveal laudable cooperation; and following the address which we print here, Nicol H. Smith, director in charge of chemistry of the Franklin Institute, gave an impressive demonstration with tests of this new material.

THAT science in industry has helped to make living safer and more comfortable is due to the coordinated efforts of a large number of capable men. Technologic progress is in fact rarely the result of one man's labors; it is usually an integration of effort to which several persons or groups of workers have contributed. It has often been said that "two heads are better than one." This maxim is recognized especially in industrial research, not because one man would necessarily be incompetent to carry out the development of something new to a successful conclusion, but simply because in many cases any one mind is too lacking in scope, one lifetime is too short to go into the many ramifications that a new development frequently involves. There is no successful substitute for teamwork, without which a contest is seldom won and a research is always slowed down. If some new development is under way that will make life safer or more pleasant, it is for the common good that it be made available to the public as soon as possible. This reason is sufficient in itself for utilizing the coordinated research efforts of many specialists.

SAFETY GLASS, THE RESULT OF COORDINATED EFFORT

Many examples show how well the system of coordinated effort functions. Fulton would probably be more astonished at seeing the *Queen Mary* than were his contemporaries when they first glimpsed a steamboat, and Wöhler would be more fascinated by today's big production of urea than were his friends when they first gazed upon a few crystals of a natural product prepared synthetically. Fulton's and Wöhler's contributions to the art of building steamships and of making synthetic organic chemicals should by no means be undervalued, but equal importance should be attached to the accomplishments of a host of other technicians who have carried these developments to their present scale of magnitude. Laminated safety glass is also the result of the efforts of many workers, coordinated through sound research management. The problems that have arisen in bringing this product to its present state of perfection have been shared and solved by many specialists: ceramists who worked out suitable formulas for both glass and refractories; engineers who devised processes and equipment for casting, grinding, and polishing plate glass as well as methods for constantly reducing the thicknesses of the glass so made; chemists who developed the plastics that have been used in the interlayer and who evolved the plasticizers that go to render this interlayer flexible; chemists and engineers who invented compositions to make some of the plastics used adhere to the glass and solved many problems involving the fabrication of the laminated glass itself so that it could be produced economically in usable quality. All these scientists contributed valuably to the art as we know it today. As is quite usual in such cases, the perfection of the product has not taken place in a uniform manner. It was sufficiently useful in its early forms of development to fill a definite need and so it was given to the public as the best available. Research continued, however, and suddenly discoveries came that markedly improved the product. In consequence, a new and better laminated safety glass is now available through the efforts of the Pittsburgh Plate Glass Company, the Libbey-Owens-Ford Glass Company, the Carbide & Carbon Chemicals Corporation, E. I. du Pont de Nemours & Company, and the Monsanto Chemical Company.

Basic Features. Nothing has yet been found which is comparable to glass in hardness and resistance to abrasion and which, at the same time, possesses its clarity. Hence glass is ideally suited for innumerable purposes where a product with such properties is desirable. In most uses glass windows, or "lights" as they are called in the industry, are seldom subject to sufficient shock to shatter or break them. But, with the advent of the motor car and other vehicles operating at high speeds, the picture changed and accidents frequently resulted in the destruction of glass with accompanying danger to anyone who might come in contact with the fragments. This hazard became even more apparent with the markedly increased popularity of the closed car during the past few years and with the higher speeds at which modern automobiles operate. Various transparent materials are available that are tougher and much more resistant to shattering than is glass, but they do not possess its abrasion resistance and hardness. They would make less durable windows or "lights" by themselves and are employed only in special instances as substitutes for glass where durability is not essential. If, however, these transparent, shock-resisting plastics are firmly adhered between two sheets of glass, the resulting lamination or "sandwich" has the desirable properties of both the glass and the plastic. So long as the light thus made is not broken, it is just as clear, just as hard, and just as resistant to abrasion as glass. And if it is broken, the fragments remain anchored to the plastic interlayer and yield thereto so that the possibility of accident from flying glass is greatly diminished.

The Strength and Stretch of the Recently Perfected Plastic for High-Test Safety Glass Give Added Protection to Motorists

History. Laminated glass was first worked out from a decorative, rather than a safety, point of view. In 1885 Fullicks, living in England, obtained a British patent on the idea of obtaining a decorated pane of glass by cementing pieces of variously colored glass between two sheets of clear glass. This invention was certainly laminated glass, but it was not laminated safety glass. The credit for inventing laminated safety glass goes to John Wood, who obtained a British patent on his product in 1905. This patent discloses a method of producing laminated safety glass by cementing a sheet of transparent cellulose nitrate between two plates of glass, using Canada balsam as the adhesive. Actual manufacture under the Wood patent was started and safety glass made by this process was exhibited at a motor show in England in the spring of 1906; but since automobile production was small at that time, there was little demand for the product. This fact, coupled with technical difficulties with the product, caused Wood's venture to be a financial failure. A Frenchman, Benedictus, was granted French and British patents in 1910 on laminated glass, in which gelatin rather than Canada balsam was used as the adhesive to hold the cellulose nitrate plastic to the glass. The product, "Triplex", was made in England in 1913. With the outbreak of the World War, a demand arose for its use in the manufacture of airplane air screens or visors, automobile windshields, goggle and gas mask lenses, and other appliances essential to military combat. The commercial production of laminated glass thus got its start. It was a product that would not now be acceptable if measured either by performance or cost, but it did have sufficient merit to prove that the principle of laminating glass with a plastic sheet was workable and that the product had a definite field of usefulness. After the war and before the production of closed automobiles reached its present high figure, there was little demand for laminated glass and the industry languished. When, however, the swing reached closed cars and the subsequent almost universal adoption of laminated glass in them, the manufacture of laminated safety glass became one of the country's important industries.

PROBLEMS IN EVOLUTION OF SAFETY GLASS

One of the first problems that confronted engineers and chemists entrusted with the development of laminated glass manufacture was to find some means of making a product that would remain clear and colorless during the period of its useful life. The plastic interlayer employed in the original "Triplex" was cellulose nitrate. This material has the undesirable characteristic of decomposing under the influence of the shorter wave-length portion of solar radiation, so that it turns brown and loses its transparency. In addition to this defect, the decomposed plastic loses its adhesion to the glass and separation occurs. With these changes the glass is no longer nonshatterable. This difficulty was successfully overcome by two methods: One was to change the composition of the glass itself so that it no longer transmitted the particular light rays that caused decomposition of the plastic; another successful solution of the problem was obtained by substituting cellulose acetate for cellulose nitrate. Cellulose acetate, unlike the nitrate, is not appreciably affected by sunlight.

Many million square feet of laminated glass have been produced in the past ten years using these two plastics, and this safety glass has been made available to every motorist irrespective of whether he drives a cheap or an expensive car. The safety glass manufactured during this period has been entirely satisfactory with regard to its ability to remain clear and colorless over a period of years; it has unquestionably reduced the possibility that flying glass may be a major cause of injury in automobile accidents.

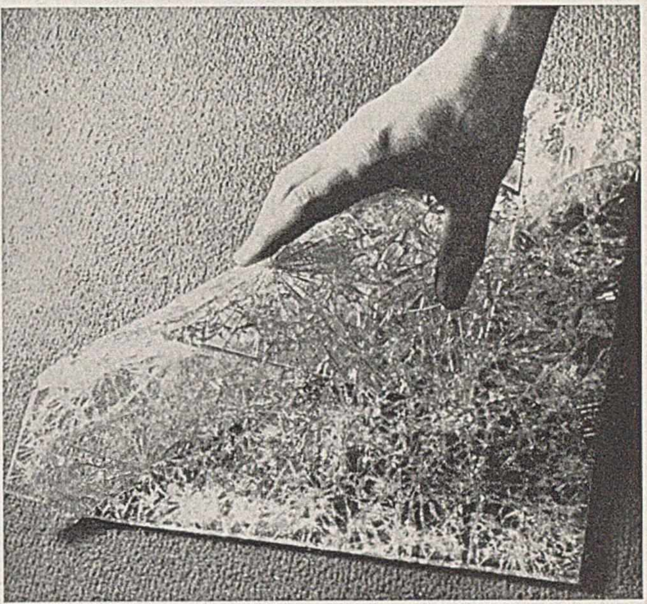
Both cellulose nitrate and cellulose acetate, however, are relatively stiff or inelastic plastics. If, therefore, some object that is traveling fast strikes a piece of laminated glass made with these plastics, it first breaks the glass portion of the sandwich, with the absorption of a certain amount of the kinetic energy of the missile; subsequently the plastic interlayer has to absorb the balance of the kinetic energy or the missile will go on through the glass. We are all familiar with the fact that a baseball catcher pulls his hand back with the ball when he is catching a "fast one." This practice is to deaccelerate the baseball over a certain displacement so that all its kinetic energy is absorbed over a greater period of time, with the result that there is less sting in the ball. The same phenomenon makes it less painful to land in a firemen's net than on a concrete sidewalk. Similar conditions hold for safety glass. If the kinetic energy of a fast-flying object that strikes a piece of laminated glass can be distributed over a greater displacement, there is much less chance that the plastic interlayer will fail; moreover, less damage is done to the object that hits the glass. This latter consideration is important if the object happens to be the driver or passenger in a car. Theoretically, then, from the standpoint of safety alone, the ideal material for the construction of windshields and sidelights in vehicles would be a very elastic substance that would act more like a fireman's net than a piece of boiler plate in case of accident. Because such an elastic material has not been found that would be acceptable for use by itself, advantage has to be taken of the clarity and hardness of glass to prevent the plastic becoming useless by abrasion. Laminated glass, however, can be rendered safer by decreasing the thickness of the glass and so decreasing the amount of energy necessary to break it before the flexibility of the plastic comes into play. In addition, thinner glass allows the making of a thinner sandwich, so that a lamination of two pieces of glass and the plastic interlayer will not be any thicker than a single piece of glass of sufficient thickness to be used alone. The production of thin plate glass, somewhat less than $^{1}/_{8}$ inch thick, is an accomplished fact and is a triumph of engineering skill. The glass manufacturers had developed improved grinding and polishing machinery which manufactured thin plate glass of high quality. That inaugurated the successful production for automotive use of a laminated safety plate glass which does not have the waviness and distortion of sheet glass.

It is advisable to point out here that another type of safety glass is available which is not a laminated product. It consists of a single sheet of glass, so heat-treated that the outer surface is in a state of compression. As a result of these forces, the glass is much more resistant to breaking than untreated glass. It does break, however, if some sharp object perforates the outer skin of glass that is under compression. When this puncture occurs, the forces released cause the glass to break into a multitude of small pieces. As the glass is very strong and rigid, it absorbs the kinetic energy of an object striking it over a very small displacement. For this reason it is apt to be more destructive to an object striking it than a more elastic material.

The ideal laminated glass would eliminate all danger of accident owing to flying glass and at the same time would minimize the danger of concussion or other damage to the person striking it.

Automobiles are operated over a wide range of temperature, and it is desirable that laminated safety glass be effective throughout this compass. If the plastic interlayer becomes much stiffer or more brittle at lower temperatures, it is unable to withstand so great an impact. On the other hand, it should not become too soft at elevated temperatures or it is likely to fail through lack of strength. Cellulose acetate and nitrate have the tendency of becoming more rigid at lower temperatures, so that laminated safety glass manufactured from them is not as effective as it is at higher temperatures. As a result of this falling off in effectiveness at lower temperatures, the industry was encouraged to seek new plastic interlayers that would give a more shatterproof product. A great amount of experimentation was undertaken and many plastics were examined and evaluated.

The requirements of a suitable safety glass plastic are varied and difficult. The material has to be transparent and colorless under all conditions that will be encountered in service and must remain so over a long period. It has to adhere to glass and must be unaffected by atmospheres of high or low humidity. These requirements, which are the most important "static" specifications to be met, may be summarized by saying that the plastic interlayer has to remain invisible and unnoticed between the layers of glass to which it remains adhered, waiting for the time when it may be called on to function. When an accident happens, the properties of the plastic that may be called "dynamic" come into play. It is the contribution of science in noticeably improving the "dynamic" properties of laminated glass that is being stressed here.



Rolling New High-Test Safety Glass Like a Rug

MANUFACTURE

Although most consumers of a product are more concerned with its performance than with the details of its manufacture, let us glance at the steps necessary in the making of laminated safety glass. The glass and the plastic are first rigidly inspected to make sure there are no defects to impair the quality of the product; then both are accurately cut to the required shape. The plastic sheet and the glass are carefully washed, and an adhesive is applied to the glass, if the plastic being used requires such a step. The sandwich is assembled and pressed together under moderate pressure and heat in order to seal the edges to some extent; then the glass is given a final pressing at higher temperature and pressure so that the whole area of the glass is brought into intimate contact with the plastic. In order to obtain uniform pressure over the surfaces, this final pressing operation is generally conducted in an autoclave rather than in a platen machine. The hydrostatic pressure of a liquid in the autoclave is used to exert the necessary pressure, and the necessary heat is supplied by the liquid. The pressing operation may be considered to weld the plastic and glass together so that they are one unit. After pressing, the lamination is cleaned of liquid and is then ready for the finishing operations that depend to some extent on the type of plastic employed. As moisture penetration into the edge of laminated glass made from some plastics results in a loss of adhesion of the plastic, it is necessary to edge-seal laminated glass in certain cases. This operation is carried out by removing a small amount of plastic from the edge of the glass and filling the void so made with an edge-sealing compound of low moisture transmission. Edge sealing also prevents the loss of the somewhat more volatile plasticizers used with some of the plastics. The two features that most impress the average visitor when he sees laminated glass being manufactured are the rigid inspection system in use and the cleanliness of the operations. A product results that is as free of imperfections as is humanly possible.

Because of this care and precision in manufacturing laminated safety glass, the available product has had excellent "static" properties and has adequately met such requirements as permanent clarity and adhesion. In other words, the laminated glass produced for some years has been very satisfactory as regards its durability; the only remaining improvements are along the line of increasing its effectiveness under impact. A lamination that would be more elastic when broken would be desirable to accomplish this improvement in dynamic properties. Because such properties are more a function of the plastic than of the laminated glass, the solution to the problem lay in the direction of finding a new plastic with the required characteristics. The cellulose esters that had given such a good account of themselves in making an adequately durable laminated glass are somewhat too stiff to yield laminated glass capable of withstanding relatively high impacts or even moderate impacts at lower temperatures. The need for softer or more elastic interlayers was accordingly recognized, and the first commercial advance in this direction was the introduction of laminated glass with a polymerized acrylic acid ester as the interlayer. This resin allows the production of laminated glass possessing somewhat improved impact or break characteristics at ordinary temperatures, an advantage over cellulose acetate that becomes less apparent, however, at low and high temperatures.

POLYVINYL ACETAL RESIN

The use of acrylate resin as the plastic interlayer gave a laminated glass that behaved quite differently under impact from glass made from cellulose acetate plastic, owing to the fact that the latter is much harder. The laminated glass made with acrylate resin was found to bulge under impact rather than to give the tight "drumhead" break that was characteristic of the cellulose plastics. This property, together with the improved impact resistance of the acrylate laminated glass at ordinary temperatures, established the product as a definite contribution to the industry. But there was still a demand for something better, an urgent need for a laminated glass that would have better impact resistance than anything yet available, especially at the lower temperatures; consequently, after extensive research a new resin was developed that appears to be satisfactory. This novel plastic is a polyvinyl acetal resin. We will not go into the details of its creation and use, but some insight into the nature of this product may show how it functions when the demonstrations to follow are carried out.

Plasticizers. Many resins are somewhat too stiff or rigid in themselves to give flexible plastics. For this reason, if flexibility is required, a material is added to the resin to impart the desired flexibility. This material may be a liquid or a solid and is usually so high boiling that it does not readily leave the plastic when once incorporated in it. For example, camphor is added to nitrocellulose for the purpose of plasticizing the latter, and some of the phthalate esters are added to cellulose acetate to accomplish the same result. With other resins various high-boiling solvents are used as plasticizers. The addition of such materials to resins increases their softness in almost direct proportion to the amount of plasticizer added, while the tensile strength of the mixture drops off at a corresponding rate. It follows, therefore, that if a soft plastic is prepared by the addition of relatively high proportions of plasticizer, it has little tensile strength. This principle applies to plasticizers that are solvents for the resins they are to soften. On the other hand, if the plasticizers are nonsolvents for the resins, it is usually impossible to incorporate sufficient plasticizer to soften them sufficiently.

Vinyl Acetal Plastic. Organic compounds can arbitrarily be divided into water-soluble and water-insoluble compounds. The compounds containing a considerable number of hydroxyl groups are generally water soluble, whereas the substances with a preponderance of hydrocarbon groups are water insoluble. Polyvinyl alcohol is water soluble because of the large number of hydroxyl groups in it. If this compound is reacted with an aldehyde so that some of its hydroxyl groups are no longer present as such, it becomes a compound known as a partial polyvinyl acetal that is partly alcoholic in nature, owing to its residual hydroxyl groups, and partly hydrocarbon, because of the presence of the hydrocarbon portion of the aldehyde. Accordingly it contains both hydrophylic and hydrophobic radicals. Under such conditions the residual hydroxyl groups tend to keep the resin from becoming completely soluble in certain plasticizers; the hydrocarbon groups impart to it the ability to absorb a sufficient quantity of plasticizer to make the plastic elastic without markedly decreasing its tensile strength.

When softened with the proper proportion of plasticizer, the new vinyl acetal plastic therefore has the remarkable property of stretching under relatively low stresses until its elastic limit is reached, at which point considerable additional stress is necessary to make it fail. Such physical properties render the material ideally suited to resist impact when used as a safety glass interlayer. When some object strikes laminated glass made with this plastic with sufficient force to break the glass, the plastic stretches to a considerable extent, and at the same time it is absorbing the kinetic energy of the blow. When the plastic has traveled through a displacement of several inches, it reaches a point where it no longer "gives ground," and at this point it has sufficient tensile strength to prevent the flying object from going through the glass. For this reason its resistance to impact is much higher than that of any other material proposed for safety glass. On the other hand, a plastic possessing such unusual mechanical properties might not necessarily be suitable as a laminated glass interlayer unless it fulfilled the other specifications required for such a product. It must be adequately clear and colorless and must remain so under all conditions that it will meet. It must have and must retain adequate adhesion to the glass. This vinyl acetal plastic appears to meet all these specifications. It is unaffected by sunlight and stays clear and colorless. It has excellent adhesion to glass, and no adhesive is necessary in making laminated glass from it. Its adhesion is not destroyed under conditions of high humidity, so that edge sealing of the glass is unnecessary. These unique properties simplify the process of making laminated glass from this plastic.

The remarkable properties of the laminated glass manufactured with this new resin are a tribute to science and industry, and another example of the progress that can be effected through concerted research effort. To humanity the benefits of such a development are enormous, for it will prevent uncountable tragedies.

TARIFF AIDS AMERICAN ENTERPRISE

DEXTER NORTH
Arthur D. Little, Inc.

THE wartime shortage of chemicals, together with our wealth of natural resources and the money and ability to develop them, gave tremendous impetus to the growth of the chemical and allied industries in 1914–18. The safeguarding of those investments adapted to peacetime needs and the incentive for subsequent development may be credited in no small measure, however, to our protective tariff policy. Not only the growth in physical size, but in diversification of the industry justifies the wisdom and foresight of our lawmakers in passing the necessary protective measures. Reciprocal trade agreements also have been given a prominence which makes appropriate a review of the important role which tariffs have played in the development of the American Way during the quarter century since 1914.

The 1914 Census of Manufactures showed a value of $173,269,000 for chemical products, and of $1,285,760,000 for chemical and related industries combined. In 1937 the respective values (allowing for changes in classification) had grown to $932,750,000 and $3,721,531,000, representing increases of 434 and 190 per cent in the groups. In the earlier years roughly five sevenths of the strictly chemical portion of the industry consisted of heavy chemicals and the remainder of organic chemicals. The latter group consisted largely of such products as acetic acid, citric acid, fatty acids, glycerol, celluloid, all derived by relatively simple processing of animal and vegetable materials; a few synthetics such as chloroform, ether, various esters, formaldehyde, vanillin; and some dyes made principally from imported intermediates.

ORGANIC INDUSTRIAL CHEMICALS

The virtual cessation of imports from Germany and greatly restricted trade with the allied powers compelled development of an organic chemical industry not only for our own needs but for those of our allies. The public was acutely aware of the ensuing shortages in dyes and in certain medicines. Tremendous handicaps, such as the absence of a by-product coke industry to provide the necessary crudes for dye intermediates, and lack of knowledge of making any but a few dyes were overcome, and, with the aid of the seized German dye patents, a well-rounded dye and coal-tar products industry was established. In 1914 American dye production amounted to 6,619,729 pounds valued at $2,470,096, or 37.6 cents per pound, and comprised about 145 relatively simple and inexpensive types. In 1917, the first year for which detailed statistics are available, the output was 45,977,246 pounds valued at $57,796,228, or $1.26 per pound. During this war year of high prices the number of dyes produced was 195. By 1937 the number had increased to 731, the quantity to 118,046,127 pounds, and the value to $64,612,914, but the average value had decreased to $0.55 per pound. In contrast to the small proportion of the consumption of dyes supplied by domestic production in 1914, the amount supplied in 1937 was about 97 per cent in quantity and 95 in value.

The new industry required little protection during the years of the war, but anticipating competition to come, the Revenue Act of 1916 provided temporary protection in the form of higher import levies on dyes, intermediates, and certain other newly developed synthetic organics. This was superseded by the Emergency Tariff Act of 1921 which prohibited the importation of such products except when satisfactory prices, quality, and terms of delivery could not be obtained from domestic sources. The Act of 1921 remained in force until superseded by the first general postwar tariff revision, the Tariff Act of 1922. On coal-tar intermediates and finished products the act of 1922 provided the first application of the so-called American valuation method of assessing duties and was continued by the Tariff Act of 1930 which, with modifications, remains in force.

The American valuation method has been of particular value to the dye industry because of the certainty of protection which it affords. On dyes not produced in this country, only a moderately high duty is levied based on United States value, which is nearly equivalent to foreign value, but as soon as domestic production of a dye comparable to the imported product commences, then the latter becomes dutiable at a higher rate based on the American selling price of the domestic product. Thus the marketing of new types of dyes is assured in advance of the exact amount of protection to be received and foreign competition is unable to chisel on duty payments by reduced valuations, while at the same time imports of non-competitive dyes, principally of the newer and more expensive types, continue in substantial volume. The cheaper dyes are dutiable at higher equivalent ad valorem rates than the more expensive dyes.

The duty on dyes was automatically reduced in September, 1924, by provision of the Tariff Act of 1922, from 60 per cent ad valorem and 7 cents per pound to 45 per cent ad valorem and 7 cents per pound, and that on intermediates from 40 per cent and 7 cents per pound to 30 per cent and 7 cents per pound. In the reciprocal trade agreement with Switzerland the rate on dyes was further reduced to 40 per cent ad valorem (but not less than 3.5

cents per pound and 22.5 per cent ad valorem) effective February 15, 1936. This change seems to have been accomplished without apparent serious effects on the domestic industry. The benefits are withheld from Germany because of her discrimination against our commerce.

An appreciable portion of our dye output is by foreign-controlled corporations. Had prewar tariff rates on dyes been in force, these plants might never have been erected, and the dyes which they produce would have been imported, as in the past. Now, as soon as demand for an imported dye reaches tonnage proportions, production is transferred from abroad to the plants in this country. When one goes back to the necessary crudes and intermediates for these dyes, the effect on employment in this branch of the chemical industry is considerable.

Dyes are not the only branch of the coal-tar products industry which have amply demonstrated the wisdom of the relatively high tariff protection accorded them. In 1917, the domestic industry produced only 23 medicinals of coal-tar origin, valued at $5,640,000 and averaging $2.33 per pound. Twenty years later the number of such products had increased to 142 with a value of $11,496,000, but an average price of only $0.96, representing an increase in volume of nearly sixfold and an average price reduction of nearly 60 per cent. Outstanding among the price reductions have been aspirin, from $5.49 to $0.51 per pound, arsphenamine from $3.50 to 30 or 40 cents (retail) per ampoule, and phenolphthalein from $9.65 to $0.85. Prewar prices of these products were substantially higher than today's, and Germany's ability to command high prices by virtue of her monopoly in these essential medicinals has been broken. The extent of the benefits of lower prices and larger range of products to public health cannot be estimated. As in the case of dyes, some of the synthetic medicinals are produced by foreign-controlled corporations; others are produced under license from foreign manufacturers.

In the same period the production of antioxidants, so important in prolonging the life of automobile tires, and of vulcanization accelerators has grown from exceedingly small dimensions to over $8,000,000. Synthetic perfumes and flavors have expanded from almost nothing to nearly $4,000,000, photographic chemicals to $1,500,000, and textile assistants to $750,000.

The comparatively new industry of synthetic resins, including those derived from both coal-tar and noncoal-tar sources, has increased from a production of 1,644,000 pounds valued at $1,352,000 in 1921 to 162,105,000 pounds with sales of 127,175,000 pounds valued at $25,846,000 in 1937. Simultaneous with this development was that of the necessary plasticizers for these resins. Sales of phthalates alone in 1937 amounted to $2,500,000. The courage to undertake the immense amount of research and development work underlying this growth is attributable in no small degree to the tariff protection which these products enjoy. Several types of synthetic resins are produced in the United States under license from foreign producers. Under less favorable tariff rates these arrangements doubtless would not have been consummated. Instead, the foreign resins would have been imported, and an appreciable portion of our plastics industry, together with the production of the necessary raw materials, would be nonexistent today.

Cellulose plastics likewise enjoyed an immense growth. In 1914 there was but one type, cellulose nitrate, sales of the partly finished material of which amounted to $3,778,374. By 1935, in spite of the threatened competition of cellulose acetate, sales had grown to $10,682,358; those of cellulose acetate totaled $7,986,489. Since that time commercial production of other esters of cellulose and of ethylcellulose has commenced.

Other branches of the organic chemical industry also have made impressive showings. In the sixteen years from 1921 to 1937 the noncoal-tar branch of the synthetic organic chemical industry expanded more rapidly than the aromatic branch, showing phenomenal increases in production from 21,500,000 to 2,500,000,000 pounds, and in sales value from $13,750,000 to $119,400,000. Perhaps the most notable instance in this field is that of the derivatives of acetylene, ethylene, and propylene first provided for in the Tariff Act of 1922 at 30 per cent ad valorem and 6 cents per pound, and continued in expanded form in the act of 1930. In 1922 nearly all the products concerned were in the developmental stage, but by 1938 over a hundred products worth many millions of dollars were in commercial production, with many others in the research stage. The most widely publicized product in this group is ethylene glycol as an antifreeze. Others include diethylene glycol for solvent and other uses, vinyl chloride for plastics, the line of Cellosolve solvents, the ethanolamines as emulsifiers, solvents, and chemical raw materials. Of related origin but dutiable elsewhere are many synthetic alcohols, ketones, esters, ethers, and certain organic acids, in which output has expanded enormously. The rates of duty on some of these products have been reduced under the trade agreements program.

Like the prices of dyes and synthetic medicinals, those of the new organic chemicals as well as many of the older ones have almost invariably declined as enlarged demand and technological improvements permitted economies in production. A glance at quotations shows striking price declines in such products as the various types of synthetic resins, cellulose acetate, cellophane, Neoprene, Thiokol, chlorinated solvents, rubber accelerators and vulcanizers, glycols, and derivatives; and in products far older but now made by improved methods, such as acetic acid and anhydride, citric acid, phenol, methanol, butyl alcohol, amyl alcohol, acetone, formaldehyde, ether, and many others.

INORGANIC INDUSTRIAL CHEMICALS

The inorganic chemical branch of the industry, although of formidable size in 1914, has not lagged far behind the growth in organic chemicals. Strangely enough, the two most notable achievements of this branch of the industry since 1914 are in fields largely enjoying no tariff protection—nitrogen and potash fertilizer materials. Owing principally to lower prices for nitrogen and potash materials, the American farmer pays substantially less for his fertilizers today than in prewar days. Associated with these developments, however, are related products, such as synthetic alcohols and nitrogen and potash derivatives, production of which has been stimulated by the protection afforded them. The value of primary nitrogen products derived from air nitrogen sources alone in 1935 amounted to $20,860,000, and the unit value of nitrogen decreased from $229 per ton in 1914 to $106 in 1935.

Our dependence on imported potash caused prices to skyrocket to more than $400 per ton during the war; but with the discovery and development of our own hitherto unsuspected resources the foreign monopoly was broken. In 1937 the value of domestic potash salts sold was $7,000,000, the great bulk of which went into fertilizers. The remainder was consumed chiefly in the manufacture of potassium carbonate and bicarbonate, potassium hydroxide, and potassium nitrate, all of which were formerly obtained from abroad. Without adequate protection, production of these potash compounds probably would not have been undertaken.

Other fields of expansion in this field include a complete line of the important barium chemicals, the important fluorides, sodium and potassium dichromates, hydrosulfites, sulfur and chlorine bleaches to cheapen and improve the bleaching of fibers, cheaper refrigerants to reduce the cost of storing food, new and better insecticides to fight the billions of dollars worth of damage by pests, chemicals for retarding rot and for fireproofing textiles and paper, and a wider variety of types and shades of pigments for paints and varnishes. Domestic production of iodine, duty-free, has been achieved in the face of monopoly and price-cutting tactics by the Chilean producers.

FLEXIBLE TARIFF PROVISIONS

The Tariff Acts of 1922 and 1930 provided several new features in rate adjustment or control of imports besides the American valuation mentioned; the most important is the so-called flexible tariff provision. This provides a means for equalizing the cost of production of a domestic product with that of a comparable foreign product plus cost of transportation of each to the principal domestic market. The increase or decrease in duty which may be proclaimed by the President upon investigation and report by the Tariff Commission is limited to 50 per cent of the existing duty. No product may be transferred from the free list to the dutiable list or vice versa. Should a 50 per cent increase in ad valorem rate be insufficient to equalize the difference in costs, then the basis of levying the ad valorem rate may be changed from foreign valuation (applied to all ad valorem rates except those on coal-tar products) to American valuation (selling price of the American product).

Although application of the flexible tariff provision requires much time and detailed work, including procurement of cost data from foreign manufacturers where possible, it has been wisely applied in many cases, both of increases and decreases in rates of duty. Among the chemicals and related products which have benefited from such increases are sodium nitrite, oxalic acid, methanol, linseed oil, potassium permanganate, barium carbonate and peroxide. Those on which decreases have been applied include phenol, cresylic acid, edible and inedible gelatin, animal glue, olive oil, sperm oil, spermaceti wax, and whiting.

For several reasons application of the flexible tariff provision has been virtually inactive since the passage of the Trade Agreements Act in 1934. Decreases in duties touching a nation with which negotiations were in progress would logically be held for trading purposes. When tariff rates have been changed under trade agreements, the possibility of obtaining relief under the flexible tariff is eliminated. The large number of decreases which have been granted on chemical products under the various trade agreements has thus substantially reduced the number of items on which relief could be granted. Furthermore, the concessions which have been made are more significant than is apparent because of increases which have occurred in American wages, the limitations imposed on working hours, and the increases in taxes.

A unique method of rate making was introduced by the provision of the 1930 Tariff Act for synthetic camphor. This required that if, during the six months preceding three, four, and five years after the enactment of the act, the domestic production of synthetic camphor by quantity did not exceed 25, 30, and 50 per cent, respectively, of the domestic consumption thereof by quantity, then the rate of duty on synthetic camphor should be decreased from 5 cents to 1 cent per pound.

The planning and erection of a synthetic camphor plant and fulfillment of the requirements for maintenance of the 5-cent duty is one of the notable accomplishments of the American organic chemical industry. Once a highly speculative commodity under Japanese monopoly and later made synthetically in Germany, camphor is now available to American consumers in ample supply at reasonable prices, free from the former price gyrations which characterized it. This method of rate making might well be tried again where domestic supplies of an important product are lacking and technical and economic considerations warrant establishment of an industry in this country.

SAFEGUARDS AGAINST ABUSES

The present antidumping law is the still-enforced Title II of the Emergency Tariff Act of 1921. This act provides for withholding entry, except upon payment of special dumping duties, of imported merchandise found to be injuring or likely to injure American industry by reason of its being sold at less than its fair value, or when it has been found to have been sold for less than the market value (or in the absence of market value, the cost of production) in the country of origin. The most important instances of invoking this provision on chemical products have been those of butyl acetate from Germany, ammonium sulfate from Belgium, Germany, and Poland, stearic acid from the Netherlands, and phosphate rock from Morocco. The ruling on phosphate rock is the only one of these now in force. Although other chemical products have been excluded from time to time and for varying periods, thus tending to make foreign exporters more cautious in invoicing their goods so as not to conflict with the law, action under this law has been virtually inoperative in recent years.

Provision for imposition of countervailing duties upon any products of a country which directly or indirectly subsidizes its exports to the United States is provided in Section 303 of the Tariff Act. It is under this section that the recent action was taken imposing a 25 per cent countervailing duty on dutiable goods imported from Germany.

Section 307 of the Tariff Act of 1930 prohibits entry into the United States of goods mined, produced, or manufactured in a foreign country wholly or partly by convict, forced, or indentured labor, unless such goods are not available from domestic sources in sufficient quantities to meet the consumptive demands of the United States. No chemicals have been denied entry. In the case of Russian goods it has been found impossible to establish proof of the use of forced labor.

Further safeguarding of American industry is provided by Section 338 of the Tariff Act of 1930 under which authority is granted to the President to impose new or additional duties not to exceed 50 per cent ad valorem or its equivalent on any or all products of a foreign country which discriminates against the commerce of the United States. The provisions of this section, however, have not been invoked.

Provision for action against unfair methods of competition of foreign with American merchandise was first made in the Tariff Act of 1922 and continued in substantially the same form in the Act of 1930. Under this provision the President may, upon investigation and recommendation by the Tariff Commission, exclude entry of articles in the importation or sale of which are employed unfair methods of competition tending to destroy or substantially injure an efficiently and economically operated domestic industry or to restrain or monopolize trade in the United States. Under this provision action of this kind was taken on imports of such chemical products or raw materials as apatite from Russia, synthetic oxides of iron from Canada, and certain forms of Bakelite from Germany. Most of these actions concerned infringement of American patents by foreign manufacturers. The courts have held at various times that process patents did not come within the scope of the provision, thus limiting the patent aspect of such cases to product patents. As a result of the court decisions disinclination has been manifested to handle cases involving unadjudicated patents.

RECIPROCAL TRADE AGREEMENTS

It has been shown that the expansion which the American chemical industries, particularly the synthetic organic chemical industry, enjoyed under the artificial stimulation of the war, continued in peacetime directions at a slower but saner pace under the beneficial effects of a protective tariff. Under this system monopolies of materials by foreign countries have been broken, and strong, well-rounded divisions of the chemical industry established. Research was encouraged and capital ventured to produce new products and to create new industries. These new developments have been characterized by almost continuous reductions in prices. Prices of many longer established chemicals are lower than before the war and, in general, the prices of chemicals are relatively lower than those of most other manufactured products when compared over the same period.

Fair application of the protective tariff system has been attempted by means of the so-called flexible tariff provision, and safeguards against abuses from imported goods have been erected by the antidumping law and by provisions for unfair methods of competition, exclusion of goods produced under forced labor, countervailing duties on goods imported with benefit of foreign export subsidies, and exclusion of merchandise from countries which discriminate against our commerce; but since the beginning of the trade agreements program in 1934 these safeguards have been resorted to with much less frequency. In fact, possibility of relief under the flexible tariff becomes more restricted as new concessions are granted to foreign countries; at the same time the anomaly arises of increased domestic costs resulting from higher wages, shorter hours, and higher taxes. The reciprocal trade agreements program has resulted in reduction of many duties without apparent serious major effect on our chemical industries but with far from equivalent recompense in the form of concessions on chemicals from foreign countries. The effect of rate reductions on products in the manufacture of which chemicals are consumed may have more serious consequences on our chemical industries, but it is still too early to appraise this situation properly.

Unlike the totalitarian states, we do not embargo imports or exports of raw materials or finished products except for reasons of neutrality, national defense or conservation, narcotic, quarantine, or other measures enacted for the common good. With protection against an influx of foreign goods produced at much lower wages than our own, the law of supply and demand is permitted to function (unless exception be made of the methods employed to aid agriculture), and the profit incentive is allowed to operate, all in an orderly fashion for the benefit, not of an autocratic government, but of all the people. Hence we are blessed with our American Way.

EQUIPMENT MEETS INDUSTRY'S CHALLENGE

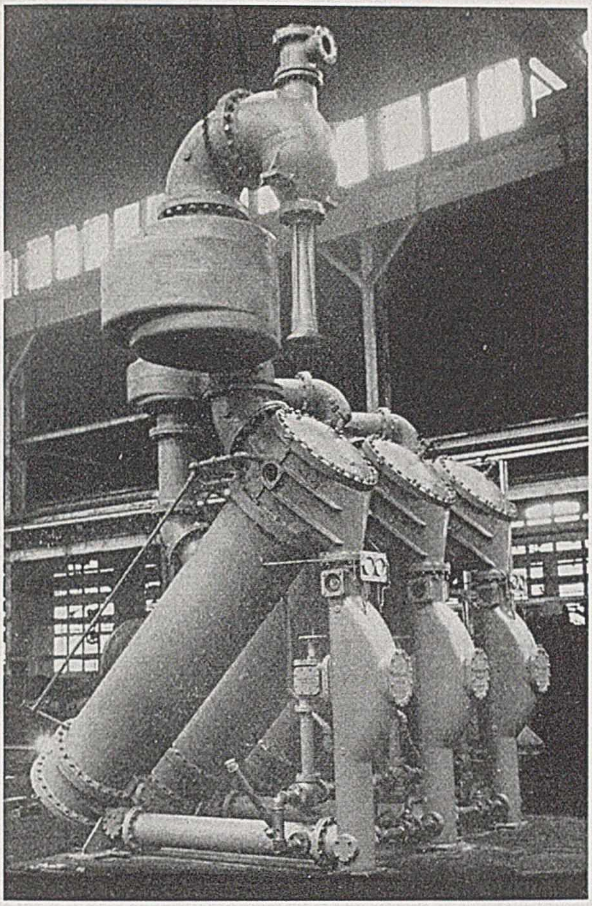
CHARLES F. ROTH
Grand Central Palace, New York, N. Y.

AN ESSENTIAL auxiliary to the chemical industry is the design and manufacture of chemical equipment—a great American industry in itself. Chemistry, carried forward in the American Way, has been supplemented effectively by the increasing availability of well-designed, durable, chemical engineering equipment. Effective coordination of research, invention, production, and finance has nowhere been better exemplified. Natural incentives and freedom under the American system of government have played a telling part in the development of the chemical industry as it has grown to industrial maturity since the days of the World War.

It is now just a quarter century since those days when the politically ebullient conditions in Europe introduced an era of international distress. The conflagration which produced the greatest international war ever engaged in by civilized peoples had been preceded by a variety of commercial clashes. However, had the commercial units of the nations, rather than the political and military, been in the ascendancy at that time, the ensuing state of events would have been very different.

Commercial intelligence services of the European governments had been functioning as effectively as the military services did later. In chemical fields this was particularly so. Developments in a consumer nation which had potentialities to create competition were met vigorously by the "dumping" of quantities of the same product made abroad. This practice was successful in causing a depression of the market and usually resulted in closing new infant industries by frightening off capital and creative ability. The United States, in fact all of the Americas, were consumer nations and to a large measure dependent upon foreign sources to augment their supply of chemicals and chemical products.

In this economic situation home products were not manufactured to an extent to give us independence of foreign sources. Even our native production was to a considerable extent carried on in equipment of foreign manufacture. Imported apparatus and machinery were in fact preferred, and suspicion existed with respect to much of the equipment made in America.

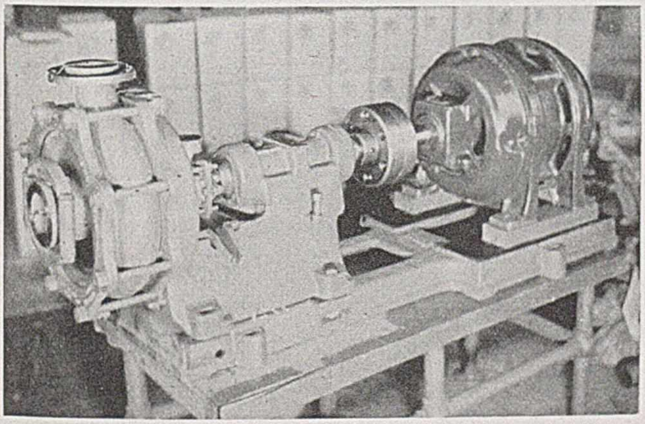


Courtesy, Struthers-Wells

RECENT TYPE OF INCLINED EVAPORATOR

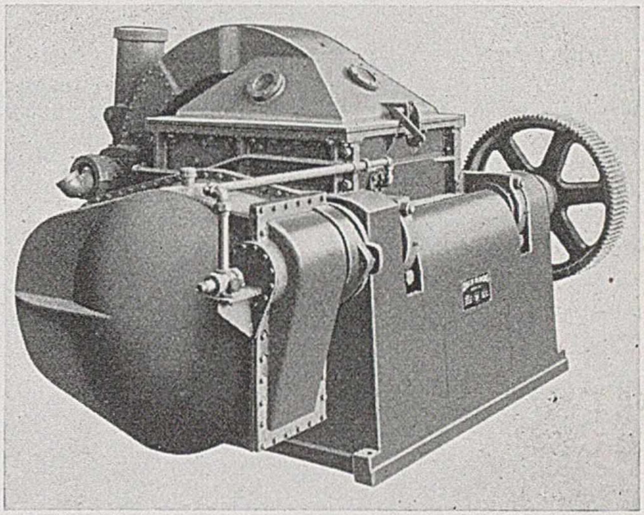
Domestic equipment manufacturers were not encouraged to greater production. Prevailing designs were those to be found in the current textbooks, and the materials of construction were the ones most commonly available—iron, steel, some nonferrous materials (less frequently alloyed than native), and, of course, wood and ceramic materials.

WAR among foreign nations changed this situation. Under pressure of orders from abroad, our own peace industry was forced to augment its supplies of chemical raw materials. The necessity of producing larger quantities called for necessary equipment expansion. Restraints on transportation reduced our imports and furnished part of the inspiration which proved desirable. Idle capital was encouraged by possible profits, and technical ability was augmented by patriotism. Existing industries expanded and gaps were filled by American business initiative.



DURIRON CENTRIFUGAL PUMP

If six hundred and fifty firms were reported as supplying the preponderance of equipment used in plants making chemicals and chemical products, approximately 10 per cent of these possessed the initiative to advertise the fact that they were ready to supply all the needs of industry. Quickly this figure was increased by the demand; within a year the number was more than doubled, and in another year it was doubled again. When the industry reached a point near saturation, the amount of increase gradually diminished. Later, demands for special types of equipment created new industries and brought new manufacturers.

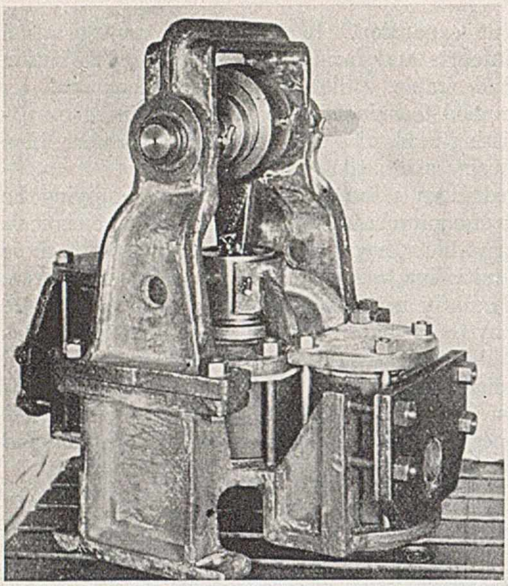


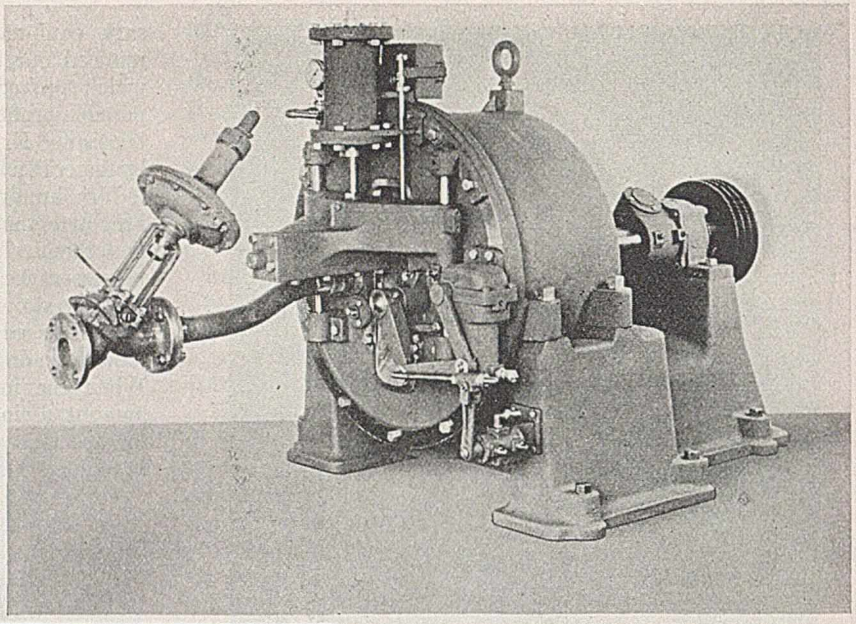
Courtesy, Baker Perkins Company, Inc.

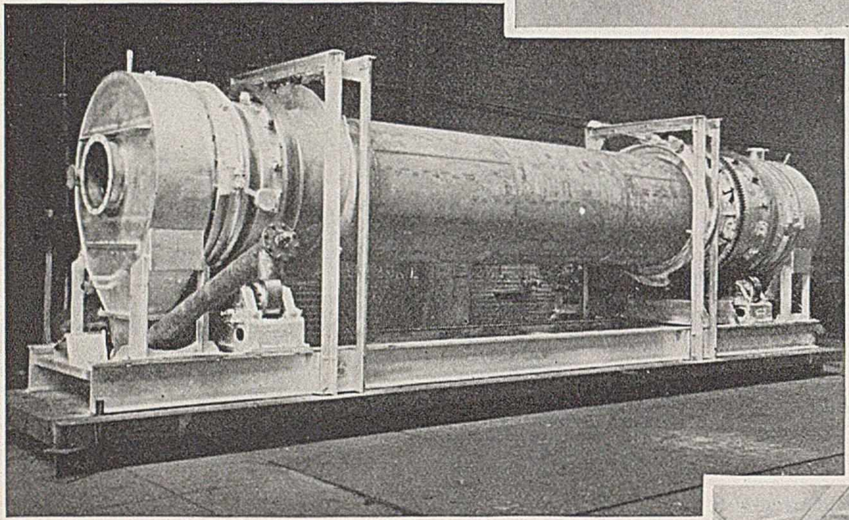
HEAVY-DUTY VACUUM MIXER DESIGNED FOR PLASTICS, RESINOUS COMPOUNDS, PAINTS, AND INKS

To the redounding credit of the equipment manufacturers of that period the point should be made that they responded to the world's need and produced equipment of all kinds quickly. By astute research, by trial and error, by Yankee ingenuity, and by all of the liberal methodism known as the American Way, they made equipment for every difficult type of chemical industrial service. Improvement followed improvement. Chemical engineering equipment made of ceramic materials unheard of before was brought forward to triumph over difficult applications. Plastic materials made from synthetic resins came into use as materials of construction. Suggestions were taken from history. The Sheffield plate makers provided the idea for plating over base metals high in mechanical strength with metals which were more highly resistant to corrosion. There were also innumerable side applications of plating (coating), involving rubber, plastics, glass, and ceramics. The values of impregnated lumber were rapidly discovered and applied.

Reactions at unheard of high pressures and temperatures were gradually accommodated successfully by equipment devised for a new scale of physical constants. Chemical engineering processes, such as distillation, evaporation, filtration, and drying, were advanced through improvements in corrosion-resistant materials. Known, but little used, metals and alloys became the sub-







(*Above*) Hydrator for Separating Crystalline Material from Mother Liquor Automatically

Courtesy, Sharples Corporation

(*Upper left*) Diaphragm Pump, a Displacement Pump with a Short Stroke and a Relatively Large Diameter

Courtesy Schutte and Koerting Company

(*Left*) Rotary Dryer with Shell Made Entirely of Solid Stainless Steel and End Sections Made of Stainless Clad Steel

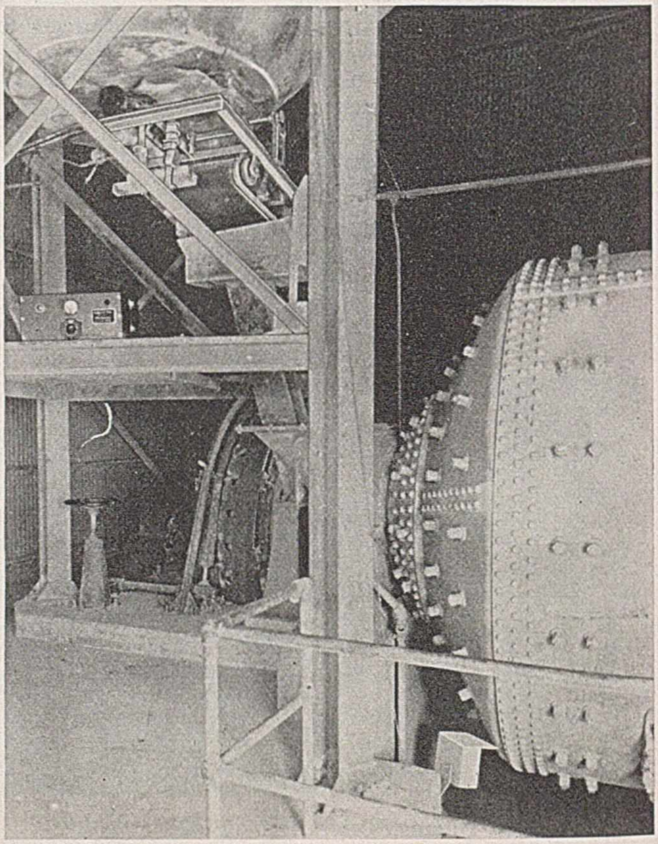
Courtesy, Struthers-Wells

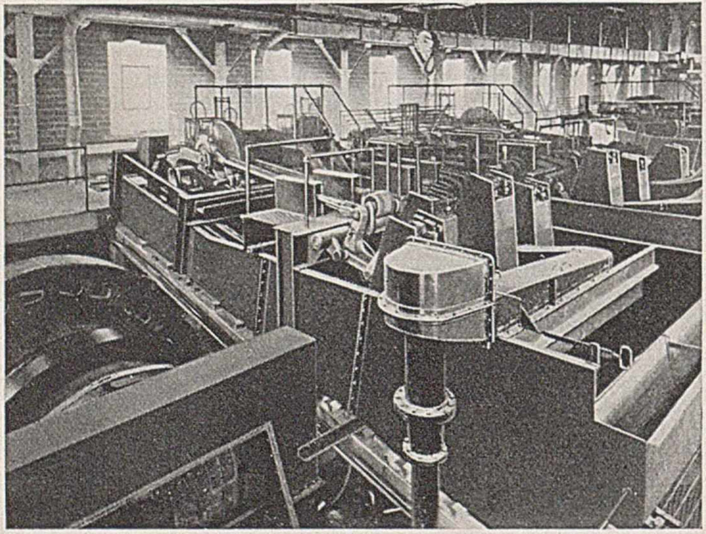
(*Right*) Electric Ear Controlling a Constant-Weight Feeder, Feeding a Ball Mill and Air Classifier in a Cement Mill

Courtesy, Hardinge Company, Inc.

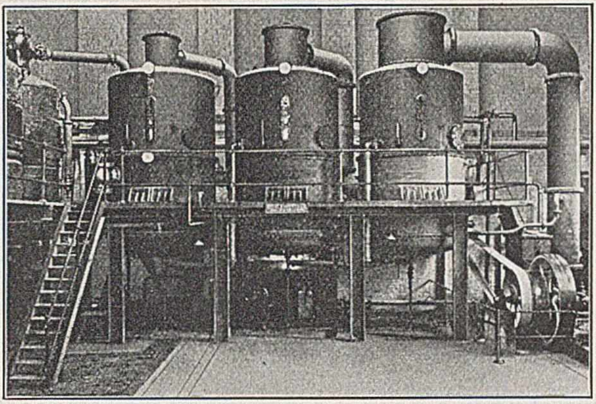
(*Below*) Four Heavy-Duty Classifiers in a Closed Circuit with Four Ball Mills, Grinding 6000 Tons of Gold Ore per Day

Courtesy, Dorr Company





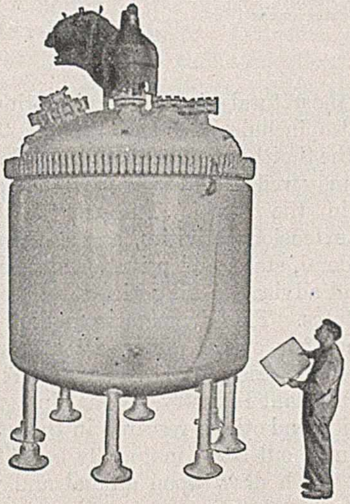
ject of experiment and pilot-plant application. Aluminum, nickel, chromium, the noble metals, the rare metals, and numerous alloys in the ferrous and nonferrous groups found new uses. It seemed as though there might be innumerable special metal combinations with properties adapted to every specialized use.



Courtesy, Ernest Scott & Company

Triple Effect Evaporator with Simple Jet Condenser and Wet Vacuum Pump, Installed in a Kraft Pulp Mill

Subsequently stabilized, the wartime period in the chemical equipment field was one of accelerated inventiveness and emergency reduction to practice. Equipment used for any special purpose prior to the war expanded its uses during the days of forced measures. Many of the new applications were strengthened subsequently through the improvement of materials, notably in strength and corrosion resistance. During the last two decades the composite objective has been lightness and compactness coupled with greater strength and corrosion resistance. As these objectives have been attained, style in design has been introduced. Ugliness of shape and form having been proved dispensable, designers have introduced art into form consistent with functional requirements.

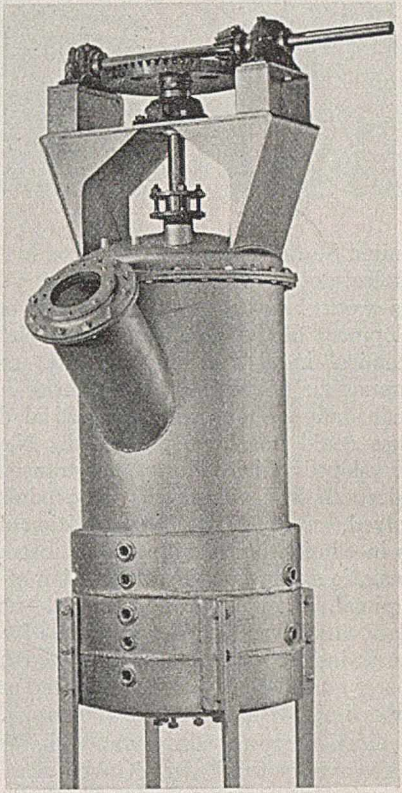


Courtesy, The Pfaudler Company

Glass-Lined Steel Chemical Reaction Kettle, 1700-Gallon Capacity

THE World War necessity, which forced the manufacture and acceptance of American-made chemical engineering equipment, had also a lasting effect upon the making of instruments of precision for production, control, and research. Basically these are the same, constructionally they are different. Designing to advanced requirements, their manufacturers have taken advantage of every phase of technical development. Progressing in the American Way, the instrument makers have provided new tools for old industries and have met the needs of new industries with broad understanding.

By comparison with a 1914 catalog of laboratory apparatus, the present output reveals that manufacturers have made great strides in this field of production. Inventiveness and improvement in apparatus have followed quickly or have led the advances in industry, research, and the teaching of chemistry—good evidence of the interrelation of scientific achievement.



Courtesy, L. O. Koven & Brothers, Inc.

Stainless-Steel Jacketed Mixing Vessel for Use on Corrosive and Easily Contaminated Material

Business initiative and patriotism, not government mandate, prompted the growth and expansion of the chemical equipment industry in this country. A desire to serve, prompted by financial profits to courageous capital, inspired experimentation and catalyzed improvement. Financial emoluments will continue the industry now firmly established.

The surface has merely been turned; when cultivation is carried deeper, even greater achievements may be expected The creation of many new industries has been a characteristi of this greater century. No equal period in all the centurie before has produced the advance in chemical equipment th has here been made. As chemical science advances by steps making each succeeding step possible, new industries will be born and new requirements for equipment, apparatus, and instruments will be met. They will be met by these manufacturers who entered a field with relatively little experience, but who, with an abundance of courage, grew with those industries they were serving and proved that the American Way of doing business is justified.

FEDERAL RESEARCH CONTRIBUTES TO THE AMERICAN WAY

DEXTER NORTH
Arthur D. Little, Inc.

THE United States Government has conducted research in chemical and related fields for many years. Much of this work has contributed directly or indirectly to the development of the American Way which characterizes our chemical industries. Fundamental research performed in numerous government laboratories has supplied basic scientific data without which industrial development in many lines could not have proceeded. New processes have been developed which industry has translated to commercial undertakings. Waste and by-product problems have been solved, some resulting in the creation of new industries, others in elimination of harmful or uneconomic practices. Systematic exploration and evaluation of our natural resources—animal, vegetable, and mineral—have yielded more abundant and diversified raw materials for the chemical and process industries to manipulate, and use of lower grades or poorer qualities of materials has been made feasible through new or improved methods of processing.

As our civilization grows more complex, it becomes more and more necessary for the Federal Government to conduct research; and it is increasingly apparent that this agency, more than any other, is better qualified to conduct certain types of research. A recent report of the National Resources Committee on government research states that the Government has certain constitutional obligations to carry on research, as in national defense, determination of standards, regulatory functions as traffic in food and drugs, supervision of power production, flood control and highway transportation, and in fields of national or interstate character such as agriculture, weather forecasting, and fisheries. It finds that the Government is better equipped to conduct research in those fields which are unusually costly in proportion to monetary return but are of great practical or social value. It also finds that the Government by means of its authority, prestige, and resources is far better able than other agencies to organize, coordinate, and direct research on a nationwide scale as exemplified in the coordination of work through the state experiment stations, through the military services, and their constant information of industrial developments, which avoids duplication of effort, and through the availability to industry of huge central research laboratories such as that of the National Advisory Committee for Aeronautics.

Funds appropriated for federal research are continually increasing as the importance of these activities grows. The amounts appropriated for the various types of research are of interest, both to show their relative importance and to facilitate comprehension of the devious ways in which this research contributes to the development of the American Way. Though no exact figures are available, reasonably accurate estimates have been obtained by the National Resources Committee. The federal budget for 1938 shows that the $57,700,000 appropriated for research was distributed approximately as shown in the following five categories into which government research, other than in the social sciences and in statistics, may roughly be divided:

	Million Dollars	Per Cent
Natural sciences	22.4	39
Engineering	21	36
Surveys and mapping	9.4	16
Public health	2.7	5
Physical sciences	2.2	4
	57.7	100

Research in the natural sciences pertains principally to agriculture but also includes the activities of the Bureau of Fisheries and the Smithsonian Institution. The Department of Agriculture may well be said to be the largest single research organization in the world. Through field laboratories, grants-in-aid, extension activities, and cooperative arrangements with federal, state, and private agencies, it effectively coordinates and advises on all agricultural research work in the United States. This democratic method is in striking contrast to methods of the dictatorial states which largely control the direction research must pursue. Through various bureaus, such as Plant Industry, Animal Industry, Dairy Industry, Fisheries, and others, research in the natural sciences (as will be pointed out later) materially benefits the processing industries which draw upon animal and vegetable raw materials.

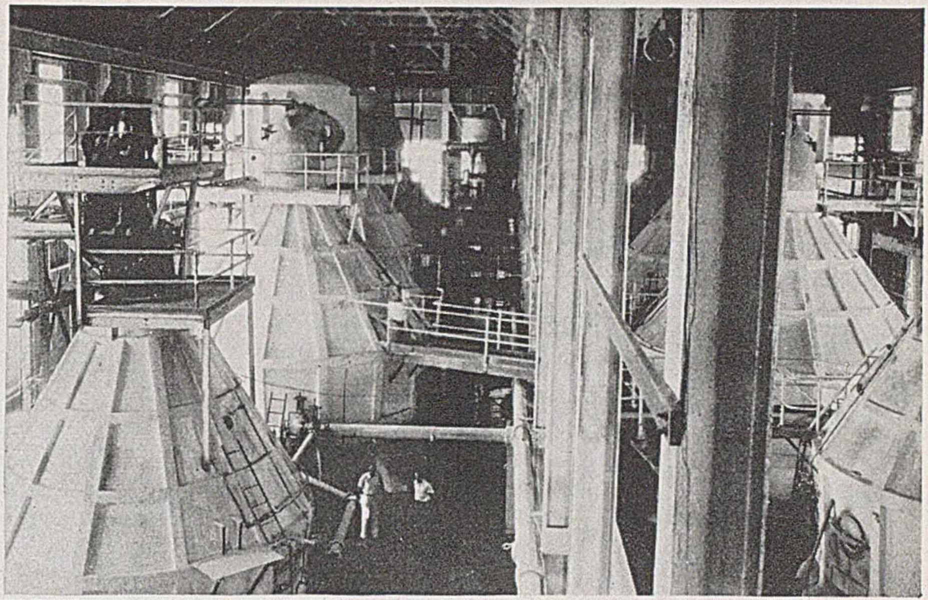
TYPES OF FEDERAL RESEARCH

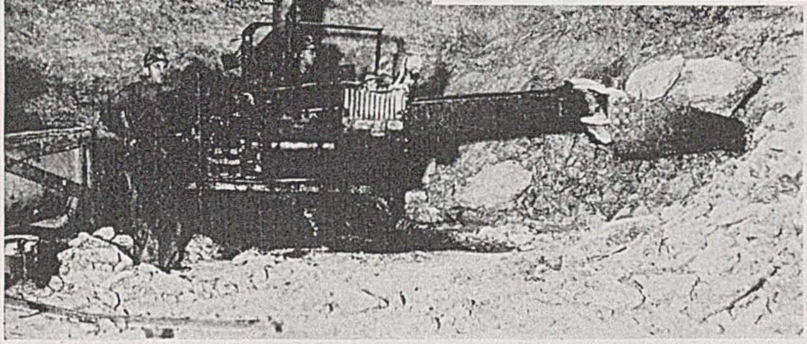
National defense is by far the largest item in engineering research, accounting for 17.3 out of 22.4 million dollars. It includes the engineering research of the air forces of the Army and Navy, and National Advisory Committee for Aeronautics, as well as other defense activities. Other items in engineering research include the Bureau of Mines, the Tennessee Valley Authority, agricultural engineering, public roads, and air commerce.

Since national defense is now largely a matter of scientific ingenuity, the combined aid of chemistry, metallurgy, and

(*Right*) EVAPORATORS AT THE POTASH REFINERY AT TRONA, CALIF.

(*Below*) MECHANICAL HANDLING OF RAW POTASH IN A MINE NEAR CARLSBAD, NEW MEXICO, WITH MODERN EFFICIENT MACHINERY





engineering are required in the procurement and development of war materials and supplies. Ordnance, armor plate, explosives, chemical warfare, communications, ship construction and propulsion, aeronautics, optics, ballistics, and constructional work necessary for our national defense all require a high degree of specialized research. To be sure, most of the results of such work are not applicable to peacetime industries, but some of them are and have proved valuable to industry. In the event of war the military branches of our Government must know where each needed material or product may be obtained, and must have plans for the large-scale procurement of these military essentials. Coordination of military and industrial research is being accomplished in this direction under provisions of the National Defense Act of 1920, and financial aid is being given to outside agencies where necessary.

Fundamental aeronautical research such as is conducted by the National Advisory Committee for Aeronautics in its splendidly equipped laboratories at Langley Field, Va., is an example of research which could scarcely be attempted without government aid. The results obtained from this research are revolutionizing concepts of national defense all over the world and have their effects on the chemical industries which supply part of the materials for the air forces.

Surveys and mappings include the work of the Army Engineer Corps, the Navy Hydrographic Office, the Geological Survey, the Coast and Geodetic Survey, and various surveys conducted by the Bureau of Public Roads, the Forest Service, soils activities of the Department of Agriculture, and surveys of the Tennessee Valley Authority. The work of the Geological Survey in large measure leads to the discovery and exploitation of mineral resources; potash, in the discovery of which it cooperated with the Bureau of Mines, is a notable example. Research services of the other organizations named contribute directly or indirectly to development of the American Way.

Public health research is becoming increasingly important and more national in scope, since most of the problems know no state lines. Industrial diseases must be curbed in order to safeguard the health of workers and so that industries may grow. Pollution of streams and of the air by industrial wastes vitally concern many chemical and processing industries.

Research in the physical sciences includes principally the work of the Bureau of Agricultural Chemistry and Engineering and the National Bureau of Standards. It is this group which is of most interest to the chemical industries and which receives the smallest amount of the research funds. The wisdom of allocating such a small portion of the funds to this important type of research may be open to question. Whether or not this is so, the situation is not so bad as may be inferred from the figures because of the large amount of both fundamental and developmental research which is necessarily involved in the other categories of research.

The extent to which government research contributes to the American Way of the economy of our chemical industries will best be appreciated by reviewing the activities of the several federal agencies which play the most important roles in this respect.

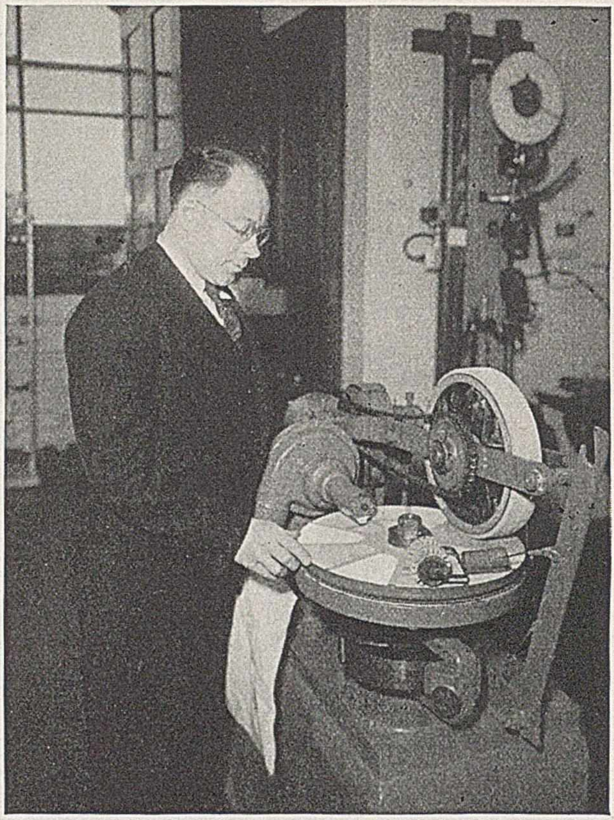
BUREAU OF AGRICULTURAL CHEMISTRY AND ENGINEERING

The Bureau of Agricultural Chemistry and Engineering (formerly the Bureau of Chemistry and Soils) is engaged principally in three major lines: (1) chemical and technological research on farm products, (2) fertilizer investigations, and (3) agricultural engineering. Of these activities the first two are of particular interest to the chemical industries which have commercialized many of the accomplishments of the bureau to the point of demonstrating their feasibility.

The first activity includes the chemistry, technology, manufacture, utilization, and preservation of agricultural nonfood products and the biological, chemical, physical, microscopical, and technological investigation of foods, feeds, and drugs, as well as materials from which these are manufactured and their physiological effects.

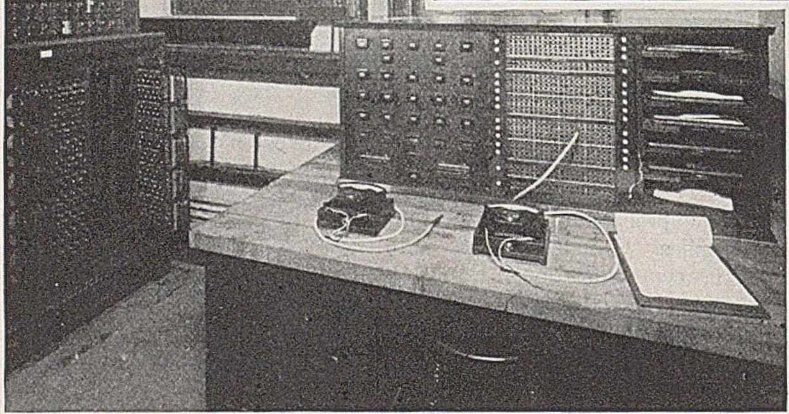
One of the outstanding accomplishments in the color investigations, formerly carried on by this bureau, is the well-known Gibbs and Conover process for producing phthalic anhydride by catalytic vapor-phase oxidation of naphthalene, also worked out simultaneously in Germany. Formerly selling for about $5.00 per pound and having no industrial use, this product now sells for 14 cents per pound and has become the source of anthraquinone, essential to the manufacture of vat dyes, and more recently the basis of a large lacquer industry based on alkyd resins. Domestic production of phthalic anhydride increased from 138,857 pounds in 1917 to 45,210,784 pounds in 1937.

This bureau developed the method of producing citric acid from lemons, successfully employed in California for many years, and later devised methods for producing lemon and orange oils and pectin from rinds, and stock feed from the waste pulps. The citrus by-products industry for the utilization of surplus and cull citrus fruits is based on these methods. Some of the early investigations on citric acid production by fermentation, now the most important process for its production in the United States, was carried out by this bureau. More recently work has been done in production of grapefruit oil, together with methods for solving troublesome waste problems in that industry. It developed the process for producing furfural from corncobs which the Quaker Oats Company later successfully applied to recovery from oat hulls.



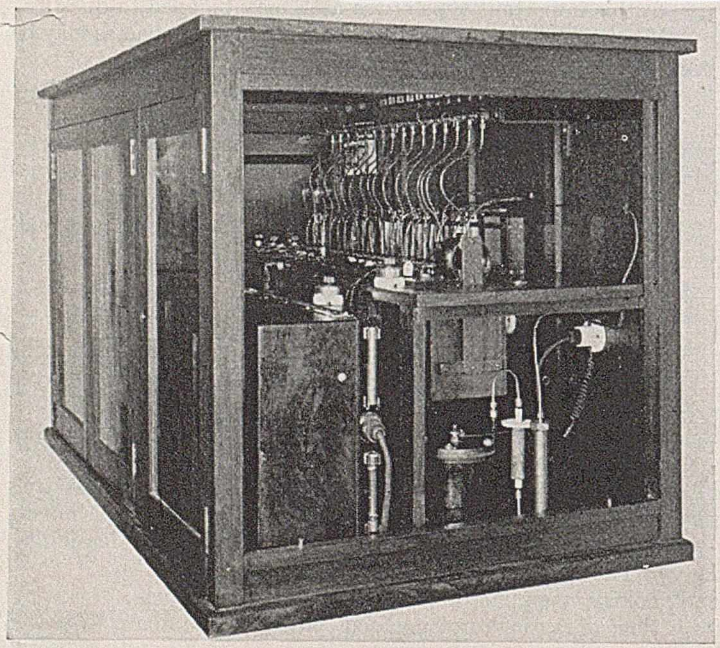
(*Top*) ACCELERATED TESTING APPARATUS FOR STUDYING THE RESISTANCE TO ABRASION OF TRAFFIC PAINTS

The vertical wheel, covered with a ring of a special rubber compound containing an abrasive, drives the horizontal concrete disk with specimens of traffic paint on it. Results can be obtained within 248 hours.



(*Left*) AUTOMATIC APPARATUS FOR TESTING DRY CELLS AND BATTERIES

The better grades now give three- to fourfold greater output than 20 years ago.



(*Bottom*) APPARATUS FOR GAS ANALYSIS BY THERMAL CONDUCTIVITY

Units like the one shown, which was designed for a large nitrate plant, are widely used in industry.

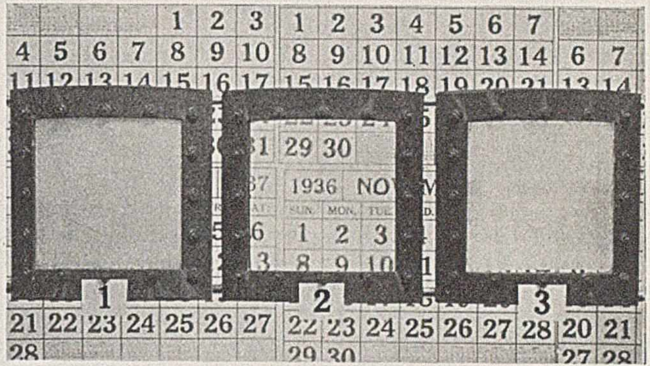
Courtesy, National Bureau of Standards

A process for obtaining chemical cellulose from sugar cane bagasse has been developed and is about to go into commercial production in Hawaii, with rayon, cellophane, and cellulose plastics and lacquers as ultimate markets. The nitric acid pulping process is employed, with which good results have been obtained on other cellulose-containing materials. Perhaps the most promising current project involving industrial utilization of farm products is the process for production of starch from sweet potatoes; an experimental plant is now in operation at Laurel, Miss. The necessary operations for producing a superior grade of starch have been fully described in several papers.

In naval stores research the bureau demonstrated that a noncrystallizing rosin can be prepared from the liquid portion of pine oleoresin separated by filtration. A rapid method has been developed for catalytic conversion of resin and rosin acids to yield highly stable pyroabietic acid in contrast to the ordinary rosin acids. Means have been found for producing rosins which do not materially color soaps made from them. It is hoped that commercial availability of these new forms will help to expand the uses of rosin. Investigation to determine the constituents of turpentine will result in better understanding of its nature and should stimulate the finding of new industrial uses for it. Engineering research on naval stores production has developed a standardized fire-still setting and an improved method of still operation, both of which are largely used.

The second major activity of the bureau that concerns the chemical industries is its studies of our fertilizer resources and methods of manufacturing fertilizer materials and mixtures of all types. It first showed that the brines of Searles Lake, Calif., now an important source, contained sufficient potash to warrant economic exploitation. A large part of the progress in developing an air nitrogen industry in the United States is attributable to its work on catalysts for direct synthesis of ammonia from nitrogen and hydrogen. The bureau developed the so-called fixed nitrogen or American process, now employed in several nitrogen fixation plants in the United States, and a process for the production of urea from carbon dioxide and ammonia, that is now used commercially. The process for the electrothermic smelting of phosphate rock in combination with the electric precipitator for producing high-strength and high-purity phosphoric acid was worked out in a pilot plant constructed for the purpose and was later adapted to large-scale production at Anniston, Ala. Later a fuel-fired furnace process for the production of phosphoric acid was developed, which was eventually elaborated by the Victor Chemical Works into a commercial blast furnace procedure. The relation of fluorine to the composition and properties of phosphate rock was pointed out and pioneer work done on the removal of fluorine by heating the rock at high temperatures in the presence of silica and water vapor to convert the phosphate to a form suitable for fertilizing purposes. The commercial possibilities of this process are being investigated. Of interest also is the work on the development of potassium metaphosphate (an insoluble, although available, 100 per cent plant food) and of a calcium-chloride-free chlorophosphate ($CaCl.H_2PO_4.H_2O$), produced by the partial substitution of by-product hydrochloric for sulfuric or phosphoric acid in superphosphate manufacture. A process for the granulation of fusible fertilizer materials, such as sodium nitrate and urea, has been developed and commercially adopted, and a more recently developed process for the granulation of mixed fertilizers to prevent segregation of the constituents and facilitate uniform distribution has also been adopted by fertilizer manufacturers. In its efforts to bring about the use of fertilizer mixtures of higher plant food contents which would decrease the fertilizer bills of farmers, the bureau has shown how high-analysis mixtures can be prepared that are equal in every respect to the best grades or ordinary-strength mixtures.

The widely publicized regional laboratory program will tremendously increase the opportunities of the Department of Agriculture to be of value to the chemical industries. New ways of processing agricultural raw materials should lead both to cheaper methods of producing old products and to means of producing new products. At the same time it is to be hoped that this long-range program will eventually provide a partial solution for some of the problems which now beset the farmer.



Courtesy, National Bureau of Standards

Sample of Cellulose Acetobutyrate (Panel 2) Practically Unchanged after $2^{1}/_{2}$ Years of Exposure Out-of-Doors

Cellulose nitrate (1) and cellulose acetate (3) were badly deteriorated by such exposure. This investigation led to the marketing of a cellulose acetobutyrate plastic by one of the leading manufacturers of cellulose plastics in the United States.

In the manufacture of chemical pulp little of the enormous quantities of lignin separated from cellulose fibers is commercially utilized. In fact, its disposal is becoming an ever-increasing problem, while the threat of stream pollution laws becomes more serious. Relatively little is known of the chemistry of lignin. The Bureau of Agricultural Chemistry and Engineering is conducting fundamental research on it and is cooperating with the Forest Service in developing commercial utilization of lignin, such as its ammoniation for fertilizer and its use in the production of plastics. Utilization of soluble bases in place of lime as a cooking liquor is being investigated from the aspects of improvement in pulp quality and recovery of chemicals from the waste liquor. Development of economically feasible methods for recovery and use of lignin from pulp cooking liquors would make available for new industries huge quantities of raw material now presenting a serious disposal problem. It is in such directions that government research can be of tremendous assistance in promoting more effective use of our natural resources.

BUREAU OF DAIRY INDUSTRY

Probably the most widely applied research done in the Bureau of Dairy Industry of the Department of Agriculture is on the development of methods of determining hydrogen-ion concentration and on the significance of hydrogen-ion concentration in biological activity. This work has had a profound influence on all biological research and wide application in many industries besides the dairy industry. Bacteriological work has led to development of scientific methods of control of the manufacture of Swiss cheese, including the use of pure cultures, and to sounder methods of pasteurization of milk.

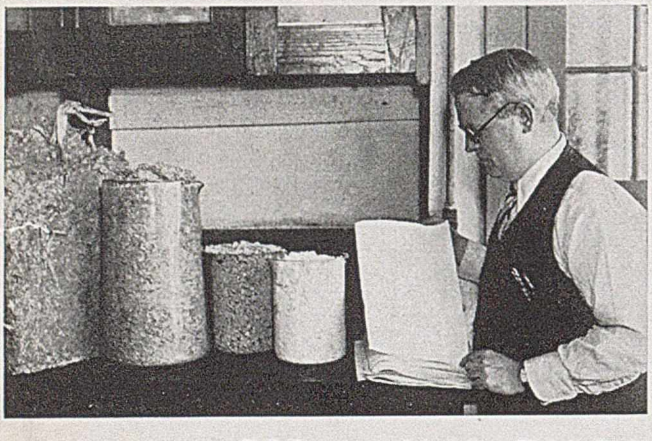
The fundamental changes involved in the deterioration of butter fat and other fats have been studied, and the results have been applied to the prevention of deterioration of fat in dairy products, especially in butter and milk powder.

A process has been developed for the production of textile fiber from casein, on which nine public service patents have been filed and one has been granted. A process for the conversion of lactic acid to esters of acrylic acid has been devised from a series of previously known reactions. The products are of interest to the plastics industry. Milk sugar may be produced from whey more cheaply than in the past by a new process devised by the bureau. This process includes also the recovery of albumin and of a residue rich in flavins which is in demand by feed manufacturers.

BUREAU OF PLANT INDUSTRY

Through plant research the Bureau of Plant Industry has contributed notably to the improvement of crops and cultural practices in all parts of the United States. Crop improvement and increased efficiency in cultural practices have tended to maintain production in the face of natural hazards and declining soil fertility. The results of plant research also constitute a broad basis for soil conservation and agricultural adjustment, and for ensuring adequate supplies of raw materials for industrial uses.

Crop improvement research has drawn upon plant species native to America, such as corn and tobacco, and upon species introduced through world-wide exploration. Some of these introduced crops, such as durum wheat, soybeans, several grasses, and many fruits and vegetables, have become crops of major importance in this country. Others are sufficiently promising to sustain the belief that they will become of considerable value as cultural and utilization methods improve. If the harvesting of pyrethrum flowers can be satisfactorily solved, we shall no longer be wholly dependent upon Japan and Jugoslavia for our supplies of this important insecticidal material. Santonin, important hog vermifuge, is already being successfully grown as a crop in Oregon and is thus partially replacing imports from Russia which formerly maintained a monopoly price on the material. Propagation of new varieties of sugar cane and sugar beets has resulted in material aid to the two branches of the sugar industry. Successful outcome of planting experiments under way with safflower would give us a new drying oil to relieve part of our dependence on foreign sources. Still other introductions, together with native species, have served as stocks from which superior varieties have been bred to combat successfully the ravages of drought, cold, disease, and insect pests. At the same time the quality of crops generally has been greatly improved.



U. S. Department of Agriculture Photo by Purdy

High-Grade Cellulose Made from Sugar Cane Bagasse by a Method Developed in the Bureau of Chemistry and Soils

BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE

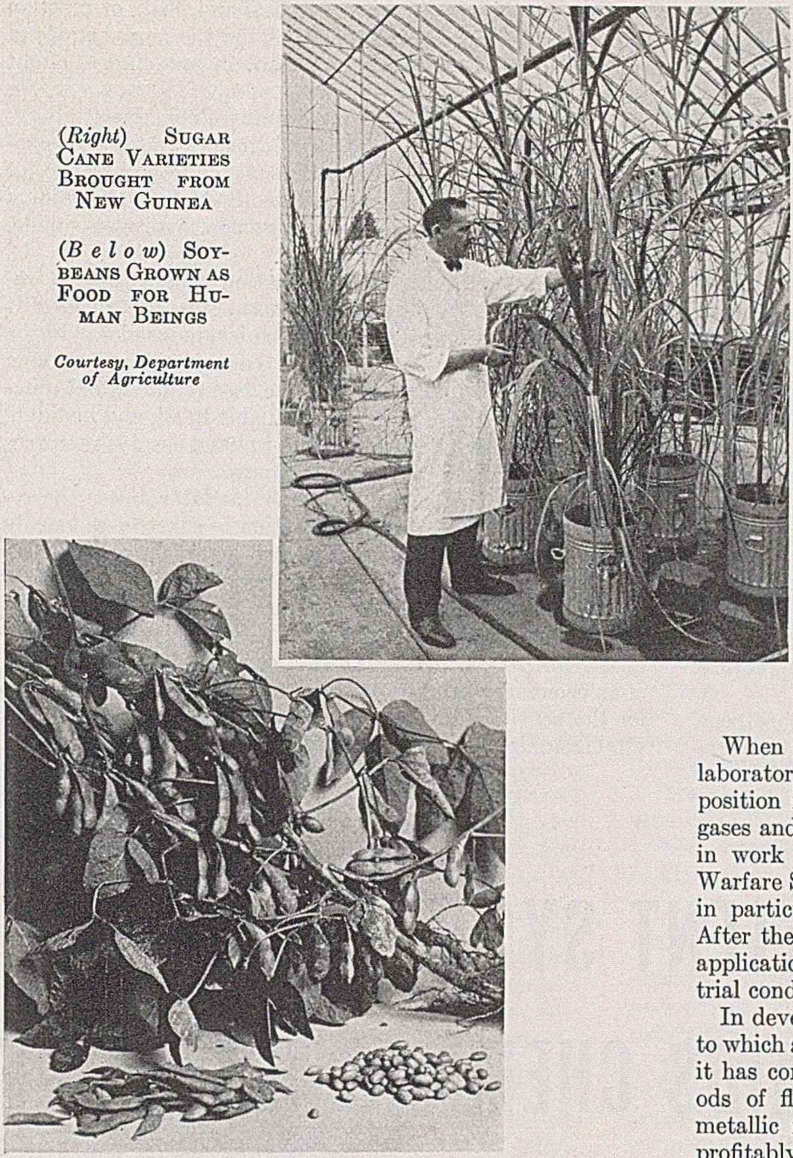
An important activity of the Bureau of Entomology and Plant Quarantine is its investigations to develop new and improved insecticides for combating the enormous damage done by parasites to crops, gardens, clothing, and homes, also in spreading disease to man and beast. This country's total annual loss from injurious insects, bacteria, and fungi is said to be in excess of three billion dollars. In late years the bureau's research work has largely taken the direction of finding less toxic organic substitutes for the inorganic insecticides (notably lead arsenate). Of such new products, rotenone from derris, the root of a plant cultivated in the British and Netherlands East Indies, and from cube and timbo roots, South American plants, is giving increasingly good results. The action of rotenone is slower but more deadly than that of pyrethrum, and a combination of both is being successfully employed against certain important pests. The structure of both rotenone and pyrethrum is being studied for better understanding of their actions and utilization of their properties. Even the lowly devil's shoestring weed has been found to contain rotenone and may become a source of supply of this product. A new nicotine-bentonite apple spray to replace lead arsenate has given good results in five years of experimentation. Much promising work has also been done in the synthesis of organic insecticides. Among the most promising of these are lauryl thiocyanate as a contact insecticide, isobutyl undecylamide as a fly spray, phenothiazine, dibenzothiophene, thiocoumarin, and phenothioxin for various kinds of insects attacking crops.

BUREAU OF FISHERIES

Few realize that about three fourths of the annual domestic catch of aquatic products are manufactured in some form before being marketed. The Bureau of Fisheries has done much to aid American fisheries by improving present practices, introducing new methods, and finding new uses for waste products. Several important industries are based largely if not entirely on the bureau's work. Among its outstanding accomplishments are introduction of the quick-freezing of fish, developments in fish oils, particularly the high-vitamin oils from fish livers, and the commercial development of fish meal. Valuable information is becoming available from investigations completed or in progress on the nutritive value of fish and shellfish, the vitamin potency of fish oils, the mineral and protein content of fish, evaluation of the amino acids in the protein, improvements in the canning of fish (including new varieties), effect of ultraviolet ray in killing bacteria in fish, detection of causes of pollution deleterious to growth of shell fish, and electrometric determination of the freshness of fish.

BUREAU OF STANDARDS

The National Bureau of Standards has achieved an international reputation as one of the foremost institutions of its kind. Probably no other branch of the Government performs more fundamental research, all of which affords basic scientific data for technological development. As such development proceeds, demands arise for new kinds of measurements, new standards, and always for more accuracy. Thus this bureau is continually carrying on research and test-



(*Right*) SUGAR CANE VARIETIES BROUGHT FROM NEW GUINEA

(*Below*) SOYBEANS GROWN AS FOOD FOR HUMAN BEINGS

Courtesy, Department of Agriculture

ing in electricity, weights and measures, optics, mechanics, sound, chemistry, metallurgy, clay and silicate products, and organic and fibrous materials. Among the more interesting projects which have been completed or are in progress may be mentioned development of new photometric standards for the measurement of light, measurements of the heights of the ionosphere layers, preparation of thermodynamic tables of ammonia and steam, precise determination of physical constants of pure substances, maintenance and extension of the international temperature scale, interferometric measurements of wave length of spectral lines, development of color standards and methods of color measurements, investigation of methods for the control of active acidity in industrial processes, studies of stresses in structures under load and when in motion, development of standards of quality and methods of measurement of textiles, paper, leather, rubber, and organic plastics, study of ceramic materials and the processes used in their manufacture, researches in metal, including melting, heat treatment, mechanical working, chemical and optical properties.

Of more immediate interest to industry, the Bureau of Standards enters into cooperative arrangements with scientific or technical groups for study of their fundamental problems which come within the bureau's field. Under its supervision approximately twenty-four groups are now conducting research projects, the results of which are published for the benefit of the public. Among the more ambitious projects now under way are the separation, identification, and determination of the constituents of petroleum, investigation of the reactions in portland cement during manufacture, development of silver alloys and new applications of silver and silver plating, study of the physical and chemical properties of textile fibers, and research on electroplated coatings.

BUREAU OF MINES

Among its numerous duties the Bureau of Mines investigates methods of mining, the treatment of ores and other mineral substances, improvements in methods of production of petroleum and natural gas, and other technological investigations pertinent to such industries. Twelve regional experiment stations strategically located in various parts of the country aid in carrying on this and other work concerned with mine health and safety, explosives, etc.

When the United States entered the World War, the gas laboratory of the Bureau of Mines, which had a leading position in the study of properties of toxic and flammable gases and protection against them, was called upon to assist in work on war gases. From this nucleus the Chemical Warfare Service developed. New gas masks were developed, in particular one for protection against carbon monoxide. After the war the Bureau of Mines was instrumental in the application of modifications of the army gas mask to industrial conditions.

In development and conservation of our natural resources, to which a substantial part of the bureau's efforts are directed, it has conducted fundamental research on differential methods of flotation and table concentration of ores and nonmetallic minerals, whereby lower grade materials may be profitably worked. Improvements in methods of recovering gasoline from natural gas have led to savings of billions of gallons of gasoline formerly wasted. The bureau first called attention to the enormous losses of petroleum by evaporation which have since been rectified by general adoption of gas-tight tanks and other equipment. The bureau developed methods for recovering helium from natural gas and operates a plant for that purpose, which is now conducting research pertaining to the conservation, production, and purification of helium. In cooperation with the Geological Survey it conducted explorations and drillings which led to the discovery of potash deposits in New Mexico and Texas, now the basis of a substantial industry potentially capable of supplying our entire needs of potash for many years. A method of separating potassium and sodium chlorides, a modification of which is employed by one of the New Mexico companies, and seven alternative methods of producing potassium sulfate and other products from polyhalite have been developed.

It recently perfected a process for obtaining 99.7 per cent pure electrolytic manganese from low-grade domestic ores. This pure metal may be useful in making new alloys of unique properties. Satisfactory methods have been developed recently for concentrating western chromite ores, and for inexpensive production of pure chromium chloride and sponge chromium; the latter may soon be commercially applied. The work on chromium may go far towards relieving our dependence on imports of chromium ore. The previously unworkable deposits of spodumene, a lithium ore occurring in large quantity in North Carolina, may lead to establishment of a new industry in the South as a result of the bureau's cheap method of concentrating the chloride and of extracting the lithium as chloride. American clays have traditionally been considered unsuitable for whiteware, but the bureau has demonstrated that high-grade ceramic products can be made from clays occurring in the South and Northwest.

In its study of the nation's fuel problems and needs, eventual depletion of our liquid fuel reserves is being anticipated by research in hydrogenation of various kinds of coal. Many thousands of coal analyses have been placed on record, and a survey of the gas-, coke-, and by-product-making properties of American coals is now being conducted. The present standard methods for testing coal were developed largely by the Bureau of Mines. As a result of extensive studies of various substances which might act as warning agents in fuel gases, several, in particular ethyl mercaptan and certain sulfur-bearing fractions of petroleum, were developed as suitable materials for addition to odorless gases. It was found also that addition of crotonaldehyde or allyl alcohol would awaken sleeping persons. These are irritant substances and at present are perhaps too costly for practical use.

In the field of metallurgy fundamental research has been conducted on the specific heats at high and low temperatures of the metal oxides and sulfides, and heats of reaction have been determined in order that the thermodynamics of various chemical reactions, important in metallurgy, might be worked out.

In cooperation with the United States Public Health Service the bureau developed the impinger apparatus now considered standard for determination of the concentration of atmospheric dusts, and various methods for determining small concentrations of carbon monoxide, hydrogen sulfide, and other toxic gases in air.

Although by far the greater portion of government research is in fields outside the physical sciences, much of it directly or indirectly benefits the chemical industries. In the physical sciences many important contributions are being made to these industries through the ascertainment of fundamental scientific data which are available to all, and in aiding the orderly development of our natural and surplus resources with no advantages to favored interests.

In contrast to the methods of the dictator states the research of which leads to the perfection of substitutes usually inferior or more expensive, for raw materials or products which these countries lack, the research of our Government is directed towards the development of new products and new industries, and to the lowering of costs and improvement of quality of old products. It is not conducted for the support of an economy planned for the security of those in power, but for the benefit of all American citizens, and it is therefore a vital factor in the maintenance of the American Way.

THE AMERICAN PATENT SYSTEM AIDS CHEMICAL INDUSTRY

BRUCE K. BROWN
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THE American patent system is as old as the American chemical industry. Our patent system, like many of our governmental institutions, had its genesis in England. As in the case of most of our inherited institutions, it has been modified and amended until it is unlike the original pattern. The various colonies granted patents for inventions, and the framers of the Constitution included in Article I (Section 8): "The Congress shall have the power....to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries."

The first patent law enacted by Congress was dated 1794. There were several revisions, and in 1836 Congress enacted the law which, with amendment from time to time, has formed the keystone of industrial development over the past century. About 2,150,000 patents have been granted, and approximately 750,000 are currently in force. Thousands of decisions of the federal courts have served to interpret, clarify, and sometimes confuse the intent of Congress as expressed in the various patent statutes.

In appraising the effect of the American patent system upon the American chemical industry, we must bear in mind that the patent system and its rules, precepts, and traditions were well established when the American chemical industry was still in an infant state. The Patent Office and the courts, in interpreting chemical inventions, have used as tools the judicial theories and precedents developed in prior decades when most developments, and consequently most inventions, were of a mechanical rather than a chemical nature.

Popular writers frequently take the position that the American chemical industry was of little consequence prior to the World War. Actually such a position cannot be justified because the American chemical industry, while more juvenile than the patent system, is not such a youngster as the romantic advocates of that hypothesis would imply. However, the writer proposes to confine his analysis of the American patent system as it has affected the American chemical industry to the events of the past quarter century. Many leaders of the chemical industry and of the Patent Bar may be offended by such cavalier treatment of the earlier era. But on the other hand, it may be pointed out in defense that the chemical industry has undergone a phenomenal growth since 1914; and if the American patent system has had any effect, favorable or unfavorable, on the chemical industry, it should be possible to judge its merit on the basis of its recent performance.

What then are the principal characteristics of the American patent system and how can it have affected the American chemical industry? Before we can erect a firm structure of fact upon which an answer can be based, we must give some attention to the most remarkable and widely used invention of them all, the "corporation." The patent system is keyed around that mysterious mortal, "the inventor." The inventor is an individual, a human being, a true *Homo sapiens*. In 1836 when the present patent system was instituted, the overwhelming majority of all useful human activity was conducted by individuals as individuals. Businesses were conducted by individuals or partnerships of individuals. The owner of a business had no option except to stake his entire personal fortune in it. Employees of the owner were, under the law, "servants" owing special duties of fidelity to the "master." For example, an employee who, in the regular course of his duties, made an invention of a patentable nature, was obligated to assign the rights and benefits thereof to his employer. This "master and servant doctrine" prevails today in a modified form and is an important factor in our patent system.

While the joint stock company, the progenitor of the modern corporation, was invented several hundred years ago, the growth of the corporate method of doing business has occurred largely since the patent law of 1836. In the eyes of the general law a corporation is an artificial person, differing from a human being only in that it is created by law to perform certain specified functions under certain specified rules. In the eyes of the patent law a corporation is the same as a natural person with one important difference—namely, it cannot "invent." It can occupy the old position of a master of a business; it can buy, sell, and license patents; it can employ inventors to make inventions for it, but it cannot itself invent. Hence, under the American patent system (unlike certain foreign systems) each patent must issue to the individual or individuals who made the invention. Such individuals may assign the patent monopolies to corporations or to other individuals, either at the time of issuance or at any subsequent date.

Commissioner of Patents Coe, testifying recently before the T. N. E. C., gave the following data on the extent to which patents are controlled by corporations: "The total patents issued during that period (January, 1931, to June, 1938) was 334,970. The large corporations had issued to them 48,427 of that total, whereas they acquired by purchase during that period 1124. Small corporations had issued to them 117,101, and they acquired by purchase 7448. Foreign corporations had issued to them 15,403 of the total, and they acquired by purchase during that period 976."

It was necessary to make this brief foray into the field of corporation and law before attempting to set forth the principal characteristics of the American patent system because the most significant single fact about the American patent system is that, to date, it has treated all persons, natural human beings and artificial persons (i. e., corporations) exactly alike. Impatient reformers sometimes sneer at the fundamental precept of democracy, "equal justice before the law." Equality and justice are both ideals difficult of attainment, but the fact remains that the cold logic of the patent law has thus far done a good job of treating all alike. In the patent field, as in other fields, wealth is of great advantage; the complexity of modern research is such that much money must be expended to get results, and patents. The cost of patent litigation is great and the results uncertain; but the Patent Office and courts have treated all with impartiality.

This is not true of certain other patent systems. In some countries patents issue directly to corporations, and the question of inventorship is secondary. In some countries the cost of obtaining patents is entirely beyond the reach of any but the wealthiest, and a patent, once issued, is practically taxed out of existence long before the period of monopoly has expired. Under some other systems a patent owner is not free to dispose of his monopoly as he sees fit but is subject to the necessity of granting licenses on terms which he cannot control. In some countries patent applications are published before the monopoly is granted, and the inventor (or assignee) must litigate his right to the monopoly (in advance of getting it and before he can have realized any funds from it) with anyone and everyone who may desire to prevent him from securing a reward. In some countries the very issuance of an important patent is a signal for the filing of annulment proceedings by wealthy interests which might be adversely affected by its existence. The word "wealthy" is used advisedly. No others could afford such proceedings. None of these things is true of the American patent system.

Having thus described our system negatively, we can express more definitely the positive characteristics of the patent system under which the American chemical industry has come to flower.

EQUALITY, SECRECY, ECONOMY

Every person, natural or artificial (corporation), of whatever walk of life, has equal rights. Foreign nationals have substantially the same rights as citizens.

The obtaining of a patent monopoly is a private affair between the applicant and the Patent Office and, barring some technical violations of the principle occasioned by our cumbersome "interference practice", is entirely secret. The applicant can obtain a patent, regardless of whose interests he might affect adversely, provided only that he satisfies the Patent Office that he is entitled to it.

At the risk of provoking gibes from the incredulous, it can be fairly stated that patents may be obtained cheaply under the American system—at least this is true when the cost is measured against the cost of other systems. Any American mechanic of the type likely to make an invention can finance the obtaining of a patent, unless he is unfortunate enough to have his application "placed in interference." Interference proceedings are extremely costly and are beyond the means of a man enjoying mechanics' wages. However, there is no question but that interference practice is on the verge of great readjustment and simplification.

EXAMINATION

A patent is granted only after the application has been "examined" by a technically trained government employee who is presumed to be skilled—at least so far as "book larnin" is concerned—in the particular field in which the invention lies. There is a considerable dispute as to the efficacy of the examination system. Certain it is that the examination system is no guarantee that the patent, when issued, is valid. This is illustrated by the fact that probably less than half of the patents which are litigated are sustained—i. e., held valid by the courts. When one considers that a patent owner must regard its validity highly in order to justify the expense of litigation in his own mind and hence that more "good" patents are litigated than are "doubtful" patents, it would appear that in spite of the examination system more than half of the patents issued are imperfect.

Nevertheless, our examination system is the most efficient and comprehensive in the world, and the search facilities of the Patent Office are, and are likely to remain, a fountainhead of technical information.

In some countries, notably France, there is no vestige of a critical examination by the Patent Office of a claim to patentable invention. The applicant pays his fee and takes his patent, and the question of whether the monopoly allegedly granted is proper is left to the courts, should the applicant have the temerity to attempt to enforce his patent.

Whatever the imperfectness of our system of examination of patent claims before issuance, there can be no doubt that the very existence of the system does much to cut down the number of improper patent monopolies and also guides the applicant in making claims of a type which are proper.

PATENTS FOR IMPROVEMENTS

The fact that one patent has issued covering, say, a process for producing acetic acid from carbon monoxide and hydrogen, does not forestall later inventors from securing more limited claims covering their own minor refinements of the process. The existence of a large number of separate patents each covering a specific feature of a process makes for considerable confusion, particularly if the patents are held by several different owners. However, this situation is a logical outgrowth of the competitive situation in research. Where a number of inventors are at work in the same field, each striving to produce approximately the same technical result, it is obvious that each may contribute one or more inventive improvements and that several patents may issue to cover various ramifications of the same process.

PATENT TO THE FIRST INVENTOR

No United States patent is valid unless it issues to the true first inventor. This is a fact of tremendous significance. In numerous instances the courts have refused to enforce patents which had been properly drafted and covered real inventions because the patents had been issued, improperly under our law, to persons other than the true inventors.

In some foreign systems patents are issued to the first applicant, regardless of whether such applicant was truly the first person to conceive the invention and reduce it to practice in such form that the public might benefit by the new knowledge when the private patent monopoly had expired. Such a procedure again puts a premium on wealth and aggressiveness rather than rewarding scientific intelligence.

Under the American system every effort is expended to the end that only the true first inventor may be rewarded by the issuance of a patent. The devotion to this principle is the basis for our interference practice, a unique characteristic of the American patent system.

When, as so frequently happens in these days of highly competitive research activities, two or more persons have applied for patents covering the same invention, our Patent Office pauses in its examination routine, refuses to issue either patent, and sets up an *inter partes* inquiry as to which applicant is truly the first inventor. An interference proceeding to determine the question as to which applicant is entitled to a patent is in the nature of a litigation with the Patent Office serving as judge.

The interference practice is probably no better or worse than any other type of litigation, but like all litigation it is full of vexations, hypertechnicalities, and delays. The practice is under violent criticism from large groups of inventors and attorneys and can doubtless be improved. Certainly it should be, because it is a blight on our patent system. Criticism is justified because it is more difficult to condone the delays in this type of litigation than in most litigation. Most litigation in the courts is between private parties whose rights have already been established in fact, and the public usually is not directly affected. On the contrary, interference procedures not only delay the rightful applicant from obtaining his patent monopoly (and he has no monopoly until he gets it), but the delay also serves to defer the issuance, and hence the eventual expiration, of a monopoly which may affect the public interest.

TEST OF PATENT VALIDITY

Barring two minor justifiable exceptions,[1] the holder of a patent monopoly cannot be in any way harassed by his adversaries or competitors. His is the choice as to whether an infringer of his claims shall be prosecuted in the courts with one of two inevitable results; that is, he may meet with success or the court may hold his patent invalid or not infringed. If he fears to submit his patent to a test in court he need not do so. He may choose the arena for the battle and, subject to the usual doctrines of laches and estoppel, he may choose the time and the adversary.

This is not true in certain foreign systems where the patent holder is in constant jeopardy of litigation brought by adverse parties to strike down his patent.

LITIGATION

A patent holder desirous of restraining others from infringing his monopoly must proceed in the Federal Courts since it was the Federal Government who granted him the patent. Barring the impediments of expense and delay which are characteristic of all litigation, he has great freedom of action and a real assurance of a fair deal. He may sue the infringer in the court having jurisdiction over the alleged infringement—for example, the factory where the infringing operation is conducted—or, at his option, in the court having jurisdiction over the defendant—i. e., the residence in the case of an individual, or the state of incorporation in the case of a corporation. Unlike the situation prevailing in some countries, he need not post a large bond in order to be heard. Assuming his suit is brought in good faith, he is not obligated to pay any of the defendant's costs, even if he loses, except certain minor court costs.

Plaintiff's case is invariably based on his belief that his patent is valid and broad. He directs his effort first to proving that defendant uses the invention, and secondly to urging the court to issue an order restraining further infringement and assessing damages or other financial penalties which must be paid by defendant to plaintiff. Defendant almost invariably disregards plaintiff's plans and sets about to prove that "there was no invention to patent; that if there was an invention, the patentee didn't make it; and that if defendant is wrong as to these points and the patent is valid nonetheless, then it is so narrow that defendant doesn't infringe it."

Whether the plaintiff likes it or not, the fundamental question to be decided by the court is almost always: "Has the

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[1] Suits *re* interfering patents under R.S. 4918, or declaratory judgment suits (28 U.S.C. 400). For example, when a manufacturer can prove that a patent owner has publicly threatened to sue for infringement, that the patent holder's conduct has adversely affected the manufacturer's business, and that the patent holder has not "followed through," the court may institute a proceeding to determine the validity and scope of the patent.

patentee made any disclosure which, when judged by the background of modern science, is a justifiable basis for a patent monopoly?"

To decide the importance of an inventor's contribution to applied science, it seems necessary to understand the science itself.

The owner of a patent seeking redress for infringement need not submit his case to a jury and thus be subject to the whims of a group of laymen skilled in neither science nor law and possibly prejudiced against him. On the other hand, he does not have the privilege of submitting his claim to having made an invention of scientific importance to the judgment of a technically trained man or men of the sort most likely to understand the significance of his invention. Our system provides a compromise or middle ground, and the destiny of the patent is decided by a federal judge (three judges in the appellate courts) who is skilled in general law, who is not presumed to have any special scientific training, and who may or may not be soundly grounded in patent principles.

Inventors and scientists are loud-spoken on the desirability of having patent cases decided by technically trained judges. This would be ideal, but it is certainly difficult of attainment. In what branch of techniques should the judge be trained? Could an electrical engineer do a better job than a lawyer in deciding a chemical case? Could an organic chemist give a fuller measure of justice than a federal judge in deciding a case relating to automatic switchboards for telephones?

In this connection it should be realized that there are some eighty-one Federal District Courts in which patent suits may be brought, and that most of these districts are manned by only a single judge.

Appeal from the decision of the District Court is taken to a Circuit Court of Appeals. There are ten such courts blanketing the geographical area of the United States. Each such court is supreme in its own territory unless overruled by the United States Supreme Court. For many years the Supreme Court has refused to review the decisions of the Circuit Courts of Appeals in patent cases except in certain special circumstances. The result is that there have been ten little supreme courts. The theories upon which patent questions have been decided have varied somewhat, and each Court of Appeals has tended through the years to build up its own body of patent law. At present it appears that the long agitation for a single Court of Patent Appeals (replacing the ten Circuit Courts) is likely to succeed. If so, the single court will make all final interpretations of patent law (except as to specific cases in which the Supreme Court chooses to take jurisdiction), and a much more uniform judicial philosophy concerning patents should result.

CHEMICAL INDUSTRY UNDER THE PATENT SYSTEM

The making of a chemical invention frequently requires background, laboratory resources, and skill to a greater degree than is required for the making of an average invention in a mechanical art. Nevertheless, chemical patents issuing nowadays are by no means confined in their origin to the great industrial research laboratories of the chemical companies. Some of the most important developments of recent years have come from university research and from research by private individuals, notably consulting chemists. It appears that up to the date of the present writing most of the important chemical inventions have stemmed from the efforts of individuals rather than from the larger research groups. The great industrial research units devote most of their effort toward the commercialization of new inventions having immediate profit possibilities; hence a great many of the multitudinous patents which issue from the large research groups are of a minor nature.

In the last decade the university research groups have coordinated their patent efforts more and more, and numerous patent foundations have been established to exploit, through industry, the inventions made by university people.

The most enterprising of the large chemical manufacturers do not rely entirely on their own research staffs for chemical progress or for patentable inventions. In addition to sponsoring research work at the various universities and foundations, they acquire new chemical patents from individuals, usually on the basis of purchase through royalty payment. The relation of the late Julius A. Nieuwland of Notre Dame to one of the largest chemical manufacturers has been described in the technical press. There are many other such instances.

In view of the large number of chemical patents and the great size of the chemical industry, there appears to be a remarkably small amount of patent infringement. From time to time there are important patent litigations, but in the main the various units of the industry seem to keep out of one another's way. This appears to be true not only because of the high ethical standards of the industry, but also because competition between chemical manufacturers has been largely a matter of brains rather than of dollars. With the exception of some of the basic chemicals which are manufactured in many places and used in tremendous quantities, the chemical business is a specialty business. When one chemical manufacturer has developed and begun to manufacture a particular compound for a particular use, it appears to be the effort of his competitors to produce another better compound for the same use, rather than merely to invade the existing market by lowering the price of the same material. This policy cuts down patent infringement.

There is no question but that the patent system has fulfilled one of its basic purposes—namely, the stimulation of new industries. This has been particularly true in the chemical field where cost of research is great and factory investment cost is large. Were it not for the temporary monopoly provided by the patent system, progress in the chemical industry would have been considerably slower than it has been. The existence of patents on specific products and processes has stimulated competitive research to produce other and better processes and products.

Members of the round table group at The Chemists' Club (New York) have delighted or irritated visitors for years by discussing the provocative theory that most industrial chemical progress has come as the result of or the fear of court injunctions. It is proposed that smelter damage done western grazing lands was responsible for the development of the electrostatic method of dust precipitation. Using this as a springboard for the discussion, members of the group build up a long and interesting story of recent chemical history in which it is demonstrated that frequently a new process or product has been brought into being as the result of desire to avoid patent monopolies already in existence. Each new patented process seems only to stimulate the development of another. Each patent infringement suit or threat of suit provides the impetus for a new research program.

Generally speaking, the law is notoriously slow in changing, and this is true of the patent law. Some of the doctrines of general application in patent law have had surprising repercussions on the patent policies of the chemical industry. One illustration is the provision concerning the obtaining of a patent on a "composition of matter." Under this branch of the law it is theoretically possible to obtain a patent giving a monopoly on the manufacture, use, and sale of each new chemical compound. The Patent Office and courts have generally taken the view that each chemical compound can be patented as such, provided it is new.

The original purpose of this doctrine was entirely justifiable. It goes back to a period when chemistry was indeed mysterious. There was no reason why the inventor of a hair tonic should not have a patent as well as the inventor of a reaper. Further, the doctrine seems equally justifiable today in the case of some newly synthesized compounds where real ingenuity has been required.

However, when a series of compounds has been discovered and reported in the literature, it seems rather like stretching the point to permit each of the members of a series to be monopolized by a separate patent. Consider, for example, the group of compounds comprising the esters of a certain organic acid. Suppose that ten of the esters have been synthesized and reported in the literature, and that no one has ever synthesized the hexyl ester of this organic acid. As the law stands, the first man to synthesize it would be entitled to a patent covering that particular compound, in spite of the fact that he and all of his colleagues in organic chemistry would be able to predict the various physical and chemical qualities of the ester without ever going to the trouble of making it in the laboratory.

Another patent law doctrine which haunts the chemical industry is the line of court decisions which says "there is no such thing as prediction in chemistry." In the field of mechanical inventions no patent will be granted or held valid unless the inventor has used a high degree of ingenuity in connecting the various elements of his machine. Many issued patents are held invalid on the ground that the alleged inventor did not really have any spark of invention but merely exercised ordinary mechanical skill in hooking up his device. In contradistinction, the courts have held in effect that chemistry is a mysterious science and that no one can tell exactly what will happen in any reaction until he has tried it. On this basis patents are sometimes granted for chemical inventions in instances where it would appear that the amount of ingenuity exercised on the part of the chemist would have been called "mere mechanical skill" had he been working in a mechanical art. It is hard to know just where to draw the line. Progress made in chemistry in the last fifty years has made it possible for chemists confidently to predict the course of certain reactions and the character of certain products. On the other hand, there are still and always will be many phases of chemical invention where prediction is impossible. Generally speaking, the courts have not been able to keep pace with the progress of science, and in the writer's opinion the courts underestimate the ability of a chemist to predict chemical matters.

While the patent law permits the patent owner to "enjoy the exclusive benefits of his invention"—i. e., to use it or not use it as he may see fit and to restrain all others from using it during the period of his monopoly—the chemical industry has not made much use of this privilege. In cases where patents have been sued upon in the courts and enforced, the usual result has been that the erstwhile defendant has paid damages for past infringement and has purchased a license on such terms that it has continued the business at a profit. Few if any patent holders, particularly the large companies, have flatly refused to license competitors. (One of the largest manufacturers reports after a careful survey of the last ten years: "1015 requests for licenses; 1000 licenses granted, 15 refusals.") Most of the companies seem content to profit from the invention mainly through the medium of having been the first to introduce it, and royalties, when received, serve to repay research costs and provide only a minor contribution to general profit schedules.

RAMIFICATIONS OF CHEMICAL INDUSTRY

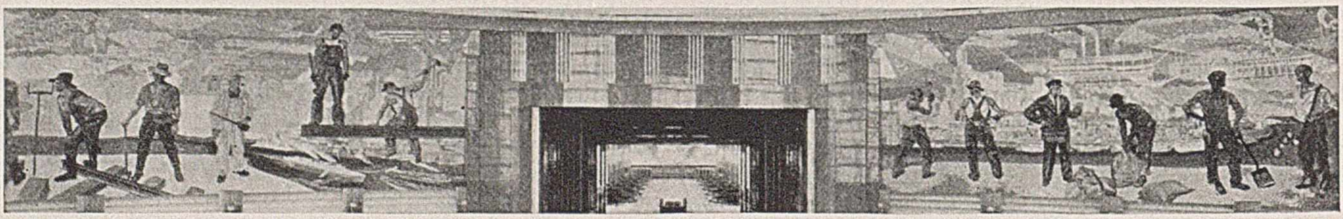
One never knows where to stop in defining "chemistry." Combustion is a chemical process, but the owner of a hot air furnace does not consider it such. Is the petroleum industry a chemical industry? The author doesn't think of it as such, yet distillation is ordinarily considered a chemical process and certainly the cracking of hydrocarbons to make gasoline and other products is an important chemical reaction. If petroleum refining is a part of the chemical industry, it is the largest single part of it, for the petroleum industry is the fifth largest industry; and gasoline, if a chemical, is the most used chemical. In any event, the patents of the petroleum refining industry are mostly patents of a chemical nature.

Most petroleum refiners are quite patent-conscious and seek to obtain patents on every new process, process feature, and product. There has been a good deal of patent litigation, but none of it has resulted in the exclusive use of any improvement by any company or group of companies. Refiners license and cross-license freely, and although the royalties have totaled large sums on account of the size of the industry, the royalties per unit product have been quite small.

One feature of the petroleum patent situation which, although not unique, has been developed by refiners to a greater degree than by other manufacturers is the principle of the fully paid license. When licenses are granted on this basis the fee is computed by first agreeing on the probable average annual production of the refining unit. The royalty per unit of goods produced multiplied by the expected annual production provides an estimate of the annual return which might be expected by the patent-holding licensor. In lieu of taking his chances on recovering such a royalty for seventeen years or the remaining life of the patent, the fee actually to be paid is set at from three to five years of the expected annual revenue. The licensee pays this, either cash down or in installments, and thus obtains the perpetual right to manufacture that amount of product each year.

Licensors generally have liked this plan because, although it concedes a tremendous discount from the possible royalty return, it also changes such return from a hazard to a certainty. Licensees like it because under this plan they are not subject to any control or supervision from the licensor who is usually a competitor.

In the writer's opinion the American patent system has contributed to the success of the American chemical industry. Such differences as exist between the American patent system and foreign systems appear to have worked to the advantage of American inventors and American Industry in pursuing industrial development along the route of free enterprise which we know as the American Way.



CHEMICAL STOREHOUSE

In the soil, worthless; before the plow, a hazard; but reduced to raw feed for Hercules' steam and solvent process, these stumps provide industry with terpene and rosin products for wide use in chemical processes.

WASTE UTILIZATION

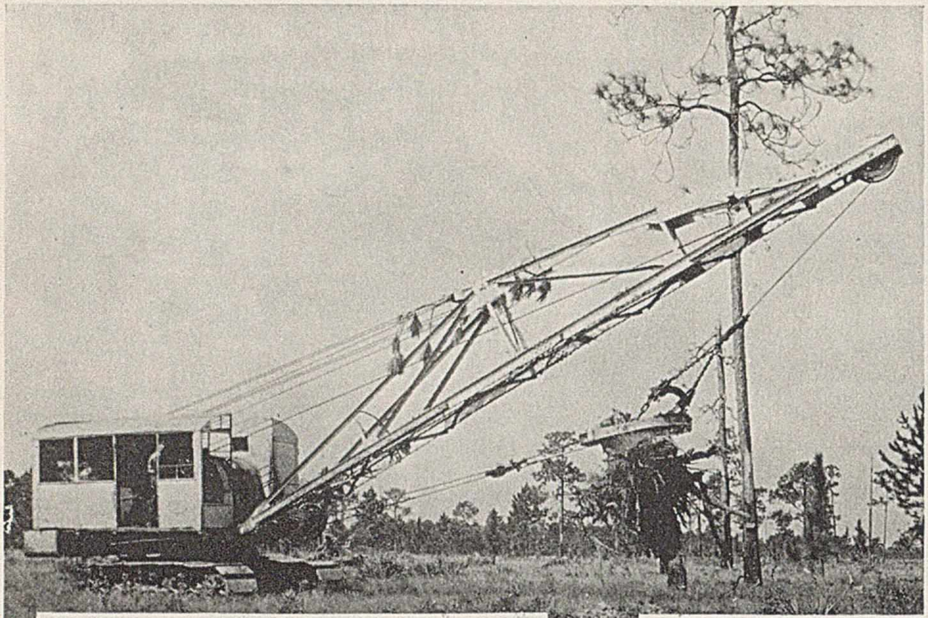
Land Reclamation through Chemical Industry

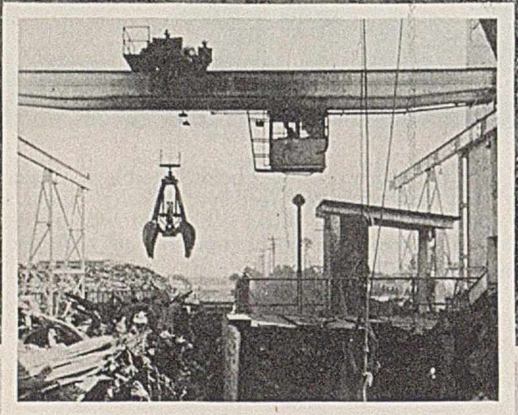
J. L. SCHANTZ AND
THEODORE MARVIN
Hercules Powder Company,
Wilmington, Del.

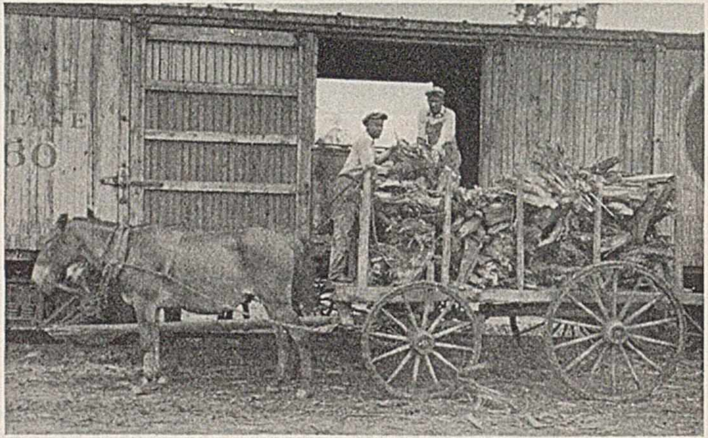
EVEN today, centuries after the establishment of the naval stores industry as a world-wide business, it is usually essential in any article on that subject to relate that "naval stores" are turpentine, pine oil, rosin, and their derivatives; that the name came into use as early as the Phoenicians who used rosin especially for caulking of ships holds and the treatment of rope. Coming closer to home, it is interesting to note that the first shipment of "hard pitche, tare, turpentyne, and rozens" was made from Virginia shores in 1608, and that that same cargo marked the first recorded commercial shipment of industrial products from this country to the Old World.

Coming down to 1939, we find a naval stores industry which produced in the 1938–39 crop year 2,661,333 round barrels of rosin and 737,000 barrels of turpentine, which were consumed for countless chemical and industrial applications. The original use that stimulated Colonial America's first industry has almost vanished.

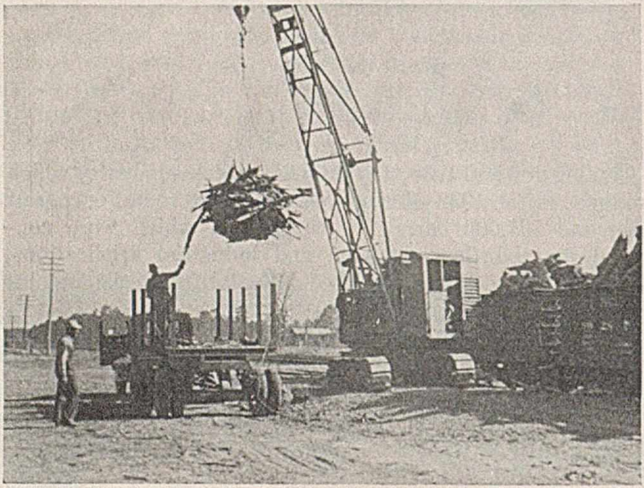
Through those 331 years there have been few fundamental changes in the original method of production of those early Colonial days. Other processes were developed at various times, but only four of them are in use today. Their present importance is indicated by these 1938–39 figures on production:

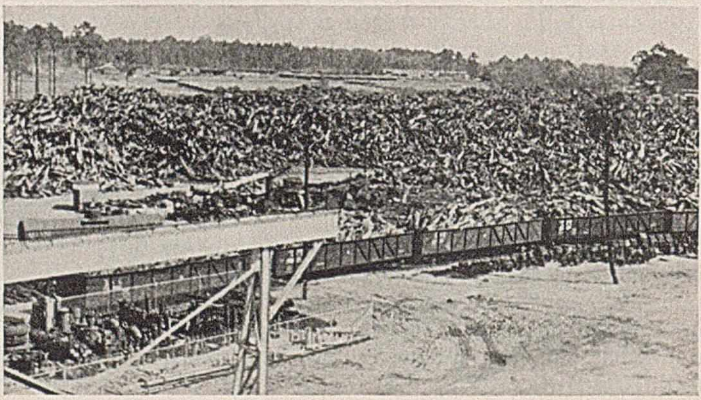






HERCULES POWDER COMPANY Inc.
HATTIESBURG, MISS.
1937





Method	Rosin, Bbl.	Turpentine, Bbl.	Pine Oil, Gal.
Gum	1,833,333	550,000	[a]
Destructively distilled wood	[b]	51,000	4,729,587
Sulfate	23,000		
Steam and solvent wood	805,000	136,000	
Total	2,661,333	737,000	4,729,587

[a] Not produced by the gum process.
[b] Not produced by the destructively distilled process.

What are these methods? Briefly, the gum process utilizes the oleoresin of living southern pines. Turpentine is obtained from this liquid by distillation, with rosin the residue. The destructively distilled method produces turpentine, pine oil, pine tar oils, pine tar, and charcoal, but no rosin, by furnace baking or retorting of cut lengths of dead wood. Sulfate naval stores are by-products of the sulfate pulping process of the paper industry. The method involves the cooking of the chips in an alkaline solution. Turpentine is recovered from the vapors; the rosin later is difficultly refined from the "curds" of the remaining liquor. The fourth process, the steam and solvent method, was invented in 1906. It consumes shredded wood of southern longleaf pine stumps and produces pine oil, turpentine, and rosin. It is in this latter method that we are interested.

It is interesting to touch on the origin of the steam and solvent process. From 1900 to 1910 the Federal Government repeatedly urged inventors and capital to find new sources of naval stores because it was greatly feared that the expected depletion of virgin longleaf stands in the South by lumbering and poor turpentine practices would soon seriously affect production. The Department of Agriculture and other government agencies helped to keep this fear alive, not only in that period, but later during the next decade. Would America lose one of its long-held world-wide markets? Not if American ability could help it, was the answer of private enterprise! Developments were launched all over the country; companies were organized by the dozens for the production of naval stores from the down wood and stumps which cluttered southern cut-over lands. All were destined to fail because of their inefficiency and their inability to make a profit even with generally satisfactory prices. The turpentine price drop in 1909 administered the final blow.

Up to 1910 the naval stores industry was usually referred to as the turpentine business, for outside of truly naval stores uses, rosin was of little value. Many years earlier it actually had been run into streams or into holes dug in the ground which later were searched for and "mined." Rosin once was considered a rank adulterant in varnish; but beginning with the 1910 decade industrial uses began to be found for it, and from then on we might more correctly refer to the industry as the "rosin business."

One of the methods which showed some promise during the 1900–10 period was a straight steam-distilled process which produced no rosin. From it, only turpentine and pine oil, then considered mainly a medicinal product, were made. Plants using this process failed along with the others in 1909. In 1906 a process involving steam distillation was evolved which did recover rosin. It was called the "steam and solvent method" and was invented by Homer T. Yaryan, of Toledo, Ohio. He built a plant at Gulfport, Miss., in 1909 and produced 14,307 round barrels of rosin in the 1909–10 12-month season.

This plant, the mother of our present steam and solvent industry, had an initial capacity of 100 tons of wood a day. Besides the rosin it produced that year, it also made 1700 barrels of turpentine and 25,000 gallons of pine oil. Although other experimental wood naval stores plants were operating prior to 1909, they all failed, and the Yaryan plant and the Yaryan process were the sole remnants of the attempts to bolster the supposedly diminishing gum naval stores industry.

The Yaryan organization constructed another plant at Brunswick, Ga., in 1911 with a daily wood capacity of 300 tons. The two plants in the 1912–13 season produced 98,000 barrels of rosin and 15,000 barrels of turpentine, besides pine oil which then had practically no important outlets of consumption.

In 1913 another drop in turpentine prices closed these two plants, but they were reopened in 1914. In the following war years much attention was paid to this process, for the demand on Southern timber had again aroused the old fear of exhaustion of gum-producing trees.

HERCULES ENTERS THE INDUSTRY

Seeking a place to utilize its excess chemical facilities and armed with latest congressional and trade-investigating organizations' reports, Hercules Powder Company in 1919 studied the possibilities which existed in the steam and solvent phase of the naval stores business. This was not the company's first contact with the industry, for its explosives department had sold dynamite for stumping purposes in the naval stores area for several years. However, it was the chemical possibilities of the industry, not the stump blasting phase, that attracted Hercules in this instance.

Deciding that government findings were right and that the steam and solvent naval stores process would become a good chemical investment, Hercules purchased the Yaryan interests in 1920 and built a third plant at Hattiesburg, Miss. Before the latter could start operations, another break in prices occurred, so not until 1923 did that plant enter production.

To add to Hercules' price woes, it soon became evident that the gum industry, instead of dying a lingering death, would recover with an overproduction bang. Second-growth slash pine, which had seeded itself in cut-over areas, had reached tapping age. This fast-growing, easily seeding tree proved to be the salvation of the gum industry, for it was found to produce in quantity and quality an oleoresin equal to that of the longleaf type. Inroads by substitutes into avenues of consumption long considered naval stores' own commenced to shrink naval stores markets. Increased production in other countries also in-

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Illustrations, page 586, reading from left to right

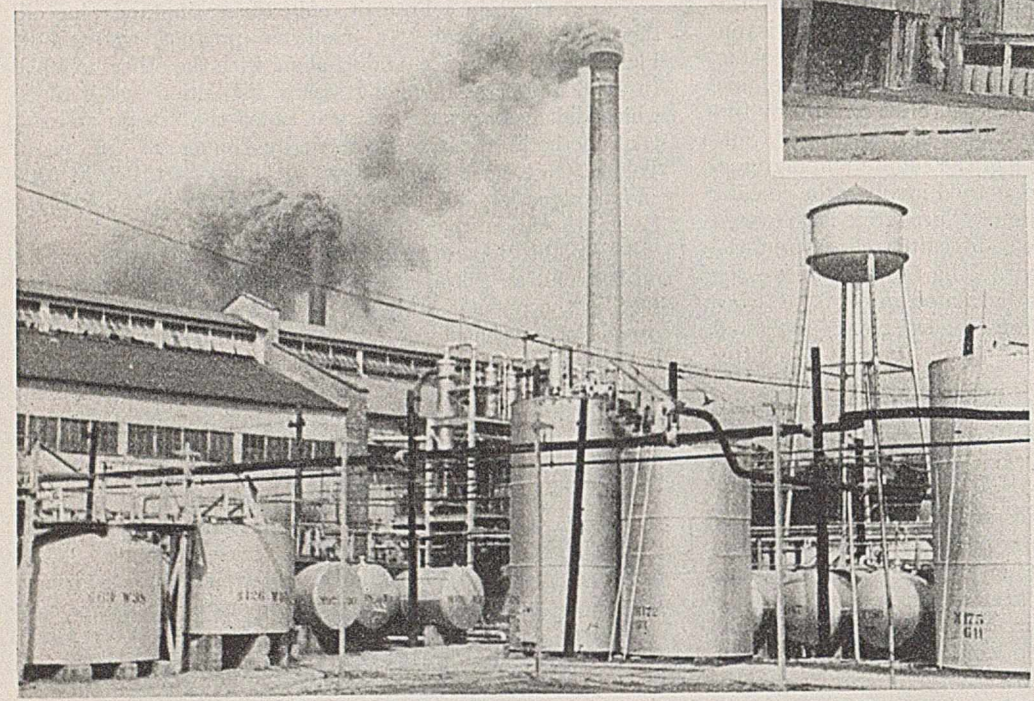
Top row: Giant tractors drag out intact the stumps to be used in the steam and solvent process. No lurking stump escapes these grovels on the stump puller's "nutcracker."

Second row: Stump wood receives a mechanical baptism at the head of the mill room where a huge orange-peel grapple dumps onto chain conveyors. In early days, mule-power brought the wood to railheads—slow, especially in bad weather.

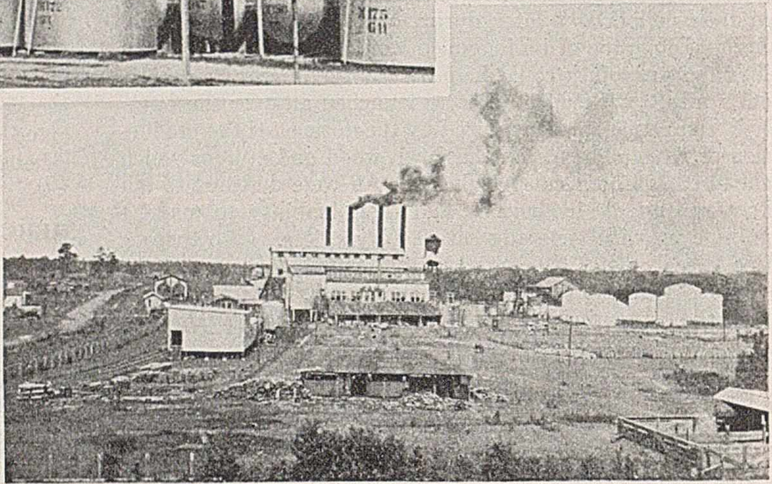
Third row: Fire prevention and plant safety methods developed this fireless plant locomotive which fills its boiler stomach every six hours from a steam pipe. Wood at Hattiesburg is bought from contractors and farmers; this farm cash crop is entering the plant.

Bottom row: At railheads today hoists dump baskets of wood, formed by cables, in open gondolas; the trucks are designed with double tires for better traction in muddy acres. To assure customers of an uninterrupted supply of products, vast reserves of stump wood are maintained at the plants.

(*Right*) Modern in 1916, this rosin refinery represented the best in the industry.



(*Left*) The Hattiesburg rosin refinery where chemical and mechanical control produce "tailor-made" products from the crude rosin base.



(*Right*) Early view of the Yaryan plant at Brunswick, bought by Hercules in 1919.

(*Left*) The modern Brunswick plant presents a great contrast to its early appearance.

creased the grief of American gum producers and similarly affected wood naval stores.

Such was the situation Hercules faced in 1921. No encouragement was derived from persons within or without the industry, including the same government agencies that had sponsored the development of the wood naval stores industry. Said one representative: "The present conditions in the softwood distillation industry do not hold out a large measure of promise for the future." And another: "The industry is characterized by a large number of commercial failures due to fluctuations in market conditions and mistakes in both chemical and commercial aspects." Another comment was: "The development of the industry will require very large capital expenditures, certainly without immediate return, and with little chance of a fair ultimate return unless investment in physical properties is followed by chemical research on a scale few companies are equipped to undertake."

That last statement was something for Hercules directors to mull over, but it did not frighten them. Accepting the challenge, Hercules proceeded on its twenty-year battle to put chemistry into the steam and solvent naval stores industry.

The development of the steam and solvent wood naval stores industry has proceeded in approximate periods of ten years. 1909 saw the completion of the Yaryan plants. Then followed a decade of operating experience, indefinite sales expansion, and gradual acknowledgment that the products of this wood process must receive the benefits of chemical research and process refinement in order to live. From 1920 to 1930 was a period during which Hercules made outstanding progress in wood-gathering methods, in process advancement, in development of consumption channels, and in product improvements. The 1930's have seen the research and operating fruits of the previous decade satisfactorily applied, and it can now be said that Hercules steam and solvent naval stores products have arrived chemically and commercially.

The accomplishments of the past twenty years are of interest industrially and socially, as well as chemically, for all phases of the business received thorough attention. Personnel relations, for example, were of as much importance to the company as were some of the purely technical problems Hercules faced. These different divisions of work, however, will be discussed separately to mark more clearly the work accomplished. We'll start with the source of steam and solvent naval stores.

JOBS FROM WASTE

In 1921, after the completion of the Hattiesburg plant and before the closing of the old Gulfport unit, the daily wood capacity of the two, plus that of Brunswick, was 630 tons. Today it is about 1300 tons, a sizable amount of wood to gather when one considers that it is shipped to the plants from points as far away as 125 miles. This does not imply that the supply of wood is becoming scarce, for today sufficient stump supplies exist to run the industry for many years.

Twenty years ago this did worry investigators of the steam and solvent process. In a Department of Agriculture report, it was urged that developers of the method consider the construction of semiportable processing plants which could be moved from point to point in the stump areas so as to be nearer the sources of supply. To do so was tempting to early producers, for freight rates and other handling charges were very high. However, the need for quantity production in large unit plants eliminated that possibility; instead, Hercules tackled the problem from the other end by devising more efficient wood gathering methods.

The stumps, which constitute the "feed" for Hercules steam and solvent plants, are found in the vast cut-over lands of Mississippi, Georgia, and Florida. These remnants of lumbering are not useful until ten to fifteen years after cutting. By that time the bark has sloughed off, leaving the heartwood in which the resinous material is concentrated.

At the Hattiesburg plant, stumps are purchased from farmers and shippers who bring their loads of wood direct to the plant. The raw material for the Brunswick unit is gathered mostly by company crews who clear cut-over lands by lease arrangement with the owners. This is chemurgy in the true sense for it utilizes a waste product of the land and creates a cash crop for farmers. Last year at Hattiesburg alone, $550,000 worth of stumps were bought. Such clearance puts back into production for farm land, for second growth timber production, or for grazing, an average of 125,000 acres annually. In this connection, the comment of the Secretary of Agriculture in 1920 is interesting: "The development of the steam and solvent process will result in increased farming acreage and will help to lower the cost of living. It should be encouraged by all."

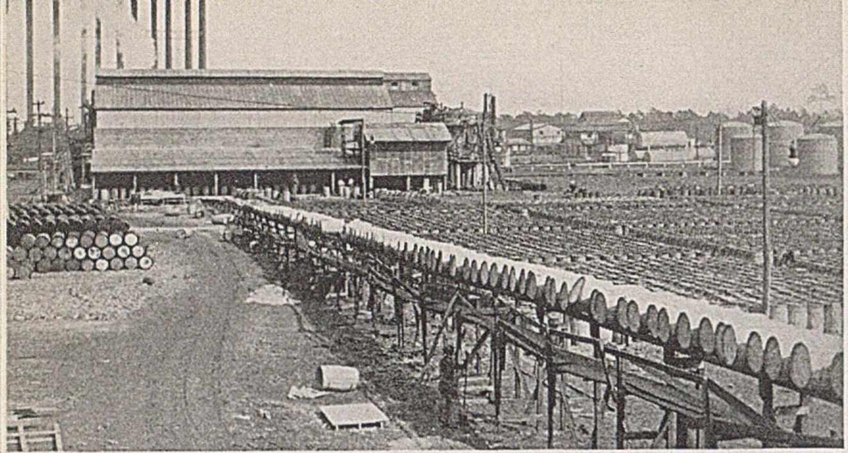
Originally, stumps were pulled by mule-power or blasted with dynamite. They were gathered together and hauled by team. With increases in stumping costs, and in lease rights and freight rates, and greater distances to the plants, it was necessary to do yeoman work in lowering costs and increasing efficiency. Today that phase of the business is like a streamlined train in comparison to 1921 methods. The stumps are now pulled by large tractors adapted to the job. After caterpillar tractors gather them into groups and the larger stumps are split by dynamite and trimmed to facilitate handling, the pieces are loaded on trailer trucks which haul them to railheads from whence the cars are shipped to the plants.

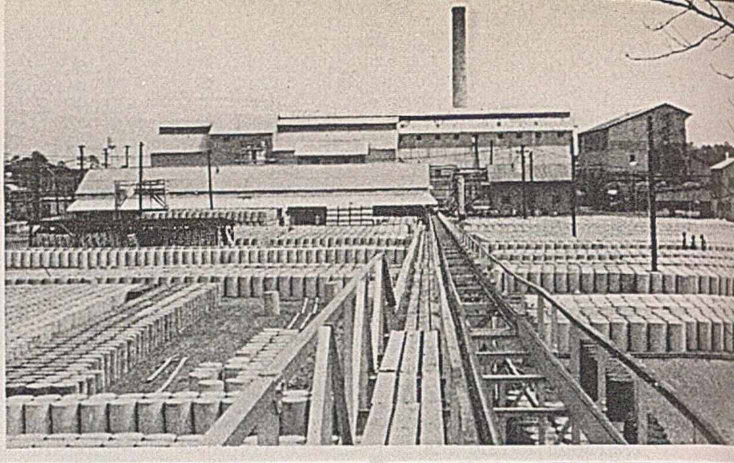
Besides the resulting reduction in stumping costs and the assurance that greater distances of stumping areas from the plants would not disturb the procurement of a steady supply of wood, the present highly efficient wood gathering method has made more continuous the work of woods camp employees. Adverse weather conditions now have little effect on operations, and even extended rainy periods do not entirely close down work.

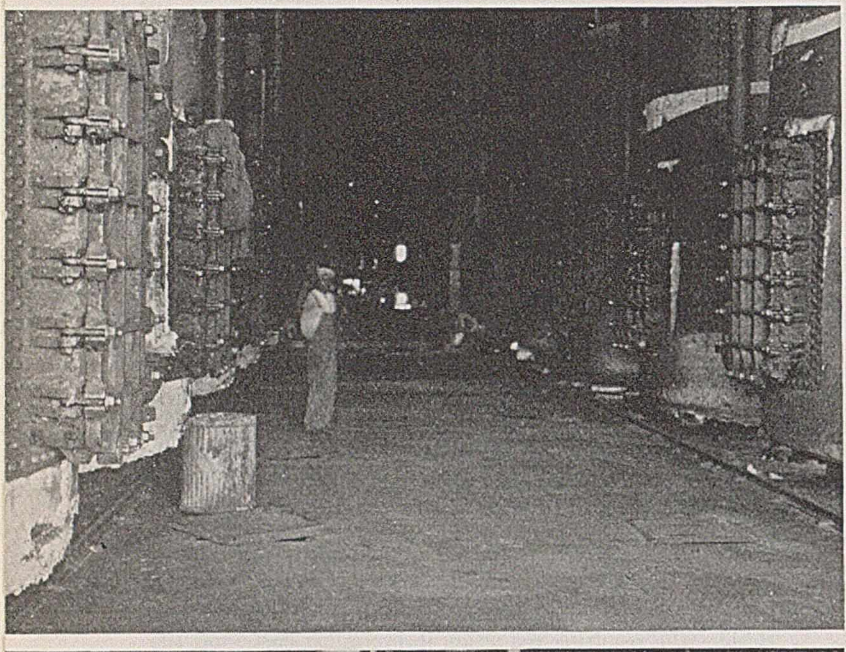
Some of the innovations and changes for the better, effected by Hercules over original methods in wood gathering, include the change from mules and tram roads (for transporting wood to railheads) to trucks properly equipped to travel over open fields in most kinds of weather. Also the development of mechanical stump pullers which can travel easily through the cut-over lands removing whole stumps, an improvement over the previous method of blasting which left half the stump deep in the ground. Another change was the use of mechanical cranes for loading stump wood onto truck trailers. Caterpillar tractors were also utilized instead of teams for gathering of pulled stumps into "groups" for splitting and trimming. Originally wood was loaded by hand at railheads into box cars. Now, large cranes swing bundles of split wood into gondolas of 30 tons capacity.

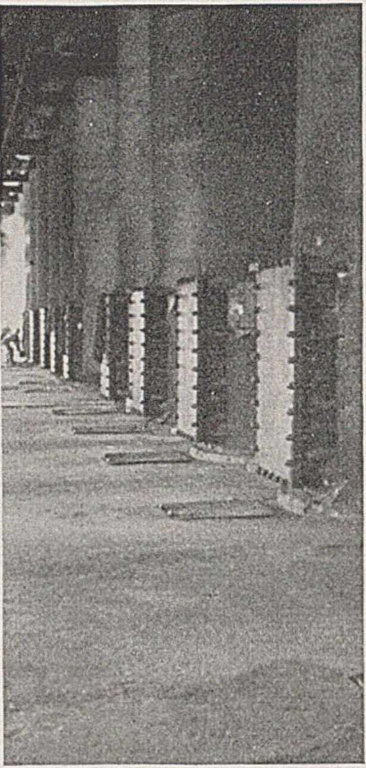
Arriving at a plant, the long trains of gondolas are shifted to reserve stock pile areas or direct to the plant mill room. In the latter instance huge grab bucket unloaders swing the wood from cars onto a traveling chain conveyer which transports the feed to the mill room. This system, only recently installed, is a great improvement over the slower, dangerous method of hand unloading.

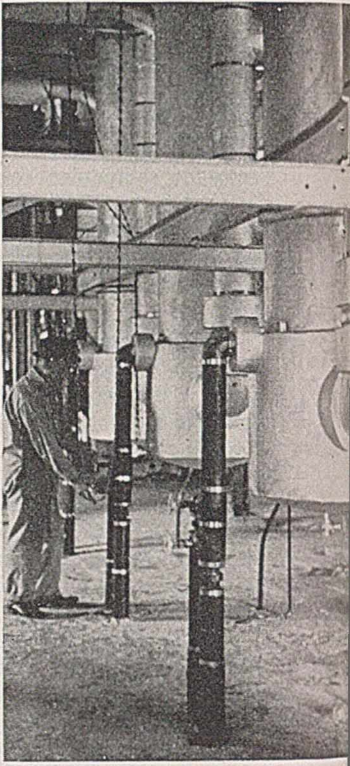
A big impetus was given to the wood naval stores business by the development of a satisfactory "hog" for the reduction of stump wood to properly sized pieces for processing. This hog followed by a shredder now devours irregularly shaped pieces of wood 8 feet long and over a foot thick with no difficulty. The mill

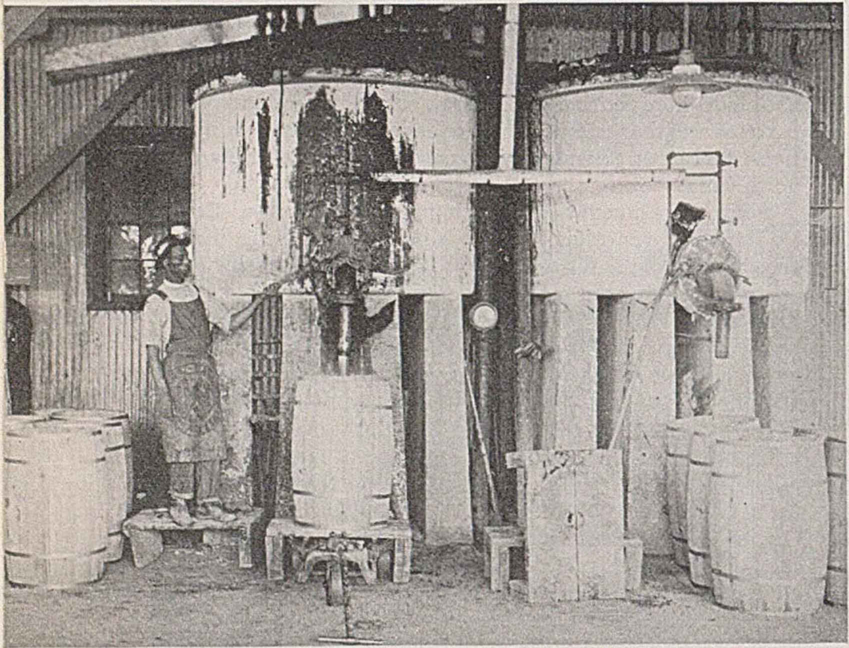


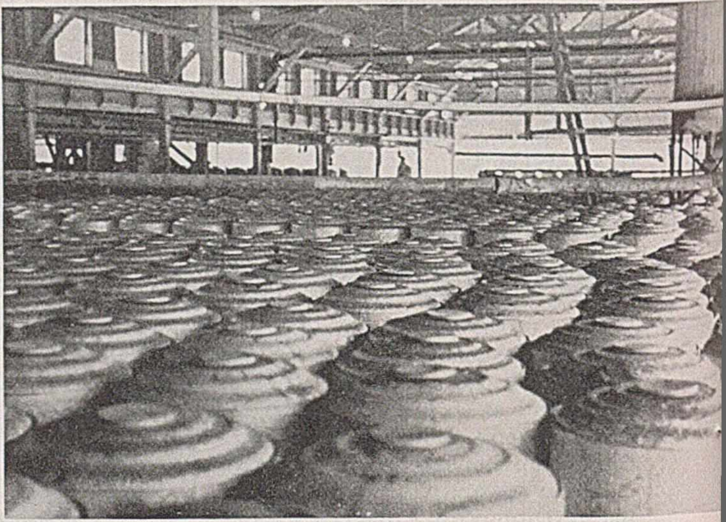


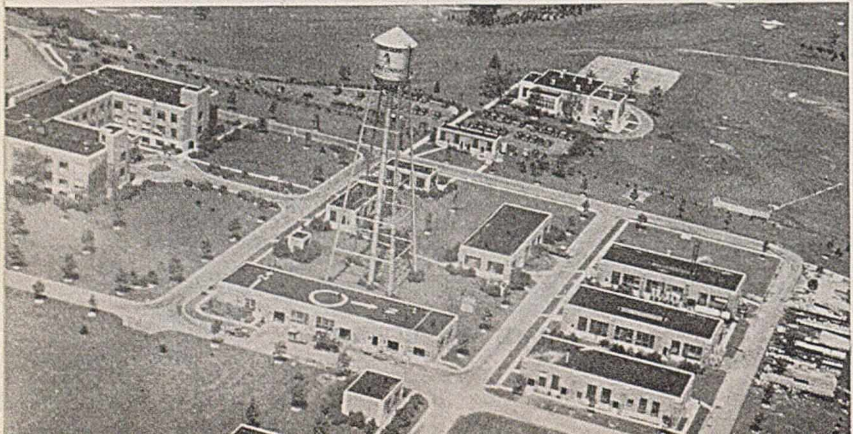












rooms of the Hercules plants are marvels in mechanical handling of stump wood. The latest in screen sizing, conveying, and belt weighing are installed. Magnetic "eyes" for the detection of pieces of scrap iron are utilized. These eyes automatically reverse conveyors on which scrap is detected, discharging the offending metal onto a reject pile.

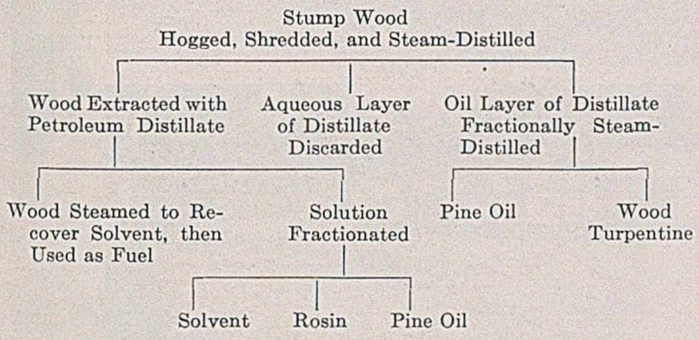
1921 PRODUCTS UNSATISFACTORY

Let us review the status of steam and solvent naval stores products in 1921. There were only the three materials available—rosin, turpentine, and pine oil. Practically no research had been carried out to determine what chemicals could be made from them. In fact, conditions governing their characteristics—and these were mostly bad—were little known. Little hope was held that much could be done to bring wood products into competitive range with gum or with the increasing number of chemicals that were competitively entering gum naval stores fields. A 1921 commentator said: "Wood rosin is generally E or F in color, which for most purposes is equal to gum of similar or lower (darker) grades. Wood rosin has a characteristic reddish or ruby color; when submitted to high temperatures, it darkens somewhat more than gum and, therefore, is inferior to gum of equal grades."

A government representative reported in 1920: "I hope the industry may improve the process to make H, to make rosin harder, and to eliminate viscous matter from it. On pine oil I hope the mineral oil can be removed and that the color can be improved to at least a straw color."

Hercules Power Company's research job was easily defined in 1921, for all that was necessary in framing a program was to assemble the long list of objections potential customers had to these so-called substitutes for gum products. As compared to the same products of 1910 plant days, the materials were better, but only slightly so, and little chemical or physical improvement had been effected.

The process in 1919 followed closely that used from 1910. As a matter of fact, today's method is little changed in principle, though it is greatly different in equipment and control. The method used in 1919 was briefly as follows:



Yields did improve through the years, as indicated by the following estimates of production per ton of wood:

	Before 1919	1921	1938
Rosin, lb.	185	225	370
Total crude oils, gal.	6	7.5	14.0

TREMENDOUS PROGRESS MADE

The present method includes many far-reaching improvements in both the mechanical and chemical phases of the process. These resulted from the years of intensely concerted work of the company's research, technical service, and operating staffs. Millions of dollars in direct research were expended partly in the main experiment station (first at Kenvil, N. J., and later at the new one near Wilmington) and at the plant testing laboratories where much of the work was done.

Some of the achievements in plant design and process should be mentioned here. For instance, in the extractor house simultaneous extraction of both turpentine and rosin with a solvent was developed. Heretofore we steamed for turpentine and then leached out the rosin with a solvent. In the refinery a partial separation of oils was effected by sending them through a packed tower without re-evaporation. By providing a better vacuum in the process, improved products were obtained. Of great importance was the Hercules design of vertical evaporators for taking rosins down to dryness.

In the still house, fractionating columns, operating under various degrees of pressure and vacuum, were developed to displace the older pot stills. This made possible a clean separation of variously desired cuts. With this facility came a large number of special products which formerly were not available, such as anethol, dipentene, and pinene. One of the greatest achievements was the treatment of turpentine to remove its objectionable odor.

These and other important developments widened the markets for Hercules steam and solvent products. Many were distinctly Hercules contributions to the science of naval stores chemistry, with each extending the naval stores market and adding to employment in the South. It should be emphasized that these transitions from the original method increased the smoothness and control of the process and made it approach more closely one of continuous operation.

Not all of the progress Hercules was called on to make was in manufacturing. Probably the biggest obstacle faced in 1919, and the most disheartening, was the poor standing of wood naval stores in the markets. Buyers considered that the quality of the rosin, turpentine, and pine oil was too low to interest them. The markets, therefore, were greatly restricted and this prejudice against wood rosin and wood turpentine stood for many years. Pine oil was still considered a new product for which there was little use.

* * *

Illustrations, page 590, reading from left to right

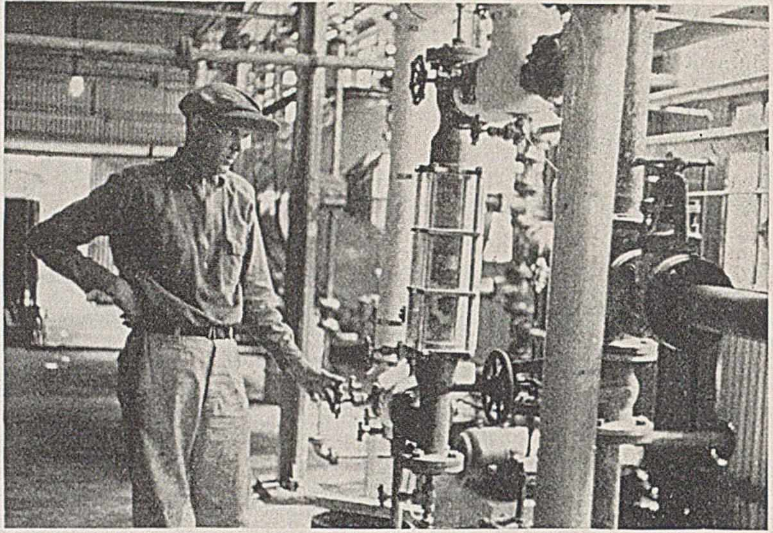
Top row: Rosin-loading end of Brunswick in the early twenties. With chemical progress came plant improvements; note that wood barrels have been replaced by steel "single trippers."

Second row: Shredded wood from the mill room is charged into tall extractors where the steam and solvent process works on the ingredients; this is an old type of extractor. The extractor building at Brunswick now uses these stream-lined units. Modern apparatus in the Brunswick refinery evaporates the rosin solution.

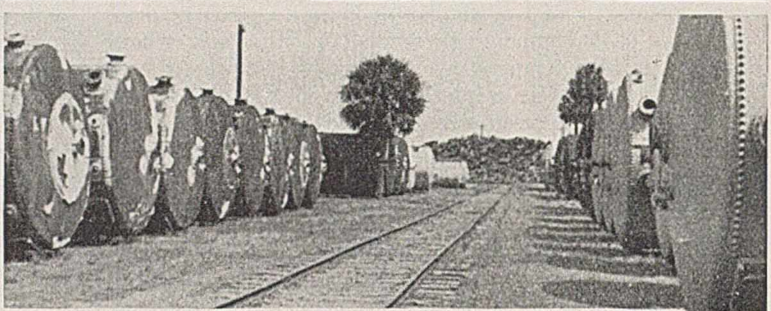
Third row: When the industry was young, this is the way rosin was loaded. In the modern plants, steam-heated channels lead the rosin stream to loading points; the rosin-loading arm crosses the picture above the steel drums; the heads of these drums will be pressed flush after their rosin charges cool.

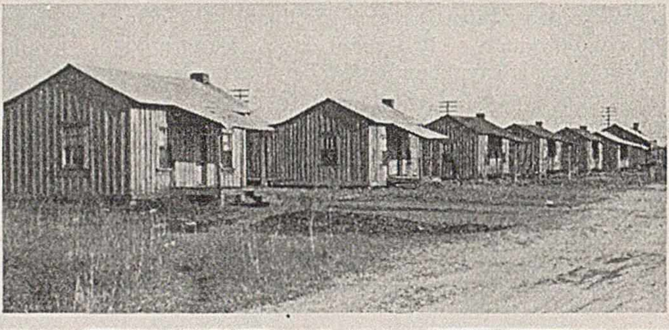
Bottom row: The Hercules Experiment Station near Wilmington, Del., is headquarters for naval stores research and technical service to customers, although much of the progress in process and products development has passed through the plant laboratories (at right).

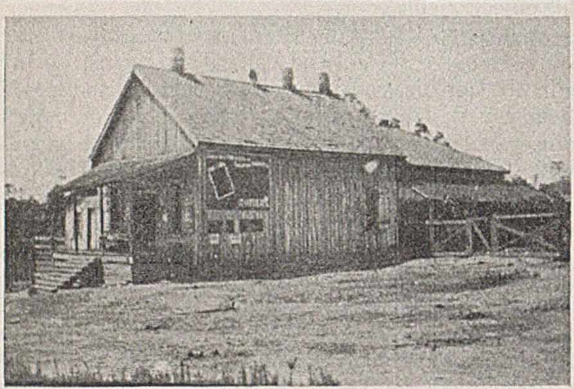

ROSIN
ROSIN

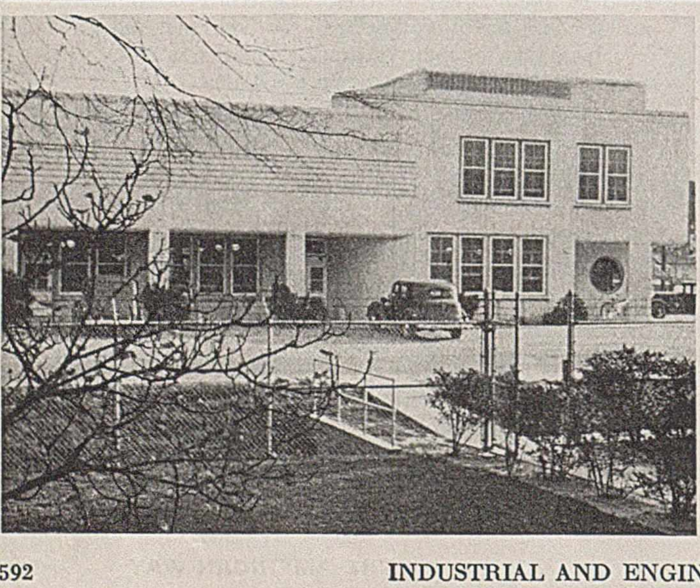


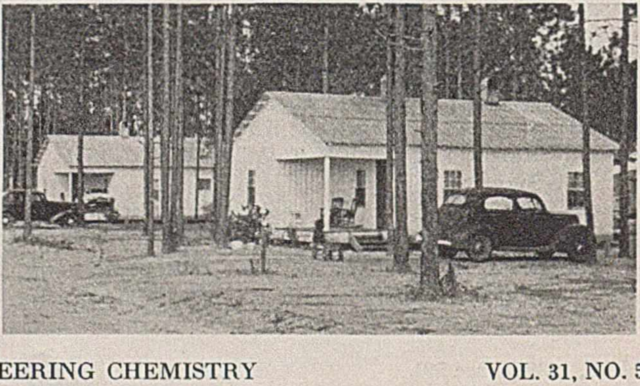

SOAP MANUFACTURE—The clearness, uniformity, and inherent brightness of color of HERCULES PALE WOOD ROSINS are properties which enable the soap maker to obtain the most satisfactory results.
PAPER—Excellent sizing qualities are being obtained with HERCULES PALE WOOD ROSINS
HERCULES PALE
MISCELLANEOUS
WOOD ROSINS











There was justification for the buyer's attitude toward the products derived from pine wood by the steam and solvent process in 1920. The rosin was dark red and varied greatly in color, melting point, and solubility. Because of its dark color its use was restricted. Its low and uncertain melting point limited or prohibited its use in many industries where dark rosin could be utilized. Its tendency to crystallize and precipitate when dissolved in petroleum oils and vegetable oils likewise decreased its use. As a result of unsatisfactory trials with FF wood rosin, many industrial consumers of rosin objected to all wood naval stores. The prejudice persisted for many years.

Steam-distilled (steam and solvent) wood turpentine in 1920 was a poorly refined distillate with a strong penetrating odor and a variable and uncertain distillation range and volatility. Many industrial consumers refused to recognize it as turpentine, insisting that it was turpentine substitute. It did have the advantage of strong solvent power which led to its use as a paint and varnish thinner. However, the strong odor and uncertain quality of steam and solvent wood turpentine in that period caused many industrial consumers to prohibit its use in their products.

Steam-distilled pine oil was a true child of the steam and solvent process for recovering naval stores from pine wood. It had not been available before this method came into being, for it is not obtained from the older gum naval stores process. In 1920 pine oil was to a large extent a straight-run distillate; no attempt had been made to fractionate or to purify it to meet certain industrial requirements. It was a new product for which only a few markets had been developed.

Some of the problems Hercules faced and the objectives which had to be reached to justify the company's entrance into the wood naval stores industry have been recited. These embraced three main objectives: (1) improvements in the basic process for deriving wood rosin, wood turpentine, and pine oil from pine stump wood; (2) improvement in the quality of the basic products to enhance their commercial value; and (3) market research and sales development to create and extend commercial outlets. To put it more simply: we had to improve the quality of rosin, pine oil, and turpentine; and markets for pine oil had to be developed.

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Illustrations, page 592, reading from top to bottom

Left: Before Hercules' production of pale wood rosins, this F grade represented approximately the best wood rosin available; today the finest, X, is produced. Not nearly the best, this block of N wood rosin denotes the improvement which the pale wood process made in the F grade. This commissary in ol' Miss' served its purpose in the days when the naval stores industry was mostly selling "turps." At Hattiesburg is Hercules' modern company store and clubhouse.

Right: In the manufacture of pale wood rosin, this type of floating valve measures the flow of an ingredient. Obsolescence in the chemical industry is both a bugbear and a blessing; this scrap pile at Brunswick denotes greater yields, better products. When these cabins were built by Hercules in 1920 they represented a real advance in camp housing. Hercules' "White cities" the natives call them. This is one of the company's new camps where running water, electric lights, playgrounds, and modern bath and toilet conveniences are provided. Two units of one of Hercules' movable camps.

RESEARCH AS THE KEYSTONE OF IMPROVEMENTS

Research directed toward improvement of the process has brought about steady progress. The installation of the fractionating stills of special design by Hercules engineers resulted in a marked improvement in steam-distilled wood turpentine. Today the crude turpentine is fractionated to yield a high-quality product that has gained world-wide acceptance in practically all consuming industries. It possesses a pleasant, mild odor, and is uniform in quality. Special treatment of the crude distillate, as well as changes in the method of extraction, aided in bringing about these improvements.

With better methods of extraction and distillation, several new products derived from crude turpentine became available. A high-quality dipentene fraction has found wide acceptance as a special solvent and thinner in varnishes and enamel paints. It also enjoys considerable application as a raw material for synthetic resin manufacture. Other terpene hydrocarbons derived from the crude turpentine are separated and used as one of the essential raw materials for the manufacture of "Petrex",[1] a synthetic resin base developed by Hercules chemists. Other fractions find application in the reclaiming of rubber, for solvents, and in disinfectants. More recently the preparation of high-grade alpha-pinene for the manufacture of synthetic camphor has been accomplished, and sales to leading manufacturers here and abroad testify to its excellent quality for this purpose.

Pine oil has been similarly improved by means of fractionation and changes in plant processing. Special pine oils are now available with superior color, odor, and other characteristics as required by various consuming industries. High-quality alpha-terpineol is now obtained by fractionation and chemical treatment. Special pine oils, high in terpene alcohols, find use in numerous industries.

ROSIN DEVELOPMENTS

The development of a process for the manufacture of pale grades of wood rosin is one of the outstanding achievements of Hercules chemists. By means of differential solvents, this pale rosin was produced which was superior to the old grade of rosin once thought to be the best obtainable from wood. This process is particularly interesting because it is believed to be the first application of the principle of differential solution to the purification of low-price chemically intricate materials. This new wood rosin was not only pale in color but was devoid of many other defects which had been associated with prior wood rosin and which had previously limited the market for that product. Contrary to the old wood rosins, these pale grades actually bleach upon heating. When the announcement was made of the availability of this new type of wood rosin, Thomas Gamble, editor of *The Naval Stores Review*, wrote: "The manufacture of this new grade of wood rosin is regarded as the most important development since wood rosin came on the market in 1910."

This development greatly extended the fields for wood rosin so that today the major portion of Hercules wood rosin finds outlets where the FF wood rosin of 1920 could not possibly be employed. With the development of this process of making pale wood came the production of a dark resin known as "Belro."[1] This, too, enjoys applications in specialized fields for which the original FF rosin would not have been suitable. More recently the perfection of a process for manufacturing hydrogenated rosin was accomplished after years of research by Hercules chemists and engineers. This product is far superior to rosin in resistance to oxidation, retention of color, and chemical stability. It is going into fields where rosin is not employed and is thus further extending the market for naval stores.

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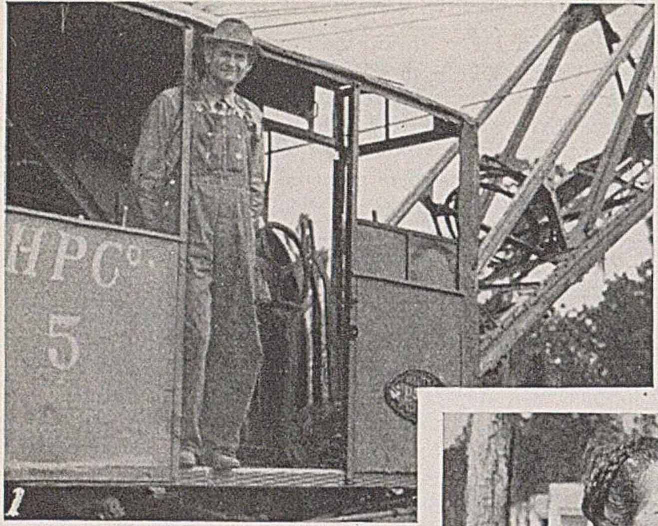
[1] Registered U. S. Patent Office by Hercules Powder Company.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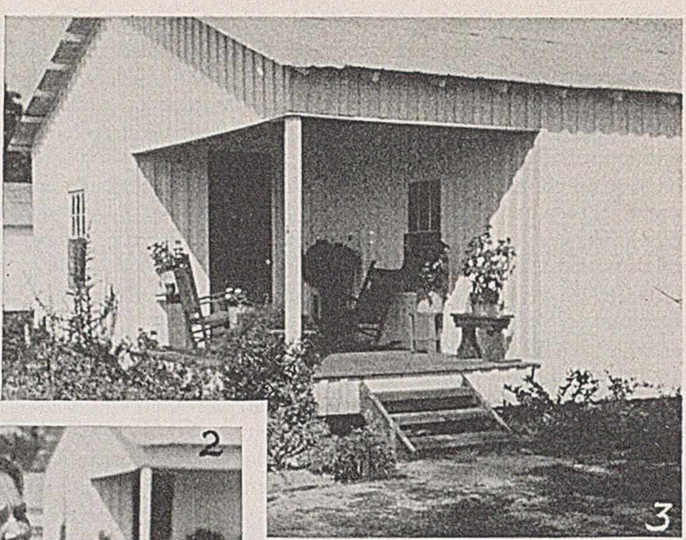
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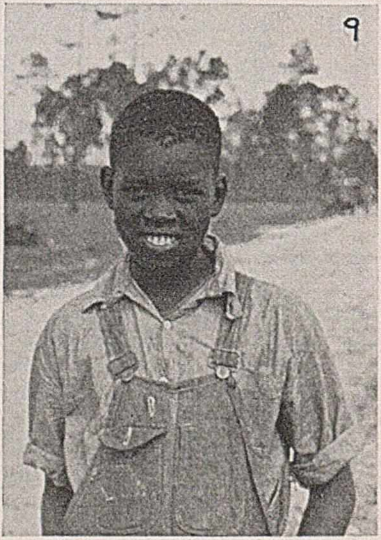
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Great strides have been made in developing uses for naval stores products by means of sales research and sales service, for this phase of the problem was of paramount importance. This work embraces advertising, technical assistance to consumers, and consumer research. By this means Hercules developed the present market for its turpentine through distributor, jobber, and dealer channels to the ultimate consumer. Advertising, technical, and sales assistance, and direct contact with consuming trades were successful in overcoming the resistance of many important consumers resulting from the poor quality of steam-distilled wood turpentine of 1920. It was in this effort that packaged turpentine in small containers was first offered for sale to consumers.

Finding markets for pine oil presented a real problem since this product had relatively few established outlets when Hercules entered this field. By direct contact with potential consumers, chemists studied industrial possibilities, and with this knowledge, special pine oils were prepared to meet specific requirements. As a result, diversified markets for pine oil were developed in textile chemicals, flotation oils, essential oils, disinfectants, detergents, insecticides, etc. Research fellowships at leading technical institutions provided a fund of information that not only assisted in establishing new uses for pine oil, but served as distinct contributions to technical improvements in these industries.

Much the same approach has been used to advance the sales of wood rosins and related resins. Direct sales service to the consuming trades resulted in the acceptance of wood rosin in many industries where, because of previous prejudice or technical difficulties, wood rosin was formerly prohibited. Today, Hercules rosin enjoys world-wide acceptance in the major rosin-consuming industries, a position gained only because of the improvement in color, solubility, odor, melting point, and general chemical purity.

"Vinsol"[1] resin is another product derived from pine stump wood exclusively by Hercules which is fitting into an ever-widening field of industrial application. Its low price, large volume, and suitability for purposes entirely outside of the usual range of rosin make it one of chemistry's most potentially important raw materials. Technical sales representatives are rendering valuable assistance in adapting it to the needs of consumers in places never thought of before as important outlets for naval stores.

PERSONNEL ACCOMPLISHMENTS

In personnel relations work the company has also made progress. One phase of this activity included the housing of woods crews. The woods camps built in 1920 do not stand comparison with today's construction, but they were a great improvement over the average housing of the areas in which we operated.

The views of several of the present woods camps in which Hercules company members live who are employed on wood gathering operations, testify to the advancement made. It should be remembered that these camps have to be movable, and that in no case can they become permanent camp sites. Nevertheless, they provide employees with most conveniences. Busses transport the men to work and their children to schools. In the newest camp cottages are provided with running water and electric lights, and many have bath and toilet facilities. The rent for these houses is at the monthly rate of $2.00 a room or $8.00 for a four-room cottage.

Medical service in most places is difficult to obtain, but in Hercules camps the company provides medical care for each man and his family at $2.00 a month. This service has been available for ten years.

The company offers all employees group accident and sickness insurance at a great saving. It is a point of outstanding interest that 82 per cent of the woods camps personnel have subscribed. Life insurance also is provided at low rates, and this is subscribed to by 20 per cent of the employees on wages.

Bringing our industrial activities into such agricultural districts presented many problems. Turnover is a major labor problem in the southern areas where we operate, but even in the woods camps which often are moved from place to place, 48 per cent of the camp personnel have service records of five years or more. This is eloquent testimony that employees like to be long-time members of the Hercules family.

SUMMARY

Hercules Powder Company looks forward with enthusiasm to the future of wood naval stores. With twenty years of experience and intensive research behind it, the company is in an excellent position to continue its utilization of one of Nature's cheapest sources of organic acids and aromatic hydrocarbons. From these bases it expects to produce additional terpene and rosin derivatives, "tailor-made" for industrial uses.

If there is any merit to be gained for those twenty years of effort, Hercules would wish to claim it on what it has accomplished in producing such tailor-made products. With the completion of its first job, to bring wood products up to gum grades, its second task became the fashioning of these improved materials into diversified and modified forms of industrial chemicals. This treatment is the outstanding development today after centuries of use of these complex compounds in the form in which they happened to occur in nature.

In performing these assignments, Hercules has taken an undeveloped industry and brought it to a high state of chemical perfection. It has given the farmers a cash return for worthless stumps and has conditioned thousands of acres of land for the plow and for second-growth timbering. It has provided steady employment in areas where employment possibilities often are almost totally lacking. Hercules is proud that it did this job in the American Way by itself, without benefit of outside help, and in the face of almost insurmountable handicaps.

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Illustrations, page 594

1. Hercules is proud of this machine expert who has been with the organization for seventeen years. There are three boys in his family, and with the encouragement of father and mother, the eldest is studying for his master's degree in chemistry, the second is a sophomore in college, and the youngest leads his high school senior class in scholarship.
2. The mother is proud of the three boys who have lived most of their days in Hercules woods camps.
3. Mother, father, and three sons call this cottage home.
4. Typical of what Hercules considers its best product!
5. These youthful residents of Hercules' Camp Baldwin thrive in the Florida spring sunshine.
6. Woods camp children go by special busses to schools like this.
7. Starched, ready for the day, is this pensive daughter of a Hercules woods camp employee.
8. They say, "Our husbands work steady for old man Hercules."
9. Some day he'll work for the same company his father has been with for many years.

AEROBIC FERMENTATION

Effect of Glutathione, Cysteine, and Hydrogen Sulfide

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SINCE the isolation of glutathione from yeast and mammalian tissues by Hopkins (*1*), a number of workers have investigated the effect of this and other sulfhydryl compounds on the metabolism of living cells and on the action of a number of enzymes.

Negelein (*2*) reported that hydrogen sulfide will stimulate the aerobic fermentation of dextrose by yeast to the anaerobic level. Quastel and Wheatley (*3*) and Runnström *et al.* (*4*, *5*) reported that cysteine or glutathione will produce a similar stimulation of the aerobic fermentation rate of baker's yeast. In a series of studies on yeast metabolism we have found that the stimulation which has been attributed to cysteine or glutathione is not due to these compounds per se, but to hydrogen sulfide which is formed when either of these compounds is added to a yeast-dextrose solution under certain conditions.

Experimental Method

The experiments were performed at 30° C., with the constant-volume type of respirometer (Warburg manometer); 5 mg. of baker's yeast (moist weight) and 80 mg. of dextrose were used in a total volume of 4 cc. of 0.1 *M* potassium acid phosphate at pH 4.5. The solids content of the yeast was determined in order to report all results on the same unit dry weight of yeast. The flasks used were of about 55-cc. volume and were equipped with two wells and a side arm. The carbon dioxide was removed, and the oxygen uptake was measured by placing 0.4 cc. of 20 per cent potassium hydroxide in one well with a paper roll; the hydrogen sulfide formed was absorbed by placing 0.4 cc. of 20 per cent lead nitrate solution in the other well with a paper roll. The figures given for fermentation carbon dioxide in Table I represent the difference between the total carbon dioxide produced and the oxygen uptake, or respiration carbon dioxide.

TABLE I. EFFECT OF HYDROGEN SULFIDE, CYSTEINE, AND REDUCED GLUTATHIONE ON THE RATE OF AEROBIC FERMENTATION

Control	Total Fermentation CO_2 per Mg. Yeast (Dry Wt.), Cu. Mm. 30 min.	1 hr.	1.5 hr.	2 hr.	3 hr.	4 hr.	6 hr.
Aerobic; no sulfhydryl added	19	39	50	...	81	90	95
Aerobic + Na_2S; $Pb(NO_3)_2$ in well	30	41	...	75	103	126	136
Aerobic + Na_2S; no $Pb(NO_3)_2$ in well	105	229	...	423	611	790	949
Aerobic + 0.1 mg. cysteine; $Pb(NO_3)_2$ in well	8	8	24	...	122	219	326
Aerobic + 0.1 mg. cysteine; no $Pb(NO_3)_2$ in well	34	124	221	...	522	705	924
Aerobic + 5.0 mg. GSH; $Pb(NO_3)_2$ in well	16	40	67	...	159	235	315
Aerobic + 5.0 mg. GSH; no $Pb(NO_3)_2$ in well	20	81	184	...	473	652	828
Anaerobic (in N_2); no sulfhydryl added	121	249	360	...	687	865	1028

The effect of hydrogen sulfide on the aerobic fermentation of dextrose was studied by placing 1 cc. of sodium sulfide solution, calculated to evolve 15.7 cu. mm. of hydrogen sulfide at 30° C., in the side arm of the Warburg flask. After a mixing and equilibration period of 20 minutes, the stopcocks were closed and the sodium sulfide solution was tipped into the yeast–dextrose–potassium acid phosphate mixture. The final volume of liquid in the flasks in all cases was 4 cc.

Discussion of Results

Hydrogen sulfide, in the absence of other added sulfhydryl compounds, is shown in Table I to stimulate the rate of aerobic fermentation to approximately the anaerobic level. This confirms a similar finding by Negelein (*2*) and, since this large stimulation does not occur when the hydrogen sulfide is absorbed by lead nitrate, serves as a test of the technique used.

In those cases where cysteine or glutathione was added, an odor of hydrogen sulfide could be detected at the end of the experiment in the Warburg flasks containing no lead nitrate. In those cases where lead nitrate was used to absorb hydrogen sulfide, a definite darkening of the lead nitrate paper was observed. When the hydrogen sulfide is absorbed by lead nitrate, cysteine or glutathione produces only a relatively small stimulation of aerobic fermentation which is far below the anaerobic level. In the case of cysteine there is a decided inhibition of aerobic fermentation during the first 90 minutes of the experiment. However, when the hydrogen sulfide, which is presumably liberated by decomposition of the cysteine or glutathione, is not removed by lead nitrate, aerobic fermentation is stimulated, almost to the anaerobic level.

It is concluded that the stimulation of aerobic fermentation by cysteine or glutathione, which has been reported by others, is mainly due to hydrogen sulfide arising from the action of yeast on these compounds.

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(4) Runnström, J., Runnström, A., and Sperber, E., *Naturwissenschaften*, 25, 540 (1937).
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Problems in Heat Exchange and Pressure Drop

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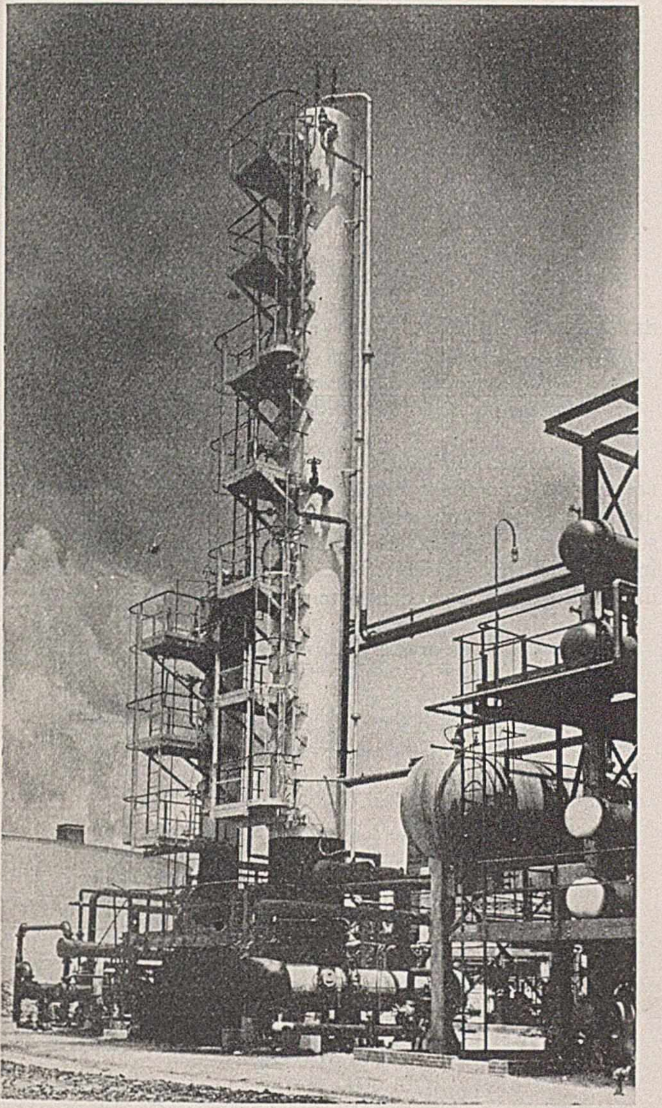
The mathematical treatment of engineering subjects is fast becoming a procedure of industrial importance and is so recognized by many successful industrial executives. The discussion presented here has been prepared as an example of the way in which this treatment may be applied. It is designed to be of value particularly to the executives of the older school who will welcome the opportunity thus to become more familiar with the current mathematical engineering technique.

In order to give examples of the use of important fundamental engineering equations, two problems involving heat transfer and pressure drop are presented. The first covers the design of a double-pipe multitubular exchanger and the calculation of required heating surface and pressure drop; and the second the pressure drop of a gas stream passing through a packed tube.



FRACTIONATING TOWER WITH REBOILER AT THE BASE

OFTEN it is found that important new fundamental engineering equations are presented in the literature for use in design without complete sample calculations or examples involving their use. Such calculations would be extremely helpful to many who, although interested in this type of work, may not be constantly dealing with the specific subject but need at times to apply such methods to a particular problem.

For this reason two typical examples of the application of proposed engineering equations have been made. The first covers the design of a double-pipe multitubular exchanger, including the required surface and the resulting pressure drop on both hot and cold sides; and the second, the pressure drop of a gas stream passing through a packed tube.

Problem I

To cool 2000 barrels (42 U. S. gallons) per day of mid-continent gas oil, of properties (*14*) shown in Figures 1 to 5, from 600° to 200° F. with water entering at 70° F. and leaving at 120° F.:

$$2000 \text{ bbl./day of } 35.3° \text{ A. P. I. gas oil} = 3500 \text{ gal./hr. at } 7.064 \text{ lb./gal.} = 24{,}730 \text{ lb./hr.}$$

Temp. in = 600° F.
Temp. out = 200° F.

$$T_a = \text{arithmetical av. oil temp.} = \frac{600 + 200}{2} = 400° \text{ F.}$$

$$C_a = \text{sp. heat of oil} = 0.659 \text{ B. t. u./lb./° F. (Fig. 2)}$$

$$\text{Cooler duty} = 24{,}730\,(600 - 200)\,0.659 = 6{,}520{,}000 \text{ B. t. u./hr.}$$

$$\text{Water required} = \frac{6{,}520{,}000}{120 - 70} = 130{,}400 \text{ lb./hr.} = 15{,}670 \text{ gal./hr.} = 0.582 \text{ cu. ft./sec.}$$

Assume that design will be of the shell and tube exchanger type with tubes 16 feet long. Assume that steel tubes are

1 inch o. d. No. 14 Birmingham wire gage (0.083 inch thickness):

O. D. of tube = 1.000 in. = 0.0833 ft.
I. D. of tube = 0.834 in. = 0.06945 ft.
Inside cross-sectional area = 0.003786 sq. ft.

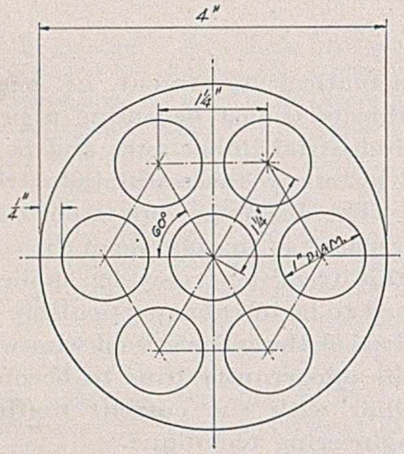
Assume cold oil (60° F.) velocity to be about 5.0 feet per second and seven tubes in parallel:

Total area of 7 tubes = 7(0.003786) = 0.0265 sq. ft.

$$\text{Cold oil velocity} = \left(\frac{3500}{7.48}\right)\left(\frac{1}{3600}\right)\left(\frac{1}{0.0265}\right) = 4.90 \text{ ft./sec.}$$

$$\text{Mass velocity} = \frac{24{,}730}{0.0265} = 934{,}000 \text{ lb./hr./sq. ft.}$$

Assume the following layout:



Using countercurrent flow:

G. T. D. (greatest temp. difference) = 600 − 120 = 480° F.
L. T. D. (least temp. difference) = 200 − 70 = 130° F.

$$\text{Log mean temp. difference} = \frac{480 - 130}{2.3 \log \frac{480}{130}} = 267° \text{ F.}$$

The shell dimensions are assumed to be as follows:

I. D. = 4 in. = 0.333 ft.
Internal area = 0.087 sq. ft.
Free area = (0.087) − 7 [0.785 (0.0833)²] = 0.0489 sq. ft.

$$\text{Velocity of water in shell} = \frac{0.582}{0.0489} = 11.90 \text{ ft./sec.}$$

Method 1 for Required Heating Surface

The first method illustrated will be that proposed by Sieder and Tate (*10*), but the fluid properties will be calculated at the arithmetical average oil temperature.

TUBE SIDE.

T_1 = 600° F.; T_2 = 200° F.; T_a = 400° F.
D = I. D. of tube = 0.06945 ft.
G = mass velocity = 934,000 lb./hr./sq. ft.
μ_a = viscosity of gas oil at T_a = 0.97 lb./hr./ft. (Fig. 3)

$$\text{Reynolds No.} = \frac{DG}{\mu_a} = \frac{(0.06945)\ (934{,}000)}{0.97} = 66{,}900$$

From Figure 6 (Sieder and Tate's Figure 5):

$$\frac{h_1 D}{K}\left(\frac{C\mu_a}{K}\right)^{-1/3}\left(\frac{\mu_a}{\mu_w}\right)^{-0.14} = 190$$

C_a at T_a (400° F.) = 0.659 B. t. u./lb./° F. (Fig. 2)
K_a at T_a (400° F.) = 0.0721 B. t. u./hr./sq. ft./° F./ft. (Fig. 4)

$$\left(\frac{C_a\mu_a}{K_a}\right)^{-1/3} = \left(\frac{K}{C\mu_a}\right)^{1/3} = \left(\frac{0.0721}{0.659 \times 0.97}\right)^{1/3} = (0.1128)^{1/3} = 0.483$$

$$\left(\frac{\mu_a}{\mu_w}\right)^{-0.14} = \left(\frac{\mu_w}{\mu_a}\right)^{0.14} = \left(\frac{\mu_w}{0.97}\right)^{0.14} = \frac{(\mu_w)^{0.14}}{0.996}$$

$$h_1 = \frac{(190)\ (0.0721)\ (0.996)}{(0.06945)\ (0.483)\ (\mu_w)^{0.14}} = \frac{408}{(\mu_w)^{0.14}}$$

Assume U = 150 B. t. u./hr./sq. ft./° F. (based on outside tube area)

$$= 150\,\frac{1.000}{0.834} = 180 \text{ B. t. u./hr./sq. ft./° F. (based on inside tube area)}$$

Assume h_1 = 400 B. t. u./hr./sq. ft./° F.

$$\text{Approx. } \Delta T \text{ across film} = \frac{(267)\ (180)}{400} = 120° \text{ F.}$$

Approx. T_w = 400 − 120 = 280° F.
μ_w = 1.72 (Fig. 3)

$$h_1 = \frac{408}{(1.72)^{0.14}} = \frac{408}{1.079} = 378 \text{ B. t. u./hr./sq. ft./° F.}$$

SHELL SIDE (No Baffles).

$$D_e = 4 \text{ times thermal hydraulic radius} = \frac{4 \text{ (cross-sectional area of streams)}}{\text{wetted perimeter of heat transfer surface}}$$

Some designers of heat exchange equipment do not differentiate between the hydraulic radius and the thermal hydraulic radius in obtaining the equivalent diameter to be substituted in heat transfer equations. Both terms are used in heat exchanger design, the choice depending upon the individual designer's particular method.

Cross-sectional free area of shell = 0.0489 sq. ft.
Wetted perimeter = 7(0.2614) = 1.830 ft.

$$D_e = \frac{(4)\ (0.0489)}{1.830} = 0.1069 \text{ ft.}$$

t_1 (water inlet) = 70° F.
t_2 (water outlet) = 120° F.

$$t_a \text{ (arithmetical av. water temp.)} = \frac{120 + 70}{2} = 95° \text{ F.}$$

K_a (for water) = 0.358 B. t. u./hr./sq. ft./° F./ft. (*5*)
μ_a (for water) = (0.72) (2.42) = 1.743 lb./hr./ft. (*9*)

$$G = \frac{130{,}400}{0.0489} = 2{,}665{,}000 \text{ lb./hr./sq. ft.}$$

$$\frac{D_eG}{\mu_a} = \frac{(0.1069)\ (2{,}665{,}000)}{1.743} = 163{,}300$$

$$\frac{h_2D_e}{K_a}\left(\frac{C\mu_a}{K_a}\right)^{-1/3}\left(\frac{\mu_a}{\mu_w}\right)^{-0.14} = 378 \text{ (Fig. 6)}$$

$$\left(\frac{C_a\mu_a}{K_a}\right)^{-1/3} = \left(\frac{1 \times 1.743}{0.358}\right)^{-1/3} = (4.87)^{-1/3} = \frac{1}{1.695}$$

$$h_2 = \frac{(378)\ (0.358)\ (1.695)}{0.1069}\left(\frac{\mu_a}{\mu_w}\right)^{0.14} = 2147\left(\frac{\mu_a}{\mu_w}\right)^{0.14}$$

Assume h_2 = 2200 B. t. u./hr./sq. ft./° F.

$$\text{Approx. } \Delta T \text{ across water film} = \frac{(267)\ (150)}{2200} = 18° \text{ F.}$$

Approx. t_w = 95 + 18 = 113° F.
μ_w (for water) = (0.59) (2.42) = 1.427 lb./hr./ft.

$$\left(\frac{\mu_a}{\mu_w}\right)^{0.14} = \left(\frac{1.743}{1.427}\right)^{0.14} = (1.222)^{0.14} = 1.028$$

h_2 = (1.028) (2147) = 2210 B. t. u./hr./sq. ft./° F.

Assume that the water is treated. Use a fouling factor of 0.002 on the water side and of 0.001 on the gas oil side (*6*):

$$U = \frac{1}{\frac{1}{h_1} + \frac{1}{h_{s_1}} + \frac{1}{h_w} + \frac{1}{h_{s_2}} + \frac{1}{h_2}}$$

$$\frac{1}{h_1} = \frac{1}{378}\left(\frac{0.0833}{0.06945}\right) = 0.003172$$

$$\frac{1}{h_{s_1}} = 0.001\left(\frac{0.0833}{0.06945}\right) = 0.0012$$

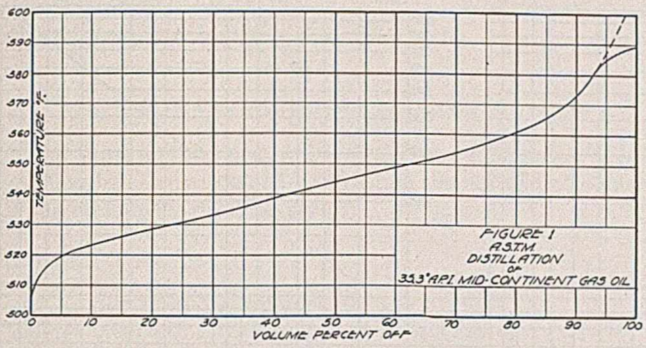


FIGURE 1
A.S.T.M.
DISTILLATION
OF
35.3° A.P.I. MID-CONTINENT GAS OIL

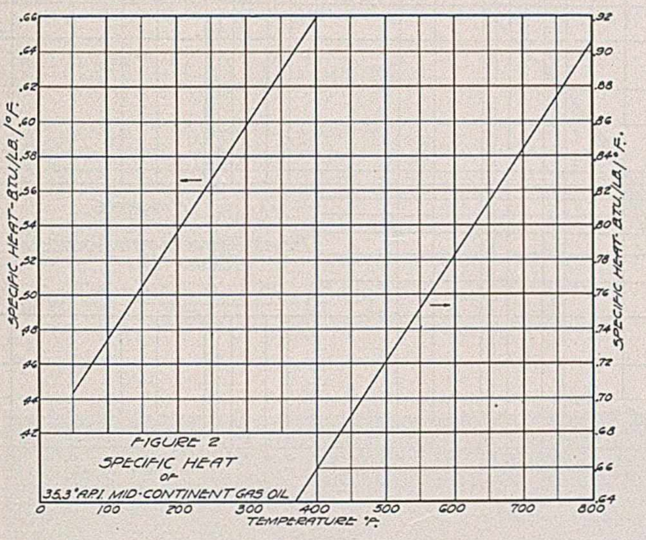


FIGURE 2
SPECIFIC HEAT
OF
35.3° A.P.I. MID-CONTINENT GAS OIL

$$\frac{1}{h_w} = \frac{L'}{K}\left(\frac{\text{O. D.}}{\text{av. } D}\right)$$

$L' = 0.083$ in. $= 0.00692$ ft.

$K = 26$ B. t. u./hr./sq. ft./° F. (*11*)

$$\frac{1}{h_w} = \frac{0.00692}{26}\left(\frac{0.0833}{0.0764}\right) = 0.00029$$

$$\frac{1}{h_{s_2}} = 0.002$$

$$\frac{1}{h_2} = \frac{1}{2210} = 0.000452$$

$$U = \frac{1}{0.003172 + 0.0012 + 0.00029 + 0.002 + 0.00045}$$

$$= \frac{1}{0.00711} = 140.6 \text{ B. t. u./hr./sq. ft./° F.}$$

$$\text{Surface required} = \frac{6{,}520{,}000}{(267)\ (140.6)} = 173.8 \text{ sq. ft.}$$

The above method, as Colburn (*3*) pointed out, gives low results because the arithmetic average temperature of the fluid is not the proper average to use when the heat transfer coefficient varies with temperature. However, the results obtained by it will be useful in making assumptions in the following more accurate methods and will thus eliminate further trial and error.

Method 2 for Required Heating Surface

This method will be that of Colburn, involving the use of his Figure 1 for F *vs.* $(\Delta T_c/\Delta T_h)$ for lines of constant C (*3*):

$\Delta T_h = 600 - 120 = 480°$ F.

$\Delta T_c = 200 - 70 = 130°$ F.

Hot End.

Assume $h_1 = 400$ B. t. u./hr./sq. ft./° F.

Assume $h_2 = 2500$ B. t. u./hr./sq. ft./° F.

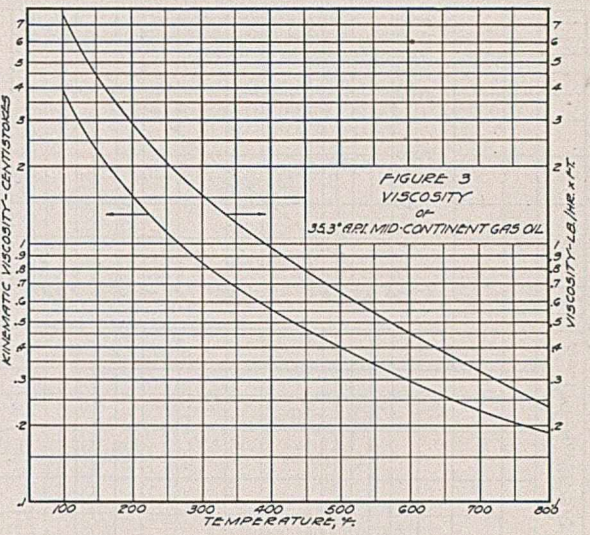


FIGURE 3
VISCOSITY
OF
35.3° A.P.I. MID-CONTINENT GAS OIL

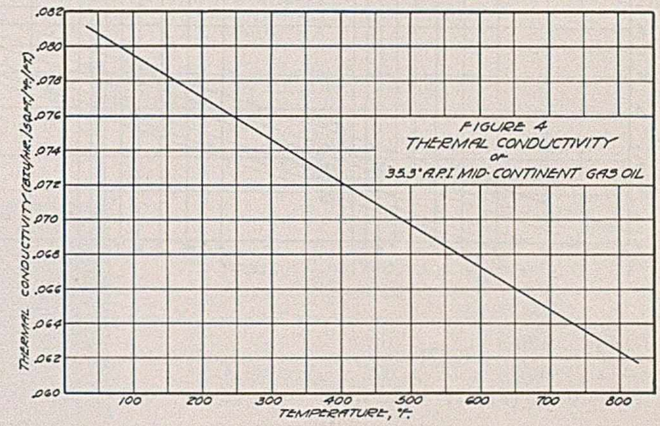


FIGURE 4
THERMAL CONDUCTIVITY
OF
35.3° A.P.I. MID-CONTINENT GAS OIL

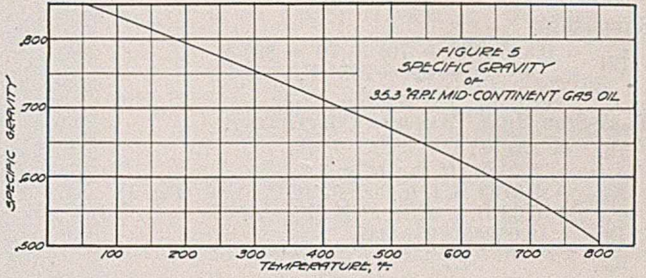


FIGURE 5
SPECIFIC GRAVITY
OF
35.3 A.P.I. MID-CONTINENT GAS OIL

$$U_h = \frac{1}{\frac{1}{2500} + (0.002 + 0.00029 + 0.0012) + \frac{1}{400}\left(\frac{0.0833}{0.06945}\right)}$$

$$= \frac{1}{0.00689} = 145.1 \text{ B. t. u./hr./sq. ft./° F.}$$

Cold End.

Assume $h_1 = 300$ B. t. u./hr./sq. ft./° F.

Assume $h_2 = 2000$ B. t. u./hr./sq. ft./° F.

$$U_c = \frac{1}{\frac{1}{2000} + (0.002 + 0.00029 + 0.0012) + \frac{1}{300}\left(\frac{0.0883}{0.06945}\right)}$$

$$= \frac{1}{0.00799} = 125.2 \text{ B. t. u./hr./sq. ft./° F.}$$

$$C = \frac{U_h - U_c}{U_c} = \frac{145.1 - 125.2}{125.2} = 0.159$$

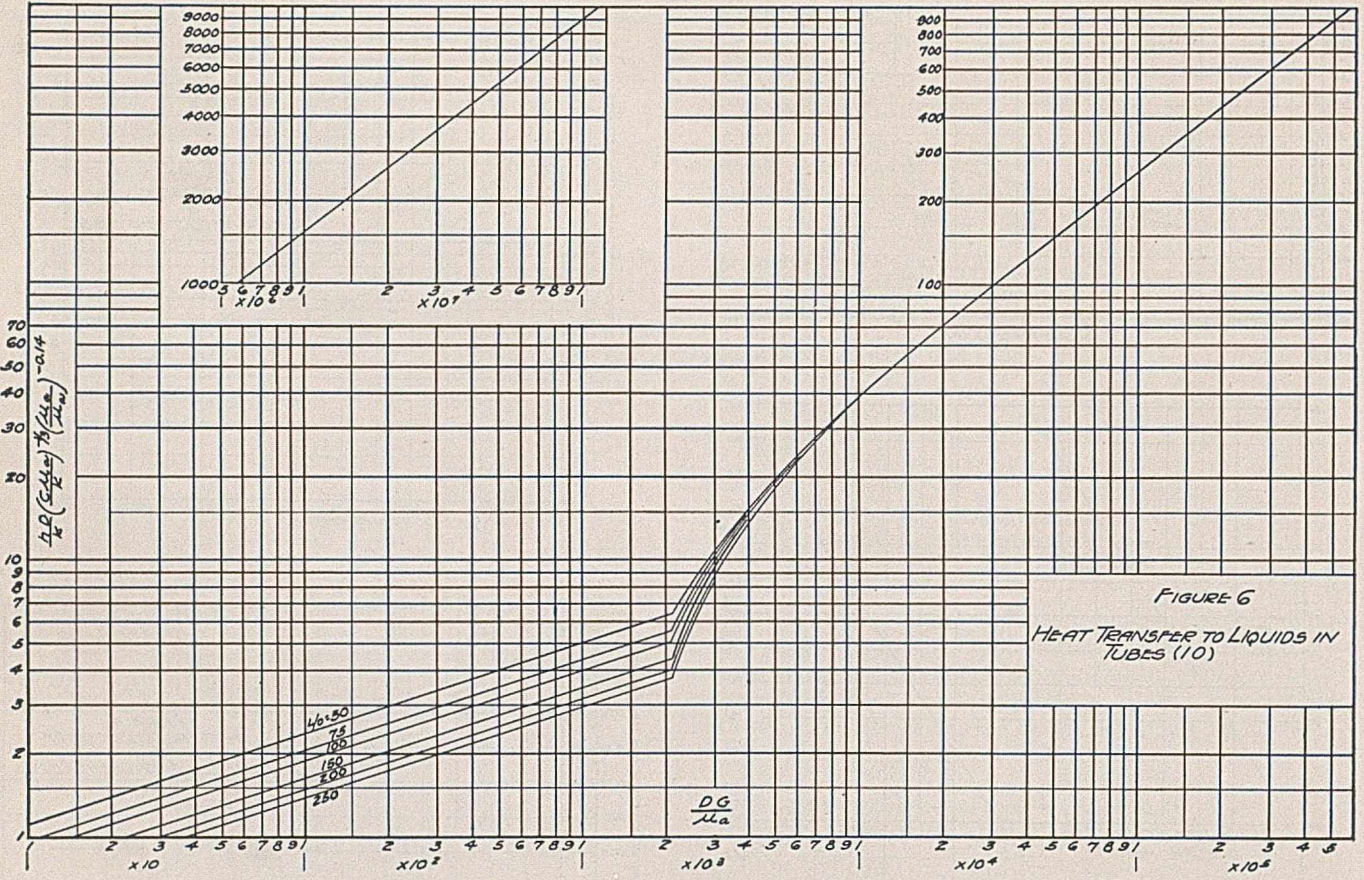


FIGURE 6

HEAT TRANSFER TO LIQUIDS IN TUBES (10)

$$\frac{\Delta T_c}{\Delta T_h} = \frac{130}{480} = 0.271$$

$F = 0.385$ (Fig. 7)

TUBE SIDE.

$T_{\text{av.}} = 0.385\ (600 - 200) + 200 = 354°$ F.

SHELL SIDE.

$t_{\text{av.}} = 0.385\ (120 - 70) + 70 = 89°$ F.

$\Delta T_{\text{median}} = 354 - 89 = 265°$ F.

TUBE-SIDE HEAT TRANSFER COEFFICIENT.

$T_{\text{av.}} = 354°$ F.

$\mu_{\text{av.}} = 1.20$ lb./ft./hr. (Fig. 3)

$K_{\text{av.}} = 0.0732$ B. t. u./hr./sq. ft./° F./ft. (Fig. 4)

$C_{\text{av.}} = 0.63$ B. t. u./lb./° F. (Fig. 2)

$$\frac{DG}{\mu_{\text{av.}}} = \frac{(0.06945)\ (934{,}000)}{1.20} = 54{,}000$$

$$\frac{h_1 D}{K_{\text{av.}}}\left(\frac{C_{\text{av.}}\,\mu_{\text{av.}}}{K_{\text{av.}}}\right)^{-1/3}\left(\frac{\mu_{\text{av.}}}{\mu_w}\right)^{-0.14} = 160 \text{ (Fig. 6)}$$

$$\left(\frac{C_{\text{av.}}\,\mu_{\text{av.}}}{K_{\text{av.}}}\right)^{-1/3} = \left(\frac{0.63 \times 1.20}{0.0732}\right)^{-1/3} = (10.32)^{-1/3} = \frac{1}{2.175}$$

$$h_1\left(\frac{0.06945}{0.0732}\right)\frac{1}{2.175}\left(\frac{1.20}{\mu_w}\right)^{-0.14} = 160$$

$$h_1 = \frac{(160)\ (2.175)\ (0.0732)}{0.06945}\left(\frac{1.20}{\mu_w}\right)^{0.14} = 367\left(\frac{1.20}{\mu_w}\right)^{0.14}$$

Assume $U = 140$ B. t. u./hr./sq. ft./° F. (based on outside tube area)

$$= 140\left(\frac{1.000}{0.834}\right) = 168 \text{ B. t. u./hr./sq. ft./° F.}$$

(based on inside tube area)

Assume $h_1 = 330$ B. t. u./hr./sq. ft./° F.

$$\text{Approx. } \Delta T \text{ across oil film} = \frac{(265)\ (168)}{330} = 135$$

Approx. $T_w = 354 - 135 = 219°$ F.

$\mu_w = 2.58$ (Fig. 3)

$$\left(\frac{\mu_{\text{av.}}}{\mu_w}\right)^{0.14} = \left(\frac{1.20}{2.58}\right)^{0.14} = 0.8983$$

$h_1 = (367)\ (0.8983) = 330$ B. t. u./hr./sq. ft./° F.

SHELL-SIDE HEAT TRANSFER COEFFICIENT.

$t_{\text{av.}} = 89°$ F.

$K_{\text{av.}} = 0.355$ B. t. u./hr./sq. ft./° F./ft.

$\mu_{\text{av.}} = (0.768)\ (2.42) = 1.86$ lb./hr./ft.

$$\frac{D_e G}{\mu_{\text{av.}}} = \frac{(0.1069)\ (2{,}665{,}000)}{1.86} = 153{,}000$$

$$\frac{h_2 D_e}{K_{\text{av.}}}\left(\frac{C_{\text{av.}}\,\mu_{\text{av.}}}{K_{\text{av.}}}\right)^{-1/3}\left(\frac{\mu_{\text{av.}}}{\mu_w}\right)^{-0.14} = 360 \text{ (Fig. 6)}$$

$$\left(\frac{C_{\text{av.}}\,\mu_{\text{av.}}}{K_{\text{av.}}}\right)^{-1/3} = \left(\frac{1.0 \times 1.86}{0.355}\right)^{-1/3} = (5.24)^{-1/3} = \frac{1}{1.736}$$

$$h_2\,\frac{(0.1069)}{(0.355)\ (1.736)}\left(\frac{1.86}{\mu_w}\right)^{-0.14} = 360$$

$$h_2 = \frac{(360)\ (0.355)\ (1.736)}{0.1069}\left(\frac{1.86}{\mu_w}\right)^{0.14} = 2075\left(\frac{1.86}{\mu_w}\right)^{0.14}$$

Assume $h_2 = 2100$ B. t. u./hr./sq. ft./° F.

$$\text{Approx. } \Delta T \text{ across water film} = \frac{(265)\ (140)}{2100} = 18° \text{ F.}$$

Approx. $t_w = 89 + 18 = 107°$ F.

$\mu_w = (0.63)\ (2.42) = 1.525$ lb./hr./ft.

$$\left(\frac{\mu_{\text{av.}}}{\mu_w}\right)^{0.14} = \left(\frac{1.86}{1.525}\right)^{0.14} = 1.028$$

$h_2 = (2075)\ (1.028) = 2133$ B. t. u./hr./sq. ft./° F.

$$U = \frac{1}{\frac{1.2}{330} + 0.00349 + \frac{1}{2133}} = 131.7 \text{ B. t. u./hr./sq. ft./° F.}$$

Over-all rate = (131.7) (265) = 34,900 B. t. u./hr./sq. ft.

$$\text{Surface required} = \frac{6{,}520{,}000}{34{,}900} = 187.0 \text{ sq. ft.}$$

Method 3 for Required Heating Surface

The third method makes use of Colburn's Equation 1, involving the calculation of U_h and U_c at the hot and cold ends of the exchanger, respectively (*3*).

HOT END, TUBE SIDE.

T_1 = 600° F.
μ_1 = 0.45 lb./hr./ft. (Fig. 3)
K_1 = 0.0673 B. t. u./hr./sq. ft./° F./ft. (Fig. 4)
C_1 = 0.782 B. t. u./lb./° F. (Fig. 2)

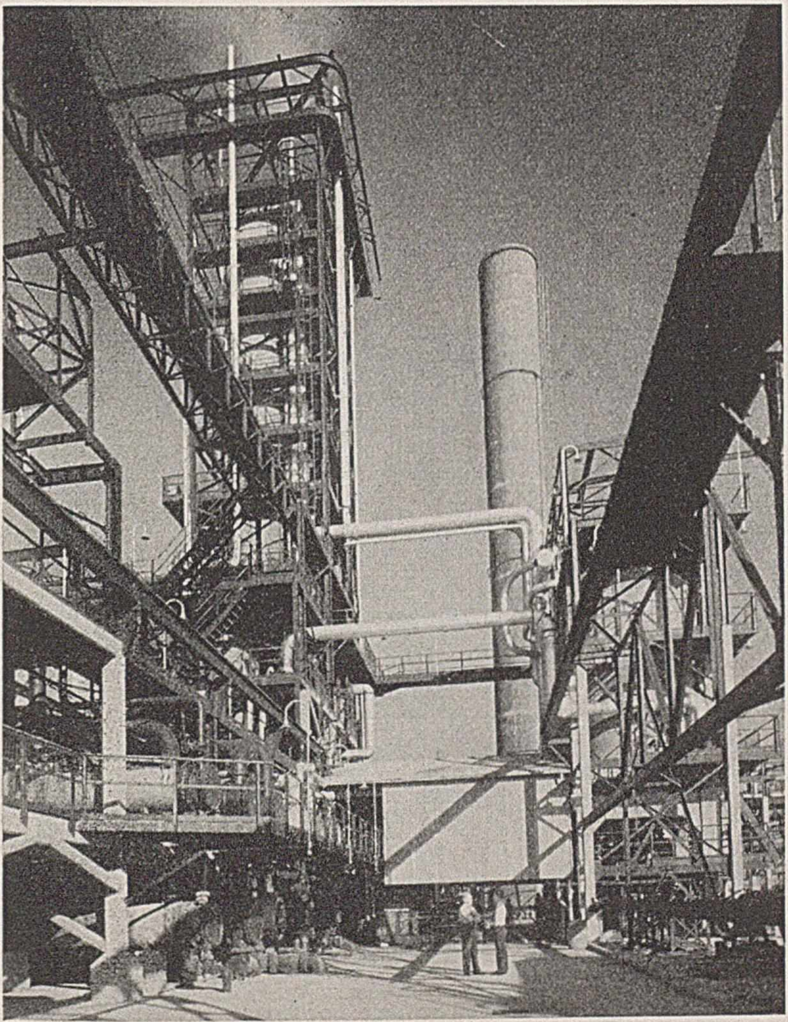
$$\frac{DG}{\mu_1} = \frac{(0.06945)\ (934{,}000)}{0.45} = 144{,}000$$

$$\frac{h_1 D}{K_1}\left(\frac{C_1\mu_1}{K_1}\right)^{-1/3}\left(\frac{\mu_1}{\mu_w}\right)^{-0.14} = 340 \text{ (Fig. 6)}$$

$$\left(\frac{C_1\mu_1}{K_1}\right)^{-1/3} = \left(\frac{0.782 \times 0.45}{0.0673}\right)^{-1/3} = (5.23)^{-1/3} = \frac{1}{1.735}$$

$$h_1\,\frac{(0.06945)}{(0.0673)\ (1.735)}\left(\frac{0.45}{\mu_w}\right)^{-0.14} = 340$$

$$h_1 = \frac{(340)\ (0.0673)\ (1.735)}{0.06945}\left(\frac{0.45}{\mu_w}\right)^{0.14} = 572\left(\frac{0.45}{\mu_w}\right)^{0.14}$$



HEAT EXCHANGERS IN A LARGE CRUDE COMBINATION CRACKING UNIT

Assume U_h = 165 B. t. u./hr./sq. ft./° F. (based on outside tube area)

$$= 165\left(\frac{1.000}{0.834}\right) = 198 \text{ B. t. u./hr./sq. ft./° F.}$$

(based on inside tube area)

Assume h_1 = 520 B. t. u./hr./sq. ft./° F.

$$\text{Approx. } \Delta T \text{ across oil film} = \frac{(480)\ (198)}{520} = 183° \text{ F.}$$

Approx. T_w = 600 − 183 = 417° F.
μ_w = 0.9 lb./hr./ft. (Fig. 3)

$$\left(\frac{\mu_1}{\mu_w}\right)^{0.14} = \left(\frac{0.45}{0.90}\right)^{0.14} = 0.9075$$

h_1 = (572) (0.9075) = 521 B. t. u./hr./sq. ft./° F.

HOT END, SHELL SIDE.

t_2 = 120° F.
K_2 = 0.370 B. t. u./hr./sq. ft./° F./ft.
μ_2 = (0.559) (2.42) = 1.352 lb./hr./ft.

$$\frac{D_e G}{\mu_2} = \frac{(0.1069)\ (2{,}665{,}000)}{1.352} = 210{,}500$$

$$\frac{h_2 D_e}{K_2}\left(\frac{C_2\mu_2}{K_2}\right)^{-1/3}\left(\frac{\mu_2}{\mu_w}\right)^{-0.14} = 460 \text{ (Fig. 6)}$$

$$\left(\frac{C_2\mu_2}{K_2}\right)^{-1/3} = \left(\frac{1 \times 1.352}{0.370}\right)^{-1/3} = (3.65)^{-1/3} = \frac{1}{1.540}$$

$$h_2\left(\frac{0.1069}{0.370}\right)\left(\frac{1}{1.54}\right)\left(\frac{1.352}{\mu_w}\right)^{-0.14} = 460$$

$$h_2 = 460\left(\frac{0.370}{0.1069}\right)(1.540)\left(\frac{1.352}{\mu_w}\right)^{0.14} = 2455\left(\frac{1.352}{\mu_w}\right)^{0.14}$$

Assume h_2 = 2600 B. t. u./hr./sq. ft./° F.

$$\text{Approx. } \Delta T \text{ across water film} = \frac{(480)\ (165)}{2600} = 30° \text{ F.}$$

Approx. t_w = 120 + 30 = 150° F.
μ_w = (0.43) (2.42) = 1.04 lb./hr./ft.

$$\left(\frac{\mu_2}{\mu_w}\right)^{0.14} = \left(\frac{1.352}{1.040}\right)^{0.14} = 1.037$$

h_2 = (2455) (1.037) = 2540 B. t. u./hr./sq. ft./° F.

$$U_h = \frac{1}{\frac{1.2}{521} + 0.00349 + \frac{1}{2540}} = 162 \text{ B. t. u./hr./sq. ft./° F.}$$

COLD END, TUBE SIDE.

T_2 = 200° F.
μ_2 = 2.95 lb./hr./ft. (Fig. 3)
K_2 = 0.077 B. t. u./hr./sq. ft./° F./ft. (Fig. 4)
C_2 = 0.536 B. t. u./lb./° F. (Fig. 2)

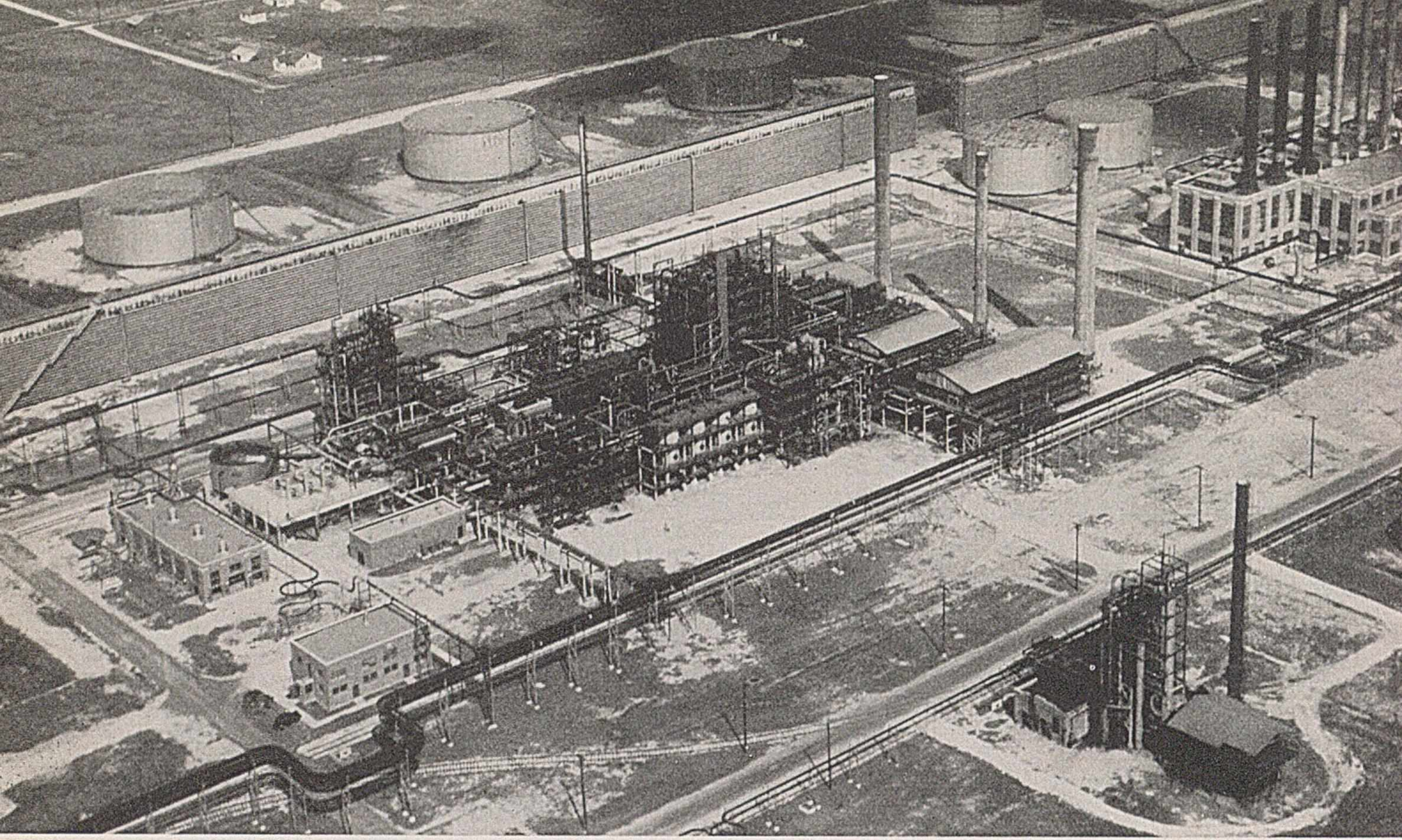
$$\frac{DG}{\mu_2} = \frac{(0.06945)\ (934{,}000)}{2.95} = 21{,}950$$

$$\frac{h_1 D}{K_2}\left(\frac{C_2\mu_2}{K_2}\right)^{-1/3}\left(\frac{\mu_2}{\mu_w}\right)^{-0.14} = 76 \text{ (Fig. 6)}$$

$$\left(\frac{C_2\mu_2}{K_2}\right)^{-1/3} = \left(\frac{0.536 \times 2.95}{0.077}\right)^{-1/3} = (20.55)^{-1/3} = \frac{1}{2.74}$$

$$h_1\left(\frac{0.06945}{0.077}\right)\left(\frac{1}{2.74}\right)\left(\frac{2.95}{\mu_w}\right)^{-0.14} = 76$$

$$h_1 = 76\left(\frac{0.077}{0.06945}\right)(2.74)\left(\frac{2.95}{\mu_w}\right)^{0.14} = 230.5\left(\frac{2.95}{\mu_w}\right)^{0.14}$$



AERIAL VIEW OF LARGE CRUDE COMBINATION CRACKING UNIT

Assume U_c = 100 B. t. u./hr./sq. ft./° F. (based on outside tube area)

$$= 100\left(\frac{1.000}{0.834}\right) = 120 \text{ B. t. u./hr./sq. ft./° F.}$$

(based on inside tube area)

Assume h_1 = 200 B. t. u./hr./sq. ft./° F.

Approx. ΔT across oil film $= \dfrac{(130)\ (120)}{200} = 78°$ F.

Approx. $T_w = 200 - 78 = 122°$ F.

μ_w = 6.0 lb./hr./ft. (Fig. 3)

$$\left(\frac{\mu_2}{\mu_w}\right)^{0.14} = \left(\frac{2.95}{6.00}\right)^{0.14} = 0.9052$$

h_1 = (230.5) (0.9052) = 209 B. t. u./hr./sq. ft./° F.

COLD END, SHELL SIDE.

t_1 = 70° F.

K_1 = 0.345 B. t. u./hr./sq. ft./° F./ft.

μ_1 = (0.981) (2.42) = 2.375 lb./hr./ft.

$$\frac{D_eG}{\mu_1} = \frac{(0.1069)\ (2{,}665{,}000)}{2.375} = 120{,}000$$

$$\frac{h_2D_e}{K_1}\left(\frac{C_1\mu_1}{K_1}\right)^{-1/3}\left(\frac{\mu_1}{\mu_w}\right)^{-0.14} = 300 \text{ (Fig. 6)}$$

$$\left(\frac{C_1\mu_1}{K_1}\right)^{-1/3} = \left(\frac{1 \times 2.375}{0.345}\right)^{-1/3} = (6.88)^{-1/3} = \frac{1}{1.90}$$

$$h_2\left(\frac{0.1069}{0.345}\right)\left(\frac{1}{1.90}\right)\left(\frac{2.375}{\mu_w}\right)^{-0.14} = 300$$

$$h_2 = 300\left(\frac{0.345}{0.1069}\right)(1.90)\left(\frac{2.375}{\mu_w}\right)^{0.14} = 1840\left(\frac{2.375}{\mu_w}\right)^{0.14}$$

Assume h_2 = 1900 B. t. u./hr./sq. ft./° F.

Approx. ΔT across water film $= \dfrac{(130)\ (120)}{1900} = 8°$ F.

Approx. $t_w = 70 + 8 = 78°$ F.

μ_w = (0.874) (2.42) = 2.12 lb./hr./ft.

$$\left(\frac{\mu_1}{\mu_w}\right)^{0.14} = \left(\frac{2.375}{2.12}\right)^{0.14} = 1.016$$

h_2 = (1840) (1.016) = 1870 B. t. u./hr./sq. ft./° F.

$$U_c = \frac{1}{\dfrac{1.2}{209} + 0.00349 + \dfrac{1}{1870}} = 102.5 \text{ B. t. u./hr./sq. ft./° F.}$$

Substituting in Colburn's equation:

$$\frac{Q}{K} = \frac{(U_c)\ (\Delta T_h) - (U_h)\ (\Delta T_c)}{2.3 \log\left(\dfrac{U_c \times \Delta T_h}{U_h \times \Delta T_c}\right)}$$

$\Delta T_h = 480;\ \Delta T_c = 130$

$U_h = 162;\ U_c = 102.5$

$(U_c)\ (\Delta T_h) = (102.5)\ (480) = 49{,}200$

$(U_h)\ (\Delta T_c) = (162)\ (130) = 21{,}050$

$(U_c)\ (\Delta T_h) - (U_h)\ (\Delta T_c) = 28{,}150$

$$\frac{(U_c)\ (\Delta T_h)}{(U_h)\ (\Delta T_c)} = \frac{49{,}200}{21{,}050} = 2.34$$

$$\frac{Q}{K} = \frac{28{,}150}{2.3 \log 2.34} = \frac{28{,}150}{(2.3)\ (0.3695)} = 33{,}050$$

Surface required $= \dfrac{6{,}520{,}000}{33{,}050} = 197$ sq. ft.

Tube surface required assumed as $\dfrac{187 + 195}{2} = 191$ sq. ft.

With tubes of 16-ft. effective length:

Tube surface per bundle of 7 tubes = (7) (16) (0.2614) = 29.3 sq. ft.

No. of sections required $= \dfrac{191}{29.3} = 6.5$

Use 7 sections = 205 sq. ft.

The above calculations show that the heating surface required, as calculated from the three methods, is:

Method 1	173.9 sq. ft.
Method 2	187.0
Method 3	191.0

Methods 2 and 3 give almost identical answers, and either may be used although the latter is preferred. For preliminary or more approximate calculations method 1 may be used.

However, when the larger temperature difference is at the hot end, method 1 may be as much as 17 per cent low, as shown by the examples of Colburn (*3*). However, experience has indicated that the results given by method 1 are usually not over 10 per cent low so that for quick estimates the answer obtained by this method may be increased by this amount. In the above example such a procedure would give an answer of 191.2 square feet, as compared to 191 square feet obtained by method 3. When the larger temperature difference is at the cold end, method 1 gives more nearly correct results.

Method 1 for Pressure Drop

The pressure drop will be calculated only for the length of actual tubes, neglecting for simplicity the length of turns and connections between the various sections of the exchanger, as well as expansion and contraction losses.

TUBE SIDE. Using $T_{av.} = 354°$ F. (as determined in method 2):

$$\frac{DG}{\mu} = 54{,}000$$

From Figure 7 of Sieder and Tate (*10*):

$(f)(\phi) = 0.0052$ (Fig. 8)

$\phi = 1.02\left(\frac{\mu_{av.}}{\mu_w}\right)^{0.14} = (1.02)\ (0.8983) = 0.918$

$f = \frac{0.0052}{0.918} = 0.00566$

Using the friction factor in the following form of the Fanning equation:

$$\Delta P = \frac{0.323\ fLS\ v^2}{d}$$

S at 354° F. = 0.732 (Fig. 5)
S at 60° F. = 0.8483 (Fig. 5)
Cold oil velocity = 4.90 ft./sec.
$v = 4.90\left(\frac{0.8483}{0.732}\right) = 5.67$ ft./sec.
$L = (16)\ (7) = 112$ ft.

$$\Delta P = \frac{(0.323)\ (0.00566)\ (112)\ (0.732)\ (5.67)\ (5.67)}{0.834} =$$

5.76 lb./sq. in.

SHELL SIDE.

$t_{av.} = 89°$ F.

$\frac{D_eG}{\mu_{av.}} = 153{,}000$

$(f)(\phi) = 0.00412$ (Fig. 8)

$\phi = 1.02\left(\frac{\mu_{av.}}{\mu_w}\right)^{0.14} = (1.02)(1.028) = 1.049$

$f = \frac{0.00412}{1.049} = 0.00392$

Wetted perimeter for pressure drop = $\pi\ (0.333) + 7(0.2614) =$ 2.876 ft.

$D_e = 4\left(\frac{0.0489}{2.876}\right) = 0.0681$ ft. = 0.817 in.

$v = 11.90$ ft./sec.

$$\Delta P = \frac{(0.323)\ (0.00392)\ (112)\ (1)\ (11.90)\ (11.90)}{0.817} =$$

24.6 lb./sq. in.

Method 2 for Pressure Drop

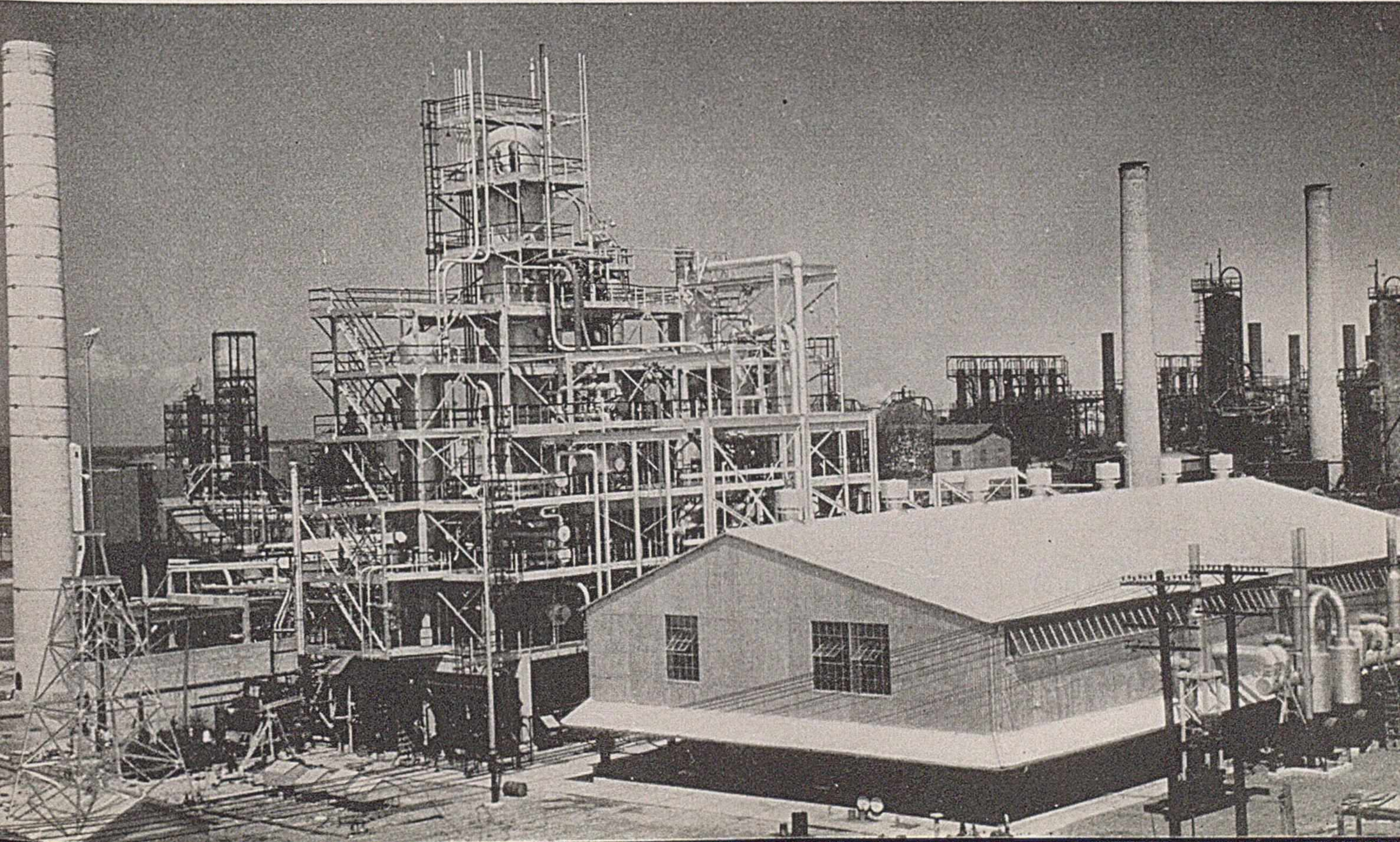
This method is based on Colburn's work (*4*).

TUBE SIDE, HOT END.

$U_h = 162$ B. t. u./hr./sq. ft./° F.
$\Delta T = 480°$ F.

Inside rate = $(162)(480)\left(\frac{0.0833}{0.06945}\right) = 93{,}200$ B. t. u./hr./sq. ft.

$h_i = 521$ B. t. u./hr./sq. ft./° F.
$\Delta T_f = \frac{93{,}200}{521} = 179°$ F.
$T_1 = 600°$ F.; $T_w = 421°$ F.
$T_f = T_1 + {}^1/_2(T_w - T_1) = 600 + {}^1/_2\ (421 - 600) = 511°$ F.
$\mu_f = 0.62$ lb./hr./ft.



THERMAL POLYMERIZATION PLANT

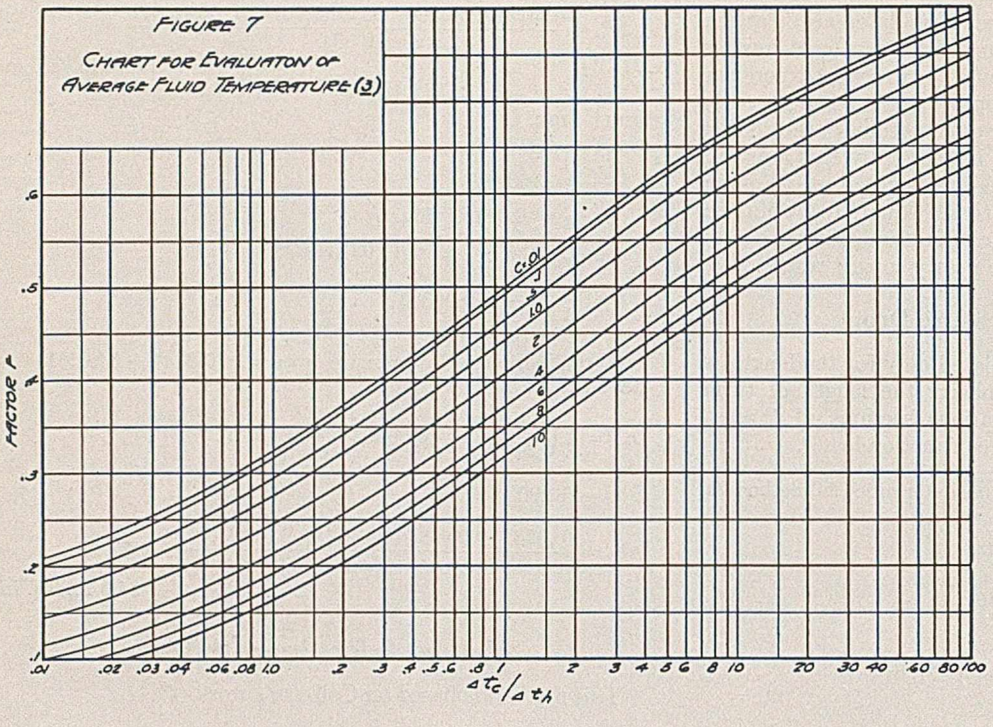


FIGURE 7
CHART FOR EVALUATON OF AVERAGE FLUID TEMPERATURE (3)

$$\frac{DG}{\mu_f} = \frac{(0.06945)\ (934{,}000)}{0.62} = 104{,}500$$
$^1/_2f$ = 0.0022 (Fig. 9)
f = 0.0044

Tube Side, Cold End.

U_c = 102.5 B. t. u./hr./sq. ft./° F.
ΔT_c = 130° F.

$$\text{Inside rate} = (102.5)\ (130)\ \left(\frac{0.0833}{0.06945}\right) = 16{,}000 \text{ B. t. u./hr./sq. ft.}$$

h_1 = 209 B. t. u./hr./sq. ft./° F.
$$\Delta T_f = \frac{16{,}000}{209} = 76° \text{ F.}$$
T_w = 200 − 76 = 124° F.
T_f = 200 + $^1/_2$ (124 − 200) = 162° F.
μ_f = 4.0 lb./hr./ft.
$$\frac{DG}{\mu_f} = \frac{(0.06945)\ (934{,}000)}{4.0} = 16{,}200$$
$^1/_2f$ = 0.0037 (Fig. 9)
f = 0.0074

Pressure Drop per Foot at Hot End.

S at 600° F. = 0.624 (Fig. 5)
S at 60° F. = 0.8483 (Fig. 5)

$$v \text{ at } 600° \text{ F.} = 4.90\left(\frac{0.8483}{0.624}\right) = 6.66 \text{ ft./sec.}$$

$$\frac{\Delta P}{L} = \frac{(0.323)\ (0.0044)\ (0.624)\ (6.66)\ (6.66)}{0.834} = 0.0472 \text{ lb./sq. in.}$$

Pressure Drop per Foot at Cold End.

S at 200° F. = 0.794 (Fig. 5)
S at 60° F. = 0.8483 (Fig. 5)

$$v \text{ at } 200° \text{ F.} = 4.90\left(\frac{0.8483}{0.794}\right) = 5.23 \text{ ft./sec.}$$

$$\frac{\Delta P}{L} = \frac{(0.323)(0.0074)(0.794)(5.23)(5.23)}{0.834} = 0.0622 \text{ lb./sq. in.}$$

$$\text{Av. } \frac{\Delta P}{L} = \frac{0.0472 + 0.0622}{2} = 0.0547 \text{ lb./ft.}$$

Total ΔP = (112) (0.0547) = 6.12 lb./sq. in.

Shell Side, Hot End.

U_h = 162 B. t. u./hr./sq. ft./° F.
ΔT_h = 480° F.

Outside rate = (162) (480) = 77,700 B. t. u./hr./sq. ft.

h_2 = 2540 B. t. u./hr./sq. ft./° F.
$$\Delta T_f = \frac{77{,}700}{2540} = 31° \text{ F.}$$
t_2 = 120° F.; t_w = 151° F.
t_f = 120 + $^1/_2$ (151 − 120) = 120 + 15 = 135° F.
μ_f = (0.491) (2.42) = 1.186 lb./hr./ft.

$$\frac{D_eG}{\mu_f} = \frac{(0.1069)\ (2{,}665{,}000)}{1.186} = 238{,}000$$

$^1/_2f$ = 0.0019 (Fig. 9)
f = 0.0038

Shell Side, Cold End.

U_c = 102.5 B. t. u./hr./sq. ft./° F.
ΔT_c = 130° F.

Outside rate = (130) (102.5) = 13,330

h_2 = 1870 B. t. u./hr./sq. ft./° F.
$$\Delta T_f = \frac{13{,}330}{1870} = 7° \text{ F.}$$

t_1 = 70° F.; t_w = 77° F.
t_f = 70 + $^1/_2$(77 − 70) = 70 + 4 = 74° F.
μ_f = (0.936) (2.42) = 2.262 lb./hr./ft.

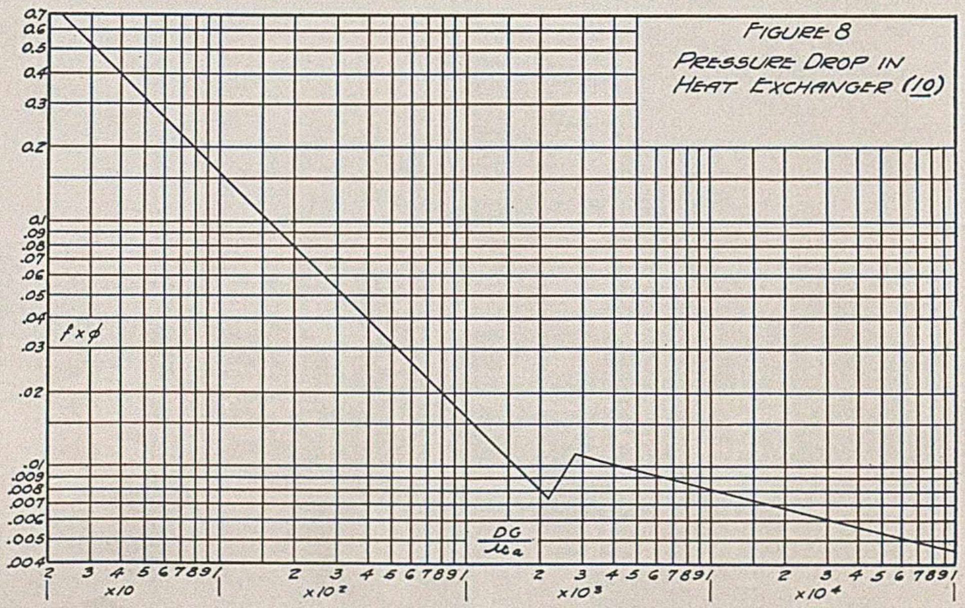


FIGURE 8
PRESSURE DROP IN HEAT EXCHANGER (10)

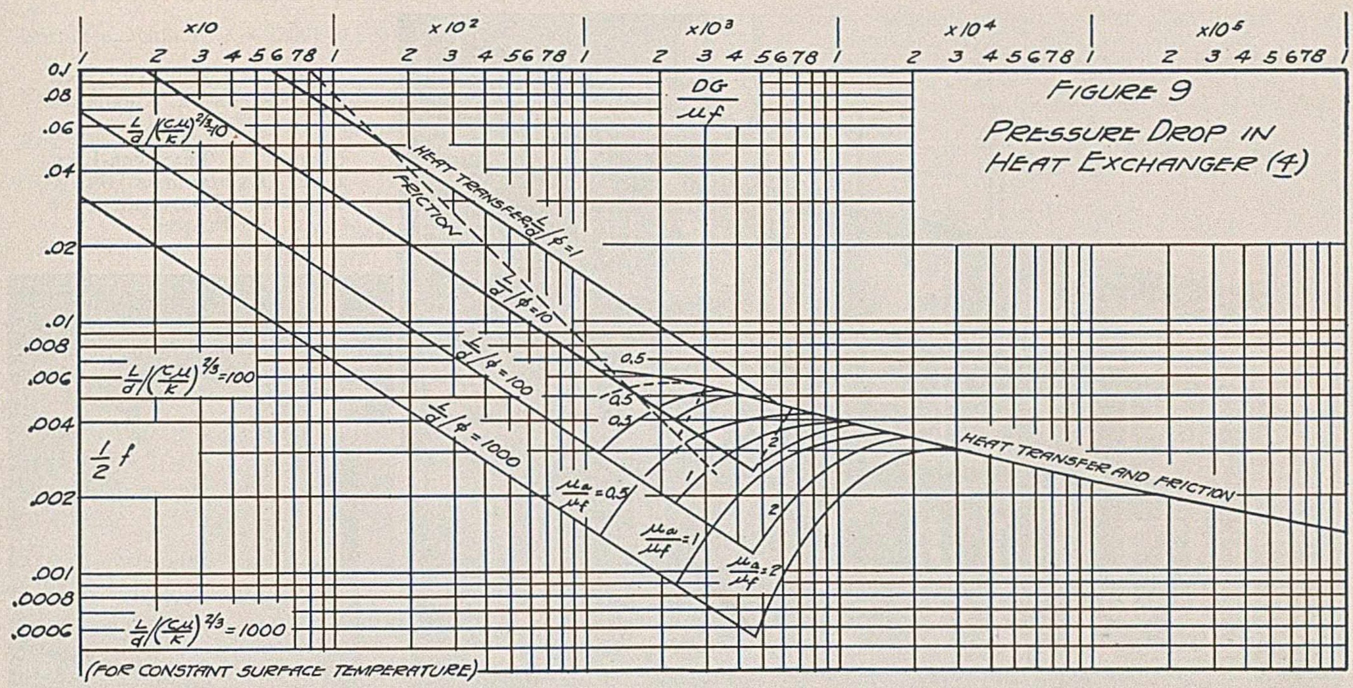


FIGURE 9
PRESSURE DROP IN HEAT EXCHANGER (4)

$$\frac{D_eG}{\mu_f} = \frac{(0.0681)\ (2{,}665{,}000)}{2.262} = 80{,}200$$

$$^1/_2f = 0.0025 \text{ (Fig. 9)}$$

$$f = 0.0050$$

$$\text{Av. } f = \frac{0.0050 + 0.0042}{2} = 0.0046$$

$$\Delta P = \frac{(0.323)\ (0.0046)\ (112)\ (1)\ (11.90)\ (11.90)}{0.817} = 28.8 \text{ lb./sq. in.}$$

The pressure drop calculated for the water side indicates that a water velocity of 11.7 feet per second is probably too high, except in those cases where a very high water pressure is readily available at no cost. Normally it would be desirable to design for a lower pressure drop on this side so that this factor should not limit the capacity of the unit.

No attempt has been made in the above example to give a general view of heat exchanger design, or to enter into a discussion of the most economical or suitable tube material, size, length, and layout. The problem has been confined to an exposition of reliable methods useful in the design of a single type of heat exchange equipment. In the majority of cases met in industrial work, it is economically necessary to use some type of baffling on the shell side in order to obtain higher fluid velocity and better film coefficients. Calculations involving such types of equipment are considerably more complicated although the same in principle.

Problem II, Pressure Drop in Packed Tubes

The most widely accepted analysis of the flow of fluids through packed tubes is that proposed by Chilton and Colburn, who applied Fanning's equation for flow through conduits to this problem (*2*):

$$\frac{\Delta P}{L} = \frac{2f\rho u^2}{gD}$$

By using a gas velocity based upon the total cross-sectional area of the tube, Chilton and Colburn experimentally determined the friction factor, f, as a function of a modified Reynolds number:

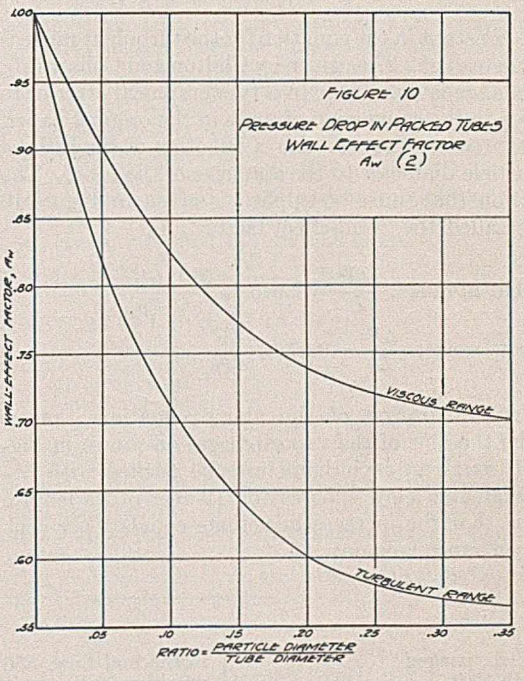


FIGURE 10
PRESSURE DROP IN PACKED TUBES
WALL EFFECT FACTOR
A_w (2)

Turbulent range: $f = 38 \left(\frac{\mu}{D_p\rho u_0}\right)$

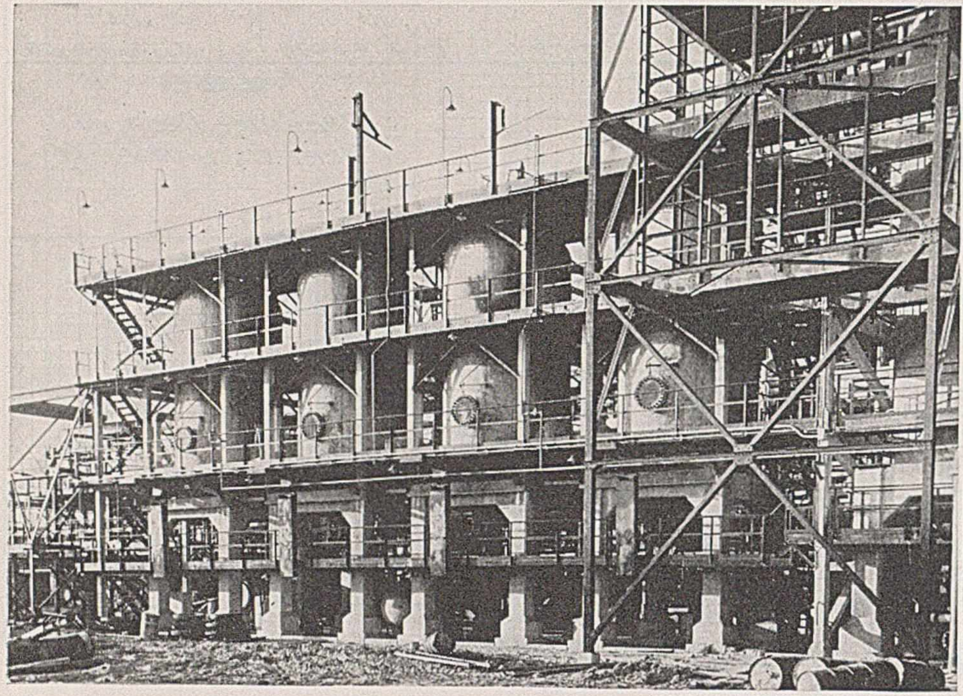
Viscous range: $f = 850 \left(\frac{\mu}{D_p\rho u_0}\right)$

Substituting these values for f in Fanning's equation and converting to more commonly used units, the equations for pressure drop become:

Turbulent range: $\frac{\Delta P}{L} = 2.645 \frac{Z^{0.15}\ G^{1.85}}{d_p{}^{1.15}\rho}$

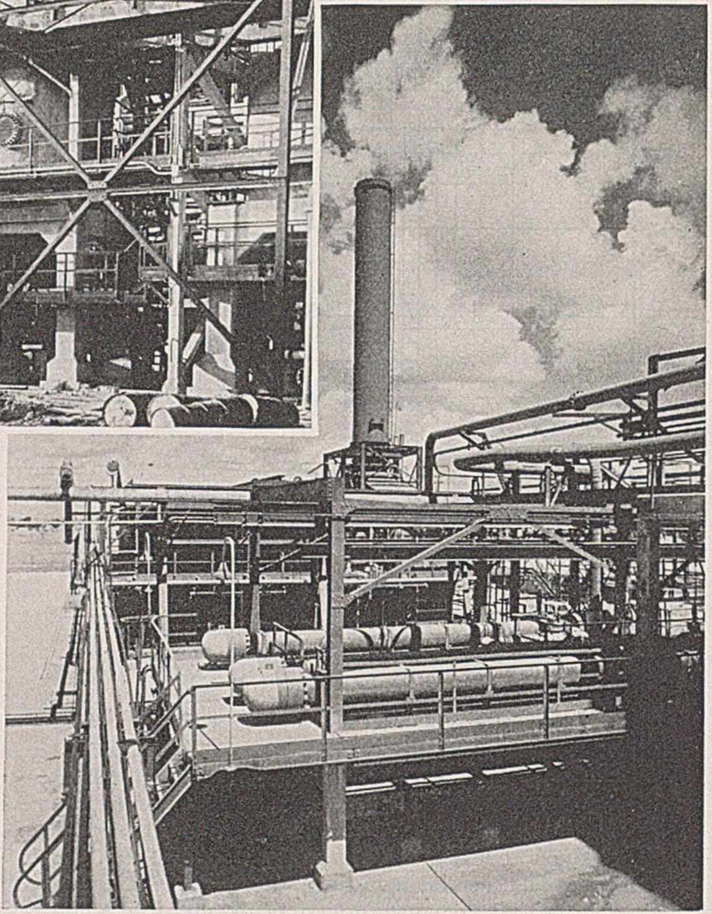
Viscous range: $\frac{\Delta P}{L} = 0.97 \frac{ZG}{d_p{}^2\rho}$

Critical velocity $\frac{d_pu_0\rho}{Z} = 0.32 \text{ to } 0.64$



(*Left*) CLAY TREATING TOWERS ON A CRACKING UNIT

(*Below*) TRANSFER-LINE HEAT EXCHANGERS ON A THERMAL POLYMERIZATION PLANT



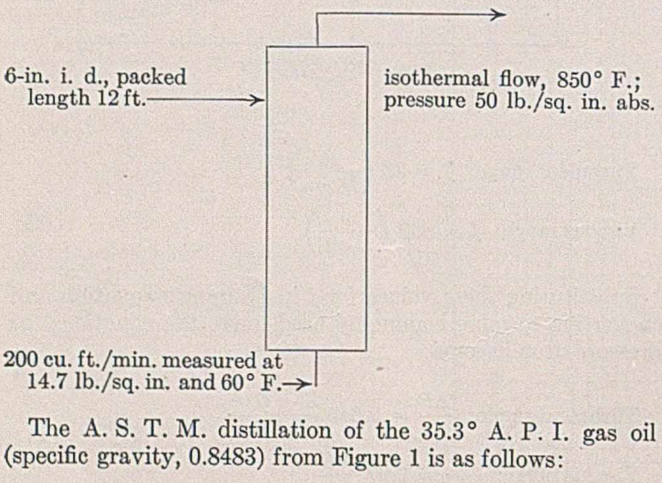
The constant in the equation for the turbulent range is 2.645 instead of 2.27 as given by Chilton and Colburn(*2*). This change is due either to a typographical error or to an error in the conversion of units in the original paper.

The pressure drop is also a function of the ratio of the particle diameter to the diameter of the tube. The correction that must be applied is given in Figure 10 and is called the "wall-effect factor", A_w:

$$\text{Turbulent range: } \frac{\Delta P}{L} = 2.645 A_w \frac{Z^{0.15}\, G^{1.85}}{d_p{}^{1.15}\rho}$$

$$\text{Viscous range: } \frac{\Delta P}{L} = 0.97 A_w \frac{ZG}{d_p{}^2\rho}$$

As an illustration of the above equations, let us consider the flow of the vaporized gas oil shown in Figure 1 through a 6-inch diameter tube packed with $^1/_4$-inch diameter clay spheres for 12 feet of its length. Assume that the increase in volume equals 5 per cent of the entrance volume:



The A. S. T. M. distillation of the 35.3° A. P. I. gas oil (specific gravity, 0.8483) from Figure 1 is as follows:

Initial b. p.	505° F.	70% over	554° F.
10% over	523	90%	573
30%	533	End point	589
50%	544		

MOLAL AVERAGE BOILING POINT (*11*).

$$\text{Volumetric av. b. p.} = \frac{t_{10\%} + t_{30\%} + t_{50\%} + t_{70\%} + t_{90\%}}{5}$$

$$= \frac{523 + 533 + 544 + 554 + 573}{5} = 545^\circ\text{ F. (Fig. 1)}$$

$$\text{Slope } (10\% - 90\%) = \frac{573 - 523}{80} = 0.625$$

Molal av. b. p. correction = 4° F. (*12*)
Molal av. b. p. = 545 − 4 = 541° F.

MOLECULAR WEIGHT = 234 (*13*).

PSEUDO CRITICAL PROPERTIES (*7*).

$$K_0 = \frac{(541 + 460)^{1/3}}{0.8483} = 11.89$$

Pseudo critical temp. = 922° F.
Pseudo critical pressure = 235 lb./sq. in.

$$T_{Rs} \text{ (pseudo reduced temp.)} = \frac{850 + 460}{922 + 460} = 0.948$$

$$P_{Rs} \text{ (pseudo reduced pressure)} = \frac{50}{235} = 0.213$$

Deviation from perfect gas at 850° F. and 50 lb./sq. in.:
$\mu = 0.895$ for $T_{Rs} = 0.948$ and $P_{Rs} = 0.213$ (*8*)
Entrance volume: $PV = \mu RT$

Entrance volume $V_1 = (200)\ (0.895) \left(\frac{14.7}{50}\right)\left(\frac{850 + 460}{60 + 460}\right) =$ 132.7 cu. ft./min.

Exit volume = (132.7) (1.05) = 139.3 cu. ft./min.

Entrance density:

$$V = \frac{\mu RT}{MP}$$

$$\rho_1 = \frac{1}{V} = \frac{PM}{\mu RT} = \frac{(50)\ (234)}{(0.895)\ (10.72)\ (1310)} = 0.930 \text{ lb./cu. ft.}$$

Total entering = (132.7) (0.930) = 123.3 lb./min.

Exit density:

$$\rho_2 = \frac{123.3}{139.3} = 0.885 \text{ lb./cu. ft.}$$

Assume that the absolute viscosity of exit vapors is the same as that of the entrance vapors. Assume that the viscosity at 50 pounds per square inch is the same as that at atmospheric pressure:

Viscosity of vapors at 850° F. and 14.7 lb./sq. in. = 0.007 centipoise (*1*)

$$\text{Av. density} = \frac{0.885 + 0.930}{2} = 0.908 \text{ lb./cu. ft.}$$

$$\text{Av. velocity} = \frac{(139.3 + 132.7)\ (144)}{(2)\ (28.27)\ (60)} = 1.153 \text{ ft./sec.}$$

$$\frac{d_p u_0 \rho}{Z} = \frac{(0.25)\ (1.15)\ (0.908)}{0.007} = 37.2$$

Critical velocity = 0.32 to 0.64

Therefore, flow is turbulent.

$$\frac{\Delta P}{L} = (2.645)\ \frac{(0.007)^{0.15}\ (1.15 \times 0.908)^{1.85}}{(0.25)^{1.15}\ (0.908)} = 7.38 \text{ in. } H_2O$$

Wall-effect factor:

$$\frac{\text{Particle diameter}}{\text{Tube diameter}} = \frac{0.25}{6} = 0.0417$$

$A_w = 0.84$ (Fig. 10)

$$\frac{\Delta P}{L} = (7.38)\ (0.84) = 6.19 \text{ in. } H_2O$$

Total pressure drop = (6.19) (12) = 74.4 in. H_2O
= (74.4) (0.03613) = 2.69 lb./sq. in.

Exit pressure = 50.0 − 2.7 = 47.3 lb./sq. in.

$$\text{Exit volume} = (132.7) \left(\frac{50}{47.3}\right) = 140.1 \text{ cu. ft./min.}$$

$$\text{Increase in volume} = \frac{140.1 - 132.7}{132.7} = 5.6\%$$

Correct volume increase was therefore assumed. If, however, a considerable difference had appeared between the assumed expansion and the calculated expansion, a second trial would have been necessary.

Acknowledgment

The helpful suggestions of S. J. Chute for the preparation of the first section of this paper are gratefully acknowledged.

Nomenclature

A_w = wall-effect factor
C = specific heat, B. t. u./lb./° F.
C_a = specific heat at arith. av. fluid temp.
d = diameter of tube, in.
d_p = av. particle diameter, in.
D_p = av. particle diameter, ft.
D = diameter, ft.
D_e = equivalent diameter, ft.
f = friction factor in Fanning equation
F = factor which, multiplied by temp. rise ($t_2 - t_1$) and added to t_1, gives temp. associated with heat transfer coefficient, U, based on log mean ΔT
g = acceleration of gravity, ft./sec./sec.
G = mass velocity, lb./hr./sq. ft.
h_1 = film coefficient of heat transfer of oil (based on inside tube area), B. t. u./hr./sq. ft./° F.
h_2 = film coefficient of heat transfer of water (based on outside tube area)
h_w = thermal conduction of tube wall metal, B. t. u./hr./sq. ft./° F.
K = thermal conductivity, B. t. u./hr./sq. ft./° F./ft.
K_a = thermal conductivity of fluid at arithmetical av. fluid temp.
K_0 = Watson's characterization factor
L = length of flow, ft.
L' = tube thickness, ft.
M = av. mol. weight of gas
ΔP = pressure difference
Q = heat exchanged
R = universal gas constant
S = specific gravity
t_1 = water temp. at oil outlet end, ° F.
t_2 = water temp. at oil inlet end
t_a = arithmetical av. water temp.
t_f = water film temp.
t_w = outside tube wall temp.
T_1 = oil temp. at oil inlet end
T_2 = oil temp. at oil outlet end
T_a = arithmetical av. oil temp.
T_f = oil film temp.
T_w = inside tube wall temp.
ΔT_h = temp. difference at hot end
ΔT_c = temp. difference at cold end
u = linear velocity of fluid, ft./sec.
u_0 = superficial gas velocity based on cross-sectional area of empty tube
U = over-all thermal conductance (based on outside tube area), B. t. u./hr./sq. ft./° F.
U_c = over-all heat transfer coefficient at cold end of exchanger (based on outside tube area)
U_h = over-all heat transfer coefficient at hot end of exchanger (based on outside tube area)
v = velocity, ft./sec.
V = volume, cu. ft./min.
Z = viscosity, centipoises
μ = viscosity of fluid, lb./hr./ft.
μ_a = viscosity of fluid at arithmetic av. fluid temp.
μ_f = viscosity at film temp.
μ_w = viscosity of fluid at tube wall temp.
$\phi = 1.1 \left(\frac{\mu_a}{\mu_w}\right)^{0.25}$ below $\frac{DG}{\mu} = 2100$
$\phi = 1.02 \left(\frac{\mu_a}{\mu_w}\right)^{0.14}$ above $\frac{DG}{\mu} = 2100$
ρ = density, lb./cu. ft.
G. T. D. = greatest temp. difference
L. T. D. = least temp. difference
M. T. D. = log mean temp. difference
$1/h_{s_1}$ = fouling factor on oil side
$1/h_{s_2}$ = fouling factor on water side

Subscript 1 applied to C, K, and μ refers to properties of fluid at stream inlet conditions

Subscript 2 applied to C, K, and μ refers to properties of fluid at stream outlet conditions

Subscript av. applied to C, K, and μ refers to properties of fluid at average temp. as determined in method 2 for required heating surface

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DISSIMILAR METAL COUPLES

Corrosion Resistance and Current Potential Measurements

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MODERN aircraft requires more from the metals and alloys entering its fabrication than any other engineering structure. Light weight combined with high mechanical properties over a wide temperature range, maximum corrosion resistance to maintain those physical properties, and a high resistance to fatigue are a few of the demands of aircraft. No metal or alloy will meet all of these requirements, and compromises must be made. Magnesium and its alloys are the lightest of the commercially available metals, but their mechanical properties and inherently poor corrosion resistance in salt water limits their present use in aircraft. The high mechanical properties demanded by airplane landing gears, axles, and numerous fittings can be satisfied only by heat-treated alloy steels. Stainless steel and nickel-chromium alloys are required for exhaust stacks to withstand the elevated temperatures and corrosive action of exhaust gases. The general requirements of the airplane designer are most nearly satisfied by aluminum and its alloys, and this metal forms the major part of today's aircraft.

With the multiplicity of metals employed, many combinations of dissimilar metal joints are found in the structure. To determine the effect of such dissimilar metal couples on corrosion resistance in salt water, the efficiency of various means of insulating such couples and the possibility of predicting corrosion resistance from laboratory measurements of the currents and potentials developed by the various couples was the purpose of this investigation.

Materials

The following materials were employed for both the salt water exposure test and the current-potential measurements. Their physical properties and chemical compositions are given in Table I.

Material	Size, Inches	Trade Name or Number
Aluminum sheet	0.032	2S-$^1/_2$ H
Aluminum alloy sheet	0.032	3S-$^1/_2$ H
Aluminum alloy sheet	0.032	4S-$^1/_2$ H
Aluminum alloy sheet	0.032	52S-$^1/_2$ H
Aluminum alloy sheet	0.032	53ST
Aluminum alloy sheet	0.032	24ST
Aluminum-covered aluminum alloy sheet	0.032	Alclad 24ST
Naval brass	0.040	
Cadmium-plated naval brass	0.040	
Chromium-molybdenum steel (normalized)	0.040	X-4130
Cadmium-plated Cr-Mo steel (normalized)	0.040	X-4130
Corrosion-resistant steel	0.040	18-8
Monel metal	0.040	
Aluminum rivets	$^1/_8 \times ^3/_8$	2S
Aluminum alloy rivets	$^1/_8 \times ^3/_8$	A-17ST
Aluminum alloy rivets	$^1/_8 \times ^3/_8$	17ST
Aluminum alloy rivets	$^1/_8 \times ^3/_8$	53ST
Aluminum alloy rivets	$^1/_8 \times ^3/_8$	24ST

With the exception of aluminum alloy 24ST, cadmium-plated chromium-molybdenum steel, and naval brass, all sheet materials were used in the as-received condition—that is, as rolled and/or heat-treated by the manufacturer. All 24ST aluminum alloy panels and attachment plates were anodically treated for 30 minutes in a 5 per cent solution of chromic acid at 35° C. (95° F.). The potential during treatment was 40 volts. The cadmium-plated brass and steel attachment plates were processed in a cyanide-cadmium plating solution. The thickness of the cadmium coating was 0.0075 mm. (0.0003 inch).

Aluminum or aluminum alloy rivets were used to fasten all attachment plates to the panels. Of the five types employed, three (2S, A-17ST, and 53ST) were driven in the as-received condition. The 17ST and 24ST alloy rivets were reheat-treated by being soaked in an air furnace for 30 minutes, followed by cold water quenching. The soaking temperature for the 17S alloy was 504° C. (940° F.) and for the 24S alloy, 493° C. (920° F.). Rivets of these two alloys were driven within one hour after quenching.

The salt water exposure test consisted of two series of panels. In the first group, four of the high-strength aluminum alloys (52S-$^1/_2$ H, 53ST, 24ST, and Alclad 24ST) were used for the panels proper. To these were riveted attachment plates, 3.2 × 12.7 cm. (1.26 × 5 inches), of all the other alloys. In the second series the five commercially available aluminum alloy rivets were used in contact with the seven different aluminum alloy sheets. The type of panel used for the salt water exposure is shown in Figure 1. In this particular test, however, each panel was punched to accommodate four attachment plates rather than two as shown on the drawing.

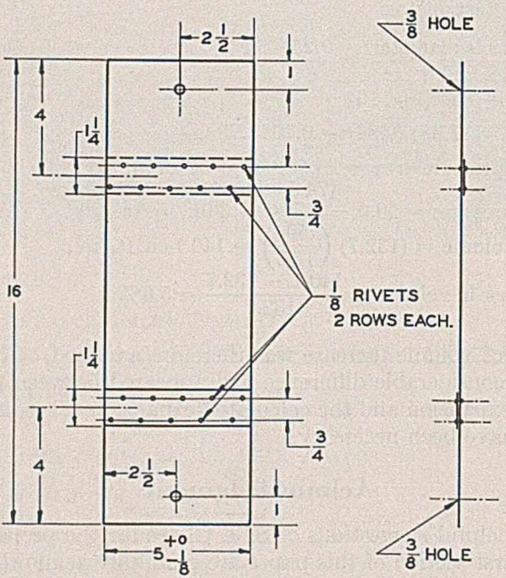


FIGURE 1. STANDARD EXPOSURE PANEL
(Dimensions in inches)

In the first group a total of ninety-six panels was prepared. In order to investigate the merits of various insulating media on the corrosion resistance of dissimilar metal couples, two panels of each of the four alloy sheets were required for each type of attachment plate, and four plates were riveted to each panel. The insulating materials were identified as follows:

A. No insulation
B. One coat of iron oxide primer
C. One coat of zinc chromate primer
D. Airplane cloth impregnated with zinc chromate pigment

TABLE I. CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF PANEL MATERIALS

Material	Si	Cu	Fe	Mn	Mg	Ni	Sn	Pb	Cr	Mo	Zn	C	Yield Strength	Ultimate Strength	Elongation,[b]
	%	%	%	%	%	%	%	%	%	%	%	%	*Lb. per sq. in.*		
2S-½ H	0.12	0.02	0.58	0.01	..	...	..	..	...	..	...	..	15,500	17,500	10.0
3S-½ H	0.22	0.15	0.61	1.19	..	...	..	..	...	..	...	..	21,000	22,000	8.0
4S-½ H	0.18	0.24	0.57	1.17	0.96	...	..	..	...	..	...	..	30,500	36,200	8.0
52S-½ H	0.17	0.05	0.14	0.01	2.39	...	..	..	0.27	..	...	..	34,800	42,400	8.0
53ST	0.64	0.09	0.13	0.01	1.16	...	..	..	0.26	..	...	..	32,500	39,000	15.5
24ST	0.16	4.29	0.27	0.63	1.49	...	..	..	...	..	...	..	56,800	72,300	18.0
Alclad 24ST	0.15	4.35	0.20	0.63	1.78	...	..	..	...	..	...	..	46,300	62,500	16.0
17ST[a]	..	4.00	..	0.50	0.50	...	..	..	...	..	...	..	37,000	60,000	20.0
A-17ST[a]	..	2.50	..	..	0.30	...	..	..	...	..	...	..	24,000	43,000	24.0
Naval brass	..	60.93	..	..	..	...	0.60	0.11	...	..	38.36	..			
Monel metal	..	28.97	1.34	0.23	..	69.48	..	..	...	..	...	0.10			
X-4130 steel	..	...	..	0.64	..	...	..	..	1.11	0.25	...	0.33			
18-8 steel	0.52	...	..	0.43	..	8.93	..	..	17.59	..	...	0.04			

[a] Nominal composition and properties.
[b] Per cent in 2 inches.

TABLE II. DISSIMILAR METAL CONTACT PANELS

Panel Material, 52S-½ H; Rivets, A-17ST		Panel Material and Rivets, 53ST		Panel Material, Anodized 24ST; Rivets, 24ST		Panel Material, Alclad 24ST; Rivets, 24ST	
Panel No.	Attachment plate[a]	Panel No.	Attachment plate	Panel No.	Attachment plate	Panel No.	Attachment plate
52S-1	2S-½ H	53-1	2S-½ H	24-1	2S-½ H	A24-1	2S-½ H
52S-2	2S-½ H	53-2	2S-½ H	24-2	2S-½ H	A24-2	2S-½ H
52S-3	3S-½ H	53-3	3S-½ H	24-3	3S-½ H	A24-3	3S-½ H
52S-4	3S-½ H	53-4	3S-½ H	24-4	3S-½ H	A24-4	3S-½ H
52S-5	52S-½ H	53-5	52S-½ H	24-5	52S-½ H	A24-5	52S-½ H
52S-6	52S-½ H	53-6	52S-½ H	24-6	52S-½ H	A24-6	52S-½ H
52S-7	53ST	53-7	53-ST	24-7	53-ST	A24-7	53-ST
52S-8	24ST (anodized)	53-8	53-ST	24-8	53-ST	A24-8	53-ST
52S-9	24ST (anodized)	53-9	24ST (anodized)	24-9	24ST (anodized)	A24-9	24ST (anodized)
52S-10	Alclad 24ST	53-10	24ST (anodized)	24-10	24ST (anodized)	A24-10	24ST (anodized)
52S-11	Alclad 24ST	53-11	Alclad 24ST	24-11	Alclad 24ST	A24-11	Alclad 24ST
52S-12	X-4130 steel	53-12	Alclad 24ST	24-12	Alclad 24ST	A24-12	Alclad 24ST
52S-13	X-4130 steel	53-13	X-4130 steel	24-13	X-4130 steel	A24-13	X-4130 steel
52S-14	Cd-plated X-4130	53-14	X-4130 steel	24-14	X-4130 steel	A24-14	X-4130 steel
52S-15	Cd-plated X-4130	53-15	Cd-plated X-4130	24-15	Cd-plated X-4130	A24-15	Cd-plated X-4130
52S-16	18-8 steel	53-16	Cd-plated X-4130	24-16	Cd-plated X-4130	A24-16	Cd-plated X-4130
52S-17	18-8 steel	53-17	18-8 steel	24-17	18-8 steel	A24-17	18-8 steel
52S-18	Naval brass	53-18	18-8 steel	24-18	18-8 steel	A24-18	18-8 steel
52S-19	Naval brass	53-19	Naval brass	24-19	Naval brass	A24-19	Naval brass
52S-20	Cd-plated brass	53-20	Naval brass	24-20	Naval brass	A24-20	Naval brass
52S-21	Cd-plated brass	53-21	Cd-plated brass	24-21	Cd-plated brass	A24-21	Cd-plated brass
52S-22	Monel metal	53-22	Cd-plated brass	24-22	Cd-plated brass	A24-22	Cd-plated brass
52S-23	Monel metal	53-23	Monel metal	24-23	Monel metal	A24-23	Monel metal
52S-24	...	53-24	Monel metal	24-24	Monel metal	A24-24	Monel metal

[a] Attachment plates *A* to *D* on panels with odd numbers, *E* to *H* on panels with even numbers.

E. Electricians' friction tape.
F. Electricians' friction tape plus marine glue.
G. Airplane cloth plus marine glue.
H. Neoprene (PAW) tape.

In preparing these test specimens, the panels proper and attachment plates were cleaned with benzene prior to insulation or assembly. Attachment plates *B* and *C* and the area of the panel covered by these plates were given one spray coat of iron oxide and zinc chromate primer, respectively. The primers were allowed to dry 24 hours before the plates were riveted to the panels. Plate *D* was insulated from the panel by one layer of airplane cloth which had been soaked in a water paste of zinc chromate and allowed to dry. Between the panel and plate *E* a strip of friction tape was inserted. With plates *F* and *G* a coating of marine glue was applied to both plates and panel. A strip of friction tape was placed on plate *F* and airplane cloth on plate *G*, and the assembly was completed while the glue was wet. Between panels and plates *H* a strip of Neoprene (PAW) tape was used. After assembly all cloth and tape strips were trimmed even with the plate. The complete series of panels in this group is given in Table II.

In the second group of panels the dissimilar metal couple was formed by the panel-rivet combination. The same type of panel was employed for exposure, but in this series the attachment plates in all cases were of the same material as the panel proper. Five panels of each of the following sheets were prepared: 2S-½H, 3S-½H, 4S-½H, 52S-½H, 53ST, 24ST (anodized), and Alclad 24ST. On one panel of each alloy the attachment plates were fastened with 2S rivets, on another 53ST, on the third, fourth, and fifth, A-17ST, 17ST, and 24ST rivets, respectively. The complete series of this group is listed in Table III.

None of the panels in either group received any paint type coating except that applied as insulators on plates *B* and *C*.

TABLE III. RIVET SERIES FOR DISSIMILAR METAL CONTACT PANELS

Panel Number	Panel Alloy	Attachment Plate	Rivets
2-1	2S-½H	2S-½H	2S
2-2			53ST
2-3			A-17ST
2-4			17ST
2-5			24ST
3-1	3S-½H	3S-½H	2S
3-2			53ST
3-3			A-17ST
3-4			17ST
3-5			24ST
4-1	4S-½H	4S-½H	2S
4-2			53ST
4-3			A-17ST
4-4			17ST
4-5			24ST
52-25	52S-½H	52S-½H	2S
52-26			53ST
52-27			A-17ST
52-28			17ST
52-29			24ST
53-25	53ST	53ST	2S
53-26			53ST
53-27			A-17ST
53-28			17ST
53-29			24ST
24-25	24ST	24ST	2S
24-26			53ST
24-27			A-17ST
24-28			17ST
24-29			24ST
A-24-25	Alclad 24ST	Alclad 24ST	2S
A-24-26			53ST
A-24-27			A-17ST
A-24-28			17ST
A-24-29			24ST

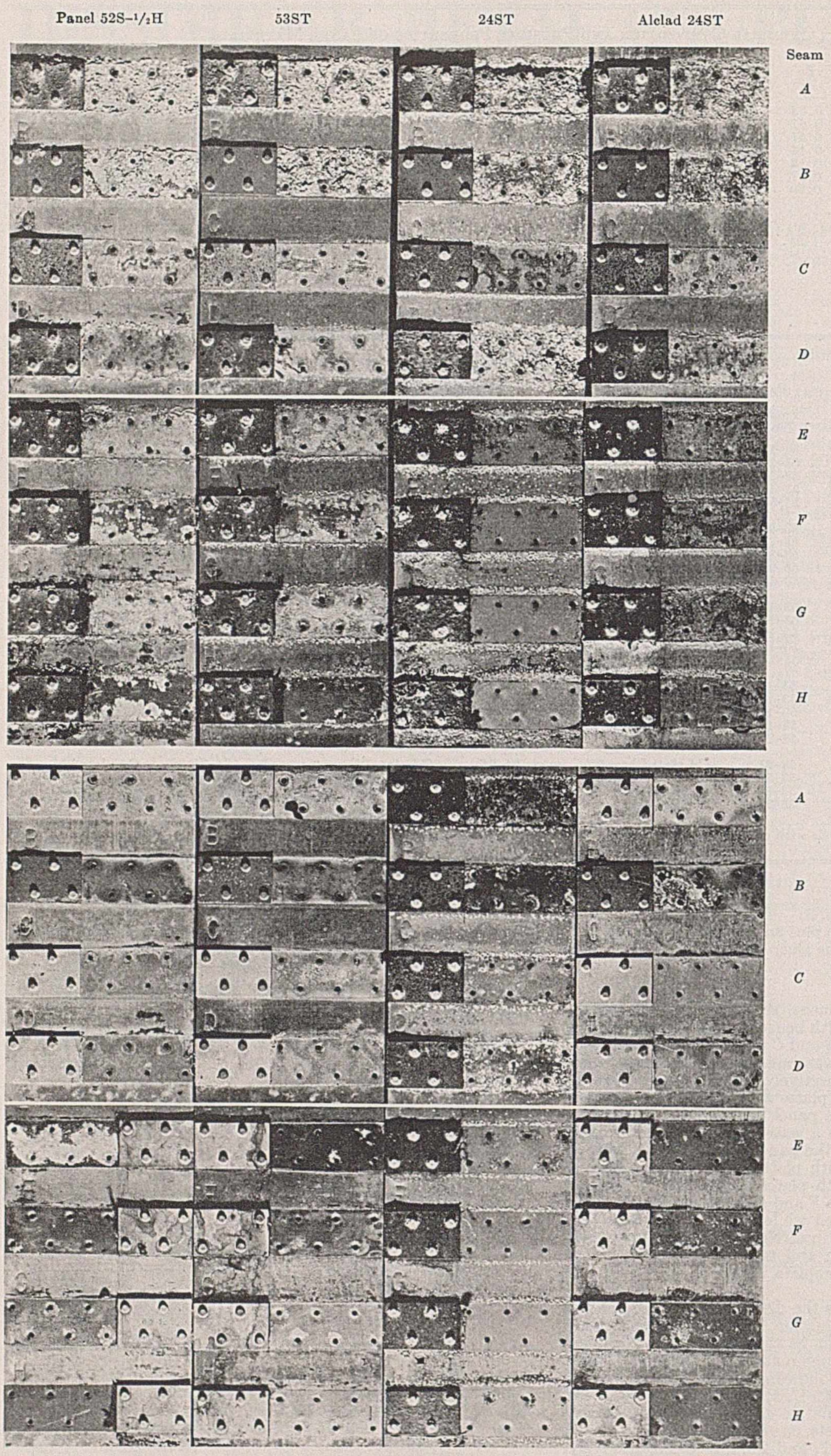


Figure 2. Effect of Exposure on Panels Made with X-4130 Steel Attachment Plates (*above*) and with Cadmium-Plated X-4130 Steel Attachment Plates (*below*)

Exposure Tests

The exposure test on the panels was made on the Air Corps tidewater rack at Chapman Field, Miami, Fla. On this rack the specimens are held at an angle of 45° from the vertical, facing due south, and are alternately immersed in the salt water (sodium chloride content 2.5 per cent) of Biscayne Bay at high tide and exposed to the atmosphere at low tide. The panels were subjected to this exposure for 6 months.

The evaluation of the dissimilar metal contact series of panels consisted of visual examination of the panel and seam area after half of the attachment plate had been removed, and reverse bend tests on specimens taken from the panels under each attachment plate and also from the panel proper. The appearance of some of the panels after exposure is shown in Figures 2 and 3. A few of the more striking observations of the visual examinations were:

1. The severity of attack produced by the X-4130 steel attachment plates on all four aluminum alloys.
2. The practically complete elimination of this attack when the X-4130 steel plates were cadmium-plated. This same comparison holds true for brass as compared with cadmium-plated brass plates.
3. The differences in durability of cadmium coatings in contact with the several aluminum alloys. On both brass and steel attachment plates the cadmium coating was still intact on plates in contact with Alclad 24ST, 52S, and 53ST alloys. On the same plates in contact with anodized 24ST alloy the cadmium had been completely removed and corrosion of the base metal had occurred.
4. The 18-8 steel attachment plates had caused appreciably less attack on the four alloys than X-4130 steel, brass, and Monel metal.

5. Rivet corrosion was far more severe on the 24ST panels than on the other alloys.

6. The protection offered to seam areas by impregnated fabrics of the friction tape and Neoprene tape, and especially by zinc chromate primer, was significant.

Reverse Bend Tests. The effect of dissimilar metal contacts, with and without insulating materials, on the corrosion resistance of the aluminum alloys is graphically depicted in Figure 4 where the results of reverse bend tests on specimens from all panels and seam areas are shown. The height of each column represents the ratio between the number of reversals, before failure, of the original material and that obtained on specimens cut from the tidewater panels. *X* represents a specimen from the panel proper; *A* to *H*, specimens from the seam areas insulated as already described. Each column is the average of five determinations. The specimens used were 0.95 cm. (0.375 inch) wide and 7.5 cm. (3 inches) long. The test was conducted by bending the specimens through an arc of 180° over a 0.95-cm. radius until failure (breaking) occurred. Each 90° reversal was counted as one bend. The machine employed (originally designed for the testing of wire) is shown in Figure 5.

Although reverse bend test values have not been standardized to afford direct conversion into ultimate strength or elongation, some unpublished data obtained here have indicated that the reduction in elongation of aluminum alloys resulting from corrosion is shown in a quantitative manner by the bend test. This method has the definite advantage of enabling several determinations to be made on a small specimen. This feature is highly desirable for corro-

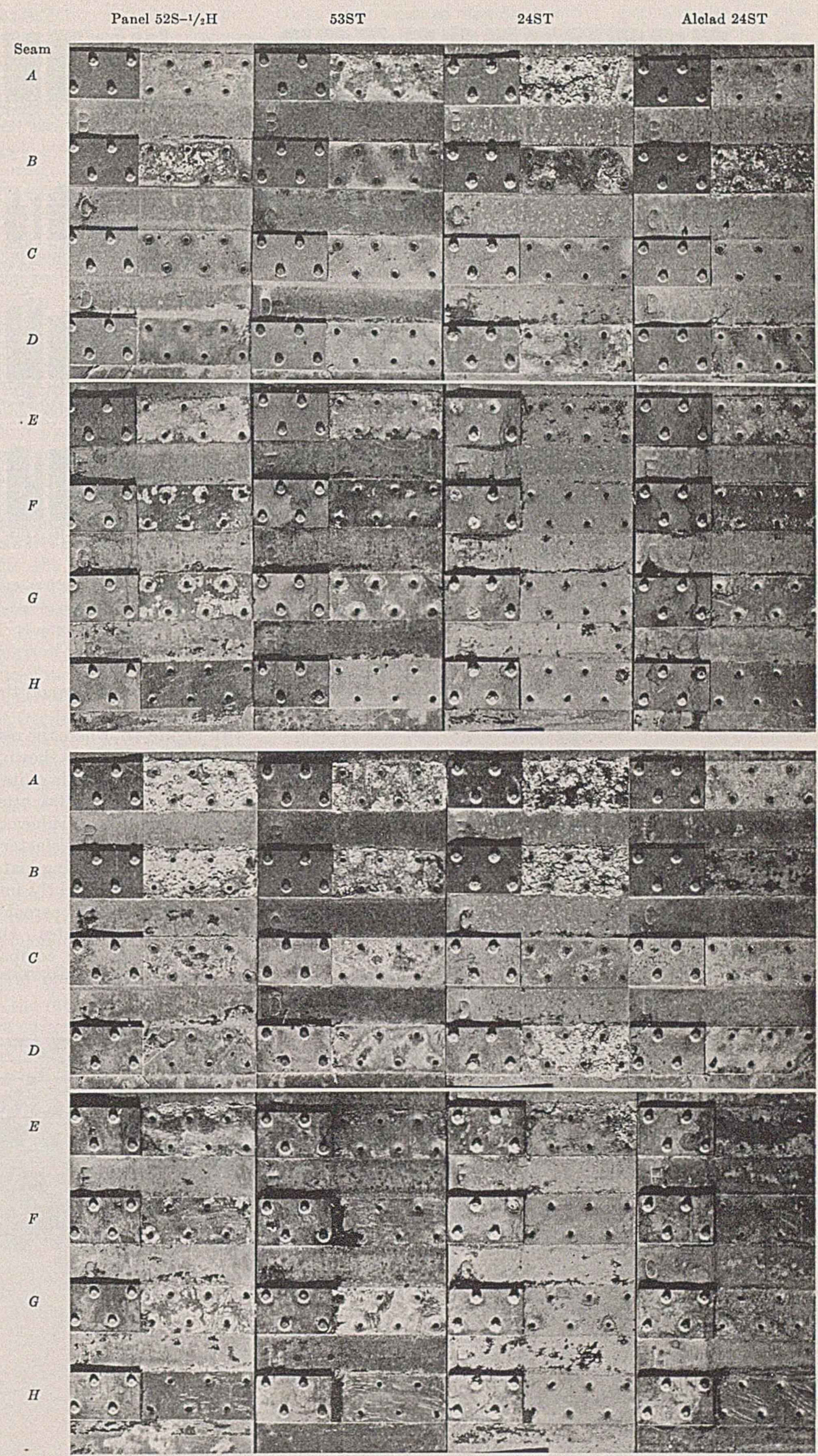
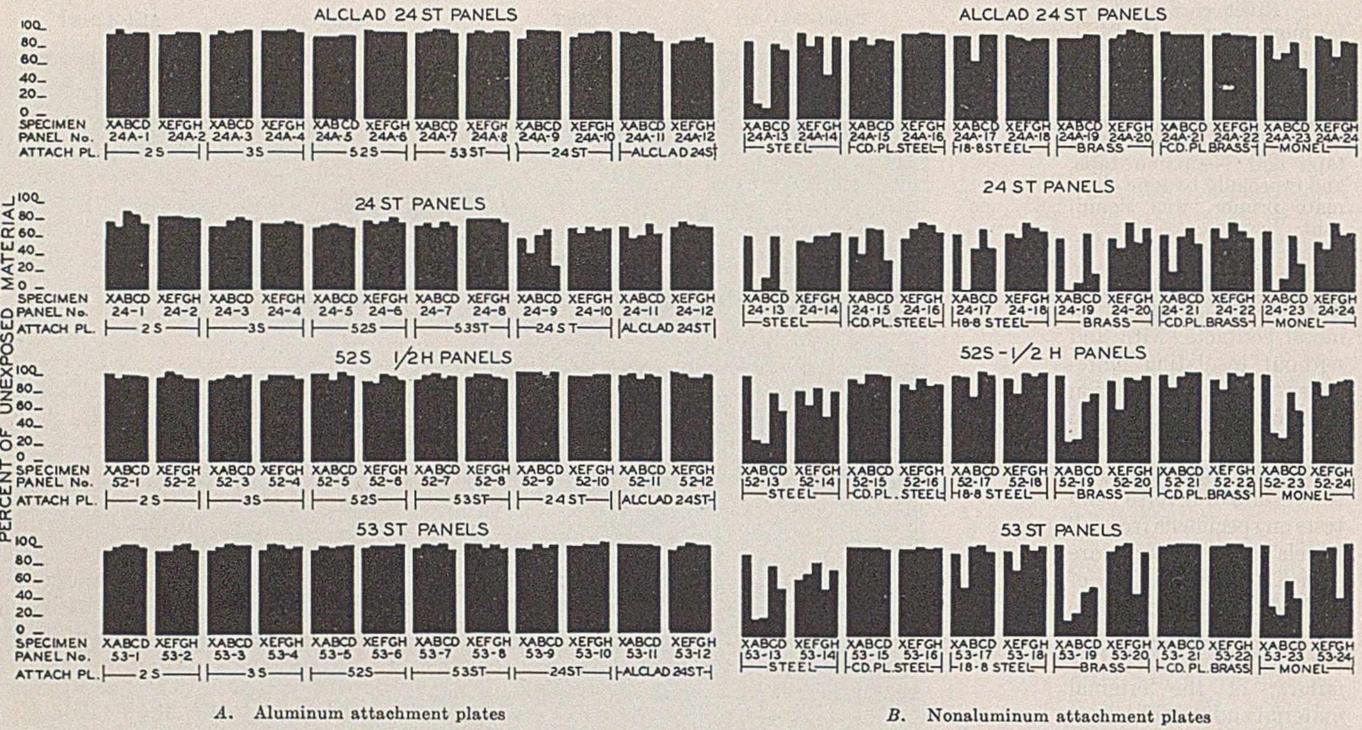


Figure 3. Effect of Exposure on Panels Made with 18–8 Steel Attachment Plates (*above*) and with Naval Brass Attachment Plates (*below*)



A. Aluminum attachment plates

B. Nonaluminum attachment plates

FIGURE 4. RESULTS OF REVERSE BEND TESTS OF WROUGHT ALUMINUM ALLOYS IN CONTACT WITH SPECIMENS FROM ALL PANELS AND SEAM AREAS

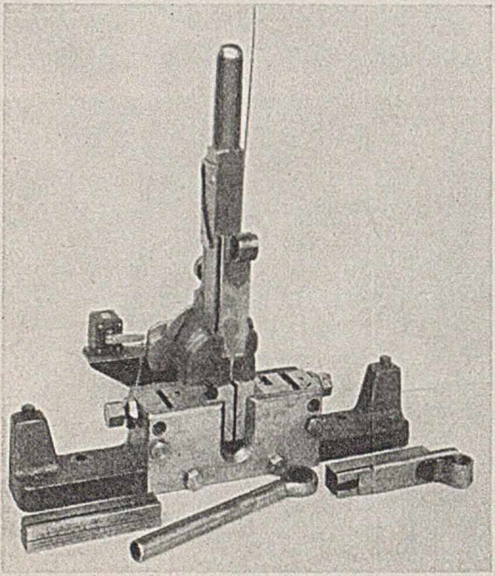


FIGURE 5. APPARATUS FOR BENDING TESTS

sion specimens, where the area under consideration is often too small for standard tension specimens and where the scatter of values always resulting from nonuniform corrosive attack demands the average of several determinations for an accurate evaluation.

It is apparent (Figure 4*A*) with the panel having the various aluminum alloys as attachment plates that there was no impairment of physical properties in either the panel proper or seam areas of the Alclad 24ST, 53ST, or 52S-$^1/_2$H panels. The anodized 24ST panels, however, showed a loss of approximately 20 per cent in the panel proper, with the seam areas being stronger than the panel in many cases. This condition would be anticipated from the fact that all of the aluminum alloy attachment plates employed were anodic to the 24ST sheet and would therefore protect the sheet in seam areas.

In Figure 4*B*, where the results obtained with nonaluminum attachment plates are shown, the superior corrosion resistance of Alclad 24ST alloy is quite obvious. With the exception of steel and Monel metal attachment plates, all seam areas showed reverse bend value equal to the original material, and with these plates satisfactory protection was obtained with several of the insulating materials. The 52S-$^1/_2$H and 53ST panels were only slightly inferior to Alclad 24ST; their inferiority was most apparent in the case of brass and Monel metal attachment plates. On all four of the aluminum alloy panel materials, the comparison between cadmium-plated and unplated steel and brass should be noted. With the

FIGURE 6. INTERGRANULAR CORROSION OF 53ST RIVET IN CONTACT WITH 24ST SHEET (×50)

(Compare Figure 8*B*)

plated metals practically complete protection of the aluminum alloys was obtained in every instance; without the cadmium coating serious corrosion occurred in most instances. Of the insulating materials, zinc chromate primer, friction tape, and Neoprene tape were most efficient; the latter in general was most effective. Iron oxide primer was definitely inferior to zinc chromate primer, a fact which has been demonstrated repeatedly in previous tidewater tests. Fabric impregnated with zinc chromate powder gave erratic results. In some seams it proved quite efficient, in others it appeared to be of little value.

These results show clearly the value of insulating materials for inhibiting corrosion in dissimilar metal joints when tested under conditions of tidewater exposure. The more efficient materials of the test (cadmium plating, paint type coatings, tapes) have been required in seam areas and dissimilar metal contacts of Army aircraft for many years.

MICROSCOPIC EXAMINATION. In the second group of tidewater panels (Table III) in which combinations of seven different aluminum alloy sheets and five different aluminum alloy rivets were employed, the evaluation of the specimens was by means of microscopic examination. In this series no apparent corrosion of either rivet or panel was observed on any except the 24ST panels. With this alloy severe rivet corrosion occurred with every type of rivet used; the attack was greatest on the 2S and 53ST rivets, the latter showing intergranular corrosion (Figure 6). Figure 7 shows the appearance of part of the 24ST and Alclad 24ST panels on which 2S, 53ST, A–17ST, 17ST, and 24ST rivets were used. Photomicrographs of the rivet-sheet joints of the 24ST and Alclad 24ST series of panels are reproduced in Figure 8 and clearly indicate both the severe corrosive attack on all rivets in contact with the 24ST alloy, and the freedom from corrosion on both sheet and rivets where the same rivets were used to join Alclad 24ST. Photomicrographs of the rivet-sheet joints of the 2S, 3S, 4S, 52S, and 53ST panels showed no attack on either sheet or rivets and were of the same general appearance as the Alclad 24ST rivet series. Figure 8 should be viewed solely from the standpoint of corrosion. All panels were riveted with a hammer and rivet set, using a flat plate to back up the heads. The various examples of crooked rivets, flattened heads, and incomplete and nonuniform settings are the result of the manual method employed.

Potentials of Dissimilar Cells

In any dissimilar metal couple the rate of corrosion is proportional to the magnitude of the current flowing in the cell. It is often assumed that the relative magnitude of this current and the resulting corrosion probabilities may be predicted from the open cell voltage as calculated from the single potentials of the metals forming the couple. That such predictions may often be erroneous is shown by comparing the results obtained on these tidewater panels with those which would be predicted from cell potentials based on the single potentials of the alloys. Table IV lists the single potential of each alloy as measured against a 0.10 N calomel electrode in normal sodium chloride containing 0.3 per cent of hydrogen peroxide. Table IV also includes the cell voltage as calculated from single potentials of each couple used on the tidewater panels and the corroding electrode of each couple. In many instances the actual results are in strict agreement with potential measurements. In others, however, corrosion is much greater or much less than potential values would indicate. The potential of corrosion-resistant (18–8) steel, for example, is 0.40 volt higher than X–4130 steel and 0.19 volt higher than brass against any aluminum alloy; yet under the exposure conditions employed in this test, 18–8 steel with the highest potential difference induced the least corrosive attack and X–4130 steel with the lowest potential difference (cadmium excepted) induced the most severe attack of the nonaluminum attachment plates employed. Here passive film formation in the case of the 18–8 steel and local cell action with X–4130 steel through their influence on current flow were the controlling factors in the corrosion process, and their effect would not be predicted from the cell voltage as calculated from single potentials. On the other hand, the successful performance of the cadmium coating on brass and steel plates in contact with Alclad 24ST, 52S–$^{1}/_{2}$H, and 53ST, and the failure of the same coating in contact with 24ST alloy are in accord with the relative currents that would be assumed from the various single potentials. The potential difference between cadmium and the first group of alloys is 0.01 volt with Alclad 24ST and 53ST, and 0.04 volt with 52S–$^{1}/_{2}$H (cadmium was the cathode in all cells). In contact with 24ST a potential of 0.14 volt exists, with cadmium anodic and its rate of solution increased by the higher potential.

In the rivet series where the corrosion is in agreement with potential measurements, the relation between the anode and cathode areas of the cell is a significant factor. The same potential obtains between 24ST rivets on 2S sheet as with 2S rivets on 24ST sheet; the 2S material is the corroding electrode in both couples. In the former, however, the entire panel forms the anode with the corrosive attack spread over a large area, resulting in no apparent damage to either appear-

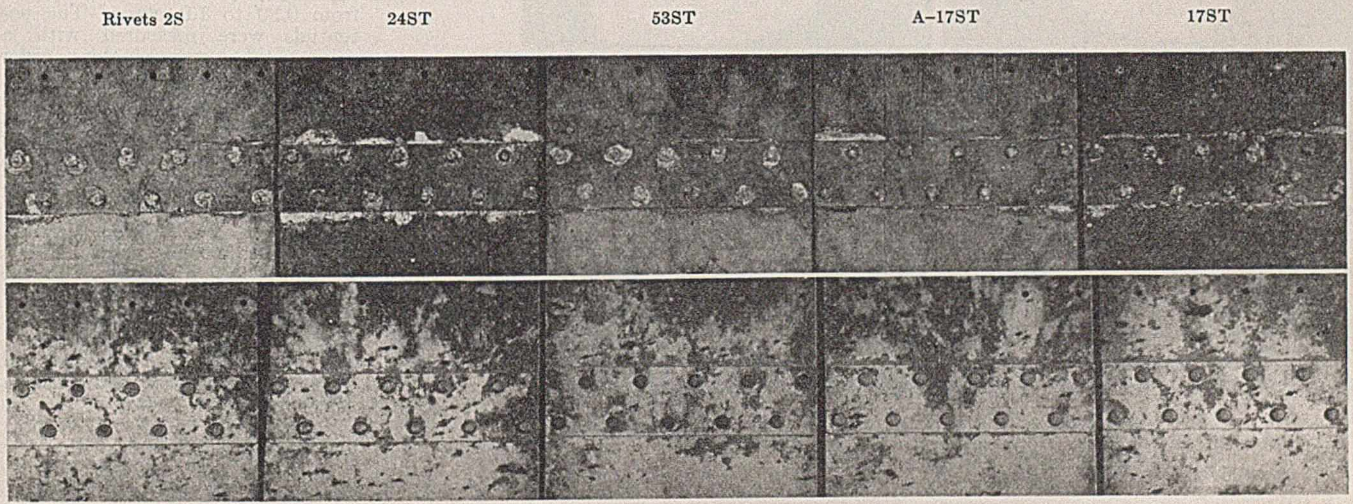


FIGURE 7. EFFECT OF EXPOSURE ON RIVETS IN 24ST PANELS (*above*) AND ALCLAD 24ST PANELS (*below*)

ance or physical properties; in the latter, corrosion is concentrated on the small area of the rivet with the high anode current density, producing severe attack in a short time. The selective corrosion of 24ST and 17ST rivets on 24ST alloy sheet, where the normal potential of both rivets and sheet is the same, may be the result of differences in quenching rates of sheets and rivets, or of strains induced by cold working of the metal in the riveting operation.

Current-Potential Measurements

Potential and current measurements of all of the dissimilar metal couples employed in the tidewater panels were determined under laboratory conditions using a 3 per cent solution of sodium chloride as an electrolyte and for electrodes, specimens taken from the same sheets as the tidewater panels. The electrodes were 5.1 × 10.2 cm. (2 × 4 inches) with a 5.1-cm. tail, coupled together and separated 1.27 cm. (0.5 inch) by a Bakelite screw and nut assembly and a Bakelite plate. A 500-ml. tall form beaker was used as the container for the 3 per cent sodium chloride electrolyte prepared from high-purity sodium chloride and air-saturated distilled water. The solution was not aerated during the test. The cell assembly is shown in Figure 9.

The current developed by a cell was indicated on a high-sensitivity suspension-type galvanometer using as a shunt a 1-ohm resistance made of No. 28 Constantan wire and mounted on top of the cell. A decade box was used as a multiplier for changing the range of the ammeter. This ammeter, which consisted of the galvanometer, decade box, and shunt, was calibrated with a precision microammeter. If a conventional multirange ammeter had been employed, the load resistance on the cell might have varied from 0.2 to 200 ohms. With the type used, the load resistance ranged from 0.90 to 1.0 ohm. The potentials were measured with a vacuum tube potentiometer in order not to polarize the cell. The apparatus for the current-potential measurements was placed in a constant-temperature room maintained at 23° ± 2° C. (73.4° ± 3.6° F.). The electrical hookup for the apparatus is shown in Figure 10.

All of the plates used for electrodes were cleaned with benzene to remove any oil film. With the exception of Alclad 24ST, anodized 24ST, X-4130 steel with mill scale, corroded X-4130 steel, and cadmium-plated X-4130 steel, all specimens were brushed with a motor-driven wire wheel to remove the oxide films. The final cleaning for Alclad 24ST was with steel wool. The anodized 24ST, X-4130 steel with mill scale, cadmium-plated brass, cadmium plated X-4130 steel, and corroded X-4130 steel

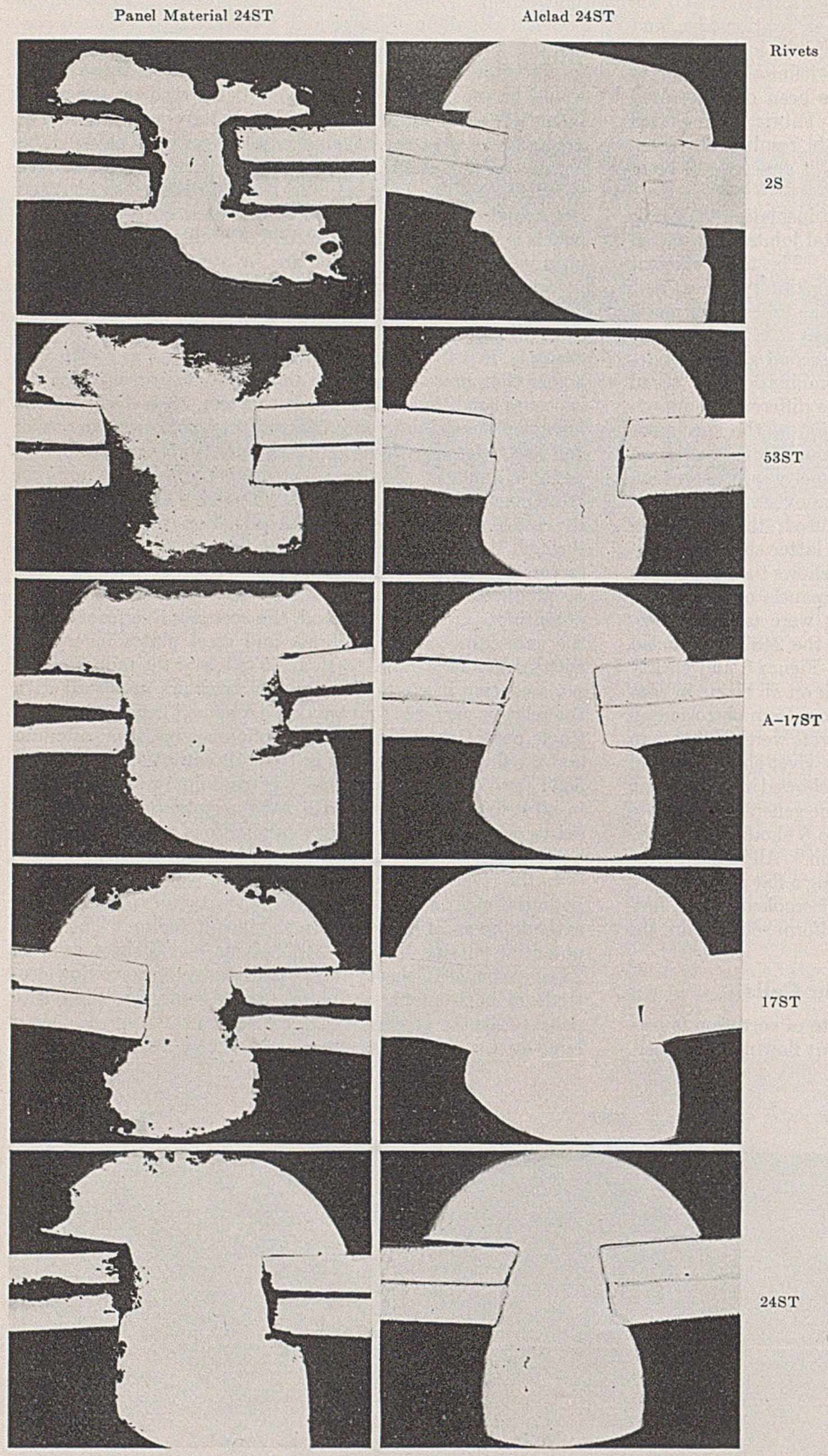


Figure 8. Photomicrographs of Rivet-Sheet Joints of 24ST Panels (*left*) and Alclad 24ST Panels (*right*)

TABLE IV. POTENTIALS OF DISSIMILAR CELLS IN NORMAL SODIUM CHLORIDE CONTAINING 0.3 PER CENT HYDROGEN PEROXIDE[a]

Other Electrode	Single Potential[b]	Common Electrode[c]															
		2S		3S		4S		52S		53ST		17ST		24ST		Alclad 24ST	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
2S	0.83	0.00	...	0.00	...	0.01	4S	0.03	52SH	0.00	...	0.15	2S	0.15	2S	0.00	....
3S	0.83	0.00	...	0.00	...	0.01	4S	0.03	52SH	0.00	...	0.15	3S	0.15	2S	0.00	....
4S	0.84	0.01	4S	0.01	4S	0.00	...	0.02	52SH	0.01	4S	0.16	4S	0.16	4S	0.01	4S
52SH	0.86	0.03	52SH	0.03	52SH	0.02	52SH	0.00	...	0.03	52SH	0.18	52SH	0.18	52SH	0.03	52SH
53ST	0.83	0.00	...	0.00	...	0.01	4S	0.03	52SH	0.00	...	0.15	53ST	0.15	53ST	0.00	....
17ST	0.68	0.15	2S	0.15	3S	0.16	4S	0.18	52SH	0.15	53ST	0.00	....	0.00	.....	0.15	Alclad
A-17ST	0.73	0.10	2S	0.10	3S	0.11	4S	0.13	52SH	0.10	53ST	0.05	A-17ST	0.05	A-17ST	0.10	Alclad
24ST	0.68	0.15	2S	0.15	3S	0.16	4S	0.18	52SH	0.15	53ST	0.00	....	0.00	.....	0.15	Alclad
Alclad	0.83	0.00	...	0.00	...	0.01	4S	0.03	52SH	0.00	...	0.15	Alclad	0.15	Alclad	0.00	....
Cadmium	0.82	0.01	2S	0.01	3S	0.02	4S	0.04	52SH	0.01	53ST	0.14	Cd	0.14	Cd	0.01	Alclad
Steel[d]	0.49	0.34	2S	0.34	3S	0.35	4S	0.37	52SH	0.34	53ST	0.19	17ST	0.19	24ST	0.34	Alclad
18-8 steel	0.09	0.74	2S	0.74	3S	0.75	4S	0.77	52SH	0.74	53ST	0.59	17ST	0.59	24ST	0.74	Alclad
Brass	0.28	0.55	2S	0.55	3S	0.56	4S	0.58	52SH	0.55	53ST	0.40	17ST	0.40	24ST	0.55	Alclad
Monel metal	0.10	0.73	2S	0.73	3S	0.74	4S	0.76	52SH	0.73	53ST	0.58	17ST	0.58	24ST	0.73	Alclad

[a] From a private communication from the Aluminum Company of America.
[b] Measured against 0.1 *N* calomel half cell.
[c] Columns A = cell voltage; columns B = corroding electrode.
[d] Rivet stock.

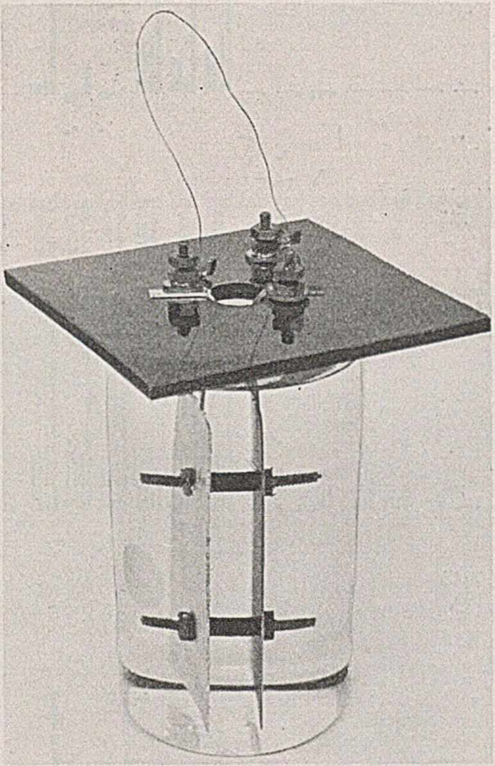


FIGURE 9. CELL ASSEMBLY

(formed by allowing the clean plate to corrode naturally in the air after immersion in 3 per cent salt solution) were used without further treatment.

The corrosion couples were run in groups of ten. The normal positions for the switches (Figure 10) were *S*3 on the left contact shorting each cell through its 1-ohm resistor and *S*1 and *S*2 open. By closing *S*1 and *S*2 on the cell under test, the current flowing in that cell could be determined without disturbing the couple. *S*1 and *S*2 were then opened before proceeding to the next cell. For potential readings, *S*3 was thrown on the right contact for all cells and *S*1 closed for each cell in turn. *S*3 was left in voltage position until all cells reached equilibrium. The 5-megohm resistor prevented accidental shorting of the cell while potential measurements were being made and prevented polarization of the cell by the potentiometer.

Current measurements were taken 1 hour after the cell was immersed and at 2-hour intervals thereafter during the working day. Potential measurements were taken after 48- and 72-hour immersion. The duration of the test was 3 days.

The current and potential values of each metal coupled with all the other metals used in this investigation are shown graphically in Figure 11. The data reported are correct only for the particular metals used and for the conditions under which the measurements were made. Modifications in any of the conditions may produce materially different values.

For aluminum alloys coupled with other aluminum alloys, these values are for the most part consistent with the results from tidewater exposure tests and with the corrosion predictions of the potential values given in Table IV. In combination with some of the nonaluminum alloys, however, the values obtained agree neither with exposure tests nor potential predictions. There is little indication, for example, from the values shown in Figure 11*F* or from the potential values of Table IV that any appreciable difference in corrosion resistance would be obtained from Alclad 24ST alloy in contact with either brass, Monel metal, or 18-8 steel. On tidewater tests, however, 18-8 steel induced far less corrosive attack than either brass or Monel metal. There is no indication that the durability of cadmium under tidewater exposure conditions would be considerably less on anodized 24ST than on Alclad 24ST, 52S-$^1/_2$H, or 53ST. This difference in the durability of cadmium is, however, predicted from potential measurement (Table IV) made in sodium chloride solutions containing hydrogen peroxide. The values in Figure 11*E* indicate that X-4130 steel, whether clean, corroded, or coated with mill scale, is anodic to 24ST alloy and therefore capable of offering to this aluminum alloy about the same electrolytic protection as either cadmium or pure aluminum. With this steel in contact with anodized 24ST alloy (Figure 11*G*), the

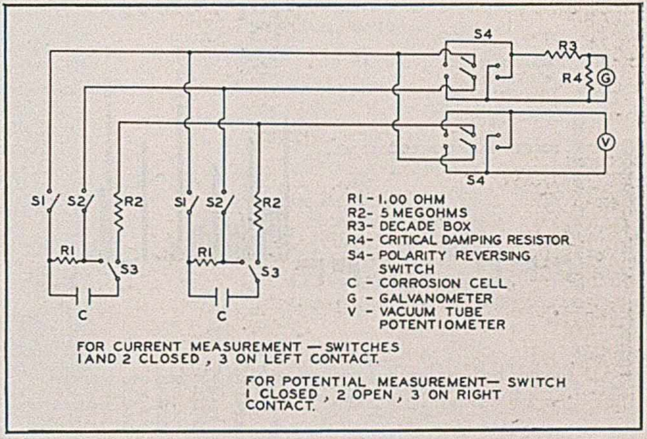


FIGURE 10. HOOKUP FOR DETERMINATION OF CURRENT AND VOLTAGE

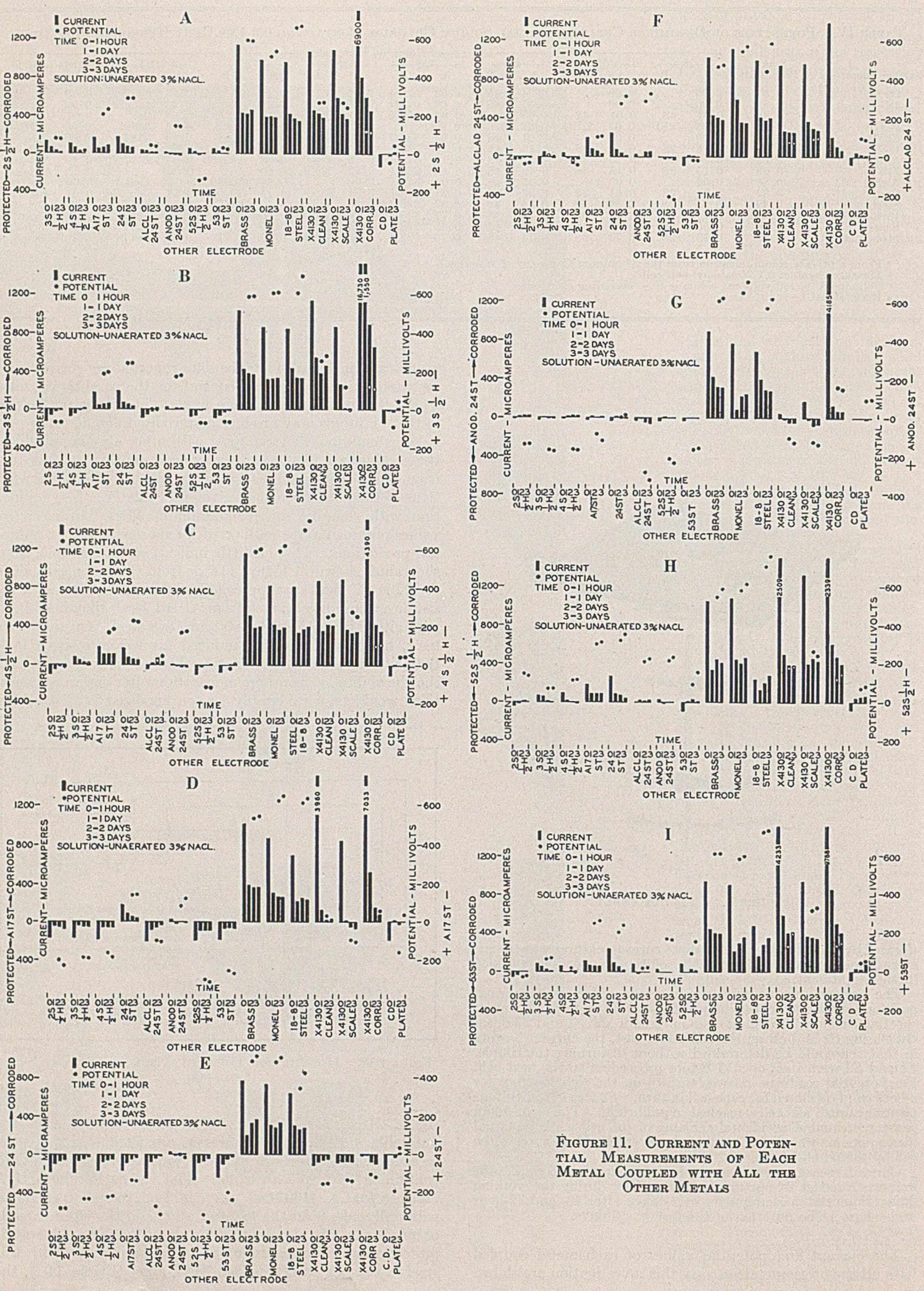


Figure 11. Current and Potential Measurements of Each Metal Coupled with All the Other Metals

polarity tends to be reversible, but in all cases except the initial current flow with corroded steel, the values would indicate good corrosion resistance from this couple. On tidewater tests X-4130 steel attachment plates caused far greater corrosive attack than any other metal.

The fact that in the present test the current-potential measurements do not agree in all cases with tidewater tests, even though both were made in the same type of electrolyte, does not indicate that the former are of questionable value; it rather indicates that to predict corrosion probabilities from current-potential measurements, the laboratory test procedure must reproduce all conditions prevailing in the exposure test. This requirement was not fulfilled in this investigation and for most exposures it would be an impossibility. The current-potential values here reported were obtained in a period of 3 days whereas the same couples on the tidewater panels were subjected to salt water for a period of 6 months. The opportunity for film failure (anodic coating, cadmium plating) and their resulting reactions were quite different in the two tests. The laboratory tests were made in a still unaerated solution with the electrodes separated and under constant immersion; on the tidewater panels the dissimilar metals were in direct contact (on plates *A* at least), and exposure was in the aerated, constantly moving solution with panels alternately wet and dry. In the laboratory test anode corrosion products were not in contact with the cathodic electrode; in the seam areas of tidewater panels corrosion products were in contact with both electrodes. The conditions of exposure control the production of passive films, the formation of concentration and oxidation-reduction cells, changes in cell resistance, and reversals of polarity, all of which affect the magnitude and direction of the corroding current. The nonagreement between actual exposure results and corrosion predictions from laboratory current-potential measurements is caused by the failure to control these secondary but important reactions in both methods. Where these reactions do not develop or are of little significance, corrosion probabilities are accurately predicted by potential differences with the severity of attack (current flow), a direct function of the magnitude of the voltage developed by the cell.

THE PHARMACIST

By Cornelis Pietersz Bega
(1620–1664)

Through the continued, kind cooperation of Sir William J. Pope we are able to reproduce a second painting by this prominent Dutch artist as No. 101 in the Berolzheimer series of Alchemical and Historical Reproductions.

The original, 14 by $12^1/_2$ inches in size, is on a panel and is in Sir William's extensive collection of alchemical paintings, prints, and memorabilia.

It will be noted that the pharmacist is performing a weighing operation on a hand scale, closely resembling those still in use.

Apparently the furnace in the background was not used as evidenced by the clothes on and near it.

Since the worker is wearing a "tam" and shows one leg bare, it might be assumed that he is a Scot. But the presence of only one small still rather contradicts this.

50 East 41st Street
New York, N. Y.

D. D. BEROLZHEIMER

A complete list of the first 96 reproductions appeared in our January, 1939, issue, page 124.
An additional reproduction appears each month.

Direct Solution of Isothermal Flow in Long Pipes[1]

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The application of dimensional analysis to the subject of fluid flow in pipes is reviewed briefly. The dimensionless ratios involved are given in terms of mass flow rate, *w*, as the most generally suitable unit for measuring flow. It is pointed out that trial-and-error solution for flow rate or pipe size is unnecessary if all of the dimensionless ratios available are made use of, and a number of different plots are presented for this purpose. Since each variable in fluid flow of this type will not appear in some one dimensionless ratio, the ratio omitting the unknown may be computed immediately, and from a plot of this ratio against any other, the latter may be read and the unknown calculated. One or two curves only can be made to cover all the possible cases.

It is believed further that the complete exposition of the several dimensionless ratios involved may serve to clarify the study of fluid flow considerably.

IN THE study of fluid flow the following variables, expressed in engineering units, are believed to constitute the most generally convenient single set:

s = dP/dL = friction pressure gradient, lb.(force)/(sq. ft.)(ft.)
w = total mass flow rate, lb.(mass)/sec.
D = pipe diameter, ft.
μ = absolute fluid viscosity, lb.(mass)/(ft.)(sec.)
ρ = fluid density, lb.(mass)/cu. ft.

That these physical variables suffice to describe isothermal flow in long pipes of given surface characteristics is shown by the excellent correlation obtained when the friction factor, f, is plotted against the Reynolds number, Re, for the case of smooth pipes. In an engineering system of units, the fundamental law of motion is

$$\text{force} = \frac{1}{g_k}\,(\text{mass}) \times (\text{acceleration})$$

where g_k is numerically equal to the standard acceleration of gravity (32.174 in the system chosen here). The factor g_k may be regarded as a dimensionless number by which forces and pressures should be multiplied in order to make the system of units equivalent to an absolute system. In an absolute system the size of the unit of force is so chosen that $g_k = 1$ in the relation between force, mass, and acceleration. If, therefore, the dimensionless ratios of the pipe flow problem are all to be invariant with respect to a change from an engineering system to an absolute system, certain ratios must contain g_k, hereafter written simply g.

Dimensionless Ratios

We may easily demonstrate that the variables involved in fluid flow can be arranged into significant dimensionless ratios other than Re and f.

In the usual dimensional analysis of fluid flow (*8*) the exponents of the other variables are solved in terms of the exponents of pressure loss and of viscosity. This causes the Reynolds number and friction factor, respectively, to be the dimensionless ratios left after gathering terms. Solving instead in terms of the exponent of velocity or flow rate causes the von Kármán number, not containing flow rate, to appear. Solving in terms of the diameter, a fourth dimensionless number appears which the author will call the "size factor", and which does not contain D.

Solving in terms of density, a fifth dimensionless number is obtained with some systems of variables, but in the system here adopted, this number is identical with the Reynolds number, s and ρ always appearing in each ratio to the same power.

Secondly, the von Kármán number and the size factor may also be obtained by multiplying together such powers of the Reynolds number and friction factor as will cause flow rate and diameter, respectively, to cancel out of the product.

Lastly, Buckingham's π theorem (*1*) shows that if there are five significant variables and three dimensions, two (five − three) dimensionless ratios, each involving no more than four variables, will generally occur in the final solution. The possible ratios may be worked out separately from different groups of four of the variables.

These methods all give the same ratios, which will be rigidly defined for this paper as follows:

$$\text{Reynolds No. } (Re_1) = \frac{w}{D\mu} \text{ (does not contain } s \text{ or } \rho)$$

$$\text{Friction factor } (f_1) = \frac{sg\rho D^5}{w^2} \text{ (does not contain } \mu)$$

$$\text{von Kármán No. } (K = Re_1 f_1^{1/2}) = \frac{(sg\rho)^{1/2} D^{3/2}}{\mu} \text{ (does not contain } w)$$

$$\text{Size factor (S. F.} = Re_1^{5/2} f_1^{1/2}) = \frac{(sg\rho)^{1/2} w^{3/2}}{\mu^{5/2}} \text{ (does not contain } D)$$

Final Graphical Presentation

Inspection of the ratio Re_1 shows that, if the unknown quantity in a flow problem is friction pressure gradient, Re_1 can be calculated from the known quantities, f_1 read from the above-mentioned chart, and s calculated. Similarly, μ might be solved directly by calculating f_1 which does not contain it, reading Re_1 from the chart, and calculating μ from Re_1.

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[1] Presented as part of the symposium on fluid dynamics at Carnegie Institute of Technology, Pittsburgh, Penna. Other papers appeared in April, 1939, pages 408–486, and on pages 622–629 of this issue.

However, many flow problems require the determination of the flow rate or of the diameter, the other quantities in either case being fixed. In both types of problem it is impossible to calculate directly either Re_1 or f_1, and many texts state that solution may be obtained only by trial and error. It is clear, however, that if the other two ratios K and S. F. are plotted against f_1, then w or D, respectively, may be solved directly without trial and error, as well as μ in both cases.

The plot of $f_1^{-1/2}$ *vs.* log K (*3*, *7*, *9*) accomplishes this result for w, with the added advantage that the line obtained in the turbulent region at usual velocities is straight, as far as can be determined by the data available. The plots of $f^{-1/2}$ *vs.* log S. F. and log Re have also been considered (*6*).

In order to make it possible to compute directly whichever variable in a fluid flow problem is unknown, Figures 1 and 2 were plotted. A decrease to 2 in the number of curves necessary is obtained by plotting f_1, Re_1, K, and S. F. against each other in pairs. In Figure 1 the curves of $1/\sqrt{f_1}$ *vs.* log K were obtained from the equations of Drew and Genereaux (*2*) by converting to the present f_1. From them, all other curves in this paper were computed, point by point.

Figure 1 has the advantage that all of the turbulent flow plots are sensibly straight. The equations for the four lines shown are as follows:

For turbulent flow:

$$\text{smooth pipe:}\quad \frac{1}{\sqrt{f_1}} = 2.22 \log_{10}K - 0.56$$

$$\log \text{S. F.} = 2.39 \log Re_1 - 0.36$$

which condenses to:

$$sg\rho = 0.1906 \frac{w^{1.78}\,\mu^{0.22}}{D^{4.78}} = 0.1906 \frac{w^2}{D^5}\left(\frac{w}{D\mu}\right)^{-0.22}$$

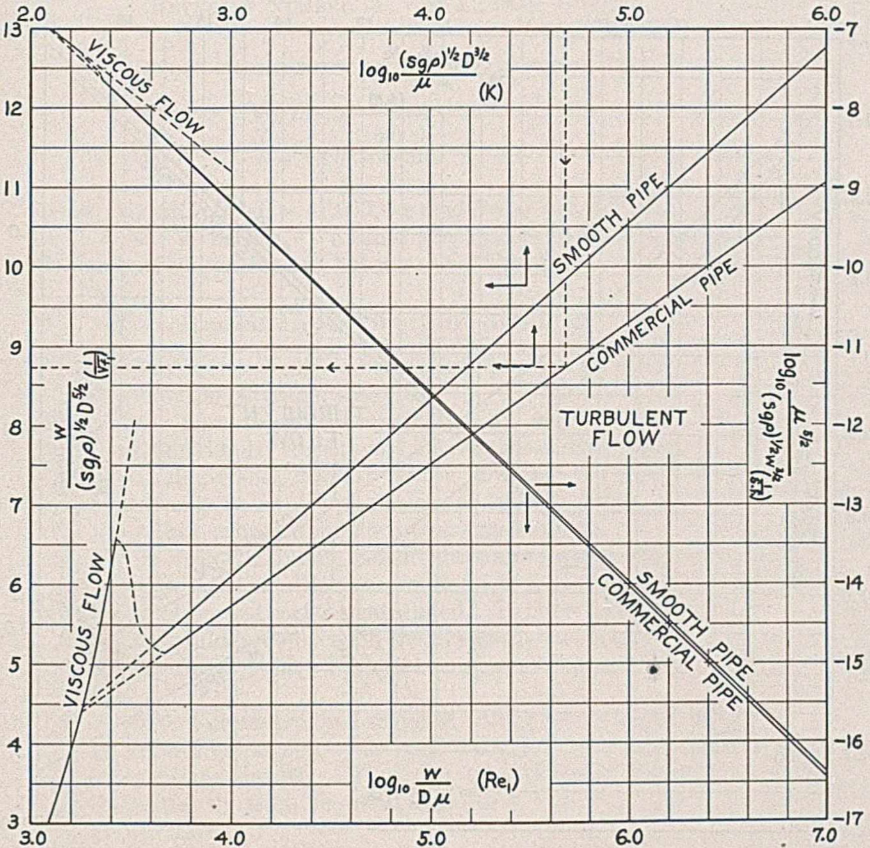

FIGURE 1. STRAIGHT-LINE CHART OF (FRICTION FACTOR)$^{-1/2}$ *vs.* VON KÁRMÁN NUMBER, AND REYNOLDS NUMBER *vs.* SIZE FACTOR

$$\text{average for commercial pipe:}\quad \frac{1}{\sqrt{f_1}} = 1.777 \log_{10}K + 0.399$$

$$\log \text{S. F.} = 2.41 \log Re_1 - 0.42$$

which condenses to:

$$sg\rho = 0.1445 \frac{w^{1.82}\,\mu^{0.18}}{D^{4.82}} = 0.1445 \frac{w^2}{D^5}\left(\frac{w}{D\mu}\right)^{-0.18}$$

[Genereaux (*4*) obtains by another means the equivalent of $sg\rho = 0.1252\,(w^2/D^5)(w/D\mu)^{-0.16}$, which includes a margin of safety beyond average conditions.]

For viscous flow:

$$sg\rho = \frac{128}{\pi}\frac{w\mu}{D^4}\ \text{(Poiseuille)}$$

Each of these formulas may be used to calculate either of the unknowns for which its plot is used. The condensed formulas may also be used in calculating w, at some sacrifice in accuracy.

In the graphical determination of s, D, or μ, Figure 2 is more accurate and for w equally accurate. The pairs of dimensionless ratios are picked in such a way that in each case the ratio omitting a given variable is plotted against the ratio in which this same variable occurs to the highest power with respect to the other variables present.

Table I is included to facilitate replotting the curves. Logarithms on linear scales were plotted for ease in interpolation, but logarithmic scales may be found more convenient in replotting the curves. All of the principles and methods described here also apply when the commoner definitions of Re and f are used, but the scales for these ratios would have to be multiplied by the proper correction factor. If for Re the ratio $DV\rho/\mu$ were to be used, the scale should be multiplied by $4/\pi$. If for f, $sgD/(2\rho V^2)$ were substituted, the multiplier is $\pi^2/32$.

The scales are labeled with the dimensionless ratios, instead of symbols (such as f), and thus eliminate the need for an auxiliary defining equation (particularly the Fanning equation, or the Darcy equation, with their additional constants of 2 and $^1/_2$, respectively).

Direct Solution by Friction Factor—Reynolds Number Chart

As previously stated s (or ρ) or μ may be determined directly by the f_1 *vs.* Re_1 chart (Figure 3). In solving for w by trial and error, a value of w is assumed, f_1 and Re_1 are calculated, and the point is plotted on the f_1–Re_1 chart. If this point does not fall on the desired curve, another is calculated with a new value of w. It is obvious that all such points in a given problem will lie on a straight line on the log-log plot. Furthermore, the lines obtained in different problems will always have the same slope (namely, -2) since Re_1 is directly proportional to w, and f_1 to w^{-2}. Therefore, a direct solution may be obtained for any problem in which w is unknown by assuming

Table I. Data for Replotting Curves

		Smooth Pipe							Average Commercial Pipe						
Log K	K	Log Re_1	Re_1	Log f_1	f_1	$\frac{1}{\sqrt{f_1}}$	Log S. F.	S. F.	Log Re_1	Re_1	Log f_1	f_1	$\frac{1}{\sqrt{f_1}}$	Log S. F.	S. F.
2.6	398	3.317	2,075	−1.434	0.0368	5.21	7.6	3.98×10^7	3.299	1,999	−1.401	0.0397	5.02	7.55	3.56×10^7
3.0	1,000	3.785	6,100	−1.571	0.0269	6.1	8.68	4.77×10^8	3.758	5,730	−1.517	0.03045	5.73	8.64	4.35×10^8
3.4	2,512	4.244	17,560	−1.689	0.02046	6.99	9.77	5.85×10^9	4.209	16,180	−1.618	0.0241	6.44	9.71	5.17×10^9
3.8	6,310	4.696	49,700	−1.793	0.0161	7.88	10.85	7.01×10^{10}	4.654	45,140	−1.709	0.01955	7.15	10.78	6.06×10^{10}
4.2	15,850	5.143	139,000	−1.886	0.01302	8.76	11.92	8.23×10^{11}	5.096	124,700	−1.791	0.01617	7.86	11.84	6.98×10^{11}
4.6	39,810	5.585	384,400	−1.970	0.01072	9.65	12.98	9.5×10^{12}	5.533	341,400	−1.867	0.0136	8.57	12.90	7.96×10^{12}
5.0	100,000	6.023	1,054,000	−2.046	0.009	10.54	14.03	1.08×10^{14}	5.968	928,000	−1.936	0.0116	9.28	13.95	8.94×10^{13}
5.4	251,000	6.458	2,870,000	−2.116	0.00765	11.43	15.09	1.22×10^{15}	6.4	2,511,000	−2.0	0.01001	9.99	15.00	1.00×10^{15}
5.8	631,000	6.890	7,770,000	−2.181	0.00659	12.32	16.14	1.37×10^{16}	6.83	6,755,000	−2.059	0.00865	10.71	16.05	1.11×10^{16}
6.2	1,585,000	7.321	20,940,000	−2.242	0.00573	13.2	17.18	1.52×10^{17}	7.257	18,100,000	−2.117	0.00763	11.42	17.09	1.22×10^{17}

a convenient value for it (usually 1, 10, etc.) that will give values of f_1 and Re_1 on the chart, plotting this point, and passing through it a line of slope −2 which intersects the appropriate f_1–Re_1 curve, then reading off Re_1 and calculating back to obtain w.

Direct solution for D may be obtained similarly, except that the lines of varying D have a slope of −5.

Figure 3 is the standard plot of f_1 *vs.* Re_1, with lines of varying w and of varying D drawn in. (A combination of versions of this plot and of Figure 4 is presented by Johnson, *5*.)

Direct Solution for w, D, and s

Inasmuch as the problem of determining μ would seldom arise, simplification is obtained by omitting f_1. Re_1 may be plotted against K, and lines of varying D (slope = $-^3/_2$) superimposed. Inspection shows that a line of varying or unknown D corresponds to a definite value of S. F. Figure 4 is plotted on logarithmic scales for scale values of S. F.

In using this chart on a problem in which w, s, or D is unknown, the dimensionless ratio not containing this quantity is calculated, the corresponding point on the appropriate curve found, and one of the other two dimensionless ratios read off and used to calculate the unknown.

Typical Problem. What water flow rate will be obtained through a 4-inch, nominal size steel pipe, 1000 feet long, if the water is at 68° F. (20° C.) and the pressure drop available is 93.73 pounds per square inch?

$$s = \frac{93.73 \times 144}{1000} = 13.5 \text{ lb./sq. ft./ft.}$$

$$D = \frac{4.026}{12} = 0.3355 \text{ ft.}$$

$$\rho = 62.3 \text{ lb./cu. ft.}$$

$$\mu = 0.000672 \times 1.00 = 0.000672 \text{ lb./ft./sec.}$$

Since w is the unknown quantity, K is the dimensionless ratio that can be calculated, giving:

$$K = \frac{(13.5 \times 32.2 \times 62.3)^{1/2}\,(0.3355)^{3/2}}{0.000672} = 47{,}600$$

$$\log K = 4.677$$

Using Figure 1, we obtain from the commercial pipe plot of K against $(f_1)^{-1/2}$:

$$(f_1)^{-1/2} = 8.73 = \frac{w}{(13.5 \times 32.2 \times 62.3)^{1/2}\,(0.3355)^{5/2}}$$

and finally w = 93.5 lb./sec. or 1.50 cu. ft./sec.

Using Figure 2, from K against Re_1:

$$\log Re_1 = 5.62;\quad Re_1 = 415{,}000 = \frac{w}{0.3355 \times 0.000672}$$

$$w = 93.5 \text{ lb./sec.}$$

Using Figure 3, let us assume a trial value of w of 50 pounds per second:

$$Re_{1\text{trial}} = 222{,}000;\quad \log Re_{1\text{trial}} = 5.346$$
$$f_{1\text{trial}} = 0.0460;\quad \log f_{1\text{trial}} = -1.337$$

Plotting this point and going from it to the commercial pipe line along a varying w line, we obtain:

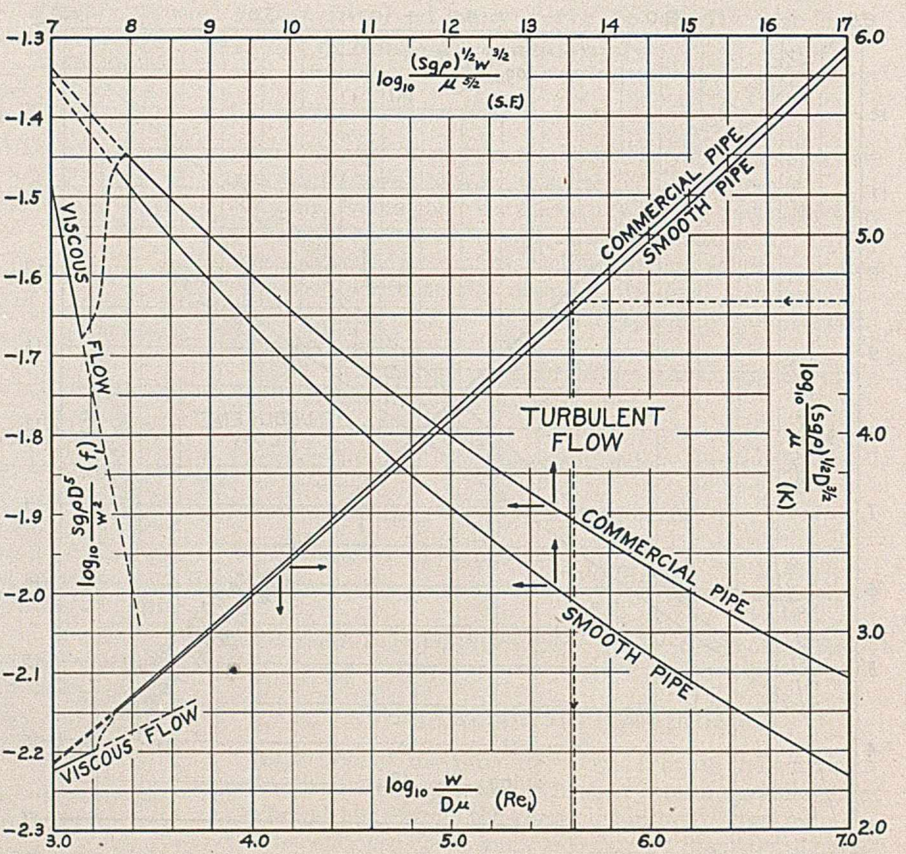

Figure 2. Precision Chart of Reynolds Number *vs.* von Kármán Number, and Friction Factor *vs.* Size Factor

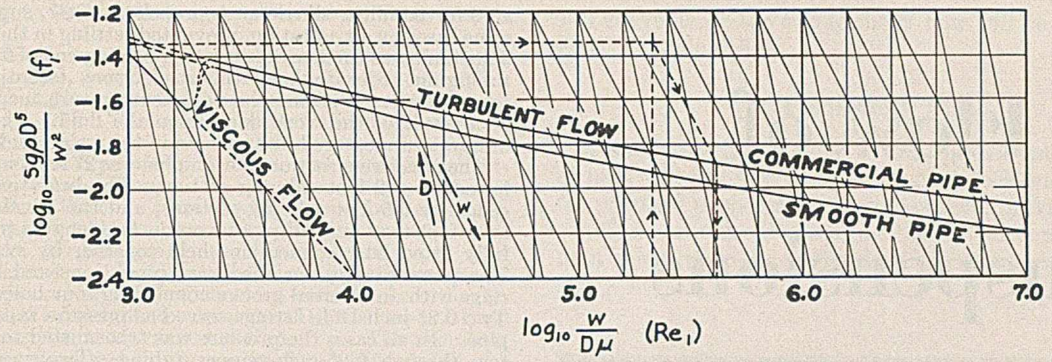

Figure 3. Friction Factor *vs.* Reynolds Number, with Lines of Varying *w* and of Varying *D*, for Direct Determination of *w* or *D*

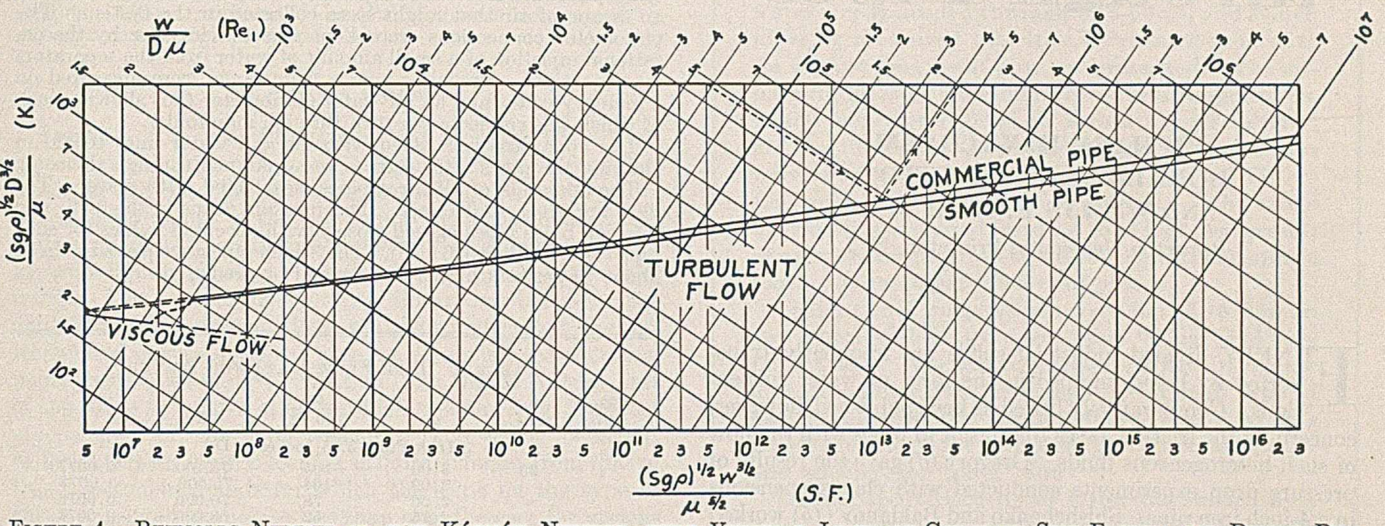

Figure 4. Reynolds Number *vs.* von Kármán Number, with Vertical Lines of Constant Size Factor, for Direct Determination of *s*, *D*, or *w*

$$\log Re_{1\text{true}} = 5.62$$
$$Re_{1\text{true}} = 415{,}000$$
$$w = 93.5 \text{ as before}$$

Using Figure 4, for $K = 47{,}600$, we read $Re_1 = 415{,}000$, and get $w = 93.5$ as before. We could also read S. F. from the curve and calculate w from it, but it is easier from Re_1.

Noncircular Cross Sections of Flow

Viscous flow in noncircular cross sections requires an equation derived for the particular case (*10*).

The charts here presented apply directly only to flow through a single circular section, and if a number of such pipes is connected in parallel, w must be the flow rate per pipe. These charts may be applied, however, to turbulent flow in noncircular sections by making the proper substitutions.

In most problems involving noncircular cross sections, the dimensions are fixed, and the hydraulic radius, m, and the cross section of flow, A, can be calculated. In order to solve for s or w, D should be replaced in the dimensionless ratios by $4\,m$ and w by $(4\pi m^2/A)w$. Figures 1 to 4 may then be used as before.

For a constant cross-sectional shape, A will be proportional to m^2, and it will be possible to solve also the problem of unknown dimensions directly. Thus, for a rectangular duct cross section, let the sides be a and b and $a/b = n$. If n is fixed, we will have:

$$m = \frac{ab}{2(a+b)} = \frac{a}{2(n+1)}$$

$$A = ab = \frac{a^2}{n} = \frac{4m^2(n+1)^2}{n}$$

Therefore, D should be replaced by $2a/(n+1)$ and w by $\pi n\, w/(n+1)^2$. The unknown a may be determined by the same plot used for D in circular-section pipes.

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(9) *Ibid.*, p. 83.
(10) *Ibid.*, p. 94.

Esters of Sodium Sulfosuccinic Acid—Correction

An error occurs in our article which appeared under the above title in the January, 1939, issue of Industrial and Engineering Chemistry. In Table I on page 47, compound 3 in group *B* should have been printed as R′—Ar—SO_3 Na.

C. R. Caryl and W. P. Ericks

Flow of Suspensions through Pipes[1]

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AND WILLIS F. LOEFFEL[3]
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FINELY divided industrial solids are frequently transported by being pumped in the form of water suspensions. Comparatively little has been published, however, concerning the friction losses that occur in pipes with the flow of such heterogeneous fluids. Gregory (*6*) gave the results of pressure drop experiments conducted with clay suspensions in a 4-inch iron pipe. Shishchenko and Baklanov (*15*) worked with a similar material. Ambrose and Loomis (*1*) studied the flow of bentonite suspensions through 0.5- and 1-inch pipes, and data on the flow of paper pulp and sand suspensions (*2, 4, 9, 11, 12, 14*) have been reported. The viscometry (*5, 8, 10, 13, 16, 19*) of suspensions as an approach to the theory of such materials has received more attention. However, the results of viscometer measurements have not been readily applicable to pipe design.

The present paper deals with a comparison of the flow behavior of cement rock and Filter-Cel suspensions in a viscometer with that in three sizes of pipe. Data were taken simultaneously with the viscometer and the pipes to eliminate from consideration any changes in the properties of the suspensions due to working or aging. Gregory (*6*), Ambrose and Loomis (*1*), and Merkel (*11*) previously compared suspension flow in pipe and viscometer. Herrick (*7*) developed an equation for the flow of drilling fluids through pipes by using plastometer measurements together with the Williams and Hazen formula for hydraulic flow. However, this equation was not verified for tubes larger than capillary size.

Materials and Method

The cement rock suspensions were made from a material ground for kiln feed, 92 per cent passing No. 200 sieve. The Filter-Cel suspension was prepared from standard Filter-Cel mixed with some Super-Cel.

Figure 1 shows the pipe system used. The 0.75- and 1.5-inch brass pipes were connected parallel to a 3-inch iron pipe by means of end manifolds so fitted with valves that any one pipe could be placed in operation. Fluid circulation was provided by a 45-gallon-per-minute, 120-foot head, Gould centrifugal pump, suitable for handling slurries. A propeller stirrer, supplemented in some cases by air agitation, prevented settling in the mixing tank. This tank was further fitted with a cooling coil of 0.5-inch copper tubing in order to keep the suspensions essentially at room temperature. Without the coil, temperature increased rapidly as a result of the work done upon the fluid. The weight rate of flow was measured in duplicate in the weigh tank.

The measuring section of each pipe was 27 feet long and was followed by a 2-foot calming section. The brass pipes were preceded by 6.5-foot calming sections, and the 3-inch iron pipe by an 8-foot section. All pipes were in two lengths joined by carefully fitted butt connections held together by sweated sleeves. The pressure taps for the brass pipes consisted of piezometer rings with an internal groove connecting four holes in the pipes. Two 0.25-inch Dole fittings served as pressure taps in the 3-inch pipe. In all cases the pressure was transmitted to the manometers through 0.25-inch copper tubing. Two vertical separating chambers, *S*, prevented solids from reaching the pressure lines. The entire pressure-measuring system was filled with water, and to keep it full, vents *V* were opened at frequent intervals to allow an escape of air that might have collected in the system. The piezometer connections were kept free of cloggage by the occasional injection of a small amount of water from the separators into the pipes. Pressures over a wide range were measured on a mercury-water and an air-water manometer (not shown), each of which was connected in turn through manifolds.

The apparatus was fitted with air and water lines to aid in cleaning the pipes after slurries were pumped through them.

The operation of all three pipes was tested with water. The data are given in Table I. The pressure drops in the 0.75- and 1.5-inch brass pipes agreed closely with accepted values for such pipe (*17*) (see Figure 6 also). The 3-inch pipe gave pressure drops about 40 per cent higher than would be predicted.

TABLE I. PIPE FLOW DATA FOR WATER

Run No.	t° C.	u	$\frac{\Delta p}{100 \text{ Ft.}}$	Re	
3-Inch Pipe (3.05 Inches I. D.)					
1	25	3.00	105	73,100	0.0077
		3.09	104	75,000	0.0072
		2.60	78	70,000	0.0076
		2.15	52	58,000	0.0074
	26	1.23	20	33,600	0.0086
		3.15	95	88,600	0.0063
		3.15	97	88,600	0.0064
		2.84	84	80,000	0.0068
	27	2.33	60	65,500	0.0073
1.5-Inch Pipe (1.59 Inches I. D.)					
2	26	10.40	1450	148,000	0.0046
	27	10.40	1450	148,000	0.0046
	28	8.56	940	126,000	0.0044
	30	5.12	383	76,000	0.0050
	31	2.72	126	43,000	0.0058
	32	1.38	37	22,200	0.0067
3	24	8.92	1070	119,000	0.0046
	26	8.51	957	119,000	0.0045
	27	8.23	920	119,000	0.0047
	28	7.70	805	113,000	0.0047
	29	7.16	712	108,000	0.0048
	30	6.58	606	102,000	0.0048
	31	5.76	455	90,000	0.0047
	32	4.61	322	73,000	0.0052
	33	3.26	167	53,000	0.0054
	33	1.75	57	28,800	0.0064
	34	1.13	27	19,100	0.0073
	36	0.81	16	14,000	0.0083
0.75-Inch Pipe (0.812 Inch I. D.)					
4	33	16.50	6950	136,000	0.0045
	35	12.90	4490	112,000	0.0048
	36	7.51	1720	66,600	0.0053
	37	2.86	308	25,700	0.0066
	37	1.50	98	13,700	0.0076
5	25	17.70	7520	125,000	0.0042
	26	16.10	6290	116,000	0.0043
	28	14.50	5200	108,000	0.0043
	29	12.00	3660	91,300	0.0045
	30	11.00	3160	85,000	0.0046
	31	9.96	2650	79,700	0.0047
	32	8.94	2230	72,500	0.0049
	32	7.95	1750	65,300	0.0049
	33	6.98	1370	58,100	0.0049
	34	5.74	980	48,600	0.0052
	34	4.59	655	39,100	0.0055
	35	3.39	407	29,300	0.0062

With this apparatus the pressure drops were measured in each of the three pipes at varying flow rates of the two suspensions. The cement rock concentration was varied from 54 to 62 per cent by weight; that of the Filter-Cel, from 21 to 34 per cent. The velocities ranged from 0.3 to 14 feet per second; the pressure

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[1] Presented as part of the symposium on fluid dynamics at Carnegie Institute of Technology, Pittsburgh, Penna. Other papers appeared in April, 1939, pages 408–486, and on pages 618–621 of this issue.

[2] Present address, Columbia University, New York, N. Y.

[3] Present address, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

drops, from 30 to 7200 pounds per square foot per 100 feet of pipe.

Viscometer measurements were made, two to three samples being taken for each concentration of suspension studied. For this purpose a rotating, motor-driven viscometer previously described was used (*18*). This calibrated instrument was capable of operating at a range of speeds; and to be comparable to pipe flow, in so far as the type of flow is concerned, its operation extended into the turbulent range.

The properties of the most concentrated suspensions, especially of Filter-Cel, varied with the amount of pumping to which they were subjected. No pressure drop readings in the pipes were therefore considered valid until the friction properties, as measured by the viscometer, reached constant values. Accordingly, the concentration by weight of a suspension in this paper has no significance except as a convenient designation. The operating temperatures in pipes and in viscometer were within 1 ° C., on the average.

The densities of the Filter-Cel suspensions were measured with a float hydrometer, those of the cement rock suspensions by weighing 100-cc. volumes. Compositions were determined by drying a given weight of suspension.

Cement Rock

Pressure drop–velocity data for two concentrations of cement rock suspensions in three sizes of pipe are presented in Table II and are plotted logarithmically in Figure 2. Two characteristic parts of the curves may be distinguished. At higher velocities the suspensions behave in a manner similar to true liquids having viscosities somewhat greater than water. The logarithmic plots are linear, have slopes characteristic of turbulent conditions, and lie higher than the corresponding curves obtained with water alone. At a critical point there is an abrupt transition from this first steep part of the curve to a flat section in which pressure drop is almost independent of the fluid velocity. The latter behavior, which occurs at lower velocities, is quite different from that of true Newtonian liquids for which the slope on the type of curve presented cannot be less than one, the case for viscous flow. The shape of the flow curves therefore suggests that cement rock suspensions, under the conditions studied, are capable of two different types of flow. The probable persistence of one form of flow through transition dips is observable in several of the curves. A similar transition behavior was also encountered by Gregory (*6*) when pumping clay slurries. For convenience the two forms of flow will be called "turbulent" and "plug" flow.

Suspensions of cement rock and of Filter-Cel in water were pumped through 0.75-, 1.5-, and 3-inch pipes at measured velocities. Pressure drop data for 27-foot lengths of pipe are presented. The apparent viscosity characteristics of all suspensions, which were determined in a rotating viscometer, are also included. The cement rock concentrations were 54 and 62 per cent by weight; those of Filter-Cel were varied from 21 to 34 per cent. The range of velocities extended from 0.3 to 14 feet per second; of pressure drops, from 30 to 7200 pounds per square foot, calculated per 100 feet of pipe.

Cement rock suspensions were found to flow in two regimes which were treated as "plug" and turbulent flow. A separate correlation, involving pipe and viscometer data, is presented for each type of flow. The variables friction factor and Reynolds number are used for turbulent flow; friction factor and velocity, for "plug" flow.

The apparent viscosity of Filter-Cel suspensions increases somewhat with rate of shear. By using viscosity at zero shear, all pumpable suspensions correlate on a friction factor *vs.* Reynolds number plot. Viscous and turbulent flow, but no "plug" flow is evident for this suspension.

Turbulent Flow

A similarity in behavior to true liquids under conditions of high velocity suggests that cement rock suspensions may for practical purposes be treated as such, provided viscosities can be measured. To this end, the r. p. m.–torque viscometer data taken with the suspensions are presented in Table III and on a log-log plot in Figure 3. The force-speed characteristics of the suspensions in the viscometer parallel those in the pipes. At low r. p. m. the torque is almost independent of speed, and at high r. p. m. the curves appear to flatten out to limiting lines characteristic of turbulent flow. The smooth shape of the curve may be due to a gradual transition from plug to turbulent flow in the presence of paddles and baffles with which the viscometer is equipped.

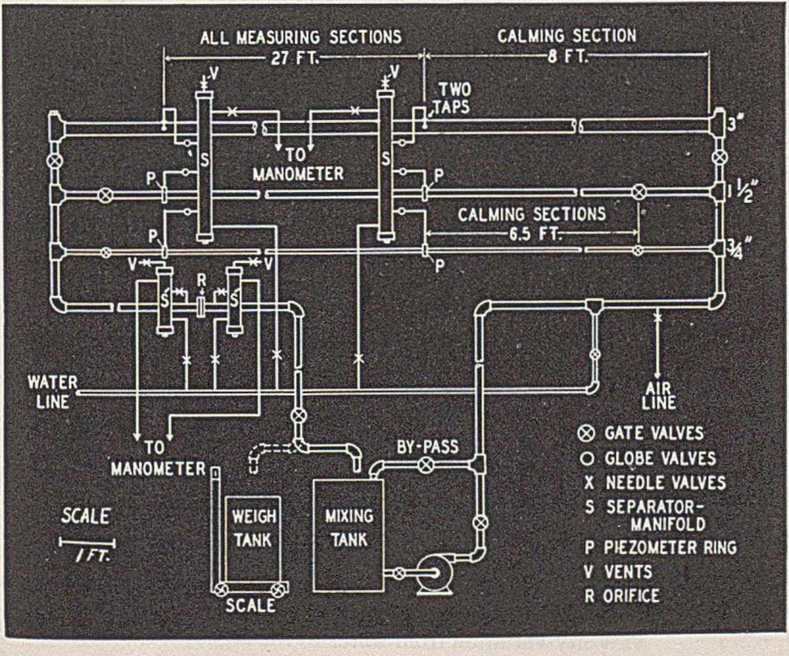

Figure 1. Pipe System

The apparent viscosities of cement rock suspensions were estimated by a method of extrapolation to high r. p. m. Under these conditions the suspensions are presumed to behave as true liquids, and the viscometer calibration (*18*) may be used to calculate an apparent viscosity, μ'. A torque–r. p. m. plot (Figure 4) indicates intercepts of definite torque values at zero speed. This characteristic behavior of many suspensions was first pointed out by Bingham (*3*). Following his procedure for calculating mobilities of suspensions, these intercept values of torque were used as subtractive constants. For ex-

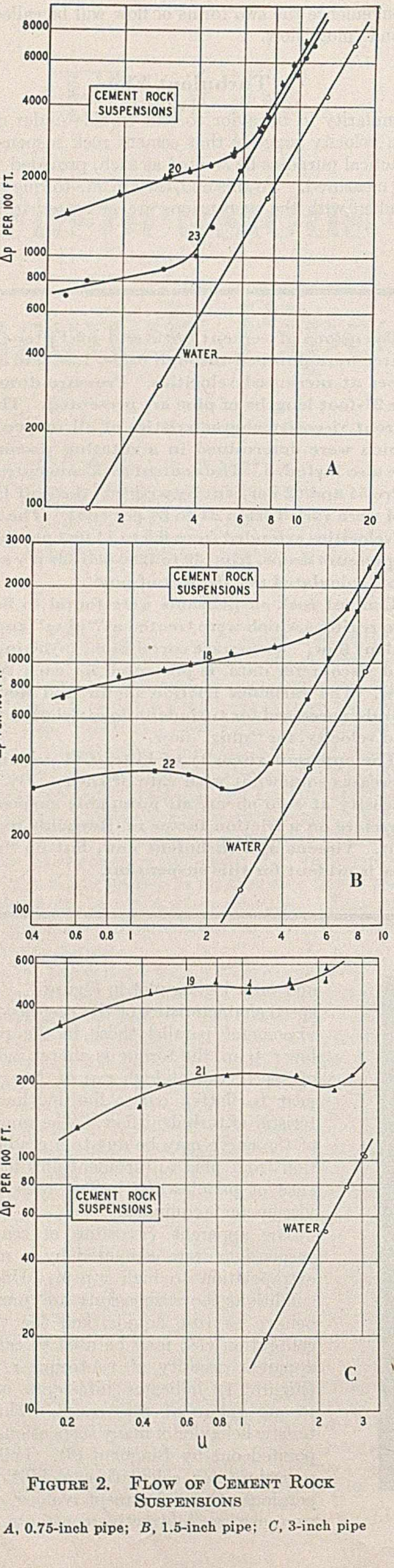

FIGURE 2. FLOW OF CEMENT ROCK SUSPENSIONS

A, 0.75-inch pipe; *B*, 1.5-inch pipe; *C*, 3-inch pipe

TABLE II. PIPE FLOW DATA FOR CEMENT ROCK SUSPENSIONS

Run No.	t° C.	*s*	*u*	Δp / 100 Ft.	*Re*	*f*
			0.75-Inch Pipe			
20 (61.2% rock by wt.)	27.5	1.63	10.7	7240	18,000	0.00675
			10.05	6500	16,900	0.00684
			9.55	5880	16,000	0.00693
			8.58	4920	14,400	0.00718
			7.58	3640	12,700	0.00680
			7.34	3360	12,300	0.00669
			5.55	2620	9,300	0.00912
			3.06	2050	5,140	0.0234
			4.49	2310	7,540	0.0123
			3.69	2180	6,200	0.0173
			5.50	2520	9,230	0.0118
			2.91	2030	4,890	0.0340
			1.92	1760	3,220	0.0678
			0.90	1390	1,510	0.244
			1.20	1470	2,020	0.144
23 (54.3% rock by wt.)	25.6	1.52	11.4	7050	33,800	0.00624
			10.6	6380	31,400	0.00648
			9.75	5370	28,900	0.00648
			7.40	3440	21,900	0.00731
			5.95	2230	17,600	0.00731
			4.51	1300	13,400	0.00736
			2.93	898	8,680	0.0120
			3.94	1010	11,700	0.00740
			1.18	698	3,500	0.0576
			1.45	807	4,300	0.0439
			1.5-Inch Pipe			
18 (62.3% rock by wt.)	26.2	1.65	8.87	2420	17,800	0.00639
			8.76	2400	17,600	0.00648
			7.15	1650	14,400	0.00671
			7.15	1660	14,400	0.00674
			5.00	1290	10,000	0.0106
			5.08	1290	10,200	0.0104
			3.73	1160	7,500	0.0172
			3.85	1160	7,730	0.0162
			3.73	1160	7,500	0.0172
			2.49	1080	5,000	0.0361
			2.45	1055	4,920	0.0366
			1.33	930	2,670	0.109
			1.71	973	3,440	0.069
			0.53	722	1,060	0.534
			0.89	874	1,790	0.228
22 (54.3% rock by wt.)	26.0	1.52	9.40	2220	55,000	0.00565
			7.92	1635	46,300	0.00585
			6.09	1050	35,600	0.00637
			4.97	722	29,100	0.00658
			3.59	399	21,000	0.00695
			2.29	318	13,400	0.0136
			1.68	361	9,800	0.0288
			1.23	370	7,200	0.0553
			0.40	318	2,340	0.447
			3-Inch Pipe			
19 (61.7% rock by wt.)	27.0	1.64	2.14	518	10,600	0.0451
			2.16	580	10,700	0.0495
			1.54	508	7,630	0.0856
			1.59	485	7,880	0.0765
			1.06	494	5,250	0.176
			1.06	460	5,250	0.164
			0.78	504	3,860	0.331
			0.43	456	2,130	0.99
			0.19	342	940	3.91
21 (54.3% rock by wt.)	27.2	1.52	2.75	218	31,000	0.0122
			2.31	190	26,000	0.0151
			1.64	218	18,500	0.0342
			0.87	218	9,800	0.121
			0.47	200	5,300	0.376
			0.22	133	2,480	1.17
			0.32	161	3,600	0.445

ample, the intercept for run 20 (Figure 4) is about 110 torque units. It was actually found by trial that 107 torque units subtracted from all experimental values gave the best straight "corrected curve." This curve (Figure 5) has the characteristics of a true liquid line to which the experimental curve becomes asymptotic at high r. p. m. The viscosity corresponding to this limit was calculated by means of the viscometer calibration (*18*) using several points on the corrected curve. The apparent viscosities for the several cement rock suspensions were thus obtained and are listed in Table III.

By means of the above apparent viscosities, the dimensionless friction factors and Reynolds numbers for all cement rock flow data in pipes were calculated and are plotted in Figure 6. The calculated points for the highest suspension flow rates in the 0.75- and 1.5-inch pipes correlate quite well on the generalized curve for turbulent fluid flow. The apparent viscosity variation from water to the highest concentration of cement rock slurry was one order of magnitude. Because of

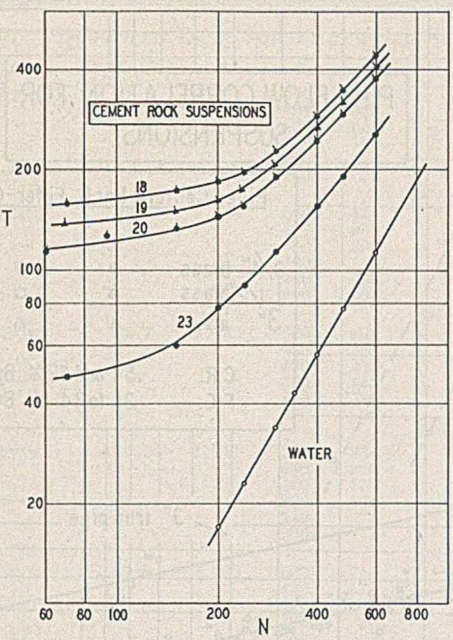

Figure 3. Cement Rock Suspensions in Viscometer

the limitations of the pump, results with the 3-inch iron pipe did not reach into the turbulent range.

The calculated points for the lower velocity or plug flow data form a series of uncorrelated lines which have a steep negative slope of about 1.8. These curves, shown as dotted lines on Figure 6, represent two cement rock concentrations in three pipe sizes. No correlative relation was found between them on the *f vs. Re* type of plot under discussion.

Plug Flow

The most satisfactory correlation for cement rock flow through pipes at low velocities was found by plotting friction factor *vs.* linear velocity (Figure 7). All data now fall on two well-defined lines, each representing a concentration of cement rock. At a given slurry concentration the data for all three pipe sizes correlate on one line. This is a convenience for design purposes. The simplified equation for these curves, involving only the factors that were experimentally varied, Δp, u, and D, is:

$$\frac{\Delta p}{L} = k\frac{u^{0.2}}{D} \qquad (1)$$

This type of equation would be expected for plug flow (*2*) which has a flat velocity distribution across the pipe and the major velocity gradient at the wall. The pressure drop in this case is related to the friction between the plug and the side walls. Since solid-solid friction varies as the area of contact, it would be expected that the pressure drop would vary inversely as pipe diameter for cement-rock plug flow. In addition, since no relative motion of solid particles may take place within a plug core, the internal friction or apparent viscosity, μ', as measured in turbulent flow, would not be a significant variable in plug flow. This was found to be the case. Observations made while handling the cement rock

Table III. Viscometer Data for Cement Rock Suspensions

Run No.	$t°$ C.	s	N	T	T_0	Z'
18 (62.3% rock by wt.)	26.7	1.65	600	435	132	11.0
			480	344		10.3
			400	289		10.2
			300	226		10.3
			240	194		8.3
			200	184		10.6
			150	172		..
			70	157		..
					Average	10.1
19 (61.7% rock by wt.)	26.7	1.64	600	403	117	8.3
			480	316		8.6
			400	266		8.7
			300	207		8.5
			240	172		5.8
			200	161		7.3
			150	149		..
			70	137		..
					Average	7.8
20 (61.2% rock by wt.)	27.0	1.63	600	373	107	6.6
			480	294		7.2
			400	244		7.2
			300	190		6.7
			240	155		3.9
			200	144		4.6
			150	133		..
			93	127		..
			60	114		..
					Average	6.1
21, 22, 23 (54.3% rock by wt.)	26.0	1.52	600	251	45	2.8
			480	187		3.1
			400	150		3.4
			300	111		3.9
			240	88		3.2
			200	76		3.0
			150	58		..
			70	47		..
					Average	3.2

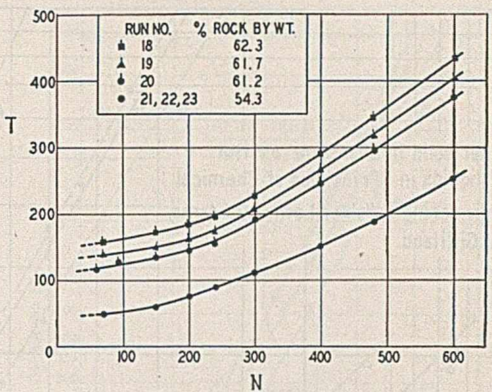

Figure 4. Cement Rock Suspensions in Viscometer to Show Apparent Torque Intercept

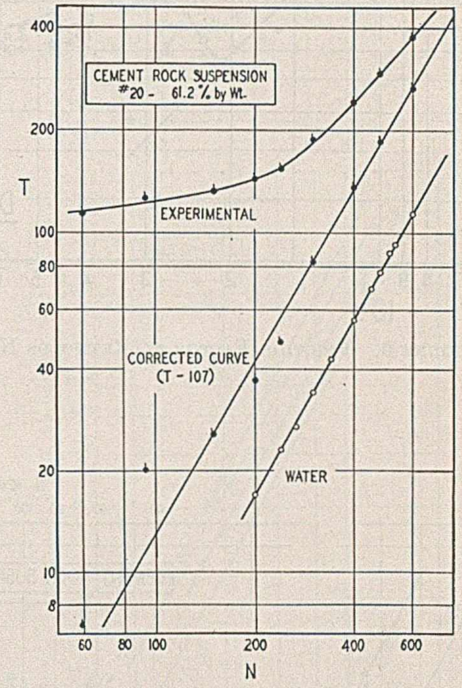

Figure 5. Extrapolation of Cement-Rock-Suspension Viscometer Data to High R. P. M.

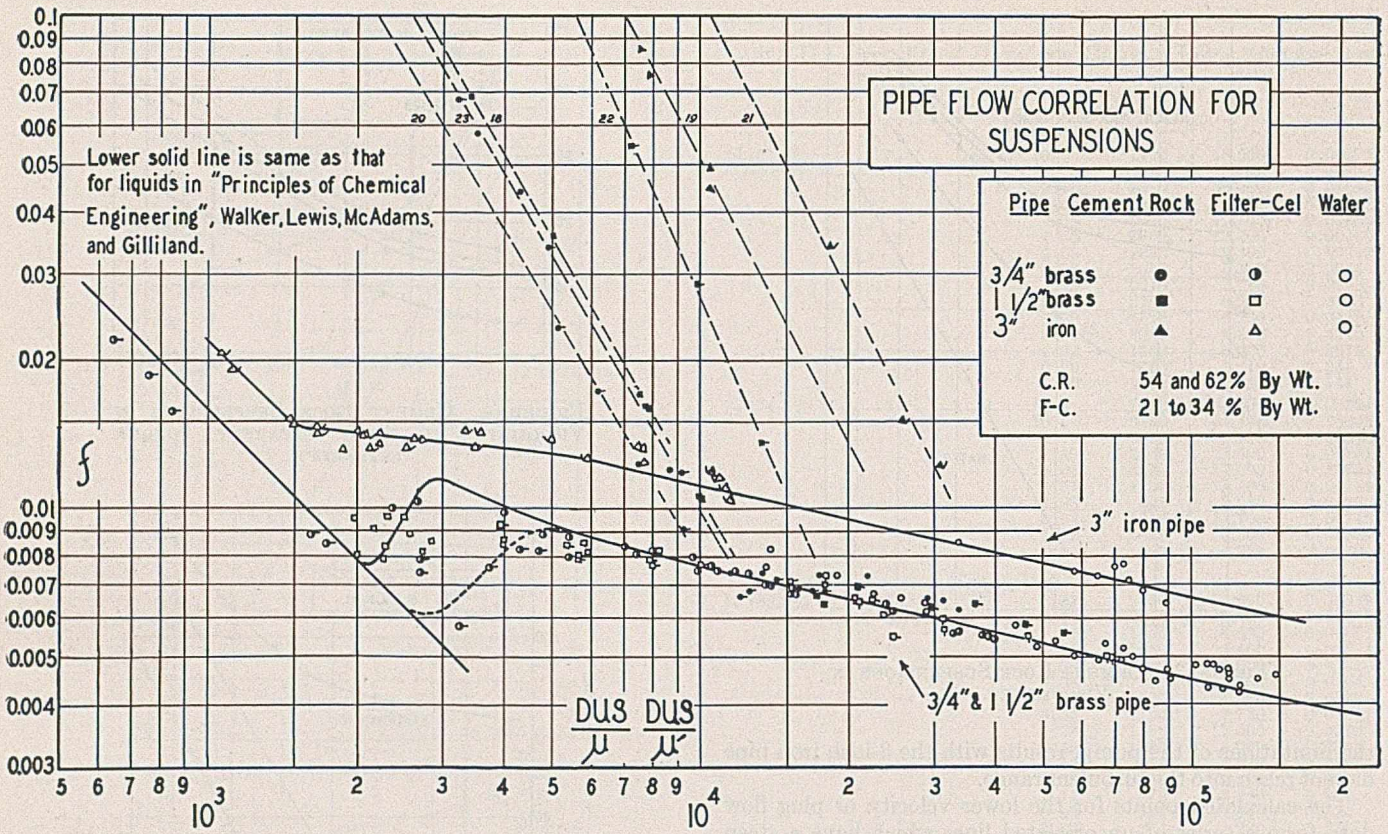

FIGURE 6. FRICTION FACTOR *vs.* REYNOLDS NUMBER FOR WATER, CEMENT ROCK, AND FILTER-CEL SUSPENSIONS

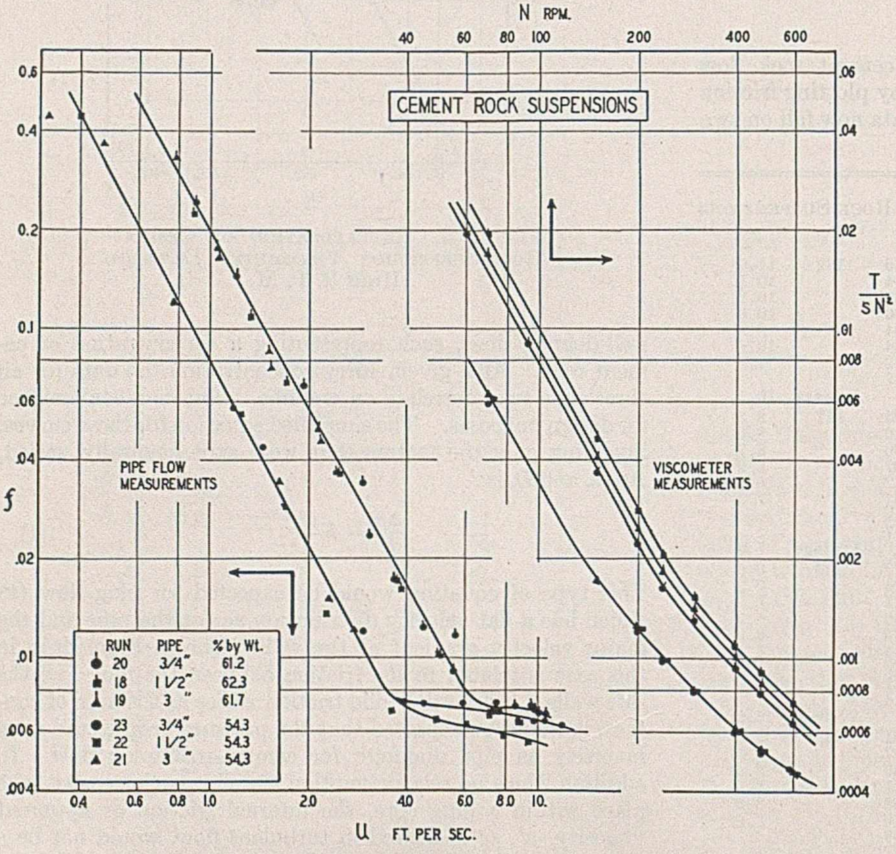

FIGURE 7. FRICTION FACTOR *vs.* VELOCITY IN PIPES, AND FRICTION FACTOR *vs.* R. P. M. IN THE VISCOMETER FOR CEMENT ROCK SUSPENSIONS

suspensions, especially while stirring, give credence to the plug flow picture. A velocity traverse would be necessary for ultimate proof (*13*).

For present purposes concentrated cement rock suspensions at rest may be thought of as a solid structure built up by the interlocking of the constituent fine particles. As such a suspension is pumped slowly through a pipe, the central core retains its rigid structure and friction is developed between the core surface and the pipe wall. As the velocity is increased, the wall friction increases very slowly, imposing a greater internal shearing stress on the semirigid plug structure. At some point a critical shear is reached, the structure breaks down, and turbulent flow sets in. When the flow of a suspension is experimentally varied from turbulent to plug conditions, the orientation of the particles into the semirigid plug structure may not be instantaneous. The dips in Figure 2 may be the result of such a time requirement.

From the type of curve obtained, it would appear that if the friction head for a suspension of a given concentration is known in one pipe size, then pressure drops

Table IV. Viscometer Data for Filter-Cel Suspensions

Run No.	t° C.	s	N	T		Z'
8 (33.1% by wt.)	28.8	1.214	600	498		52.5
			480	339		47.8
			400	251		45.4
			300	155		41.9
			240	106		38.4
			200	78		36.3
					Limit	31.0
9 (33% by wt.)	29.7	1.213	600	430		38.3
			480	294		35.3
			400	220		34.2
			300	135		31.0
			240	93		29.3
			200	67		26.8
					Limit	24.0
11 (34.3% by wt.)	28.7	1.223	600	408		33.4
			480	280		31.2
			400	207		30.0
			300	128		27.4
			240	88		25.5
			200	65		24.7
					Limit	21.0
12 (33.6% by wt.)	29.0	1.217	600	335		21.9
			480	230		20.6
			400	173		20.3
			300	109		19.7
			240	74		17.9
			200	53		16.0
					Limit	16.0
13 (28.7% by wt.)	27.3	1.192	600	248		10.4
			480	171		10.4
			400	127		10.0
			300	80		9.8
			240	54		9.1
			200	41		9.2
					Limit	9.0
14 (28.7% by wt.)	28.2	1.192	600	231		8.4
			480	158		8.2
			400	116		8.1
			300	73		8.3
			240	50		7.7
			200	38		7.8
					Limit	7.7
15 (28.4% by wt.)	27.5	1.182	600	213		6.9
			480	145		6.8
			400	107		6.6
			300	65		6.4
			240	44		5.7
			200	34		6.1
					Limit	6.0
16, 17 (21.4% by wt.)	27.5	1.132	600	166		3.0
			480	112		3.0
			400	82		3.0
			300	49		2.8
			240	33		2.7
			200	24		2.7
					Limit	2.6

in other pipe sizes may be predicted within the range of plug flow. Baldwin and Van den Akker (*2*) recently arrived at a relation similar to Equation 1 in a study of the friction of paper pulp suspensions in pipes. They also explained their results in terms of plug flow.

A further examination of the pipe flow results in Figure 7 shows that the data which were satisfactorily correlated in Figure 6 are now bunched together at the lower extreme of the plug flow curve. Plug and turbulent flow are not easily correlated on one graph. The usual variables apparently do not act similarly in these two types of flow.

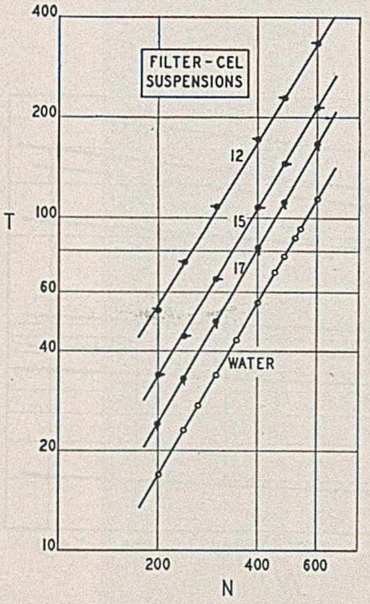

Figure 8. Filter-Cel Suspensions in Viscometer

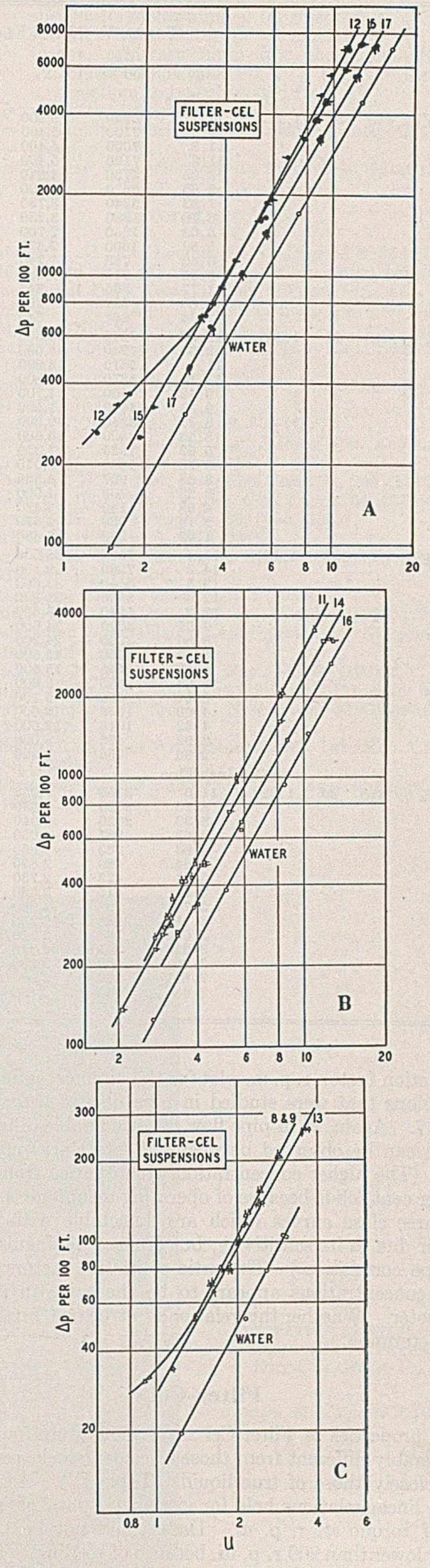

Figure 9. Flow of Filter-Cel Suspensions

A, 0.75-inch pipe; *B*, 1.5-inch pipe; *C*, 3-inch pipe

Table V. Pipe Flow Data for Filter-Cel Suspensions

Run No.	t° C.	s	u	$\frac{\Delta p}{100 \text{ Ft.}}$	R_e	f
0.75-Inch Pipe						
12 (33.6% by wt.)	30	1.217	11.1	6950	5,300	0.0081
			11.3	7100	5,400	0.0080
			11.3	7000	5,400	0.0079
			11.3	7190	5,400	0.0081
			9.05	4730	4,310	0.0083
			9.85	5620	4,700	0.0083
			7.83	3240	3,730	0.0076
			6.78	1880	3,230	0.0058
			5.65	1650	2,700	0.0074
			5.39	1600	2,570	0.0079
			3.65	788	1,740	0.0085
			3.39	713	1,620	0.0089
			1.77	366	845	0.0158
			1.60	332	760	0.0186
			1.34	261	640	0.0209
15 (28.4% by wt.)	28	1.182	12.5	7240	15,500	0.0068
			12.6	7240	15,600	0.0067
			11.1	5870	13,800	0.0070
			11.1	5870	13,800	0.0070
			9.42	4500	11,700	0.0075
			9.33	4400	11,500	0.0075
			8.72	3840	10,800	0.0075
			8.56	3820	10,600	0.0077
			5.93	1925	7,350	0.0081
			5.70	1860	7,050	0.0084
			3.88	907	4,800	0.0089
			3.23	703	4,000	0.0099
			4.38	1140	5,420	0.0088
			2.16	328	2,680	0.0104
			1.92	252	2,380	0.0101
17 (21.4% by wt.)	28	1.131	14.1	7120	38,500	0.0055
			14.3	7200	39,100	0.0054
			12.3	5540	33,600	0.0056
			12.0	5530	32,800	0.0059
			12.3	5540	33,600	0.0056
			9.02	3290	24,600	0.0062
			8.86	3250	24,200	0.0064
			5.69	1450	15,500	0.0069
			5.62	1445	15,400	0.0071
			3.63	636	9,900	0.0075
			3.54	650	9,700	0.0080
			4.60	1015	12,600	0.0074
			4.62	1015	12,600	0.0074
			2.92	456	8,000	0.0083
			2.90	456	7,900	0.0083
1.5-Inch Pipe						
11 (34.3% by wt.)	30	1.222	11.0	3550	7,950	0.0082
			8.15	2020	5,830	0.0085
			8.30	2020	5,940	0.0082
			5.63	987	4,030	0.0087
			5.63	963	4,030	0.0085
			3.94	480	2,820	0.0086
			3.81	423	2,730	0.0082
			3.61	415	2,580	0.0089
			2.74	257	1,960	0.0096
			3.18	286	2,280	0.0079
			3.03	301	2,170	0.0092
			3.22	355	2,310	0.0096
			3.20	306	2,290	0.0084
			2.82	230	2,020	0.0081
			3.48	415	2,490	0.0096
1.5-Inch Pipe						
14 (28.7% by wt.)	29	1.192	12.9	3210	24,600	0.0055
			11.8	3230	22,500	0.0067
			12.4	3260	23,600	0.0061
			8.08	1610	15,300	0.0071
			8.22	1620	15,700	0.0069
			5.27	750	10,000	0.0077
			5.27	750	10,000	0.0078
			4.21	480	8,000	0.0077
			4.14	470	7,900	0.0079
			2.80	230	5,340	0.0085
			2.97	279	5,650	0.0081
			2.94	264	5,600	0.0079
			2.06	137	3,930	0.0093
16 (21.5% by wt.)	27	1.132	12.6	2660	67,500	0.0051
			12.6	2640	67,500	0.0050
			8.72	1380	46,700	0.0055
			8.65	1370	46,300	0.0055
			5.86	680	31,400	0.0060
			5.86	646	31,400	0.0057
			3.99	342	21,400	0.0065
			3.90	332	20,900	0.0066
			3.36	263	18,000	0.0070
			3.34	269	17,900	0.0073
3-Inch Pipe						
8 (33.1% by wt.)	30	1.214	2.86	211	2,640	0.0139
			2.86	210	2,640	0.0139
			2.42	154	2,240	0.0142
			2.47	153	2,280	0.0135
			2.18	126	2,010	0.0143
			2.22	128	2,050	0.0140
			2.01	98	1,860	0.0131
			2.04	99	1,880	0.0129
			1.61	71	1,490	0.0148
			1.59	70	1,470	0.0151
9 (33.0% by wt.)	31	1.212	2.92	209	3,480	0.0133
			2.80	209	3,340	0.0144
			2.15	114	2,560	0.0133
			2.15	114	2,560	0.0133
			2.15	116	2,560	0.0136
			1.74	81	2,070	0.0144
			1.79	79	2,130	0.0133
			1.40	52	1,670	0.0142
			1.40	53	1,670	0.0147
			0.94	31	1,120	0.0192
			0.90	31	1,070	0.0207
13 (28.7% by wt.)	28	1.192	3.44	255	10,700	0.0119
			3.64	264	11,400	0.0110
			3.74	263	11,700	0.0104
			3.54	262	11,000	0.0115
			2.42	142	7,550	0.0133
			2.42	139	7,550	0.0130
			2.38	138	7,430	0.0134
			2.47	140	7,700	0.0127
			1.87	83	5,830	0.0132
			1.90	79	5,930	0.0120
			1.87	80	5,840	0.0126
			1.15	34	3,590	0.0143
			1.62	72	5,050	0.0151
			1.62	66	5,050	0.0139

A friction factor–r. p. m. plot for the viscometer data of the suspensions that were studied in pipe flow is also shown in Figure 7. Again, as in pipe flow, a considerable difference in friction can be observed between the two slurry concentrations. (The higher concentration which varied from 62.3 to 61.2 per cent solids because of operating technique is resolved into three close curves which are detectable with the viscometer due to its sensitivity, but are not distinguishable in the pipe correlation.) The ratio of friction factors between slurry concentrations appears to be the same in pipe and viscometer. Whether this relation is a true one, further work must determine.

Filter-Cel

The properties of Filter-Cel suspensions were found to be considerably different from those of cement rock, resembling more closely those of true liquids (Table IV). As Figure 8 shows, linear relations hold for viscometer data on a log-log plot of torque *vs.* r. p. m. Data could not be taken for speeds lower than 200 r. p. m. because of settling. The complete absence of plug flow characteristics is to be noted. This was also found to be the case for pipe flow data, which are given in Table V and presented on a log-log plot in Figure 9.

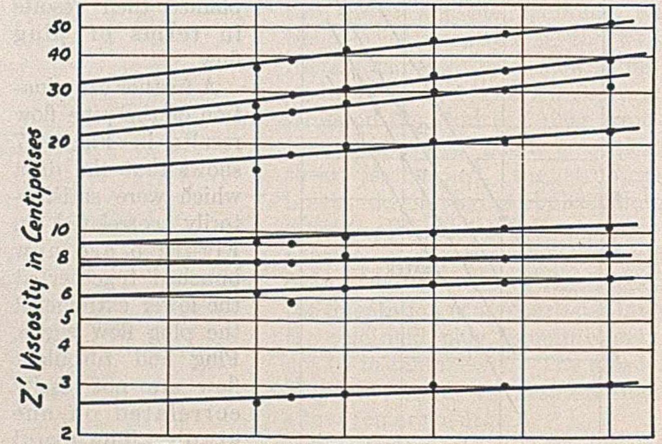

Figure 10. Variation of Apparent Viscosity of Filter-Cel Suspensions with R. P. M. of Viscometer

The apparent viscosities of these suspensions were calculated by means of the viscometer calibration against true liquids (*18*). It was found that the apparent viscosity of Filter-Cel suspensions increases with the rate of shear. This effect is shown on a semilog plot in Figure 10.

Furthermore, it was found that pipe flow data for suspensions of all pumpable concentrations can be empirically correlated on the usual friction factor–Reynolds number plot for true liquids when the viscosity used is that obtained by extrapolation to zero shear, or r. p. m. in the viscometer. The correlation is shown in Figure 6. A turbulent section, an unstable region, and a viscous section are observable. It is believed that the line of viscous flow is real, although only few points appear, since similar results were obtained in the viscometer with suspension of higher concentrations than could be pumped. The data for the 0.75- and 1.5-inch brass pipe fall within 15 per cent of usual true liquid line. That for the 3-inch iron line falls quite high but is consistent with data taken with water flowing through the same pipe. It is believed that the high pressure drops obtained were due in part to the method of attaching the pressure taps to this pipe.

Acknowledgment

The authors wish to acknowledge the contribution of cement rock by the Lehigh Portland Cement Company.

Nomenclature

$Du\rho/\mu$ = Reynolds number for pipes = Re
f = friction factor for pipes = $\Delta pgD/2Lu^2\rho$
μ = absolute viscosity, lb./sec. ft.
μ' = apparent viscosity of suspensions, lb./sec. ft.
Δp = pressure drop, lb./sq. ft.
L = length of pipe, ft.
u = average velocity, ft./sec.
D = diameter, ft.
ρ = density, lb./cu. ft.
Ns/Z = specific Reynolds number for viscometer
T/sN^2 = specific friction factor for viscometer
T = torque, arbitrary units (for the viscometer used, 1 unit = 0.334 gram cm.)
T_0 = a correction, to be subtracted from T
Z = viscosity, centipoises
Z' = apparent viscosity of suspensions, centipoises
N = speed, r. p. m.
s = density = specific gravity referred to water at 25° C

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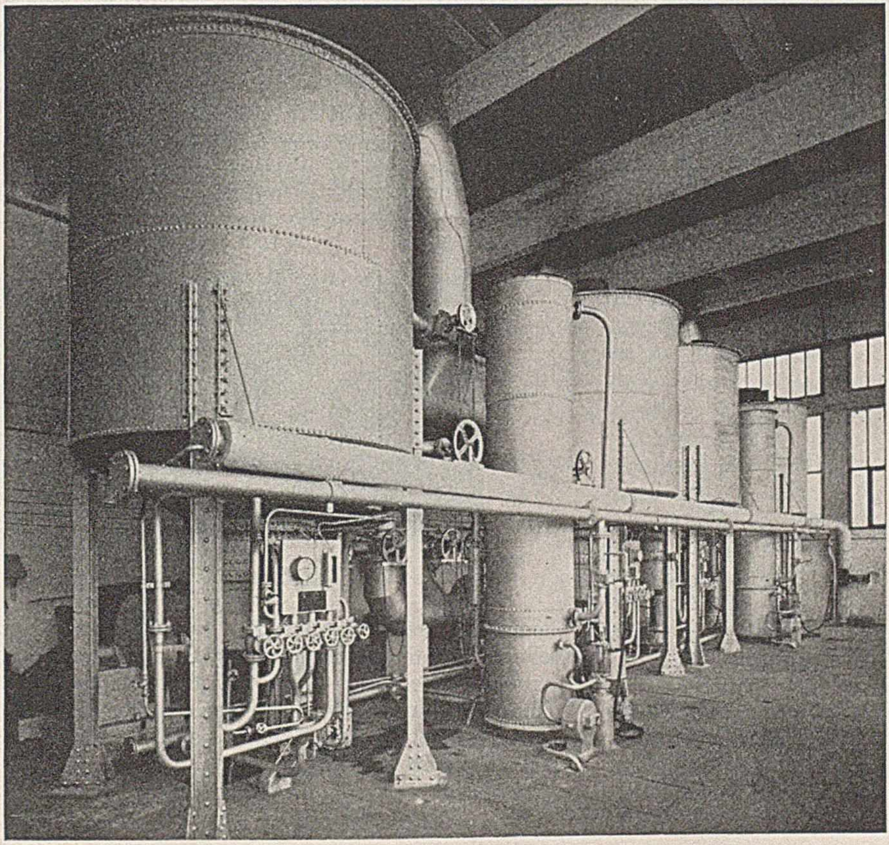


Adsorption System for Recovering Naphtha in a Dry-Cleaning Plant

Courtesy, E. L. Luaces Associates

TEXTILE FIBERS

Chemical and Physical Aspects

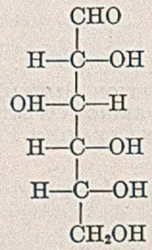
JEROME ALEXANDER
50 East 41st Street, New York, N. Y.

THE textile industry, basically dependent on textile fibers, stands second in value of output only to the food industry. Consequently, for centuries past, much time and effort have been expended on attempts to understand the structure and behavior of the various textile fibers so that the numerous processes and products of the textile industry might be controlled and improved. This paper aims to fit together some of the knowledge which has emerged from scientific investigations of textile fibers, including the most recent results available and a few personal observations.

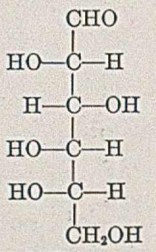
The main textile fibers fall into two groups—those of vegetable origin (e. g., cotton, linen, rayons) and those of animal origin (e. g., silk, wool). The former consist mainly of substances classed chemically as carbohydrates, the latter mainly of substances classed chemically as proteins. Research on textile fibers is therefore closely interwoven with all the diverse methods which have been used to investigate the ultimate units constituting carbohydrates and proteins, and the aggregates formed by such units. Furthermore, since the purification, bleaching, and dyeing of fibers and fabrics are widely practiced, much knowledge regarding fibers was garnered by scientific investigators in these fields.

Complexity of Apparently Simple Substances

In looking over chemical textbooks of various ages, it is interesting to see how research with new methods and apparatus has revealed the rather profound complexity of what had at one time appeared to be simple substances. Consider, for example, the evolution of ideas regarding the chemical structure of so common a carbohydrate as glucose (grape sugar). First an ultimate organic analysis established the empirical formula, $C_6H_{12}O_6$, which later knowledge of radicals expanded into a structural formula, that of an aldohexose, $CH_2OH.CHOH.CHOH.CHOH.CHOH.CHO$. From the work of van't Hoff, Emil Fischer, and others, there emerged the stereoisomeric formulas for dextro- and levoglucose. It should be noted that these prefixes refer to molecular configuration in space, and not to the optical activity of the compounds:

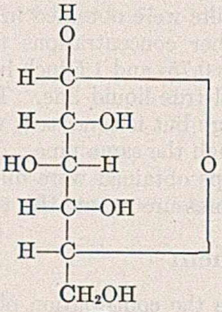


d-Glucose

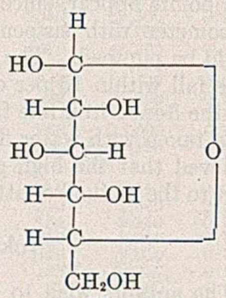


l-Glucose

Then came the so-called amylene oxide formulas of Tollens, with the concept of a lactone ring and the explanation of the experimentally observed mutarotation of glucose as a reversible transition from an alpha to a beta form through formation of an unstable intermediate oxonium compound:

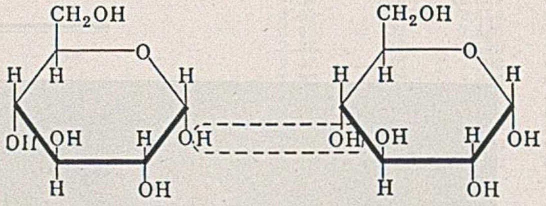


α-Glucose

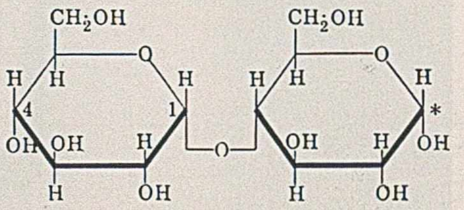


β-Glucose

The final advance came in 1925 when W. N. Haworth proposed the six-atom ring form as the structural model for glucose, based on pyran, while the comparatively little known labile or gamma form of glucose and allied sugars was based on furan, a five-atom ring. This necessitated a new nomenclature, which is being adopted as fast as educational hysteresis will permit.



Union of two α-Glucopyranose molecules



α-Maltose

FIGURE 1

In earlier days chemists expressed the formation of a biose from two molecules of monose sugars by some such formula as

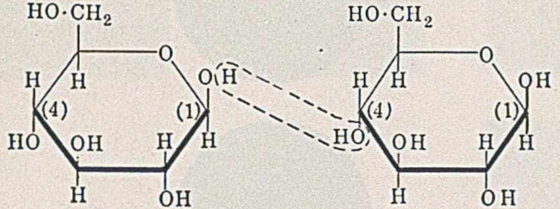
$$C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + H_2O$$

merely indicating the union of two hexose residues with the elimination of a molecule of water. Haworth gives a much more definite notion of the actual mechanical picture in the illustrations of the formation of α-maltose, the parent substance of starch, and β-cellobiose, the parent substance of cellulose (Figures 1 to 4).

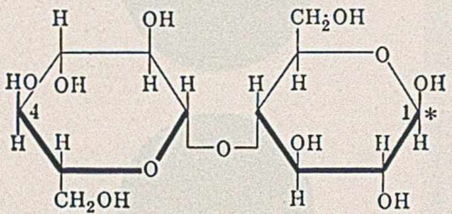
Although these illustrations indicate how great a difference in physical properties may follow upon comparatively slight differences in the chemical and spatial ordering of the same atoms, they represent conditions which are, in order of size, far below anything within the range of the microscope.

Structure and Structure Size Levels

The great importance of structure in addition to ultimate or empirical atomic constitution has long been recognized. Only recently, however, has the development of research with the ultramicroscope and the x-ray spectrometer, checked by refinements in chemical experimentation, given us a closer insight into architecture of molecules, into the varied and often intricate modes of aggregation whereby molecules become masses, and into what may be termed the "emergent" properties of the successive aggregative groupings of material units.



Union of two β-Glucopyranose molecules



β-Cellobiose

FIGURE 2

There is a common but mistaken popular notion that a "chemical analysis" (usually presented in the form of atomic percentages) will tell all one wants to know about a natural or a manufactured product. The consulting chemist frequently has to stress the importance and delicacy of structure by pointing out, for example, that although dropping a watch on the floor will not change its chemical composition, its value as a timepiece will probably be ruined.

Scientifically, recognition of the importance of structure has been a matter of gradual growth, because scientists are prone to magnify and reason with only such factors as they can understand and explain. This has often led to the recording of "rigorously exact" or "strictly quantitative" measurements which, as von Weimarn has pointed out (*45*), may have no value at all, because in determining them essential factors have been omitted from consideration. One factor of this kind is the presence of "impurities", either unsuspected or else considered as "negligible", which often greatly affect the structure and behavior of the material in which they occur.

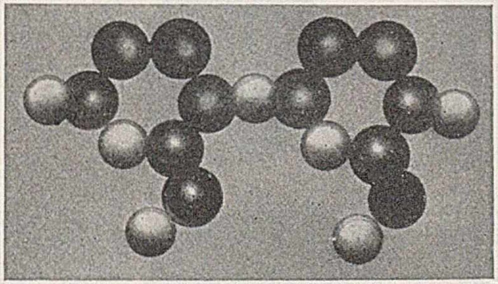


FIGURE 3. α-MALTOSE UNIT

Until recently, for example, vanadium had been described as a brittle, nonductile substance, but thin wires are now drawn from vanadium which has been sufficiently purified. Furthermore, 0.15 per cent of vanadium gives steel wire the ability to remain intact and strong after it is twisted like a peppermint stick and then bent almost double. From mixtures of substances surprising properties are apt to emerge, because of the manner in which the finer structure of the mass is affected. Very small percentages of colloidal substances may greatly influence the crystallization forces otherwise operative, so that globulitic, dendritic, and fibrous formations may appear. The various textile fibers, natural and artificial, are mixtures, not chemically pure substances; and their structures may vary materially with changes in the proportions and nature of their secondary constituents.

Structure Levels in Textile Fibers

The structure levels will be considered under the following heads:

1. ATOMIC. Chemical elements found in main constituents.
2. MOLECULAR. The main molecular "residues."
3. MACROMOLECULAR. The linear "giant" molecules or valency chains.
4. MICELLAR. "Crystallites" resulting from apposition of linear molecules, or molecular sheets.
5. MICROSCOPIC. Adsorption groups, fibrils.
6. VISIBLE. (*a*) Fibers, (*b*) threads and yarns, (*c*) fabrics.

Below the atomic level we have the complexities of atomic and nuclear structure; at the other extreme the fabric becomes a basic material for the tailor, the dressmaker, and the milliner.

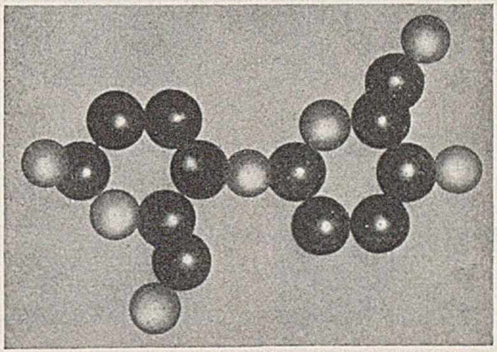


FIGURE 4. β-CELLOBIOSE UNIT

In order to facilitate this panoramic view, Table I gives the results of research at the various size levels on a number of the principal natural and synthetic fibers. The two crossed fibers of acetate rayon shown, as well as the fibers and fibrils of silk, were taken in polarized light; all of the other photomicrographs were taken in ordinary light. The photomicrographs of linen are taken from an Egyptian mummy cloth from a tomb of 1500 B. C. The typical flax structure is visible throughout, and the photomicrograph of the fabric shows with what care the selvage was constructed. This mummy cloth, though yellowish brown, is quite strong despite its age.

Knowledge as to the structure of fibers has grown progressively with improvements in methods of investigation. Apparently opposed views are sometimes due to observations made at different structure levels. The author has been obliged to select, from among the varied and often conflicting data, what appears at present to be most reliable, in order to bring out his main point—the existence and significance of successive orders of structural levels. The reader must consult the extensive literature for the progressively changing

Table I. Data on Natural and Synthetic Fibers

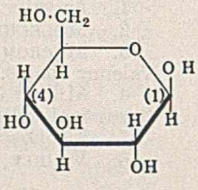
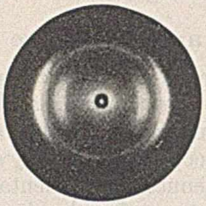
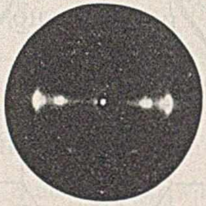
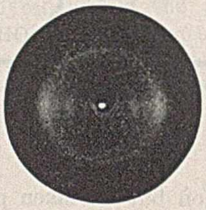
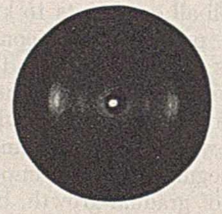
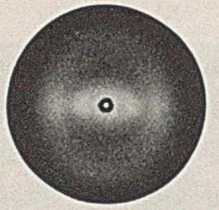
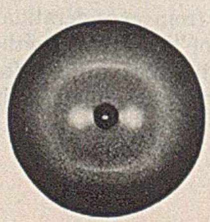
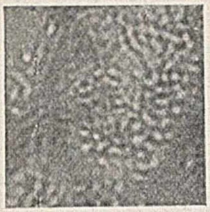
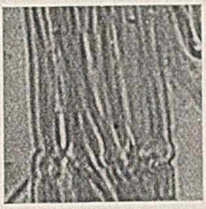
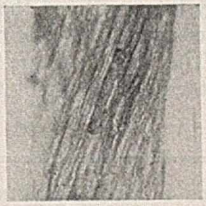
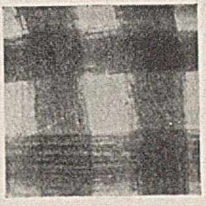
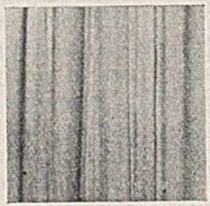
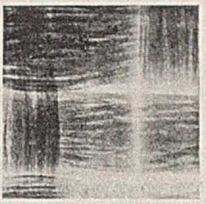
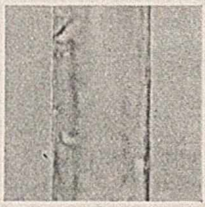
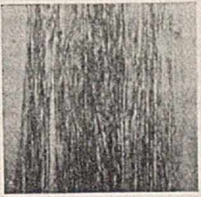
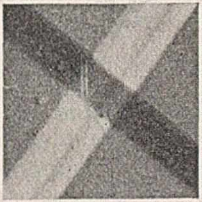
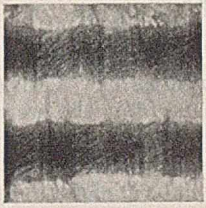
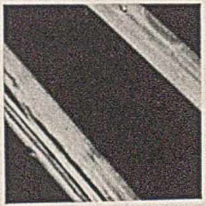
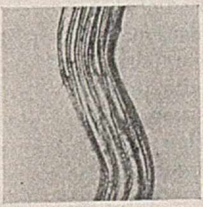
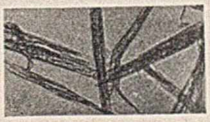
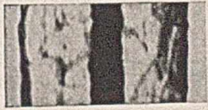
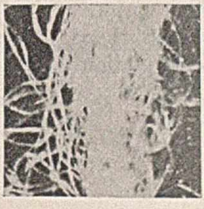
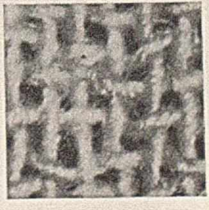
Fiber	Atomic Structure	Molecular Structure	Macromolecular Structure	X-Ray Diagrams (supplied by W. A. Sisson)	Secondary Constituents or "Impurities"
Cotton (the x-ray diagram has a faint outer ring not shown here)	C,H,O	 β-glucose	Cellulose chain, see Figure 7		....
Linen	C,H,O		....		Lignin
Ramie	C,H,O		....		Lignin
Viscose rayon	C,H,O		....		....
Cuprammonium rayon	C,H,O		....		....
Acetate rayon	C,H,O	Acetates	Acetates		....
Silk	C,H,O,N	Glycine Alanine Tyrosine	See Figure 8		....
Wool (upper fibril picture in NaOH; lower, cortical cells)	C,H,O,N,S	Glutamic acid Aspartic acid	See Figure 9		....

Table I (*Continued*)

Micellar Structure	Fibrils	Fibers	Yarns	Fabrics	Fiber
					Cotton
					Linen
....	....				Ramie
....	....				Viscose rayon
					Cuprammonium rayon
....	....				Acetate rayon
					Silk
....	 	 			Wool

views, and for the evidence and arguments pro and con. For example, Astbury's ideas on wool were attacked by Harrison (*27A*); Astbury *et al.* (*15A*) replied. Farr's views on cellulose were attacked by Anderson and Kerr (*8*) who conclude: "The micellar hypothesis appears to satisfy all of the observations here made upon cotton fibers. Therefore, it seems to offer a more satisfactory explanation of the physical properties associated with cotton fibers than the ellipsoidal particle hypothesis." Farr's rebuttal appeared recently (*26A*).

Atomic Structure

The fibers listed are built up mainly from carbon, hydrogen, and oxygen. Silk has in addition some nitrogen, and wool has nitrogen and sulfur.

Molecular Structure

The various vegetable fibers listed are built up mainly from the monose sugar, β-glucose; two molecules of β-glucose unite, with the elimination of water as above indicated, to form cellobiose, a biose which may be considered the parent substance of cellulose. Two α-glucose residues yield maltose, the parent substance of starch. The term "residue" means what remains of the molecule after abstraction of the elements of water.

TABLE II. RATIO OF AMINO ACIDS IN SILK FIBROIN AFTER HYDROLYSIS

Amino Acid	Weight Per Cent	Mol. Weight	Gram Mol./100 Grams Protein		Ratio	Fraction of Total Residues (Frequency)
			Found	Calcd.[a]		
Glycine	43.8	75	0.584_0	0.584_0	1296	2
Alanine	26.4	89	0.296_6	0.292_0	648	4
Tyrosine	13.2	181	0.072_9	0.073_0	162	16
Arginine	0.95	174	0.005_5	0.005_4	12	216
Lysine	0.25	146	0.001_7	0.001_8	4	648
Histidine	0.07	155	0.0004_5	0.0004_5	1	2592

[a] Base, 0.584_0 (gram molecule of glycine).

The silk fiber, as spun by the caterpillar of *Bombyx mori*, is a double filament composed of a protein called "fibroin" cemented together by another protein called "sericin" (silk gum or silk glue) which is boiled off in the course of preparation of the yarn or goods. On hydrolysis, fibroin yields the α-amino acids shown in Table II.

The figures on lysine and histidine are those of Vickery and Block (*44*); the rest were redetermined by new methods by Bergmann and Niemann (*21*), who prepared Table II.

Keratin is the main protein of wool; it is also found in hoof, hair, nail, and horn. It must be emphasized that keratin is not a definite chemical individual, any more than is gelatin. The wool fiber is composed of three types of cells which differ in composition, and the same fiber is not of uniform composition throughout its entire length. Speakman (*38*) states: "Even the average composition of any one wool differs from that of another, and it is clear that there is no one wool substance, but many possible wool substances varying but little in physical properties, since they can all be recognized and utilized as wool." A similar situation exists with the various starches, which are mixtures rather than chemical individuals, though they all function as starch (*5*).

TABLE III. AMINO ACID ANALYSES OF WOOL KERATIN[a]

Acid	Grams/100 Grams Wool	Frequency	Gram Residue in 100 Grams Wool	
			Calcd.	Obsvd.
Glutamic acid (*40*)	15.27	8 (2^3)	0.106	0.103
Aspartic acid (*40*)	7.27	16 (2^4)	0.053	0.054
Amide nitrogen (*40*)	1.37	9 (3^2)	0.094	0.098
Arginine (*33*)	10.2	10 (2^4)	0.053	0.059
Lysine (*33*)	2.8	48 (2^4.3)	0.018	0.019
Histidine (*43*)	0.66	192 (2^6.3)	0.004_5	0.004
Tyrosine (*33, 49*)	4.8	32 (2^5)	0.027	0.027
Tryptophane (*33*)	1.8	96 (2^5.3)	0.008_9	0.009
Methionine (*17*)	0.44–0.67	192 ($2^6$6.3)	0.004_5	Mean value
Cystine[b]	About 3½% S, as a mean of wide variations	8 (2^3)	0.106	Mean value
Leucine (*1, 33*)	11.5	9 (3^2)	0.094	0.088
Alanine (*1, 33*)	4.4	16 (2^4)	0.053	0.050
Proline (*1, 33*)	4.4	24 (2^3.3)	0.035	0.038
Serine (*1, 33*)	2.9 .	32 (2^5)	0.027	0.028
Valine (*1, 33*)	2.8	36 (2^2.3^2)	0.024	0.024
Glycine (*1, 33*)	0.6	96 (2^5.3)	0.008_9	0.008

[a] The estimates in the first two sections of the table are reliable; those in the last section are unreliable. The first three items were determined on Cotswold wool.

[b] The sulfur content of the keratins, all equivalent to cystine except for the small amount of methionine quoted, varies from about 2 to 5 per cent, the average for wool being about 3.5 per cent. There are apparently no systematic steps, such as might be expected on the Bergmann-Niemann hypothesis, but all sorts of values of the sulfur content between about 2 and 5 per cent have been observed (*16, 18, 38*).

In all cases of this kind, we must remember that mixtures commonly have supermolecular structures which may differ materially from what would be shown by pure substances. Even very small amounts of "impurities" may be potent in producing such variations (*2, 4, 35*).

Table III gives data supplied by Astbury (*11*) on the products of the hydrolysis of wool keratin.

According to Astbury (*11*) from the x-ray measurements and density of β-keratin, the average residue weight of all residues (whether they have been estimated chemically or not) is approximately 118. One eighth of the residues are glutamic, one sixteenth arginine, one sixteenth aspartic, one

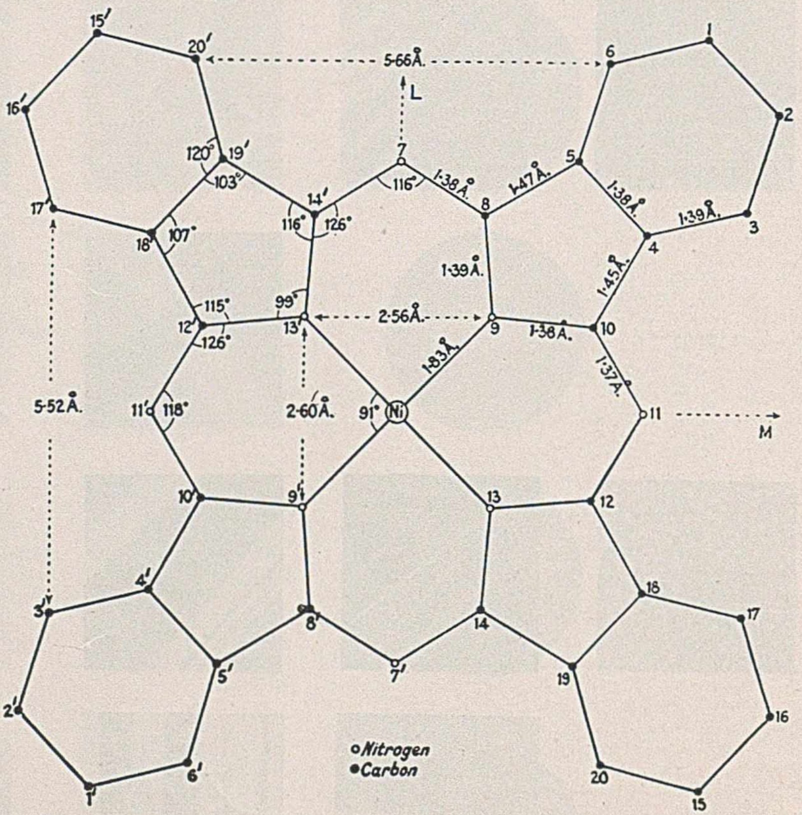


FIGURE 5. DIMENSIONS OF THE NICKEL PHTHALOCYANINE MOLECULE

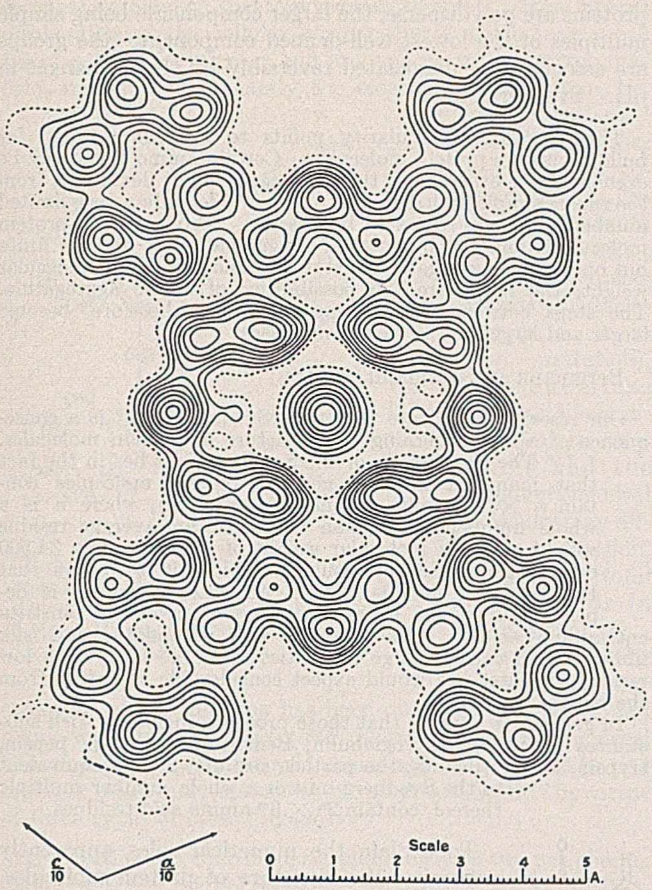


FIGURE 6. PROJECTION OF NICKEL PHTHALOCYANINE ALONG THE *b* AXIS WHICH MAKES AN ANGLE OF 44.2° WITH THE MOLECULAR PLANE

Each contour line represents a density increment of one electron per Å.², except on the central nickel atom where the increment is five electrons per Å.² for each line. The one-electron line is dotted.

thirty-second tyrosine, one forty-eighth lysine, one ninety-sixth tryptophane, and one hundred-and-ninety-second histidine. The molecular weight is therefore at least 192 × 118.

Macromolecular Structure (*9*, *23*, *34*)

Ever since Emil Fischer had shown how amino acids could be built up into long polypeptide chains, it was conjectured that natural proteins consisted of similar but more highly complicated chain structures. It is only about ten years since the application of x-ray spectrographic analysis to fiber structure has been able to demonstrate that textile and other fibers consist of submicroscopic, more or less imperfectly crystalline, molecular aggregates whose crystallographic direction is approximately parallel to the crystallographic axis or is inclined to it at some approximately constant angle. The x-ray spectrograms do not, therefore, give the geometric definiteness yielded by single macroscopic crystals. Astbury and Sisson (*14*) stated it thus:

> Speaking briefly, the main trouble lies in the difficulty or impossibility of measuring sufficient interdirection angles to define the molecular arrangement without ambiguity. Sometimes it is possible to draw very plausible conclusions, or even conclusions almost certainly correct; but in others the diffraction effects are so ill-defined as to preclude altogether the use of direct geometrical argument and compel us to fall back on indirect reasoning based on evidence from various sources, including comparative photographs of related structures. The x-ray investigation of proteins in particular is a many-sided inquiry of this nature, for the diffraction effects are susceptible of interpretation only in relation to other physical and chemical data. The x-ray photographs then serve to give form, so to speak, to such data—to provide the three-dimensional framework necessary to build them into a coherent whole.

Space does not permit a detailed consideration of the experimental data and deductions which lead to the views outlined below. Although these views are considered to be the most reasonable in the light of our present knowledge, it must be emphasized that further experimental data may require their modification. To give some notion as to the type of results obtainable by x-ray analyses, Figure 5 reproduces what may be termed a "surveyor's map" of the nickel phthalocyanine molecule; Figure 6 shows a "physical contour map" of the same molecule. Both were determined by Robertson (*36*). Cook (*23A*) recently showed that iron phthalocyanine has properties like the enzyme catalase.

Robertson also gives (*37*) a table of experimentally determined internuclear distances or bond lengths in the case of carbon showing that they "can vary considerably in different compounds, and in fact may adopt almost any value between that of a pure single bond and a pure double bond":

C—C	Diamond, aliphatic hydrocarbons	1.54 (single bond) Å.
C—C_6H_5	Diphenyl, phthalocyanines	1.48–1.49
C—C_6H_5	Stilbene	1.44–1.45
C—C	Oxalic acid	1.43
C—C	Graphite	1.42
C—C	Naphthalene, anthracene	1.41
C—C_6H_5	Tolan	1.40
C—C	Benzene	1.39
C═C	Stilbene	1.33–1.35
C═C	Ethylene	1.33 (double bond)
C≡C	Acetylene, tolan	1.20 (triple bond)

These figures indicate how such "constants" as atomic bonds may shift in value under the influence of the electronic fields of other atomic groups.

CARBOHYDRATE FIBERS. In the case of the carbohydrate fibers, the linear macromolecules or valency chains are hundreds of times as long as their cross section. In the case of the cotton fiber Staudinger (*41*) by viscometric methods estimated the chain to approximate 600–800 glucose residues; Haworth, on the basis of analysis by the end-group method (*28*), considers the chains to average about 200 glucose residues. From the x-ray diagram of ramie, Hengstenberg and Mark (*29*) concluded that the "cellulose crystals" are at least 600 Å. long and of the order of 50 Å. thick.

Figure 7 reproduces Haworth's diagram of part of a cellulosic chain.

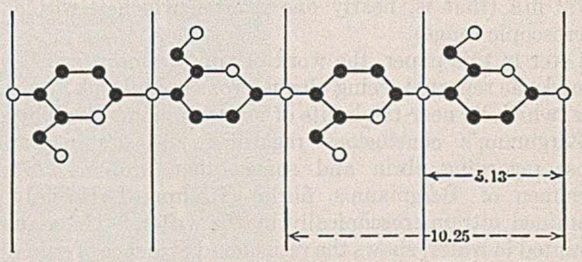


FIGURE 7. CELLULOSE CHAIN, BASED ON X-RAY DATA OF HAWORTH (*28A*)

Dimensions are in Ångstrom units

The length and orientation of the macromolecular chains are important factors in the strength of rayon. Thus the "stretch spinning" of the filaments makes a more perfect lengthwise orientation, which adds to their strength. In the case of cellophane and "Lumarith—Protectoid", however, random orientation is desirable so that the sheets will show no lines of selective weakness along which they would more readily tear.

SILK. The macromolecular structure of silk fibroin is so comparatively simple that the question has been raised as to whether a substance of such extreme composition should be classed as a genuine protein. Based on a recent redetermination of the hydrolysis products of fibroin, Bergmann and Niemann (*21*) calculated (Table II) that the six amino acids comprising about 85 per cent of those in the original intact protein are present with the following frequencies and ratios:

	Frequency	Ratio
Glycine (G)	2	1296
Alanine (A)	$4 = (2^2)$	648
Tyrosine (T)	$16 = (2^4)$	162
Arginine (Ar)	$216 = (2^3 \times 3^3)$	12
Lysine	$648 = (2^3 \times 3^4)$	4
Histidine	$2592 = (2^5 \times 3^4)$	1

Figuring the average residue weight at 84, they find that this indicates an approximate molecular weight of 217,700. They suggest the following diagrammatic structure for a fragment (one sixth) of the fibroin molecule; X stands for amino acid residues other than those whose abbreviations are given above:

—G—A—G—T—G—A—G—Ar—G—A—G—X—G—A—G—X—
(G—A—T—G—A—G—X—G—A—G—X—G—A—G—X)$_{12}$—
G—A—G—T—G—A—G—X—G—A—G—X—G—A—G—Ar—
(G—A—G—T—G—A—G—X—G—A—G—X—G—A—G—X)$_{13}$—

It is not yet possible to determine which of the 432 isomers of this fragment is present, but six such fragments make the complete fibroin macromolecule of 2592 amino acid residues. Following the scheme previously proposed by Meyer and Mark and by Astbury, the spatial configuration of the "backbone" of silk fibroin is represented in Figure 8.

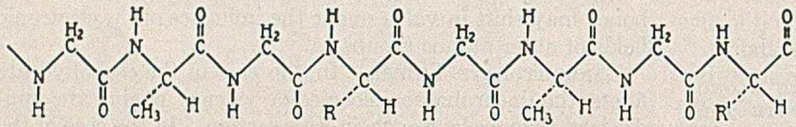


FIGURE 8. SPATIAL CONFIGURATION OF THE BACKBONE OF SILK FIBROIN

The hydrogen atoms attached to the asymmetric carbon atoms are supposed to stand above the plane of the paper; the CH_3, R, and R′ groups are below this plane.

From the x-ray data Astbury (*12*) estimated the distance between adjacent peptide bonds to be 3.5 Å.; assuming that no crumpling or rolling up of the fibroin macromolecule exists, this indicates a minimum length of 2592 × 3.5 = 9072 Å. = 907.2 mμ (that is, nearly one micron, which is within the microscopic range).

Later in this paper, the work of von Weimarn will be discussed; he reported seeing ultramicrons in both silk and cellulose, which lie near the limits of microscopic resolvability.

Bergmann's conclusions regarding silk fibroin parallel those regarding fibrin and some other proteins (*19*). A specimen of Bergmann's fibrin (Hoffman-LaRoche) was examined ultramicroscopically by the writer. The material, mounted in water, shows the reticulated evidence of submicroscopic structure. On addition of 85 per cent formic acid, the fibrin particles begin to disperse. Ultramicrons at the edges appear to be incased in a viscous or gelatinous unresolvable phase, and the field becomes full of actively moving ultramicrons, many of which are still grouped together in twos and threes. As the slide dries out, the ultramicrons adhere to the glass, forming globulitic chains (margarites) and dendritic groups. All this seems to indicate that the structure of fibrin is at least duplex in the ultramicroscopic range. The ultramicrons disappeared with ordinary microscopic illumination.

Svedberg showed (*42*) that the numerous proteins examined by ultracentrifugal methods have macromolecular weights of 35,200 or some multiple of this figure. Many proteins are polydisperse, the larger components being simple multiples of the lowest well-defined component; the groups are associated or dissociated reversibly by slight changes in pH. Svedberg states:

> This remarkable regularity points to a common plan for building up the protein molecules. Certain amino acids may be exchanged for others, and this may cause slight deviations from the rule of simple multiples, but on the whole, only a very limited number of masses seems to be possible. Probably the protein molecule is built up by successive aggregation of definite units but only a few aggregates are stable. The higher the molecular weight, the fewer are the possibilities of stable aggregation. The steps between the existing molecules, therefore, become larger and larger as the weight increases.

Bergmann and Niemann (*20*) say:

> Our researches indicate that the "Svedberg unit" is a consequence of a law governing the structure of protein molecules. * * * The significance of the Svedberg unit lies in the fact that many, if not all, genuine protein molecules contain $n \times 288$ units (amino acid residues), where n is a whole number other than 0. With an average residue weight of 120, a molecular weight of approximately 34,500 or a multiple thereof results. From this it follows that the Svedberg unit is not an absolute value but is dependent upon the average residue weight of the constituent amino acids. With proteins such as gelatin and silk fibroin which contain large quantities of amino acids with low residue weights, one would expect considerable deviation from the Svedberg unit.
>
> In general, it appears that those proteins, including such substances as insulin, thyroglobulin, Bence-Jones protein, pepsin, trypsin, and antibodies, the particle size of which is equivalent to the Svedberg unit or a whole number multiple thereof, contain $2^n \times 3^m$ amino acid residues.

To explain the numerical rules apparently governing the structure of protein molecules, Bergmann and Niemann advance the hypothesis that in every protein each amino acid residue is distributed throughout the entire peptide chain at constant intervals; i. e., each amino acid residue recurs with a characteristic whole number frequency. The protein macromolecule therefore contains many superimposed frequencies and cannot yield fragments of uniform structure.

Bergmann and Niemann (*22*) point out that their discussion has been restricted to simple homogeneous proteins. With proteins which are truly reversible association products of two or more simple molecular species, if the association product is considered as a single molecular species, numbers other than 2 and 3 may appear in the formulation $2^n \times 3^m$, though the stoichiometrical laws outlined would apply to the simple protein constituents.

In the macromolecular stage of organization we seem to reach the zone where the residual attractive forces of the combining units are so diminished that slight alterations in milieu conditions (e. g., of pH) can make or break the combination; or where structural peculiarities or absorbed impurities may prevent units from getting sufficiently close to establish powerful forces of mutual attraction. Although Maxwell had assumed these forces to vary inversely as the fifth power of the distance, Langmuir found the variation to be of the order of the ninth power; so that the force would fall to half-value if the distance increased only 8 per cent. Different parts of complex molecules may be considered as having different surface energies (*30*).

Here we enter the intermediate zone between the preciseness of chemical stoichiometry and the statistical continuum of physical structure (*48*). One reason why biocolloids of large macromolecular size tend to have so uniform a structure appears to lie in the fact that they are the result of a physicochemical determinism (*6*); the units are molded, as it were, against the highly specific surfaces of biocatalysts which serve as mastermolds or macromolecular templets. The precise duplication of the cellular chromosomes, which may reach the size of many microns and are well up in the microscopic field, indicates how exactly the biocatalysts can group, tie, or "crochet" molecules together into uniform, coherent units. Incidently it should be noted that when the templets undergo modification (e. g., as in gene mutation), the chemical course of life is diverted at its very source and the output of chemical molecules may differ in proportion, in kind, in total quantity, or in arrangement (*7*).

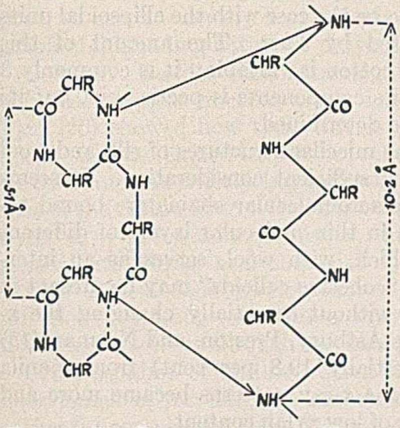
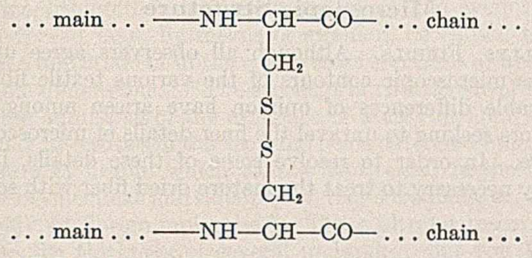


FIGURE 9. INTRAMOLECULAR TRANSFORMATION FROM α-KERATIN TO β-KERATIN THAT TAKES PLACE WHEN ANIMAL HAIRS ARE STRETCHED (AFTER ASTBURY, *9*)

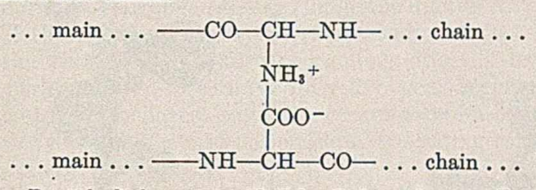
KERATIN. The macromolecular structure of the keratins has been deduced by Astbury and his co-workers from their x-ray diagrams and their physical behavior (*9, 10*). Amino acid chains are considered to be tied together into a molecular sheet or "polypeptide grid" by virtue of three types of cross linkages:

1. Cystine can contribute simultaneously to two neighboring main chains and thereby link them through a covalent bridge:



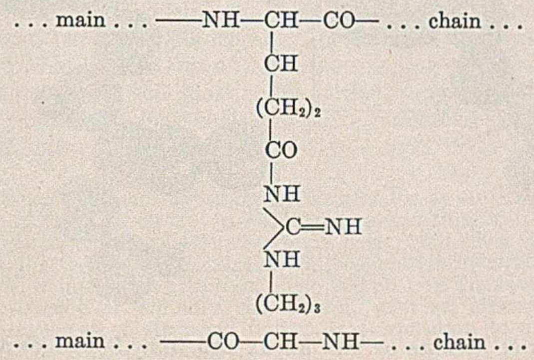
$$\begin{array}{rcl}
\ldots\text{main}\ldots\text{—NH—} & \text{CH} & \text{—CO—}\ldots\text{chain}\ldots \\
 & | & \\
 & \text{CH}_2 & \\
 & | & \\
 & \text{S} & \\
 & | & \\
 & \text{S} & \\
 & | & \\
 & \text{CH}_2 & \\
 & | & \\
\ldots\text{main}\ldots\text{—NH—} & \text{CH} & \text{—CO—}\ldots\text{chain}\ldots
\end{array}$$

2. Salt linkages (*39*) between electropositive and electronegative side chains:



$$\begin{array}{rcl}
\ldots\text{main}\ldots\text{—CO—} & \text{CH} & \text{—NH—}\ldots\text{chain}\ldots \\
 & | & \\
 & \text{NH}_3^+ & \\
 & & \\
 & \text{COO}^- & \\
 & | & \\
\ldots\text{main}\ldots\text{—NH—} & \text{CH} & \text{—CO—}\ldots\text{chain}\ldots
\end{array}$$

3. Peptide linkages, typified by linkage between residues of arginine and glutamic acid:



$$\begin{array}{rcl}
\ldots\text{main}\ldots\text{—NH—} & \text{CH} & \text{—CO—}\ldots\text{chain}\ldots \\
 & | & \\
 & \text{CH} & \\
 & | & \\
 & (\text{CH}_2)_2 & \\
 & | & \\
 & \text{CO} & \\
 & | & \\
 & \text{NH} & \\
 & \text{>C=NH} & \\
 & \text{NH} & \\
 & | & \\
 & (\text{CH}_2)_3 & \\
 & | & \\
\ldots\text{main}\ldots\text{—CO—} & \text{CH} & \text{—NH—}\ldots\text{chain}\ldots
\end{array}$$

Ordinarily the main chains of the grid are not fully extended but are partly buckled up "accordion" fashion out of the plane of the grid. When pulled they exhibit reversible extensibility, stretching out on tension and shortening when release of the tension permits the buckling to re-establish itself. The unstretched or normal form is termed "α-keratin", the stretched "β-keratin." Each form shows a characteristic x-ray diagram; the average length of an amino acid residue in β-keratin is about 3.4 Å. Astbury (*10*) states that "the normal state of wool is one of contraction, a lesson that might well be written in large red letters over the entrance to every woolen and worsted mill."

Astbury and Woods (*10, 15*) represent the molecular readjustment which takes place when α-keratin is stretched out into β-keratin as shown in Figures 9 and 10.

If thoroughly dried while stretched, the contraction of keratin is inhibited. Water or weak alkali appears to loosen enough of the secondary or other bonds to permit a readjustment of stresses in the grid. "The tendency of stretched wool to contract to its original unstretched length is a property not of wool alone but of wool plus water" (*9*).

Very brief steaming of a stretched wool fiber while under tension usually fixes it in the stretched condition. This is commonly done in "pressing" woolen clothing. However, if the wool is steamed for more than a couple of minutes while free of tension, a "supercontraction" occurs, which may make the fiber a third shorter than its original unstretched length.

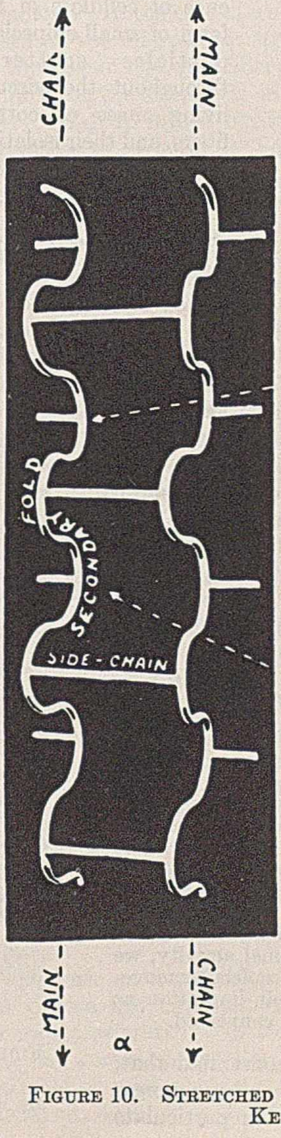


FIGURE 10. STRETCHED AND NORMAL UNSTRETCHED KERATIN

How often have we seen the disaster which follows when woolen underwear is boiled instead of being quickly washed in tepid water and stretched out to dry at a low temperature. The supercontracted, the alpha, and the beta forms of keratin, as represented by Astbury, are shown in Figures 11 and 12.

Micellar Structure

Macromolecules group together to form the next units in particulate aggregation, which (following Nägeli) are termed "micelles." The union of the macromolecules may be consequent upon their union by residual electronic attraction (secondary valence forces) or else through the agency of absorbed surface layers of secondary constituents or "impurities" which serve the part of cohesive colloids, a macromolecular cement or glue. Nature generally operates by all available methods and refuses to accept pedagogic alternatives.

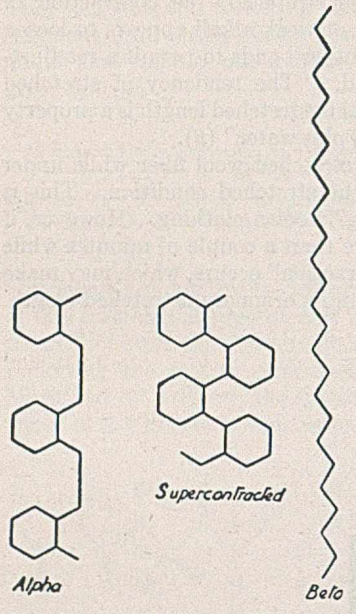


FIGURE 11. FORMS OF KERATIN

CARBOHYDRATE FIBERS (*32*). The existence of cellulose in the form of small ellipsoidal particles scattered throughout the viscous living mass of cotton fibers, and their isolation from the ripe cotton fiber has been demonstrated by Farr and Eckerson (*26*, *27*). These particles are invested with a pellicle of a material (probably of pectinous nature) which had rendered nugatory the optical and the microchemical tests for cellulose. The particles tend to form chains reminding one of the strepto forms of capsulated bacteria. Farr estimates the approximate length of a single particle to be 1.5 microns, and states that uniformity in size is one of the most impressive properties of a mass of particles.

The uniformity in size of biological units is a general phenomenon, though it is not stressed as frequently as its importance warrants. An early reference to this matter is found in Ord's book (*35*):

> In animal and vegetable bodies colloids of different composition and reactions are everywhere intermingled and sometimes, as in blood corpuscles, most intimately. The structures going by the name of "nuclei" in organic tissues have just the characters likely to arise out of their being composed of masses of one kind of colloid suspended in another. Their naturally spherical form is one character of importance. Another interesting point is the limitation of their size, and their adherence to one size in each kind of animal. Regarding them as masses of colloid, having, as their relations show, great functional activity, we can be certain that their internal molecular movements are active. With this their limitation as regards to size is very possibly connected.

The ultramicroscope has demonstrated that, as particles increase in size either by aggregation or by chemical growth, the particulate kinetic activity drops off sharply, until particles at the lower limits of the microscopic range show only a relatively small Brownian motion (*3*).

Such slowly moving units could readily absorb and hold surface films of substances specifically capable of being absorbed, and this seems to be the case with the ellipsoidal units of cellulose demonstrated by Farr. The amount of this cementing substance in cotton is variable; it is commonly 3 to 4 per cent. One of its components is pectic acid, but its composition is still to be determined.

SILK AND WOOL. The micellar structures of silk and wool have not yet been given sufficient consideration. It seems possible that the long macromolecular chains are bound together by or embedded in thin molecular layers of different nature or structure, which, with wool, serves as an intercellular cement. Such "cohesive colloids" may be present in considerable quantities without essentially changing the x-ray spectrogram. Thus Astbury, Preston, and Norman (*13*) removed the xylan (initially 19.8 per cent) from manila hemp, and found that the x-ray patterns became more and more like those of fibers of low xylan content.

However, Speakman (*38*) stated that "the wool fiber consists of long, folded peptide chains in parallel, linked together in one plane by cystine and salt linkages, such planes of linked peptide chains being held together by van der Waals' forces to form the micelles of the fiber."

The work of von Weimarn, referred to later, seems to show that the structure of silk is more complicated than is represented by Bergmann and Niemann. Either the amino acid residues may be differently assembled, or else the 15 per cent of material unaccounted for in the analysis may represent substances which influence the final structure of silk fibroin.

Microscopic Structure

MICELLES, FIBRILS. Although all observers agree upon the gross microscopic contours of the various textile fibers, considerable differences of opinion have arisen among investigators seeking to unravel the finer details of microscopic structure. In order to resolve some of these details, it is generally necessary to treat the mature dried fiber with some

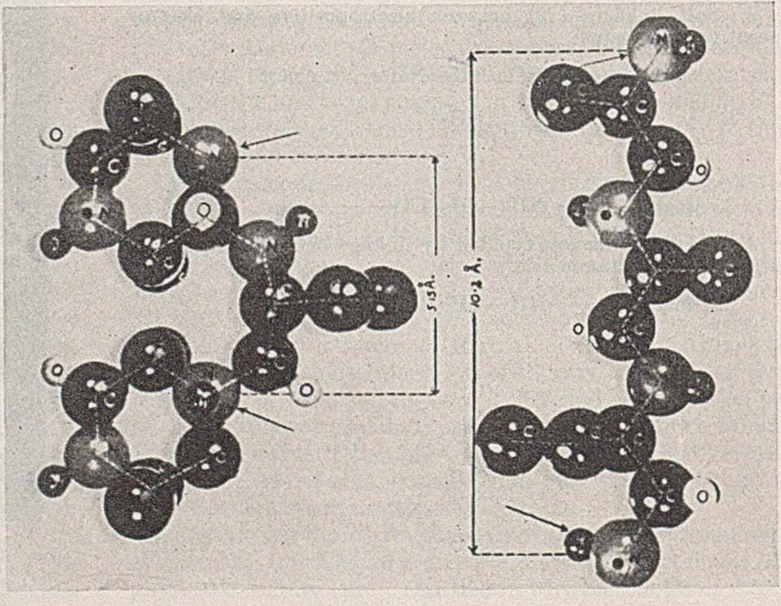


FIGURE 12. SKELETON MODELS OF THE ALPHA AND BETA FORMS OF THE KERATIN CHAIN

By means of the transformation from one type of chain to the other, a maximum elongation of about 100 per cent can be realized without rupturing the fiber.

swelling or disintegrating agent. Apart from the technical difficulty of focusing high-power lenses upon the proper object so as to reveal its true nature, slight errors in manipulation may create artifacts, which are then photographed as "proof positive." Just as the devil can quote Scripture to his purpose, so can an unwary investigator produce a photomicrograph of misleading nature to prove his point.

COTTON. Besides demonstrating the physical reality of elliptical cellulose micelles about 1.5 × 1.1 microns in size, Farr (*26*) showed how these line up into chains constituting fibrils which, embedded in a colloidal pectin-containing matrix, form an interlacing elongated mesh running lengthwise of the cotton fiber. By suitable treatment, resulting in a swelling of the pectinous matrix, the fiber may be disintegrated into fibrils, and these into particles. "During the period of membrane development the fibers within the boll are moist, and the membranes may be disintegrated into fibrils and particles through mechanical action alone."

Cross sections of mature cotton fibers show rings of the fiber lamellae, recalling the annual rings of trees and indicating the complexity of the fiber structure (*8*).

SILK AND WOOL. If the deductions of Bergmann and Niemann are correct, the macromolecule of silk is large enough to constitute a microscopically visible micelle. However, it seems possible that some of the amino acids of silk fibroin may be arranged in the form of macromolecular chains or layers which are cemented together by some substance composed of the remaining amino acids; that is, the ultramicroscopic structure of silk may not be quite as simple as is represented by Bergmann and Niemann.

For example, von Weimarn (*46*) followed ultramicroscopically the dispersion of silk in hot concentrated solutions of calcium chloride, calcium nitrate, calcium thiocyanate, sodium iodide, lithium bromide, etc.; he found that every detached silk thread may, by means of swelling, be caused to divide into a multitude of fibrils whose cross section is of ultramicroscopic dimensions: "The excellent fibril cleavage of silk leads to the admission of the existence of a very unequal distribution of intensities in the vectorial fields of forces of the smallest masses of fibroin which cannot be divided further without loss of chemical individuality of this substance, or, speaking briefly, of fibroin molecules." These ultramicroscopic fibrils have the thickness of several molecules; but von Weimarn found that the fibrils in a swollen thread are distributed spirally; the stronger the swelling, the tighter the spirals, until the spiral curls are almost perpendicular to the length of the silk fiber. On further swelling, the silk assumes a rubberlike state, described fully by von Weimarn (*47*). This state, he believes, is due to spiral fibrils of a higher polymeride incased in a viscous semifluid, consisting of a simpler substance.

When solutions of silk are "spun", the motion tends to orient the long macromolecules lengthwise to the thread, the strength of which is enhanced by stretching or rubbing the thread parallel to its length. Incidentally this seems to be just what the silk worm does in its spinning operation. This coagulation or solidification by motion, as von Weimarn calls it, enables the long chains to make numerous side contacts and units. He states (*47*):

> When by means of strong mastication, or by further swelling, the quantity of destroyed fibrils increases, a transition from the rubberlike to the plastic state takes place; and when the thread is subjected to stronger stretching (coagulation by stretching) or when it undergoes syneresis, there will ensue a transition to the consistency of ordinary silk thread, with an almost parallel arrangement of stretched fibrils, or a transition to an almost perfectly solid consistency.
>
> A silk coagulum in the relaxed rubberlike state acts relatively very weakly upon polarized light, and the determination of its ultramicrostructure is very difficult; nevertheless, in spite of these difficulties, its ultramicrostructure is established with certainty as consisting of spirally curled fibrils.
>
> During the stretching out of the silk thread in its rubberlike state, the spiral fibrils become lengthened by stretching, they are brought close to each other, and in some places, where the liquid is squeezed out, they develop vectorial cohesion, which is accompanied by a release of heat; during this process of stretching, the micro- and ultramicrodrops of the viscous liquid, which is between the fibrils, assume the shape of streamlets strongly extended and arranged parallel to each other; i. e., they assume a structure which is extremely unstable for the liquid state.
>
> As soon as the stretching has ceased, the streamlets of the viscous liquid, under the influence of surface energy, tend to assume volumes with the smallest possible surfaces under the given conditions. The stretched-out fibrils become again curled into spirals, breaking up their vectorial cohesion with the adjacent fibrils (as yet not at full strength); i. e., the system practically returns to its initial state and to its former length.

The writer examined silk, wool, and hairs under the ultramicroscope, and found that they all have a demonstrable ultrastructure which vanishes on ordinary microscopic illumination. The silk and wool were mounted in formic acid and in caustic alkali; the hair, in caustic alkali. The wool fibers give off ultramicrons, which may be isolated or in groups; in the fibers the ultramicrons appear, as a rule, to have a chainlike grouping, and to be surrounded by a pellicle. This, however, may well be an optical effect, and further investigation is needed. The ultramicrons in silk appear to be much smaller than 0.9 micron, the estimate of Bergmann and Niemann. In the case of wool, the ultrastructure is superimposed on the microscopic structure of imbricated scales, etc. In the case of one wool fiber with a free end, one side swelled more than the other did in sodium hydroxide so that the fiber curled up into a tight spiral indicative of sidewise irregularity of structure. The cut ends of some silk fibers showed what looked like fibrils held in a cementing matrix. Hairs varied considerably in structure, according to the animal from which they came.

Fibers

We now come to the commercial level, which begins with the various fibers of trade, the basic raw materials of the textile industry. The great differences in each of the natural fibers, cotton, silk, wool, etc., are reflected in the wide differences in the prices of their many market grades. But even this does not indicate the high degree of variability in natural fibers. Individual wool and cotton fibers vary in composition and structure throughout their length and breadth, and a single silk worm filament is not uniform over the whole of its length.

In contradistinction to the natural fibers, the manufactured rayons are much more uniform if they are carefully made. With viscose rayons, the spinning operation must be carried out when the xanthate solution has reached the proper "ripeness" or "age." A shutdown may cause deterioration in quality of the finished product if the spinning liquid becomes "overripe." On the other hand, the acetone solutions of acetyl cellulose used in spinning acetate rayons are quite stable and permit of long shutdowns. Furthermore, acetate rayons have a specific gravity approximating that of silk, an evidence of similar molecular "fluffiness", as the following figures for average specific gravity show: viscose and cuprammonium rayons, 1.5–1.6; acetate rayon, 1.3; silk, 1.36.

The basic chemical difference between acetate rayons and the viscose and cuprammonium rayons (the latter are regenerated cellulose) is reflected upward into many of the practical working properties. For example, acetate rayons do not mold or mildew, do not rot with perspiration (any stain washes out readily); do not absorb body odor, tobacco smoke, etc., absorb relatively little moisture[1] and do not become "wet" or soggy. Dirt and water do not adhere strongly to acetate rayon, so that it quickly becomes clean on washing and dries rapidly. The crispness of acetyl cellulose tends to prevent chill due to dampness, a quality in which it surpasses linen. Acetate rayons have a relatively low coefficient of friction, so that they weave easily; the finished fabrics slide and do not stick, a factor valuable in linings for clothes since it prevents wear or "cutting", and in underwear because outer garments do not bind.

There is no scientific foundation for lumping together under one commercial name "rayon", materials having such basically different properties as acetate yarns and yarns consisting of regenerated cellulose (viscose and cuprammonium rayons).

In manufactured fibers, apart from a lengthwise orientation of the crystallites which makes for strength, the makers really aim at the proper relation between colloid matrix and dispersed units; thus they steer between strength and stretch, just as the steel maker tempers his steel to obtain the desired hardness accompanied by the suitable toughness.

Over a period of two weeks the writer followed ultramicroscopically some cellulose acetate spinning solution from which the solvent was slowly, but not entirely, escaping. Ultramicrons soon appeared in an unresolvable but luminous matrix, and these increased in number and in brilliancy with lapse of time, and tended towards chain formation.

The following figures are indicative of the increasing demand for rayons; especially for acetate rayon (in thousands of pounds produced per year in the United States):

	Silk	Viscose, Cuprammonium, and Nitro Rayon	Acetate Rayon
1911	....	363	....
1920	29,000	10,005	120
1930	65,600	117,543	9,790
1936	57,800	214,926	62,700

Yarns

There are two general classes of yarns: (*a*) those made by assembling or twisting filaments or continuous threads—e. g., of silk or of rayon—and (*b*) those spun from fibers of varying length or staple—e. g., cotton and wool. Recently rayon filaments have been cut into fibers (known commercially as cut staple) which are spun into yarns of various kinds.

Yarns may be made from any quality of any single fiber, from mixed fibers, or from assembled threads of different kinds. They may be regular or irregular, exceedingly fine or relatively coarse.

Space does not permit us to consider the diverse and sometimes complicated processes whereby fibers are spun or twisted into yarns, or the specialized machinery developed for this purpose, or the various modes of purification or pretreatment to which fibers are subjected prior to yarn making. However, the attractive forces which enable fibers to form strong threads and yarns demand some discussion. They represent the effect of the outwardly direct electronic molecular fields, complicated by the gross interlocking physical asperities of the fibers as these are twisted together (*31*).

These forces come into evidence in "house moss", that horror of meticulous housekeepers. The backbone of house moss consists of textile fiber debris set free by sweeping carpets, brushing clothes, shaking out sheets, or other types of wear and tear. Such fibers are carried by air currents due to ventilation or heating, and deposited on walls or in corners. Surface electrification seems to play a role here. The air currents frequently cause the fibers to roll together to form a weak but definite "roving" which can be twisted into a weak thread. In contradistinction to fibers, wind-blown sand is noncoherent; a "rope of sand" is illustrative of lack of strength.

Fabrics

The production of finished fabrics, mainly by weaving and knitting, is the terminal operation of the textile industry. But the interest of the industry extends into all the subsidiary fields where textiles are used. Only by keeping in touch with consumer reaction and consumer requirements can the textile manufacturer supply exactly what the market demands.

"HAND." Although the final test of a fabric is the satisfaction it gives to consumers, years of experience enable most textile buyers to form a preliminary judgment regarding the desirability of a fabric simply by handling it or determining its "hand." Good "hand" is not always coincident with good service or wear. In fact, by clever sizings, softeners, finishes, etc. (cosmetics of the textile industry), inferior textile bases may be given a deceptively good "hand." But of two fabrics alike in other essentials, the buyer generally selects the one which, to him, has the better "hand."

On what does "hand" depend? We here face the fact that the human body is an extremely complex testing instrument, surprisingly accurate within its limitations; in one quick operation it can evaluate a number of properties and register a complete and final judgment. Scientific instruments which evaluate isolated properties are valuable only as their results check with the human response. The Grecian architects made the silhouettes of their columns show a tapering bow rather than a mathematically straight line because the result was more pleasing. The final court of appeal for fabrics is in the buyer's senses.

Even what we commonly think of as simple senses are generally complex, an integration of several senses and body reactions. Individual variations in the sense of touch are still to be explored. To have commercial value, a tester should be able to gage the reaction of the average purchaser. "Hand" in textiles appears to involve mainly tactual reactions and tactual and visible flexibility—that is, how the fabric feels and how it drapes, as compared with fabrics of similar construction.

Subjectively, the "feel" of a fabric involves a relative determination as to whether it is smooth or rough, soft or hard, even or uneven, sheer or thick, warm or cold, etc. Objectively, these qualities depend upon the nature, closeness, and regularity of the weave, the fineness, twist, and "fuzziness" of the warp and filling threads, and the structure and chemical nature of the fiber. The chemical nature of that portion of the fabric and its cosmetics (sizing or finishing) which constitute the tactual surface determines the complex, outwardly directed, electronic contour whose integration and appraisal form an unexplored though unquestionably active factor in differentiation by touch.

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[1] To obviate the frictional electric charges on acetate rayons, due to their insulating power, a hygroscopic size is often used during weaving. According to the "Rayon Handbook" [1st ed., p. 105 (1934)], this becomes an important factor in the use of rayon yarns for bathing suits and underwear, and in the shipping of rayon yarns to tropical climates. Acetate yarns and goods have a special resistance to sea water and tropical conditions as well as microorganisms. The resistance of other rayons range in this order: nitro, viscose, cuprammonium. Silk is not subject to the action of microorganisms which cause mildew, etc., to any great extent. Cotton is affected by bacteria through dampness, foul air, and lack of ventilation. Rayon is highly hygienic and is little affected by body excretions and perspiration. This is particularly true of cellulose acetate yarns and goods. The "Rayon Handbook" further states (p. 100) that, everything else being equal, nitrocellulose yarns have the greatest moisture content, whereas cellulose acetate yarns have the lowest moisture content under all conditions. This moisture is not sufficient to cause the rayon yarn or goods to feel "clammy" in extremely damp days, as it does with wool.

The following nerve-end organs in the skin have been identified by physiologists (*24*):

1. Pacinian corpuscles, for deeper pressure.
2. Meissner's corpuscle, for touch or contact.
3. Krause's end bulb, for temperature change. There are separate "spots" for feeling "cold" and "warmth", which psychologists are able to locate but not to identify.
4. Corneal nerve plexus, for pain.
5. Nerve plexus of hairs, involved in contact.

In addition, physiologists recognize a system of sensory qualities deriving from stimulation in muscles, tendons, and joints, which is called "kinesthesis." It is also termed "proprioception" because it provides afferent impulses essential to accurate adjustment of body movements.

There is some difference of opinion regarding the histological differentiation of nerve-end organs in the skin, and still less certainty regarding the functions of each receptor, the integration between receptors, and possible chronaxy within a single receptor nerve. Chronaxy is a response, consequent upon different speeds of reaction or conduction of the constituent nerve fiber elements or axons of a nerve.

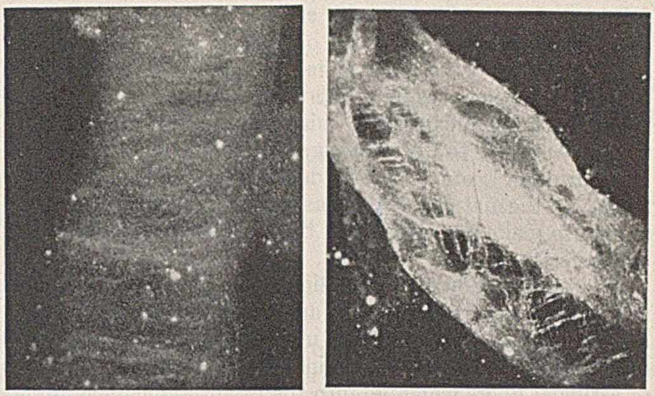
The nerve-end organs form a particularly rich mosaic in the four cutaneous layers of the fingers. This fact, coupled with the results of experience in that part of the brain to which these nerves run, give the sense of touch a complex but efficient power of discrimination, provided a sufficient area of the skin is affected. The amount of pressure exerted by the musculature in feeling regulates the degree of "contact" between the skin and the substance felt. Discrimination is not possible if the skin is touched by fine points. In determining "hand", the fingers are moved over the surface, the cloth is drawn through the fingers, or else the cloth is rubbed between the thumb and forefinger.

Temperature. The temperature response of the skin to a textile does not depend merely upon the thermal gradient, if any, between the fabric and the skin. Much more important are the thermal conductivity, specific heat, and contact area of the fabric, and the speed of escape of water from the skin, which also affects the local feeling of temperature change. In turn, the evaporation of water from the skin is influenced by the hygroscopic atmosphere of the fibers and fabric, at least initially. For example, linen bed sheets at first feel cool; but an equilibrium is soon reached, or evaporation may be restrained by blankets or quilts. Cotton sheets (cellulose) on the other hand, hold more moisture, do not permit so ready a transpiration, and feel warmer than linen.

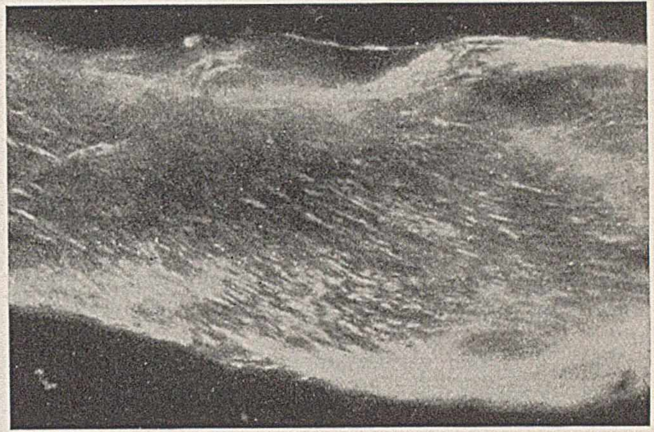
Comfort involves a certain balanced transpiration of moisture from the skin through the garments worn. If this is too rapid, we "feel" cold or chilly; if too slow, we "feel" hot or sticky. Fabrics that absorb too much moisture become loaded with an unseen fog, lose their crispness, cling and stick to the body, interfere with proper transpiration, and are uncomfortable.

Air circulation (wind, drafts) aids in removal of moisture from the outer surfaces of garments, and we control this by the use of a series of textile sheathings (shirts, skirts, suits, dresses, coats, overcoats) over the intimate undergarments, changing our clothes to suit the uncontrollable vagaries of the weather. However, if the undergarments are "sticky" we are in trouble, for social convention demands outer garments.

The reason why undergarments of acetyl cellulose[2] are found to be cool in summer and warm in winter is thus understandable. They permit free transpiration and readily respond to the freedom or restrictions of such outer garments as we choose to add.



Cellulose (× 200 Cellulose (× 200)



Natural silk (× 1200)

Figure 13. Cellulose and Silk Fibers, Swollen in Concentrated Aqueous Solutions of Salts, Represent a Collection of the Finest Fibrils Curled into Spirals

Between these fibrils is enclosed a more or less viscous salt solution containing cellulose or silk in a colloidally dissolved state.

The relation between comfort and skin transpiration came to the fore when the Broadway subway in New York was first opened, and there was general public complaint that the "air was bad." Charles F. Chandler made numerous analyses which proved that there was no trouble with the chemical composition of the air, but that in stations and trains the stillness of the air inhibited transpiration so that people felt the same discomfort one feels on entering a closed house. The difficulty was solved by installing ceiling fans in the cars and ventilating the stations.

Drape. As a fabric is handled, the eye notes its color, weave, and visible flexibility, which is coordinated with its tactual flexibility. The subtle kinesthetic system of the body here reinforces the eye which, however, exerts its influence. Thus reds commonly look and feel "warm", while blues and greens look and feel "cool." A swatch of fabric is generally held up or draped over the hand or knee to see how its folds fall or flow. Except for special purposes (e. g., ruffs, collars, interlining, millinery, etc.) stiff fabrics do not find favor. Buckram and haircloth have their uses in stiffening lapels, shoulders, etc., but garments are not made of them.

Selection of Fabrics

The main factors involved in the selection of a fabric for any specific purpose are adaptability, appearance, service, and cost.

Adaptability is determined largely by the results of experience; with clothes comfort is the criterion, and the type of

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[2] Observations were made by the writer on the Celanese type of acetyl cellulose.

fabric preferred will vary with climate and season. Appearance is subject to the whims of fashion or is regulated by social or religious considerations; thus certain sects abstain from bright colors, while others wear haircloth. Service depends upon the purpose for which the fabric is used, and involves resistance to wear, fading, washing, distortion (stretching, shrinking), etc. Cost is determined by market conditions, by the nature of the basic fiber or mixture of fibers chosen to make the fabric, and by the nature of its weave or construction.

The textile trade meets the limitless demands arising from varying combinations of these and other buying factors with a multitude of beautiful and useful fabrics. Here we will discuss only those differences in certain of the fabrics made of artificial fibers which go into the essential chemical differences between them.

The major portion of the shrinkage of many fabrics is consequent upon the nature of the weave and treatment on finishing—e. g., tentering. In treating cotton fabrics by the Sanforizing process, the amount of shrinking is first determined by washing and drying a swatch. The goods are then pulled down to the width thus determined, and the cloth is forced mechanically to take the length indicated by the washing test. A Sanforized fabric is thus preshrunk mechanically.

The chemical difference between the regenerated cellulose rayons (viscose and cuprammonium) and the acetate rayons is responsible for their marked difference in behavior to moisture and water;[3] fabrics made of the former are greatly affected by water; fabrics of the latter show slight effects, if any.

When a certain viscose-cuprammonium-filled crepe was creped, it shrank from 39 to 26 inches in width (32 per cent); when air-dried, it worked out to 32 inches in width for the market, a net shrinkage of 18 per cent. This fabric is distorted by wet washing or rain, and it is practically impossible to correct this by ironing.

It has only recently been discovered how to crepe acetate rayon. A certain all-Celanese acetate crepe fabric is remarkable since the process of making crepe fabrics is basically dependent on shrinkage, and the finished Celanese fabric shows practically no shrinkage on washing.

Moiré effects on viscose and cuprammonium rayons, like those on real silk (watered silk), promptly wash out. With acetate rayons the moiré persists, as a piece of Celanese permanent moiré indicates (*25*). The half that has been washed shows no loss of the moiré impression.

Acknowledgment

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[3] This peculiarity of acetyl cellulose also extends to acetyl starches. Thus Higgenbotham and Richardson [*J. Soc. Chem. Ind.*, 57, 238 (1938)] state: "Starch acetates are very resistant to wetting by water."

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COMPOSITION OF LUBRICATING OIL

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The wax distillate fraction of a Van Zandt Texas crude was separated by alternate distillation and solvent extraction processes to the point where the oil fractions represented 0.05 per cent of the original crude. When reduced to this degree, the oil is still very complex, for by further refining several of these fractions in an efficient reflux extraction unit, products of widely different properties were obtained.

There appears to be no appreciable quantity of materials present in this oil with intermediate viscosity indices. In all cases where close-cut fractions were processed in the reflux extractor, the transition from the negative viscosity index region to the highly positive region was very sharp.

The viscosity of polynuclear compounds that are undoubtedly in the extract samples increases with boiling point at a rate that is as much as ten times the rate at which the viscosity of the more paraffinic raffinates increase with the same change in boiling point. Hence, many samples of identical boiling points differ in viscosity by several hundred per cent.

The data offer a measure of the extreme complexity of lubricating oil. A material balance was maintained so that the percentage of any one sample which was present in the original crude is known.

PRESENT knowledge of the composition of lubricating oil is meager. This is true because of its extreme complexity and also because methods of refining it into satisfactory products have been developed industrially without the direct need for such fundamental knowledge. There is now, however, a marked interest in the subject, and steps have been taken towards a systematic study. For example, the American Petroleum Institute supports a research program (Project No. 6) on the "Separation, Identification, and Determination of the Constituents of Petroleum." Although in the past most of this work has been done on the gasoline fractions, the lubricating oil fractions are now being studied also, and some interesting results were published by Mair and Willingham (*7*) and Mair and Schicktanz (*6*). An excellent summary of this work, together with a detailed discussion of the equipment employed, was presented by Rossini (*9*, *10*).

An approach from the synthetic side was made by Mikeska (*8*) who prepared a number of different types of molecules of relatively high molecular weight such as might occur in light lubricating oils. This work has made some interesting data available for comparison with highly refined fractions from petroleum. The purpose of this paper is to show the types of products that may be obtained by a combination of distillation and solvent extraction processes and thus to indicate in a general way the composition of this particular petroleum fraction. Electrical and chemical studies on some of these fractions have already been made (*2*).

Apparatus and Procedure

Forty-five gallons (170 liters) of the wax distillate comprising 10 per cent of a Van Zandt Texas crude were fractionated under vacuum in a packed column of seven theoretical plates using a reflux ratio of seven to one. During the fractionation the pressure was 0.2 mm. of mercury at the top of the column and 2.0 mm. at the still. The unit has a capacity of 6 gallons (approxi-

TABLE I. PROPERTIES OF CUTS FROM VACUUM FRACTIONATION OF VAN ZANDT WAX DISTILLATE (10 PER CENT OF ORIGINAL CRUDE)

Cut No.	% of Charge	Vol. % Distd.	Viscosity: Centistokes 100° F.	Viscosity: Centistokes 210° F.	Viscosity: Saybolt Sec. 100° F.	Viscosity: Saybolt Sec. 210° F.	Viscosity: Kinematic index	50% B. P., ° C. 10 mm. Hg	50% B. P., ° C. 1.0 mm. Hg	Sp. Gr. (20/20° C.)	Gravity, ° A. P. I.	Refractive Index, n_D^{20}	A. S. T. M. Color	Pour Point, ° F. Before dewaxing	Pour Point, ° F. After dewaxing	Dewaxing Temp., ° F.	% Yield of Wax
Feed	...	...	168.8	12.55	777	68.6	59.8	308	...	0.9232	21.4	1.5137	8+	110	55	50	4.2
1	4.36	4.36	36.13	4.97	168.3	42.5	56.4	244	...	0.9169	22.5	1.5115	8+	65	50	40	2.3
2	4.48	8.84	89.95	7.99	414.4	52.4	31.7	272	...	0.9305	20.2	1.5190	8	85	35	30	4.8
3	4.46	13.30	122.8	9.58	565	57.8	34.1	283	...	0.9305	20.2	1.5190	8	90	45	50	4.3
4	4.56	17.86	135.4	10.34	623	60.4	40.0	289	...	0.9288	20.4	1.5183	8	95	55	45	5.1
5	4.46	22.32	147.3	10.95	678	62.6	42.7	293	...	0.9265	20.8	1.5180	8+	95	40	40	4.9
6	4.40	26.72	153.6	11.24	707	63.7	43.3	293	...	0.9271	20.7	1.5173	8+	100	50	30	4.7
7	4.42	31.14	160.7	11.62	740	65.1	45.6	298	...	0.9267	20.8	1.5168	8+	100	40	30	5.2
8	4.49	35.63	161.3	11.83	743	65.9	50.2	299	248	0.9246	21.1	1.5160	8+	100	45	50	5.7
9	4.48	40.11	162.9	12.00	750	66.5	52.5	302	250	0.9236	21.3	1.5150	8+	100	45	50	6.1
10	4.57	44.68	167.8	12.28	773	67.6	53.6	304	252	0.9230	21.4	1.5147	8+	105	50	50	6.4
11	4.52	49.20	170.6	12.52	785	68.5	56.5	310	254	0.9222	21.6	1.5141	8+	110	50	45	6.4
12	4.50	53.70	175.8	12.80	809	69.6	57.7	...	258	0.9212	21.7	1.5140	8+	110	50	40	6.9
13	4.47	58.17	180.5	13.09	831	70.7	59.4	...	258	0.9206	21.8	1.5138	8+	105	55	40	5.2
14	4.50	62.67	190.8	13.52	878	72.3	59.3	...	262	0.9209	21.8	1.5138	8+	105	45	40	5.5
15	4.47	67.14	192.8	13.77	888	73.3	62.2	...	263	0.9201	21.9	1.5133	8+	110	50	30	7.8
16	4.44	71.58	200.3	14.16	922	74.8	63.4	...	266	0.9194	22.0	1.5128	8+	110	55	20	9.1
17	4.52	76.10	208.6	14.56	960	76.3	63.7	...	268	0.9192	22.1	1.5128	8+	110	55	45	...
18	4.42	80.52	219.4	15.08	1010	78.3	65.3	...	271	0.9191	22.1	1.5127	8+	115	55	55	7.5
Bottoms	11.36	...	468.0	24.64	2154	118.6	71.7	...	291	0.9268	20.8	1.5130	8+	80	55	..	3.5

TABLE II. PHYSICAL PROPERTIES OF PRODUCTS OBTAINED BY THE VACUUM FRACTIONATION OF EXTRACTS FROM BLENDS *A*, *B*, AND *C*

Cut No.	Weight, Grams	% of Blend	% of Crude	Viscosity					50% B. P. at 10 Mm. Hg, ° C.	Sp. Gr. (20/20° C.)	Gravity, ° A. P. I.	Refractive Index, n_D^{20}	A. S. T. M. Color	Pour Point, ° F.
				Centistokes		Saybolt Sec.		Kinematic index						
				100° F.	210° F.	100° F.	210° F.							
Extract from Blend *A*														
Blend *A*	25,880	100.0	1.6	97.4	8.67	449	54.7	45.5	282	0.9270	20.8	1.5160	8+	50
Ext.	13,160	50.7	0.8	164.3	10.40	757	60.6	1.4	286	0.9634	15.0	1.5423	8+	40
1	860	3.3	0.05	16.1	3.08	81.6	36.5	50.4	212	0.9225	21.4	1.5152	3	30
2	858	3.3	0.05	32.3	4.48	151	40.9	34.8	239	0.9346	19.4	1.5249	3	45
3	869	3.3	0.06	64.7	6.44	298	47.3	19.7	257	0.9463	17.6	1.5321	4	45
4	867	3.3	0.06	109.3	8.33	504	53.5	3.4	268	0.9555	16.2	1.5371	4	40
5	878	3.3	0.06	148.2	9.56	683	57.7	−10.3	278	0.9600	15.5	1.5403	4	35
6	874	3.4	0.06	179.8	10.52	827	61.1	−15.1	280	0.9630	15.0	1.5423	4	35
7	886	3.4	0.06	203.3	11.23	936	63.7	−15.4	285	0.9625	15.1	1.5429	4	35
8	872	3.4	0.06	229.1	11.96	1,053	66.4	−16.6	287	0.9638	14.9	1.5446	4	35
9	896	3.4	0.06	255.4	12.59	1,178	68.7	−20.0	290	0.9664	14.5	1.5452	4	35
10	888	3.4	0.06	280.9	13.25	1,297	71.3	−20.4	291	0.9670	14.4	1.5462	4	35
11	892	3.4	0.06	316.8	14.05	1,460	74.4	−23.3	295	0.9686	14.2	1.5480	4	35
12	901	3.5	0.06	361.4	14.95	1,662	77.8	−27.5	298	0.9711	13.8	1.5498	4	35
13	887	3.4	0.06	447.1	16.56	2,060	84.3	−33.0	300	0.9767	13.0	1.5530	7	35
..	....	...	..	....	...	...	...	....	...	....	..	....	...	..
Bottoms	1,360	5.3	0.08	884	23.30	4,070	112.7	−44.8	308	0.9905	11.0	1.5540	8	35
Extract from Blend *B*														
Blend *B*	30,600	100.0	2.0	163.6	12.35	755	67.8	59.5	307	0.9238	13.2	1.5140	8+	55
Ext.	15,630	51.0	1.0	260.6	14.17	1,200	74.8	13.3	306	0.9495	17.2	1.5328	3	35
1	805	2.6	0.05	31.6	4.87	148	42.3	83.8	252	0.8827	28.3	1.4900	4	5
2	832	2.7	0.05	61.7	6.94	285	48.9	62.3	275	0.9017	24.9	1.5035	4	10
3	835	2.7	0.05	149.2	10.75	688	61.9	34.2	293	0.9349	19.4	1.5232	4	35
4	869	2.8	0.06	194.0	12.22	894	67.3	27.0	298	0.9407	18.4	1.5288	4	40
5	853	2.8	0.05	214.0	12.82	986	69.6	24.2	302	0.9436	18.0	1.5310	4	35
6	859	2.8	0.06	230.4	13.29	1,060	71.4	22.3	302	0.9457	17.8	1.5321	4	35
7	857	2.8	0.05	245.0	13.70	1,128	73.0	20.8	304	0.9475	17.5	1.5330	4	35
8	843	2.8	0.05	260.0	14.06	1,197	74.4	17.4	305	0.9487	17.3	1.5339	4	35
9	855	2.8	0.05	288.2	14.77	1,327	77.1	15.3	306	0.9508	16.9	1.5363	5	35
10	910	3.0	0.06	303.4	15.11	1,397	78.4	13.3	306	0.9526	16.7	1.5376	5	35
11	870	2.8	0.06	312.4	15.32	1,438	79.3	12.3	307	0.9541	16.4	1.5382	5	35
12	873	2.8	0.06	337.9	15.98	1,556	81.9	11.3	309	0.9554	16.2	1.5400	5	35
13	874	2.8	0.06	347.1	16.10	1,598	82.4	9.2	310	0.9564	16.1	1.5405	5	35
14	866	2.8	0.06	364.9	16.62	1,680	84.5	10.4	313	0.9570	16.0	1.5411	6	35
15	841	2.7	0.05	395.2	17.33	1,820	87.5	9.5	314	0.9586	15.7	1.5426	7	35
16	872	2.8	0.06	434.0	18.04	1,998	90.4	5.5	326	0.9612	15.3	1.5440	8	35
17	874	2.9	0.06	598.0	20.81	2,753	102.1	−7.0	322	0.9688	14.2	1.5490	8	30
Bottoms	820	2.7	0.05	684.2	65.82	31,500	306.9	−76.0	328	1.005	13.0	....	8+	65
Extract from Blend *C*														
Blend *C*	28,800	100.0	1.8	212.0	14.85	976	77.4	66.5	323	0.9201	21.8	1.5121	8+	45
Ext.	15,890	55.2	1.0	478.0	20.20	2,200	99.5	23.8	323	0.9528	16.6	1.5331	8+	40
1	845	2.9	0.05	175.6	11.66	809	65.2	30.4	306	0.9389	18.7	1.5263	8+	40
2	897	3.1	0.06	272.4	14.93	1,254	77.7	28.5	311	0.9432	18.1	1.5300	5	45
3	848	2.9	0.05	290.3	15.50	1,336	80.0	29.4	314	0.9440	18.0	1.5308	5	45
4	875	3.0	0.06	306.5	15.94	1,411	81.8	28.5	317	0.9454	18.8	1.5313	5	45
5	846	2.9	0.05	320.3	16.41	1,475	83.7	29.4	316	0.9461	17.7	1.5321	4	45
6	850	2.9	0.05	336.0	16.86	1,547	85.5	29.5	317	0.9466	17.6	1.5329	4	45
7	831	2.9	0.05	346.1	17.13	1,593	86.6	29.2	319	0.9474	17.5	1.5333	5	45
8	885	3.1	0.06	357.7	17.44	1,647	87.9	29.0	320	0.9478	17.4	1.5334	6	40
9	870	3.0	0.06	372.9	17.86	1,717	89.6	29.0	321	0.9479	17.4	1.5341	6	40
10	864	3.0	0.06	392.6	18.43	1,809	92.0	29.5	323	0.9490	17.2	1.5348	7	45
11	847	2.9	0.05	411.4	18.86	1,894	93.8	28.5	324	0.9496	17.1	1.5351	7	40
12	838	2.9	0.05	440.7	19.47	2,029	96.4	26.4	328	0.9511	16.9	1.5361	7	40
13	854	3.0	0.05	478.3	20.32	2,202	100.0	25.3	329	0.9522	16.7	1.5380	7	45
14	890	3.1	0.06	538.6	21.62	2,480	105.5	23.8	...	0.9524	16.7	1.5397	7	35
15	887	3.1	0.06	617.2	22.94	2,842	111.1	18.7	...	0.9590	15.7	1.5420	7	40
16	904	3.1	0.06	727.0	25.00	3,347	120.2	17.0	...	0.9613	15.3	1.5425	7	35
17	395	1.4	0.03	865.8	27.31	3,986	130	14.0	...	0.9649	14.8	1.5465	7	35
Bottoms	1,765	6.1	0.11	2626	49.06	12,090	229	7.2	...	0.9782	12.8	1.5300	8+	40

mately 23 liters). Consequently, eight separate fractionations were performed. Cuts corresponding to the same volume per cent distilled were blended after physical tests showed them to be very similar. Eighteen overhead cuts of 2 gallons (7.6 liters) each were obtained. All of these were solid at room temperature. They were partially dewaxed by diluting with one volume of *n*-butanol, cooling, and filtering off the wax. After stripping the butanol from the oil, physical properties of all cuts were measured and are summarized in Table I.

The eighteen cuts were then blended into three fractions designated as blends *A*, *B*, and *C*. Blend *A* is composed of cuts 1 to 6, inclusive; blend *B*, cuts 7 to 12, inclusive; and blend *C*, cuts 13 to 18 and a sample of the bottoms. Each of these blends was then extracted with acetone to approximately the 50 per cent point at room temperature by a successive batch process and a solvent-oil ratio of one to one. Three extractions were necessary to cut blend *A* to the 50 per cent point; six were necessary for blend *B*, and eight for blend *C*. The extracts from any one blend were combined so that there were now six samples of oil of approximately 5 gallons (19 liters) each. Three of these were extracts and three were raffinates.

After the solvent was removed from the six oil samples, their physical properties were determined, and they were then fractionated in the vacuum column under the same conditions as the fractionations described earlier. Cuts of approximately 800 grams (4.4 per cent) were taken; their physical properties were determined and are summarized in Tables II and III. A selected number of the six series of fractions were then further separated in the efficient reflux extraction unit previously described by the authors (*3*). Acetone was used as the solvent, and the extractor was operated under total reflux until equilibrium was reached and the extract cut was then removed. Physical properties of the products were measured and are presented in Table IV.

All viscosities reported were measured by the simple, precise, modified Ostwald viscometers, developed by the authors (*4*), which are now in extensive use in the petroleum industry. Saybolt viscosities are those converted from the kinematic viscosities by means of the conversion tables recently published for infor-

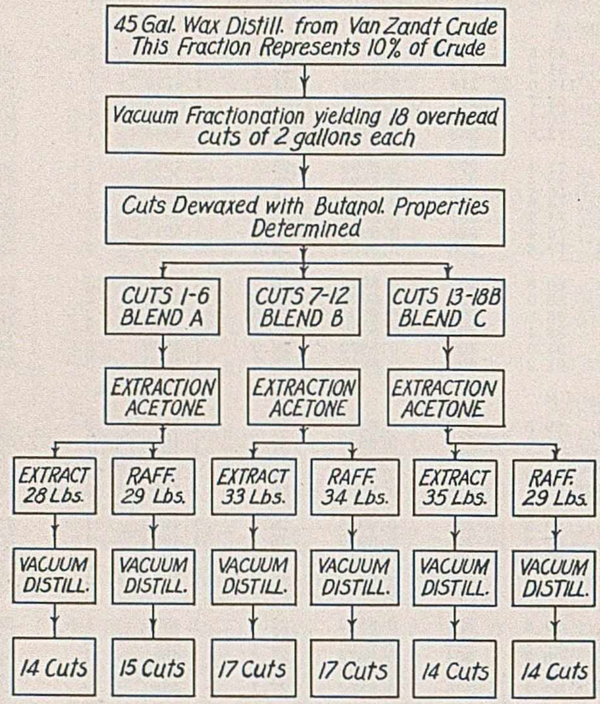
TABLE III. PHYSICAL PROPERTIES OF PRODUCTS OBTAINED BY THE VACUUM FRACTIONATION OF RAFFINATES FROM BLENDS *A*, *B*, AND *C*

Cut No.	Weight, Grams	% of Blend	% of Crude	Viscosity					50% B. P. at 10 Mm. Hg, ° C.	Sp. Gr. (20/20° C.)	Gravity, ° A. P. I.	Refractive Index, n_D^{20}	A. S. T. M. Color	Pour Point, ° F.
				Centistokes 100° F.	Centistokes 210° F.	Saybolt Sec. 100° F.	Saybolt Sec. 210° F.	Kinematic index						
						Raffinate from Blend *A*								
Blend *A*	25,880	100.0	1.6	97.4	8.67	449	54.7	45.5	282	0.9270	20.8	1.5160	8+	50
Raff.	12,712	49.2	0.8	62.1	7.45	287	50.6	84.0	285	0.8915	26.9	1.4911	6	55
1	824	3.2	0.05	13.2	2.98	70.5	35.9	113.0	219	0.8684	31.0	1.4796	1	50
2	826	3.2	0.05	30.2	4.85	142	42.1	93.7	244	0.8828	28.3	1.4874	1	55
3	844	3.3	0.05	45.8	6.08	212	46.1	76.4	260	0.8923	26.8	1.4921	1+	50
4	861	3.3	0.05	59.6	7.03	275	49.2	72.6	268	0.8974	25.8	1.4944	1+	50
5	882	3.4	0.06	68.9	7.62	318	51.1	71.4	272	0.8992	25.5	1.4953	1+	50
6	855	3.3	0.05	74.2	8.01	342	52.4	72.2	276	0.8986	25.6	1.4960	1+	50
7	840	3.3	0.05	77.4	8.24	357	53.2	73.4	279	0.8984	25.6	1.4955	2	50
8	837	3.2	0.05	79.2	8.38	365	53.7	74.2	281	0.8975	25.8	1.4948	2	50
9	845	3.3	0.05	80.4	8.53	370	54.2	76.4	285	0.8960	26.1	1.4941	2	50
10	837	3.2	0.05	80.7	8.59	372	54.4	77.8	286	0.8950	26.3	1.4935	2	50
11	843	3.3	0.05	81.4	8.73	375	54.9	80.8	290	0.8933	26.6	1.4922	2	55
12	851	3.3	0.05	81.3	8.79	375	55.1	83.0	294	0.8929	26.6	1.4916	2	55
13	830	3.2	0.05	81.1	8.91	374	55.5	86.8	297	0.8904	27.0	1.4905	2+	55
14	831	3.2	0.05	81.8	9.02	377	55.9	88.4	298	0.8899	27.2	1.4900	3	55
15	361	1.4	0.02	84.2	9.28	388	56.8	91.0	304	0.8873	28.0	1.4888	3+	55
Bottoms	790	3.1	0.05	129.8	12.29	597	67.6	91.2	308	0.8946	26.3	1.4900	8+	45
						Raffinate from Blend *B*								
Blend *B*	30,600	100.0	1.95	163.6	12.35	755	67.8	59.5	307	0.9238	13.2	1.5140	8+	55
Raff.	14,980	49.0	0.95	77.4	8.83	357	55.2	91.6	303	0.8850	28.0	1.4880	5	55
1	801	2.6	0.05	25.7	4.54	122	41.1	109.0	254	0.8621	32.3	1.4752	1	10
2	819	2.7	0.05	44.4	6.23	206	46.6	94.5	275	0.8747	29.8	1.4825	1	20
3	835	2.7	0.05	72.0	8.16	332	52.9	83.4	288	0.8888	27.2	1.4900	1	45
4	849	2.8	0.05	81.4	8.78	375	55.1	82.3	294	0.8915	26.7	1.4910	1	45
5	828	2.7	0.05	84.5	9.01	390	55.8	82.8	294	0.8919	26.7	1.4912	1	50
6	842	2.7	0.05	85.8	9.11	395	56.2	83.5	299	0.8911	26.8	1.4912	1	50
7	836	2.7	0.05	86.3	9.26	398	56.7	86.5	299	0.8900	27.0	1.4909	1	55
8	837	2.7	0.05	86.9	9.35	400	57.0	87.7	302	0.8996	27.1	1.4902	1+	55
9	833	2.7	0.05	87.2	9.45	402	57.3	89.8	304	0.8882	27.3	1.4895	1+	55
10	823	2.7	0.05	87.6	9.46	403	57.4	89.4	304	0.8879	27.4	1.4893	2	55
11	829	2.7	0.05	88.0	9.53	405	57.6	90.3	304	0.8875	27.4	1.4891	2	55
12	830	2.7	0.05	88.4	9.58	407	57.8	90.8	307	0.8870	27.5	1.4883	2	55
13	827	2.7	0.05	89.0	9.68	410	58.1	92.2	306	0.8862	27.7	1.4882	2	55
14	827	2.7	0.05	89.5	9.75	412	58.4	92.9	310	0.8835	28.2	1.4879	2	55
15	831	2.7	0.05	90.4	9.86	416	58.7	94.0	310	0.8830	28.2	1.4875	2	55
16	821	2.7	0.05	91.1	10.01	420	59.2	96.2	314	0.8811	28.6	1.4870	3	60
17	793	2.6	0.05	93.8	10.22	432	60.0	96.7	318	0.8820	28.4	1.4866	4	60
Bottoms	973	3.2	0.06	108.9	11.27	502	63.8	96.5	321	0.8844	28.0	1.4865	8	50
						Raffinate from Blend *C*								
Blend *C*	28,800	100.0	1.8	212.0	14.85	976	77.4	66.5	323	0.9201	21.8	1.5121	8+	45
Raff.	12,940	45.0	0.8	108.4	11.35	499	64.1	98.5	319	0.8841	28.2	1.4871	8+	60
1	840	2.9	0.05	89.6	9.55	413	57.7	88.2	308	0.8892	27.3	1.4890	3	50
2	839	2.9	0.05	98.0	10.20	451	59.9	90.1	309	0.8888	27.3	1.4887	2	50
3	835	2.9	0.05	98.4	10.26	453	60.1	90.8	310	0.8878	27.5	1.4879	2	55
4	837	2.9	0.05	98.1	10.36	452	60.5	93.3	313	0.8871	27.6	1.4875	2	55
5	846	2.9	0.05	98.5	10.40	454	60.6	93.7	314	0.8843	28.0	1.4875	2	55
6	836	2.9	0.05	98.1	10.52	452	61.1	96.4	317	0.8852	28.0	1.4870	2	55
7	841	2.9	0.05	98.8	10.63	455	61.5	97.7	318	0.8824	28.5	1.4866	2	55
8	825	2.9	0.05	98.6	10.68	454	61.7	98.8	320	0.8806	28.8	1.4859	2	55
9	820	2.8	0.05	100.2	10.77	461	62.0	98.4	323	0.8807	28.8	1.4855	2	55
10	813	2.8	0.05	101.2	10.87	466	62.3	99.0	322	0.8804	28.8	1.4853	2	55
11	820	2.8	0.05	103.4	11.07	476	63.1	99.8	326	0.8793	29.0	1.4852	2+	55
12	816	2.8	0.05	106.6	11.29	491	63.9	99.6	327	0.8801	28.9	1.4851	3	55
13	797	2.8	0.05	109.9	11.54	506	64.8	100.0	331	0.8798	28.9	1.4852	3+	55
14	464	1.6	0.03	115.3	12.05	531	66.7	101.9	334	0.8803	28.8	1.4854	3+	55
..	....	...	..	...	...	...	..	...	...	....	..	....	...	..
..	....	...	..	...	...	...	..	...	...	....	..	....	...	..
Bottoms	1,565	5.4	0.10	19.12	16.30	880	83.2	96.4	342	0.8837	26.5	1.4880	8−	40

mation by Committee D-2 of the American Society for Testing Materials (*1*). Kinematic viscosity indices were calculated from the published tables of Hersh, Fisher, and Fenske (*5*). The use of kinematic viscosity for this purpose rather than Saybolt viscosity greatly increases the accuracy of the viscosity index and enables one to determine this property for light oils.

Results of Vacuum Distillation

A flow sheet showing the sequence of the various operations is presented in Figure 1. The results obtained by vacuum fractionation of the Van Zandt wax distillate are shown in Table I, and for clearer presentation several properties are plotted in Figure 2. It is evident that the fractionation yielded products of widely different properties and that the types of molecules were quite different from fraction to fraction. A sharp maximum is reached in the refractive index curve, and a sharp minimum exists in the viscosity index curve at the same point. This probably means that these particular fractions are rich in polynuclear compounds such as polynuclear aromatics or polynuclear naphthenes. This particular charge, with the exception of the first fraction, steadily increases in degree of paraffinicity as the molecular weight increases. This is clearly indicated by the kinematic viscosity index curve which increases from 32 to 72 in going from the second cut to the bottoms. It is interesting to point out that the fractionation of a coastal oil from Sugarland crude reported by Hersh (*4*) showed just the opposite trend; paraffinicity steadily decreased with increasing molecular weight, as evidenced by the fact that the kinematic viscosity index went from 28 to −28 from the first to the last distilled fraction of this coastal crude. However, in the case of the Van Zandt crude, it appears that heavy oils of high viscosity index could be obtained in greater yields than would be possible for light oils of high viscosity index.



Selected cuts from the above six fractionations were further extracted in reflux extractor

FIGURE 1. FLOW SHEET

Tables II and III give the properties of the products obtained by the vacuum fractionation of the extracts and raffinates from blends *A*, *B*, and *C*. The blends were separated into approximately equal portions by extraction before being distilled. Several properties are plotted in Figure 3. The abscissas give the percentages referred to the over-all original blend, and since each extract and raffinate comprises 50 per cent of the original blend, it follows that the 50 per cent point represents the limit on the abscissas. This facilitates direct comparison of extract and raffinate fractions.

Within the limits of experimental error, the corresponding extract and raffinate cuts have the same 50 per cent boiling point at 10 mm. of mercury, absolute pressure. However, in practically every case there is a difference in viscosity of several hundred per cent. More striking is the rate at which the viscosity increases with molecular weight or boiling point. In going from a 50 per cent boiling point of 280° to 290° C. the extract cuts from blend *A* increase in 100° F. (37.8° C.) viscosity from 180 to 255 centistokes (41 per cent increase); the corresponding raffinate cuts increased in 100° F. viscosity from 79 to 81 centistokes (2.5 per cent increase). Apparently cyclization, which has an enormous effect on viscosity, increases consistently with increasing molecular weight in the extract fractions. In the more paraffinic raffinate fractions, on the other hand, the viscosity increase may be due to an increase in hydrocarbon chain lengths or an increase in the number of branches in the hydrocarbon chains since the molecular size may be increased by these methods with the least change in viscosity. These fractions at 210° F. (98.9° C.) increase by 20 and 3 per cent, respectively, for the same boiling range.

The kinematic viscosity indices of the various fractions from the fractionation of the extracts and raffinates increase with boiling point. It is apparent that the viscosity index (V. I.) and the refractive index at 20° C. (R. I.) have shown consistently opposite trends. A rough empirical correlation exists between the refractive index and the viscosity index which may be expressed by the equation:

$$\text{V. I.} = 2920 - 1900 \text{ R. I.}$$

This relation is not general but applies to the oils reported in this paper. It is of interest to point out that for a given viscosity index the only pure compounds prepared by Mikeska (*8*) with refractive indices at all close to those obtained from this oil are derivatives of cyclohexane and decahydronaphthalene. The derivatives of benzene, naphthalene, and tetrahydronaphthalene have refractive indices considerably higher than the above oil fractions of similar viscosity index. The close-cut fractions which are correlated by the above equation differ in 50 per cent boiling point as much as 100° C. and in viscosity by several hundred per cent so that comparison with the low-boiling, less viscous compounds is not unreasonable.

The specific gravities of the viscous fractions of low viscosity index were from 10 to 18 per cent higher than the fractions of high viscosity index. The color becomes darker with increasing molecular weight and is much darker for the extract fractions than it is for the raffinate fractions.

Table IV summarizes the properties of the products obtained by extracting selected cuts in the reflux extractor. Figure 4 is a plot of the viscosities and viscosity indices of the oils produced by one of these extractions. The oil samples charged to this unit had been refined to the extent where they represented only 0.05 per cent of the original crude. The most striking fact revealed here is that no materials of intermediate viscosity index exist in these samples to any appreciable extent, for the transition from the region of low viscosity index to that of high viscosity index is very sharp. The products obtained from this unit represent approximately 0.01 per cent of the original crude or 0.1 per cent of the original wax distillate. Their wide variation in physical properties indicates the extreme complexity of this oil.

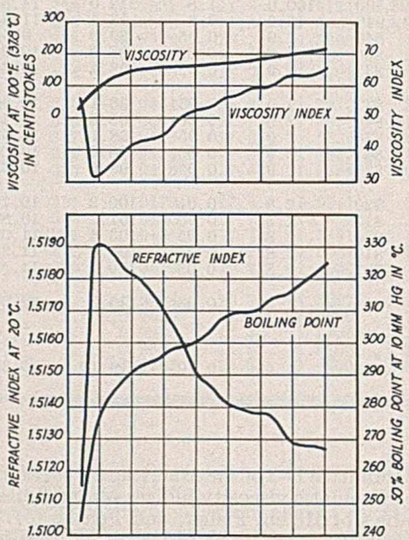


FIGURE 2. VACUUM FRACTIONATION OF VAN ZANDT WAX DISTILLATE

In the foregoing, comparison of viscosity indices of various fractions have been made although wax concentration varied. The effect of dewaxing on the viscosity index of this oil was to

TABLE IV. EXTRACTION OF HIGHLY REFINED CUTS IN THE REFLUX EXTRACTOR

Designation	Extn. Time, Hr.	Tower Temp., ° C.	Liters Acetone per Hr.	Weight of Sample, Grams	Per Cent Yield	Refractive Index, n_D^{20}	Sp. Gr. (20/20° C.)	Viscosity: Centistokes 100° F.	Viscosity: Centistokes 210° C.	Viscosity: Saybolt Sec. 100° F.	Viscosity: Saybolt Sec. 210° F.	Viscosity: Kinematic index	A.S.T. M Color
Charged Cut 8 of Extract from Blend *A*													
Charge	..	..	...	300	..	1.5450	0.9652	224.9	11.71	1,035	65.4	−21	8
Extract 1	4.0	13	3.6	95	32	1.5670	0.9959	591	16.38	2,720	83.6	−114	8+
Extract 2	2.25	12	4.4	92	31	1.5609	0.9879	475	15.38	2,187	79.5	−84	8+
Extract 3	2.25	11	4.5	43	14	1.5513	0.9768	346	13.87	1,593	73.7	−51	8+
Holdup in solvent	..	..	...	36	12	1.4953	0.8965	74.7	8.14	344	52.9	76	4
Raffinate	..	..	...	10	3	1.4781	0.8684	52.3	7.08	233	49.4	101	2
Charged Cut 8 of Raffinate from Blend *A*													
Charge	..	..	...	340	..	1.4974	0.9040	88.5	8.70	408	54.8	63	3
Extract 1	2.75	13	4.4	66	19.2	1.5402	0.9694	384.3	14.76	1,769	77.1	−48	8+
Extract 2	3.0	13	4.4	40	11.6	1.5290	0.9717	269.5	13.16	1,241	70.9	−14	8+
Raffinate	..	..	...	194	56.4	1.4799	0.8748	57.1	7.27	264	50.0	92	3
Charged Cut 9 of Extract from Blend *B*													
Charge	..	..	...	370	..	1.5290	0.9483	168.4	11.17	775	63.4	24	8
Extract 1	3.75	13	4.2	90	24.4	1.5681	0.9966	1,050	22.61	4,834	109.7	−103	8+
Extract 2	2.25	12	4.3	95	25.6	1.5641	0.9931	962	22.09	4,429	107.5	−91	8+
Extract 3	2.50	13	4.8	51	13.8	1.5570	0.9834	802	21.10	3,692	103.3	−65	8+
Holdup in solvent	..	..	...	62	16.7	1.4976	0.8999	101	9.71	465	59.1	73	4.5
Raffinate	..	..	...	43	11.6	1.4732	0.8954	57.2	7.84	264	51.9	109	3
Charged Cut 9 of Raffinate from Blend *B*													
Charge	..	..	...	423	..	1.4909	0.8899	89.7	9.44	413	57.3	85	6
Extract 1	2.75	13	4.6	66	15.6	1.5348	0.9669	433	17.28	1,994	87.3	−5	8+
Extract 2	2.75	13	4.4	27	6.4	1.5253	0.9472	330	15.72	1,590	80.9	10	8+
Raffinate	..	..	...	280	66.3	1.4787	0.8709	64.9	8.22	299	53.2	105	3
Charged Cut 9 of Extract from Blend *C*													
Charge	..	..	...	380	..	1.5349	0.9526	358.3	17.23	1,650	87.0	25	8
Extract 1	3.25	13	4.0	98	25.8	1.5697	1.0026	2,252	33.56	10,368	158.5	−108	8+
Extract 2	2.25	12	4.0	82	21.6	1.5700	1.0056	2,397	34.48	11,036	162.7	−111	8+
Extract 3	2.25	13	4.6	45	11.8	1.5600	1.9931	1,729	31.44	7,960	148.9	−72	8+
Holdup in solvent	..	..	...	61	16.0	1.4989	0.9018	139.0	12.02	640	66.6	76	6
Raffinate	..	..	...	73	19.2	1.4739	0.8601	69.2	8.99	319	55.8	109	3
Charged Cut 9 of Raffinate from Blend *C*													
Charge	..	..	..	356	..	1.4880	0.8862	118.4	11.50	545	64.7	90	4
Extract 1	3.0	13	4.5	31	8.7	1.5360	0.9626	838	25.10	3,858	120.6	−6	8+
Extract 2	3.0	13	4.3	12	3.4	1.5238	....	472	20.75	2,173	101.8	33	8+
Raffinate	..	..	..	282	79.3	1.4808	0.8763	91.6	9.92	422	58.9	94	2

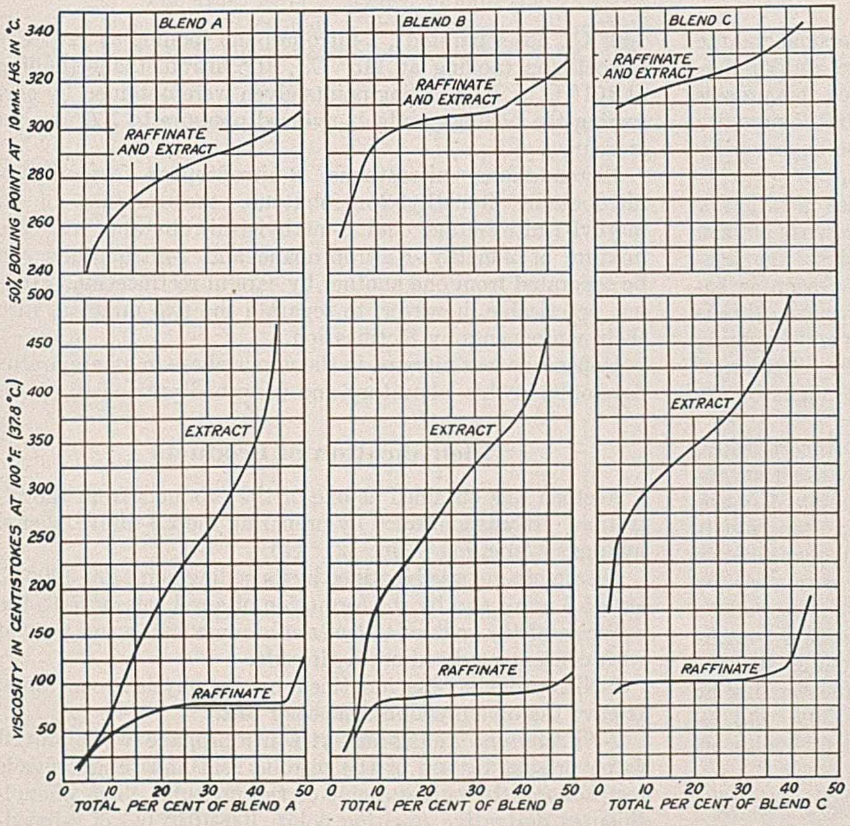


FIGURE 3. VACUUM FRACTIONATION OF EXTRACTS AND RAFFINATES FROM BLENDS *A*, *B*, AND *C*

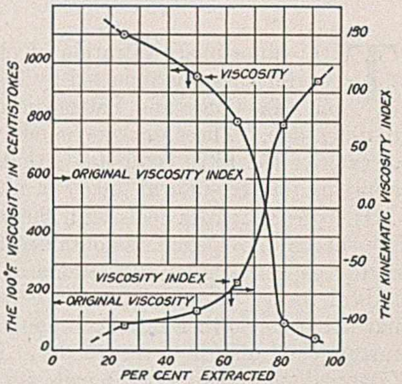


FIGURE 4. FURTHER SEPARATION OF CUT 9 OF THE EXTRACT FROM BLEND *B* IN THE REFLUX EXTRACTOR WITH ACETONE

lower the viscosity index approximately one point for every 6° F. (3.3° C.) change in pour point. Since the difference in pour points of the fractions was never more than 30° F. (16.7° C.), it is obvious that very little of the marked difference between comparable fractions can be due to differences in wax content.

Summary

To summarize briefly, it was found that starting with a lubricating oil distillate from Van Zandt crude having a viscosity index of 60 and a 100° F. viscosity of 169 centistokes (780 Saybolt Universal Seconds, S. U. S.) products ranging in viscosity index from −114 to 109 were obtained. Approximately half of this oil could be made into a product with a viscosity index of 100. The 100° F. viscosity of the various constituents ranged from 14 to 2400 centistokes (74 to 11,000 S. U. S.). The materials of low viscosity index are very viscous, whereas those of high viscosity index are relatively nonviscous. The 100° F. viscosity of the high-viscosity-index materials ranged from 13 to 190 centistokes (70 to 880 S. U. S.); the low viscosity index materials, from 200 to 2400 centistokes (920 to 11,000 S. U. S.). The spread in viscosity between materials of low and high viscosity index increases with increasing molecular weight.

Although the oil fractions charged to the reflux extraction unit had already been highly refined to the point where they represented only 0.05 per cent of the original crude, products of widely different properties were obtained but no appreciable quantity of intermediate viscosity index material (i. e., between 10 and 90) exists, for the transition from the negative to the highly positive viscosity index region is very sharp.

Acknowledgment

The authors are indebted to the Standard Oil Company of Louisiana for furnishing the oil investigated and to A. T. Paik, R. M. McCormick, and J. H. Bresnowitz for their aid in securing many of the data. This paper is published by permission of the Graduate School of The Pennsylvania State College.

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NITRATION OF ISOPENTANE[1]

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THE vapor-phase nitration of ethane, propane, and the two butanes was reported by Hass, Hodge, and Vanderbilt (*4*). Hass and Patterson (*6*) extended this process to *n*-pentane. These workers found evidence for the presence of each of the nitro compounds that would be expected by applying the free-radical theory of nitration (*4*, *8*).

The present paper deals with the vapor-phase nitration of isopentane. Evidence was obtained for the presence of each of the expected nitro compounds as predicted by the free-radical theory of nitration. Since there is no reason to believe that any other nitro compounds were formed, this is further confirmation of this theory. McCleary and Degering (*8*) previously analyzed the exit gases from the nitration of isopentane and found each of the olefins that might be expected from a free-radical mechanism.

The free radicals which can be obtained, theoretically, from isopentane by the loss of hydrogen or by a carbon-to-carbon fission include 2-methyl-1-butyl, 3-methyl-1-butyl, 3-methyl-2-butyl, 2-methyl-2-butyl, 2-butyl, 2-methyl-1-propyl, 2-propyl, ethyl, and methyl. Every nitroparaffin has been obtained that is theoretically possible by adding a nitro group to these free radicals. These radicals correspond to the nitro compounds found, which were 2-methyl-1-nitrobutane, 3-methyl-1-nitrobutane (a mixture boiling at 164–165° C., not separated), 3-methyl-2-nitrobutane (boiling at 155° C.), 2-methyl-2-nitrobutane (boiling at 150.5° C.), 2-nitrobutane, 2-methyl-2-nitropropane (a mixture boiling at 140° C., not separated), 2-nitropropane (boiling at 120° C.) nitroethane (boiling at 115° C.), and nitromethane (boiling at 101° C.). The boiling points given were obtained by correcting the boiling points at reduced pressure to 760 mm. of mercury.

Nitromethane, nitroethane, 2-nitropropane, 2-methyl-2-nitrobutane, 3-methyl-2-nitrobutane, the mixture of 2-methyl-1-nitrobutane and 3-methyl-1-nitrobutane, and the mixture of 2-methyl-1-nitropropane and 2-nitrobutane can be separated from one another by careful rectification. It is not practicable, however, to separate the two mixtures into their components by rectification.

Isopentane was nitrated in the vapor phase in an apparatus developed in this laboratory and described previously (*4*, *6*).

Identification of Products

Acetone was obtained as one of the products from the nitration. It was identified by preparing the 2,4-dinitrophenyl hydrazone (melting point, 127° C.).

Nitromethane was identified by its boiling point (99–100° C. at 745.5 mm.) and by the formation of a red color due to the presence of the sodium salt of methazonic acid when treated with concentrated sodium hydroxide.

2-Nitropropane was identified by its physical constants. It gave the blue pseudonitrole color test.

2-Nitrobutane and 2-methyl-1-nitropropane were proved to be present by use of the nitrolic acid and pseudonitrole test and by the boiling point of the mixture. The phenylthiourea derivative (melting point, 100–101° C.) of 2-butylamine was obtained from the reduction product of the mixture.

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[1] This article, which contains material abstracted from the doctoral dissertation of L. W. Seigle, is the ninth in a series on the subject of syntheses from natural gas hydrocarbons. The others appeared in Industrial and Engineering Chemistry, **23**, 352 (1931); **27**, 1190 (1935); **28**, 333, 339, 1178 (1936); **29**, 1335 (1937); **30**, 67 (1938); **31**, 118 (1939).

2-Methyl-2-nitrobutane was identified by its boiling point (149.8° C. at 752.3 mm.) and by its insolubility in a sodium hydroxide solution.

3-Methyl-2-nitrobutane, boiling at 154° C. (746.2 mm.), was identified by the fact that it formed a blue pseudonitrole when treated with an alcoholic solution of sodium hydroxide and sodium nitrite with subsequent neutralization of the solution.

The analysis of the mixture containing 2-methyl-1-nitrobutane and 3-methyl-1-nitrobutane involved the reduction of the mixture to the amines. The amine fraction of boiling range 94–97° C. was collected and converted to the hydrochlorides. The melting point of the hydrochloride mixture was compared to the melting point of known mixtures of the hydrochlorides of 2-methyl-1-butylamine and 3-methyl-1-butylamine.

Mixture Containing 2-Nitrobutane and 2-Methyl-1-nitropropane

A fraction of the distillate within the range of the boiling point of 2-nitrobutane and 2-methyl-1-nitropropane was reduced to the amines with iron and hydrochloric acid. The amines were rectified and the fraction of boiling range 61–62.2° C. was collected. The phenylthiourea derivative melted at 100–101° C. This proves the presence of 2-nitrobutane in the original mixture.

Another portion of the nitrobutane mixture was rectified, and the fraction boiling at 77–81.6° C. (100 mm.) was collected. This material was dissolved in sodium hydroxide, and a slight excess of the calculated amount of sodium nitrite was added. The solution was made acid with sulfuric acid. The aqueous solution was blue. This color was due to the pseudonitrole of 2-nitrobutane which was known to be present. The aqueous solution was extracted with ether, and the ether extract shaken with an aqueous solution of sodium hydroxide. The ether layer remained blue in color, but the aqueous layer was orange-red. The orange-red color of the aqueous solution is characteristic of the sodium salts of the nitrolic acids. Demole (*2*) showed that the nitrolic acid derived from 2-methyl-1-nitropropane yields isobutyric acid upon treatment with sulfuric acid. Upon treatment with sulfuric acid the orange-red aqueous layer gave a distinct odor of isobutyric acid, which confirmed the presence of 2-methyl-1-nitropropane. From the boiling point of the fraction and the color reaction it is believed that 2-nitrobutane and 2-methyl-1-nitropropane are present. The amounts of each component of the mixture could not be determined.

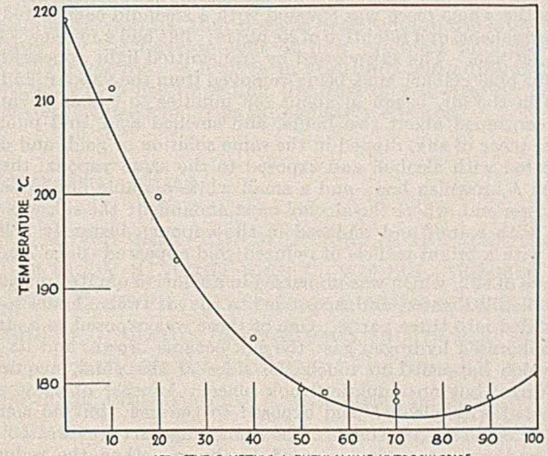

FIGURE 1. COMPOSITION–MELTING POINT CURVE FOR 2- AND 3-METHYL-1-BUTYLAMINE HYDROCHLORIDE

Preparation of Amine Hydrochlorides

In order to determine the amounts of the hydrochlorides of 2-methyl-1-butylamine and of 3-methyl-1-butylamine present, a melting point–composition curve was prepared from the pure compounds.

sec-Butyl alcohol was converted to the bromide by the use of bromine in the presence of phosphorus (*3*) and purified by rectification. The *sec*-butyl bromide was converted to the nitrile according to the procedure of Hass and Marshall (*5*). The yield was very poor. The nitrile was purified by rectification. The fraction boiling at 123–125° C. was collected.

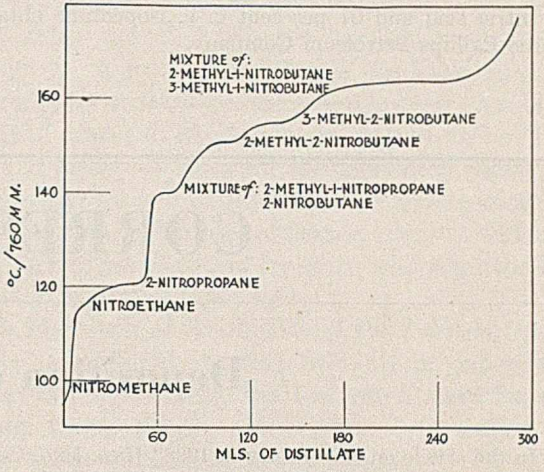

FIGURE 2. RECTIFICATION CURVE OF THE PRODUCT OBTAINED BY NITRATING ISOPENTANE AT 420° C.

The nitrile was reduced to the corresponding amine by the method of Adams and Marvel (*1*). After unreacted sodium was destroyed, the reaction mixture was steam-distilled. The distillate was made acid with hydrochloric acid and evaporated to dryness. The salt was taken up with a sodium hydroxide solution. The alkaline solution was extracted with ether, and the ether extract was dried over anhydrous potassium carbonate. The ether was stripped from the amine in a modified Podbielniak column, and the amine was rectified. The fraction of boiling range 94–96.5° C. was collected. The amine was dissolved in ether and treated with dry hydrogen chloride in the cold. The amine hydrochloride was filtered off and dissolved in a small amount of anhydrous butyl alcohol. The solution was filtered, and the 2-methyl-1-butylamine hydrochloride was reprecipitated by the addition of dry ether. The melting point of the salt was 180–181° C. The melting point given in the literature is 176° C. (*9*).

The hydrochloride of isoamylamine (3-methyl-1-butylamine) was prepared in a manner similar to that just described. The conversion of the isobutyl bromide to the nitrile was less than that obtained in the previous preparation. The phenylthiourea derivative of the isoamylamine was prepared. Its melting point was 103.6° C. The melting point in the literature is 102° C. (*10*). The remainder of the amine was converted to the hydrochloride by the method previously described. The melting point of the isoamylamine hydrochloride was 218–219° C.

Ten samples of mixtures of the two amine hydrochlorides were weighed out and mixed, and five melting points of each mixture were taken with calibrated Fisher short-stem thermometers (*7*). The curve shown in Figure 1 was obtained by plotting the average melting point against the percentage composition.

Isopentane was nitrated at 380° C. The average yield per pass, based upon the nitric acid reacting, was 17.5 per cent. The average mole ratio of hydrocarbon to acid was 1.71. At 420° C. the average yield per pass was 23.5 per cent, and the average mole ratio of hydrocarbon to acid was 4.73. The approximate percentage composition of the material obtained by nitrating isopentane at the two temperatures is as follows:

	380 ° C.	420 ° C.		380 ° C.	420 ° C.
Nitromethane	6	2	2-Methyl-2-nitrobutane	19	14
Nitroethane	6	6	3-Methyl-2-nitrobutane	27	16
2-Nitropropane	6	11	2-Methyl-1-nitrobutane	11	28
2-Methyl-1-nitropropane 2-Nitrobutane	12	10	3-Methyl-1-nitrobutane	13	13

The materials used were ordinary c. p. concentrated (68 per cent) nitric acid and 97 per cent c. p. isopentane obtained from the Phillips Petroleum Company.

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CORRESPONDENCE

Deposition of Gold on Fabrics

Sir: In the article on "Chemistry in 1938" [Ind. Eng. Chem., **31,** 3 (1939)] reference is made on page 5 to a novelty which may become of commercial interest in the production of new fabrics. The discovery has to do with a new process by which a film of gold of nearly colloidal thickness can be deposited on a fabric. According to the information, the fabric is dipped into an organic compound of gold which breaks up into its constituent parts when slightly heated.

This information is far too scanty for us to pass judgment on the commercial importance of such a development. However, the basic principle of this discovery is not only not new from a purely scientific standpoint, but a complete book devoted entirely to this method of dyeing was published nearly one hundred and fifty years ago ("An Essay on Combustion, with a View to a New Art of Dyeing and Painting", by Mrs. Fulhame, published by J. Cooper in London in 1794).

The preface of this book, which deserves greater recognition than it has so far obtained, states: "The possibility of making cloth of gold, silver, and other metals, by chymical processes, occurred to me in the year 1780. . . .Though I was, after some considerable time, able to make small bits of cloth of gold, and silver, yet I did not think them worthy of public attention; but by persevering I at length succeeded in making pieces of gold cloth, as large as my finances would admit."

The following are quotations of experiments discussed by Mrs. Fulhame:

> I dipped a piece of silk in the solution of phosphorus, when the ether evaporated, and the phosphorus began to fume, a solution of gold in water was applied; instantly the silk was covered with a splendid coat of reduced gold. Nothing can be more striking than this experiment, which was repeated times without number, or demonstrates the necessity of water in these reductions in a more convincing manner. This piece, viewed by transmitted light, had a purple colour with a considerable tinge of blue; and the margin of the reduced gold was fringed with purple (page 49).
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> A piece of silk was immersed in a solution of nitromuriate of gold in water, suspended in the glass funnel, and exposed, while wet, to vapour of sulphur, formed by a burning match; no sooner did the vapour touch the silk, than the reduction commenced; and in a few seconds the whole piece was covered with a splendid coat of reduced gold, permanent, and retentive of its lustre; but had a few specks of a dull violet hue. The silk viewed by transmitted light appeared of a beautiful blue colour; and being removed from the vapour, and suspended in the air, began in about ten minutes to exhale a vapour, which continued about two hours, and smelled acid, and pungent. Another piece of silk, dipped in the same solution of gold, and dried, was wetted with alcohol, and exposed to the same vapour: the silk acquired a brownish hue; and a small white metallic film appeared on its lower end, where the alcohol most abounded: the silk was then wetted with water, and replaced in the vapour; instantly a lively purple with a bright pellicle of reduced gold appeared (page 70).
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> A piece of silk, which was immersed in a solution of nitro-muriate of gold in distilled water, and suspended in the air twelve hours to dry, was divided into three parts. One of these was exposed to a stream of phosphorated hydrogen gas: the silk became brown, and its margins, which happened to touch the sides of the phial, acquired a violet tinge: but no reduction took place. Another of these parts was wetted with alcohol, and exposed to the gas; but no signs of reduction could be perceived. The remaining part was wetted with water, and was no sooner exposed to the gas, than the reduction commenced over the whole silk, which was soon covered with a bright coat of reduced gold (page 114).

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