CHEMICAL
& METALLURGICAL
ENGINEERING

ESTABLISHED 1902

S. D. KIRKPATRICK, *Editor*

APRIL, 1942

"Because, Too Little and Too Late ....."

President Hotchkiss of Rensselaer Polytechnic Institute is a careful student as well as a great admirer of Rudyard Kipling. When certain munition plants were closing down for certain February birthdays, he went to his library and dug up these famous lines of Britain's militant poet:

EPITAPH, 1918

The battery's out of ammunition, sir!
If any mourn us at the shop, say
"We died because the shift kept holiday."

As we move still further into our own war program, the great problem that is obvious to us all is the need to speed production—to rid our war machine, once and for all, of the deplorable and damnable slowdowns that are sometimes costing us 10 or 20 or even 50 percent of vital output. So Dr. Hotchkiss, with his mind on Bataan and Batavia, followed Mr. Kipling's lead with these stirring words:

EPITAPH, 1942

For lack of ships and planes and tanks
We lie here where we fought, in serried ranks,
Because, too little and too late,
The shift made six instead of eight.

That, perhaps, is negative psychology and therefore contrasts unfavorably with the positive fighting slogans of Don Nelson's lieutenants in the War Production drive. Yet to some of us nothing brings the war home so quickly as the casualty lists and the uncolored reports of valiant fighting against enemies that are not only numerically superior but better equipped and better supported by air and naval forces.

Gradually the people of this country, led by the parents and relatives of the boys already in the Army and Navy, are getting mad. They are in no mood to trifle with those who offer excuses for something less than "all-out" production. They are getting tired of congressional wranglings over wages and hours, of labor and management bickering over "union security" agreements, of political persecutions of American industrialists whose only fault has been that they have been too busy with war work to waste time fighting in the courts for their own defense. The time has come for a showdown with anybody and everybody who is not proving by his every activity that from now on war production comes first!

The job to be done is not in Washington, even though we look there for better leadership. "The war will be won," said Lloyd George in 1917, "in the workshops and laboratories of industry." That is even more true today in this country than it was in England then. We've got to produce ships and tanks and planes at higher rates and in better quality than any other nation or group of nations in history. We've also got to have more powder and ammunition and better weapons.

This is the first and most pressing challenge that our chemical industries must meet. Nothing can be permitted to interfere with building, equipping, manning and operating the many new plants needed to make munitions. But of almost equal importance is the need for literally hundreds of critical chemicals and strategic metals that are essential some place in the war program. It is in these plants that chemical engineers will find their best chance to help in speeding production. Obviously this can seldom be done by putting on more shifts or utilizing idle equipment, because we are already approaching our limits there. But there are many places, we suspect, where yields can be increased or quality improved by intensive application of engineering knowledge and methods. A few good men with no other jobs than to smooth out the wrinkles, eliminate lost motion and waste effort, will more than earn their pay in most plants. Our biggest new supply of essential raw materials is through better utilization of what we are now wasting. No one knows this better than the chemical engineer who is really on his job. No one can help management more in making the most of what we've got.

We, the men who man America's workshops and laboratories, must make certain *now* that the epitaphs which will be written on American graves in far-away countries won't say that death came "Because, too little and too late, the shift made six instead of eight!"

INDUSTRIAL AMERICANIZATION

On Feb. 16, 1942, the Secretary of the Treasury, under an executive order signed by the President of the United States, took title to approximately 97 percent of the stock of the German-owned General Aniline & Film Corp. Early in March four widely known American engineers and executives were named by the Treasury as a managing board to direct the affairs of the corporation and to operate it as an American company. One of their number, Robert E. McConnell, mining engineer, chairman of the Engineers Defense Board and former OPM official, was elected president and chairman of this managing board which consisted of Albert E. Marshall, president of Rumford Chemical Works, George M. Moffett, chairman of the board of Corn Products Refining Co., and Robert E. Wilson, President of Pan American Petroleum & Transport Co. and former petroleum consultant to OPM. Subsequently Mr. McConnell announced the appointment of three operating executives: Mr. Marshall to serve as first vice president; Joseph S. Bates, president of the Bates Chemical Co. of Philadelphia, to be vice president in charge of production, and Dr. William F. Zimmerli, former European technical director of the du Pont Company, to serve as vice president in charge of research and patents.

Thus the decks are cleared for an experience in Americanization which will be watched with absorbing interest for a number of different reasons. In the first place, genuine American control is of greatest strategic importance because this $67,000,000 offspring of the I. G. Farbenindustrie A. G. owned many patents, covering inventions that are essential to modern warfare as well as to peacetime progress of the pharmaceutical, dyestuff, chemical and photographic industries. Hence it is essential that these resources be rid completely of German control and influence in order that they may serve American war needs.

A second reason that this move is so significant lies in the fact that it is the first time the U. S. Government has taken over an alien industrial property and tried to operate it as a going enterprise. This is in marked contrast with the practices of the Alien Property Custodian in the last war. We are assured by the directors and the Treasury Department that this is not to be a yardstick to measure government vs. private operation, but it may well serve as a model for handling other foreign properties whose funds now frozen in the Treasury Department will aggregate approximately $7,000,000,000.

Finally there is no dodging the fact that this particular property is a "blue chip" in the inevitable poker game at the peace table when this war is over. Germany used it to play for pretty big stakes—as the American link in a projected chain to control world organization of chemical industry. Uncle Sam will remember that when the time comes. Meanwhile he has put the property in the capable hands of honest, technically trained Americans whose sole purpose will be to conserve its resources for the public good.

ARNOLD, RUBBER, WAR AND TREASON

Most heartening of all the news to come from Washington this month is the announcement that the trust-busting activities of Thurman Arnold are to be postponed for the duration of the war,—that is, wherever either the Secretary of War or Navy feels that the prosecution would delay the war effort. Had this agreement come two years ago, we would have had more aluminum, magnesium, potash and ammonia with which to fight this war. Likewise, in our opinion, we would have had more synthetic rubber despite the charges made in the vitrolic attack on the Standard Oil Company (N. J.) by this same zealous crusader when he appeared before the Truman Committee of the Senate.

It is quite significant, we believe, that the moratorium on trust-busting was disclosed at the end of the same week in which Mr. Arnold had used the Senate investigation as a sounding board for broadcasting the same sensational charges which he had just withdrawn from an anti-trust suit against the company in order to obtain a consent decree. Thus he got what he probably wanted most—publicity for his contentions while more or less effectively spiking the guns of those who now have no chance to have their defense heard before an impartial tribunal.

Chem. & Met. readers who have followed the course of the many technical developments that have resulted from the Jersey company's original relations with the German I. G. know that the United States has benefitted greatly from these international exchanges of technology. Likewise, most of us have a pretty good idea about the character and motives of the chemists, engineers and executives who have figured so prominently in the stream of inventions that has flowed out of the original transaction for the hydrogenation patents. To insinuate that these men were disloyal to the United States or as Senator Truman put it, guilty of "treason" to their own government, is an insult which we can join Mr. Farish in condemning with "indignation and resentment."

Unfortunately, the whole synthetic rubber picture is so complicated with accusations and denials, charges and counter-charges, that the American public is ready to believe almost anything. It is looking for a scapegoat and where could a better one be found than in our largest corporation which for a dozen years has been dealing not only with the Germans but also with the Italians and the Japanese? That these relations were well known to everybody—some of them actually carried on at the insistence of our State Department—all means nothing now that the witch hunt is on in earnest. But it is probably bringing some snickers and perhaps some sneers for democracy from Berlin and the "Big House" of the I. G. at Frankfort-am-Main. Strangely enough, when Germany decided to fight a total war involving an all-out mobilization of her technological and industrial resources, she did not start by pillaging the executives of I. G. Farben who could contribute most to her war effort. That would have been sabotage and real treason over there. Here it is social reform, political capital and personal publicity.

WASHINGTON HIGHLIGHTS

PRIORITIES mean little any more unless they are very high in the *A* series. So many people have been given some sort of a priority rating that the goods actually available cannot go very far down the list. This Spring it appears that anyone with less than a A-1-j priority can get no copper at all. Thus the program of replacing priorities with allocations builds up more and more momentum. Anyone who must have something in order to do business for Uncle Sam must see to it that he gets a definite allocation of the required materials, whether they be war materials or materials of construction. It is no longer safe merely to have a priority rating.

SPEED, NOT COST, is the primary criterion for an award to bidders who compete for business on war contracts. Under the plan of negotiated contracts, a preference is also given to small firms over big ones since the smaller firms can usually handle simpler jobs and the big firms are reserved for more complicated and difficult assignments. Where new construction is required before manufacture of needed goods can begin, the bidder has preference who imposes a minimum requirement for scarce machinery, equipment and materials of construction. All these considerations show how far Uncle Sam has varied his buying practices to meet wartime conditions.

CONTAINER SHORTAGES seem likely to develop. Bottles, jars and other glass containers, as well as tin cans and metal packaging material, are affected. For a time it appeared that the glass shortage might be due to limited supplies of soda ash. Now it is evident that two other factors will have a much earlier and more serious influence. Rubber, cork and other very scarce materials for closure gaskets are going to be severely restricted. In fact these materials may be prohibited for many types of goods. Only a little less imminent is the restriction on the use of metals for closures. Although the problem of getting metals is going to be difficult no matter what container is ordered, extensive re-use is being urged on every division of industry.

SECRECY in industry disappears as military secrecy increases. Process industries will be disturbed to note two possibilities that may result from over-zealous administration of Federal regulations. Under the guise of proving that a corporation is entitled to an explosive license, the lawyers of the Department of the Interior may pry into minute detail of your company's stock ownership. The effect appears like malicious meddling but may have to be tolerated. Little less objectionable is the recent authorization by Presidential order that the Office of Price Administration may inspect corporation tax rates in the form of transcripts. There is nothing to indicate that this does not lay open much of the confidential information of corporations to unfriendly scrutiny.

FREEZING OF LABOR RELATIONSHIPS seems to be one answer to the slow-down problem. So long as the labor situation is subject to jurisdictional disputes, possible changes in working conditions and wages, the worker is distracted from his main job of all-out production. Meanwhile management is constantly plagued with demands that must soon be answered, once and for all.

INVENTORIES have been rising despite shortages of raw materials. Balance sheets for 15 leading chemical companies for 1941 reported inventories of $300,068,000 compared with $248,382,000 in 1940—up about 20 percent. For industry as a whole the rise is estimated at more than a third of last year's stocks.

CHEMICAL PRODUCTION GOALS rise constantly. With military demands as now anticipated, it is almost unbelievable that there will be surpluses of any important chemicals no matter how hard the industry may work on expanding production schedules. Temporary exceptions to this rule are expected, as, for example, instances where it is difficult to find storage space at the point of production because of delays in shipping instructions or facilities. But the overall demand for war chemicals seems insatiable.

STORAGE FACILITIES in many chemical plants will be strained to the limit. Under current impending increases of demand, irregularities in transportation make it necessary that every management plan for maximum possible storage space for incoming raw materials, partly finished goods in process and finished products. No one can foretell the emergency that may increase the need for any or all of these facilities. Wise executives and engineers will have their plans well laid.

PRICES, in the opinion of some Washington observers, are now getting out of hand. The situation is described as "dangerously explosive." Inflation in national income to the extent of at least 20 billion dollars in 1942 is almost certain.

RESEARCH LABORATORIES, as well as control laboratories, using certain specified chemicals defined as "ingredients of explosives" must have licenses before they can buy or use such materials. Responsible persons in charge of these materials must keep a careful record of use or disposition. Theft or loss must be promptly reported or serious penalty may follow if diverted materials are used for sabotage. All of the technicalities of wartime are involved in this set of rigid and restrictive rules.

Producing Smokeless Powder By 1942 Methods

R. E. HARDY *Colonel, U. S. Army*

Chem. & Met. INTERPRETATION

This article and the pictorial flowsheet on pages 110-113 describing operations in one of the new smokeless powder plants it is hoped will serve the useful purpose of instructing new operators in this and similar plants in the operations with which they will be concerned. Also this information should be of assistance to raw material and equipment supplies of these plants and those still to be built.—*Editors.*

One of the world's greatest war machines for the production of combat equipment is being built by the Ordnance Department of the U. S. Army. This multi-billion dollar program, which is already partly completed, consists of numerous department-owned factories for the manufacture of rifles, machine guns, cannon, tanks, bombs, shells, ammunition, gunpowder, ammonium nitrate, picric and other acids, toluene, etc.

Created shortly after the Revolutionary War, the Ordnance Department ever since has had the responsibility of designing, developing, manufacturing and procuring the war material used by the army, which includes 1,200 major items, 250,000 components. Startling innovations in the realm of munitions have constantly stemmed from the research and manufacturing arsenals of the Ordnance Department. Their influence on industry in general has been profound. Through their efforts America's combat materiel today is superior to that of any country in the world. Also under the guidance of the Ordnance Department, American factories are fast being converted to the production of these many war items.

Included in the department's building program are smokeless powder plants. Typical of these is a plant which covers an area of several thousand acres, and which cost in the neighborhood of $100,000,000. Several hundred buildings with a combined floor space of more than 2,000,000 sq. ft. were erected. It was necessary to build 50 miles of automobile roads and lay 67.5 miles of standard gage railroad track within this area. Service piping, including steam, water, brine, fire and electric, totals 186 miles, and for sewage and additional 27.5 miles. There are 15 miles of wire fencing.

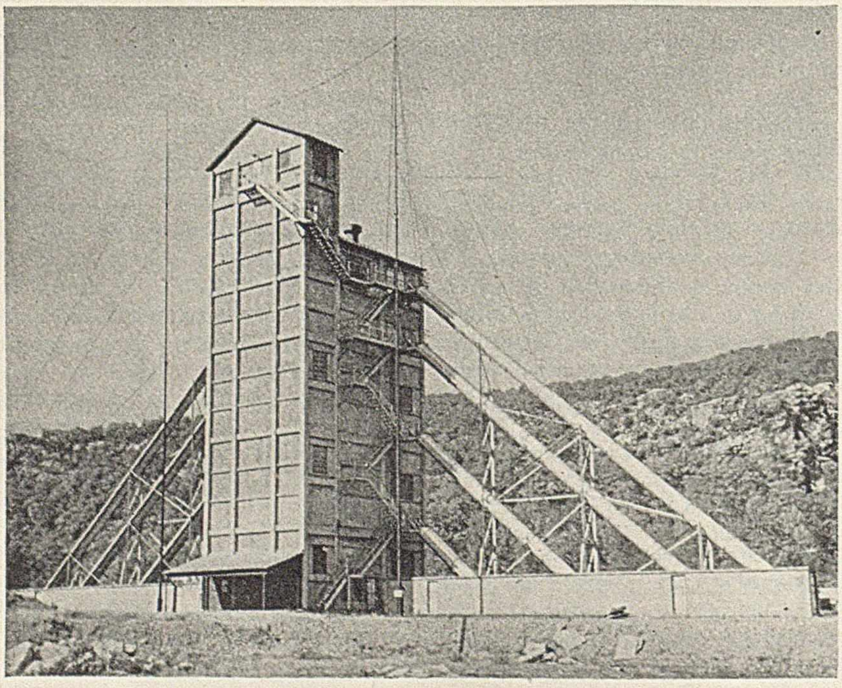
The water supply is not taken from a river. To avoid the necessity for filtration, wells were sunk through approximately 90 ft. of sand and gravel close to the shore of the river. These are of the Ranney water collector type. Motor-driven pumps will supply approximately 50,000 g.p.m. The water is pumped into two reservoirs, each of immense capacity.

Adjoining the two reservoirs are two steam-electric plants. Considerable distance separates each power plant and reservoir from the other power plant and reservoir. An electric transmission line in the form of a loop connects the two power units so that in case one fails current can be sent from the other to the affected areas.

The 11 kv. distribution loop has 5.3 miles of pole line with 54 steel transmission towers. Current at 2,300 volts is distributed through 39 miles of pole lines. In addition there are 46.4 miles of pole lines for road and fence lighting. The telephone and fire alarm systems utilize 25 miles of cable.

The base of smokeless powder is nitrocellulose, made by nitrating cel-

Cannon powder blending house equipped with drop hoppers. When the trap door of a filled hopper is pulled, powder drops onto an inverted umbrella-shaped baffle



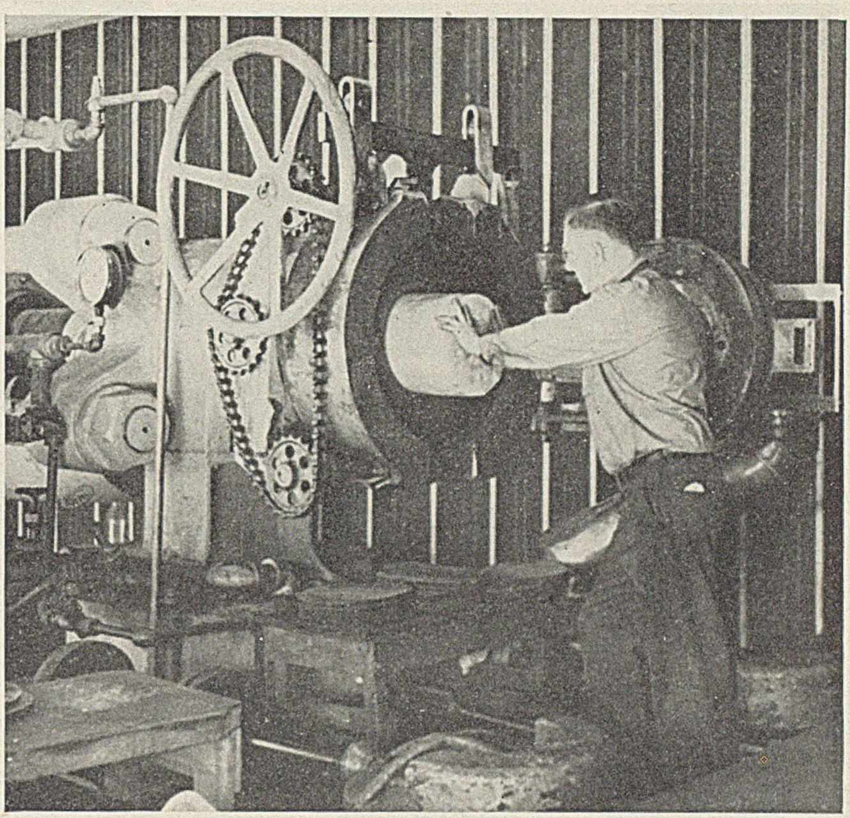
lulose. Wood or cotton can be used as the source of cellulose, but as wood contains lignin, which must be eliminated, cotton is employed at this plant as the source for cellulose. Cotton linters are used, since long staple cotton balls up and plugs slurry lines and valves. If the supply of linters should run low, it can be replaced with long staple cotton which has been chopped up. Oils and other impurities in the cotton are removed with a sodium hydroxide treatment and the cotton is then washed free of alkali and bleached. Cotton received is already processed to this stage. The first treatment given it here reduces the external moisture. Since the heat of dilution of sulphuric acid by this moisture would be considerable with subsequent danger of fires during nitrating, drying is imperative. This is accomplished in a long continuous conveyorized oven heated by radiation with steam pipes, the cotton being fluffed out of the solid bales at the entrance.

Military nitrocellulose is composed of a mixture of high-grade nitrocellulose and pyro-nitrocellulose. The first of these contains an excess of nitrogen and contributes ease of ignition and high potential characteristics, the latter contains a small amount of nitrogen and acts as the vehicle for the insoluble variety (the high-grade type is insoluble in ether-alcohol).

In the nitrating process the cotton, after being weighed into fiber cans, is sent by conveyor to the third floor of the nitrating houses where there are several groups of charging hoppers these supply the dipping pots suspended below the floor. Four pots are included in one nitrating unit. Cotton and nitrating acids are charged into the dipping pots. Beneath these pots and on the second floor are several wringers, one serving each of four dipping pots. Suspended under the wringers are immersion basins serviced with water. The four pots, wringer, and one immersion basin make a complete nitrating unit. In operation the pots are dipped in their order, properly timed so that by the time the fourth pot is dipped, the first charge is ready to be dropped into the wringer. Nitrocellulose is discharged from the wringer into the immersion basin, drowned with water, and flushed into slurry tanks.

A system of collecting pipes from the dipping pots conducts acid fumes to a cyclone where the nitric acid is dissolved in water for concentration and reuse.

Impurities remain to be washed out in the next building in the line. This operation is known as the boiling tub procedure or stabilization. With the cellulose is always some degraded or decomposed cellulose known as hydrocellulose or oxycellulose. As cellulose is treated with nitric acid, nitric esters of other substances are also obtained. There also accumulate sulphuric esters as a result of esterfication with sulphuric acid. The function of the boiling tub house is to remove these foreign ester impurities which are inherently unstable and unsatisfactory.



Powder is first pressed into blocks so that it can be handled easily. It is being charged into a screening press by the operator

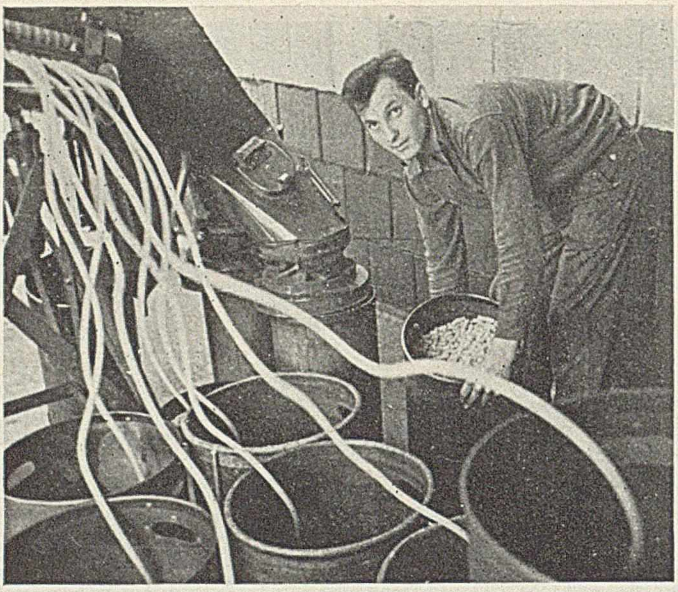
The slurry entering the boiling tubs contains a small amount of acid expressed as sulphuric. The acid is that resulting from the dilution of the acid left in the nitrocellulose after nitration. The acidic solution is pumped over to the boiling tub house where it is put into wooden tubs and heated indirectly with steam which is introduced under a false bottom.

After the boil is complete, the material is run out of the tubs and put into another intermediate slurry tank. Any free acid is neutralized with sodium carbonate, but the nitrocellulose must be broken up to get at the acid held between the micelle and fibrils of the fibers. This is accomplished, together with preparation for colloiding, in the pulping house. The line is still divided into high-grade and pyro nitrocellulose.

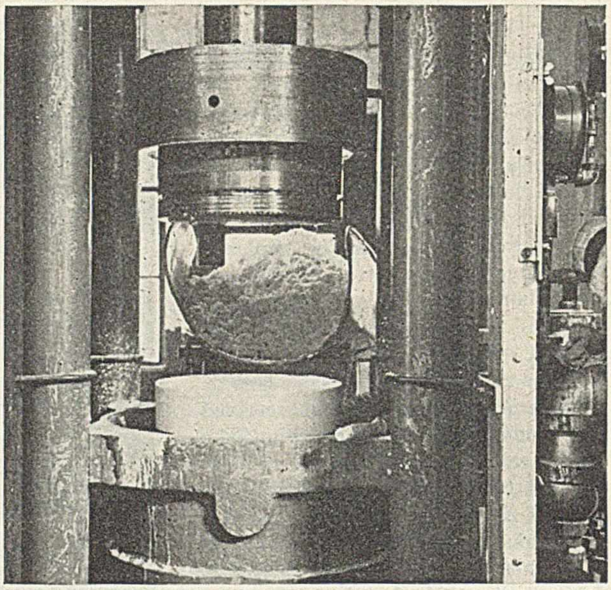
To accomplish the pulping the alkaline slurry is passed through a series of three Jordan refiners and pumped to the poacher house. The final neutralization is accomplished here by the addition of more sodium carbonate. Heat and agitation insures the reaction between the acid and sodium carbonate. Boilings, settlings, decantations, and rewaterings follow, and the residual sodium carbonate and salts are removed by cold water washes. After each boiling and washing, the slurry is allowed to settle and at least 40 percent of volume must be decanted.

Each high-grade and pyro poacher charge is analyzed and then pumped to huge vats with umbrella baffles and agitators in the blending and wringer house, and blending produces the desired nitrogen content. After a sample of the blend has been approved by the laboratory, nitrocellulose is dewatered as much as possible before going to the dehydrating press. Centrifuging reduces moisture in pyrocotton to desired percent. The product is now held in transfer cars ready for the smokeless powder area.

Smokeless powder was the chief propellant during the World War,



Strings or ropes of powder are cut into pieces of desired length and then loaded into cans for conveying



Block of nitrocellulose being ejected from dehydrating press. New charge appears above

but it had two serious defects which have been corrected since. First, moisture was absorbed by pyro powders; and second, the combustion products of the powder flashed (burned) at the muzzle. Deviation from ballistic standard was caused by moisture absorption by pyro powders used during the World War which were quite hygroscopic. Composition of du Pont "FNH" and "NH" powders permits adjustment of moisture to normal humidity at average temperature and because of composition, is much less hygroscopic than pyro powders.

Production lines in the smokeless powder area start with a dehydration press house. Here water present in the nitrocellulose is removed and alcohol is substituted. The nitrocellulose is charged into a hydraulic press and compressed by a low-pressure ram. Alcohol is forced in at the bottom of the press under a higher pressure, displacing the water. This process is aided by a partial vacuum applied through perforations in the ramhead.

The pressure exerted by this ram is then increased and some of the alcohol forced out of the cake. Enough alcohol is left in the block so that all alcohol requirements will be satisfied for the colloidizing action within the mixer house.

Actual colloidizing is accomplished in the mixer house where the dehydrated alcohol-containing blocks are charged into mixers. In a few minutes the action breaks up the blocks and partially mixes the nitrocellulose and insoluble compounding agents, and then ether containing a stabilizer and plasticizer is added. These ingredients act as plasticising agents and control the burning of the finished product, and thus aid in the elimination of flash. The ingredients used form a fairly complete colloid of the nitrocellulose and affect the hygroscopicity of the nitrocellulose to a much greater extent than would be expected from the percentage compositions. Thus the World War difficulty of absorption of water by pyro powders is eliminated. When powder decomposes, nitrogen-oxide fumes (NO_2) are given off which react with moisture to form nitric acid. The acid, in turn, catalyzes the decompositions of nitrocellulose. The stabilizer reacts with the NO_2 and removes it.

Material for cannon powder is mixed for a given time, and since rifle powder manufacture differs from this point, further discussion will deal only with cannon powder. The colloidal formation is completed in mixers of a slightly different type, known as macerators; then blocked in presses for convenience in handling.

The next building in line is the screening and graining house. Here the powder is put through screens in a press in order to remove lumps and impurities. This is called a macaroni press, as powder comes out in string or rope-like form. This powder is blocked once more and then sent to graining presses which extrude the powder through screens followed by a perforated die. Strings or ropes of powder so obtained are then sent to a cutter where powder grain lengths are regulated.

Removal of alcohol and ether is accomplished by distilling the solvent out of the grains with hot air and then passing the air through a condenser in order to remove the solvent. The powder is put into covered cars which are sent to the solvent recovery building. Here air heated by steam coils is passed through the cars and then partially by-passed through a condenser where much of the picked-up solvent is condensed. By-passed and unby-passed air is sent back over the coils for recirculation.

After passing through the dump shed house, the uniform powder is conveyed to the water-dry-house on a conveyor, or pumped by fast flowing water and put into storage tanks in the water-dry-house. Here the remaining solvent is removed. Water preheated by steam is pumped through the tanks so that the solvent may be quite rapidly dissolved out of the powder grains. A portion of the water in the tub is always thrown away with the differential amount of water being made up from a hot water tank within the water-dry-house. This procedure is followed until the residual solvent left in the powder grains has been decreased to a low percentage. After the powder has been in the water-dry-tanks for the required length of time, the removal of solvent is considered complete. The powder now contains water and small amounts of ether and alcohol, and the removal of that water is left to the so-called C. C. (control circulation) dry-house. Here the mass is dumped into a bin and hot air, obtained by passing air over a steam coil, is passed through the powder for a sufficient length of time to bring the moisture content down to an average value to be expected under normal conditions of temperature and humidity. The powder is now finished as far as the actual manufacturing processes are concerned.

Blending is next in order, and blending towers with drop hoppers are provided for this purpose. When the trap door of a filled hopper is pulled, the powder drops onto an inverted umbrella-shaped baffle, is scattered, and collected in another hopper. This procedure is carried out until a good blend is obtained. The powder is then sent to the packing houses, weighed into containers, which are then sealed, air-tested, stenciled, and routed to the shipping and storage houses.

Rifle powder manufacture differs in that the powder is coated with various ingredients in order to control the rate of burning. A graphite coat completes the series of steps in the operation.

A description of the acid and organic areas is now in order. Nitric acid is made in the acid area by the direct oxidation of ammonia. The ammonia is received in liquid form in tank cars and stored. It is first volatilized in a vaporizer equipped with steam coils and then mixed with hot air. This mixture is passed into a catalytic converter in which the fundamental chemical reaction occurs.

The resulting nitrogen oxide gases are cooled in a heat exchanger and partially condensed in a bank of condensers. The vapors are eventually put through an absorption tower and the condensate leaving the condenser as dilute nitric acid is also sent to the absorption tower. Counter-current scrubbing of the rising vapors results in 60 to 61 percent nitric acid.

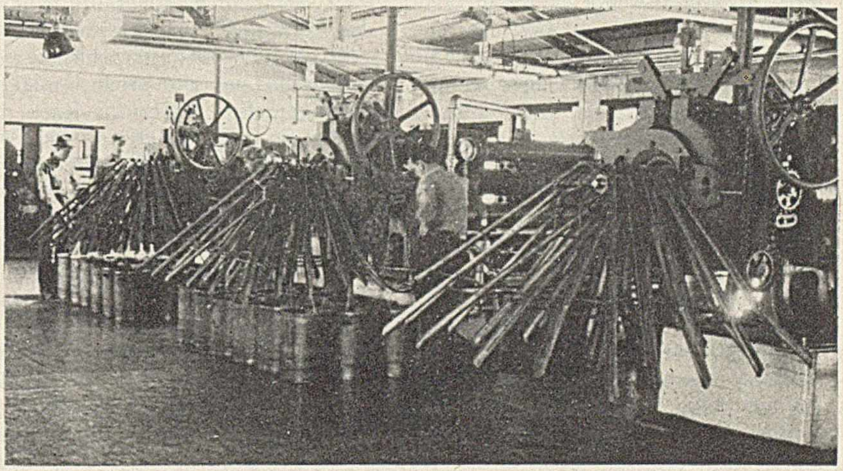
Gases from the top of the absorption tower are passed through a portion of the heat exchanger, through which the hot converted gases are sent, removing latent heat from the converted gas while being themselves heated. After accomplishing this cooling, the warmed gases are exhausted to the atmosphere through secondary compressors which pump 40-45 percent of the air needed for the oxidation process.

If it is to be used for nitrocellulose 60 percent acid must be concentrated to approximately 92 percent strength. Therefore, it is mixed with 92 to 96 percent sulphuric acid and concentrated. First, the mixture of nitric and sulphuric acids is preheated by steam coils and then sent into the top of a dehydrating column packed with chemical ware. From here it goes into a series of steam-heated boiler tubes and the heat drives the nitric acid gases back into the bottom of the dehydrating column. The nitric gases rise in the column and dilute nitric acid falls down, thus producing a stripping action. The sulphuric acid, since it is not volatile and is combined with water, is concentrated for reuse. The nitric acid vapors are then passed through a bleaching column, also packed with chemical ware, and thence to a condenser where the nitric acid is condensed out. It is now 92 to 95 percent nitric acid.

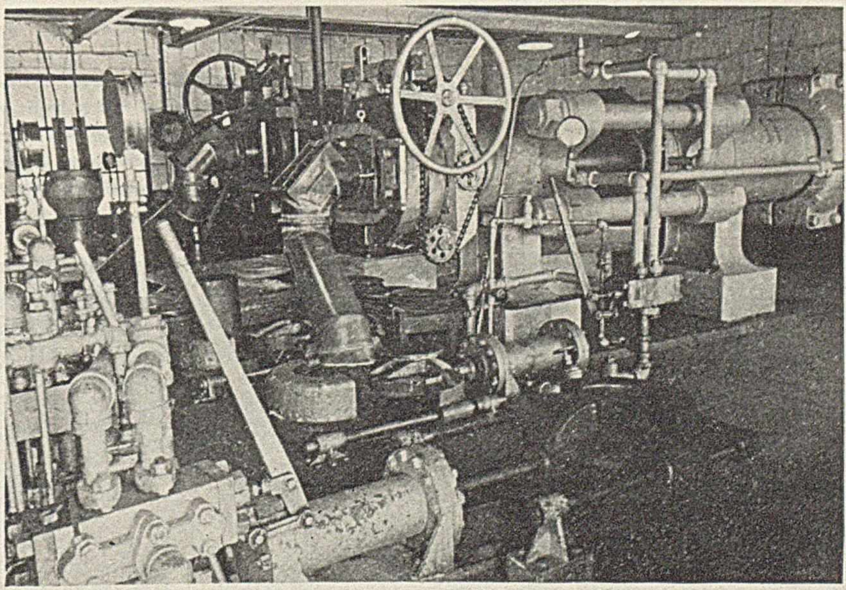
The organic area is divided into several sections. In the first, benzene is reacted with nitric and sulphuric acids to form nitro-benzene. The nitrobenzene is reduced to produce aniline, which is then either reacted catalytically under pressure with heat to form diphenylamine, or is allowed to react with methyl alcohol and sulphuric acid to obtain dimethylaniline.

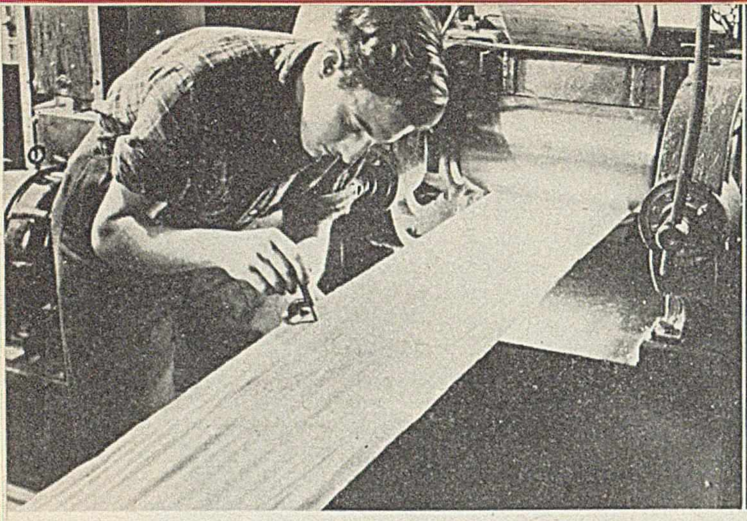
Smokeless powder is employed almost entirely as a propellant, and when finished is either stored or shipped out to nearby plants for bag or shell loading, as the case may be. If it is to be incorporated in the complete round, it is loaded into the cartridge shell cases. If, on the other hand, it is to be used in large guns as separate charges, it is loaded into cloth bags.

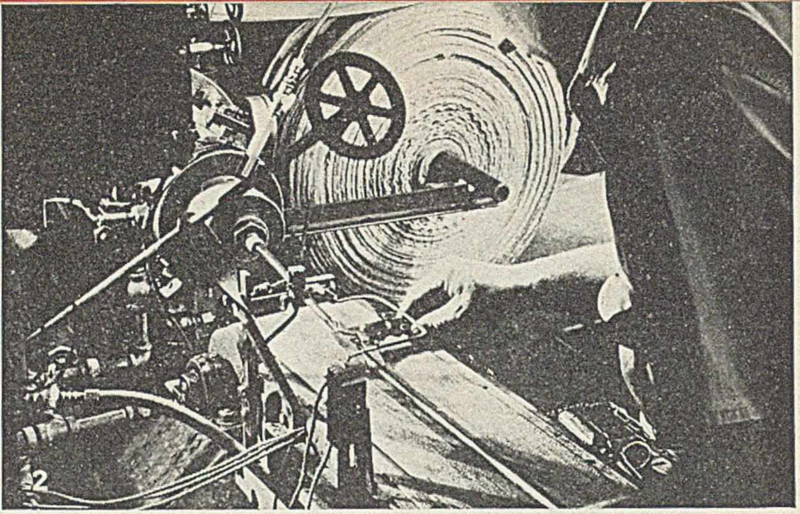
Graining presses extrude the powder through screens followed by a perforated die. Strings are then sent to the cutters



Powder is put through screens in a macaroni press in order to remove lumps and impurities. This powder is blocked once more







Producing a Rubber-Like Synthetic

EDITORIAL STAFF ARTICLE

Resistant to a high degree against refrigerant gases and organic solvent materials including petroleum products, chlorinated, aromatic and aliphatic hydrocarbons, and ketones, the rubber-like synthetic known as Resistoflex PVA is finding application in numerous types of use ranging from work gloves and aprons, to fuel, lubricant, hydraulic and vacuum hose for land and air transportation equipment. Versatility in methods of fabrication is one factor accounting for the diversity of applications. The material may be extruded as tubing, molded into sheets for gaskets, washers and diaphragms, cast, laminated and dipped. Molded sheets may, if desired, be re-molded for the production of various types of molded mechanical goods.

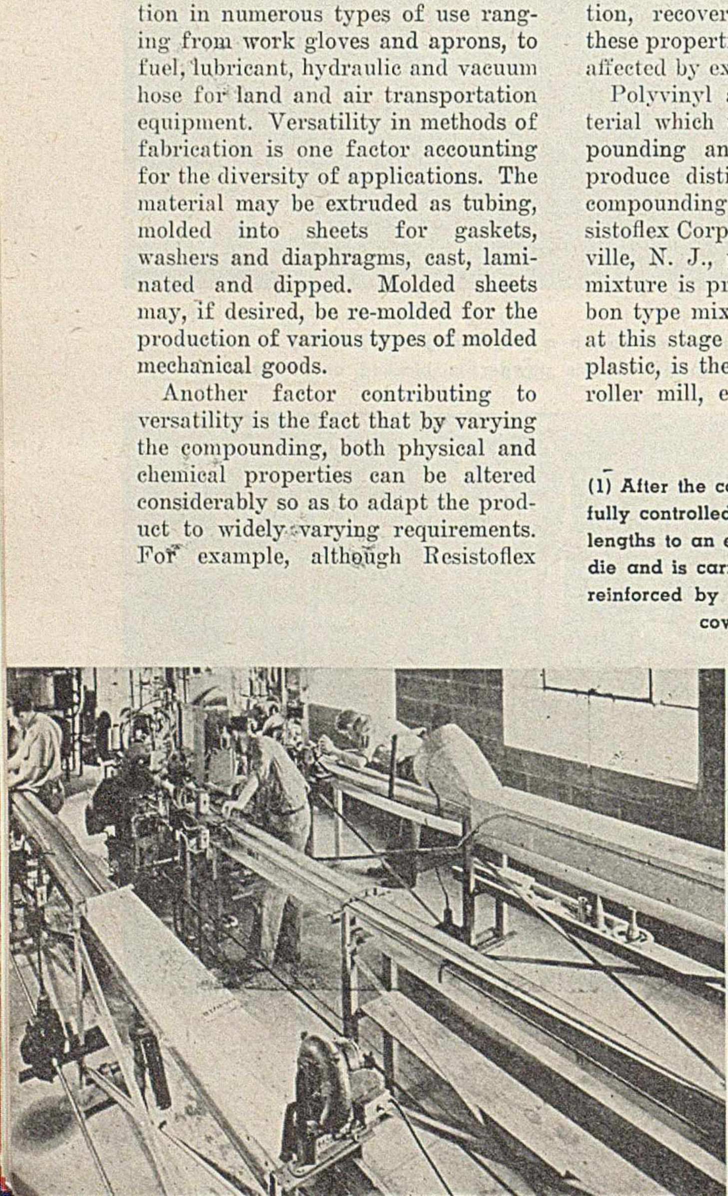
Another factor contributing to versatility is the fact that by varying the compounding, both physical and chemical properties can be altered considerably so as to adapt the product to widely varying requirements. For example, although Resistoflex PVA compounds generally tend to shrink slightly in the presence of most solvents, this characteristic can be modified so as to produce a slight swelling action under the same use conditions. The material has extremely high tensile strength, elongation, recovery and toughness, and these properties are only very slightly affected by exposure to most solvents.

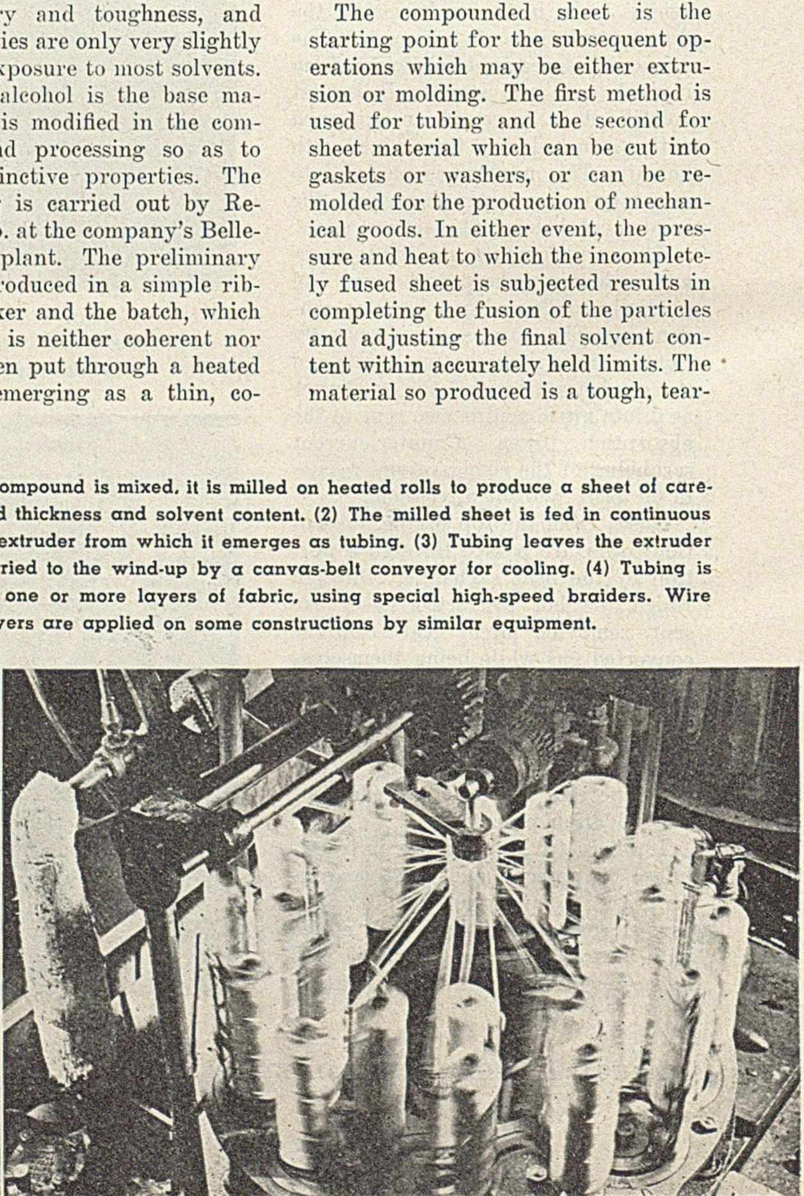
Polyvinyl alcohol is the base material which is modified in the compounding and processing so as to produce distinctive properties. The compounding is carried out by Resistoflex Corp. at the company's Belleville, N. J., plant. The preliminary mixture is produced in a simple ribbon type mixer and the batch, which at this stage is neither coherent nor plastic, is then put through a heated roller mill, emerging as a thin, coherent sheet somewhat resembling crepe rubber. This step, in which roll temperature and the thickness of the sheet produced are both carefully controlled, results in incipient fusion of the compounded particles, and a "sintering" together of adjacent particles.

FORMING OPERATIONS

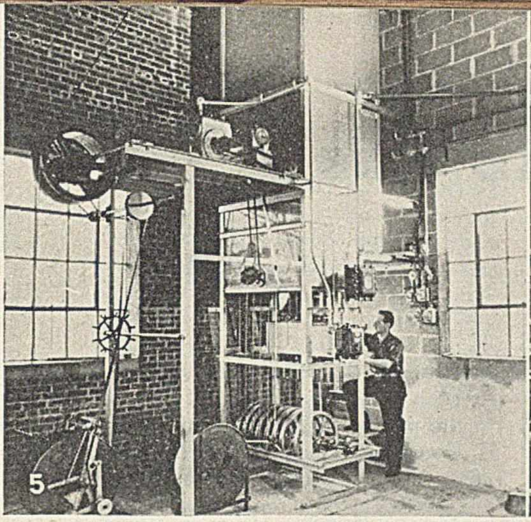
The compounded sheet is the starting point for the subsequent operations which may be either extrusion or molding. The first method is used for tubing and the second for sheet material which can be cut into gaskets or washers, or can be remolded for the production of mechanical goods. In either event, the pressure and heat to which the incompletely fused sheet is subjected results in completing the fusion of the particles and adjusting the final solvent content within accurately held limits. The material so produced is a tough, tear-

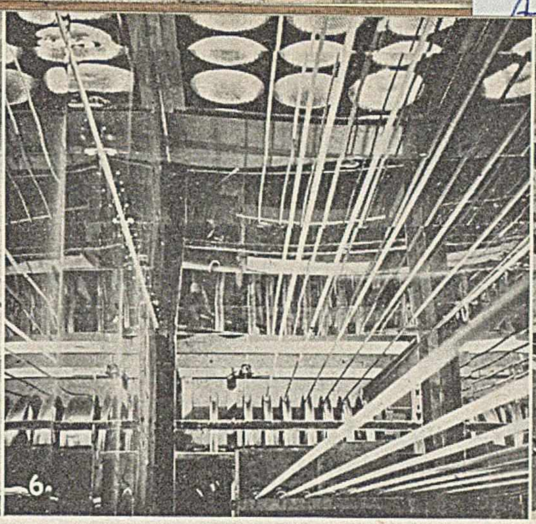
(1) After the compound is mixed, it is milled on heated rolls to produce a sheet of carefully controlled thickness and solvent content. (2) The milled sheet is fed in continuous lengths to an extruder from which it emerges as tubing. (3) Tubing leaves the extruder die and is carried to the wind-up by a canvas-belt conveyor for cooling. (4) Tubing is reinforced by one or more layers of fabric, using special high-speed braiders. Wire covers are applied on some constructions by similar equipment.

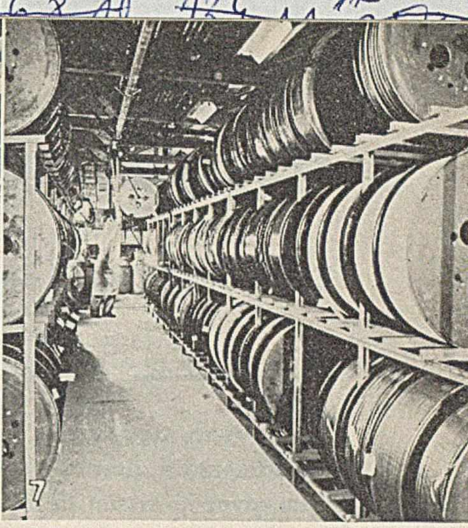




A6 & A1







resistant plastic, having an amorphous structure which is best described as a solidified colloidal solution.

Although resins of this type have been known for nearly 20 years, they have been seriously considered only in the last ten. Some five years ago the American and Canadian patents on the processing of this class of materials were purchased by Resistoflex Corp. which then set about the development of methods for large-scale commercial production. Extrusion had already been practiced but one of the first problems of the company was perfection of this process. It was found to be particularly difficult to assure accurate dimensional control, but the problem was solved with a heated die and the adaptation of existing automatic control equipment which was modified on the basis of extensive experiment. Control of the tension in the extruded tube, produced by the belt which conveys the tube from the die, was also a difficult task which was finally solved by a sensitive electric control which senses the tube tension, maintaining it at the desired value by control of a variable speed transmission driving the belt.

Tubing can be extruded in a variety of diameters ranging from about ⅛ to 1 in. Leaving the die, it is carried by a canvas cooling belt some 40 or 50 ft. to the point where it is wound on a large metal reel, to await further processing. Depending on the requirements of each construction, the hose produced is reinforced by a number of layers of cotton or metal braid, applied by high-speed braiders of special design. An outer coating is provided of rubber, synthetic rubber, wire or lacquer, as required.

INFRA-RED DRYING

The hose lacquering operation is especially interesting. A drying tower has been developed, the inner surface of which is lined with brightly polished chrome-plated sheets. A battery of infra-red drying lamps is used, drying the lacquer at rates up to 4,000 ft. per hour. As many as 12 passes of hose can be threaded through the tower, to allow as many coats of lacquer to be applied. The coatings, incidently, are appled by Resistoflex PVA wipers which are said to give much longer life in this service than other materials that have been tried.

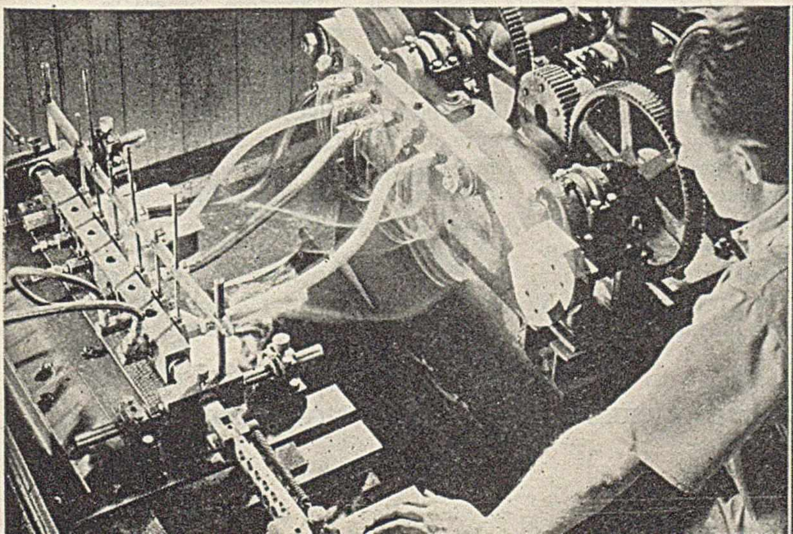
A considerable part of the company's output of hose and tubing is in the form of finished hose assemblies, cut to length and supplied with a variety of coupling designs spun or pressed on to the hose ends.

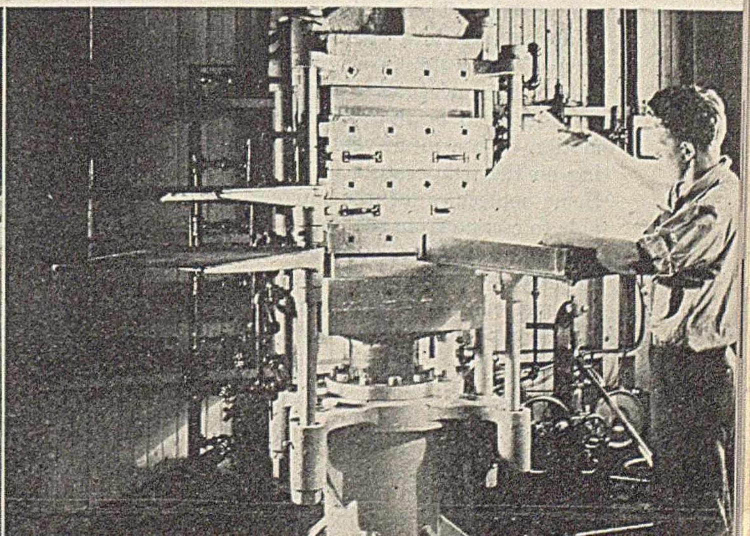
Resistoflex PVA sheets are produced by the simple process of molding the crude milled sheet between heated platens in a hydraulic press. If desired for added strength, fabric backing or inserts can be fused to the stock at this stage. The material can then either be delivered to the user in sheet form, or die-cut to desired final dimensions.

For dipping operations, as in the production of gloves, Resistoflex PVA is dissolved in a suitable mixture of solvents to form a viscous solution in which the porcelain forms are dipped, much as in the production of dipped rubber goods. Aprons and similar products are made by coating fabric with such a solution.

For permission to inspect the plant, and for assistance with the manuscript, *Chem. & Met.* is indebted to E. S. Peierls, president of Resistoflex Corp.

(5) This coating and drying tower can apply as many as 12 lacquer coats to braid-covered tubing at speeds up to 4,000 ft. per hour. (6) Looking downward inside the lacquer-drying tower; the infra-red drying lamps are clearly visible. (7) Here finished and semi-finished tubing is stored on metal reels. (8) One of the tests for finished hose is to subject it simultaneously, on this machine, to temperature, pressure, flexing, vibration and torsion. (9) Flat sheets are molded by pressing between heated platens.





Psychrometry of Cooling Towers

EDWARD SIMONS *Engineer, Redwood Manufacturers Co., San Francisco, Calif.*

***Chem. & Met.* INTERPRETATION**

Three years ago Chem. & Met. published a group of articles on the fundamentals of water cooling tower design. Practical information was given to assist in actual design. Since their appearance, there have been a number of developments in both theory and practice. A new series, prepared by the same author, brings the subject up-to-date. The introductory article, presented here, is a quick review of fundamentals and a tie-in with the previous series.—*Editors.*

PSYCHROMETRY is the branch of physics that treats of the measurement of the degree of moisture, especially the moisture mixed with the air. The basic tools of this science are the gas laws, the principles of heat exchange, and the principles of molecular diffusion. It is often necessary for the engineer to use psychrometric formulas, even though he has lost the intimate impression of the fundamental actions. This article is a review of some of the basic principles and a projection of the principles into the field of cooling tower design and operation.

A water cooling tower may be defined as an apparatus in which the temperature of circulated water approaches the wet-bulb temperature of circulated air during the heat intersection that occurs between the air and the water.[1] During the evaporation which occurs with the heat exchange, the water which is evaporated changes from a liquid to a vapor. Therefore, the materials involved in the tower process are liquid water, water vapor, and gaseous air.

A closed container which is partially filled with water is illustrated in Fig. 1a; the container and its contents are maintained at a constant temperature. The portion of the container space which is above the surface of the water is originally evacuated. The molecules in the water are considered to be in a state of rapid motion with a mean velocity depending on the temperature of the water. Some molecules at the surface are able to escape from the liquid because their velocities are sufficiently high to project them into the vacuum. As this molecular escape continues, some of the vaporized molecules strike the surface of the liquid from which they emanate, and again become part of the liquid. When the number of molecules re-entering the surface is just equal to the number of molecules leaving it, a balance is established between the two phases, and the molecules which finally occupy the space of the original vacuum exert a pressure on the walls of the container. This pressure is called the pressure of the saturated vapor or saturation pressure. This pressure depends upon the nature of the liquid and upon the temperature.

A similar container in which the space above the water level is originally occupied by air is shown in Fig. 1b; the container and its contents are held at the same temperature as the container of Fig. 1a. If the pressure in the space above the water does not materially exceed one atmosphere, the tendency of the water molecules to escape is the same as in the case of the container of Fig. 1a, since the voids between the air particles are sufficiently large and numerous to enable the saturation process to proceed. However, the vaporized molecules do not distribute themselves so rapidly throughout the vessel, since collisions with the air molecules act to retard the vaporization. Consequently, the water evaporates more slowly into air than into a vacuum, but eventually the saturation pressure of the water vapor is built up to the same intensity that it would develop if the air were not present. The partial pressure of the water vapor is independent of the gas (air) which is also present in the container.

Dalton's Law states that in a mixture of gases the pressure of each constituent gas is independent of the presence of the others, and each gas exerts a partial pressure that is equal to the pressure which it would exert if it occupied the entire volume of the mixture at the temperature of the mixture. Furthermore, it states that the partial pressures of the constituents are additive. Therefore, the total pressure of a mixture is the sum of all of the partial pressures of the constituents. Dalton's Law may be applied to mixtures of dry air and water without the introduction of significant error. The total pressure of a mixture of air and water vapor is commonly the barometric pressure and is equal to the sum of the partial pressures of dry air and water vapor.

The perfect gas equation may be written

$$PV_g = 1{,}543wT_R/M_w \qquad (1)$$

where

P is the total absolute pressure in lb. per sq. ft. V_g is the total volume in cu. ft., w is the weight of the gas in lb. in volume V_g, T_R is absolute temperature in deg. R. (T_R = deg. F. + 460) and M_w is the molecular weight of the gas.[2a]

Moisture-free air has the following average analysis:[2b]

Component	Percent by Volume	Molecular Weight	Lb. in 1 molal volume of air
Oxygen (O_2).........	20.95	32.00	6.70
Nitrogen (N_2)........	78.08	28.02	21.88
Carbon dioxide (CO_2).	0.03	44.00	0.01
Argon, etc...........	0.94	40.	0.38
Total weight of 1 mol of air is..........			28.97 lb.

Similarly, for water vapor:

Component	Atomic Weight	Lb. in 1 molal volume of vapor
Hydrogen (H_2).........	1.008	2.016
Oxygen (O)............	16.00	16.00
Total weight of one mol of water vapor....		18.02 lb.

The weight of a column of mercury one sq. ft. in area and one in. deep is 70.73 lb. Therefore, where a column of mercury is used as a pressure indicator, a variation of one in. in the indicating column represents a variation in the intensity of pressure of 70.73 lb. per sq. ft. (0.4912 lb. per sq. in.) If P_G is equal to the pressure of a gas in in. Hg,

$$P = 70.73P_G \qquad (2)$$

The volume occupied by one lb. of dry, moisture-free air is selected for use in Eq. (1); accordingly, w is

NOMENCLATURE

B = Barometric pressure, in. Hg.
C_v = Volume of air per minute passing through a given tower cross section, cu. ft. per min.
G = Rate of air flow through tower, lb. bone dry air per min.
H = Air humidity, lb. of water vapor per lb. bone dry air.
H_s = Saturated humidity at T_R, lb. water vapor per lb. dry air.
L = Water rate through cooling tower, lb. per min.
M_w = Molecular weight of a gas, general case.
p_a = Partial pressure of water vapor in the main air stream, in. Hg.
p_w = Saturated pressure of water vapor at the wet bulb temperature, in. Hg.
P = Absolute pressure, lb. per sq. ft.
P_a = Total absolute pressure, atm.
P_G = Pressure of a gas, in. Hg.
r_w = Latent heat of vaporization of water vapor at t_w, B.t.u. per lb.
t = Temperature of the air-water mixture, or dry-bulb temperature, deg. F.
t_w = Wet-bulb temperature.
T = Bulk temperature of the water, deg. F.
T_R = Absolute temperature of a gas, deg. Rankine.
V_G = Total volume of a gas, cu. ft.
V_H = Humid volume of air, cu. ft. moist air containing 1 lb. dry air.
w = Weight of a gas, lb.
Σ = The Sigma Function, in main air stream, B.t.u. per lb. dry air.
$\cong$ = Denotes sensible equivalence.

SUBSCRIPTS

T = Refers to conditions at water temperature, T.
w = Refers to the wet-bulb condition.
1 = Refers to the conditions at the air entrance and water exit of a counter-flow tower.
2 = Refers to the conditions at the water entrance and air exit of a counter-flow tower.

equal to one lb. The weight of water vapor associated with one lb. of dry air has been variously called: mixing ratio, proportionate humidity, mass or density ratio, absolute humidity and specific humidity. In this article, this quantity is given the symbol H; and, since the lb. of dry air is used as a basic unit, H is defined as the humidity of the air for the purposes of this article. Eq. (1) is used as follows:

$$\text{For air, } 70.73\,(B - p_a)\,V_H = 1{,}543 \times 1 \times T_R/28.97 \qquad (3)$$

$$\text{For water, } 70.73 p_a V_H = 1{,}543 H T_R/18.02 \qquad (4)$$

Eq. (4) divided by Eq, (3) yields

$$p_a/(B - p_a) = 28.97H/18.02 \qquad (5)$$

or

$$H = 0.6220 p_a/(B - p_a) \qquad (6)$$

In the preceding equations, P_a is equal to the partial pressure of water vapor in the air, and B is equal to the barometric pressure, both are expressed in inches of mercury.

The value of P_a must be known in order that Eq. (6) may be solved. If the water in the container of Fig. 1b were maintained at a constant temperature during the saturation process, the air in the upper portion of the container would become saturated at the temperature of the water, and the temperature of the air would be the temperature of adiabatic saturation. On the other hand, if it were possible to expose the portion of the container above the water to a moving stream of air of infinite quantity, the water in the lower part of the container would ultimately assume the temperature of adiabatic saturation of the air supply. The wet-bulb temperature of the air determined by a proper psychrometric technique may be used as the temperature of adiabatic saturation. Carrier's equation [3a] may then be used in the following form:

$$p_a = [p_w - (B - p_w)(t - t_w)]/(2{,}800 - 1.3t_w) \qquad (7)$$

where

p_a = actual partial pressure of water vapor in the air, in. Hg.; p_w = saturation pressure at wet-bulb temperature, in. Hg. (Table I gives values of the saturation pressures at intervals of 0.1 deg. F.); B = barometric pressure, in. Hg.; t = dry-bulb (air) temperature, deg. F.; t_w = wet-bulb temperature, deg. F.

Fig.1a

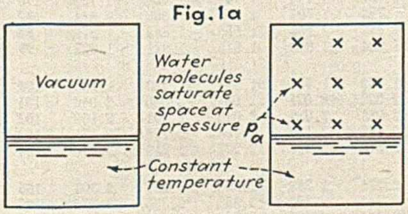
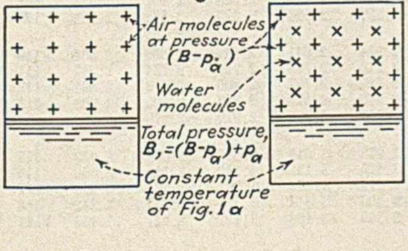


Fig.1b



The volume which is occupied by one lb. of dry air and its associated water vapor is known as the humid volume of the air-water mixture. If V_H is used to designate the humid volume, Eq. (3) may be rewritten as follows:

$$70.73\,(B - p_a)\,V_H = 1543\,T_R/28.97 \qquad (8a)$$

or

$$V_H = 0.7531\,T_R/(B - p_a) \qquad (8b)$$

Thus, if the cubic feet per minute of air-water mixture passing through a given cross section of an apparatus are designated by C_v, and if pounds per minute of dry air passing through this apparatus are designated by G,

$$C_v = G V_H \qquad (9a)$$

or

$$G = C_v/V_H \qquad (9b)$$

The weight of moisture per lb. of dry air in a mixture of air and water vapor depends on the dew point temperature alone. As long as there is no condensation of moisture, the dew point temperature remains constant. Let P_s equal the saturated vapor pressure at T_R, and let H_s equal the corresponding saturated humidity at T_R. Then, for a given unchanged space (as one cu. ft.), and with constant temperature,

$$p_a/p_s = \text{Relative humidity} \qquad (10)$$

For saturation conditions, Eq. (6) becomes

$$H_s = 0.6220 p_s/(B - p_s) \qquad (11)$$

Eq. (6) divided by Eq. (11) gives

$$H/H_s = p_a\,(B - p_s)/\,p_s\,(B - p_a) \qquad (12)$$

The percent humidity is $100H/H_s$; it is the humidity of air at a given temperature expressed as a percentage of the humidity of saturated air at the same temperature. Relative humidity is based upon fixed volume; percent humidity is based upon fixed weight of bone dry air. Eq. (12) indicates that percent relative humidity equals percent humidity only at saturation.

If an air-water mixture is cooled without change of barometric pressure, the partial pressure of the water vapor will not change during the cooling, since the ratio $p_a/(B-p_a)$ of Eq. (6) remains constant with constant humidity. Under these conditions the partial pressures of air and water vapor will remain constant. When, therefore, the temperature is decreased until the air becomes saturated, the partial pressure of the water vapor becomes a saturated pressure, the temperature is the dew-point temperature, and the percent humidity equals the percent relative humidity. Consequently, the humidity at any temperature is equal to the humidity at the dew-point temperature, and the partial pressure of water vapor is equal to the saturated pressure at the dew-point.

The Sigma Function of W. H. Carrier for an air-water mixture[3b] may be written:

$$\Sigma = 0.24\,(t - 0) + Hr_w + 0.45H\,(t - t_w) \qquad (13)$$

The coefficient of 0.24 is the mean specific heat at constant pressure for dry air, and the coefficient 0.45 is the mean specific heat at constant pressure for water vapor; r_w is the latent heat of vaporization at T_w, and is expressed to B.t.u. per lb. The Sigma Function is a constant for any two states of the air-water mixture at the same temperature of adiabatic saturation (wet-bulb temperature). It should be noted that the temperature of make-up water for evaporation should be at a temperature equal to the wet-bulb .temperature of the air. In a cooling tower, both the temperature of the make-up water and the wet-bulb temperature of the air vary throughout the apparatus. Therefore, it is necessary to apply a slight correction to the direct use of the sum of the Sigma Function of air entering the apparatus plus the heat to be rejected into the air.

It may be noted that the heat quantity defined by the Sigma Function excludes the enthalpy of the liquid water at the temperature of the wet-bulb, t_w. If the specific heat of liquid water is taken as one B.t.u. per lb. per deg. F., the enthalpy of the liquid at t_w above a temperature base of 32 deg. F. is equal to $H(t_w-32)$.

At low partial pressures the enthalpy of steam, whether superheated or saturated, may be expressed by a straight-line empirical formula.[3c] William Goodman[4] has stated that for pressures below 5 lb. abs. and temperatures below 500 deg. F., a value of the enthalpy per lb. of water vapor equal to 1,061 + 0.45t will introduce deviations that will be less than 0.25 percent of the values given by the Keenan and Keyes[5] steam tables. Furthermore, he states that for saturated steam at 200 deg. F., and a pressure of 11.53 lb. abs., the deviation is slightly less than 0.50 percent. With Goodman's enthalpy as a basis,

$$r_w = 1{,}061 + 0.45t_w - (t_w - 32)$$

or

$$r_w = 1{,}093 - 0.55t_w \qquad (14)$$

The rectangle of Fig. 2 represents a typical counter-flow cooling tower apparatus. In such a gas-liquid phase exchange system, operating with continuous flow, it is justifiable to neglect the generally small mechanical and potential energy changes in considering the energy transfer between the phases. The water inlet is at 2 and the air inlet is at 1; the water outlet is at 1 and the air outlet is at 2.

Table I—Pressure of saturated water vapor in inches of mercury for temperatures in degrees Fahrenheit

Temp.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Temp.
30	0.1664	0.1671	0.1678	0.1685	0.1692	0.1699	0.1706	0.1713	0.1720	0.1727	30
31	.1734	.1741	.1748	.1755	.1762	.1769	.1775	.1782	.1789	.1796	31
32	.1803	.1811	.1818	.1826	.1833	.1841	.1848	.1856	.1863	.1871	32
33	.1878	.1886	.1893	.1901	.1909	.1917	.1924	.1932	.1940	.1947	33
34	.1955	.1963	.1971	.1979	.1987	.1995	.2003	.2011	.2019	.2027	34
35	0.2035	0.2043	0.2052	0.2060	0.2068	0.2077	0.2085	0.2093	0.2101	0.2110	35
36	.2118	.2127	.2135	.2144	.2152	.2161	.2169	.2178	.2186	.2195	36
37	.2203	.2212	.2221	.2230	.2239	.2248	.2256	.2265	.2274	.2283	37
38	.2292	.2301	.2310	.2319	.2328	.2338	.2347	.2356	.2365	.2374	38
39	.2383	.2393	.2402	.2412	.2421	.2431	.2440	.2450	.2459	.2469	39
40	0.2478	0.2488	0.2498	0.2507	0.2517	0.2527	0.2537	0.2547	0.2556	0.2566	40
41	.2576	.2586	.2596	.2606	.2616	.2627	.2637	.2647	.2657	.2667	41
42	.2677	.2688	.2698	.2709	.2719	.2730	.2740	.2751	.2761	.2772	42
43	.2782	.2793	.2804	.2815	.2826	.2837	.2847	.2858	.2869	.2880	43
44	.2891	.2902	.2914	.2925	.2936	.2948	.2959	.2970	.2981	.2993	44
45	0.3004	0.3016	0.3027	0.3039	0.3050	0.3062	0.3074	0.3085	0.3097	0.3108	45
46	.3120	.3132	.3144	.3156	.3168	.3180	.3192	.3204	.3216	.3228	46
47	.3240	.3252	.3265	.3277	.3290	.3302	.3314	.3327	.3339	.3352	47
48	.3364	.3377	.3390	.3403	.3416	.3429	.3441	.3454	.3467	.3480	48
49	.3493	.3506	.3520	.3533	.3546	.3560	.3573	.3586	.3599	.3613	49
50	0.3626	0.3640	0.3654	0.3667	0.3681	0.3695	0.3709	0.3723	0.3736	0.3750	50
51	.3764	.3778	.3792	.3807	.3821	.3835	.3849	.3863	.3878	.3892	51
52	.3906	.3921	.3935	.3950	.3964	.3979	.3994	.4008	.4023	.4037	52
53	.4052	.4067	.4082	.4097	.4112	.4128	.4143	.4158	.4173	.4188	53
54	.4203	.4219	.4234	.4250	.4265	.4281	.4297	.4312	.4328	.4343	54
55	0.4359	0.4375	0.4391	0.4407	0.4423	0.4440	0.4456	0.4472	0.4488	0.4504	55
56	.4520	.4537	.4553	.4570	.4586	.4603	.4620	.4636	.4653	.4669	56
57	.4686	.4703	.4720	.4738	.4755	.4772	.4789	.4806	.4824	.4841	57
58	.4858	.4876	.4893	.4911	.4929	.4947	.4964	.4982	.5000	.5017	58
59	.5035	.5053	.5072	.5090	.5108	.5127	.5145	.5163	.5181	.5200	59
60	0.5218	0.5237	0.5256	0.5275	0.5294	0.5313	0.5331	0.5350	0.5369	0.5388	60
61	.5407	.5426	.5446	.5465	.5485	.5504	.5523	.5543	.5562	.5582	61
62	.5601	.5621	.5641	.5661	.5681	.5702	.5722	.5742	.5762	.5782	62
63	.5802	.5823	.5843	.5864	.5885	.5906	.5926	.5947	.5968	.5988	63
64	.6009	.6030	.6052	.6073	.6094	.6116	.6137	.6158	.6179	.6201	64
65	0.6222	0.6244	0.6266	0.6288	0.6310	0.6332	0.6354	0.6376	0.6398	0.6420	65
66	.6442	.6465	.6487	.6510	.6533	.6556	.6578	.6601	.6624	.6646	66
67	.6669	.6692	.6716	.6739	.6763	.6786	.6809	.6833	.6856	.6880	67
68	.6903	.6927	.6951	.6975	.6999	.7024	.7048	.7072	.7096	.7120	68
69	.7144	.7169	.7194	.7218	.7243	.7268	.7293	.7318	.7342	.7367	69
70	0.7392	0.7418	0.7443	0.7469	0.7494	0.7520	0.7546	0.7571	0.7597	0.7622	70
71	.7648	.7674	.7701	.7727	.7754	.7780	.7806	.7833	.7859	.7886	71
72	.7912	.7939	.7966	.7993	.8020	.8048	.8075	.8102	.8129	.8156	72
73	.8183	.8211	.8239	.8267	.8295	.8323	.8350	.8378	.8406	.8434	73
74	.8462	.8491	.8520	.8548	.8577	.8606	.8635	.8664	.8692	.8721	74
75	0.8750	0.8780	0.8809	0.8839	0.8868	0.8898	0.8928	0.8957	0.8987	0.9016	75
76	.9046	.9077	.9107	.9138	.9168	.9199	.9230	.9260	.9291	.9321	76
77	.9352	.9383	.9415	.9446	.9478	.9509	.9540	.9572	.9603	.9635	77
78	.9666	.9698	.9731	.9763	.9795	.9828	.9860	.9892	.9924	.9957	78
79	.9989	1.002	1.006	1.009	1.012	1.016	1.019	1.022	1.025	1.029	79
80	1.032	1.036	1.039	1.042	1.046	1.049	1.053	1.056	1.060	1.063	80
81	1.066	1.070	1.073	1.077	1.080	1.084	1.088	1.091	1.095	1.098	81
82	1.102	1.105	1.109	1.112	1.116	1.120	1.123	1.127	1.131	1.134	82
83	1.138	1.142	1.145	1.149	1.153	1.156	1.160	1.164	1.168	1.171	83
84	1.175	1.179	1.183	1.186	1.190	1.194	1.198	1.202	1.206	1.209	84
85	1.213	1.217	1.221	1.225	1.229	1.233	1.237	1.241	1.245	1.249	85
86	1.253	1.257	1.261	1.265	1.269	1.273	1.277	1.281	1.285	1.289	86
87	1.293	1.297	1.301	1.306	1.310	1.314	1.318	1.322	1.326	1.331	87
88	1.335	1.339	1.343	1.348	1.352	1.356	1.360	1.365	1.369	1.373	88
89	1.378	1.382	1.386	1.391	1.395	1.400	1.404	1.408	1.413	1.417	89
90	1.422	1.426	1.431	1.435	1.440	1.444	1.449	1.453	1.458	1.462	90
91	1.467	1.471	1.476	1.481	1.485	1.490	1.495	1.499	1.504	1.508	91
92	1.513	1.518	1.523	1.527	1.532	1.537	1.542	1.546	1.551	1.556	92
93	1.561	1.566	1.571	1.575	1.580	1.585	1.590	1.595	1.600	1.605	93
94	1.610	1.615	1.620	1.625	1.630	1.635	1.640	1.645	1.650	1.655	94
95	1.660	1.665	1.670	1.676	1.681	1.686	1.691	1.696	1.701	1.707	95
96	1.712	1.717	1.722	1.728	1.733	1.738	1.744	1.749	1.754	1.759	96
97	1.765	1.770	1.776	1.781	1.787	1.792	1.797	1.803	1.808	1.814	97
98	1.819	1.825	1.830	1.836	1.842	1.847	1.853	1.858	1.864	1.870	98
99	1.875	1.881	1.887	1.892	1.898	1.904	1.910	1.915	1.921	1.927	99
100	1.933	1.938	1.944	1.950	1.956	1.962	1.968	1.974	1.980	1.986	100
101	1.992	1.998	2.004	2.010	2.016	2.022	2.028	2.034	2.040	2.046	101
102	2.052	2.058	2.064	2.070	2.077	2.083	2.089	2.095	2.101	2.108	102
103	2.114	2.120	2.127	2.133	2.139	2.146	2.152	2.158	2.165	2.171	103
104	2.178	2.184	2.191	2.197	2.204	2.210	2.217	2.223	2.230	2.236	104
105	2.243	2.250	2.256	2.263	2.270	2.276	2.283	2.290	2.297	2.303	105
106	2.310	2.317	2.324	3.331	2.337	2.344	2.351	2.358	2.365	2.372	106
107	2.379	2.386	2.393	2.400	2.407	2.414	2.421	2.428	2.435	2.442	107
108	2.449	2.456	2.464	2.471	2.478	2.485	2.492	2.500	2.507	2.514	108
109	2.521	2.529	2.536	2.544	2.551	2.558	2.566	2.573	2.581	2.588	109
110	2.596	2.603	2.611	2.618	2.626	2.634	2.641	2.649	2.656	2.664	110
111	2.672	2.679	2.687	2.695	2.703	2.710	2.718	2.726	2.734	2.742	111
112	2.749	2.757	2.765	2.773	2.781	2.789	2.797	2.805	2.813	2.821	112
113	2.829	2.837	2.846	2.854	2.862	2.870	2.878	2.887	2.895	2.903	113
114	2.911	2.919	2.928	2.936	2.945	2.953	2.961	2.970	2.978	2.986	114
115	2.995	3.003	3.012	3.021	3.029	3.038	3.046	3.055	3.063	3.072	115
116	3.081	3.089	3.098	3.107	3.116	3.125	3.133	3.142	3.151	3.160	116
117	3.169	3.178	3.187	3.196	3.205	3.214	3.223	3.232	3.241	3.250	117
118	3.259	3.268	3.277	3.287	3.296	3.305	3.314	3.324	3.333	3.342	118
119	3.351	3.361	3.370	3.380	3.389	3.399	3.408	3.417	3.427	3.436	119

Table I—Pressure of saturated water vapor (Cont.)

Temp.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Temp.
120	3.446	3.455	3.465	3.475	3.485	3.494	3.504	3.514	3.523	3.533	120
121	3.543	3.553	3.563	3.572	3.582	3.592	3.602	3.612	3.622	3.632	121
122	3.642	3.652	3.662	3.672	3.683	3.693	3.703	3.713	3.723	3.733	122
123	3.744	3.754	3.764	3.775	3.785	3.796	3.806	3.816	3.827	3.837	123
124	3.848	3.858	3.869	3.879	3.890	3.901	3.911	3.922	3.933	3.943	124
125	3.954	3.965	3.976	3.987	3.998	4.008	4.019	4.030	4.041	4.052	125
126	4.063	4.074	4.085	4.096	4.108	4.119	4.130	4.141	4.152	4.163	126
127	4.175	4.186	4.197	4.209	4.220	4.232	4.243	4.254	4.266	4.277	127
128	4.289	4.300	4.312	4.324	4.335	4.347	4.359	4.370	4.382	4.394	128
129	4.406	4.417	4.429	4.441	4.453	4.465	4.477	4.489	4.501	4.513	129
130	4.525	4.537	4.550	4.562	4.574	4.586	4.598	4.611	4.623	4.635	130
131	4.647	4.660	4.672	4.685	4.697	4.710	4.722	4.735	4.747	4.760	131
132	4.773	4.785	4.798	4.811	4.824	4.837	4.849	4.862	4.875	4.888	132
133	4.901	4.914	4.927	4.940	4.953	4.966	4.979	4.992	5.005	5.018	133
134	5.031	5.045	5.058	5.072	5.085	5.098	5.112	5.125	5.139	5.152	134
135	5.165	5.179	5.193	5.206	5.220	5.234	5.247	5.261	5.275	5.289	135
136	5.302	5.316	5.330	5.344	5.358	5.372	5.386	5.400	5.414	5.428	136
137	5.442	5.456	5.471	5.485	5.499	5.514	5.528	5.542	5.557	5.571	137
138	5.585	5.600	5.614	5.629	5.644	5.658	5.673	5.688	5.702	5.717	138
139	5.732	5.747	5.762	5.776	5.791	5.806	5.821	5.836	5.851	5.866	139
140	5.881	5.896	5.912	5.927	5.942	5.958	5.973	5.988	6.004	6.019	140
141	6.034	6.050	6.065	6.081	6.097	6.112	6.128	6.143	6.159	6.175	141
142	6.190	6.206	6.222	6.238	6.254	6.270	6.286	6.302	6.318	6.334	142
143	6.350	6.366	6.383	6.399	6.415	6.432	6.448	6.464	6.481	6.497	143
144	6.513	6.530	6.546	6.563	6.580	6.597	6.613	6.630	6.647	6.663	144
145	6.680	6.697	6.714	6.731	6.748	6.765	6.782	6.799	6.816	6.833	145
146	6.850	6.867	6.885	6.902	6.920	6.937	6.954	6.972	6.989	7.007	146
147	7.024	7.042	7.060	7.077	7.095	7.113	7.131	7.149	7.166	7.184	147
148	7.202	7.220	7.238	7.257	7.275	7.293	7.311	7.329	7.348	7.366	148
149	7.384	7.403	7.421	7.440	7.458	7.477	7.495	7.514	7.532	7.551	149
150	7.569	7.588	7.607	7.626	7.645	7.664	7.683	7.702	7.721	7.740	150
151	7.759	7.778	7.798	7.817	7.836	7.856	7.875	7.894	7.913	7.933	151
152	7.952	7.972	7.992	8.011	8.031	8.051	8.071	8.091	8.110	8.130	152
153	8.150	8.170	8.190	8.210	8.230	8.251	8.271	8.291	8.311	8.331	153
154	8.351	8.372	8.392	8.413	8.433	8.454	8.475	8.495	8.516	8.536	154
155	8.557	8.578	8.599	8.620	8.641	8.662	8.683	8.704	8.725	8.746	155
156	8.767	8.788	8.810	8.831	8.853	8.874	8.895	8.917	8.938	8.960	156
157	8.981	9.003	9.025	9.047	9.069	9.091	9.112	9.134	9.156	9.178	157
158	9.200	9.222	9.245	9.267	9.290	9.312	9.334	9.357	9.379	9.402	158
159	9.424	9.447	9.470	9.492	9.515	9.538	9.561	9.584	9.606	9.629	159
160	9.652	9.675	9.699	9.722	9.745	9.769	9.792	9.815	9.838	9.862	160
161	9.885	9.909	9.932	9.956	9.980	10.00	10.03	10.05	10.07	10.10	161
162	10.12	10.15	10.17	10.19	10.22	10.24	10.27	10.29	10.32	10.34	162
163	10.36	10.39	10.41	10.44	10.46	10.49	10.51	10.54	10.56	10.59	163
164	10.61	10.64	10.66	10.69	10.71	10.74	10.76	10.79	10.81	10.84	164
165	10.86	10.89	10.91	10.94	10.97	10.99	11.02	11.04	11.07	11.09	165
166	11.12	11.15	11.17	11.20	11.22	11.25	11.28	11.30	11.33	11.36	166
167	11.38	11.41	11.44	11.46	11.49	11.52	11.54	11.57	11.60	11.62	167
168	11.65	11.68	11.70	11.73	11.76	11.79	11.81	11.84	11.87	11.89	168
169	11.92	11.95	11.98	12.00	12.03	12.06	12.09	12.12	12.14	12.17	169
170	12.20	12.23	12.26	12.28	12.31	12.34	12.37	12.40	12.43	12.45	170
171	12.48	12.51	12.54	12.57	12.60	12.63	12.66	12.69	12.71	12.74	171
172	12.77	12.80	12.83	12.86	12.89	12.92	12.95	12.98	13.01	13.04	172
173	13.07	13.10	13.13	13.16	13.19	13.22	13.25	13.28	13.31	13.34	173
174	13.37	13.40	13.43	13.46	13.49	13.52	13.55	13.58	13.61	13.64	174
175	13.67	13.70	13.73	13.76	13.80	13.83	13.86	13.89	13.92	13.95	175
176	13.98	14.01	14.05	14.08	14.11	14.14	14.17	14.21	14.24	14.27	176
177	14.30	14.33	14.37	14.40	14.43	14.46	14.50	14.53	14.56	14.59	177
178	14.63	14.66	14.69	14.72	14.76	14.79	14.82	14.86	14.89	14.92	178
179	14.96	14.99	15.02	15.06	15.09	15.12	15.16	15.19	15.22	15.26	179
180	15.29	15.33	15.36	15.39	15.43	15.46	15.50	15.53	15.56	15.60	180
181	15.63	15.67	15.70	15.74	15.77	15.81	15.84	15.88	15.91	15.95	181
182	15.98	16.02	16.05	16.09	16.12	16.16	16.20	16.23	16.27	16.30	182
183	16.34	16.37	16.41	16.45	16.48	16.52	16.55	16.59	16.63	16.66	183
184	16.70	16.74	16.77	16.81	16.85	16.88	16.92	16.96	16.99	17.03	184
185	17.07	17.11	17.14	17.18	17.22	17.26	17.29	17.33	17.37	17.41	185
186	17.44	17.48	17.52	17.56	17.60	17.63	17.67	17.71	17.75	17.79	186
187	17.83	17.86	17.90	17.94	17.98	18.02	18.06	18.10	18.14	18.18	187
188	18.21	18.25	18.29	18.33	18.37	18.41	18.45	18.49	18.53	18.57	188
189	18.61	18.65	18.69	18.73	18.77	18.81	18.85	18.89	18.93	18.97	189
190	19.01	19.06	19.10	19.14	19.18	19.22	19.26	19.30	19.34	19.38	190
191	19.43	19.47	19.51	19.55	19.59	19.63	19.68	19.72	19.76	19.80	191
192	19.84	19.89	19.93	19.97	20.01	20.06	20.10	20.14	20.18	20.23	192
193	20.27	20.31	20.36	20.40	20.44	20.49	20.53	20.57	20.62	20.66	193
194	20.70	20.75	20.79	20.84	20.88	20.92	20.97	21.01	21.06	21.10	194
195	21.14	21.19	21.23	21.28	21.32	21.37	21.41	21.46	21.50	21.55	195
196	21.59	21.64	21.68	21.73	21.78	21.82	21.87	21.91	21.96	22.00	196
197	22.05	22.10	22.14	22.19	22.24	22.28	22.33	22.38	22.42	22.47	197
198	22.52	22.56	22.61	22.66	22.70	22.75	22.80	22.85	22.89	22.94	198
199	22.99	23.04	23.08	23.13	23.18	23.23	23.28	23.32	23.37	23.42	199
200	23.47	23.52	23.57	23.62	23.66	23.71	23.76	23.81	23.86	23.91	200
201	23.96	24.01	24.06	24.11	24.16	24.21	24.26	24.31	24.36	24.41	201
202	24.46	24.51	24.56	24.61	24.66	24.71	24.76	24.81	24.86	24.91	202
203	24.97	25.02	25.07	25.12	25.17	25.22	25.27	25.32	25.37	25.42	203
204	25.47	25.53	25.58	25.63	25.69	25.74	25.79	25.84	25.90	25.95	204
205	26.00	26.06	26.11	26.16	26.21	26.27	26.32	26.37	26.43	26.48	205
206	26.53	26.59	26.64	26.70	26.75	26.80	26.86	26.91	26.97	27.02	206
207	27.08	27.13	27.19	27.24	27.30	27.35	27.41	27.46	27.52	27.57	207
208	27.63	27.68	27.74	27.79	27.85	27.91	27.96	28.02	28.08	28.13	208
209	28.19	28.25	28.30	28.36	28.42	28.47	28.53	28.59	28.64	28.70	209
210	28.76	28.81	28.87	28.93	28.99	29.05	29.11	29.16	29.22	29.28	210
211	29.34	29.40	29.46	29.51	29.57	29.63	29.69	29.75	29.81	29.86	211
212	29.92										

The mean specific heat at constant pressure for the dry air is taken as 0.25 B.t.u. per lb. per deg. F.; the mean specific heat at constant pressure for water vapor is taken as 0.45 B.t.u. per lb. per deg. F.

Let L = the water flow, lb. per min.; G = the air flow, lb. per min, bone-dry air; T = water temperature, deg. F. (not deg. R.); t = dry-bulb temperature of the air, deg. F.; t_w = wet-bulb temperature of the air, deg. F.; H = humidity, lb. of water vapor per lb. of bone-dry air.

The subscript 1 refers to conditions of both water and air at the air inlet; the subscript 2 refers to conditions at the air outlet.

A heat balance is written using T_1 as the datum temperature:

$$\text{Input} = \text{Output} \tag{15}$$

$$\text{Input} = L_2 (T_2 - T_1)/\mathrm{G} + 0.24 (t_1 - T_1) + 0.45H_1 (t_1 - T_1) + H_1 r_{T1} \tag{16}$$

$$\text{Output} = L_1 (T_1 - T_1)/\mathrm{G} + 0.24 (t_2 - T_1) + 0.45H_2 (t_2 - T_1) + H_2 r_{T1} \tag{17}$$

The respective values of input and output of Eq. (16) and (17) are substituted in Eq. (15) as follows:

The input is equal to the output; Eq. (16) equals Eq. (17). The algebraic equalities clear to

$$L_2 (T_2 - T_1)/\mathrm{G} = 0.24 (t_2 - t_1) + 0.45 (H_2t_2 - H_2T_1 - H_1t_1 + H_1T_1) + r_{T1} (H_2 - H_1) \tag{18}$$

From Eq. (14)

$$r_{T1} = 1{,}093 - 0.55T_1 \tag{19}$$

Therefore,

$$r_{T1} (H_2 - H_1) = 1{,}093H_2 - 0.55H_2T_1 - 1{,}093H_1 + 0.55H_1T_1 \tag{20}$$

Eq. (20) is substituted in Eq. (18), and the clearing yields

$$L_2 (T_2 - T_1)/G = (0.24t_2 + 0.45H_2t_2 + 1{,}093H_2) - (0.24t_1 + 0.45H_1t_1 + 1{,}093H_1) - T_1 (H_2 - H_1) \tag{21}$$

From Eq. (13) and Eq. (14)

$$\Sigma_2 = 0.24t_2 + 1{,}093H_2 - 0.55H_2t_{w2} + 0.45H_2t_2 - 0.45H_2t_{w2} \tag{22}$$

or

$$\Sigma_2 + H_2t_{w2} = 0.24t_2 + 0.45H_2t_2 + 1{,}093H_2 \tag{23}$$

Likewise,

Terminal 2, water inlet and air outlet
Conditions: $T_2, t_2, t_{w_2}, H_2, \Sigma_2, \Sigma_2', h_2$

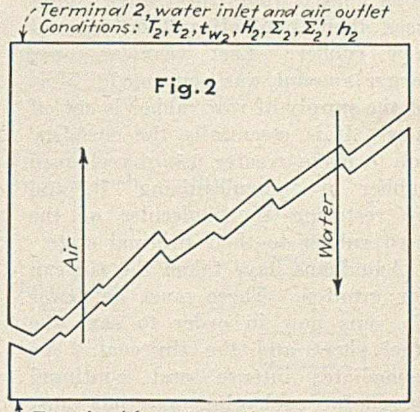


Fig.2

Terminal 1, water outlet and air inlet
Conditions: $T_1, t_1, t_{w_1}, H_1, \Sigma_1, h_1$

$$\Sigma_1 + H_1 t_{w1} = 0.24 t_1 + 0.45 H_1 t_1 + 1{,}093 H_1 \qquad (24)$$

Expressions in Eq. (21) which are identical with those in (23) and (24) are replaced by their equalities as given in Eq. (23) and (24) respectively. Thus,

$$L_2\,(T_2 - T_1)/G = \Sigma_2 + H_2 t_{w2} - \Sigma_1 - H_1 t_{w1} - H_2 T_1 + H_1 T_1 \quad (25)$$

Finally,

$$\Sigma_2 = L_2\,(T_2 - T_1)/G + \Sigma_1 - H_2\,(t_{w2} - T_1) - H_1\,(T_1 - t_{w1}) \quad (26)$$

In Eq. (26), the expression

$$-H_2(t_{w2} - T_1) - H_1(T_1 - t_{w1})$$

is small numerically compared to the rest of the equation to the right of the sign of equality. Therefore, for purposes of practical cooling tower design,

$$\Sigma_2 \leqq (L_2/G)\,(T_2 - T_1) + \Sigma_1 \qquad (27)$$

The approximate outgoing wet-bulb may be determined by the use of Eq. (27).

BIBLIOGRAPHY

(1) "Water Cooling Tower Fundamentals," by Edward Simons, *Chem. Met Eng.*, Feb. 1939, p. 83.

(2) "Principles of Chemical Engineering," by Walker, Lewis, McAdams, and Gilliland, McGraw-Hill Book Co., Inc., 3rd Edition, 1937: (2a) p. 5; (2b) p. 4; (2c) p. 582; (2d) p. 591; (2e) p. 581.

(3) "Heating, Ventilating, Air Conditioning Guide," 1940 Vol. 18, published by A. S. H. V. E.; (3a) p. 2; (3b) p. 23; (3c) p. 23.

(4) "New Tables of the Psychrometric Properties of Air-Vapor Mixtures," by William Goodman, *Heating, Piping and Air Conditioning*, 10, Jan. 1938, pp. 1–2.

(5) "Thermodynamic Properties of Steam," by Keenan and Keyes, John Wiley and Sons, Inc.

Wartime Problems to be Solved

Some of the problems of chemical warfare that must be solved by this country were outlined by Col. M. E. Barker speaking before the student body of the College of William and Mary in February. This article is a brief abstract of a portion of the talk.

THERE are numerous problems of a chemical or engineering nature the solution of which will be desperately needed within the next year to aid the nation's war efforts. Some of these problems are being investigated by the National Defense Research Committee, the Chemical Warfare Service and other organizations. Never before in the nation's history has such a vast coordinated research and development program been undertaken.

Progress in chemistry, in physics, in industry, in methods and weapons of warfare, come from those who dare to dream logical dreams as well as by the unremitting toil of the technicians who gather the facts which the engineer can use in reducing the invention to practical utility.

Let us consider a few examples of specific jobs ahead of us and point out some of the tasks confronting the chemist today, keeping in mind all the time that the chemist is just one player on our ball team.

In normal years the United States uses about one-half million tons of new rubber. Last year an even larger amount was consumed. Most of the supply of raw rubber is cut-off now. It is essentially the chemists' job to make greater use of reclaimed rubber by "unvulcanizing" it, and by restoring the molecules of the used rubber to their original state.

Americans have taken the tin can for granted. There must be fewer tin cans now in order to save the steel sheet and the tin coat. An immediate, intense and continual search for packaging materials must be made from plentiful domestic materials. Why not make such containers from cotton and corn cobs? It can be done. The cotton could be formed into sheets and these bonded with plastics from the corn cob, or from the protein residue left from the corn during its processing into sirup.

Quinine. What a challenge to the organic chemists! Are they going to sit placidly by and watch our own malaria-bearing mosquitoes wage a terrible bacteriological warfare for the Japs? We need several million ounces yearly. Most of this comes from the plantations of the East Indies.

Who knows what may be accomplished by the proper heat, sound, X-ray, or physical treatment of iron alloyed with such cheap and plentiful domestic raw materials as silicon, carbon and titanium. We must have huge quantities of corrosion-resistant metals for chemical plant equipment. Perhaps the gold and silver in our vaults might well be put to work as the linings of reaction kettles and stills. What a joy a gold-lined reactor would be to the man who prays each day that his thousand-gallon precious glass-lined reactor will not crack that day. And why not? The gold would not be used up. It would be doing its bit for National Defense. Therefore, let's take out a few tons of gold and a few hundred tons of silver from the vaults and use them to overcome some of our serious corrosion problems which are bound to get worse due to the growing scarcity of Monel and stainless steel. Then, too, other solutions to the corrosion problem might be found.

There are not enough sheep to furnish all the wool needed. If cotton could be converted into a fiber having the desirable effects of wool, what a boon it would be to the cotton farmer, the cotton mill owner, and the worker. Here is a problem that every Southern chemist should take to heart. Who knowns that a process cannot be worked out that will make cotton the King of all fibers? We know now that it can be made water resistant and almost fireproof.

A good start has been made in solving the problem of vitamins. At least it is known that vitamins are useful and can be produced. A plentiful supply is essential for the national health and well-being. Improvements are in order.

A few years ago synthetic toluol was a dream. Now, thousands of gallons are made every day. The job has just started, for without toluol there will be no TNT. There is plenty of room for progress.

Five years ago butadiene was a rare chemical. Next year thousands of tons will be made. That will be a fair beginning, but a beginning only. Here is a great field for the organic chemist and the chemical engineer. Synthetic rubber is here to stay. For this we must have butadiene in great quantity and low price. The same applies to styrene and to acrylo nitrile.

There is comparatively little bauxite in the United States. Other supplies available here are not inexhaustible, but there is plenty of aluminum in clay which is scattered over this entire country. The aluminum is there. We need it. It can be extracted and a commercial process will be a real contribution to National Defense and to America. We need aluminum for airplanes, for making thermit fillings for incendiary bombs, and for many other uses, both military and civil.

A lot of better things are required such as a good ten-cent dust mask; waterproof, air permeable unwettable fabrics of many kinds for tents, gloves, clothes; fire-resistant cloth for use of guards in munition works, workmen in powder and incendiary plants, and soldiers in tanks and airplanes; better smoke filters for air purifying devices; new synthetic fibers having a diameter of a micron or less; and others.

Pidgeon Ferro-Silicon Process For Magnesium

FRANK A. BREYER *Singmaster and Breyer, New York, N. Y.*

Chem. & Met. INTERPRETATION

The process for the production of magnesium developed by L. M. Pidgeon of the Canadian National Research Laboratories is of current interest in view of the fact that several plants in which this process will be used are now under construction in the United States. They will, however, use natural gas instead of electricity for fuel.—*Editors.*

THE PIDGEON PROCESS for the production of metallic magnesium consists essentially in reacting burnt dolomite lime with crushed ferro-silicon in an externally heated, sealed, metallic retort, which is kept under vacuum by means of vacuum pumps. The metal, 99.98 per cent pure, is recovered in a solid, dense crystalline mass, which is subsequently melted down under flux and poured into ingots. The crystalline masses may also be added direct to molten aluminum for the production of aluminum-magnesium alloys.

The process is similar to ordinary commercial zinc practice. It differs only in the fact that the retorts for distilling magnesium are of metal instead of fire clay, and the distillation takes place under vacuum in the case of magnesium, whereas zinc is distilled at atmospheric pressure.

The retorts are approximately the same size as used for zinc, the operating temperatures are the same, and the quantity of magnesium recovered per retort per day (40-60 lb.) is the same as recovered from a zinc retort. When the recoverable zinc in zinc ore costs the zinc distiller 2.5c. per lb., metal can be produced by the retort process and sold at a profit of 6c. per lb.

The fact that the retorts are small and the amount of magnesium collected and removed at one time is limited to 15-20 lb., and the fact that the charging and discharging of the retorts is carried out after the breaking of the vacuum and the admission of air to the retort establishing ordinary pressures means that the fire and explosion hazard is reduced to a minimum.

The size of a plant is dependent upon the number of retorts operated. A bank of retorts is set in a heating chamber and constitutes a furnace. The larger the furnaces and the more of them, the easier it is to establish the maneuvers necessary to hand charge and hand discharge the retorts and remove the residues economically. Handling facilities for placing and replacing the retorts are also simplified and cheaper with the large scale operations.

The principal items of operating cost are:

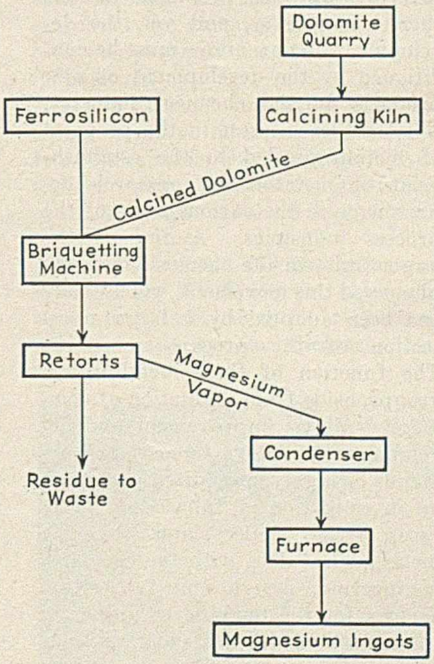
1—Ferro-silicon
2—Metallic retort maintenance
3—Heat
4—Maintenance of vacuum equipment
5—Labor
6—Burnt dolomite
7—Maintenance of electric heaters
8—Power for crushing, grinding, briquetting

Due to the ease of control and uniformity with which electric power can be converted into heat, electricity is the ideal method of heating the metallic retorts of the Pidgeon process. Canada has as cheap or cheaper electric power than any other place in the world, hence it should have the most favorable costs in these two items. Similarly, the alloy metal retorts, which are high in nickel (35 percent) and have electric power as a considerable item in their cost of production, can be produced as cheaply in Canada as anywhere else. Dolomite limestone is abundant and can be quarried cheaply in the vicinity of low cost electric power. Technically trained engineers for the supervision of the vacuum aspects of the operation are available in Canada and any ordinary furnace labor can within a reasonable time be developed into skilled operatives for the charging and discharging operations.

First estimates of capital cost for a 10 ton per day plant indicate $1.25 to $1.50 capital outlay for each dollar's worth of sales per year. This is figuring the magnesium as selling at 25c. per lb. under present conditions. This is only slightly above the capital costs per annual sales dollar of product of most chemical and metallurgical operations and is very much below the figures that may be calculated from the published data for any other magnesium process.

The indicated low capital and operating costs are due primarily to the fact that the flowsheet for the Pidgeon process is extremely simple. The quarrying of limestone and the burning of lime is an old art and very cheap. There is no elaborate purification of the raw materials. Ferro-silicon is bought on the open market and crushed fine in standard crushing equipment. Solid metal is made direct from the briquetted burnt dolomite and ferro-silicon mixture without any intermediate stages. Finally, there are no elaborate services to be maintained for the operation. Power for crushing, grinding, briquetting, heat, vacuum, and cooling water are all that is necessary, so that auxiliary expenses are minimized.

A Pidgeon process plant could be built and put into operation in a much shorter time than any other magnesium process.



Stainless Steel Developments in Process Industries

GEORGE A. SANDS *Metallurgical Engineer, Electro Metallurgical Co., New York, N. Y.*

Chem. & Met. INTERPRETATION

Chemical engineers who are interested in materials of construction will find much valuable information in this article on chromium steels, including a description of the standard nitric acid test which is widely used throughout the United States as a means of measuring quality of stainless steel. A later article will discuss the chromium-nickel steels.—*Editors.*

THIS DISCUSSION considers the subject of stainless steel from the viewpoint of a large consumer, the process industries. It is well known that the advent of stainless steel encouraged the chemist and chemical engineer to greater endeavor which has resulted in many new developments in the process industries. On the other hand, we know that continuous demands made by the chemical engineer for better materials for the construction of equipment to resist corrosion, erosion and oxidation over a wide range of temperatures and pressures are in a large measure responsible for the progress made in metallurgy. It is obvious that the steel industry cannot justify research covering all the problems of the chemical industry, and yet, the development of new alloys must be conditioned by the development of new products in the chemical industry. This mutual interest in the progress of metallurgy led to the establishment of metallurgical research departments in the various units of the process industries. A few of the larger units in the chemical industry pioneered this movement, which today has been adopted by a large cross-section of the process industries. The function of these metallurgical groups, aside from evaluation of commercial alloys, improvement and development of alloys to meet the demands of highly specialized processes, an investigation of fabrication processes, is to collect and correlate metallurgical data with the chemical, engineering, design and fabrication factors for the purpose of aiding in the selection of the most suitable materials for process equipment. In the selection of material for a specific process, the following factors must be considered:

1. Time element
2. First cost vs. equipment obsolescence
3. Service life
4. Effect of material on product (contamination and catalytic effects)
5. Design and fabrication limits

These factors are well known to the chemical engineer. However, the metallurgist rarely appreciates that in the development of a new product the time element is probably the most important factor in its financial success. Competing companies conducting research in the same field may develop essentially the same product by somewhat different processes at approximately the same time. Speed in getting the plant into production will establish a market precedence for the new product or the value of the increased production often will offset the initial cost of the equipment. Then again, the pace of research development is so rapid that within a relatively short period, a new and better method for manufacturing the same product may be discovered, making all or most of the original process equipment obsolete. Therefore, first cost must be weighed against equipment obsolescence. It would be foolish to select a high cost material which tests indicate would last 100 years when a lower cost material is suitable for the life of the process.

During the experimental stage of a new development, the research chemist should cooperate with the metallurgist concerning materials for the future plant. This enables the metallurgist to make corrosion tests on the most promising alloys in the process reactions while they are still being conducted in glass apparatus. These or similar tests duplicating process conditions determine the relative corrosion resistance and the catalytic effect of the metal on the product. It is sometimes necessary to reject an alloy because some alloying element has an adverse effect on the yield of the product. Based on results of these preliminary tests, the pilot plant is constructed and during the same period in which the engineer is stepping up the process from the laboratory to the semi-plant operations, the metallurgist and the design engineer are testing the alloys as fabricated equipment or as additional test samples under actual service conditions. Because of the many variables encountered in process reactions, the only safe method for selecting an alloy is to test the material under exact process conditions.

Fabrication and design limitations must be kept constantly in mind in considering test materials. An alloy steel may have all the necessary qualifications for a specific application, and yet these qualifications may be destroyed by improper fabrication and design of equipment. It is also useless to make a long series of tests and find that the favorite alloy cannot be produced or fabricated in the form necessary for the application.

With this in view, it is planned to cite some of the problems in the process industries and trace developments in the field of metallurgy which have contributed in overcoming the difficulties that have arisen in the use of stainless steel for process equipment.

Stainless steel covers over 50 compositions that may be classified in accordance with their structural characteristics into three broad groups as martensitic, ferritic and austenitic steels. With the exception of a brief description of the martensitic steels, this article will be confined to the group known as ferritic steels, which are used very extensively in the fabrication of process equipment. Let us first review the basic alloys in these three groups, noting their outstanding structural, chemical and physical characteristics, which are briefly designated in the accompanying table.

Martensitic Steels

Martensitic steels can be hardened by heat treatment to give a wide variety of physical properties. The stainless steels covered in this group are those containing from 12 to 14 percent chromium, 0.15 percent max. carbon, and the 12 to 18 percent chromium grade containing 0.20 to 1.00 percent carbon. The low-carbon grade, commonly called turbine steel, is generally used for engineering purposes where its superior physical properties may be used to advantage. This grade is also used extensively as a clad veneer or lining for large vessels and columns in the oil industry to resist moderate corrosion conditions. The high-carbon grades are the well-known cutlery steels, which were discovered by Harry Brearley in England, in 1912. It has been said that approximately 50 tons of this material was produced in England in 1914, and the first commercial heat was made in the United States the next year.

Ferritic or Straight Chromium Steels

The ferritic chromium steels are those containing chromium from 15 to 30 percent with low carbon content, maximum 0.15 percent. These steels show no significant transformation on quenching from a high temperature, and hence remain essentially ferritic at all temperatures. Actually, the steels of this group with less than 20 percent chromium contain a slight amount of high-temperature austenite and therefore harden slightly on cooling rapidly from a high temperature.

Although the use of martensitic steels developed rapidly after their introduction in the United States, it was not until the development of a new process for the manufacture of nitric acid that the straight chromium steels became commercial. During the first World War, nitric acid was made by reacting sodium nitrate with sulphuric acid. Steel, lead, cast iron, Duriron, brick and glass were the commercial materials available for handling this process. These materials permitted the chemical industry to meet the production demands of the time, but they were unsatisfactory from the standpoint of maintenance due to either lack of corrosion resistance or poor mechanical properties. For a number of years prior to this period, chemists were investigating a process for making nitric acid synthetically by the direct oxidation of ammonia with the oxygen in the air. This process involved the handling of corrosive liquids and gases at high temperatures and pressures. Therefore, the major problem was one of construction materials and one which remained unsolved until the advent of stainless steel. The 15 to 18 percent chromium steels were found suitable, and hence, the first synthetic nitric acid plant was built by the duPont company at Gibbstown, N. J., in 1926. In a relatively short period of time, the old method for manufacturing nitric acid became obsolete, and as a result, ammonia oxidation plants similar to the duPont plant, requiring huge tonnages of 15 to 18 percent chromium iron, were built all over the world.

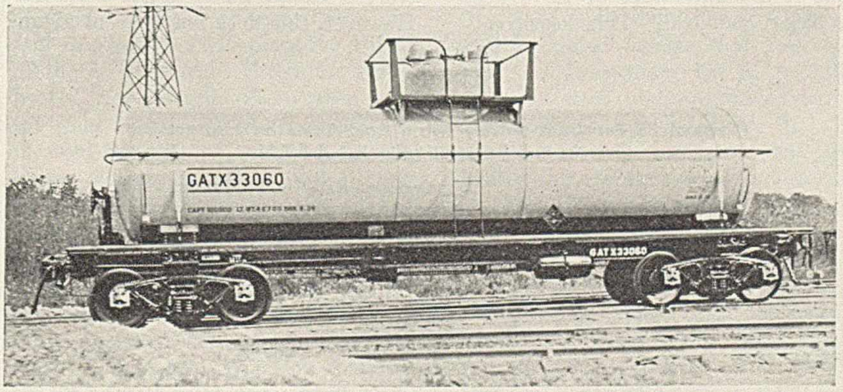
Classification and Properties—Stainless Steels

	Martensitic		Ferritic		Austenitic		
	% Cr	% C	% Cr	% C	% Cr	% Ni	% C
	(4- 6	.15 max.)	15–16	.10 max.	18	8	.20 max.
	(8–10	.15 max.)	16–18	.12 max.	25	12	.20 max.
	12–14	.15	20–28	.25 max.	25	20	.20 max.
	12–18	.20–1.00					
Hardenable	Yes		No		No		
Magnetic	Yes		Yes		No		
Toughness	High		Low		Very High		
Oxidation	1,200–1,400 deg.F.		1,400–2,000 deg.F.		1,400–2,100 deg.F.		
Abrasion	Very good		Good		Good		
Corrosion Intergranular	No		No		Yes		
Effective additions	Cb-Ti-Mo-Ni-Se-Al		Cb-Ti-Mo-N-Ni-Mn-Se		Cb-Ti-Mo-Mn-Cu-Si-N-S-Se		

Equipment in this plant was of riveted construction. The size of the structures compare favorably with the largest tanks and columns manufactured today. The assembled absorption column, which contained a series of trays, bubble caps, down pipes, etc., was approximately 60 ft. high, about 5 ft. in diameter, with a wall thickness of approximately ½ in.

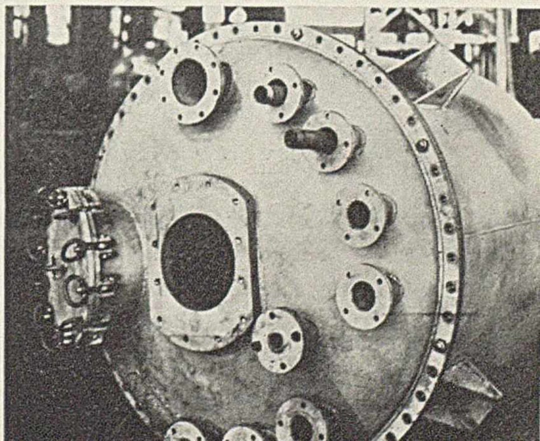
In order to produce this steel and assemble equipment in these quantities and in such large pieces at this stage in their development required the utmost cooperation between steel producers, fabricators and consumer. Although this period precedes the establishment of metallurgical research in the chemical industry, the idea was probably born in this initial installation.

The next most important step in the fabrication of equipment made from these steels was the lowering of the chromium content slightly in order to improve shock resistance.



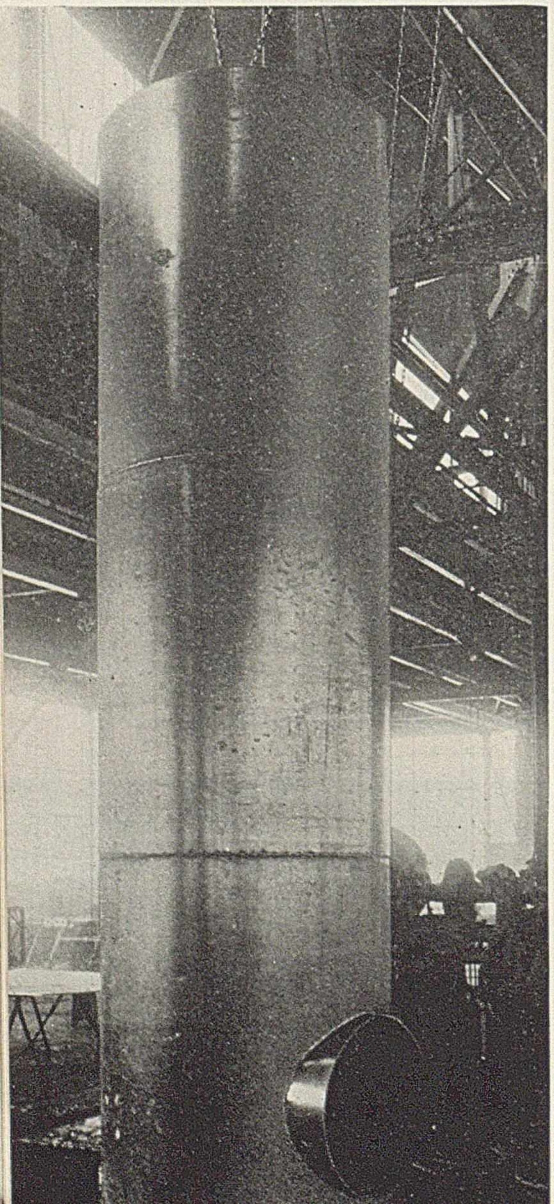
An all-welded tank car used for transporting strong nitric acid. The car is made of 15-16 percent chromium steel, which is considered best for handling nitric

This steam jacketed still has been constructed from 15-16 percent chromium steel. It will be used for reclaiming nitrocellulose for lacquer



This resulted in the development of the 15-16 percent chromium grade containing 0.10 percent maximum carbon, which is in use today. It was found after a series of corrosion and physical tests that this was the range of chromium content which would give the optimum combination of chemical and physical characteristics. All other elements being equal, the corrosion resistance of the straight chromium steels to boiling nitric acid or other strong oxidizing media is increased as the chromium is increased. Therefore, the adoption of a lower chromium content for the manufacture of nitric acid equipment meant sacrificing some corrosion resistance to obtain better shock resistance. Holding the chromium within this narrow range also contributed to the early development of welding and fabrication of pressure vessels of the straight chromium steels.

Absorption tower fabricated from 28 percent chromium steel. This tower will be used for reclaiming dilute nitric acid from waste NO_2 gases



Welding

The commercial welding of the straight high chromium steels began in 1928 but little progress was made until about 1931 because of the inability of the fabricator to produce corrosion-resistant welds. However, during this three-year period, or shortly afterward, this problem was solved by the application of special fabrication precautions and improved welding technique. Successful welding was accomplished by the electric arc process using a rod of such a composition that the deposited metal was essentially the same as the base metal. The chromium and carbon were adjusted in the weld rod to compensate for chromium lost by oxidation and the carbon picked up during welding. The rod required a special carbon-free coating which blanketed the molten metal with a slag containing deoxidizing and fluxing agents. A factor of prime importance was the adoption of small diameter rods which resulted in less heat input and increased the number of weld layer beads necessary to fill a given welding groove. The lower heat input inhibited grain growth and the multi-layer construction afforded some grain refinement of the underlying beads.

During fabrication, the work was preheated to a temperature of approximately 300 deg. F. to increase its ductility. In some cases, the welds were peened immediately following welding while the weld was still hot to refine the grain structure. When necessary, the equipment was given intermediate anneals during welding or forming operations, but in all cases it had to be followed by a final heat-treatment. The final heat-treatment consisted of holding equipment for a period of four hours per inch of thickness at a temperature between 1,400 and 1,450 deg. F. and cooling slowly (100 deg. per hr.) in the furnace to a temperature of 1,100 deg. F. before removal. This heat-treatment, which relieved stresses, eliminated the detrimental effects of cold working, and restored the maximum corrosion resistance of the plate, weld, and area adjacent to the weld, was found to be mandatory for fabricated straight chromium iron equipment to be used for corrosive service. Welded specimens, cut from 15-16 percent chromium-iron equipment welded in this manner, were bent flat through 180 deg. without cracking and the weld metal had a Charpy impact value between 10 and 25 ft. lb.

Gradually, welded construction began to displace riveted construction so that by 1936 nearly all straight chromium steel equipment was fabricated by welding. Several nitric acid plants of all-welded construction are being fabricated today of 15 to 16 percent chromium iron as a part of the war program to expand the production of ammunition. Also, all-welded tank cars are being constructed of this material to transport nitric acid for our munition plants manufacturing TNT and smokeless powder.

The fabrication of the higher chromium steels (20-30 percent chromium) closely parallels that of the 15-18 percent chromium steels in all fields except welding of pressure vessels or equipment requiring high resistance to shock at relatively low temperatures. The shock resistance of welds made in vessels containing over 18 percent chromium is very low as measured by standard impact methods. However, in spite of this deficiency, considerable process equipment welded with 25 percent chromium rods, or 25 percent chromium, 12 percent nickel rods are in use today. The austenitic 25-12 chromium-nickel rods are often used in welding 20-30 percent chromium steel for the purpose of maintaining tough weld deposits where corrosion due to electrolysis of the metal is not a factor. However, this does not prevent grain

Typical 65 Per Cent Boiling Nitric Acid Tests on Martensitic, Ferritic and Austenitic Steels—A.S.T.M.

	Corrosion Rate* In. Penetration Per Mo.		
Laboratory	18% Cr. 8% Ni	17% Cr	13% Cr
1	.00096	.00225	.00917
2	.00089	.00342	.00839
3	.00102	.00245	.00884
4	.00095	.00232	.00915
5	.00101	.00250	.00989
Total average	.00096	.00258	.00908

Cr	Ni	C	Heat Treatment
17.5	9.24	.09	Water quenched from 2,000 deg. F.
17.3	.09	.09	Annealed 1,600 deg. F. Furnace cooled.
13.1	....	.12	Annealed 1,300 deg. F. Furnace cooled.

---

* Each Rate = Average 8 specimens.

growth in the area adjacent to the weld, which area has slightly inferior physical properties and, because of stresses set up in welding, will have lower corrosion resistance. It is preferred to use filler rod of the same composition as the deposit metal and to heat treat the equipment in order to relieve stresses and retain maximum corrosion resistance, by holding for several hours at a temperature of 1,600 deg. F. followed by rapid cooling in air.

It should be made clear that the lack of toughness ascribed to welds of 20-30 percent chromium steels is a condition that exists only at temperatures below 500 deg. F. These materials are highly ductile at higher temperatures, which makes welded construction ideal for high-temperature applications.

Research is being conducted to improve further the ductility of the weld deposits of these steels at atmospheric temperatures. The low-ductility values obtained in weld deposits of 28 percent chromium steel is due to a large columnar grain structure which cannot be refined by heat-treatment. These steels are subject to rapid grain growth when exposed to processing or welding temperatures. The only method for reducing grain size of these steels is cold or hot working which is illustrated by the greatly increased toughness of rolled sheets or drawn tubes. Grain growth can be inhibited by the presence of nitrogen in the ratio of 130 to 180 parts chromium to 1 part of nitrogen. This practice has been used by the steel industry for some time to increase the yield from high-chromium ingots as well as increase the toughness of the wrought steels.

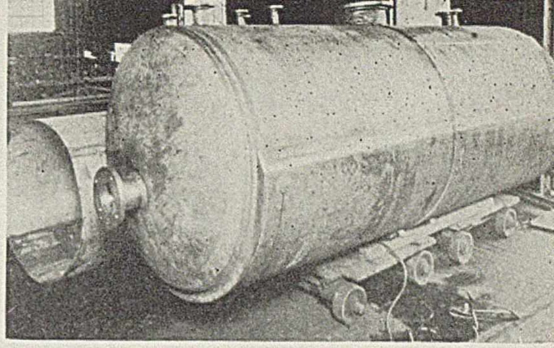
Nitrogen in Weld Rod

Several experiments have shown that the addition of nitrogen to weld rod greatly improves the toughness of weld deposits. Investigations are now in progress to increase the utility of the 18-20 percent chromium steels by the introduction of nitrogen into the weld metal. Improved toughness in weld deposits of the steels in the higher chromium range will permit the process industry to take advantage of the increased corrosion resistance, particularly in those processes involving high pressure. Preliminary data from at least three of the concerns cooperating in this study lead to the prediction that the use of nitrogen and a special heat-treatment will become commercial practice in future welding of these steels. Results show that nitrogen reduces the grain size of weld deposit metal similarly to the reduction in grain size illustrated for high-chromium ingots, and that the toughness is increased to give Charpy impact values between 20-25 ft.-lb.

Development of the Nitric Acid Test For Stainless Steels

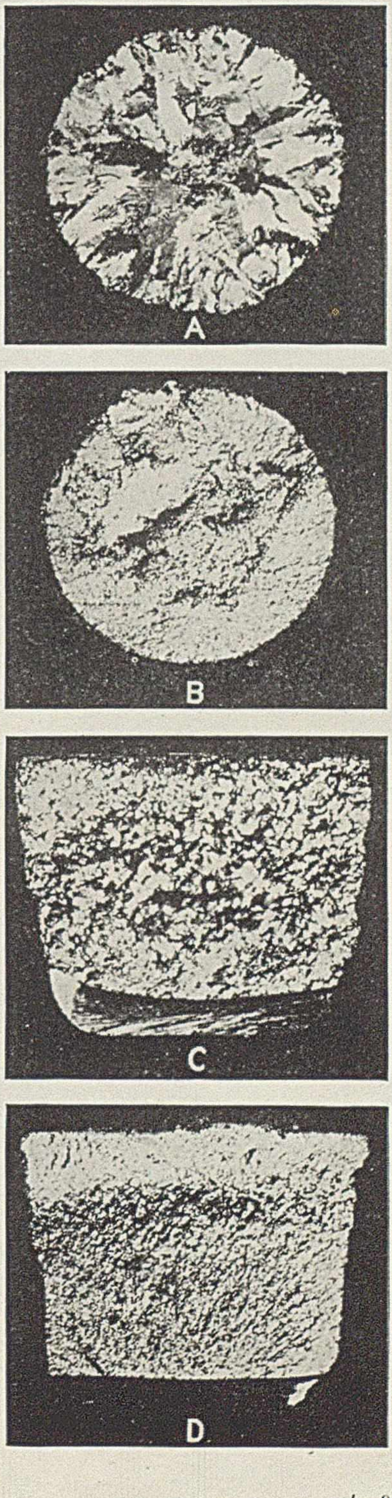
Before leaving the straight chromium steels, it is advisable to discuss briefly the standard 65 percent boiling nitric acid test which is widely used throughout the United States as a means of measuring the quality of stainless steels. This test is an outgrowth of the early laboratory investigation for a suitable material for equipment handling nitric acid. The investigators were amazed at the accurate results obtained and the ease of reproducing corrosion data when testing stainless steels in strong nitric acid. As a result of further research evaluating all factors involved, such as concentration and volume of acid, size of specimen, surface condition, time exposure, etc., the standard nitric acid test that is known today was developed. The test consists of determining the loss in weight on a prepared specimen of stainless steel for each of five successive 48-hr. periods in boiling 65 percent nitric acid. The loss in weight is converted by a factor to corrosion rate in inches penetration per month. A collaborative testing program sponsored by Sub-Committee A-10 of the A.S.T.M. and the laboratories of 16 companies investigated this test in 1932 and found it to be satisfactory.

The use of this test as a tool for determining the quality of stainless steel has been adopted by most of the research laboratories in the steel industry as well as the process industries. This test is only a measure of quality of stainless steels, and nitric acid results obtained have no bearing upon the resistance of a given stainless steel to various corrosive media. It was stated earlier that this can only be determined by testing the stainless steel under actual operating conditions. However, if the nitric acid test indicates that the quality of stainless steel is inferior to that of the sample tested under exact process conditions, there is no assurance that this inferior steel will be suitable for the process. This test has been of value in investigating plant equipment failures. Many fabricators have testified that the test has contributed more than any other factor to the development of a good quality stainless steel weld metal.



All-welded 18 percent chromium steel pressure vessel for benzoate of soda

Nitrogen in straight chromium steels reduces grain size and increases toughness. A and C contain low nitrogen while B and D contain high nitrogen

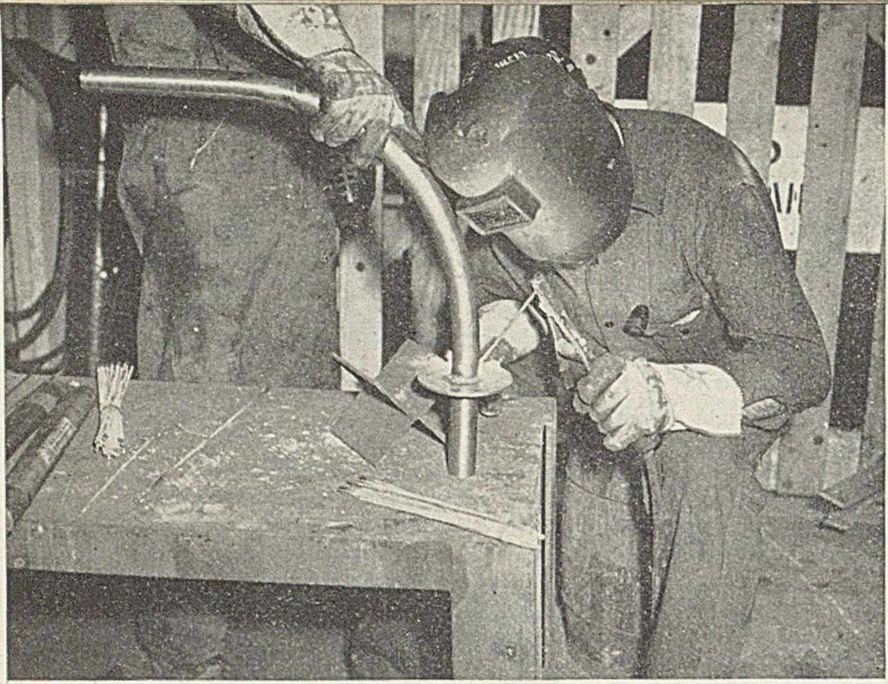


Arc Welding

CARL A. CRANE

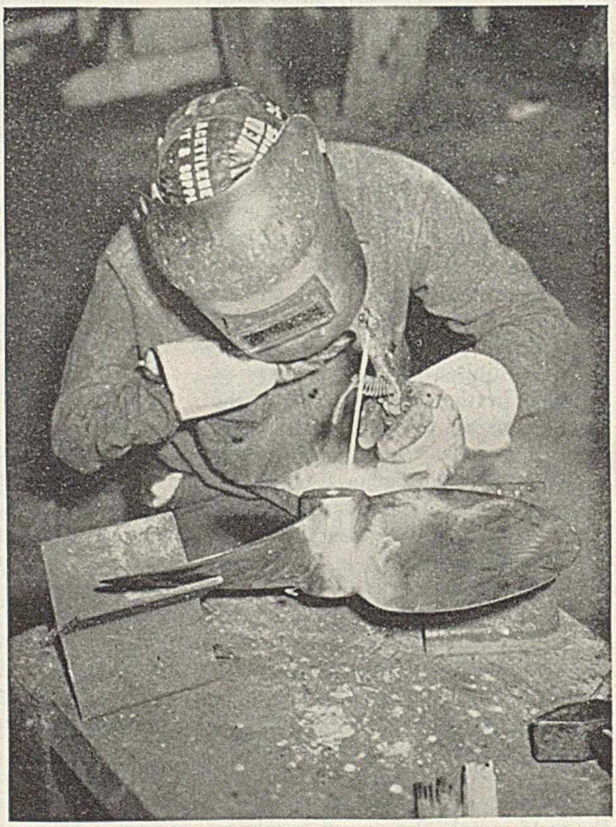
Like many other plants throughout the country, the Amino Products Co., has been faced with the necessity of keeping maintenance costs down to a minimum. This is a feat which, without arc welding, would have become increasingly difficult with the rise in cost of materials due to the defense program and the severe priorities on metals such as stainless steel, bronze, Monel metal and nickel.

Arc welding is used almost continuously by our plant for general maintenance work. It has been our

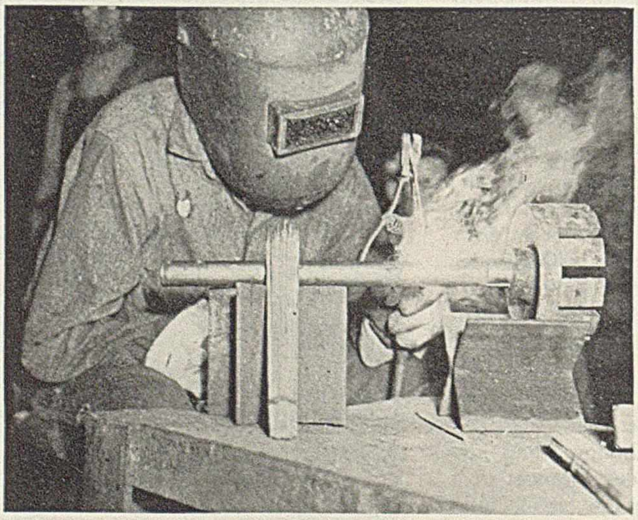


Using a corrosion-resistant electrode in welding a flange to a stainless steel evaporator vent pipe. Such electrodes give welds with corrosion-resistance equal to or greater than the parent metal

Arc welding fixed the pin holes in the fitting for this stainless steel feed line for a centrifugal in ten minutes at a cost of about $1. Replacement would have cost $18



Pitted portions of this propeller were built up by use of electrodes for arc welding bronze, brass and copper. Welding costs were $7 as compared to a replacement cost of $27



This stainless steel shaft, worn down about ¼-in. from contact with the packing, was built up by welding and then machined to proper dimensions. Welding took 30 minutes and cost about $3 as against $40 for replacement

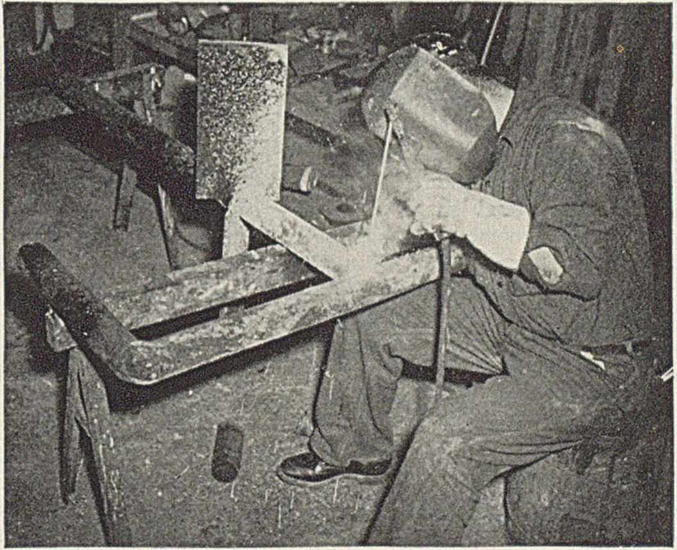
Cuts Maintenance Costs

Superintendent, Amino Products Co., Rossford, Ohio

experience that large savings in both time and money can be made by this all-purpose repair process. Arc welding can be used for any type of metal, whether it be ordinary rolled steel, sheet metal, stainless steel or many others. On these pages are illustrated a few typical examples of how this welding procedure has been applied in the plant of the Amino Products Co. Experienced maintenance men can easily get ideas for applying arc welding to their own particular maintenance problems and thus conserve both materials and man-power.

Monel metal responds readily to arc welding. The Monel cutter bar for a centrifugal unloader shown here was built up by welding at a saving of about $146 over replacement

This 5-minute arc welding job saved $42.50. The pitted pump housing would have cost $44 for replacement. "Aerisweld" electrodes were used



This rotor agitator was fabricated from 2½-in. steel pipe and ⅜-in. plate for the paddle. It was built in the shop of the Amino Products Co., which is equipped with a 150-amp. arc welder

This steam manifold was arc welded from extra heavy 4-in. pipe and a 3-in. outlet. This and all other photographs on these pages were taken and supplied through the courtesy of the Lincoln Electric Co., Cleveland, Ohio

Varnish Cooking With Radiant Burners

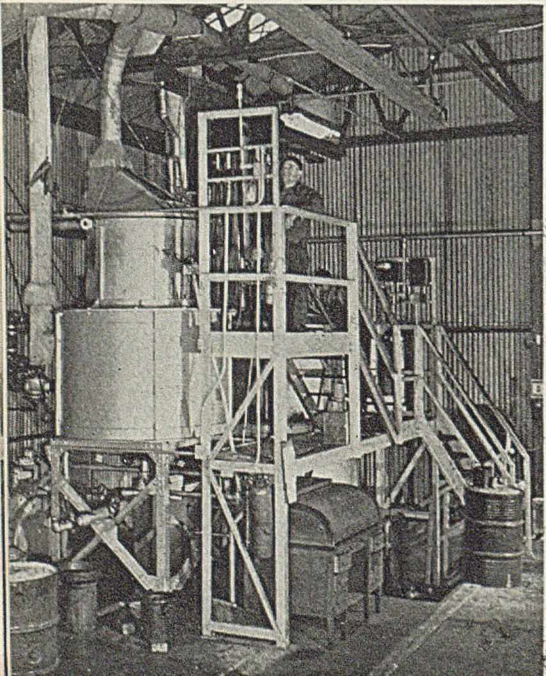
Chem. & Met. INTERPRETATION

Cooking techniques adapted for ink-making purposes may be of interest to chemical engineers because of the possibilities for process improvement wherever batch cooking is involved in the chemical, printing ink or paint and varnish industries. — *Editors.*

Better control, labor savings, greater production, convenience and improved plant cleanliness have been attained by the C.W.H. Carter Co. of Brooklyn, N. Y., by the use of four radiant-gas-fired kettle settings in the bodying, cooking and blending of ink varnishes and premium varnish oils.

The new facilities for processing varnish oils and transparent burnt litho varnishes went into operation last November, when a new fabricated steel building was put in service. In the new building there are four settings, all of which were designed and constructed by The Selas Co. of Philadelphia. Three are closed and the other is an open setting for the production of special burnt plate oils and Damar varnishes. All four utilize manufactured gas (525 B.t.u. per cu.ft.) automatically mixed by low-pressure proportioning-inspirator sets supplied with air at 1¼ lb. pressure. Gas is supplied to each inspirator set through a zero governor reducing the gas to atmospheric pressure before entrainment by the air. The proportioned mixture of air and gas then flows through controls to clusters of radiant refractory-cup burners which comprise the essential elements of the settings.

Cooker with bottom discharge; used for bodying heavy viscosity vehicles



In each refractory-cup burner, the mixture of gas and required air burns in a radial series of tiny flames which scrub the corrugated concavity of the ceramic cups. The cup surface temperature is thus raised to a point of brilliant incandescence which promotes complete combustion in a compact space, gives stability and speed to the combustion reaction, and develops a substantial percentage of radiant heat. Thus is insured the highest efficiency of distributed heat transfer to the kettle bottom without hot spots or flame impingement.

Setting "A" is closed, uses a cluster of 60 Selas hexagonal Duradiants arranged in four concentric hexagonal rings, carries a large stainless steel kettle and has a welded steel casing 6 ft. in diameter, lined with 4½ in. of insulating brick and 1 in. of block insulation. The burner cluster is so arranged it may be lowered out of the setting as a unit from below. All three closed settings are equipped with electric spark ignition for igniting a gas pilot which lights the burner nest. The system is protected by a safety device which automatically shuts off solenoid valves in both main and pilot fuel supply lines in the event of pilot flame failure. Temperature control is essentially manual although indicating pyrometers and air-gas mixture pressure gages as well as "limitrol" devices are installed. The setting accommodates 15-drum batches and is principally used for bodying linseed stand-oils and litho-varnishes at temperatures up to 625 deg. F. With the negligible heat retention of this type of setting it is possible to cut off all heat input to the kettle instantly enabling precise control of the ultimate batch viscosity.

Setting "B" is smaller and handles 5-drum batches. It uses a cluster of 26 gas burners in three concentric rings and has a centrally located bottom outlet from the kettle. This outlet pipe goes directly through the center of the burner cluster with a special refractory sleeve and permits batch removal by gravity flow rather than by pumping. This is important because the setting is principally used for bodying only the heaviest viscosity vehicles.

Setting "C" is also closed. It accommodates a 75-gal. kettle and is principally used for compounding drying oils with various synthetics, for blending, and for producing non-scratch specialties in reasonably small quantities. A 36-cluster of radiant burners is manually controlled for temperatures generally not over 600 deg. F.

The open setting "D" also has 36 radiant burners flush with the floor level and is used for trial cooks, special formulas and the production of burnt plate oils. (Burnt plate oils are clean-wiping and grease-free oils for bank-note plates and fine copper engravings.)

Using the radiant gas settings, one man can now body 15 bbl. in less time than it previously took one man to body of 5 bbl. with coke fires. Per unit of production, over all operations, labor requirements are now ½ to ⅓ less. In addition, there is no need for coke storage space and plant cleanliness is much improved. It is estimated that the gas cost for bodying the higher production products in settings "A" or "B" amounts to about 0.45 cents per gallon. Estimates of production speeds show that kettle "A" is capable of bringing 500 gal. of linseed oil from room temperature to 630 deg. F. in less than 2¼ hr. with a gas consumption of 1,400 cu.ft. per hr. Kettle "B" consumes only 570 cu.ft. per hr. which is sufficient for heating 250 gal. of linseed oil to the same temperature in the same time. The versatile kettle "C" uses 880 cu.ft. per hr. and will bring 75 gal. of batch to temperature in 30 to 40 minutes. The maximum gas consumption of setting "D" is 700 cu.ft. per hr.

All kettles are fitted with hoods connecting to fume incineration and exhaust equipment. The exhaust hood over the burnt litho ladling station is a complete structural iron shed mounted on rollers so that it can be moved out of the way except when actual cooking is in progress.

Fire hazards are much reduced by the inclosed settings which are flue-connected so that there is no connection between the combustion system and the atmosphere of the room. A simple shut-off valve is installed on all fuel supply lines to further promote fire protection.

CHEM & MET PLANT NOTEBOOK

Timesaving Ideas for Engineers

NEW TABLES SIMPLIFY CALIBRATION CALCULATIONS FOR HORIZONTAL TANKS WITH VARIOUS HEADS

RICHARD DEANE *Engineer, Rossland, B. C., Canada*

(*Editor's Note:* In spite of the fact that several previous methods have been published dealing with the common problem of calibrating horizontal tanks with bulged ends, there is always room for still another method if it offers a new approach or simplifies the usually arduous calculations. The method presented by Mr. Deane does offer such a new approach, in that in a single tabulation of volumes, it offers an immediate comparison of standard heads, spherical and elliptical heads and conical heads. The table is equally useful for tanks with flat heads.)

In an earlier article the writer presented a simple graphical method for the calibration of horizontal tanks with flat heads. (*Chem. & Met.*, Jan. 1939, p. 39). The accompanying article carries the problem farther, presenting a table of volume values in terms of percent depth vs. percent capacity (Table I), for both the cylindrical portion of any horizontal cylindrical tank, and for heads of standard dished shape, as well as spherical, elliptical and conical heads. While the great majority of horizontal cylindrical tank heads are either flat or approximately of the standard dished design, with the radius of the head equal to the diameter of the tank, some heads are intentionally elliptical, others are between elliptical and the standard dish, and still others are spherical, conical, or approximately so. The present table, therefore, can be used with a sufficient degree of accuracy to calibrate tanks with almost any type of head. If analysis of a given head reveals it to be of none of the shapes listed, a close approximation of its actual volume at various heights can be made by interpolating between the two mathematical types which it most nearly approximates.

The standard dished head is the type for which most of the calibration methods have been worked out in the past. Some handbooks carry extensive tables which, however, in use require rather lengthy computation. Elliptical, spherical and conical heads seem to have received little attention, although C. A. Lee (*Chem. & Met.*, Feb. 1941, p. 137) has presented a method which is adaptable to the calibration of any type by means of a step-integration device. Lee's method was worked out primarily to deal with tanks having heads with radii either larger or smaller than the tank diameter, and hence of non-standard dished design. It would seem to be equally suitable, however, for other shapes, combining as it does a graphical approximation of the horizontal area of the heads at various levels, with a summation of increment volumes in small steps up to the half-full tank level.

The present tabulation for the standard dished head was computed by the writer by a step-integration method, since it was not found possible to obtain a function for the volume of the head at a given depth. The calculation involved taking the horizontal area within the head at each small interval of depth, averaging adjacent areas, and multiplying by the vertical interval. In this manner a very close approximation of the volume for each such interval was obtained. The volume of the first interval from the bottom was treated as a pyramid. The volume of the various intervals so obtained were then divided by the total volume of the head, multiplied by 100, and the resulting percents progressively summed to give the desired table.

A test of the accuracy was obtained by the degree of approximation attained as the summation approached the actual half volume of the head at 50 percent of the depth. For the dished head, the summation at 50 percent depth came to 50.0025 percent. For the cone head, which was similarly calculated, the total was 49.9980 percent. Since the tables are given to two decimal places, all figures are presumed to be accurate.

The columns in Table I for the cylindrical portion, and for the elliptical and spherical heads were taken from Marks' Handbook (Fourth Ed., 1941, pp. 35 and 38 resp.). Marks'

Table I—Percent Depth Vs. Percent Capacity for Horizontal Cylindrical Tanks with Standard Dish, Elliptical, Hemispherical and Cone Heads

(Expressions for volume of heads at top of columns are for *two* heads)

Percent Depth, 100 h/D	Percent Capacity				Percent Depth, 100 h/D	Percent Capacity			
	Cyl. Section, $V = \frac{\pi D^2L}{4}$	Standard, Dish Rad. = Dia. $V = 0.8041\ D^2d$	Elliptical & Hemispherical, $V = 1.047\ D^2d$	Cone Type Heads, $V = 0.524\ D^2d$		Cyl. Section, $V = \frac{\pi D^2L}{4}$	Standard, Dish Rad. = Dia. $V = 0.8041\ D^2d$	Elliptical & Hemispherical, $V = 1.047\ D^2d$	Cone Type Heads, $V = 0.524\ D^2d$
1	0.17	0.005	0.03	0.004	26	20.66	13.99	16.76	12.06
2	0.48	0.03	0.12	0.023	27	21.78	15.16	17.93	13.16
3	0.87	0.09	0.26	0.06	28	22.92	16.37	19.13	14.31
4	1.34	0.17	0.47	0.13	29	24.07	17.62	20.35	15.51
5	1.87	0.30	0.73	0.22	30	25.23	18.91	21.60	16.76
6	2.45	0.47	1.04	0.35	31	26.40	20.23	22.87	18.05
7	3.08	0.68	1.40	0.51	32	27.59	21.59	24.17	19.39
8	3.75	0.94	1.82	0.71	33	28.78	22.98	25.48	20.78
9	4.46	1.24	2.28	0.95	34	29.98	24.41	26.82	22.22
10	5.20	1.59	2.80	1.22	35	31.19	25.86	28.17	23.69
11	5.98	1.99	3.36	1.54	36	32.41	27.34	29.55	25.26
12	6.80	2.45	3.97	1.91	37	33.64	28.85	30.94	26.78
13	7.64	2.95	4.63	2.32	38	34.87	30.38	32.35	28.38
14	8.51	3.50	5.33	2.77	39	36.11	31.93	33.77	30.02
15	9.41	4.11	6.07	3.27	40	37.35	33.51	35.20	31.70
16	10.33	4.76	6.86	3.92	41	38.60	35.10	36.65	33.41
17	11.27	5.47	7.69	4.42	42	39.86	36.71	38.10	35.16
18	12.24	6.22	8.55	5.07	43	41.12	38.34	39.57	36.94
19	13.23	7.03	9.46	5.77	44	42.38	39.98	41.04	38.74
20	14.24	7.88	10.40	6.52	45	43.64	41.63	42.52	40.57
21	15.27	8.79	11.38	7.31	46	44.91	43.30	44.01	42.43
22	16.31	9.74	12.39	8.16	47	46.18	44.97	45.51	44.30
23	17.38	10.73	13.44	9.06	48	47.45	46.64	47.00	46.19
24	18.46	11.78	14.52	10.01	49	48.73	48.32	48.50	48.09
25	19.55	12.86	15.62	11.01	50	50.00	50.00	50.00	50.00

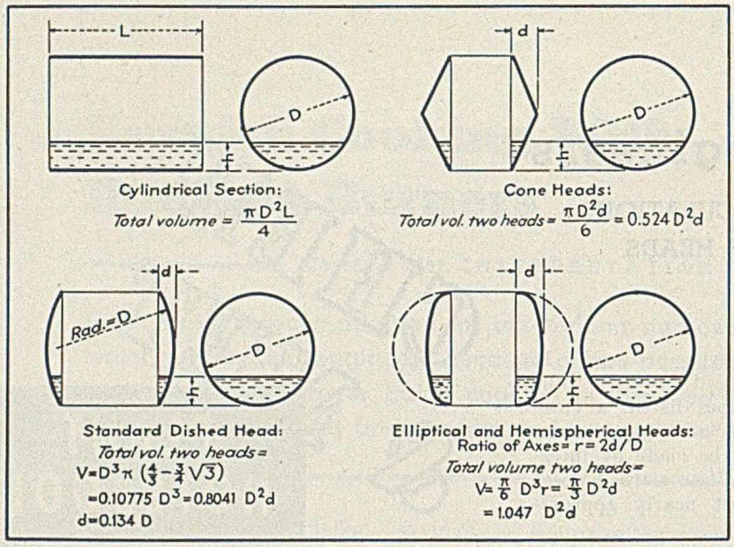


Fig. 1—Types of heads and their formulas

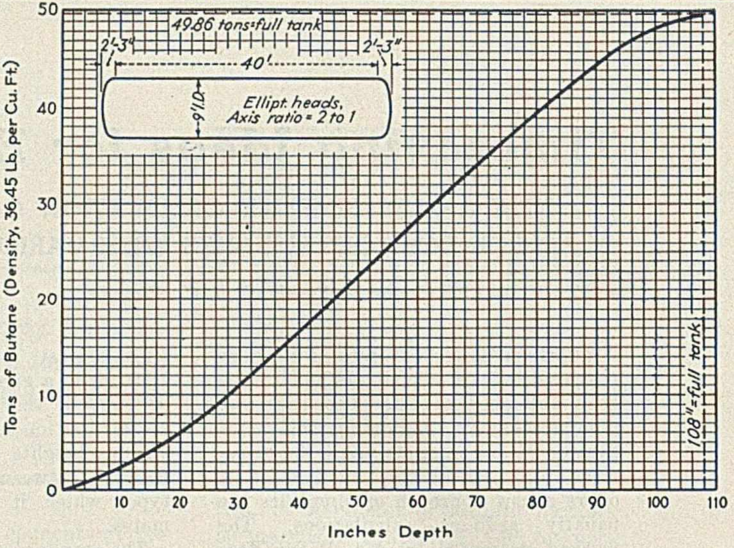


Fig. 2—Calibration for tank in text problem

tabulation on page 35 for the ratio of the area of a circular segment, to that of the circle, applies directly to the cylindrical portion of the tank. In the case of an elliptical head, it can be proved that such a head of any axis ratio has the same characteristic depth vs. capacity curve as a spherical head and therefore Marks' tabulation on page 38 of the ratio of the volume of a spherical segment, to the volume of the sphere, applies directly to both elliptical and spherical heads.

In the case of a cone head, it can be proved that the depth vs. capacity curve is independent of the central angle so long as the cone is of right, circular shape. As in the case of the standard dished head, the tabulation for conical heads was worked out by taking the horizontal area at each interval, averaging adjacent areas, multiplying by the height of the intervals, dividing each incremental volume by the volume of the head to obtain the percent of the total head volume at each height, and summing these percents progressively.

With the exception of the standard dished head, the total volume expressions given in Fig. 1 and Table I were simply calculated by evaluating the well known mathematical expressions for the volumes of the several head shapes. The expression for the total volume of two standard dished heads, namely, $V = D^3 \times \pi \times (4/3 - 3\sqrt{3/4})$, is not quite so easy to evaluate since it involves a subtraction of nearly equal numbers. It was carried out to eight decimal places in the calculation to insure accuracy.

In this connection, it should be noted that the expression for the total volume of two standard dished heads, given as $V = 0.8041\ D^2d$, applies only to the standard head, with the head radius equal to the diameter of the tank. It does not apply to any other head radius. However, another point worth noting about this formula is that for heads which deviate slightly from a true spherical segment of $R = D$, this formula gives a more accurate volume than the alternate form, $V = 0.10775\ D^3$.

Table I, as already indicated, summarizes the data for calculating the volumes at various depths for the various types of tanks, listing the percents of the total capacity of the tank at various percents of the total depth. The second column of the table gives percents of total capacity of the cylindrical portion at various percents of total depth, while the third, fourth and fifth columns list percents of total capacity for the several types of heads noted. At the top of each column are given the expressions for the total capacity of the element covered in that column. Note that the total volume expressions for the heads give the volume of *two* heads. Note also that Table I covers only the lower half of the tank. For the calibration of that part of the tank above the mid-point, the volumes at the various higher levels are obtained by subtracting the volumes at the corresponding distances above the bottom of the tank, from the total volume of the tank.

As an example of the use of the table, consider the calibration of a horizontal, cylindrical tank for liquid butane, as shown in Table II and Fig. 2. The length of the cylindrical portion is 40 ft., the inside diameter is 9 ft., and the heads are elliptical, with an axis ratio of 2 to 1 (i.e., d = 2 ft. 3 in.). The density of liquid butane at 60 deg. F. is 36.45 lb. per cu. ft. Hence, the capacity of the cylindrical portion of the tank is $\pi \times D^2 \times L/4$ cu. ft., or $(9^2 \times \pi \times 40 \times 36.45)/(4 \times 2{,}000) = 46.38$ tons. The capacity of the two elliptical heads is $\pi \times D^2 \times d/3$ cu. ft., or $(9^2 \times \pi \times 2.25 \times 36.45)/(3 \times 2{,}000) = 3.48$ tons. The total capacity of the tank is therefore $46.38 + 3.48 = 49.86$ tons.

For ordinary work in making a calibration curve, it is usually sufficient to calculate the capacities for, say, each 5 percent of depth. For highest accuracy, closer calibration may be needed, but since a tank is gaged for each inch of depth, rather than for each percent, it will in any event be necessary to make a calibration curve, from which the capacities at each inch of depth can be read off if a tabulation is to be made. The calculations for the butane tank are shown in Table II, for each 5 percent of depth. A calibration curve drawn from these data is shown in Fig. 2. With care in the calculation and curve drawing, such a curve will be accurate enough for most purposes, and can be read off to permit the listing of capacity values for each inch of depth. It should be observed, however, that when the calibration is in terms of weight rather than volume, as in the example given, a temperature correction factor may be necessary when measurements are made at temperatures other than that for which the calibration was made. This is true in the case of butane which has a considerable expansion coefficient.

Table II—Calibration of Butane Tank as Described in Text

Percent Depth	Depth, in., % Depth × 108 in.	Tons Capacity		Total Tons at Percent Depth
		Cyl. Section, % Cap. × 46.38	Two Heads, % Cap. × 3.48	
5	5.4	0.87	0.03	0.90
10	10.8	2.41	0.10	2.51
15	16.2	4.36	0.21	4.57
20	21.6	6.60	0.36	6.96
25	27.0	9.07	0.54	9.61
30	32.4	11.70	0.75	12.45
35	37.8	14.47	0.98	15.45
40	43.2	17.32	1.22	18.54
45	48.6	20.24	1.48	21.72
50	54.0	23.19	1.74	24.93
55	59.4		49.86—21.72	28.14
60	64.8		49.86—18.54	31.32
65	70.2		49.86—15.45	34.41
70	75.6		49.86—12.45	37.41
75	81.0		49.86— 9.61	40.25
80	86.4		49.86— 6.96	42.90
85	91.8		49.86— 4.57	45.29
90	97.2		49.86— 2.51	47.35
95	102.6		49.86— 0.90	48.96
100	108.0		Full tank	49.86

CHEM & MET REPORT ON

Electronic Devices For Process Control—II

TO CHEMICAL ENGINEERS, SUPERINTENDENTS
AND PRODUCTION EXECUTIVES

Electronic tubes and photocells have already made an enormous impact on communications, television and sound reproduction. What is not so well known to many engineers is the fact that these devices are beginning to take an important place in industry applications, including measurement and control, and the handling and conversion of electric currents. For many purposes they furnish a better answer than any other means to the problem of speeding up operations and improving processes, so necessary in these critical days. Last month *Chem. & Met.* presented the first of two reports on this important subject, written by a well known authority in the field of industrial applications. The earlier article dealt with the fundamentals of those devices used in control. The present paper is concerned with their industrial uses, and also with several of the more complex varieties, for measurement and current handling.

CHEMICAL AND METALLURGICAL ENGINEERING · APRIL, 1942

Electronic Devices For Process Control—II

THEODORE A. COHEN *Vice-President, Research and Development*
Wheelco Instruments Co., Chicago, Ill.

Chem. & Met. INTERPRETATION

This is the second of two *Chem. & Met.* Reports on the subject of electronic devices, their principles and applications to process control. The first report, which appeared on pages 99 to 106 of the March issue, explained the operation of such equipment and described a considerable number of types of both thermionic tubes and photoelectric cells. This report goes somewhat farther in explaining the principles of certain more specialized types which are used primarily for rectification of power, for inversion of direct to alternating currents, and for direct measurements of electrical quantities, pH, light, opacity and color values. It also covers briefly a number of types of application, of which many are current, in which the electronic equipment is used primarily as a switch or relay for counting, measurement and control of many factors.—*Editors.*

In the first part of this article (*Chem. & Met.*, March 1942, pp. 99-106) it was pointed out that electron tubes are classified into two groups: (1) Photoelectric cells, in which a flow of electrons is brought about or controlled by the action of light for the purpose of controlling some useful mechanism; and (2) non-photoelectric electron tubes, in which electrons are emitted from a surface within the tube without light impingement, also for the purpose of controlling a useful mechanism. To make it easier to visualize some of the ramifications of these two general types, Fig. 1 is presented, giving in simplified form an outline of the principal types and their general fields of application.

Referring to the non-photoelectric types, the first article explained that in general, high-vacuum tubes are employed for rectification, amplification, generation of alternating currents (oscillators), measuring, and as relays. Gas-filled tubes, in general, are used for rectification, generation of direct current (inverters), and as relays. The fundamentals underlying the operation of both high-vacuum and gas-filled tubes were explained.

This second article has a two-fold purpose: First, it goes somewhat farther into some of the more specialized tube types, particularly those which are used for industrial purposes other than control, such as rectification and inversion of currents, and the direct measurement of certain quantities. Its second purpose is to describe a number of the commoner applications of the less specialized tubes and photocells.

There has been a certain amount of confusion in the study and application of electronics, since tubes may be described in at least three ways: (1) By function; (2) by construction; and (3) by a trade name. Certain of the trade names are so commonly employed that any confusion on this score should be cleared up here and now so far as this discussion is concerned. The following definitions deal only with non-photoelectric tubes. In the high-vacuum class there are two well-known types which are often referred to by trade names. The Kenotron is defined as a high-vacuum thermionic tube in which no means is provided for controlling the uni-directional current flow. Such tubes have two elements and are used solely for rectification. The Pliotron is a high-vacuum thermionic tube which in addition to an anode and cathode has one or more electrodes for controlling the uni-directional current flow. Such tubes are used as amplifiers, oscillators, measuring devices, relays, and for similar purposes. A variety of other names, some generic and some trade names, are applied to this class of tube including Radiotron, radio tube, Thermion, tetrode (four electrodes), triode (three electrodes), and Oscillion.

As the first article explained, there is an important fundamental difference in the characteristics of high-vacuum, and gas- or vapor-filled electronic tubes, owing to the process of gas amplification which occurs in the second class. Consider the comparative character of rectifiers of the two types: In either type plate current can flow, of course, only when the anode is positive. In the high-vacuum type the amount of current that flows is dependent on the difference in potential of the anode and cathode and so, for any applied potential, the more electrons there are, the more current can be carried, consistent with the heat dissipating abilities of the tube. In a high-vacuum rectifier a considerable voltage drop exists across the tube, which decreases the available voltage across the output terminals of the rectifier.

On the other hand, when an inert gas is present in the tube, or a vapor such as mercury, the collisions of the electrons with the gas or vapor molecules produce new electrons and materially augment the electron stream flowing from the cathode to the anode (gas amplification). The number of electrons flowing continues to increase as the voltage is raised until a point is reached where the current in the gas space rapidly increases to some ultimate value at the "break-down" or glow point of the tube. When this has occurred, the current through the tube is limited only by the resistance of the circuit, and the tube is illuminated with a glow characteristic of the gas or vapor filling. Many times the current can be carried that can be passed by an equivalent high vacuum tube. Furthermore, voltage drop in the tube is low, and a greater external rectifier voltage is available across the output terminals of the tube. Fig. 2 illustrates the relations between rectifier current and applied voltage in the two types of tube.

The gas- and vapor-filled groups of tubes comprise three general classifications including: (1) The cold-cathode type; (2) the hot-cathode type with filament-heated cathode; and (3) the mercury-pool type employing arc discharge.

1. The cold-cathode tube was not mentioned in the first article since it has relatively little application in the field of industrial control. Very briefly, a tube containing a gas or vapor at low pressure will contain a number of free ions and electrons and if a potential difference is applied between the electrodes, the tube will become conducting by the process of gas amplification. In such a tube either electrode (since neither is heated) can serve as the anode, depending upon the direction of polarity. If a third element, similar to a grid, is added to serve as a starter, this grid can be biased more negatively than a certain critical value (depending on the plate potential), and thus prevent what few electrons originally are present from reaching the anode. Such a tube is extremely

sensitive to slight grid potential changes; even bringing one's hand near the grid connection is sufficient to cause the tube to break down and produce a glow discharge.

2. Hot-cathode tubes of the gas- and vapor-filled variety, like the high-vacuum type, are divided into those tubes with but two elements, and those with three or more. Among the two-element type are the three well-known trade names of Tungar and Phanotron (G.E.) and Rectigon (Westinghouse). Gaseous tubes having one or more additional electrodes for the purpose of controlling or starting the flow of uni-directional current include the well-known Thyratron type. These tubes are used as high capacity current contactors, relays and as inverters.

3. Tubes of the mercury-pool type have in recent years become extremely important as industrial rectifiers. Included in this type are the older mercury-pool rectifiers employing a continuous arc as a "keep-alive" mechanism. An industrial modification of this early type is the tank-type multi-anode mercury-arc rectifier. A more recent development is the Ignitron mercury-arc rectifier developed by Westinghouse and now also manufactured by several other concerns.

Mercury-pool type tubes may be built either with or without control grids. The use of a control grid, as in tank-type multi-anode rectifiers and in Ignitrons, makes possible control of the point in the voltage cycle at which the tube becomes conducting and hence permits accurate regulation of the quantity of current flowing.

INDUSTRIAL RECTIFIERS

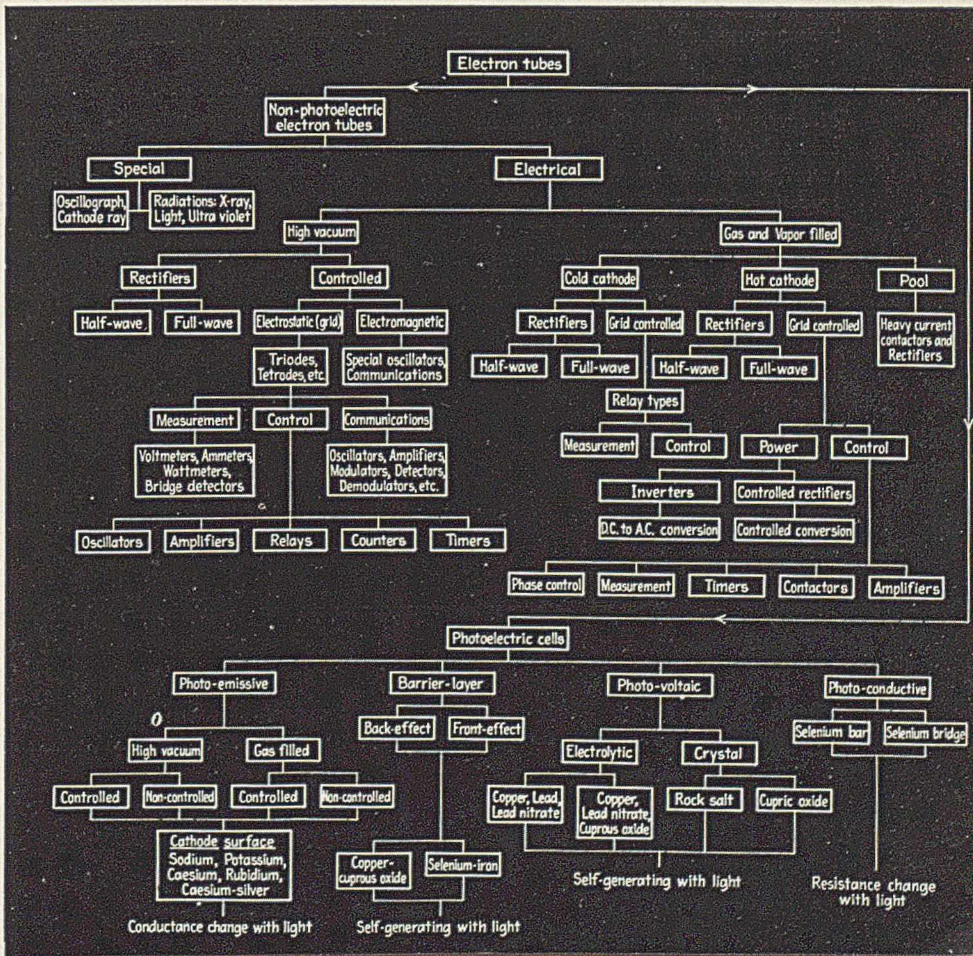
Large capacity mercury-arc rectifying devices are important industrial tools, particularly in electrochemical industries. In recent years, the tendency has been away from motor-generators and synchronous converters for this purpose, and toward the more efficient mercury-arc devices. The first of these, the steel-tank, multi-anode rectifier, was introduced from Europe shortly after the last war and gained commercial importance about ten years later. The arc rectifier was rather slow in being introduced to electrochemical uses because of its considerable voltage drop (25-30 volts), which made it relatively inefficient except at high voltages (600 volts). This difficulty was to a large extent overcome with the development by Westinghouse in 1937 of the Ignitron rectifier, a type of mercury-arc rectifier in which each anode and cathode pair are individually inclosed in an evacuated steel chamber, as compared with the practice of employing 6 to 12 anodes and a single mercury-pool cathode in the tank-type rectifier. Another difference is that, while the multi-anode type is continuously excited, for the continuous maintenance of a "cathode spot" on the surface of the mercury, in the Ignitron this cathode spot is permitted to go out at the end of each positive half of the cycle (conducting portion of the cycle) and then is re-ignited by means of a high-resistance ignitor rod dipping in the mercury, when the cycle again becomes positive. This construction permits the anode and cathode to be placed quite close together so that the arc voltage drop is small.

The Ignitron is the type of rectifier being employed in the new aluminum and electrolytic magnesium installations. It operates on a basically new principle which permits a closer approach to the theoretical efficiency of the mercury arc than any other type of rectifier tube. The Ignitron at present is the most efficient method of producing direct current by rectification. As shown in Fig. 3, it consists essentially of a metal chamber cooled by water circulation. In the lower portion of the chamber is a mercury pool into which dips a high-resistance ignitor rod of a suitable refractory material, such as silicon carbide or boron carbide. An anode suspended in the chamber above the mercury is suitably insulated from the vessel with a vacuum-tight insulating bushing. Starting is accomplished by passing a current between the high-resistance rod and the low-resistance mercury pool. When this is done a small spark occurs at the junction, at a definite value of voltage and current, producing what is termed a cathode spot which liberates sufficient electrons to initiate electron flow to the positively charged anode. This process requires less than 25 micro-seconds. When the anode becomes negative during the succeeding portion of the alternating current cycle, the discharge ceases. Thus the Ignitron is extinguished every half cycle. The illustration shows a grid which has been added for current control.

The Ignitron principle makes possible practically unlimited emission and therefore extremely high overload capacity. As the mercury is vaporized from the pool, it condenses upon the cold surface of the Ignitron shell and runs down again, replenishing the pool. The life of a pool cathode is many times longer than that of a hot-cathode or thermionic type rectifier. To insure high efficiency, water cooling is necessary in the larger units and generally continuous vacuum pumping as well.

For full-wave rectification, two Ignitrons are used, one rectifying each half of the wave. For three-phase rectification, three units are used for each half wave, or a total of six. Because the arc is extinguished every half cycle when the anode becomes negative, and since the source of ionization is eliminated during this half cycle, the Ignitron can withstand high reverse voltages without danger of the arc-back which is relatively common in other forms of mercury rectifier. Smaller Ignitrons with glass inclosures are capable of passing single-cycle pulses up to 1,000 amp. for making spot welds at 60 spots per minute. For larger power capacity, the water-cooled metal-incased type is capable of passing single-cycle pulses up to 3,500 amp.

Fig. 1—"Organization Chart" of principal types of photoelectric and non-photoelectric devices used primarily in industrial applications



In addition to their uses in electrochemical industries, Ignitrons are now being used extensively for controlling currents in the spot welding of metals, particularly stainless steel and aluminum. In this application, a pulse of current having a large magnitude and a carefully controlled short duration must be fed into the weld. Such a hook-up is illustrated in Fig. 4, in which two Ignitrons control the current flow through the primary of a welding transformer. The system is caused to fire by some form of starter such as a pushbutton or, more frequently, by a specially set timer which completes its circuit through both ignitor electrodes and their respective cathodes. Starting arcs are formed at both cathodes and the tube whose anode is positive conducts during a half cycle. At the next half cycle the previously conducting tube is extinguished, while the anode of the second tube becomes positive and conducts for a half cycle. Because of the very low internal voltage drop, a large current can flow to the welding transformer and such flow will continue in pulses as long as the control circuit remains closed. Under these conditions the Ignitrons act as contactors which close their circuits in a matter of micro-seconds and open them positively. Only a small amount of energy in the pool circuit is required to permit control of tremendous amounts of current in the anode circuit of the Ignitron tube. Control of the pool circuit can be accomplished by small grid-controlled rectifiers, such as Thyratrons.

THYRATRONS

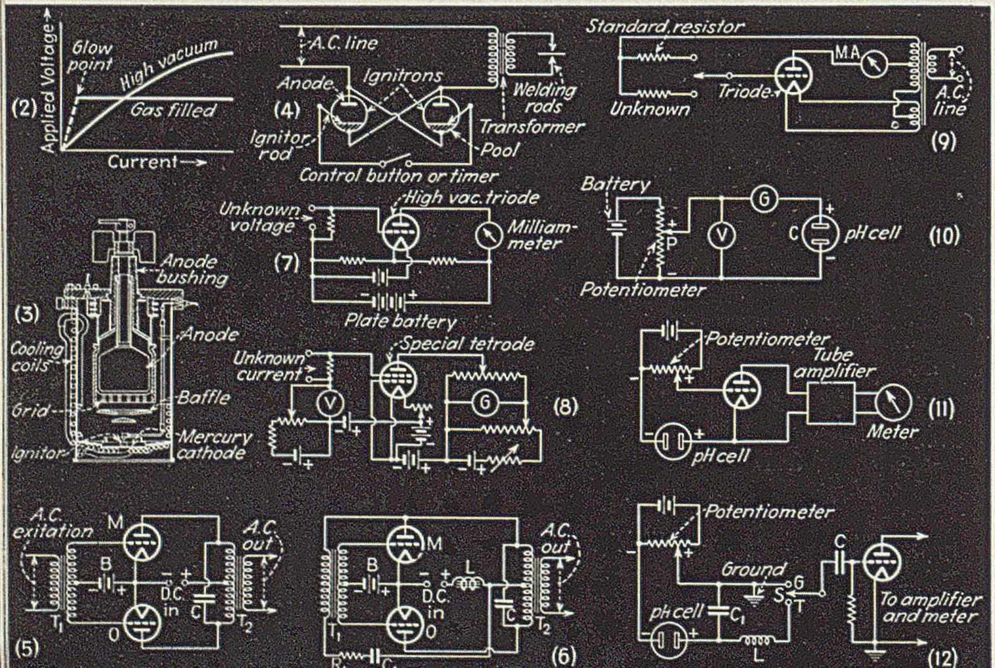
Three-electrode gas- or vapor-filled tubes with heated cathodes, of the type known commercially as the Thyratron (and sometimes called grid-controlled hot-cathode rectifiers), are becoming extremely important from the industrial standpoint. Basically, such tubes are similar in construction to the three-electrode high-vacuum tube, with the exception that in some cases they are filled with an inert gas such as neon or argon, while in other cases a mercury vapor filling is employed.

As has previously been pointed out, the gaseous tube gains tremendous current carrying capacity at the loss of linearity of response, but the response may be "triggered" so that large current values can readily be controlled. Hence, such tubes as the Thyratron have become increasingly valuable industrial tools, ranging in application from relay tubes to contactors and inverters in power transmission.

Thyratron Inverters—Broadly applied, the term inverter is any machine or mechanism capable of converting direct current to alternating current. In the past the term has been applied to arc-tube power oscillators which are capable of producing inversion but only at relatively low efficiencies. The advent of the Thyratron inverter has supplied a highly efficient apparatus for this necessary function. The Thyratron is glass-inclosed for lower power output, and metal-inclosed, usually with water cooling, for higher power output. In the larger types, Thyratrons (like Ignitrons) are kept continuously pumped by automatically controlled vacuum pumps.

Basic inverter circuits are essentially of two types. The first group, termed "external-excited inverters," are illustrated by the typical diagram of Fig. 5. The second group, termed "self-excited inverters," are illustrated by Fig. 6.

(2) Comparative current outputs of high-vacuum and gas-filled rectifiers under influence of varying potential. (3) Cross section of Ignitron rectifier. (4) Circuit using Ignitrons to control welding current. (5) Thyratron inverter circuit with external excitation. (6) Thyratron inverter circuit with self-excitation. (7) Vacuum tube voltmeter of plate detection type. (8) Vacuum tube microammeter. (9) Vacuum tube ohmmeter. (10) Potentiometer circuit for low-resistance pH cell. (11) pH cell circuit illustrating grid current error. (12) pH cell circuit employing grid current error eliminator.



External-Excited Inverters—The output of an inverter of the external-excited type (Fig. 5) is directly related in frequency and phase to the alternating current grid excitation. It will be noted that a low value alternating voltage is placed across the primary of the grid-control transformer T_1. The secondary of this transformer, which is center-tapped, is connected to the grids of two Thyratrons. A battery *B* applies a negative bias to the control grids of the Thyratrons. Hence, upon excitation by the exciting alternating voltage, one grid will be positive, while the other grid will remain negative. During the positive half cycle of grid excitation, Tube *M* will conduct, while the anode of Tube *O* is at line potential. Thus, during this half cycle, a current flows in the anode circuit of Tube *M*, through the primary of the output transformer T_2. This current flow takes place from the direct current input source which may be a direct current power line. During the negative half cycle, the Tube *O* conducts, thus lowering its anode voltage to the tube drop. Since the anodes of both tubes are connected through the condenser *C*, the anode voltage of *M* goes negative because this condenser has previously been charged and cannot discharge immediately.

The circuit constants are chosen so that the exciting ions within the tube cannot diffuse before the anode voltage becomes positive, and thus the grid of Tube *M* resumes control. When the grid of Tube *O* is made positive, and that of Tube *M* negative, the current again shifts tubes. The action is equivalent to a pair of interconnected mechanical switches which switch the direct current first in one direction through the transformer, and then in the other, at the desired frequency. This alternating switching of the two tubes continues indefinitely as long as the exciting voltage is maintained.

The switching of anode current through the primary of the output transformer T_2 produces an induced alternating voltage in its secondary. The frequency of this alternating voltage is directly dependent upon the frequency of alternating exciting voltage at T_1, which may be obtained from a small alternator or similar device.

Self-Excited Inverters—The self-excited circuit illustrated in Fig. 6 shows the original external-excited circuit converted so that the grid-exciting transformer T_1 has its primary connected to the anode supply system which contains an inductance *L* and a capacitive resistance network, C_1 and R_1. This network supplies an alternating current pulse whose frequency is dependent upon the constants of the network and the transformer T_1. This alternating current is used to supply grid excitation in a manner similar to the externally excited circuit above described. Such a circuit can supply alternating current in the frequency range from 10 cycles to well over 5,000 cycles, depending upon the constants chosen for the circuit.

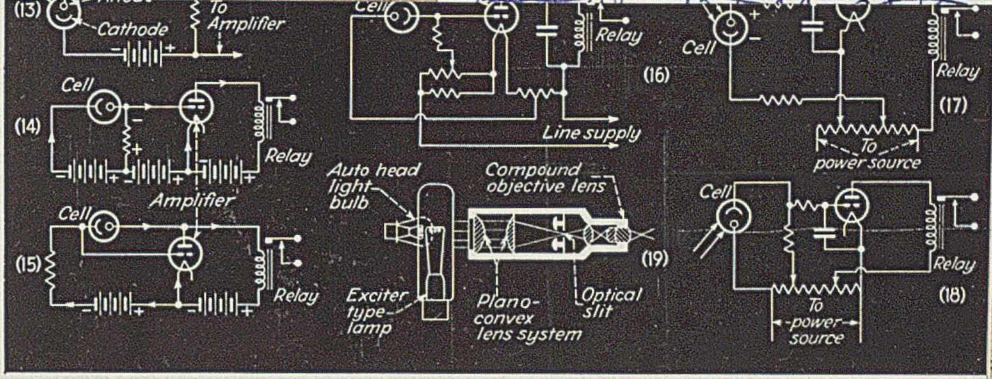
D. C. Transmission—It is common knowledge that it is much more economical to transmit electricity at high voltage than at low, when a large amount of power is to be handled, owing to the smaller line losses. However, distribution problems arise in alternating current systems, both in line losses due to corona at high voltages, and in the difficulty of interconnecting systems of different frequencies. To a considerable extent it is possible to overcome these problems by the transmission of high-voltage direct current. This can be done electronically, and has been carried out on a considerable experimental scale. The method will doubtless become an important one in the future.

The maximum alternating current that can be transmitted is less than the maximum direct current because it is the crest of the alternating voltage wave which determines the corona loss. Also direct current transmission eliminates dielectric loss and line reactance. It is quite simple to produce high-voltage direct current from high-voltage alternating current through the use of hot-cathode and arc-discharge rectifiers. And with the Thyratron inverter it is possible to re-convert this high-voltage direct current to alternating current with good efficiency and without the need for expensive converter sub-stations. The scheme is to take low-voltage alternating current supply, step it up with transformers to high voltage, and then convert to direct current with rectifiers. The high-voltage direct current is sent out over the transmission line and at the point of use inverted to high-voltage alternating current and finally stepped down with transformers to yield the desired lower alternating voltage for distribution. Delivery can be either single- or multi-phase, and of any frequency desired. This therefore solves the problem of interconnecting alternating current sources of different frequencies and eliminates the difficulty of synchronization. Furthermore it makes available the most efficient frequency for the machinery used.

CURRENT CONTROL

In reference to the use of grids on gaseous tubes supplied with an alternating potential, it has previously been mentioned that these elements can be used to control the point in the alternating cycle at which the tube fires, and hence control the current output. Grids are used in two alternative ways, the first called amplitude control, and the second, phase control.

Amplitude control may be explained as follows: For each voltage of the anode there is a certain critical voltage of the grid which will just permit the tube to fire. If now the grid is biased negatively with a certain voltage less than the maximum critical value, this voltage will be critical for some anode potential less than the peak value that will be imposed during the alternating cycle. Hence, the tube will fire at some point before the peak of the cycle is reached, dependent on the value of grid bias. By controlling the value of the bias, the conduction of the tube can be made to start at any point in the first half of the positive half of the cycle, and thus the passage of rectified current will continue from this point until the end of the positive half of the cycle.



(13) Basic photocell circuit for use with amplifiers. (14) Standard photocell and amplifier circuit. (15) Photocell-amplifier circuit simplified to eliminate the cell battery. (16) Line supply photocell amplifier relay. (17) Single-tube photocell circuit which operates relay on break in illumination. (18) Single-cell photocell circuit which operates relay when cell is illuminated. (19) Special light source delivering a fine light beam.

Phase control differs in that the bias is applied to the grid by means of an alternating voltage, which varies in phase from the alternating voltage on the anode. Hence, as the grid becomes less negative during each positive cycle of the anode, the critical voltage will be reached and the tube will fire. By shifting phase, it can be made to fire at *any* point during the positive cycle of the anode, and hence to conduct for any part of the period.

MAGNETIC CONTROL

So far in the discussion, all tubes with grids have been controlled by electrostatic charge on the grid. One class of tube, not much used for industrial purposes, employs electromagnetic control, by virtue of the fact that electrons can be deflected by a magnetic field. When such a field is produced in the proper direction in the electron space of the tube, electrons can be prevented entirely from reaching the anode, and forced back to the cathode. Such tubes are being used in exploring the strength and direction of magnetic fields, as in a special aircraft compass.

MEASURING INSTRUMENTS

Since a three-element high-vacuum tube acts as a voltage amplifier, and can be designed for linearity of output, a group of interesting measurement applications hinges on this amplifying property. Uses of this sort fall into five classes: (1) Voltage-unbalance sensing instruments (galvanometers and electrometers); (2) vacuum tube voltmeters (electrometers, etc.); (3) vacuum tube ammeters; (4) vacuum tube wattmeters; and (5) vacuum tube ohmmeters.

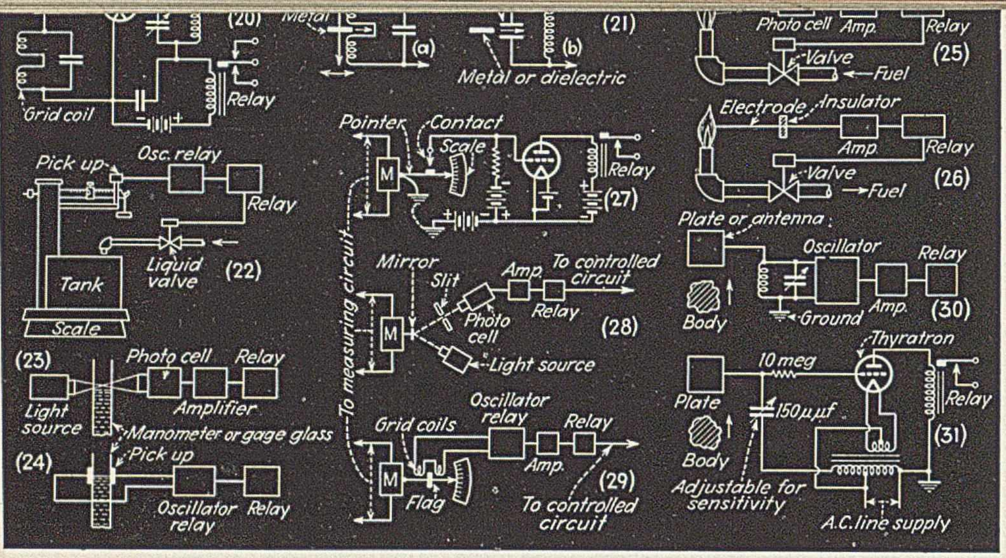
With the advent of the electronic tube, this field of measurement has been able to advance greatly in range, and many types of apparatus rugged enough for industrial use have become available where heretofore apparatus for equivalent measurement was necessarily relegated to the research laboratory. In addition to ability to measure voltage, current, power and resistance, electron tubes have been adapted to the measuring of variables such as time, speed and frequency. Still other variables such as hydrogen-ion concentration are regularly being measured in terms of voltage with vacuum tubes.

Probably the most useful of the electronic measuring instruments is the vacuum tube voltmeter. One of its advantages over the electromagnetic or electrostatic measuring instruments is the high sensitivity that can be attained in an instrument of rugged form. Its principal value is in the measurement of voltages in circuits in which the available power is so small that appreciable flow of current would measurably alter the voltage. Such measurements are involved in those of charged condensers and ion-concentration cells. This voltmeter is known in many different forms, one of the most useful of which appears in Fig. 7.

This circuit is of the plate-detection variety. A milliammeter of the D'Arsonval type, connected in the plate circuit of the voltmeter tube, is calibrated in terms of input voltage. It will be noted that as the input voltage changes, the grid bias of the tube is changed, which in turn causes a plate current change through the calibrated meter. The circuit is self-compensating against voltage variation of the batteries and against tube aging.

A vacuum tube milliammeter or ammeter is essentially a vacuum tube voltmeter designed to measure current flow by means of the drop across a high resistance through which the current flows. Special tubes have been developed for this type of application, which allow very high resistances to be used. They attain high sensitivity by limiting the external leakage present in the grid circuit of ordinary tubes. Such a circuit is illustrated in Fig. 8.

For measurement of high resistances, electron circuits have been developed



(20) Oscillator relay circuit. (21) Methods of controlling oscillator relays: (a) Flag enters grid coil; (b) Object enters grid tank condenser. (22) Oscillator relay applied to weight control. (23) Level control with photocell. (24) Level control with oscillator relay. (25) Photoelectric flame safety system. (26) Flame safety system using flame conductivity and oscillator relay. (27) Contact-making relay for instruments. (28) Photoelectric non-contact instrument relay. (29) Non-contact instrument relay employing oscillator and amplifier system. (30) Approach relay with high-vacuum tube oscillator. (31) Approach relay with Thyratron tube.

which measure such resistances in terms of grid-current flow. In the circuit of Fig. 9, the milliammeter in the plate circuit of the tube is calibrated in terms of resistance.

pH MEASUREMENT

From the standpoint of process industries, one of the most important applications of electronic tubes in the field of measurement is in glass electrode pH meters. It is not the purpose of this paper to go into pH measurement in detail (it was treated at considerable length in the *Chem. & Met.* Report for August 1940.—*Editor*). It will be worth while, however to indicate the part which the electronic tube is playing.

When a metal is immersed in a solution, the electrode potential produced is the algebraic sum of the electrolytic solution pressure and the osmotic pressure. The measurement of pH is accomplished by determining the potential between an electrode immersed in the solution, and a standard reference electrode whose potential with respect to the solution is known. Thus the unknown potential of the test electrode can be determined.

To allow the potential produced by such a cell to cause current flow through the cell, however, would cause rapid polarization of the electrode, so that the apparatus used for measuring the cell potential must be of a noncurrent variety such as a potentiometer, which balances the cell potential against an equal and opposite voltage drop in the potentiometer slide wire, using a galvanometer to indicate the balance point of no current flow. Since an electronic voltmeter can measure such a potential without appreciable current flow in the grid circuit, this method is available for energizing a rugged indicator.

Compared with the glass electrode for pH measurement, the earlier electrodes were considerably limited in range. However, these were generally of not over 1,000 ohms resistance, and their potentials were measurable with the potentiometer and galvanometer arrangement of Fig. 10. In this drawing the potential of the pH cell is balanced against the potential drop of the potentiometer *P*, the galvanometer *G* indicating when the potentials are equal. The voltmeter *V* can then be used to read the potentiometer drop (i.e., the cell potential). It can be calibrated in pH rather than voltage.

The glass electrode, however, is not a low resistance device and if made rugged enough for ordinary use would require a galvanometer of too great fragility, which fact brought the electron tube into use. The glass electrode is a thin bulb of special glass, into which is sealed an internal electrode dipping into an inner reference solution. The cell is completed by means of a standard calomel electrode. This combination, while not a cure-all, gives excellent results in range, freedom from poisoning and from oxidation and reduction effects. With the use of the electronic tube for measuring the exceedingly small energy output of the cell, its disadvantage of fragility is overcome, for it has been found that the cell wall resistance can be increased by many millions of ohms and still supply sufficient energy for operating the electronic meter. The apparatus used is essentially that shown in Fig. 11, employing an electron tube electrometer whose grid voltage is dependent on the difference between the potentiometer and the concentration cell potentials. The exceedingly minute energy is amplified through successive stages until sufficient energy is available for a comparatively rugged meter.

This combination of high resistance electrode and electronic meter, however, introduced new possibilities for error not formerly met. It was first necessary to eliminate leakage between the inner electrode and the immersed outer glass surface, which were at different potentials. This was accomplished by satisfactory design and sealing. The second and more important problem was to find a means of connecting the cell with the electron amplifier, which would not add the self-generated grid potential of the tube to the potential of the potentiometer. In Fig. 11 it will be noted that the grid circuit of the vacuum tube is connected directly into the circuit. The potentiometer, therefore, reads not only the potential generated by the glass electrode, but also the grid potential of the tube, thus introducing an error in measurement.

By use of specially designed electrometer tubes, self-generated grid potentials may be eliminated and accurate measurements made possible, but such electrometer tubes are expensive and fragile and are hardly applicable to a rugged industrial application. This objection has been eliminated by the development of special circuits, one of the most satisfactory of which is illustrated in Fig. 12. In this circuit, the grid-current error is eliminated by so-called impulse amplification.

In Fig. 12 it will be noted that the grid is insulated from the potentiometer circuit by a low capacity condenser *C*. The other side of *C* is normally connected to ground through a switch *S*. On depressing *S*, the condenser *C* is connected to the glass electrode. If the cell-potentiometer circuit is in balance, this point is at ground potential and no change in the condenser charge takes place in *C*. If the potentiometer is out of balance when the switch *S* contacts *T*, the condenser *C* will be charged to the difference of potential in the circuit, and the grid potential of the tube will momentarily be altered, with a consequent pulse of power to the output meter, indicating the lack of potentiometer balance. The potentiometer is then balanced correctly, using the switch *S* after each trial until no deflection occurs at the meter. The condenser *C* is made small so that its momentary energy consumption cannot polarize the electrode.

In a properly proportioned circuit, it is impossible to polarize the glass electrode, even when the potentiometer is far out of balance. Furthermore, it is impossible for the grid current to enter the measurement and upset the accuracy of the potentiometer circuit. The system is entirely independent of battery voltages or tube aging, owing to its use as an impulse amplifier. Some circuits provide an additional resistance *L* and condenser C_1 in order to make the electronic circuit independent of stray electrostatic interference, thus eliminating the necessity for lead shielding.

COLOR AND OPACITY

Photoelectric cells also are being employed extensively in measuring applications, notably in the measurement of such variables as light reflection and transmission of materials, and for the analysis and comparison of colors. This branch of electronics has become so specialized and extensive that it can only be mentioned here. In general, there are three classes of instruments for these purposes: (1) Spectrophotometers capable of producing a complete analysis of the color reflected or transmitted by a material; (2) comparators capable of determining whether two colors are a visual match; and (3) instruments which measure the intensity of light of desired wave length (or mixture of wave lengths) transmitted or reflected by a substance. In the last class are the opacity, turbidity and reflection meters. Both barrier cells and photo emissive tubes are used in the various types of instruments. Generally some method is employed to rule out the characteristics of the cell, together with other variables of the system. Otherwise a means is provided for ready recalibration in the event of changes in the system.

Some of the instruments of this group are extremely ingenious, especially the spectrophotometers. One of the latter automatically draws a continuous color curve, based on either the reflection or transmission of the sample, for the entire visible wave length range, in about 2½ minutes. Another produces a similar curve photographically in a few seconds. In spectrophotometers the illumination of the sample is supplied by a lens and prism system (spectrometer) which permits successive production of all the wave lengths of light desired. Comparators and other instruments generally use only the light produced by an incandescent filament, with or without filters.

"SWITCH" APPLICATIONS

Whereas the measurement applications just described generally employ electronic devices, directly for their *measuring* ability, there are a tremendous number of applications, well in the thousands, where the tube or photocell operates as a sensitive switch or relay, under control of a beam of light or some measuring element. In many of these applications more than one method is possible and, when feasible, parallel solutions will be given.

The applications discussed here, of course, deal only with those for industrial control. The more common ones of sound recording and reproduction, television and radio communication are entirely omitted since they have no bearing on control problems.

Fig. 13 illustrates the basic photocell circuit for use with either high-vacuum or gas-filled photo emissive cells. In this circuit it will be noted that the battery polarizes the anode of the cell through a resistor. When light falls on the cell and the cell in turn becomes conducting owing to the flow of electrons, the current flows from the anode, through the resistor, causing a voltage drop in the resistor which varies as the light upon the cell varies. As shown in several other diagrams, this voltage drop is then led to one or more amplifiers. Figs. 14 and 15 shows two ways this may be done.

In Fig. 14 the photocell is shown in series with a battery and resistor, the resistor being placed across the grid-cathode circuit of an electron amplifier. Variations in voltage across the resistor with variation in light upon the cell cause variation in the grid voltage of the tube. Flow of anode current, in turn, causes operation of the relay. A somewhat simpler circuit, shown in Fig. 15, eliminates the cell battery. In this case the anode of the photocell is polarized by the potential applied to the anode of the amplifier. A commonly used industrial photocell amplifier assembly which operates direct from the power supply lines is shown in Fig. 16. This circuit, it will be noted, is analogous to the circuits of Figs. 14 and 15. Where greater sensitivity is required, so as to operate a relay with less light, a two-stage amplifier may be employed.

Two different methods of relay operation are required in industrial practice. Fig. 17 shows a circuit designed to operate the relay mechanism when a light beam falling on the photocell is broken. This circuit is commonly employed for counters, safety devices and similar applications. Fig. 18 is a circuit used when it is desired to operate the relay of a normally dark cell when light falls on the cell. This is a common application for such problems as daylight control of signs, store lighting, road safety mechanisms, etc.

In addition to the photocell, amplifier and relay, photoelectric applications commonly require use of a light source which will project a beam of light through an appropriate lens system on to the photocell receiver and thus operate the relay mechanism. Fig. 19 illustrates the construction of a light source for producing a fine beam of light suitable for interruption by small objects, and for level control.

Not all photoelectric applications require complete interruption of the light beam, however. A change in the light intensity is the method used for detection of dust, smoke and fumes. A beam of light traversing a duct or stack falls on a photocell. Should smoke or fumes appear in greater than a predetermined concentration, the drop in light intensity can be used to operate an alarm or signal, or to control some automatic correcting means.

In most of the remaining applications to be mentioned here, both photoelectric and non-photoelectric solutions are possible. Although the former type has gained many adherents, a new type of control mechanism has become prominent in recent years, employing the oscillator relay circuit illustrated in Figs. 20 and 21. The electronic oscillator circuit illustrated in Fig. 10*c* of the first article of this series (March 1942) is employed in combination with an electromagnetic relay in the anode circuit. As described in the first article, the anode current of an oscillator is low if the strength of oscillation is high due to efficient feed-back. In such a case, the relay will remain open because of low anode current. If the strength of oscillation is decreased by decreasing the feed-back energy, however, the anode current increases, thus closing the relay. The feed-back energy may be decreased by changing either the inductance or the capacity of the oscillator system, or both. Hence, the anode current will increase and close the relay. Use can be made of this system in a variety of ways, several of which are illustrated in later figures. One method is to use a metal flag inserted by the function-

A Few Typical Applications of Electronic Devices

(Key: Amp., amplifier; Rect., rectifier; P.E., photoelectric; M/C, measurement and/or control; Osc., oscillator; Elect., electronic instruments)

Detecting buried pipe leaks (Amp.)
Geophysical prospecting (Osc., Amp.)
Thickness of sheet metal (Osc.)
Control of coating thickness (P.E., Osc.)
Paper mill pulp control (P.E., Osc.)
Pre-routing on conveyors (P.E., Osc.)
Synchronizing conveyors (P.E., Thyra.)
Leveling elevators (P.E., Osc.)
Elevator door guard (P.E., Osc.)
Automatic batch weighing (P.E., Osc.)
Bag piling by conveyors (P.E.)
Smoke, water hardness alarm (P.E., Osc.)
Welding current and timing (Rect., Amp.)
Traveling bed thickness (P.E., Osc.)
Limit switches for mechanisms (P.E., Osc.)
Motor speed control (Amp.)
High-speed counting (Thyra., Osc.)
Turbidity measurement (P.E.)
Color measurement (P.E.)
Color matching (P.E.)
Opacity measurement (P.E.)
Burner safety devices (P.E., Amp.)
Transparency measurements (P.E.)
Dangerous gas detection (Various)
Detecting missing labels (P.E.)
Lighting control (P.E.)
Automatic voltage control (Amp., Osc.)
Circuit breakers (Thyra., Osc.)
Telemetering (Amp., Osc.)
Synchronizing power circuits (Thyra., Amp., Osc.)
Trespass alarms (P.E., Osc., Thyra.)
Temperature, pressure, liquid level, flow, density, etc. M/C (P.E., Osc., Various)
Titration control (Amp., Osc.)
Distillation control (Osc.)
Ion concentration M/C (Amp., Osc.)
Polarigraph control (P.E., Amp., Osc.)
Interface level control (Amp., Osc.)
Saccharimetry M/C (Amp., Osc.)
Refractometry M/C (P.E.)
Contaminating gas M/C (P.E., Osc.)
Centrifuge control (P.E., Osc.)
Vacuum filter control (Osc.)
Vitamin determinations (P.E., Osc.)
Dust counting (P.E.)
Acidity, alkalinity control (P.E.)
Sorting operations (P.E.)
Bottle fillers (P.E.)
Tube fillers (P.E.)
Tank and bin level control (P.E., Amp.)
Paper mill digester control and white water recovery (P.E., Osc.)
Moisture control in sheet material (Osc.)
Stroboscopes (Grid-Glow)
Electrical quantities M/C (Various)
Rotational speed M/C (Various Elect.)
Viscosity measurement (P.E., Osc.)
Humidity control (Amp., P.E., Osc.)
High capacity contacting (Thyra.)
Current rectification (Rect.)
Current inversion (Thyra.)

ing mechanism into the grid coil of the oscillator (Fig. 21*a*), whereupon the relay contacts will operate. Another method is to change the capacity of the grid tank condenser to achieve the same effect (Fig. 21*b*). The capacity of the condenser or the inductance of the coil can be altered by moving objects. This mechanism is as flexible as most photoelectric assemblies, it is extremely simple and requires no light source.

Use of the oscillator relay of Fig. 20 is often made interchangeably in industrial applications with photoelectric apparatus. Several applications which follow may be handled either way. For example, an electronic micrometer can be made to function with either a photoelectric or oscillator circuit. In the first case an optical lever carrying a mirror will be brought to bear on the material being "miked," with a beam of light reflected by the mirror on to a photocell so that changes in thickness of the material alter the intensity of light falling on the cell. The cell output is amplified and thus operates an indicator, recorder or alarm. If the same result is to be accomplished with an oscillator, a stylus for sensing the thickness of the material can be connected to a small variable condenser used to control the plate current of the oscillator.

Other applications for both photoelectric and oscillator equipment are common in industrial weighing operations and also in liquid level control. Fig. 22 shows diagrammatically the oscillator type control applied to a platform scale beam. Figs. 23 and 24 show both photoelectric and oscillator equipment employed for liquid level control. In the photoelectric application, a change in light falling on the photo head as the level increases causes the relay to operate, while in the oscillator application a capacity pick-up placed on the gage column controls the oscillator through change in the capacity of the pick-up as the liquid level rises. Such a control may be applied equally well to a manometer tube for flow control. Still another method of level control is to use a probe inserted through the tank wall, employing conductivity as the measured factor.

Figs. 25 and 26 illustrate an important electronic application in which either photoelectric or electronic relay equipment may be used. In order to prevent the entry of raw fuel into the combustion chamber of an industrial boiler in the case of flame failure, a method of detecting the absence of flame which is capable of operating a relay to close off the fuel valve is necessary. The photoelectric type of Fig. 25 employs a photo-head sighted on the flame. The electronic type depends upon the fact that a flame is capable of conducting an electric current. An electrode contacting the flame causes a voltage change on the grid of an electronic relay. As long as the flame is present, the relay maintains the fuel valve open. Should the flame be extinguished, the conducting circuit of the electrode is broken, whereupon the grid bias of the tube changes, operating the relay and closing the valve.

Reprints of this 8-page report are available at 25 cents per copy. Address the Editorial Department, *Chem. & Met.*, 330 W. 42nd St., New York, N. Y.

Many instruments for the indication, recording and control of such variables as temperature, pressure, flow, liquid level and pH are now employing electronic relays. Delicate instruments are disturbed in their measurement if required to do any considerable mechanical contacting work. Many ingenious contacting mechanisms based on electronic means have been developed to overcome this difficulty. Since such mechanisms can be made to function with a minute expenditure of energy, they have become increasingly important.

Systems of this type are divided roughly into two classes: (1) Contact-making systems; and (2) non-contact-making systems. The latter class includes relay mechanisms of both photoelectric and oscillator types. Fig. 27 shows an example of the first type in which it will be noted that the measuring instrument *M* carries on its pointer an extremely light contact which is placed in the grid circuit of an amplifier tube. When the contact is open the grid of the tube is negatively biased to maintain the plate current low and hold the relay open. When the contact is made, a positive bias is applied to the grid of the relay tube from the biasing battery, whereupon plate current rises sufficiently to close the relay contacts. Because of the minute quantity of energy present in the grid circuit, the contact system carries no appreciable current.

Fig. 28 shows how a similar result may be accomplished without contact, by photoelectric means. The measuring system *M* carries a small mirror which reflects a beam of light into or away from a photoelectric pick-up head whose output controls a relay through an amplifier stage. Several different methods including slits and special mirrors are used for sharp cut-off.

A second non-contact method using an oscillator relay is illustrated in Fig. 29. Here the measuring instrument pointer *M* carries a small metallic flag capable of passing into the field of the pick-up system. When such action takes place the oscillator relay changes its tuning so as to cause relay contact operation. In any of the three systems just discussed, the measuring system may be a galvanometer, millivoltmeter, microammeter or similar instrument, depending on the measuring problem.

Both photoelectric and oscillator relays are often used as limit switches in the limiting of various kinds of mechanical motion. The application, of course, is similar to level control.

Counting objects passing on a conveyor, or objects or persons approaching a given point, is another common type of application. Photoelectric counting is readily accomplished by connecting an electromagnetic counter to the relay mechanism and arranging the light source and photo-head so that each object passing interrupts the light beam, causing the relay to operate and add one digit to the counter. Such apparatus may be arranged to count one unit for every five or ten objects passing, in which case it is called a multiplying counter. Objects passing at considerable speed can be handled. Oscillator relays may be used similarly for small objects by passing the objects between the plates of a condenser in the grid circuit.

In the case of larger objects, one of several varieties of "approach relay" can be used. Such relays operate by the approach or recession of a body or mass which in most cases is a conductor. The circuit may be built around either a high-vacuum or gas-filled tube circuit. In the former case an oscillator, amplifier and relay mechanism will be used, and in the latter, a tube of the Thyratron variety. Figs. 30 and 31 show the two alternate circuits. The circuit in Fig. 30 consists of an oscillator which is tuned to resonance, as described in the first article of this series. An approach plate or antenna is connected across the oscillator inductance. Upon approach of a mass to this plate or antenna, the capacity of the antenna to ground is varied, whereupon the oscillator is detuned or retuned as desired. The oscillator consequently varies its plate current which in turn varies the bias on the grid of the amplifier and operates the relay.

Fig. 31 shows the Thyratron type of approach relay, with a plate or antenna connected to the control electrode of the Thyratron. Normally, because the control electrode is "free" (i.e., no external voltage is applied to it), an accumulation of electrons collects on the control grid, from the space charge within the tube. The electrode is therefore negative and no discharge occurs in the tube. When a body approaches the antenna, electrons leak from the control electrode to the body, permitting the tube to fire and thus operate the relay mechanism. Such systems are used for counting metallic objects passing on conveyors, as limit switches, conductivity alarms, ignition alarms, for liquid level control, for the detection of intruders and for personal safety controls about machinery.

Manifestly, this article and the one that preceded it have been unable to do more than scratch the surface of a subject which has already grown beyond the bounds of many volumes. The electronic art is a tremendous one and it is still expanding rapidly. If these pages have given chemical engineers some conception of the things electronic devices are doing, or can do for them, they will have served their purpose.

Machinery, Materials and Products

CHEM & MET PROCESS EQUIPMENT NEWS

Vibrating Screen

Smoother operation, maximum flexibility, greater overloads and the ability to handle more capacity are claimed for the new Type M vibrating screen recently announced by Robins Conveying Belt Co., Passaic, N. J. This screen is of the high-speed type, rubber-cushioned and supported on leaf springs, with a sharp vibrating action produced by adjustable counterweighted arms. Elimination of flywheels and their high inertia, coupled with the use of oil-lubricated bearings, equipped with double bronze centrifugal flingers to prevent lubricant loss and contamination, are said to minimize power requirements. Screen cloth sections are rubber-cushioned and maintained under arched transverse spring tension. It is claimed that vibration cannot be transmitted to the building structure, while objectionable start-and-stop bounce is eliminated. Floor mounting is possible and foundation requirements minimized. Screen inclination, operating speed and vibration amplitude are all readily changed to fit the requirements.

Welder Trailer

Road towing at speeds up to 35 m.p.h. is possible with the new two-wheel light weight pneumatic-tired welder trailer recently announced by Hobart Bros. Co., Troy, Ohio. This trailer, intended for the mounting of 200, 300 and 400 amp. Hobart electric drive welders, is designed particularly for hurry-up trips to different locations for emergency repair and maintenance work. Mounting is accomplished easily by means of three bolts through the trailer frame which register with three holes in the legs of the welding machine. A combination tow bar and standing support has a hand-operated ratchet for locking the support arm in position. Owing to under-slung construction, narrow tread and careful balancing, the unit may readily be moved by hand.

Disk Filters

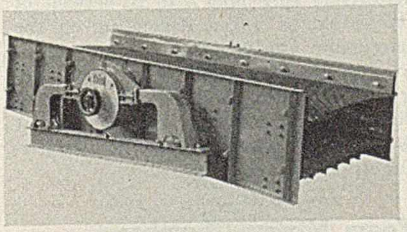
A new design of filter known as the Sealed Disk type, intended primarily for the clarification of liquids containing relatively small amounts of solids, has been announced by Alsop Engineering Corp., Milldale, Conn. According to the manufacturer, the new design provides more filtering area in proportion to the space occupied by the filter than has heretofore been available in filters of this type. The new filter, shown in cross section in the accompanying drawing, employs throw-away filter disks composed of fibers. A single disk is formed from a large number of superimposed layers with the fibers on one side long and loosely matted, and each succeeding layer toward the other side containing shorter and more closely packed fibers. Thus the loose side can catch coarse particles while each additional layer stops finer particles. Various disk densities are available for different filtration jobs.

From the cross section it is evident that the liquid to be filtered enters in the space surrounding the stack of filter elements, then passes through holes in the spacing rings and flows upward and downward through adjacent filter disks. Having passed through a disk, the liquid drains through a perforated screen support to the center tube and leaves the filter. Spacing rings are of various designs, depending on the quantity of solid material (impurities, activated carbon, filter aids, etc.). In cleaning, the screw at the top is removed, after which the cover and outer cylindrical wall lift off and the individual filter elements may then be removed, the disks thrown away and replaced with new ones. Filters are regularly supplied on a supporting stand equipped with a pump and motor.

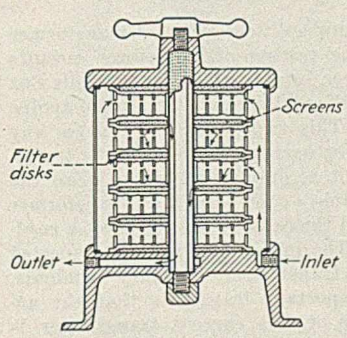
Fuse Holder

Simplifying the changing of fuses in close quarters is an important feature of the spare fuse holder and puller, recently announced by Littelfuse, Inc., 4797 Ravenswood Ave., Chicago, Ill. Adapted to all 4 AG and

Type M vibrating screen



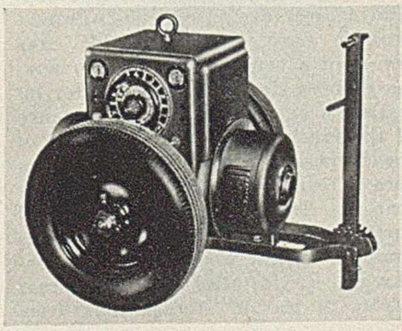
"Sealed Disk" filter



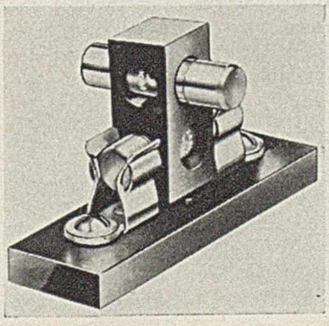
New Design Jaw Crusher

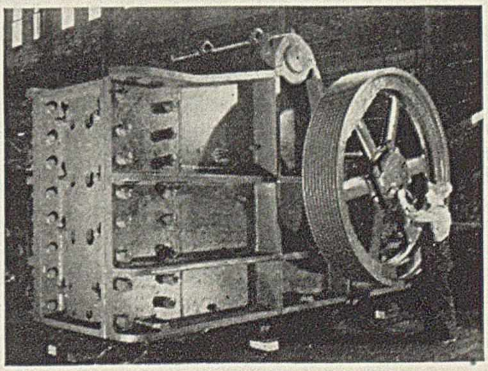
The crusher shown here is a new design recently completed by Allis-Chalmers Mfg. Co., Milwaukee, Wis. Weighing about 130,000 lb., the crusher has a receiving opening 48x42 in. and is intended for crushing of extremely hard ore. This machine, one of several being built, is made with rolled-steel welded side frames to obtain greater strength and less weight, replacing the older type of crusher made with cast iron frames and reinforced by steel tension bolts.

Light-weight welder trailer



Fuse holder and puller





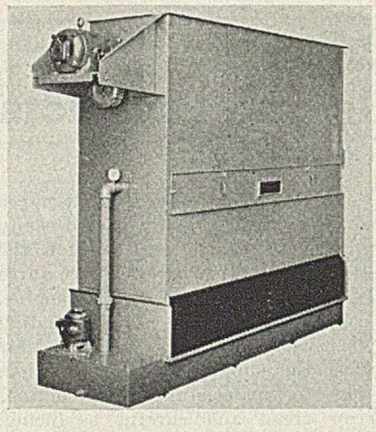
5 AG fuses, the device consists of a soft rubber rectangular holder which, as shown in the accompanying illustration, is put to use by inserting two fuses through the holes in opposite directions. The block is employed as a handle in inserting one fuse in the circuit, while the second fuse is held as a spare. When the fuse blows, the holder is then used to pull the fuse and to insert the spare in position. One end of the holder is painted red. Until a fuse change is necessary, the red end is concealed but when a reverse is made, putting the spare fuse into the circuit, the red end is brought into view to indicate to all concerned that another spare is required.

Evaporative Cooler

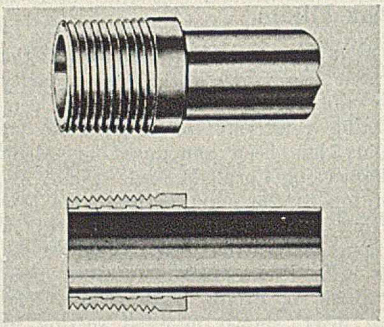
Rapid cooling of many industrial liquids such as oils, chemicals and jacket water is possible with a new unit type evaporative cooler introduced by the Niagara Blower Co., Buffalo, N. Y. The new unit consists of a casing containing tubes through which the hot liquid passes. A spray system drenches the tubes constantly with recirculated water while air, drawn through the sprayed coils by a fan, evaporates about 5 percent of the water in producing the desired refrigeration effect. Provision is made for bypassing the air, under control of thermostatically operated dampers, to maintain constant liquid temperature. A heating coil in the liquid tank is provided for preventing freezing in winter and also for preventing the separation of high-melting-point compounds from solution. The unit is built in a variety of refrigeration capacities and is particularly recommended by the manufacturer for use where cooling water economy is necessary. It is pointed out that water consumption amounts to only about 5 percent of that required by shell and tube heat exchangers.

Tubing Joint

A new joint for thin-walled stainless steel tubing which can be used in conjunction with standard threaded i.p.s. fittings of all kinds is now being offered by Tri-Cover Machine Co., Kenosha, Wis. The Wallace joint, for the manufacture of which this company possesses an exclusive license, consists of a specially threaded enlarging ferrule which is inseparably joined to a length of stainless tubing by expanding the tubing into grooves in the ferrule. The joint can be furnished either attached permanently to tubing or separately, to be attached by the customer. No welding or soldering is necessary and the pipe may be attached to valves and fittings by simple plumbing. Owing to the high strength of thin-walled stainless tubing, it is able to replace much heavier pipes of standard i.p.s. thickness (which must be much thicker than necessary to accommodate the threads). For example, a 1½ in. standard pipe weighs 2.717 lb. per ft. whereas the tube used with the Wallace joint to do a comparable job, weighs 0.759 lb. A saving of about 65 percent in material is said to result without loss in effectiveness. Sizes are available from ½ to 4 in. iron pipe size, to accommodate tubing of the same nominal outside diameter.



Industrial evaporative cooler



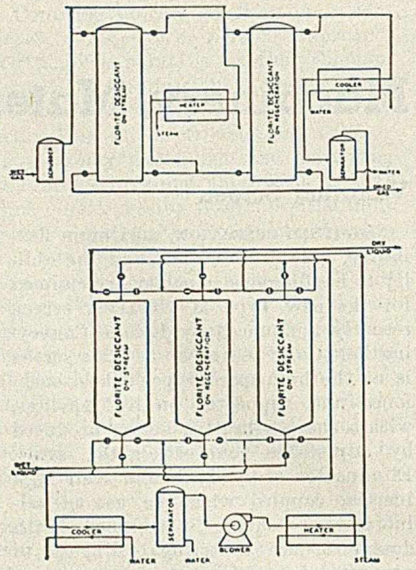
Joint for thin-walled tube

Testing Transformer

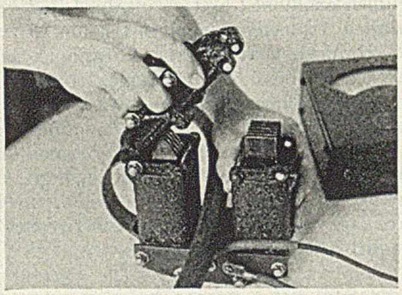
A new split-core current transformer for the testing of a.c. power circuits has been introduced by R. B. Annis Co., 1101 North Delaware St., Indianapolis, Ind. This transformer eliminates any need for opening a circuit to be tested, since it is only necessary to close the separable core of the transformer around the cable or buss to effect a reading. The instrument is then connected to the transformer secondary terminals. An important feature is that the accuracy of this current transformer is said to be practically independent of the tightness of closing of the magnetic core. By looping the cable through the transformer two or three times, two additional primary current ranges are made available.

Desiccating Agent

What is claimed to be a suitable desiccating agent for both gases and liquids is Florite Desiccant, a new granular drying agent now being marketed by the Floridin Co., 126 Liberty St., Warren, Pa. Among the products dehydrated by this means, according to the company, are natural gas, propane, gasoline, air, nitrogen and carbon dioxide. The material is said to maintain high drying efficiency under difficult conditions, adsorbing water instantly without swelling, disintegrating or appearing wet at the end of the adsorption cycle. It is hard, stable, non-corrosive and non-poisonous, selectively adsorbing 4 to 20 percent of its weight of water, depending on the particular application. It is regenerated by heating to 300-350 deg. F. Suggested flow diagrams for the desiccation of gases (at top), and liquids (at bottom), are shown in the accompanying drawing.



Dehydration set-ups for gases and liquids



Split-core test transformer

Foam Mixing Chamber

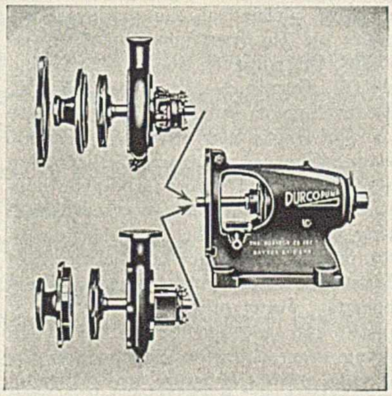
For the protection of petroleum products and other flammable liquid supplies against fire, American-LaFrance-Foamite Corp., Elmira, N. Y., has developed a new "Evertite" foam mixing chamber designed especially for installation on modern oil storage tanks of the pressure type. The purpose of the chamber is to mix the two solutions used in foam production and permit the foam to flow on to the burning oil surface in the tank. The chamber is equipped with a vaporproof glass diaphragm so installed as to prevent vapors in the oil storage tank from entering the body of the mixing chamber or escaping therefrom. The diaphragm, glazed in a metal frame, holds gas tank pressure yet ruptures fully under foam pressure at the time of fire, allowing free access of the foam blanket to the burning surface. Diaphragms are readily replaced. The chamber is of the expansion type with increasing cross-sectional area to provide intimate mixing of the foam chemicals and permit low delivery velocity.

Convertible Chemical Pumps

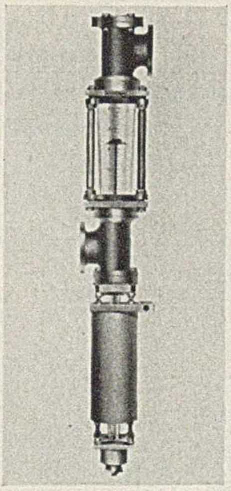
As many as 480 combinations of alloys, types and sizes, with heads and capacities to meet almost any requirement, are found in a new series of corrosion resisting pumps announced by The Duriron Co., Dayton, Ohio. Convertible features said to be obtainable only in this series of Durcopumps, which are made of the high-silicon irons, Duriron and Durichlor, permit them to be converted to stainless steel pumps simply by substituting stainless steel wet-end parts. The exchange can be made without disturbing the setting of the pump, a feature said to be especially valuable where frequent changes in process or in chemicals handled must be met.

Other features of interchangeability include newly designed interchangeable open and closed impellers, with negative pressure on the stuffing box. The pumps feature over-sized ball bearings throughout, and micro-adjustment of the impeller for maximum operating efficiency.

Interchangeable Durcopump



Flow control transmitter

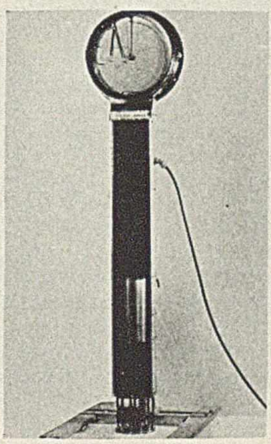


Rotameter Controller

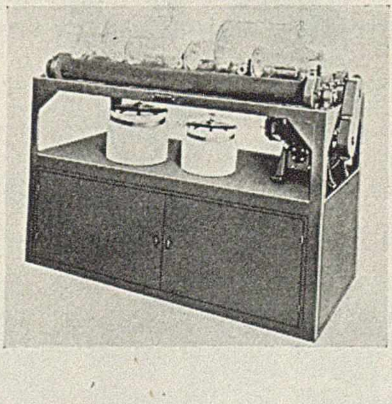
Combination of electrical transmission of the flow indication, with pneumatic control of the flow, is featured in the new Rota-Matic flow controller recently announced by Fischer & Porter Co., Hatboro, Pa. The indicating instrument consists of a Rotameter flowmeter, the sensitive element of which may be either of conventional type, or may employ the company's new Ultra-Stablvis float which is unaffected by changes in viscosity of the liquid metered. Connected to the float is a soft iron armature which is positioned by the float in the coils of a self-balancing induction bridge beneath the metering tube. A similar pair of impedance coils in the receiving instrument causes the receiving armature to be positioned similarly to the sending armature, and hence adjusts the indicating pen or pointer of the receiver.

The pen arm is so connected with a control index arm that if the two are not in identical position in respect to the indicator scale or recorder chart, a flapper is moved nearer to or farther from a fixed air nozzle, resulting in changed air pressure within a bellows type control system. This in turn results in a change of air pressure on the diaphragm motor valve installed in the pipe line being controlled. The bellows control mechanism has a 0–150 percent throttling range adjustment and an adjustable reset mechanism.

Viscosity-density recorder



Three-roller jar rolling machine



The receiving instrument may be of either indicating-controlling, recording-controlling or recording-integrating-controlling type. Two instruments may, if desired, be mechanically coupled together for ratio control of two flows. Time cycle variations of the control point are also possible. Visual flow rate indication at the Rotameter can be used for manual control in event of power failure. The instrument is built in suitable construction materials for handling a wide variety of materials of both high and low viscosity, ranging from acids, tars and organic liquids to caustics and other chemicals.

Viscosity Recorder

Employing a new recording instrument recently introduced by the Petroleum Instrument Corp., 738 East 3d St., Los Angeles, Calif., it is possible to make accurate continuous measurements of both viscosity and specific gravity of liquids. Originally designed for measurements on fluids used in drilling oil wells, the instrument has been adapted for employment in many other industries. The continuous record is recorded on a 12-in., 24-hr. chart, with viscosity in centipoises and gravity in units as desired. The viscosity measuring element is a smooth cylindrical solid metallic rotor, revolving at constant speed in the liquid and turning inside a cage which contains six stationary blades. The motor torque is a measure of the viscosity, which is transmitted to the recording mechanism. Furthermore, the rotor is suspended on a weighing mechanism so that the buoyant force of the liquid, which is proportional to the specific gravity, is also transmitted to the instrument in terms of liquid density. Features include light weight, simple design, rugged construction, operation from an ordinary lighting circuit, and ease of calibration against water.

Jar Rolling Machine

For batch grinding and mixing of process materials of all kinds, Abbé Engineering Co., 50 Church St., New York, N. Y., has developed a new line of jar and bottle rolling machines built in a variety of sizes and types. In its simplest form, the machine consists of two parallel rubber-covered steel rollers, mounted in large bearings and driven by means of a geared head motor, the assembly being mounted on a welded steel base. Jars or bottles of various sizes can be placed on the rollers and turn as the rollers turn.

One design employs three parallel rollers for two lines of bottles or jars. Another is a double-decked model with four rollers arranged in two tiers, capable of handling eight 2.75-gal. jars.

Equipment Briefs

INCREASE in combustion efficiency in boiler furnaces is claimed by Photoswitch, Inc., 21 Chestnut St., Cambridge, Mass., when its new photoelectric smoke alarm Type A 25C is employed for indicating the degree of smoke density passing through the stack. The equipment includes a photoelectric control, light source and indicator. The photoelectric control and light source are mounted on opposite sides of the flue or stack, so aligned that the light beam, falling on the photoelectric cell, is modulated depending on smoke density. The design of the lens system mounting is said to minimize effects of soot and dust. The indicating equipment may be located at any point to facilitate observation by the operator. A green signal light indicates efficient combustion, while a red light indicates excessive smoke density passing through the stack.

C M METEOR is the designation of a new line of heavy duty electric hoists announced by Chisholm-Moore Hoist Corp., Tonawanda, N. Y. The hoist is compact and designed to eliminate excess weight. Cooling fins are provided for quick dissipation of heat generated by gears and load brake. Construction is fully inclosed and weatherproof, with a specially designed electrical system which permits only 110 volts to pass through the pushbutton station. Sizes range from ½ ton capacity, up.

MANUFACTURE of reclaimed rubber V-belts has been announced by B. F. Goodrich Co., Akron, Ohio. These belts are claimed to give 80 percent of customary service without requiring any crude rubber. Thus, unless additional rationing of reclaimed rubber is required, the company believes that these V-belts will continue to be available for the multitude of uses to which V-belts are now being put.

TO FACILITATE attachment of its air-motored agitators to 30- and 50-gal. drums, Eclipse Air Brush Co., 400 Park Ave., Newark, N. J., has developed two sizes of V-shaped brackets which clamp across the top of the drum by means of a screw clamp which allows for variations in drum size. The mixer, attached to the bracket, can be adjusted to any angle.

Carbon Monoxide Recorder

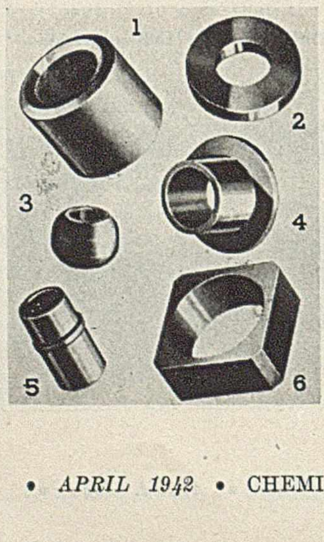
AN IMPROVED carbon monoxide recorder, available either for high sensitivity or wide range, has been developed by Mine Safety Appliances Co., Braddock, Thomas and Meade Sts., Pittsburgh, Pa. The new instrument is a refinement of the company's original carbon monoxide recorder. It consists of a dryer, analyzer and potentiometer recorder. Range and sensitivity can be varied to suit the conditions. If sensitivity is of primary importance, the instrument is calibrated to cover a range from 0 to 500 p.p.m., permitting a sensitivity of 1 p.p.m. When a wider range is needed the instrument is designed to cover a range from 0 to 2,000 p.p.m., permitting a sensitivity of 4 p.p.m. Both ranges can be provided in the same instrument, by providing two calibrations. This sensitivity is said to be about ten times greater than that of the most refined analytical determination.

In operation a motor-driven pump draws a sample continuously from the point of sampling and forces a part of this sample through the dryer and then through an analyzer employing a "Hopcalite" cell. Carbon monoxide in the sample is oxidized to carbon dioxide with the liberation of heat proportional to the amount of CO present. The heat liberated is measured by thermocouples imbedded in the "Hopcalite" and the resultant current is measured by the recorder potentiometer, indicating on a chart as percent CO. Up to six contactors can be provided on the potentiometer to operate valves, ventilation controls, or warning signals.

Porous Iron Bearings

SAID TO BE stronger than porous bronze bearings, a new line of porous iron bearings which are interchangeable with comparable bronze bearings, in most applications, has been introduced by the Keystone Carbon Co., 1935 State St., St. Marys, Pa. The new Selflube porous iron bearings are made of powdered iron, molded to size, in the shape desired, then baked and finally saturated with lubricating oil. Having an average porosity of 25-35 percent, these bearings hold sufficient oil to last, in many cases, for the entire life of the application. A low coefficient of friction, combined with self-lubrication, is said to prevent excessive temperature, speed reduction, noise and scoring of shafts. The accompanying illustration shows a variety of types including (1) sleeve or plain cylindrical bearing, (2) washer or thrust bearing, (3) spherical or self-aligning bearing, (4) flanged bearing, with special shapes shown at (5) and (6).

New porous iron bearings



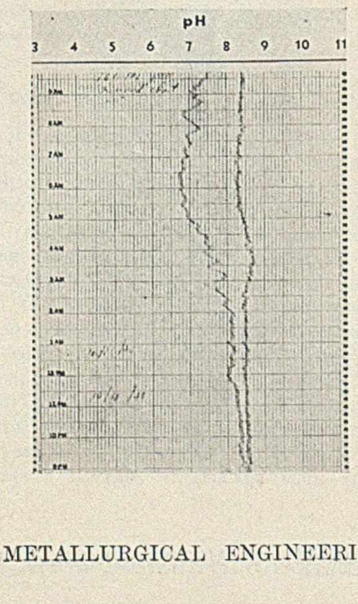
Stainless Steel Tubing

A NEW, closely controllable electric welding process is now being used in the production of stainless steel tubing by Globe Steel Tubes Co., Milwaukee, Wis. This process, developed after a long period of research and experiment, is said to produce tubing of high strength and corrosion resistance, and uniformity of structure. The process welds the stainless strip with a minimum of "flash", hence minimizing work in producing a smooth-finished tube. The weld metal structure is said closely to approximate that of the tube. It is claimed that the new tubing can be readily bent, coiled, swaged and formed. Marketed under the name of "Gloweld", it will soon be available in a wide range of diameters and wall thicknesses, in practically all stainless steel analyses.

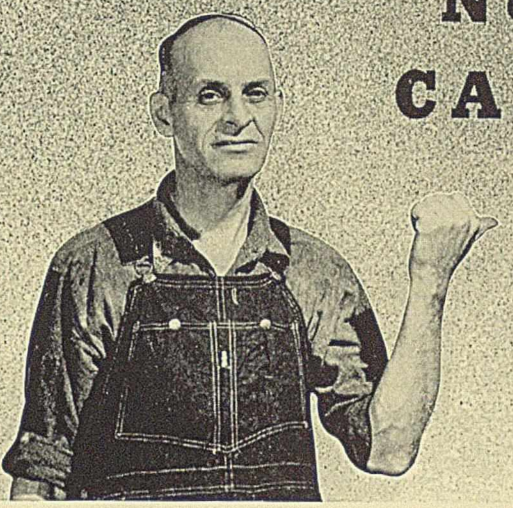
Multi-Point pH Recorder

TO PERMIT the recording of pH from separate and independent points in a fluid-flow system and thus enable the operator to see continuously the before-and-after picture of the pH as it responds to the treatment used, Cambridge Instrument Co., 3732 Grand Central Terminal, New York, N. Y., has developed a multi-point pH recorder incorporating a new advance in circuit design. The accompanying illustration shows an actual record from the condensate system of a large steam-generating plant where the multi-point control is used in observing the effect of treatment to eliminate turbine blade deposits. Many other types of use of multi-point instruments are suggested, among them being applications in the brewing, pulp and paper, and oil-refining fields as well as in sugar refineries and in water treatment.

Two-point pH record

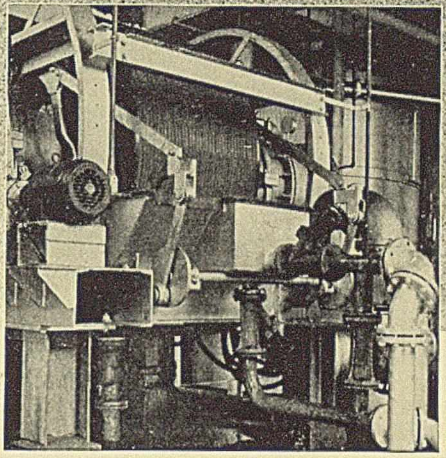


"Corrosion Problems? Not with SWENSON CAST LEAD FILTERS!"

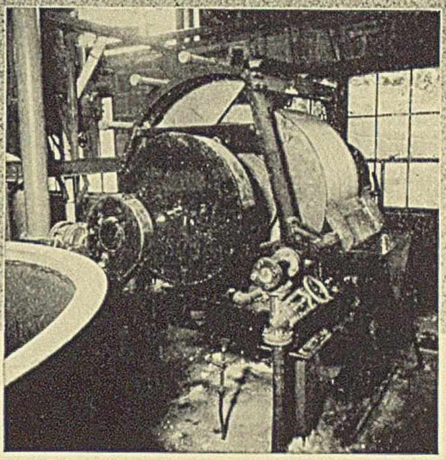


"The development of Swenson cast lead filters has certainly been a life saver for us in handling corrosive liquors. The use of cast and heavy sheet lead in the construction of these units means that they are exceptionally satisfactory in resisting corrosion. As a result, we have less interruptions to our processes, less repairs, lower maintenance charges, and lower operating costs.

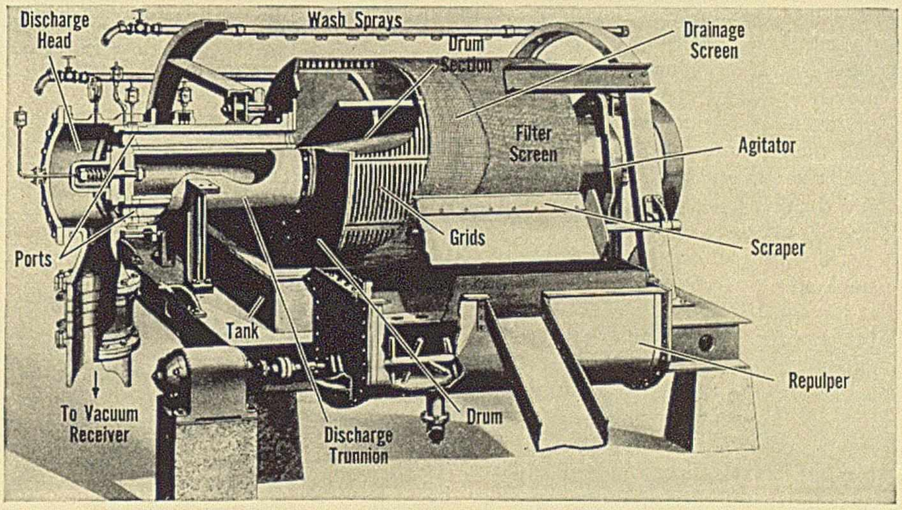
"Not only that, but the rotary drum design gives us high capacities. Cloth blinding is practically eliminated, the filtrate is clear, and the cake uniform and easy to wash. These are the reasons why we prefer Swenson cast lead filters."



Swenson cast lead filters have proven remarkably successful in handling Glauber's salt, zinc sulphate, copperas, etc., from acid solutions.



The simple mechanical construction of the lead type rotary drum vacuum filter and its resistance to corrosion greatly reduce maintenance costs.



The main foundation is of heavy sheet lead. Grids and discharge head are of cast lead. Filter screens may be of Monel metal, stainless steel, or perforated rubber. Some of the external parts are constructed of rubber-lined steel.

SWENSON EVAPORATOR COMPANY

Division of Whiting Corporation • *15669 Lathrop Ave., Harvey, Ill.*

SWENSON

LEAD FILTERS • EVAPORATORS • CRYSTALLIZERS

Smokeless Powder

When peace comes to a country the smokeless powder industry has the unusual habit of almost entirely vanishing for the duration. However, when trouble appears on the horizon great smokeless powder plants reappear as vegetation does in the spring of the year. Already they are to be found scattered over the country.

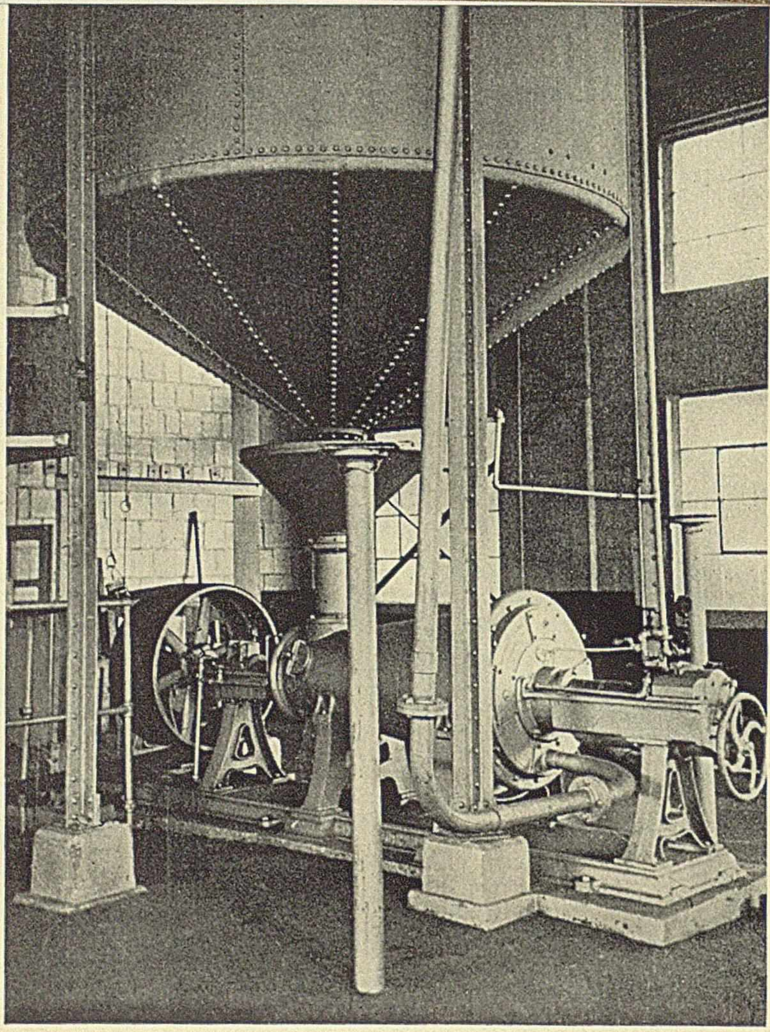
The base of smokeless powder is nitrocellulose made by nitrating cellulose. Wood or cotton linters are used as the source of the cellulose. Purified cellulose is conveyed to the nitrating house where it is charged into dipping pots along with acids. After dipping the contents is dropped into the wringer and from there into the immersion basin, drowned with water and flushed into slurry tanks. Impurities are removed in the boiling tub procedure. After the boil is complete, the material is run out of the tubs and into another intermediate slurry tank. Any free acid is neutralized with sodium carbonate. Final neutralization is accomplished in the poacher house by addition of more carbonate. Boilings, settlings, decantations, and rewaterings follow, and the residual carbonate and salts are removed by cold water washes. Each high-grade and pyro poacher charge is analyzed and then pumped to huge vats with umbrella baffles and agitators in the blending and wringer house. Blending produces the desired nitrogen content.

The product is now ready for the smokeless powder area. The first action is the substitution of alcohol for water in the powder. The mass is pressed leaving enough alcohol to satisfy the colloidizing action in the mixers. Here blocks are broken and partially mixed with insoluble compounding agents and then ether, containing a stabilizer and plasticizer, is added. In the case of cannon powder the colloidal formation is completed in macerators, then blocked in presses for convenience in handling. It is screened and pressed into strings and cut in desired lengths. Solvents are removed and recovered. The powder is blended, weighed into containers which are then sealed, air-tested, stenciled, and routed to shipping and storage departments.

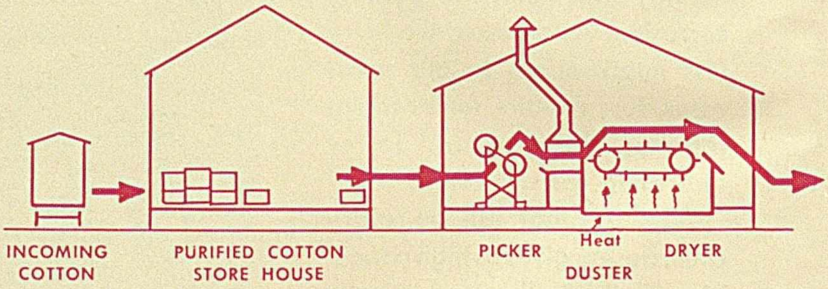
CHEMICAL & METALLURGICAL
ENGINEERING

April, 1942

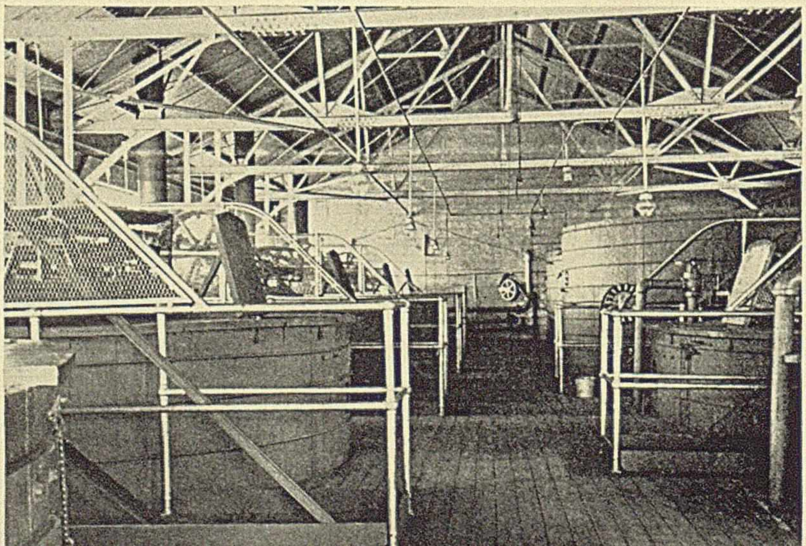
PAGES 110-4 to 113-4

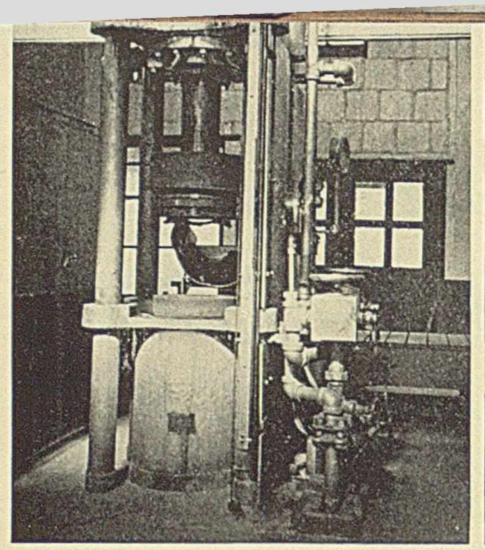


1 In the purification of the nitrated cellulose it is necessary to pass it through a series of three jordan refiners with an alkaline slurry

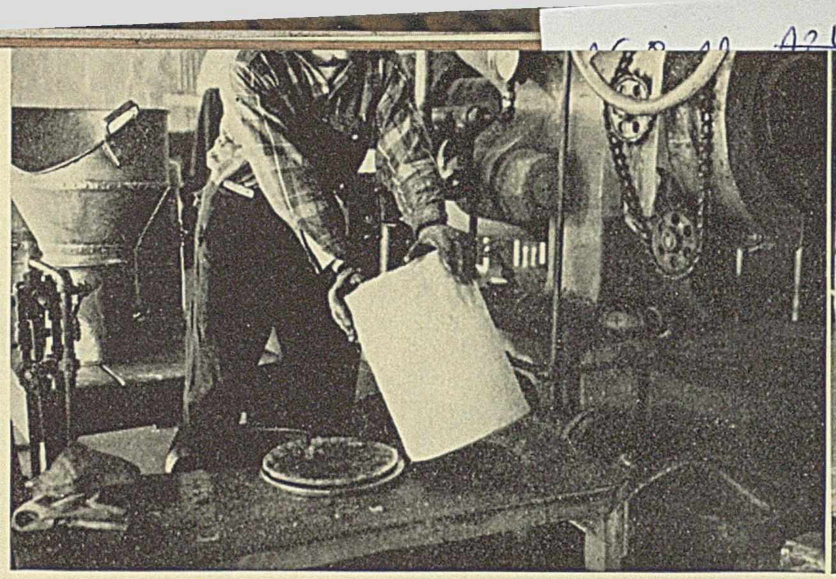


2 Final neutralization of the nitrocellulose is accomplished in the poacher house by the addition of more sodium carbonate

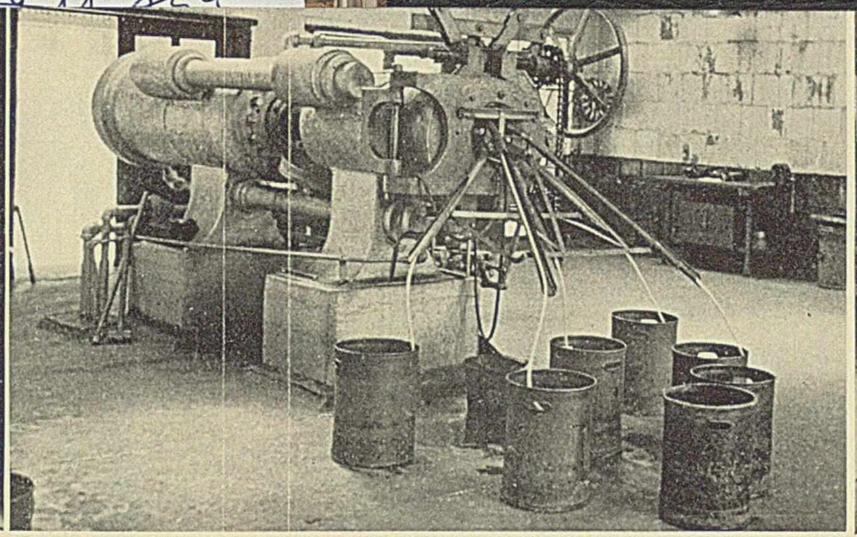




3 Alcohol is forced in at the bottom of the press displacing the water

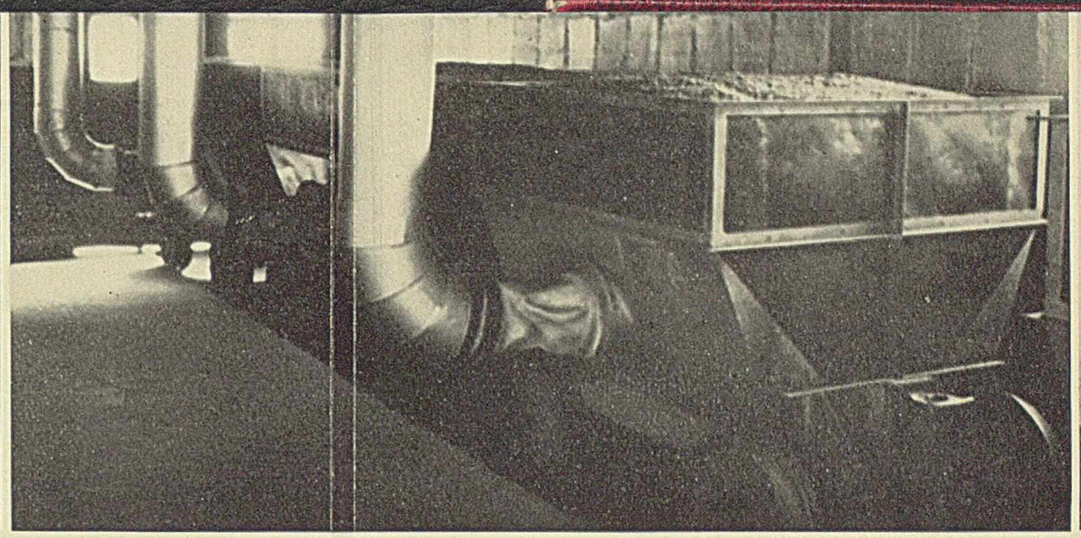


5 The colloidal formation is completed in mixers of a slightly different type and then blocked in presses for convenience in handling

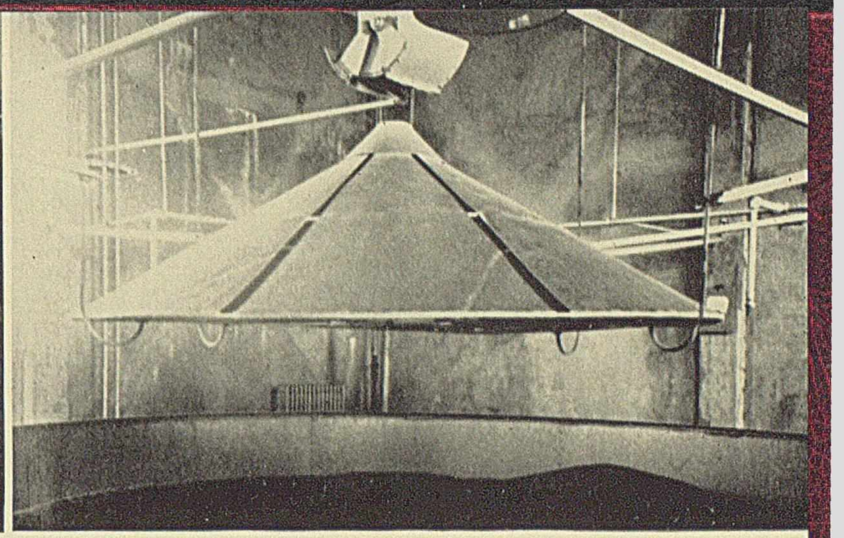


7 This powder is blocked once more and sent to graining presses which extrude the powder through screens followed by a perforated die

9 Powder is put into covered cars which are sent to the solvent recovery building

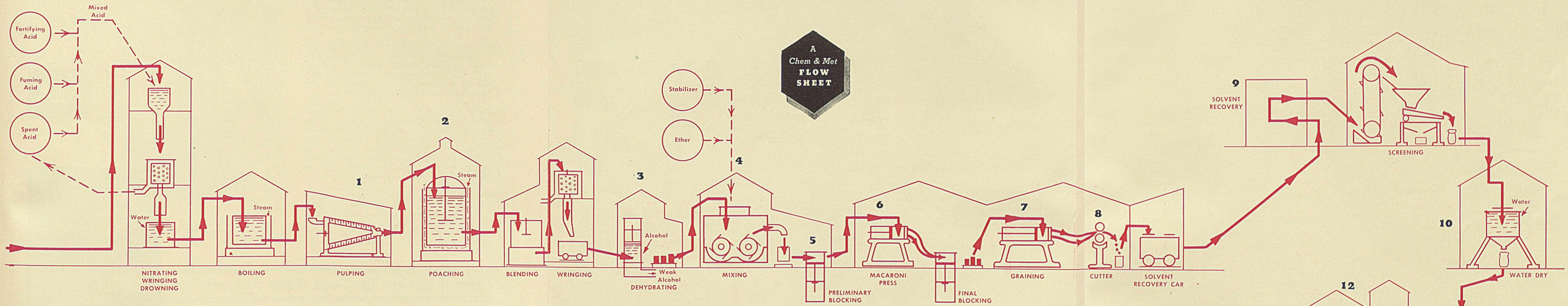


11 The mass is dumped into a bin and hot air is passed through the powder for a sufficient length of time to bring the moisture content down to an average value



12 Blending is next in order, and blending towers with drop hoppers are provided for this purpose

A *Chem & Met* FLOW SHEET



4 Actual colloidizing is done in the mixer house where the dehydrated alcohol-containing blocks are charged into mixers

6 Powder is put through macaroni press in order to remove lumps and impurities. It comes out in rope-like form

8 Strings of powder so obtained are sent to a cutter where powder grain lengths are regulated

10 In the water-dry house the remaining solvent is removed. Preheated water is pumped through the tanks so that solvent may be dissolved