

CADMAN MEMORIAL LECTURE.

THE First Cadman Memorial Lecture, organized by the Institute of Petroleum, was delivered by SIR WILLIAM FRASER, C.B.E., on March 27, 1946, in the Lecture Hall of the Royal Institution, London. The chair was taken by SIR ANDREW AGNEW, C.B.E., President of the Institute, and among the large gathering were: Lily, Lady Cadman; the Lord Cadman of Silverdale; the Hon. Anthony Cadman; the Hon. Mrs. Tatum and Mr. John Tatum; Mr. James Cadman, D.S.C.; and Major W. H. Cadman, M.B.E.

THE FIRST CADMAN MEMORIAL LECTURE

By SIR WILLIAM FRASER, C.B.E.

On the beautiful memorial medal which Mrs. Gillick has designed to commemorate Lord Cadman's work there is a Latin inscription which, when translated, reads:

*"THROUGH THE LIGHT OF INTELLIGENCE TO THE
INCREASE OF KNOWLEDGE"*

These words sum up in an admirable fashion Lord Cadman's natural mission in life—a mission to advance and apply knowledge by intelligent research.

It seems to me fitting in this first Memorial Lecture, and by way of introduction to future lectures, to dwell a little on the significance of Lord Cadman's personal contribution, which was great, to the evolution of petroleum. He was a man of vision who looked on the world through many windows, but the latter half of his life was preponderantly concerned with the part that petroleum in all its complexities was destined to occupy in the world at large. In the chair of the company in which, after his lamented death in 1941, I had the honour to succeed him, he had, and used, a great opportunity for making his views effective over a very wide range of administrative responsibility. The wisdom of his policy and the widespread acceptance of much that he publicly and persistently urged on the need for a full liaison between science and industry gave him a position of exceptional credit amongst the foremost world figures of the oil industry.

I knew him for nearly forty years. For twenty of these we were not only daily colleagues, but very great friends. When, therefore, your President and Council honoured me with an invitation to give this lecture, I felt privileged to accept.

It is natural that in what I have to say I shall not infrequently refer, by way of illustration, to instances of technical progress in matters concerning Iran, and of Cadman's association therewith, for these are subjects on which I am personally best informed and with which I have been, and remain, intimately concerned. But I would not like it to be inferred—





THE LATE LORD CADMAN OF SILVERDALE.

[To face p. 241.]

and this I must stress—that I am otherwise than acutely conscious of the fact that the progress of which I shall speak is due to many men, in many countries (the U.S.A. particularly), and that the contributions made in one sphere have often been paralleled by similar or analogous work in others.

Now let me say a few words about Cadman's career. As a young man, well equipped with a scientific training, a most inquiring mind, great tenacity of purpose, and an engaging personality, he served as an Inspector of Mines in Scotland, his district covering not only many collieries, but also the productive oil-shale areas. It was from distillates of coal and shale that James Young first produced an illuminating oil over fifty years before Cadman's time (in fact, the centenary of this pioneer effort falls in 1947), and it was particularly from a study of Young's work, combined with the nature of his own official duties, that Cadman derived a strong directive impulse towards petroleum.

Let me add here that in mentioning Young's work and its inspiration to Cadman, I have not overlooked the fact that in one sense the birth of the petroleum industry took place here in the laboratories of the Royal Institution. It was, I understand, about twenty years before Young's work, that Faraday, working not many yards from this lecture theatre, first isolated benzene, and on this spot on which I stand to-day he described the results to an enthusiastic audience.

From Scotland Cadman proceeded to Trinidad, where his advice had been sought by the Governor on various asphalt problems, the search for oil in that island being then only in an exploratory stage. There he remained four years, saw the beginnings of that oil-well enterprise which has since been so successful, took a vigorous part in the genesis of a sound oil policy, and promoted the establishment of a Mines and Petroleum Department. As an early example of his demand for a scientific approach, then badly needed, to the search for petroleum let me quote from his first lecture to the Institution of Petroleum Technologists read at its second General Meeting and published in the first volume of the Journal. This is the first paper published by the Institution on oilfields :

“The lessons which have been learnt in the development of the Trinidad oilfields indicate that drilling should be undertaken only after minutely detailed geological survey has been accomplished ; that plan of substantial design only should be used ; that a staff of more than ‘rule of thumb’ practitioners should be employed, and that they should live under conditions suitable to the climate, obeying the laws of health which a tropical country demands.”

It was about then that the case for the substitution of oil fuel for coal was engaging the attention of the Admiralty, notably of Lord Fisher, First Sea Lord. The first beginnings were tentative and experimental, but gradually the technical and tactical advantages became so evident that it only remained to settle the complementary problem of how best to assure adequacy of supply for the Fleet in being instead of meeting the relatively minor needs of a few oil-fired cruisers and destroyer flotillas. In 1913 Mr. Winston Churchill, then First Lord, decided, with his customary acumen, to send a Commission to Persia to report on the potentialities of

that region. Fig. 1 is a photograph of that Commission, in which the central figure is Professor Cadman, as he then was. The eventual outcome of their report is too well known to need recapitulation by me. All that need be said here is that, as a leading member of the Commission, Cadman's reputation was still further enhanced. It was not therefore surprising that during the first World War; and at a time when the oil-supply situation was becoming critical, he was called upon to direct the newly formed Petroleum Executive, and, later on, to take the Chair of the Allied Petroleum Council. The war ended, and thereafter, as a director and eventually chairman of the Anglo-Iranian Oil Company, he finally reached that large sphere of industrial and scientific activity so congenial to his many plans for furthering the approach of science to industry, which only ceased with his death nearly five years ago.

It will be realized from what I have to say that his life bridged a great evolutionary period in the history of petroleum, a period, indeed, in which oil finally became arterial in the world's circulation; and in the course of that evolution he played a notable part.

Geological Exploration

Let me therefore now turn your attention to certain of these evolutionary aspects starting some forty years back, when world production was barely 10 per cent of what it is to-day, and when most of the great oilfields since found lay hidden in their primeval secrecy. Oil then came from fields which had been discovered not by careful investigation of the geological conditions, but by the "wild catter," aided, in the majority of cases, by surface evidence from actual seepages in the form of oil or gas.

Geological exploration was first confined to those areas where surface outcrops admitted of certain deductions regarding what lay beneath them, and the geologist was not much helped to structural conclusions through drill penetration to very great depths, for drilling technique was still somewhat elementary. There was little complementary knowledge regarding the age of the rocks or of their fossil contents; nor, as is now current practice, were drilling samples examined and correlated. The tools which the geologists normally used were confined to the compass and dipmeter, the plane table when it could be used, or the sketch-block when it could not. The microscope, now so indispensable in the oilfield laboratory, was still to come.

So it came about that the authoritative application of geological science to oil discovery was a relatively slow process. A first departure from old practice was made in the search for anticlinal structure, notwithstanding the absence of provisional evidence in the shape of visible seepages; for in early days the drilling pioneers preferred to operate close to the sometimes illusory evidence of surface oil. In Iran such seepages have been known for thousands of years, but it was not until the early days of this century that they attracted much attention, except from the local tribes and for very simple purposes.

In Fig. 2 an old friend of mine, Sir Arthur Hearn, is seen looking at such a seepage.

To-day geological control plays a very different rôle, for it has become

standard practice to unravel and interpret the past history of the oil-bearing sediments and all the circumstances of their original deposition. To this progress contributions have come from many directions.

Amongst them must be numbered the introduction of air surveys, particularly for the topographical inspection of areas very difficult of access. The geologist is, in fact, no longer earthbound. In arid countries the air photographs and their specialized interpretation provide a geological map which is more accurate than that which can be obtained by geologists on the ground, except at a very high cost in money and time.

Again, prior to 1918 palæontology was little to the fore, but thereafter great progress was made particularly in micropalæontology applied to correlation problems in oilfield areas. Now, and additionally, we have electrical methods for determining the permeability and resistivity of the strata passed by the drill and surveys with gamma rays and neutrons are in progress.

Application of Geophysical Methods

But, of all these efforts to substitute knowledge for guesswork, the greatest benefit has come from the application of geophysical methods to measure the density, magnetic susceptibility, elasticity, and electrical resistance of underground structures by means of delicate instruments specially designed for oil-prospecting work.

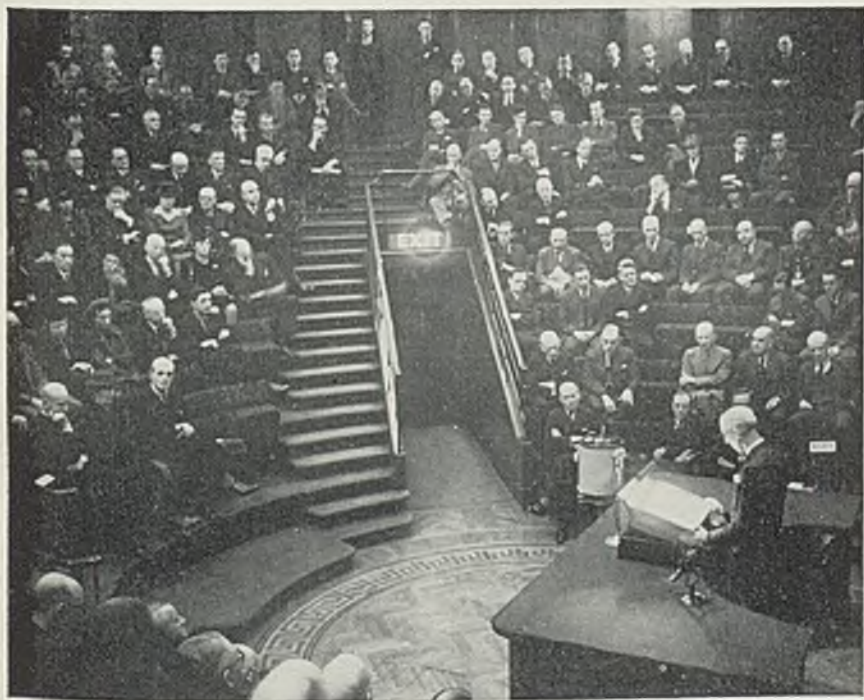
In many oil-bearing countries most of the anticlines traceable at the surface by well-defined outcrops have been drilled and definitely proved or disproved as oilfields. It is now known that adjacent to areas with such outcropping anticlines there are, as a rule, extensive alluvial plains underlying which anticlines often occur, but no clue is given to their exact position by the existence of surface outcrops. The need for a new method to discover such anticlines and determine their general shape and size was met by geophysical workers. The first method used was based on the fact that many underground anticlinal structures produce a slight increase in the intensity of gravity as measured at the surface, the increase being due to a mass of rocks in the structure having a greater density than those in adjacent synclines. The first instrument used in this way was a torsion balance, and gravitational surveys were carried out in Iran as early as 1924. The torsion balance has now been superseded by a different type of instrument called a gravimeter. The new type is more portable, more speedy in operation, and will measure a change in the intensity of gravity as small as one part in a million. There is a difference in gravitational attraction between the level of the floor of this room and the top of this table, and I am told that it has been measured with this instrument.

It may interest you to know that gravimetric surveys are now applied to the search for oil in Great Britain. Fig. 3 shows the result of one such survey in the West of England. Anticlines have been located, but unfortunately they are not necessarily associated with oil.

It is usual for gravity and magnetic surveys to be combined, as the cores of anticlines often have magnetic properties differing from those of their surroundings; the magnetic results help, therefore, in the inter-



THE CADMAN MEMORIAL MEDAL.



SIR WILLIAM FRASER, C.B.E., DELIVERING THE FIRST CADMAN MEMORIAL LECTURE.

[To face p. 244.]



FIG. 1.

ADMIRALTY COMMISSION TO PERSIAN GULF, 1913. LEFT TO RIGHT: CAPT. NOYES (O. C. ESCORT), E. H. PASCOE, PROF. CADMAN, ADMIRAL SLADE, S. LISTER JAMES.



FIG. 2.

AN OIL SEEPAGE IN SOUTH IRAN BEING INDICATED BY MR. (NOW SIR) A. C. HEARN.

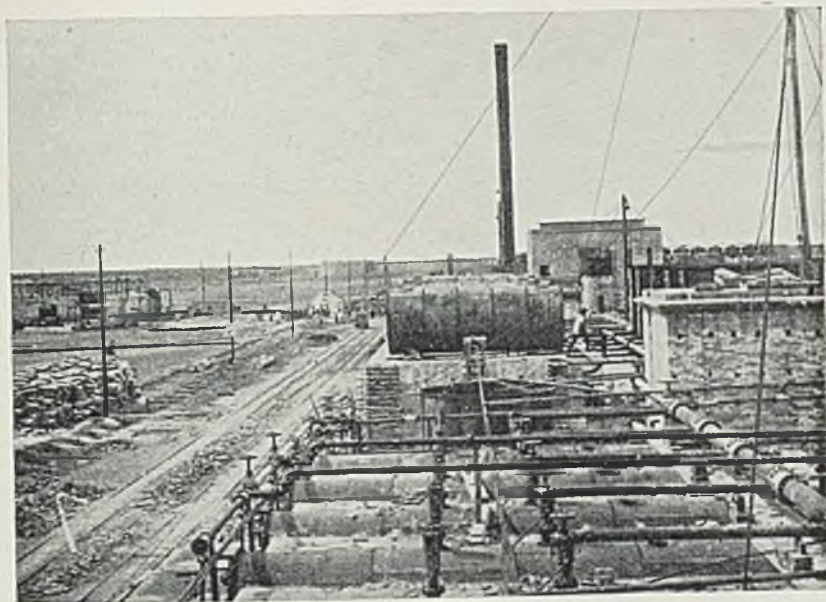


FIG. 6.
OLD TYPE OF BATCH STILL IN OPERATION IN ABADAN IN 1913.

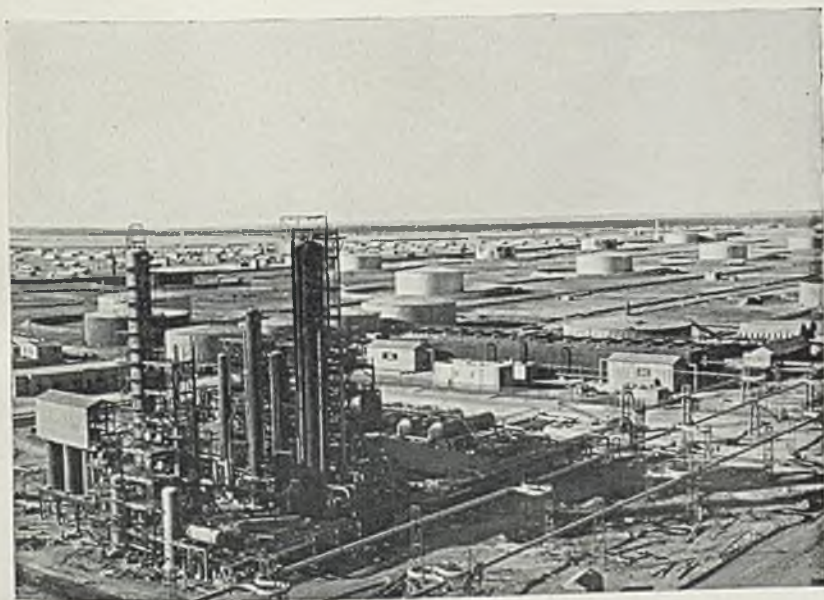


FIG. 7.
A MODERN ALKYLATION PLANT AT ABADAN.

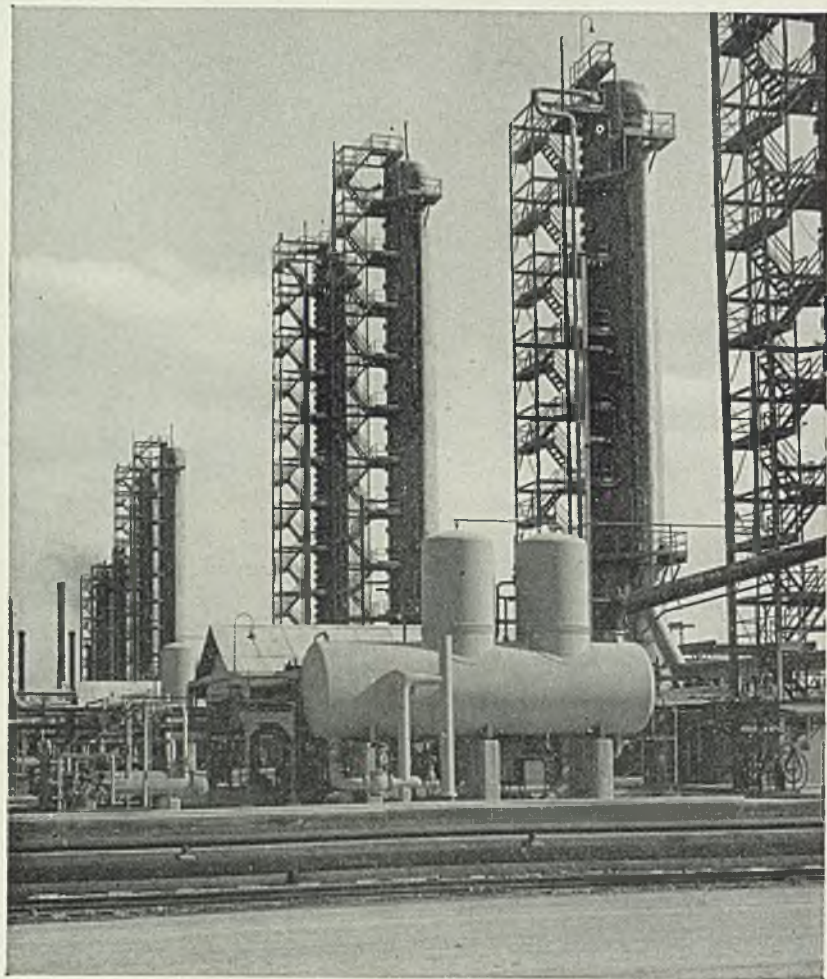


FIG. 8.

PRESENT-DAY SUPERFRACTIONATORS IN OPERATION IN ABADAN.

pretation of the gravity measurements. Magnetic instruments which have been used up to the time of this war have been capable of measuring changes in the vertical intensity of the earth's magnetic field of a few parts in one hundred thousand. A much more sensitive magnetometer was later produced for the detection of submarines at depth. This has

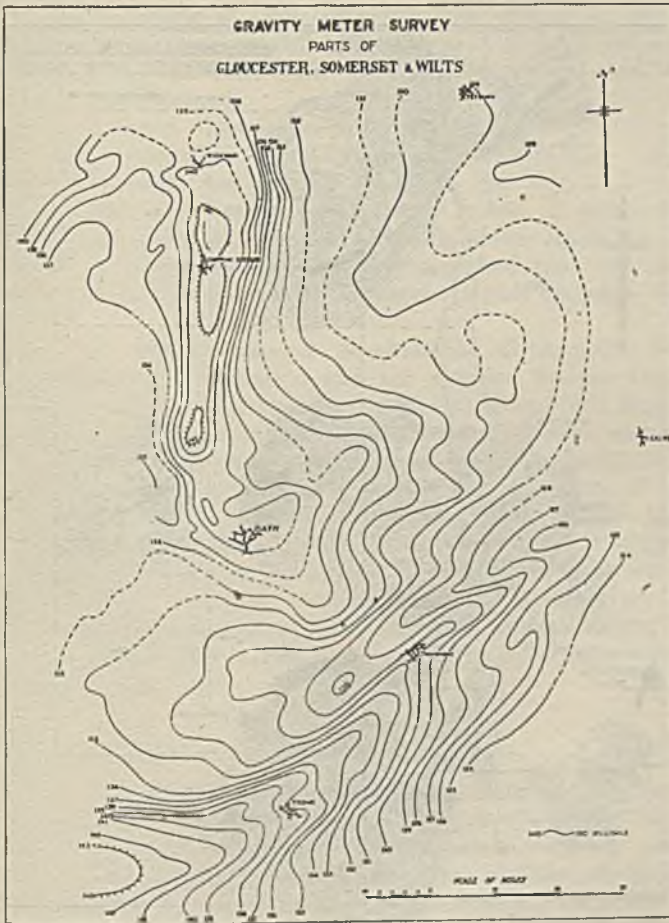


FIG. 3.

GRAVITY METER SURVEY OF PARTS OF GLOUCESTER, SOMERSET AND WILTSHIRE.

been flown in aircraft but, so far as I know, has not yet been used in a magnetic survey of potential oilfields.

The gravimeter and the magnetometer make it possible to explore for oil in shallow territorial waters. The gravity method has already been used at sea with instruments carried in a submarine, but unfortunately much greater precision is needed than can be obtained in this way.

Another geophysical principle which has been applied in recent years

is the seismic method based on the detection of earth tremors set up by small artificial earthquakes made by explosions of gelignite in drilled or dug holes. It was this method which led to the finding of the Eakring oilfield in England, and this is still being used in this country. Fig. 4 shows the result of the seismic surveys in the Eakring area. The anticlines are well shown.

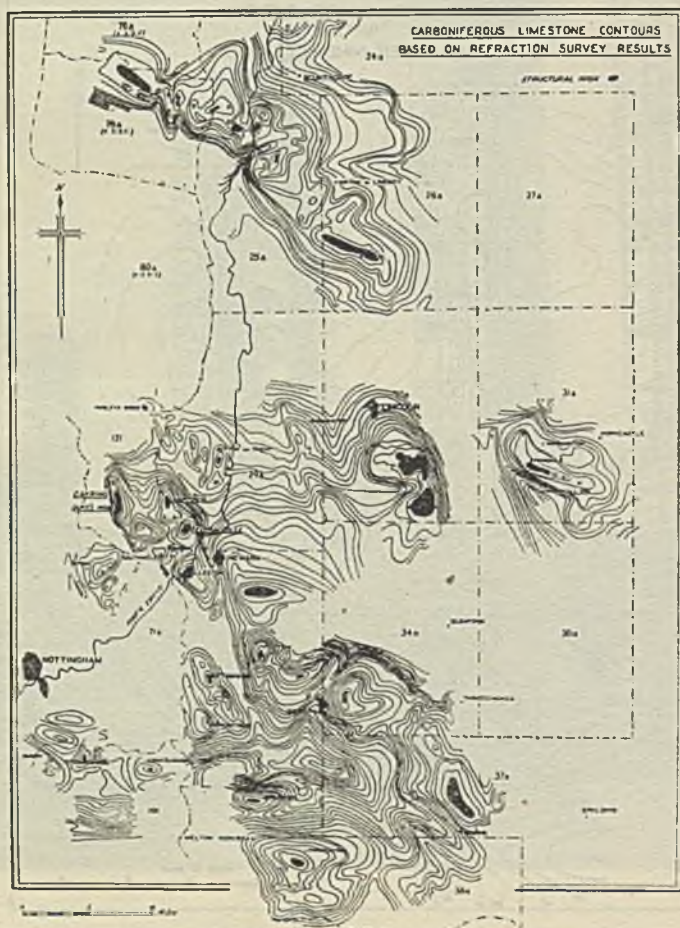


FIG. 4.

CARBONIFEROUS LIMESTONE CONTOURS BASED ON REFRACTION SURVEY RESULTS.

Iran presents unusually favourable conditions for the use of the seismic refraction method of survey, owing to the existence of extremely large, simple anticlines formed of thick, massive limestones concealed beneath disturbed gypsum-salt series. The reflection method, now more commonly used elsewhere, has not been successful on account of this confused structure in the overburden, and a special technique of refraction survey

had to be evolved. Shots of from 1 to 2 tons of gelignite are necessary to impel sufficient energy through the ground to reach the recording stations.

The history of discovery must be thought of in terms of the development and experience in geological and geophysical methods throughout the years.

Exploration-drilling in Iran commenced in 1903 in an area where oil-seepages emerge from sandstone; it was hoped to strike large-scale production in similar sandstones at depth, but only small, short-lived production was obtained.

Drilling was next undertaken in the Masjid-i-Sulaiman area, where oil-seepages issue from thin, porous limestones in a strongly folded gypsum-salt series. Success was quickly achieved, the first wells encountering large-scale sustained flowing production. It was at first supposed that the rocks yielding the oil were lenticular limestones similar to the seepage-rocks, but it eventually came to be recognized that the reservoir-rock was the 1000 feet thick Asmari Limestone which underlies the gypsaceous series.

Subsequent drilling showed considerable disharmony between the surface gypsum-salt formation and the massive Asmari Limestone, the Asmari being folded in a simple, regular anticline much larger than any of the folds seen at the surface. The disharmony is such that large surface synclines are in some places underlain by major Asmari anticlines. The geologist had been handicapped in making his deductions of underground structure, until the development of geophysical methods gave him an essential diagnostic approach similar to that of X-rays in surgery.

Of the oilfields shown in Fig. 5, Haft Kel and Gach Saran were discovered independently of seepages, while Agha Jari, Pazanum and White Oil Springs were discovered some years later, and in determining the position and trend of the hidden anticlinal structures in these fields seismic surveys have played a great part.

Oilfield Developments

Up to 1921 drilling was generally undertaken by the percussion system. The rotary was in very limited use, as the type of bit could not cope with hard rock formations. After a time a combination system came into use, the rotary being employed for soft formations and the percussion for hard rocks. With improvement in special alloy steels for rock-bits the balance swung in favour of the rotary, and practically all drilling for oil is now so undertaken.

Until the 1920's oilfield control was largely in the hands of practical oil-men, the pioneers of the industry, to whom we owe so much, and whose art preceded the scientific approach which was rapidly developed during the years between the war. Geologists, who had alone largely held the scientific field in oil exploration and exploitation, were joined by geophysicists and physical chemists, and a true picture of underground reservoir conditions was brought to light, and consequently the most effective method of exploitation evolved.

Cadman was a strong believer in the principle of unit development, to

which, very fortunately for all concerned, the oil-bearing areas in Iran lent themselves, and each oilfield there was, and still is, operated at a rate which ensures that no excess of gas is produced. Care is taken to keep the oil, water, and gas levels uniform throughout the limits of an individual field; in this way uneven encroachment of edge-water is prevented. By such control the lives of the oil-wells have been prolonged to a degree otherwise impossible.

It is of interest to note that the Masjid-i-Sulaiman oilfield, which commenced commercial production in 1911 and has produced to date some 100 million tons of crude oil by natural flow, is still so operating.



FIG. 5.

THE OILFIELDS OF SOUTH IRAN.

It is significant that Cadman was in the van of this movement, both administratively in Iran, and later in supporting the advocates of unit operation in the United States of America. In this latter connection he was, of course, able to cite what had been so successfully done in Iran, where it has been possible to develop the oilfields as natural units to the best advantage, and also to observe the effect of control on the pressures in the reservoir and on the movements of the gas-oil and oil-water contacts over great distances. These observations created a profound impression on those production experts whose operating circumstances had not afforded them the opportunity for such widespread control.

In the early days of the oil industry if a well started to produce water it was considered to be just bad luck. Nowadays, the policy is to determine the position of oil-water level, and to maintain control of this, watch-

ing any changes due to production by means of observation wells on the field perimeter. Not only does this reduce the water problems connected with the refining of "wet crude," but the natural rise of edge-water, the traditional enemy of the pioneer producer, is now used as an ally in connection with drainage of oil from its reservoir.

With the increasing depths of well completions, higher and higher reservoir pressures and temperatures—pressures of thousands of pounds per square inch against hundreds in the earlier days—have called for the scientific development of drilling operations and production practice.

Cadman played an important part in the discovery of oilfields in the United Kingdom, and as long ago as 1918 was associated with the late Lord Cowdray in the exploration undertaken at that time which resulted in a small discovery of oil at Hardstoft. Cadman's faith in the possibility of oil being proved in the U.K. at least inspired the passing of the Petroleum Bill, after which an active scientific investigation was carried out under the direction of Dr. Lees.

Intensive geological and geophysical surveys have been carried out, and, as I have already remarked, are still continuing. Incidentally, the drilling operations have led to the discovery at great depths of hitherto unknown coalfields, of potash deposits, and of ironstone beds. Gravity, magnetic, and seismic methods have all contributed, and the network of observations from these surveys has now covered a large part of Central and Southern England.

Utilization of Petroleum Products

With the advance in scientific ways of finding and producing oil, there has been an even more impressive advance on the chemical side, leading in turn to new ideas of the multiple products obtainable from crude petroleum.

True it is that within the walls of the Royal Institution, Faraday, 121 years ago, isolated benzene and discovered that the two gases, ethylene and butylene, which we know so well to-day, had the same chemical composition, but very different physical and chemical properties. It might have been anticipated that great advances in our knowledge of petroleum chemistry would have followed within the next few decades, but in fact it was not until the early part of this century that the scientific study of petroleum began in earnest; even the presence of toluene and many other aromatic hydrocarbons in natural petroleum created no great interest at the time of their discovery; far less, as you may imagine, than the annual production of 250 million gallons of toluene from petroleum during the war so recently ended.

It is probably true to say that the first great awakening to the enormous complementary potentialities of petroleum and the internal-combustion engine took place in the first World War. The quantity of oil used in that war (about 30 million tons) was, of course, small by to-day's standards, but in those days it was looked upon as a large quantity, and it was then that we saw the first large-scale use of motor fuels for fighting vehicles and military transport, of aviation spirit and of fuel oil by the Navy.

Developments in Petroleum Refining

It is of some interest at this point to consider for a few moments the elementary character of the petroleum products of those days, for they were very different from those now available. The old-type motor spirit was largely a straight-run distillate from crude oil, since, although the war considerably encouraged the cracking process, it was not operated on an important scale. Indeed, in 1914 motor spirit derived from cracking amounted to little more than 1 per cent of the total output. The bulk was produced by distillation in shell-stills, and most refineries of the world were so equipped associated with auxiliary chemical refining plants. Fig. 6 shows such a unit in operation over thirty years ago, and it was this sort of unit that Cadman saw on his first visit to Iran in 1913.

There were then no thermal crackers, polymer units, fractionating towers, superfractionators, alkylation plants, or other refinery units such as we know to-day. The main quality requirements to be met by the motor spirit supplied were those concerning specific gravity and boiling range, both of which were mainly thought of in terms of the ease with which the fuel vaporized in the carburettors and remained vaporized in the cylinder without diluting the lubricating oil. A similar state of affairs existed with regard to aviation spirit, the main requirement in this case also being ease of vaporization and a low final boiling point.

It is understandable that, with the early war demonstration of what the internal-combustion engine and petroleum could jointly accomplish, the immediate post-war years saw an increased demand which, accustomed as we all are now to astronomical figures, is still very impressive. That for motor spirit was particularly great, and since the cracking process was still in its infancy, resource was had to the addition of the volatile portion of kerosine. In 1920 the volatility of the petrol produced was relatively very poor, in spite of admixture of low-boiling fractions derived from natural gas. This state of affairs, however, did not last long, and with the extension of the cracking process, by which motor fuels were produced from heavier oils, much larger quantities of better quality became available; so much so that in 1936 the volume of cracked gasoline produced in the United States slightly exceeded that of gasoline from crude-oil distillation.

The rapid extension of the cracking process after 1920 was stimulated by three different considerations. In the first place, the demand for motor fuel was so great that simple distillation from the available crude oils could not meet it, and this, coupled with a large price differential between the gasoline, which was in short supply, and the heavier oils, which were not, directed attention to ways and means of converting the one into the other. A yet further incentive was given by the fear that natural reserves were being very gravely depleted. This was over twenty years ago, since when enormous quantities of petroleum have been, and still are being removed from the earth; so perhaps it is not surprising that, notwithstanding many great new discoveries, fears of petroleum shortage are still much alive to-day.

An additional impetus to cracking was given by the classical researches of Ricardo, which, started in 1919 and published in 1921 in the Institution

of Petroleum Technologist's *Report of the Empire Motor Fuels Committee*, revealed for the first time that gasolines of different chemical compositions varied to a considerable degree in the extent to which they cause detonation or knocking in an engine, and that the knocking properties of a fuel determine its limiting engine performance. This revelation was of the greatest significance; moreover, it was demonstrated that cracked gasolines had better anti-knock qualities than straight-run gasolines, thus giving the cracking process a qualitative as well as a quantitative advantage. From these discoveries, followed by that of tetra-ethyl lead in America in 1922, evolved the modern motor fuels. Solution of the considerable problems involved in the refining of fuels produced by cracking, and removal of the health objections to the wide use of tetra-ethyl lead, greatly assisted this new advance, since it was now possible to produce good-quality motor fuels from a wide range of crude oils, including those which hitherto had not been considered suitable for making motor fuels owing to their straight-run fractions being of poor anti-knock value.

With the advent of the cracking process and the widespread use of tetra-ethyl lead, the quality of motor fuels was much improved over the period between the two World Wars. The development of the internal-combustion engine proceeded simultaneously, and in the net gain of efficiency which resulted, motor fuels contributed an important part.

About 1930-1935, however, another revolution in petroleum refining methods took place. Its first rumblings were heard in the reports coming from the petroleum research laboratories, where attention was being attracted to the utilization of the gases produced in very large volumes by cracking operations. The research chemists had for some time been engaged on finding commercial applications for natural gases, but, although they evolved several processes by which these gases could be converted into high-octane gasoline components, few were economic, and, except in certain isolated cases, were not developed. With the advent, however, of the more reactive olefins contained in gases from cracking processes, attention turned to these much more promising materials, from which developed synthetic processes which were later destined to play a valuable, if not essential part in the second war period.

Thus it was that the synthetic hydrocarbon products, of vital importance in the manufacture of aviation spirit, came to the fore. The first of these to be made commercially was *iso*-octane, which previously had been available only in very small quantities for use in research and engine-testing laboratories. *iso*-Octane was made from the butane fraction of cracked gases by successive steps of polymerization in sulphuric acid and hydrogenation; its coming greatly aided the development of high-performance aero engines which have recently served us so well. However, research still proceeded on its inevitable course, and barely two or three years later, the large-scale manufacture of *iso*-octane was superseded by hydrocodimer, a similar material obtainable in almost double the yield from the same butane fraction; in addition, it gave rather better aero-engine performance. Polymerization and hydrogenation again played their part, but the former was carried out under more severe conditions in order to make a greater portion of the butane feed-stock react.

1937, however, saw a yet greater advance through the discovery of the alkylation process, where I am proud to feel British research workers did some really fine work. It now became possible, in one stage, to produce a much greater yield of high-grade aviation fuel component direct from the butane fraction of cracked gases by the action of concentrated sulphuric acid. How great was the contribution made by this process to the supply problems of the war is evidenced by the fact that, on an average, all Allied aviation fuels contained 20 to 30 per cent of this material, the quality being largely determined by the alkylate content. A modern alkylation plant is shown in Fig. 7.

The years immediately preceding 1939 also saw important new developments in the application of catalytic methods of oil refining and oil conversion, among which the catalytic cracking process is outstanding. Petroleum chemists have, for many years, been keenly interested in the application of catalysts in petroleum refinery technology. Bauxite and clays have been used since the earliest days of refining, and it is of more than passing interest to note that this same general class of inorganic material is used in catalytic cracking processes. The urge to use catalysts in the cracking of heavier oils to make gasoline arose out of a growing dissatisfaction with the inability of the conventional cracking methods to produce products having octane numbers of much above 74 to 75, and because the technicians thought that the use of catalysts would enable them to control the cracking process more effectively, and so obtain products better suited to particular requirements. So successful were their efforts that the installed catalytic cracking capacity is now as great as that employing the older non-catalytic process. Of considerable war importance was the additional fact that the gasolines refined after catalytic cracking could, with much advantage, be incorporated in aviation fuels, whereas this was never considered feasible with thermally cracked gasolines. Another wartime advantage of catalytic cracking was the large amount of cracked gases produced as a by-product which served as excellent raw materials for alkylate manufacture, and catalytic cracking plants with alkylation units attached were of the greatest value in producing enormous quantities of aviation fuels when most wanted. Perhaps of as great importance to the Allies was the production in the U.S.A. of synthetic rubber from the butadiene simultaneously produced in the process. Thus, of the processes installed in American refineries during the war, catalytic cracking was probably the most significant, since it provided the basic materials for both aviation fuel and synthetic rubber manufacture.

Other oil-conversion processes were also developed in the years 1935 to 1939. These included a catalytic process for naphtha reforming, a process in which straight-run fractions of low octane number, such as those normally processed in thermal reforming units, are subjected to the action of catalysts to form high-octane materials of high aromatic content. This process was destined to play an almost vital part in the manufacture of toluene for explosives, and, being applicable to a very wide range of crude oils, was, of course, a great improvement over earlier methods. In the first World War toluene was extracted from light distillates obtained from a few special types of crude; in the second it was

produced by the catalytic conversion of naphthas containing methylcyclohexane, a much more widely distributed source of supply.

Another process which, developed in the research laboratory in the period 1936 to 1939, was destined to make a large contribution to aviation-fuel manufacture is butane isomerization, a process by which *isobutane*, essential to the alkylation process, could be produced by changing the chemical configuration of normal butane. This was also a catalytic process.

As distinct from most of the processes above mentioned, which were so largely concerned with highly scientific attacks on the intimate molecular structure of petroleum, the distillation process for the separation of petroleum oils into their primary components has been made highly effective during recent years, and the size of the distillation units installed in the refineries has correspondingly increased. Distillation was originally effected in simple stills equipped with rudimentary fractionating columns, and the degree of separation achieved between the various fractions was in most cases very poor. The change was mainly brought about by the large-scale adoption of the pipe-still and bubble tower for continuous distillation, and this equipment gradually attained a high standard of reliability and efficiency. For economy of operation these continuous units were built in very large sizes; some are capable of processing up to three million gallons per day of crude! Fig. 8 shows some of these large fractionating units at Abadan.

These developments on the commercial scale had a pronounced effect in stimulating research on distillation methods, which had hitherto appeared to offer little scope for improvement. It soon became practicable to separate crude oil not only into more sharply defined fractions of its major constituents, but even into fractions of very narrow boiling range, consisting of pure or nearly pure hydrocarbons; thus was made possible the isolation of some of the individual components of petroleum, the individual bricks of the petroleum structure. During the late war enormous quantities of these hydrocarbons were prepared from petroleum by such superfractionating processes for use in aviation fuel.

And so we come to lubricating oils which were once distilled direct from petroleum, the wax being separated by chilling and filtration. The oil itself was then refined by sulphuric acid and soda or by the use of clays. To-day, however, the processes are much more complex, and the products of much better quality and adaptability. The basic distillation process has been radically improved, and a new process introduced through which materials in the raw stock which have a bad effect on engine behaviour or oil stability are removed by solution in selective solvents. Wax removal has also been assisted by the use of solvent dewaxing methods. A further major development is the use of additives. Compounds have been developed which are capable of improving the lubricity of a lubricating oil, of improving its resistance to oxidation, of improving its low-temperature behaviour, of improving its behaviour in an engine, and of bettering its properties in several other directions. So it has now become possible to manufacture high-quality lubricants from a much wider range of petroleums than was formerly thought feasible, and hence the range of potential production has been much extended. The lubricants now made

from petroleum range from aero-engine oils to sewing-machine oils, from high-duty motor oils to watch and instrument oils, and from cutting lubricants to brake oils and rust-preventing oils, a considerable variety to meet all the many needs of modern life.

These illustrations will show that, in the years between the wars and greatly during the last 6 years the petroleum industry, quite apart from its vast supply activities, made a large contribution to final Allied victory on the technological side by the research and development work it fostered and by the rapidity with which laboratory work was translated to large-scale operation.

I do not think I can have given the impression that on the outbreak of war all this recent contributory effort was at once mobilized, or mobilizable. The war brought a great challenge to science, not least to that science which, in so many forms, is concerned with petroleum. It brought constantly increasing and constantly varying demands, and it brought, as we know, many hazards. That challenge and those demands were, I think, fairly met by petroleum and the men who dealt with it. Personally, I feel that the most significant achievement was the eventual production of the spirit which kept the Allied aviators victoriously on the wing, and in that achievement I shall always be proud of the part played by the industry.

What of the future? Some years ago, Dr. Dunstan prophesied that petroleum would be regarded as a confused collection of chemical substances which, by careful selection and rearrangement, could be converted into practically any organic material required, be it fuel or lubricant, chemicals for synthesis or synthetic food-stuff. His prophecy is now coming true, and we have before us an ever-widening panorama of possibilities. So far, the rearrangement and chemical conversion of petroleum hydrocarbons have been largely limited to the lower-boiling fractions, but research is well in hand on the heavier fractions, and we shall soon see similar radical changes elsewhere.

The petroleum industry cannot rest content with its past achievements. It must progress, for the evolutionary process continues. New and better products of all types must be elaborated to satisfy new wants in the days to come. The internal-combustion engine, assisted to its present state of excellence by the petroleum expert, may be past its zenith, and a helping hand must now be given to the prime movers of the future. In 1939, when Lord Cadman gave what proved to be his last address to members of this Institute, he said :

"The internal combustion engine might still be improved in matters of degree. For any revolutionary change, however, I think we must look elsewhere. My own hope is pinned to the development of an internal combustion turbine using heavy fuel."

Since 1939 developments have been rapid. The internal-combustion turbine for aircraft has been produced, and super fuels must be created for it, as super fuels were developed for reciprocating engines.

A word or two in conclusion. During the course of this talk I have had occasion, quite inevitably, to dwell much on the part played by petroleum in the operations of war. It is indeed regrettable that, in

common with so much other scientific advancement in so many other spheres of human knowledge, the science associated with petroleum and the petroleum engine should have contributed so much to accentuate the horrors and intensity of the conflict. But there is, fortunately, another and happier side in respect of their contributions to the advance of civilization and in the arts of peace. It may, and doubtless will, fall to some future lecturer to dwell on so congenial a topic. I should, indeed, have liked myself to have enlarged on it, but time unfortunately does not permit.

Petroleum is, indeed, a very protean substance; it can assume all shapes, even, I think, the shape of things to come! Of one thing, however, I am sure. The men and the materials and the organization exist which can make these things practicable. The future is theirs but, in their assured advance, one fleeting glance backward, such as I have given you to-day, will make it clear that, in a somewhat earlier decade, the late Lord Cadman did much, very much, to help them on their way.

Presentation of Cadman Memorial Medal.

THE CHAIRMAN, proposing the thanks of the gathering to Sir William Fraser and presenting to him the first Cadman Memorial Medal, said :

I feel sure you will all wish to join with me in thanking Sir William Fraser for the very valuable and interesting lecture we have just heard.

But before asking you formally to record your appreciation there is a ceremony which must be carried out.

In 1941 it was suggested by Sir Frank Smith, who is with us this evening, that a fund should be established, to be known as the Cadman Memorial Fund, for the endowment of a memorial lecture to be delivered at least once every three years. The proceeds of that fund were to provide a medal for the lecturer and an honorarium. The subscriptions to the fund were limited to the employees of and those associated with the Anglo-Iranian Oil Company.

Sir William Fraser has had the proud privilege of delivering the first lecture in this series, and there is no one who is more entitled to that privilege or who is more fitted to fill the position which he has so ably filled to-night.

It is with very great pleasure indeed, therefore, that I now present to Sir William the first Medal, as a memento of the lecture which he has just delivered.

In doing so I may say that Sir William has decided that the money shall remain in the fund for use on future occasions.

(The Medal was formally presented to Sir William, amid applause.)

I will now ask you to join with me in thanking Sir William by acclamation for the lecture we have just heard. (Prolonged applause.)

Finally, I should explain that, in accordance with the terms of the trust, on the occasion of the first lecture a medal should also be handed to Lily, Lady Cadman, and one to the Anglo-Iranian Oil Company at Abadan. Owing to the present difficulty of obtaining supplies these two medals will be presented at a later date.

(The proceedings terminated.)

THE INSTITUTE OF PETROLEUM.

A meeting of the Institute of Petroleum was held at 26, Portland Place, London, W.1, on Wednesday, February 13, 1946, the Chair being taken by Professor F. H. GARNER, O.B.E., President.

The PRESIDENT announced that the Council of the Institute had nominated Sir Andrew Agnew, C.B.E., as the next President.

The Chair was then taken by Lt.-Col. S. J. M. AULD, O.B.E., M.C., and the following Presidential Address delivered :

PETROLEUM IN WARTIME.

By PROFESSOR F. H. GARNER, O.B.E., Ph.D., M.Sc., F.R.I.C. (President).

There is nothing that maketh a man of more fortitude, or sooner great and mighty, than the triall of a perverse fortune ; nor anything breedeth a more stability of faith and patience, then the exercise of adversities. (Wits Common-wealth, 1650.)

Research and technical developments dependent on the petroleum industry have permeated in wartime many fields—some of them outside those normally included even in the wide range of industries using petroleum products.

All these developments were due to the needs of war, mainly in the primary fields of the petroleum industry, fuels, and lubricants, but a number were to meet transient, all-important, needs of the moment.

Among the first category belongs catalytic cracking—Houdry, Fluid Catalytic, and Thermoform—for making aviation gasoline and synthetic rubber. Use of these processes has resulted in total plant capacities comparable with those of the earlier thermal cracking processes. With the manufacture of isooctane from cracked gases has come the expansion of the polymerization, isomerization, and alkylation processes : isomerization bringing in one special application—the use of antimony trichloride as a carrier for aluminium chloride—and alkylation the use of hydrofluoric acid on a large scale as a refining agent into the petroleum industry.

Other antiknock agents have been developed, such as cumene, partly from British benzol, and isobutyl benzene, Victane. Smaller proportions of aromatic amines, such as mono-methyl aniline and xylydines, have been used for improving the rich mixture rating of aviation gasoline, thus allowing increased power output for take-off and climbing.

Toluene, another aromatic hydrocarbon, has been made from petroleum in far larger quantities than from coal, and for its separation superfractionation and azeotropic distillation have been developed on a scale hitherto unknown in the petroleum industry.

The Trimpell plant for the hydrogenation of gas oil, which was designed to be as proof against air-raid damage as possible, was entirely constructed in wartime, and achieved a production of two-million barrels a year of aviation fuel. Lead tetraethyl, essential in all aviation fuels and, for the first time, ethylene dibromide, the other important component in aviation ethyl fluid, were manufactured in Great Britain from sea-water.

The full story of the development of hydraulic oil for use in aircraft control actuation, such as lowering landing-wheels, has not yet been told, but this relatively small subject has been the object of long and comprehensive researches in order to find products which have little change in viscosity over the wide temperature range in which an aircraft operates, and have at the same time satisfactory lubricating properties.

Wartime requirements of fuels and lubricants for land transport have resulted simultaneously in a reduction in the number of grades required to an extent hardly conceivable before the war, and in an improvement of quality which is particularly important bearing in mind that such huge quantities demanded an assessment of the over-all quality and quantity available in crude petroleums and of the refinery plant available. The quantities of petroleum products required have been of the order of 60 per cent of the total of all supplies to the armies in the field.

The oilfields at Eakring were developed in wartime under the abnormal conditions of extreme shortage of material and labour, and made a most valuable saving in ocean transport at a critical season.

Three special applications of petroleum products in the recent war have been for flame defence and offence, particularly flame-throwers, for the production of artificial fogs for hiding ground areas from detection from the air, and for the dispersal of natural fogs, so that safe landings could be made by returning bombers. Engineer Rear-Admiral Dight has described the methods which he devised for the production of smoke-screens from simple gas-oil vaporizers for the protection of a number of industrial areas, particularly in the period 1940-1942, and showed that the screening so effected was a very important part of our defence measures. Later, our American friends developed highly efficient fog generators which were used in the final campaign against Germany, in which, by the choice of a carefully selected petroleum product and vaporization at high temperatures with the aid of steaming, the maximum screening power was obtained by the production of oil droplets which were of suitable size to remain suspended in the air for long periods of time.

It is worth while mentioning some of the lesser achievements of wartime. As regards asphaltic bitumen, plastic armour, consisting of a relatively thin sheet of steel, coated on the outside with two inches of a bitumen-aggregate mixture, was developed to save steel. It was shown that machine-gun bullets striking the stones in such a bitumen mixture were deflected, and that weight for weight it was more effective than steel. Bituminous emulsions and paints were extensively used in camouflage and in "blacking-out" windows, and extracts obtained in the solvent refining of lubricating oils were used to provide the lighter camouflage paints. Prefabricated bitumen surfacing was made by treating fabric with high-softening-point bitumen; rolls of this surfacing could be easily transported to the site of a new road or emergency aerodrome and stuck together by fuel oil to give a serviceable road surface. Bitumen was used largely in the manufacture of runways for the multitudinous airfields in Great Britain, with the aid of large American road-making machinery. Other subsidiary uses of bitumen were in the sealing of batteries for torches and other purposes, and in the manufacture of roofing felt used for house repairs after air-raids. A minor use of fuel oil was in dust-

laying in connection with the temporary airport runways of open steel netting laid in France, which before treatment were adversely affected by dust-clouds in dry weather.

Technical white oil, used in the manufacture of hydraulic fluids, instrument oil, and agricultural spray oil, has been made in wartime on a relatively large scale in Great Britain, together with sulphonated hydrocarbons for use as corrosion inhibition, detergents, and fat-splitting agents.

Extended use of petroleum waxes and petroleum ceresins has been made in the manufacture of flexible water-proofing packages for the Far East; special rust preventatives were developed for the same war area to protect engines and other equipment during and after shipment.

A compound containing asbestos, developed for water-proofing tanks and lorries so that they could land rapidly on "D" day, represents the results of a great deal of research in the laboratory combined with practical tests made under conditions of extreme urgency. The work was completed successfully in practice with over 150,000 vehicles waterproofed.

New or extensions of known uses for all petroleum products were found: gas oil to supplement gas supplies in areas affected by air raids, white spirit containing D.D.T. for dry-cleaning military uniforms, and a three-fold increase in tractor fuels for increased food production.

Vanadium, for toughening steel, was recovered from the ash of fuel oils, and naphthenic acid soaps, particularly copper naphthenate, put to extensive use for such purposes as the rot-proofing of sandbags and ground-sheets.

In the transport of petroleum the performance of the men on the tankers is worthy of comparison with that of any of the finest deeds in our history, and this glory was shared by men at some of the petroleum installations in this country in the early air raids of 1940-1941.

The position of Great Britain as the military base for the invasion of Europe required not only an enormous increase in the quantity of petroleum supplies, but concurrently, and as all-important, flexibility in handling by road, rail, and coastal tanker; this was supplemented as early as 1941 by the first stage of the inland pipelines, ultimately of a total length of 1000 miles. These pipelines also facilitated the supply of aviation spirit to the airfields for bombers and fighters. Later connected to Pluto, the pipeline system under the Channel, and to the army pipelines in France, they supplied part of the requirements of the advancing armies. The underground oil storage erected before the war was greatly extended, and the need of protection of overground storage against splinters in air raids was met by the construction of brick protecting walls, in itself a colossal task.

There has never been such intensive and close working between members of the petroleum industry as in the war just ended, and this co-operation has been largely due to the efficient and inspiring leadership of the Petroleum Board with Sir Andrew Agnew, C.B.E., as chairman.

The co-operative working with the United States petroleum industry was developed to such an extent that it is sometimes difficult to ascertain to whom credit belongs for this or that process, as ideas initially from

one or the other side of the Atlantic were developed by groups in close collaboration throughout. The co-operation between industry and government, particularly the Petroleum Division of the Ministry of Fuel and Power, was greatly helped by the exchange of personnel and reports, and particularly by the American and British technical personnel sent to effect more close and intimate contacts with their colleagues in Great Britain and the United States.

The Technical Advisory Committee of the Petroleum Board played an increasingly important part in this liaison as time went on. The members of the Technical Advisory Committee were Colonel S. J. M. Auld, O.B.E., M.C., Mr. G. H. Coxon, Mr. J. A. Oriel, M.C., Mr. H. C. Tett, with Mr. C. Chilvers as Secretary.

This committee became the medium through which the petroleum industry was able to contribute technical advice and information quickly to any Government Department or war agency, and through which industry representatives were appointed to sit on Government Committees, some of which were suggested by the Technical Advisory Committee. Very substantial overall reductions were made in the number of grades of petroleum products used by the Allied Forces through the activities of the Committee for Co-ordination of Service Specifications.

Mention should also be made of the work of the Ministry of Aircraft Production Committees on fuels and on lubricants, which resulted in close co-operation between the petroleum industry, engine industry and Government, together with a very complete liaison with our American Allies. Aviation fuel production in particular was one of the major bottle-necks of war supply due to the vast concurrent increase in quantity and quality. Allied production rose from less than 2 million tons in 1941 to more than 20 million tons in 1944.

The co-ordination of aviation fuel specifications between Britain and America was in hand before Pearl Harbour, with the result that supplies to a common specification were available in all theatres of war thereafter.

Towards the end of the war and since the war many of the leading technical personnel of the petroleum industry have been engaged on the selection and investigation of German targets likely to yield technical information on petroleum and related subjects of use to the Allies. The joint reports of the American and British investigators are being issued by the Combined Intelligence Objectives Sub-Committee (C.I.O.S.), and by the British Intelligence Objectives Sub-Committee (B.I.O.S.) giving an account of Germany's wartime developments in research, on the refining of petroleum and on petroleum products, together with the hydrogenation and Fischer-Tropsch plants.

In the remainder of this paper some account is given in more detail of one or two phases of the wartime developments in connection with the petroleum industry, representing some of those with which I have been myself concerned.

Early in the war meetings were called of a committee to deal with the enemy resources in petroleum products. At the first meeting it was suggested that samples of all enemy petroleum products should be examined in order that a check might be kept on the quality available to the enemy.

This suggestion arose out of work done in the first world war when enemy aircraft parts were examined in order to determine the type of lubricants being used. The work of this Committee extended in two directions :

- (1) An Enemy Fuels and Lubricants Committee, dealing with the quality of the products, and
- (2) A Committee on enemy petroleum resources, dealing with the plants and equipment available.

Both of these committees were under the Chairmanship of Colonel S. J. M. Auld, O.B.E., M.C.

At first the work of these committees was of especial importance in connection with aviation fuels, as the large number of aircraft shot down during the Battle of Britain provided supplies of aviation fuel for analysis, and an efficient scheme was organised by Mr. C. Chilvers (who was secretary of this committee) for the collection of samples of all fuels and lubricants from enemy sources, whether from aeroplanes which were shot down or from small motor-boats which escaped to this country from the Continent. It was only at a later stage, when marked advances were made in North Africa, that samples of the fuels used for motor transport became available, and mobile laboratories were instituted in the field to deal with enemy samples. These laboratories were primarily used to determine whether such fuels and lubricants could be used satisfactorily in the equipment of our own services in the field, but, in addition, the samples gave information as regards the quality of petroleum products used by the enemy. When America came into the war an extensive co-operative organization was established, which later developed a similar scheme as regards the Japanese fuels and lubricants supply.

A sub-committee of the Enemy Fuels and Lubricants Committee was formed to develop the use of infra-red and ultra-violet spectroscopy in the analysis of aviation fuels : Dr. G. B. B. M. Sutherland of Cambridge and Dr. H. W. Thompson of Oxford were members of this committee, and a large number of hydrocarbons were obtained through the kindness of the American Petroleum Institute and others were made in Great Britain. Later, the emphasis was changed to the examination of high-octane aviation fuels being produced in Britain, and the supervision of the work was transferred to the Technical Advisory Committee of the Petroleum Board with continuing full co-operation of the Ministry of Aircraft Production. Later still, it forms part of the first large research project on hydrocarbons sponsored by the Institute of Petroleum.

Many of the most important wartime developments were made as a direct result of the events of 1940 after the fall of France, when the position of Great Britain seemed hopeless to all the world except the British Empire.

It had been shown in France and elsewhere that the Germans were able to make rapid advances by using the fuel storage available in various parts of the country, so that the anti-invasion plans of Britain included either the destruction of all petroleum stocks in front of any invasion troops, or the treatment of such stocks so that they would be unusable by the enemy. The Petroleum Board set up a committee on this subject,

on which all the more important Government Departments were represented, and reached decisions very quickly, a most unusual habit for a committee but very usual in those critical days. One of the requirements was that the fuel should be treated in such a way that it would be impossible for a motor vehicle using it to move even 10 miles; it was found surprisingly difficult to treat fuel so as to stop an engine even within 50 miles. The first suggestion was to add sugar to the petrol, and it was astonishing from how many sources (including various military commands) this futile suggestion came. Chemical contaminants of different kinds did not prove effective, partly because of the difficulty of mixing, and more success was achieved with the use of such materials as soaps or rubber which in relatively small proportions thickened up the petrol so that it was of too high a viscosity to be used as a fuel. A number of very ingenious variations of these thickeners were made, but the inherent difficulty was that of introducing these materials through the small filling hole of a storage tank and of distributing the material throughout the whole of the petrol. This work was thus of no value for this particular requirement, but did prove very helpful in that these thickened fuels, produced in the attempt to contaminate petrols, gave the lead to the thickened fuels which were used with so much success later on as flame-thrower fuels. As with much other similar work, procedures which had been developed for one particular purpose were later used successfully in some other quite different application. Some of the information developed during the investigation of the destruction of stocks, particularly by firing, proved of value in connection with the destruction of petroleum in enemy territory and, for example, in the ignition of decoy fires which were erected in the neighbourhood of petroleum installations.

After our armies retreated from the Continent, leaving behind them practically the whole of their equipment, a new Department, called the Petroleum Warfare Department, was organized by Mr. Geoffrey Lloyd, as a result of suggestions put forward by Colonel M. Medlicott, D.S.O., who had been impressed with the possibility of flame warfare as a method of utilizing petroleum stocks rather than that they should be used by the enemy; the initial work was to devise means of using petroleum stocks for war purposes in case the Germans attempted an invasion of Britain. The organization of this Department, under Sir Donald Banks, K.C.B., D.S.O., as Director-General with Colonel Medlicott as Deputy Director-General, proved to be very successful. At first the scientific staff was limited to the technical personnel from the petroleum industry, particularly of the Anglo-American Oil Co., Ltd., the Anglo-Iranian Oil Co., Ltd., the Shell Company and the Vacuum Oil Company; from the tar industry, particularly Captain F. J. E. China, O.B.E., of Messrs. Burt, Boulton and Haywood, Ltd.; and from the Fuel Research Board. A loose research organization was built up which allowed plenty of initiative, but with efficient committees which gave a general, rather than too precise, direction to the work in hand. The co-operation effected by the Director-General with the fighting services provided a sense of urgency related to military requirements which was one of the keynotes of the success of the department.

The fougasse, which was one of the earliest improvised weapons, con-

verted the ordinary 40-gallon barrel into a much larger and more efficient "Molotov cocktail" for the destruction of tanks and road vehicles. The oil in the barrel could be projected as a flaming mass on to tanks and road vehicles: thickened fuels were developed which remained on the target instead of running on to the road surface.

One of the earliest forms of static defence was a pipe system along which oil could be allowed to flow under a gravity head across a road or railway and ignited from a safe distance. This was developed into the Land Flame Barrage, in which a mixture of petrol and gas oil was pumped through specially-designed burners in order to produce a continuous sheet of flame some 25 to 30 feet wide. The pump-houses and storage tanks were heavily camouflaged or built into houses, so that they could not be detected from the air. The pumps used were mainly petrol driven, although later diesel engine operated pumps were employed. In the whole of this work, which was mainly carried out in 1940, great emphasis had of necessity to be placed on the use of available material, and trailer pumps of the kind used by the N.F.S. were those mostly employed. The lines from the pumps to the firing points were built and dispersed as widely as possible. The burner was cylindrical in shape, with a hemispherical end in which a slot was cut diagonally and three small holes drilled into the slot. The two outer holes were drilled at an angle of 45° to the central hole, and the three holes provided a penetrating stream of oil, while the slot produced a fan of oil between the three sprays. In this way the maximum travel forward of the flame was obtained with the pressure obtainable from the available pumps—namely, 70 lb maximum at the burner. The flame obtained was very intense, and was unbearable at a distance of 50 yards. Large quantities of smoke were produced, and at a later stage this could have been reduced very considerably by the use of pumps capable of giving higher pressures, and consequently greater forward travel with smaller drops; the incomplete combustion was a consequence of the oil spray present, and compelled the enemy to investigate the use of asbestos suits for protection, since even if men succeeded in passing the barrage, they would have been soaked in flaming oil.

A committee to study ignition problems was set up by the Petroleum Warfare Department in 1940, and this committee made a very comprehensive study of various methods of igniting petroleum products. The information obtained was used at first in connection with the ignition of the land barrage, and later of the sea barrage and flame-throwers.

The whole question of the ignition of petroleum products, particularly under open-air conditions with wind and rain, proved to be a most interesting and difficult problem. The provision of means of ignition which was absolutely certain under all possible conditions proved to be very difficult.

For the ignition of this land flame barrage, two methods were provided:

- (1) A specially designed form of firework in which relatively large burning magnesium particles were driven forward into the zone covered by the oil; and

- (2) As an alternative method of firing for repeated ignition a hot wire burner was designed in which the oil was brought into contact with a nicrome wire heated to redness by means of L.T. batteries.

The whole apparatus was of very simple design, using materials readily available, but a great deal of effort had to be put into the details in order to obtain satisfactory working. The team on this work consisted of Mr. E. W. Hardiman with his two colleagues, Mr. A. Prizeman and Mr. A. J. F. Kenyon, who were primarily responsible for the burners and ignition, together with Mr. H. J. Zass, who was responsible for the pipelines and storage, and Lt.-Commander W. A. D. Twysden of the Petroleum Warfare Department, who acted as guide, philosopher and friend in all the work described in this section. Special attention was given to maintenance, and these land flame barrages always worked satisfactorily, even on beaches where the level varied after rough weather.

At one land-flame installation an entirely automatic scheme was worked out for remote control, using a diesel engine to operate the pump. It was necessary to have compressed gas available to operate the means of control for diesel engine, as a sufficient length of travel could not be obtained by an electrical solenoid. The type of apparatus used for opening omnibus doors and underground railway carriage doors was employed in the working out of these automatic arrangements, in which the whole operations of pumping, firing, shutting down, and re-firing could be controlled by push-buttons from a central point a considerable distance away. Mr. K. Arter gave valuable assistance on these devices.

The problem of the ignition of a pool of oil on the water proved very difficult. After a number of experiments in which attempts were made to introduce an igniting medium with the oil proved unsuccessful, it was decided to employ an electrical method of ignition. The wires from the land to the sea had to be very carefully protected, in order to ensure repeatable, infallible operation, and a special form of calcium phosphide igniter was developed. One feature which presented considerable difficulty was the silting up of the ignition device by sand, and a special form of protecting cover had to be devised. Ultimately, after many months' experiments, a satisfactory form of ignition was provided which could be refilled in the often very short time available at low tide for this purpose.

This problem proved to be one of the most difficult, and for the success in ignition, particular, acknowledgment should again be made to Mr. Hardiman and his two co-workers.

The work already described on ignition also played its part in the ignition of flame-throwers; it had been early realized that a high-tension spark alone was not a satisfactory method of ignition for flame-throwers, and it was desirable to provide a subsidiary jet of inflammable fuel. The Ignition Committee of the Petroleum Warfare Department investigated all the various possible methods of ignition, including high-tension and low-tension sparks, fireworks, heated coils of wire, as in the land flame barrage, spontaneously ignitable chemicals incorporated in the fuels, and many other devices.

The greatest advance which was made in flame-throwing was in the selection and production of suitably thickened flame-thrower fuels, as it was only with these fuels that the longer range and target effects could be produced. Unthickened fuels, such as petrol or diesel fuels, broke up in the air, whereas suitably thickened fuels remained as a rod, travelled very much farther, and produced good target effect, although with some

loss of the terrifying appearance obtained by the unthickened fuel. As has already been mentioned, these fuels grew out of the work on the contamination of petrol in storage to deprive invasion forces of such supplies. Although in fact such methods of denial were never needed in practice, the advantages of thickened fuels in flame-throwers were realized as early as August 1940. The selection of the fuels, particularly from the point of view of stability in storage, was the result of a great deal of co-operative work by the Mixtures Committee of the Petroleum Warfare Department, first under the Chairmanship of the late Dr. F. Sinnatt, and more recently that of Sir Alfred Egerton. The Fuel Research Department played a large part in the development of these fuels, and the two secretaries, Dr. J. G. King and Dr. C. M. Cawley, both of the Fuel Research Dept., made a most important contribution to the success of the Mixtures Committee.

Most of this work took place in 1940-1942, and this is an account of some of the phases of the early history of the Petroleum Warfare Department, on which the later successes, particularly flame-throwers and F.I.D.O., were based. Reference should be made in particular to the most valuable work of Mr. S. W. Adey and to Mr. R. P. Russell, who was responsible for much of the corresponding work in the United States of America; they contributed largely to the closeness of co-operation on petroleum warfare matters between the United States and Britain, which played so great a part in the ultimate results achieved.

Reference has already been made to the requirements of a high viscosity for flame-thrower fuels if satisfactory range is to be obtained, and a considerable amount of work was done in the early stages of investigation to ascertain what properties in addition to viscosity were involved. Also the composition of the fuels was the subject of much investigation, both in order to obtain the desired properties and the requisite stability in storage.

Work was begun in the Oil Engineering Department of the University of Birmingham in August 1942 to investigate systematically the following three problems :

- (1) The physical properties of flame-thrower fuels which were important in determining whether long range could be obtained ;
- (2) The flow characteristics of such fuels ;
- (3) The discovery of flame-thrower fuels which had the special properties required to give long range.

The general principle of flame-throwers is that the fuel is ejected from a nozzle at high pressure and ignited immediately on leaving the nozzle. It is desirable that a large proportion of the fuel shall reach the target in a burning condition, and the question of continuous burning of the fuel in its flight through the air is largely dependent on its physical characteristics. The types of flame-thrower fuels developed were non-Newtonian fluids—that is, the viscosity varies with the rates of shear, usually falling with increased rates. Furthermore, these fuels possessed a remarkable degree of ductility and elasticity, and long threads could be drawn out, each contracting at a rapid rate when broken. The two properties of these fuels which appear to be of most importance, as far as range in

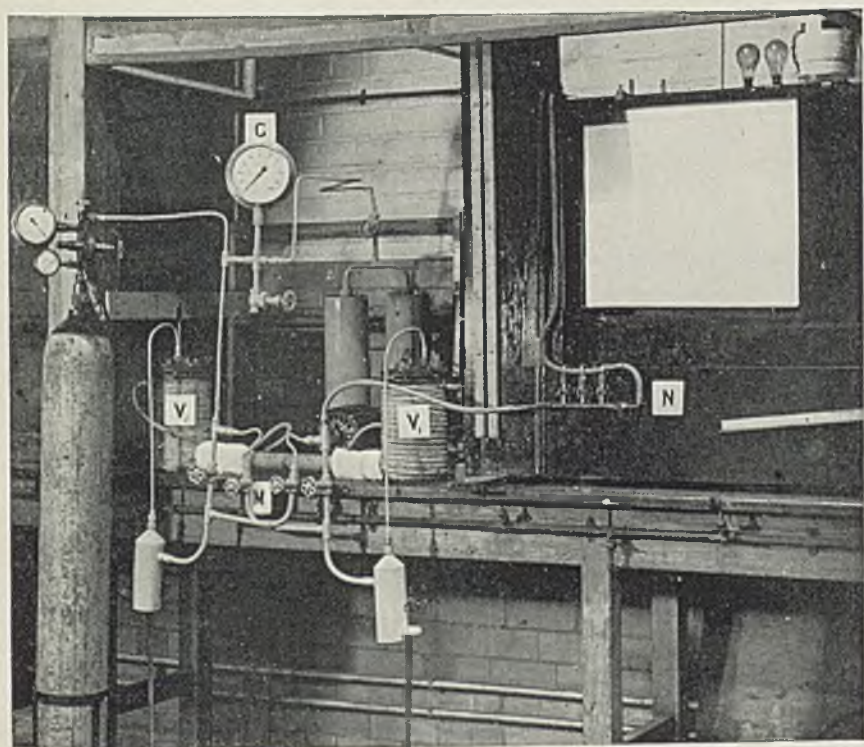


FIG. 2.

[To face p. 264.

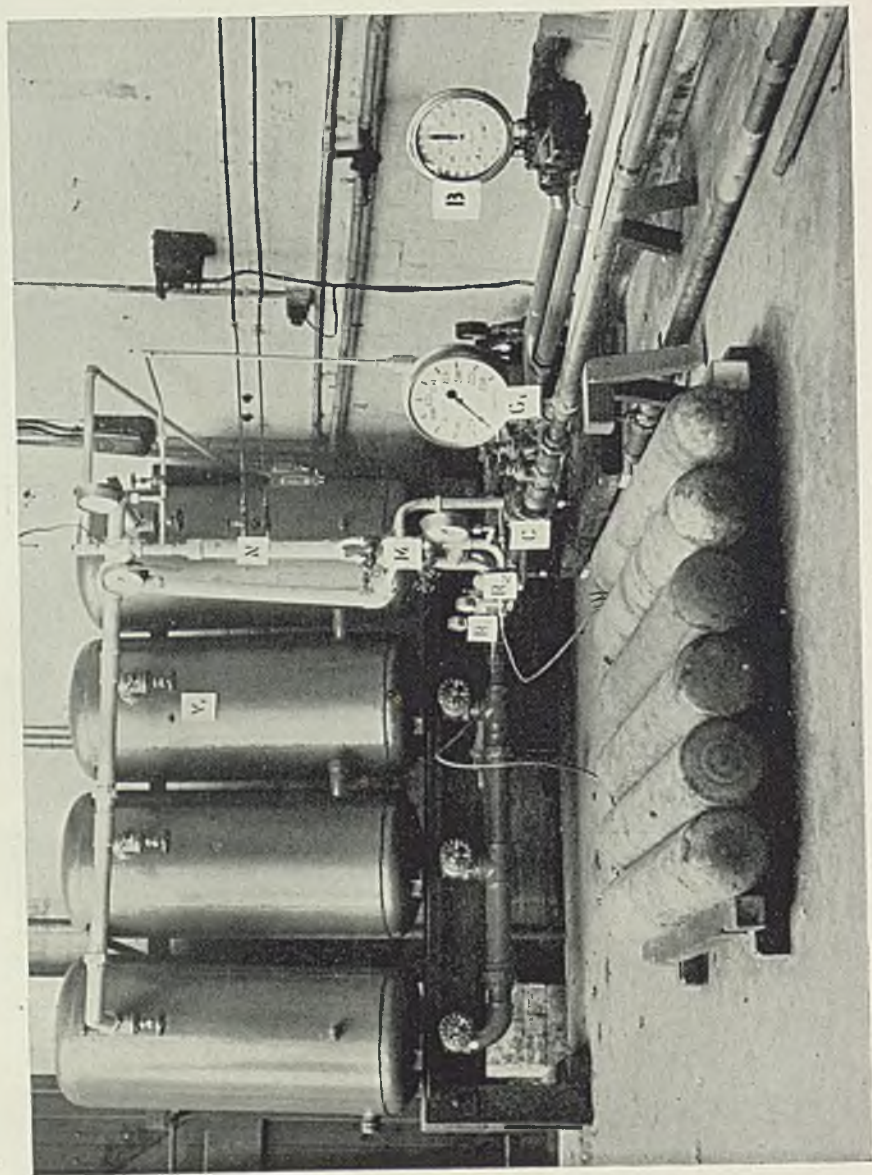


FIG. 3.

flame-throwers is concerned, are viscosity and elasticity. As mentioned, the threads showed both ductility and elasticity, and thus were somewhat similar to rubber. There was, however, this difference, that rubber is apparently more elastically compressible than these fluids, as they relaxed much more readily than rubber. For long range, in addition to suitably high viscosity, a combination of high cohesive forces with ductility was required.

As regards viscosity, the classical method of calculation by Poiseuille's equation was not applicable, since the velocity distribution in a tube was not necessarily parabolic; but even accepting this method of calculation, the viscosity of such liquids changes with the rate at which the liquid flows. If viscosity is plotted against shearing-stress curves over a wide range of values for non-Newtonian liquids, the curves fall into three main, but overlapping types, as shown in Fig. 1, in which

- (1) and (2) represent one type of Non-Newtonian liquid,
- (3) represents dilatant Non-Newtonian liquids.

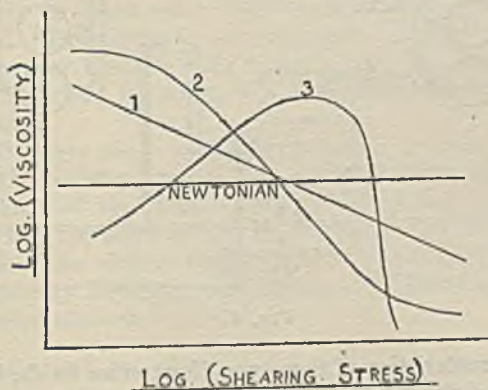


FIG. 1.

In order to apply the results obtained in the laboratory to the design of flame-throwers, particularly as regards size of pipes, effect of elbows, valves, and bends, and so on, it was necessary to study the viscosity characteristics, not only on small-scale laboratory apparatus, but also with viscometers employing as much as 300 gallons of fuel and 20 feet of "capillaries" of as much as 1 inch or more diameter. In the course of these investigations, other properties of these non-Newtonian fuels were studied.

Fig. 2 shows the laboratory-scale viscometer which was used in evaluating the rheological properties of the fuels, and Fig. 3 the large-scale model, which served to correlate the laboratory findings with practical applications. Fundamentally these two models were the same, except that the large-scale apparatus had not temperature control. In Fig. 4 is a diagrammatic representation of Fig. 3, and this can serve to describe the action of both models. The fuel was stored in V_1 when flow took place to the right and in V_2 when flow was to the left. Starting with V_1 full of fuel,

nitrogen under pressure was allowed through reducing valves R_1 and R_2 and manifold M , to force it through the filter, valve C , through the experimental pipe on which gauges G_1 , G_2 , and G_3 were attached by piezo-rings and into reservoir V_2 . The fuel displaced nitrogen from V_2 to manifold M and orifice N , and thus the rate of flow was determined. High-pressure gas could be also transferred from one set of reservoirs to the other by means of the compressor. The orifice was calibrated by means of the meter B when water with a layer of petrol on top was used as the flowing medium. The orifice calibration showed insignificant effects of petrol vapour on its coefficient of discharge. The apparatus could be filled or emptied through W .

It would take too long even to summarize all the work done on the

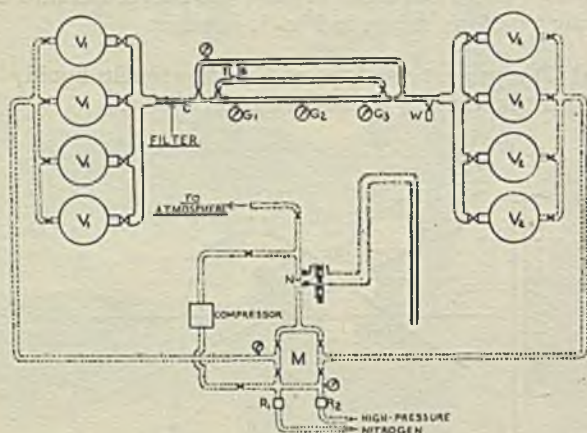


FIG. 4.

“viscosity” characteristics of these non-Newtonian fluids, but it is hoped to publish some of the results shortly.

The work in this section was done by the following research workers: Dr. G. F. Wood, Dr. A. W. Pearce, and Mr. F. Mayo, with the enthusiastic co-operation of the Department Staff. The Petroleum Warfare Department work was under the charge of Dr. A. H. Nissan.

The British incendiary bomb used in very large quantities by the R.A.F. for the bombing of German towns and cities was essentially a 30-lb bomb filled with a special benzol gel together with white phosphorus. The benzol gel filling used, produced on burning a large amount of black carbon smoke which obscured the target, and resulted also in an appreciable portion of the filling being wasted as unburned carbon. In addition, copious white smoke produced by the burning phosphorus increased the obscuring effect over the target.

The possibility of replacing this benzol gel-phosphorus combination with a smokeless filling of a satisfactory nature was investigated.

The smoking tendency of a large number of organic compounds was assessed in a special lamp based on the I.P. smoke lamp, and several promising bases for the manufacture of a smokeless filling were selected. The smoke formation from gels prepared from these selected materials,

and also of the standard benzol gel, was determined by measuring the optical density of the atmosphere produced by burning a standard weight of gel in a glass box one cubic metre in volume. The unburned carbon present in the smoke was also collected and weighed.

Using this equipment a satisfactory smokeless filling was developed with approximately one-sixth the obscuring effect of the standard benzol filling, and with a considerable reduction in the wastage of filling material as unburned carbon.

Burning tests, static and dynamic bomb firing trials, and dropping trials from aircraft, were employed to assess the performance of bombs containing the developed smokeless filling. In this manner a satisfactory smokeless incendiary bomb was produced.

This work was done by Dr. A. E. Clarke under the charge of Dr. T. G. Hunter.

In conclusion, looking back on the six years of war, the feeling is one of admiration for the work of the petroleum industry in wartime, and again particularly in those years 1940 to 1943, when the seeds of future victory were laid. During the two critical years, 1940 to 1941, the achievements of our people made a near approach to the maximum possible performance, a standard for which it is difficult to find a precedent even in our own history.

Finally, I will quote some words of Cromwell in 1658 when the name and fame of this country abroad had attained a pre-eminent position, reviving the glory of the Elizabethan era, and this position was not reached again till the days of Queen Anne by the feats of the Duke of Marlborough. The simple halting words from the speech of Oliver Cromwell on January 20, 1658, have a ring of understatement said to be one of our national characteristics.

"It is very well known unto you all what difficulties we have passed through. . . . I am persuaded that most of you have been actors in it ; it was the maintaining of the Liberty of these Nations."

At the conclusion of the address films illustrating some of the developments referred to were shown.

Col. S. J. M. Auld, proposing a vote of thanks to the President, said that the address to which they had listened with the greatest interest was a stimulating record of the achievements of the petroleum industry during the war years and no less of the great part which the President himself had played in those achievements.

Mr. E. J. Dunstan, seconding the proposal, said that if any evidence was needed that the British possessed imagination, technical ability and industriousness, that evidence had been supplied in plenty by Professor Garner. He personally thought that that industriousness and technical ability was worthy of an industry for the British people in peacetime.

He took the opportunity of paying a tribute to Professor Garner because during his term of office as President he had spent a large portion of his time on those technical developments in addition to his educational

duties. It was very seldom that one found someone so public spirited as to make such self-sacrifice as Professor Garner must have done in order to carry out the work of the Institute. He wished to thank him in particular for the interest he had taken in the branches and, from personal knowledge, for the amiable way in which he had accepted onerous duties although overwhelmed with others.

The Vote of Thanks was carried by acclamation.

THE CHAR VALUE OF KEROSENE.*

By F. W. H. MATTHEWS and W. H. THOMAS, A.R.S.M., F.R.I.C. (Fellow).

SUMMARY.

This paper summarizes the development of the Burning Test for kerosine and describes investigations into the reproducibility of the test when carried out according to I.P. Method 10/44 (T).

It is shown that the reproducibility of estimations of char value may not always be of the order claimed by the above method, and that a considerably improved reproducibility may be obtained by the use of wicks extracted successively with water, alcohol, and petroleum ether.

Data are given for a variety of kerosines showing the reproducibility of char value determinations by the standard method.

The various steps taken in attempts to improve the test are described, and details of experiments carried out in this connection are given. It is shown that, with the exception of the properties of the wicks used, none of the variables connected with the test materially influences the char value.

Experiments using extracted wicks have given results which suggest the desirability of modifying the standard test. They are given in detail, the reproducibility data being furnished by two operators using a number of different lamps and chimney glasses and by tests carried out on high, medium and low char value kerosines.

INTRODUCTION.

The purpose of this paper is (a) to summarize the development of the Burning Test up to the date of issue of the present I.P. Method 10/44 (T); (b) to show that this method in its present form leaves a great deal to be desired as regards the reproducibility of char value results; and (c) to describe work recently carried out which has resulted in improved reproducibility.

HISTORY OF THE DEVELOPMENT OF THE BURNING TEST.

The development of the burning test for kerosine has occasioned considerable interest for many years. Prior to 1927 various methods for carrying out burning tests were in use, but few of these proved entirely satisfactory, owing to the difficulty of carrying out each test under absolutely identical conditions.

In a paper published in 1927, Thomas¹ described the original Saybolt lamp, the Canadian lamp, Redwood's apparatus, and the modern Saybolt lamp. He pointed out the disadvantages of these methods, and introduced a new lamp, which is the one now in use in the current I.P. test.

The modern Saybolt lamp appears to have been the most popular, and it was improved by the addition of self-filling devices which obviated the necessity of having to refill the reservoir three times during the 24-hour test. This, however, made the apparatus complicated, and the new lamp was more convenient, simpler to handle and gave much better repeatability of results.

* The results presented in this paper have been communicated to the Burning Test Panel of Standardization Sub-Committee No. 3. The Panel is engaged in co-operative work designed to ascertain (a) whether the suggestions made in the paper will lead to the elimination of major discrepancies between char values obtained in different laboratories, and (b) what modifications, if any, are desirable to the present standard method I.P.—10/44 (T).

At this time methods for assessing the burning quality were based on measurements of illuminating power, kerosine consumption, chimney deposits, and inspection of the wick, after burning. Although it was realized that char formation was related to the characteristics of the kerosine, no attempt to determine the amount of char was described in the literature until 1933, when Jackson² introduced the idea.

He used a Saybolt lamp equipped with a Richardson constant level device, and showed that the char value was a satisfactory measure of the quality of the kerosine. He did not, however, take any steps to remove residual kerosine from the char before drying to constant weight.

In 1935 the burning test for kerosine was published by the Institute of Petroleum³ as a tentative method of test under the designation K.35(T). The lamp introduced by Thomas¹ was adopted, and the char was estimated by the present-day procedure, the results being expressed as milligrams per litre of kerosine consumed. The consumption was recorded, and the description of the bloom on the glass left to the discretion of the observer. No attempt to assess the precision of the test was then made.

During the year 1939 co-operative tests were carried out by various interested laboratories to provide data for the precision of the test, and attempts were also made to improve the reproducibility by the use of the acid separation method for the estimation of the char.

The outcome was the publication⁴ in 1940 of a revised I.P. Method under the designation K.35 (T). The more important modifications embodied in the revised test were as follows :—

- (a) The wick was more closely specified, and a clause relating to its purification by washing with boiling distilled water was included;
- (b) Provision was made for a 48 hour test;
- (c) Details relating to the trimming of the wick were given and the flame shape more closely specified;
- (d) Details regarding manipulation for removal of the char from the wick were given;
- (e) The char was required to be expressed as milligrams per kilogram of kerosine consumed;
- (f) The bloom on the glass was required to be expressed in terms of a predominating colour—brown, grey-brown or grey;
- (g) The repeatability was given as ± 15 per cent or ± 2 milligrams, whichever was the greater;
- (h) Abnormal atmospheric conditions were required to be recorded.

This test was adopted as a tentative method under the designation I.P. 10/42 (T) in 1942⁵ with little modification, except that the precision was further and more closely defined.

In 1943 a Burning Test Panel was instituted by the Institute of Petroleum for the purpose of consideration of the improvement of the test. Under the auspices of this panel, further co-operative work was undertaken in 1943 and 1944. Comparison between mechanical and acid separation of the char was again attempted, and wicks with char attached were also distributed from one laboratory to different centres for separation of the char by various operators using the current I.P. procedure.

Finally, the method under designation I.P. 10/44 (T), published in 1944,⁶ was substantially the same as that of 1942 except that the provision for a 48-hour test was withdrawn.

During the war years a marked deterioration in the precision of the test was observed by a variety of workers, and became so serious as to render the test useless for certain purposes.

EXPERIMENTAL WORK.

Reproducibility of the Char Value by I.P. Method 10/44 (T).

The I.P. Method 10/44 (T) quotes the following precision :

Char value, mg/kg.	Repeatability.	Reproducibility.
0-15	2 mg.	2 mg.
16-20	2 "	3 "
21-30	10 per cent. of the mean.	15 per cent. of the mean.
Above 30	No specific permissible variations can be given.	

Since it was found that this precision could not always be obtained, it was considered advisable, as a preliminary to the investigation, to obtain data on the variations in the char value experienced on a variety of kerosines. In Table I is shown the range of values obtained by different operators for six kerosine samples, and also the frequency of occurrence of a particular value.

TABLE I.

Range of Char Values Obtained by I.P. Method 10/44 (T) Showing the Frequency of Occurrence of Each Particular Value.

A. High Char Kerosine.

Char value, mg/kg.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	Total No. of tests.
Kerosine I.															
Tests by Operator A .	3	—	3	2	3	4	4	5	2	2	1	1	1	1	32
" " B .	1	1	2	5	—	1	—	—	—	—	—	—	—	—	10
" " C .	1	1	1	—	1	2	—	—	—	—	—	—	—	—	6
Kerosine II.															
Tests by Operator B .	—	—	—	1	—	1	1	2	1	—	—	—	—	—	6
" " C .	—	—	—	—	—	—	—	1	—	4	1	—	—	—	6

B. Medium Char Kerosines.

Char value, mg/kg.	12.	13.	14.	15.	16.	17.	18.	Total No. of tests.
Kerosine III.								
Tests by Operator B .	—	—	—	1	3	1	—	5
" " C .	—	1	4	—	1	—	2	8
" " D .	—	—	3	—	—	1	—	4
Kerosine IV.								
Tests by Operator B .	1	1	1	1	—	—	1	4
" " C .	—	1	1	—	1	—	—	4

TABLE I.—*continued.*
C. Low Char Kerosines.

Char value, mg/kg.	5.	6.	7.	8.	9.	10.	11.	Total No. of tests.
Kerosine V.								
Tests by Operator A	—	6	4	6	8	4	2	30
Kerosine VI.								
Tests by Operator B	—	—	3	1	1	—	—	5
" " C	—	1	—	4	2	1	—	8
" " D	1	2	—	—	1	—	—	4

The average char values, the total spread of results, and the percentage of tests carried out meeting the reproducibility stated by the standard method are as follows:

Kerosine.	I.	II.	III.	IV.	V.	VI.
Average char value, mg/kg	22	25	15	14	8	8
Total spread of results, mg/kg	17-30	20-27	13-18	12-18	6-11	5-10
Percentage of tests meeting I.P. reproducibility	73	92	88	87.5	93	94

In no case, therefore, is the reproducibility claimed for the test completely satisfied, but the most serious deviations are those for kerosines I, III, and IV.

When considering the actual spread of results, however, the differences between the maximum and minimum char values obtained are very large, particularly in the case of the Kerosines I, V, and VI, where the maximum figure is approximately twice the minimum.

It is therefore apparent that the test in its present form cannot be of much value unless the reproducibility is improved. It is shown subsequently that this has been satisfactorily accomplished.

Variables Connected with the Burning Test.

Apparatus. At the outset every care was taken to ensure that, as far as possible, the apparatus in use conformed to the requirements of the I.P. standard method.

All the lamps and wick guides were examined, and found to be satisfactory.

At the time operations were commenced difficulty was experienced in obtaining supplies of lamp glasses and it was necessary to use a number which did not completely satisfy wartime requirements. The dimensions of these, together with the specification, are shown in Table II. This detailed examination of the glasses was carried out in case it should be found that "stray" results were obtained with the glasses off specification.

In order to determine whether the apparatus used had any influence on the char value, several tests were carried out by one operator using the same lamp and glass. The procedure was also varied by changing the glass on a particular lamp.

The results of this work, detailed in Tables III and IV, on high and low

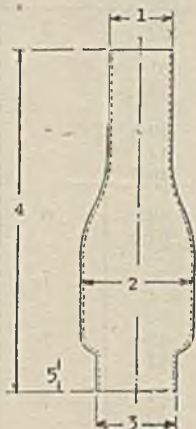
char value kerosines show that no apparent relationship exists between apparatus used and char value.

At this stage the data given in Tables III and IV were considered statistically from every angle, to see whether any other relationships existed between the variables—*e.g.*, between char value and consumption. No success attended these efforts, and therefore attention was next directed to the conditions under which the test was conducted.

Atmospheric Conditions. The room in which the tests were carried out

TABLE II.

Dimensions of Glasses used not Satisfying I.P. Wartime Specification.



Glass No.	1.	5.	9.	13.	14.	Wartime specification.	
	Measurement, cm.					Maximum cm.	Minimum cm.
1	3.50	3.57	3.44	3.56	3.61	3.81	3.17
2	6.52	6.59	6.39	6.42	6.68	6.67	6.03
3	4.49	4.50	4.51	4.56	4.64	4.75	4.11
4	18.63	18.82	18.94	18.63	18.74	19.37	18.73
5	1.78	2.37	2.26	2.01	1.98	2.24	1.60

satisfied, as far as practicable, the conditions set out in the standard method and 2-ft.-diameter screens were used for each lamp.

Temperature variations were followed by means of an ambient temperature recorder and humidity conditions by wet and dry-bulb thermometer readings.

These data are also recorded in Tables III and IV, and tests not conducted under the requisite temperature conditions were rejected. Thus the recorded data, except in one or two instances, satisfy the minimum temperature requirement of 60° F.

Detailed consideration of the data obtained again yielded no evidence of a relationship between conditions and char value.

TABLE III.

Tests on High Char Kerosine I Carried Out to Determine the Effect of the Apparatus used and the Ambient Conditions, on the Char Value.

Date of test, 1944.	Ambient conditions.			Apparatus.		Average consumption, g/lr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
June 8	63	72	55	3	9 *	17.5	23
July 14	62	81	—			18.8	17
Aug. 3	64	91	51			18.5	21
Aug. 21	61	71	73			17.8	26
July 19	62	85	49.5	3	6.	19.8	17
July 20	64	89	41			18.2	20
July 27	67	90	46.5			17.1	24
June 12	60	70	42	6	11	18.8	22
July 10	64	78	67.5			18.5	21
July 24	60	81	50	7	14 *	18.3	19
July 26	66	87	—			18.4	24
July 19	62	85	49.5	7	1 *	18.5	22
Aug. 1	66	86	47.5			19.1	24
Aug. 21	61	71	73	7	11	16.9	29
Aug. 22	66	85	72			19.0	30
June 6	—	—	—	8	11	18.1	21
July 7	71	78	62			17.5	17
June 15	66	78	48	8	5	20.0	27
Aug. 2	64	83	45.5			17.5	26
June 19	—	—	—	8	13 *	17.7	25
June 22	68	73	43			18.7	25
June 27	66	72	59	9	11	18.6	23
July 19	62	85	49.5			17.6	19
July 20	64	89	41			17.2	22
July 26	66	87	—	9	1 *	17.7	22
July 28	66	90	43			18.3	23
June 21	68	74	50.5	10	5 *	19.7	23
July 18	66	91	39			16.8	19
July 31	64	86	47.5			16.4	28
June 16	64	91	48	10	13 *	16.5	24
July 17	63	91	51			16.8	20
Aug. 3	66	78	51			19.0	24

*.Not satisfying I.P. dimension requirements, vide Table II.

TABLE IV.

Tests on Low Char Kerosine V Carried Out to Determine the Effects of the Apparatus used and the Ambient Conditions on the Char Value.

Date of test.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
Dec. 12, 1944	60.5	73.5	41	1	1	19.2	10
Jan. 23, 1945	61	73.5	39			20.5	9
Dec. 14, 1944	60	71	63	1	4	19.9	10
Jan. 4, 1945	59	72	—	1	9 *	21.2	7
Jan. 8, 1945	62	71	52			20.8	8
Jan. 24, 1945	62.5	72.5	39	1	16	20.2	7
Jan. 25, 1945	59.5	74	—			20.5	6
Dec. 27, 1944	56	71	—	2	2	20.1	8
Jan. 3, 1945	63	72	48			19.1	9
Dec. 6, 1944	64	73	43.5	2	4	19.9	9
Dec. 7, 1944	60.5	73.5	41			19.5	9
Dec. 14, 1944	60	71	63	2	9 *	20.1	10
Jan. 8, 1945	62	71	52	2	16	20.0	8
Jan. 9, 1945	62	72	45			19.5	8
Dec. 13, 1944	61	71	56	3	2	21.0	11
Dec. 15, 1944	62	69.5	50			19.8	11
Jan. 8, 1945	62	71	52	3	19	20.3	6
Jan. 25, 1945	59.5	74	—			19.9	6
Dec. 6, 1944	64	73	43.5	3	9 *	20.3	8
Jan. 23, 1945	61	73.5	39			20.9	6
Jan. 5, 1945	60	71.5	52	3	16	19.5	9
Jan. 8, 1945	62	71	52	4	2	20.8	6
Jan. 9, 1945	62	72	45			20.9	6
Jan. 5, 1945	60	71.5	52	4	19	21.1	9
Jan. 23, 1945	61	73.5	39			19.7	8
Jan. 25, 1945	59.5	74	—	4	9 *	22.7	7
Dec. 6, 1944	64	73	43.5	4	12	22.0	9
Dec. 7, 1944	58	72	41			21.9	10
Dec. 14, 1944	60	71	63	4	16	20.2	9
Dec. 15, 1944	62	69.5	50			21.5	7

* Not satisfying I.P. dimension requirements, vide Table II.

As will be shown later, this is further proved by the fact that when using extracted wicks, excellent reproducibility was obtained even though the temperature and humidity variations were considerable.

TABLE V.

Tests on Kerosine I, the Char being Separated by S.I.L. Method.

Date of test, 1944.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
June 6	59	70	42	3	9	18.5	21
July 17	62	91	51			18.9	17
Aug. 2	64	83	45.5			17.2	22
July 7	71	78	62	3	6	19.9	22
July 31	64	86	47.5			18.2	21
June 8	63	72	55	6	11	18.0	22
July 14	62	81	—			20.0	22
June 19	—	—	—	7	14	20.4	22
July 18	66	91	39			20.2	21
June 15	66	78	48	7	1	19.2	29
Aug. 3	64	91	51			19.2	24
June 22	68	73	43	7	11	19.6	18
July 27	67	90	46.5			18.8	16
June 26	65	77	69	8	11	17.4	20
Aug. 3	64	91	51			18.6	23
July 26	66	87	—	8	5	18.8	22
Aug. 22	66	85	72			19.8	20
July 19	62	85	49.5	8	13	19.1	17
July 31	64	86	47.5			17.8	24
Aug. 21	61	71	73			19.0	21
June 16	66	78	48	9	11	18.2	25
July 25	66	86	49			17.5	19
Aug. 11	66	86	47.5			18.0	16
June 21	68	74	50.5	9	1	18.7	19
July 20	64	89	41	10	5	19.5	15
July 28	66	90	43			17.8	21
Aug. 21	61	71	73			19.0	19
July 25	66	86	49	10	13	18.0	19
July 27	67	90	46.5			17.7	21

Separation of the Char from the Wick. It was thought probable that the mechanical separation of the char from the wick might be subject to a large personal error. In order to eliminate this factor as far as possible, a method devised by the Standard Inspection Laboratories of Standard Oil Develop-

ment Company was tried out. This consists essentially in digestion of the small portion of the wick to which the char is attached in 72 per cent by weight sulphuric acid. The cotton is dissolved by acid of this strength, and

TABLE VI.

Tests on Kerosine V the Char being Separated by S.I.L. Method.

Date of test.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
Dec. 11, 1944	62	71.5	43	1	2	20.6	11
Dec. 12, 1944	61.5	72	47.5			20.0	12
Dec. 20, 1944	64	72	60	1	19	21.3	8
Jan. 9, 1945	62	72	45	1	9	19.8	8
Jan. 10, 1945	61	72	39			21.1	9
Dec. 18, 1944	64	73.5	50	1	16	19.7	7
Jan. 4, 1945	59	72	—	2	2	19.8	7
Dec. 11, 1944	62	71.5	43	2	4	19.7	12
Dec. 18, 1944	64	73.5	50	2	9	21.3	8
Jan. 10, 1945	61	72	39	2	16	20.3	7
Jan. 22, 1945	62	72	42			20.3	8
Dec. 19, 1944	64	74	40	3	2	19.5	6
Dec. 21, 1944	65	75	60			20.2	7
Jan. 9, 1945	62	72	45	3	19	20.2	8
Jan. 10, 1945	61	72	39			19.8	8
Dec. 11, 1944	62	71.5	43	3	9	20.1	11
Dec. 12, 1944	61.5	72	47.5			20.0	9
Jan. 10, 1945	61	72	39	4	2	20.4	7
Jan. 24, 1945	62.5	72.5	39	4	19	22.2	10
Dec. 11, 1944	62	71.5	43	4	12	21.0	11
Dec. 12, 1944	61.5	72	47.5			20.3	10
Dec. 19, 1944	64	74	49	4	16	21.2	6
Dec. 21, 1944	65	75	60	4	16	20.2	8

the char is separated by filtration through a sintered glass crucible. Washing with the acid followed by water and subsequent drying and weighing of the char completes the determination.

Tables V and VI give the results obtained by this method on kerosines I and V.

An analysis of these results gives the following information:—

Kerosine.	I.	V.
No. of tests carried out	29	23
Average char value, mg/kg	21	9
Total spread of results, mg/kg	15-29	6-12
Percentage of tests meeting I.P. reproducibility	72	82

Comparing the spread of results with similar data previously given for tests using the I.P. mechanical separation method, we have for kerosine I a spread of 15 to 29 mg/kg for the S.I.L. method and 17 to 30 mg/kg for the I.P. method, and for kerosine V, 6 to 12 mg/kg for the S.I.L. method and 6 to 11 mg/kg for the I.P. method. There is therefore little to choose between the methods.

It thus appears that none of the variables so far dealt with materially influences the char value. The only remaining source of discrepancies appears to be the wicks used, and examination of the I.P. wicks as received from the makers was next undertaken.

TABLE VII.

Char Values on Kerosine V using the same Wick for Three Tests.

Date of test, 1945.	Wick No.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
		Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
Char by I.P. 10/44 (T).								
Feb. 26	1	54	64	78	4	9	19.6	7
Feb. 27		53	64	72.5			19.1	9
Mar. 1		47	62	71			20.2	9
Mar. 1	2	47	62	71	1	3	19.6	8
Mar. 6		51	66	56			21.1	8
Mar. 12		49	62	61			19.6	8
Char by S.I.L. Method.								
Feb. 27	3	53	64	72.5	2	16	18.6	9
Feb. 28		51	58	88			19.5	8
Mar. 1		47	62	71			18.8	9
Feb. 27	4	53	64	72.5	8	2	18.4	9
Feb. 28		51	58	88			19.7	8
Mar. 1		47	62	71			18.5	9

Wicks.

It is well known that cotton articles may contain appreciable quantities of oily material,⁷ and the examination of cotton waste in connection with work on engine-oil filters has indicated that the amount of such material can vary considerably.

Again, previous work has shown that traces of contaminants, such as

residues or lubricating oils, give rise to markedly increased char value results, and hence it was considered that a possible explanation for the char value discrepancies might be given if the wicks contained variable amounts of oily or waxy material.

These considerations caused attention to be directed more closely to the I.P. requirement for wicks that, "after weaving, they shall be treated with boiling distilled water and thoroughly dried." It is evident that considerable latitude in treatment could result from the interpretation of this requirement.

As a preliminary, therefore, it was decided to attempt three tests on a single wick, retrimming each time after removal of the portion with the char attached from the previous test, using the same sample of kerosine throughout.

The char was estimated both by the I.P. standard method and by the S.I.L. method to see whether results of value were obtainable. Table VII shows these results, and it is seen that very good agreement was obtained in spite of the adverse temperature conditions.

As is evident from the previous work detailed in Table IV, this agreement would not have been maintained over a series of tests, but it is probable that each wick would give three results in substantial agreement.

The matter was therefore pursued a stage further by ascertaining whether the amount of extractable material varied from wick to wick.

Accordingly, wicks were treated with water by boiling in a beaker for three hours and with alcohol and petroleum ether by extraction in a Soxhlet extractor for the same period. After evaporation of the solvent, the extract was weighed.

Two wicks gave water extracts of 41 and 38 mg respectively, two others gave alcohol extracts of 43 and 22 mg, and a further two petroleum ether extracts of 5 and 11 mg respectively. Thus it was evident that the extracts varied and bearing in mind the influence of traces of contaminants on the char value, it was considered that the above figures varied sufficiently to account for char value discrepancies. Even if they were not char-forming, it was thought that they might impede an even flow of kerosine to the flame.

As will be shown subsequently, it was found that they were in fact char-forming, since a diminution in the char value occurred when using extracted wicks.

Burning tests were next carried out on the wicks resulting from the above-mentioned extractions, and the results are set out in Table VIII. It will be observed that, particularly in the case of the alcohol- and petroleum ether-extracted wicks, a great improvement in the reproducibility is apparent.

As a result of this work it was considered that to obtain universally concordant results it would be necessary to remove from the wick as far as possible all the extractable material soluble in each of the three solvents used—i.e., water, alcohol, and 70/90 petroleum ether.

As a preliminary check on this view, two wicks were treated in boiling distilled water for three hours, partially dried between filter paper and then transferred to a Soxhlet extractor and extracted with absolute alcohol for three hours. The alcohol was then removed and the extraction continued

for a further three hours with petroleum ether. The wicks were then dried and burning tests carried out, three char values being determined on each wick. The results obtained were as follows:—

Kerosine I.

Wick No.	Char value, mg/kg.
11	16, 16, 16
12	16, 17, 16

These results appeared so promising that it was decided to carry out a number of tests on various samples using fully extracted wicks. For these

TABLE VIII.

Char Values Obtained on Wicks Extracted with a Single Solvent.

Three tests being carried out on each wick.

Date of test, 1945.	Wick No.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
		Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
(a) Wicks after water extraction—Kerosine I.								
Mar. 13	7	54	68	65.5	2	A	20.1	20
Mar. 21		49	66	52			19.0	21
Mar. 22		50	70	52			19.1	19
Mar. 13	8	54	68	65.5	1	3	20.6	18
Mar. 21		49	66	52			20.1	19
Mar. 22		50	70	52			20.8	18
(b) Wicks after alcohol extraction—Kerosine V.								
Mar. 6	5	51	66	56	6	16	21.0	7
Mar. 12		49	62	61			19.2	7
Mar. 13		54	68	65.5			20.2	7
Mar. 6	6	51	66	56	4	2	21.1	8
Mar. 12		49	62	61			21.1	7
Mar. 13		54	68	65.5			21.5	7
(c) Wicks after 70/90 petroleum ether extraction—Kerosine I.								
Mar. 22	9	50	70	52	4	E	18.5	19
Mar. 26		52	68	65			20.7	19
Mar. 27		62	71	64			21.1	19
Mar. 22	10	50	70	52	6	10	19.9	19
Mar. 26		52	68	65			20.7	19
Mar. 27		62	71	64			19.7	20

tests, batches of wicks were extracted and the procedure adopted was that mentioned above—i.e. three hours boiling with water followed by Soxhlet extraction with alcohol and petroleum ether. Opportunity was also taken to evaluate the amounts of extract obtained.

These results are given in Table IX.

TABLE IX.
Amounts of Extract from Wicks Extracted Batchwise.

	Water extract.		Alcohol extract.		Petroleum ether extract.	
	Total, mg.	Mg./wick.	Total, mg.	Mg./wick.	Total, mg.	Mg./wick.
Batch 1 (24 wicks) . . .	522	22	565	24	25.6	1.1
Batch 2 (25 wicks) . . .	812	32.5	660	26	58.6	2.3
Batch 3 (24 wicks) . . .	439	18	616	26	29.8	1.2
Batch 4 (12 wicks) . . .	426	35.5	237	20	18.4	1.5

Burning Tests on kerosines I, II, III, and VI were carried out using these extracted wicks. It will be seen from the individual results recorded in Table X, that while excellent repeatability was obtained for kerosine I and

TABLE X.
Char Values obtained by Different Operators using Different Apparatus and Wicks Extracted Successively with Water, Alcohol and Petroleum Ether.

Individual results are given.

Kerosine I.		Kerosine II.		Kerosine III.			Kerosine VI.		
Operator.		Operator.		Operator.			Operator.		
B.	C.	B.	C.	B.	C.	D.	B.	C.	D.
16	15	23	22	15	12	14	7	6	7
16	17	21	21	15	12	12	6	8	6
16	15	20	21	12	13	13	6	6	4
16	16	21	20	15	12	10	6	7	4
17	16	—	—	14	12	—	6	5	—
16	16	—	—	—	16	—	—	6	—
16	—	—	—	—	15	—	—	4	—
16	—	—	—	—	13	—	—	5	—
16	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—

VI by operator B, the reproducibility in no case came up to expectations, the total spread of results being as follows :—

Kerosine.	Spread, mg/kg.
I	15-17
II	20-23
III	10-16
VI	4-8

It was therefore considered probable that the procedure for the water extraction was at fault and that simple boiling in water in a beaker might have left sufficient material in the wicks to cause the persistent discrepancies, which were especially evident in the case of the lower char value kerosines.

The extraction technique was therefore investigated to find out the best conditions for wick treatment.

This was done by using the Soxhlet extractor for the water extraction as well as for the alcohol and petroleum ether extractions. The amounts of material extracted hourly from batches of six wicks each were determined.

The data given in Table XI show this more clearly, and it may be deduced

TABLE XI.

Effect of Time of Extraction when Wicks are Extracted in a Soxhlet Apparatus Successively with Water, Absolute Alcohol and 70/90 Petroleum Ether.

Each batch represents six wicks.

Batch No.	5.		6.		7.		8.	
	Total extract, mg.	Increase per hr., mg.	Total extract, mg.	Increase per hr., mg.	Total extract, mg.	Increase per hr., mg.	Total extract, mg.	Increase per hr., mg.
Water Extraction.								
2	172	—	205	—	157	—	153	—
3	199.5	27.5	225.5	20.5	171	14	172	19
4	213	13.5	239	13.5	190	19	185	13
5	230	17	256	17	—	—	—	—
Alcohol Extraction.								
1	133	—	119	—	99	—	161	—
2	150	17	143	24	186.5	87.5	190	29
3	167	17	163	20	194	7.5	198	8
4	171	4	176	13	—	—	—	—
Petroleum Ether Extraction.								
1	9.5	—	9.4	—	27.2	—	24.0	—
2	16.5	7.0	11.9	2.5	34.5	7.3	24.7	10.7

therefrom that only a very small quantity of material remained in each wick after a three hours water extraction, and similarly for the alcohol extraction, whilst one hour's extraction was deemed sufficient for the petroleum ether extraction.

It is obvious from the nature of the wicks that to free them completely from extracts would be impracticable.

It was not considered relevant to find the nature of the extracts for the purposes of this paper, but a description of their appearance may not be out of place.

The water extract when dry is a brown-coloured, brittle substance resembling caramel. The alcohol extract contains some dye from the coloured threads in the wick, and has a waxy appearance. The petroleum ether extract is brown coloured and oily.

A series of burning tests was carried out using wicks extracted by the new technique, full experimental details for which are given in the appendix, on kerosines, II, III, IV, and VI.

It was not possible to carry out tests on kerosines I and V, since the available supply of these samples had been exhausted.

The kerosines mentioned, however, cover high, medium and low char values and are considered representative of types likely to be met in practice.

Tables XIII to XVI give full details of these tests and show that the new technique has finally resulted in very good reproducibility for all the samples.

Analysing these results, the frequency of occurrence of particular values and the spread of results is as follows:—

Kerosine.	II.					III.		
	19.	20.	21.	22.	23.	10.	11.	12.
Char value, mg/kg.								
Tests by Operator B	1	—	4	5	—	3	3	—
“ “ C	—	1	2	1	6	—	1	5

Kerosine.	IV.			VI.			
	10.	11.	12.	3.0.	3.5.	4.0.	4.5.
Char value, mg/kg.*							
Tests by Operator B	3	5	2	1	7	1	1
“ “ C	1	3	6	3	3	3	1

* To nearest 0.5 mg.

Comparing the results with those given by the normal I.P. procedure, we obtain the figures given in Table XII.

TABLE XII.

Comparison of Results by the I.P. Standard Method and those Obtained using Extracted Wicks.

Kerosine.	II.		III.		IV.		VI.	
	Method.		Method.		Method.		Method.	
	Standard I.P.	Extr. wicks.	Standard I.P.	Extr. wicks.	Standard I.P.	Extr. wicks.	Standard I.P.	Extr. wicks.
Average char value, mg/kg	25	22	15	11	14	11	8	3.6
Percentage of tests giving:								
I.P. reproducibility	92	100	88	100	87.5	100	94	100
2 mg. “	83.5	95	88	100	87.5	100	94	100
1 mg. “	66.5	90	70.5	100	62.5	100	70.5	100
0.5 mg. “	—	—	—	—	—	—	—	80

From these data it is evident that the reproducibility of the test has been considerably improved by the use of extracted wicks.

It is also observed that the diminution in average char value is from 3 to 4 mg/kg which would indicate that the extracted material is char-forming and is the source of the discrepancies found when using the standard I.P. wicks.

TABLE XIII.

Burning Tests Carried Out using Wicks Extracted as Described in Appendix.

Kerosine II.

Date of test, 1946.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
Operator B.							
Oct. 8	52	66	57.5	4	4	21.0	22
Oct. 8	52	66	57.5	5	10	20.1	22
Oct. 9	58	72	65	16	7	21.5	21
Oct. 9	58	72	65	17	U	20.2	19
Oct. 10	57	72	61.5	4	I	20.2	22
Oct. 10	57	72	61.5	5	10	20.5	22
Oct. 11	62	72	73.5	16	Y	20.5	21
Oct. 11	62	72	73.5	17	V	20.5	21
Oct. 15	52	64	62	6	10	20.3	22
Oct. 15	52	64	62	7	Z	21.4	21
Operator C.							
Oct. 8	52	66	57.5	6	12	20.7	23
Oct. 8	52	66	57.5	7	Z	21.0	21
Oct. 9	58	72	65	14	V	20.0	20
Oct. 9	58	72	65	15	A	19.3	22
Oct. 10	57	72	61.5	6	4	19.7	23
Oct. 10	57	72	61.5	7	3	20.8	21
Oct. 11	62	72	73.5	14	7	20.4	23
Oct. 11	62	72	73.5	15	A	20.4	23
Oct. 15	52	64	62	4	X	20.1	23
Oct. 15	52	64	62	5	Y	20.7	23

DISCUSSION.

The development of the burning test for kerosine reached its most important phase when it was found that the quality of kerosine could be assessed by the determination of the amount of char found on the wick. This factor has now become, by reason of its simplicity, considerably more important than measurements of illuminating power and assessment of deposits on the glass, etc.

The test in its present form, however, has never shown a precision which would justify its adoption by the I.P. as a standard method, and it has remained a tentative test since its introduction.

Its usefulness has occasioned a considerable amount of co-operative work in attempts to improve its precision and the main consideration in this respect appears to have been the personal error in separation of the char from the wick.

Serious variations in the char value on the same sample of kerosine appear

to have been more prevalent during the war years, but "stray" result have always been a not uncommon feature of the test.

The work described has shown that these variations can be considerable, nor are they confined to any particular class of kerosine.

That the mode of separation of the char from the wick has little influence on the results has been adequately proved, and the work on the variables connected with the test has also shown that these factors are not contributory to the variations encountered.

The properties of the wicks have been studied in the past only so far as their capillarity is concerned, and the I.P. specification in this respect adequately defines the type of wick to be used. In the treatment of the

TABLE XIV.

Burning Tests Carried Out using Wicks Extracted as Described in Appendix.

Kerosine III.

Date of test, 1945.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
Operator B.							
Oct. 18	55	74	57.5	16	4	18.8	10
Oct. 18	55	74	57.5	17	I	19.3	10
Oct. 20	69	75	85	16	U	19.1	10
Oct. 20	69	75	85	17	10	20.2	11
Oct. 22	62	70	74	16	P	19.9	11
Oct. 22	62	70	74	17	T	19.0	11
Operator C.							
Oct. 19	58.5	74	71	6	Z	19.7	11
Oct. 19	58.5	74	71	7	V	19.8	12
Oct. 21	63	72	74	6	13	19.6	12
Oct. 21	63	72	74	7	Z	19.9	12
Oct. 22	62	70	74	6	A	19.5	12
Oct. 22	62	70	74	7	V	20.2	12

wick, however, the stipulation that "after weaving, they shall be treated with boiling distilled water and thoroughly dried" appears to give grounds for criticism. The purpose of the washing is evidently intended to remove foreign matter and to purify the wicks, but it cannot be assumed that the treatment described removes all water-soluble material or even leaves a constant amount in the wick.

If, then, it could be shown that the wicks contained appreciable and variable amounts of extractable material and that this material was char-forming, it would be a step forward in elucidating the reason for char value variations.

The knowledge that traces of contaminants in kerosine, such as lubricating oil or residues, markedly increase the char value lends support to the above considerations. In fact, it has been shown that as little as 0.01 per cent of lubricating oil can raise the char value of a kerosine from 14 to 24 mg/kg.

The work described has furnished ample evidence that the wicks as

received from the makers contain extractable material, not only water soluble, but soluble also in alcohol and petroleum ether. It has also been shown that these extracts are present in variable amounts and that they are char-forming, for a diminution of 3 to 4 mg/kg in the char value was observed when comparing the results obtained using extracted and unextracted wicks (Table XII).

It is pertinent to observe at this stage that the extracted wicks are easier to trim than the non-extracted ones and that if reasonable care is taken in

TABLE XV.

Burning Tests Carried Out using Wicks Extracted as Described in Appendix.

Kerosine IV.

Date of test, 1945.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
Operator B.							
Sept. 17	68	78	70	4	K	20.2	11
Sept. 17	68	78	70	5	L	19.8	11
Sept. 18	65	78	61	15	7	19.9	12
Sept. 18	65	78	61	16	12	19.1	11
Sept. 19	66	76	77	5	L	19.6	10
Sept. 19	66	76	77	6	K	20.0	10
Sept. 20	60	72	66	15	A	19.4	12
Sept. 20	60	72	66	16	I	19.3	11
Oct. 16	55	64	73.5	16	12	19.0	10
Oct. 16	55	64	73.5	17	4	19.7	11
Operator C.							
Sept. 17	68	78	70	6	5	19.5	11
Sept. 17	68	78	70	7	10	19.9	11
Sept. 18	65	78	61	13	3	18.7	12
Sept. 18	65	78	61	14	4	18.3	12
Sept. 19	66	76	77	7	J	19.5	12
Sept. 19	66	76	77	17	10	19.8	10
Sept. 20	60	72	66	13	7	19.2	11
Sept. 20	60	72	66	14	12	20.1	12
Oct. 17	60	67	74	5	10	19.6	12
Oct. 17	60	67	74	6	5	20.5	12

the insertion of the wicks into the absorption apparatus, no distortion occurs, provided they are straightened out before drying.

Turning now to the precision of the test using wicks extracted as completely as possible with water, alcohol, and petroleum ether, reference to Table XII shows that there is now no difficulty in meeting the present I.P. requirements. Moreover, the reproducibility is much better in most cases, and the following precision could be quoted with confidence :

Char value, mg/kg.	Repeatability.	Reproducibility.
0-15	1 mg.	1 mg.
16-20	2 "	2 "
21-30	2 "	3 "

It is therefore considered that this development of the test has so far increased its value that, with the modification described, it merits consideration for inclusion as an I.P. standard method. This would necessitate the insertion of a clause in I.P.—10/44 (T) para 3 (b) on the lines of the extraction procedure described in the Appendix.

From this point it is obvious that the development of tests for the

TABLE XVI.

Burning Tests Carried Out using Wicks Extracted as Described in Appendix.

Kerosine VI.

Date of test, 1945.	Ambient conditions.			Apparatus.		Average consumption, g/hr.	Char value, mg/kg.
	Minimum temp., ° F.	Maximum temp., ° F.	Relative humidity, per cent.	Lamp No.	Glass No.		
Operator B.							
Oct. 18	55	74	57.5	14	U	18.7	3.4
Oct. 18	55	74	57.5	15	12	17.3	4.3
Oct. 19	58.5	74	71	1	Y	20.4	3.9
Oct. 19	58.5	74	71	2	A	19.2	3.3
Oct. 20	69	75	85	14	7	20.5	3.7
Oct. 20	69	75	85	15	4	18.8	3.1
Oct. 22	62	70	74	8	7	20.1	3.3
Oct. 22	62	70	74	13	N	20.3	3.7
Oct. 22	62	70	74	14	3	20.3	3.5
Oct. 22	62	70	74	15	M	19.0	3.3
Operator C.							
Oct. 18	55	74	57.5	8	3	19.7	3.2
Oct. 18	55	74	57.5	13	7	19.2	4.1
Oct. 19	58.5	74	71	4	5	20.5	4.3
Oct. 19	58.5	74	71	5	T	20.4	3.5
Oct. 20	69	75	85	8	3	20.4	4.1
Oct. 20	69	75	85	13	12	18.6	3.6
Oct. 21	63	72	74	1	10	21.0	4.0
Oct. 21	63	72	74	2	U	18.1	3.0
Oct. 21	63	72	74	4	Y	20.5	3.3
Oct. 21	63	72	74	5	12	19.7	3.0

burning quality of kerosine should continue, but they may take a somewhat different form from the test under discussion in this paper.

The future trend of kerosine utilization both for illuminating and heating purposes is towards blue-flame type burners and here is as yet an almost unexplored field. Tests for burning quality in these modern burners will undoubtedly have to be devised by the petroleum chemist, whose ingenuity and technical ability will certainly be put to the test.

ACKNOWLEDGMENT.

This work was carried out in the Research Laboratories of the Anglo-Iranian Oil Company Ltd. at Sunbury and the authors express their thanks to the Chairman of the company for permission to publish this paper.

References.

- ¹ W. H. Thomas, *J. Inst. Pet. Tech.*, 1927, 13, 402.
- ² J. S. Jackson, *Proc. World Petr. Congress*, 1933, 11, 699.
- ³ *Standard Methods for Testing Petroleum and Its Products*, 3rd ed., 1935.
- ⁴ *J. Inst. Petrol.*, 1940, 26, 91.
- ⁵ *Standard Methods for Testing Petroleum and Its Products*, 4th ed., 1942.
- ⁶ *Standard Methods for Testing Petroleum and Its Products*, 5th ed., 1944.
- ⁷ C. N. Conrad, *Ind. Eng. Chem. Anal.*, 1944, 16, 745.

APPENDIX.

METHOD FOR EXTRACTION OF WICKS PRIOR TO USE IN THE I.P. BURNING TEST.

A suitable number of wicks are coiled, or otherwise arranged to prevent distortion, and introduced into the extractor of a Soxhlet apparatus which has been well lagged with cotton wool or other convenient material.

Extraction is carried out with water, which should be vigorously boiling in the flask, for three hours after the first siphoning cycle.

At the end of this period the wicks are removed from the extractor and laid flat on filter or blotting-paper, and a sheet of filter paper is laid over them. By gentle pressure the excess moisture is removed from the wicks.

The moist wicks are then reintroduced into the Soxhlet extractor, from which the lagging has been removed, and extracted with absolute alcohol for three hours after the first siphoning cycle.

At the end of this period the alcohol is removed from the apparatus, as much as possible being drained from the wicks in the extractor without removing them.

One hour's extraction with petroleum ether of boiling range 70° to 90° C is then carried out.

The wicks are then removed and dried in an oven at 105° C. They are then ready for use in the usual way.

THIRD LIST OF DEFINITIONS.*

BY STANDARDIZATION SUB-COMMITTEE NO. 11—
NOMENCLATURE.

Amorphous Wax. See Microcrystalline Wax.

Blending. Intimate mixing of the various components in the preparation of a product to meet a given specification.

Blown Oil. Fatty oil, of which the viscosity has been increased by blowing with air at an elevated temperature.

Casinghead Gasoline. See Natural Gasoline.

Ceresin. A hard, brittle wax obtained by purifying ozokerite (*q.v.*). The commercial product is nearly always adulterated with paraffin waxes. See Petroleum Ceresin and Microcrystalline Wax.

Compounding. A blending operation usually involving the addition of fatty oils to mineral lubricating oils.

Co-polymers. See Polymerization.

Crude Oil. See Petroleum. (*Note.*—In rare cases only can such untreated material be used as a fuel.)

Earth Wax. See Ozokerite.

Extract. Material removed from petroleum products by the selective action of a solvent in solvent-refining processes other than dewaxing. Extracts are generally aromatic in character (*cf.* Raffinate *q.v.*).

Hydraulic Fluid. A fluid supplied for use in hydraulic systems. Low viscosity, low rate of change of viscosity with temperature, and low pour point (*q.v.*) are desirable characteristics. Hydraulic fluids may be of petroleum or non-petroleum origin.

Insulating Oil. Suitable petroleum distillates of low volatility and viscosity used for cooling and insulating purposes in electrical equipment such as circuit breakers, switches, transformers, etc.

Long-Time Burning Oil. A grade of kerosine suitable for continuous burning in wick-fed lamps for prolonged periods without attention. It is often referred to as Signal Oil, and is largely used in railway signal lamps.

Marine Engine Oil. Oil used to lubricate the motion and bearings of reciprocating marine steam engines; may contain up to 15 per cent of blown (*q.v.*) vegetable or marine animal oils in order to assist good emulsification.

Microcrystalline Wax. Wax extracted from certain petroleum residues and having a finer and less apparent crystalline structure than paraffin wax (*q.v.*). It is usually more opaque than paraffin wax, and may vary from soft and plastic to hard and brittle and from white to dark brown in colour. The term "Amorphous" has been widely applied to the plastic crystalline waxes, but is incorrect, and should be abandoned. The term "petroleum ceresin" is occasionally applied to the hard brittle waxes.

* The first and second lists were published in the September, 1944, and June, 1945, issues of the *Journal* respectively.

Mineral Colza. A well-refined petroleum distillate, normally boiling within the limits 250° C to 350° C, used as a burning oil where a high flashpoint (above 250° F) is required. Largely utilized for lighthouse-illumination and in signal lamps, when it is sometimes compounded with fatty oils. Also known as Mineral Sperm and Mineral Seal.

Mineral Jelly. See Petrolatum.

Mineral Oil. Any oil derived from a mineral source. Such oils include liquid products obtained from petroleum, shale and coal.

Mineral Seal. See Mineral Colza.

Mineral Sperm. See Mineral Colza.

Ozokerite (Earth Wax). A naturally-occurring mineral wax, usually dark brown in colour, and containing mineral matter and oil. On purification it yields a white to yellow microcrystalline wax which may contain small quantities of oil. Fully refined ozokerite is a hard, white, microcrystalline wax, substantially free from oil, that was formerly, and is still occasionally, known as ceresin.

Paraffin Scale. Similar to paraffin wax, but less highly refined and having a higher oil content. It may vary from white to light yellow in colour.

Paraffin Wax. Wax, of solid consistency, and having a relatively pronounced crystalline structure, extracted from certain distillates from petroleum, shale oil, etc. Refined paraffin wax has a very low oil content, is white, with some degree of translucency, almost tasteless and odourless, and is slightly greasy to the touch.

Petrolatum (Petroleum Jelly, Mineral Jelly). A soft, salve-like material obtained from petroleum oils, and consisting essentially of microcrystalline waxes in association with substantial quantities of oil. It may vary in colour from white to dark brown, but when refined to white or amber colour it is termed by the British Pharmacopoeia "soft paraffin."

Petroleum Ceresin. This term is sometimes applied to the hard and brittle microcrystalline waxes (*q.v.*).

Petroleum Jelly. See Petrolatum.

Petroleum Resins. Solid or semi-solid resinous products obtained mainly by the distillation of special crude oils or lubricating-oil extracts. They are used as substitutes for natural resins in paints, etc., where asphaltic bitumen would be unsuitable because of its dark colour.

Polymerization. Polymerization is the combination of identical molecules to form materials of higher molecular weight. The term selective polymerization has been applied to such polymerization and the term co-polymerization denotes combination, between molecules of similar chemical type but different structure. The combination is normally carried out under controlled conditions of temperature and pressure in the presence of catalysts, and the products obtained are known as polymers or co-polymers. Typical polymers may range from a light liquid, such as diisobutylene, to polyisobutylene, a rubber-like material.

Polymers. See Polymerization.

Pour Point. The pour point of a petroleum oil is the lowest temperature at which the oil will pour or flow when it is chilled without disturbance under prescribed conditions.

- Power Kerosine.** A volatile kerosine with distillation limits essentially between 150° C and 260° C and of good anti-knock value. It is used as a fuel for spark ignition engines, and is alternatively known as Vaporizing Oil.
- Pressure Distillate.** The untreated distillate product of thermal cracking (*q.v.*).
- Raffinate.** The refined product resulting from a solvent refining process (*cf. Extract q.v.*).
- Scale Wax.** See Paraffin Scale.
- Shale Oil.** The distillate obtained when shale is heated in retorts.
- Signal Oil.** See Long-Time Burning Oil.
- Soft Paraffin.** See Petrolatum.
- Solar Oil.** The term formerly applied to gas oil (*q.v.*). The term derives from the original use of a light distillate oil for the production of illuminating gas by direct cracking.
- Special Boiling Point Spirit.** A petroleum solvent fractionally distilled to specially selected distillation characteristics. Such distillates are normally manufactured from well-refined straight-run naphthas. The various volatilities are designed to enable a suitable grade to be chosen for any particular industrial purpose.
- Spindle Oil.** Originally used to describe a stable low-viscosity oil used in the lubrication of textile spindles. The term now includes any low-viscosity mineral lubricating oil.
- Stabilized Gasoline.** Gasoline after subjection to fractionation by which the vapour pressure has been reduced to a specified maximum. See also Natural Gasoline.
- Steam Cylinder Oil.** Oil used to lubricate the cylinders of steam engines. Usually dark, viscous petroleum oils of high flash point, sometimes compounded with fatty oil.
- Transformer Oil.** A well-refined pale petroleum distillate of low viscosity, resistant to oxidation under conditions of use. Used in transformers for cooling and insulating.
- Turbine Oil.** A well-refined specially selected petroleum distillate or mixture of such with a bright stock. Used for the lubrication of steam turbines. These oils show high resistance to emulsification with water and to oxidation under conditions of use.
- Vaporizing Oil.** See Power Kerosine.
- White Scale.** See Paraffin Scale.

THE INSTITUTE OF PETROLEUM.

THE Thirty-third Annual General Meeting of the Institute of Petroleum was held at Manson House, Portland Place, London, W.1, on Wednesday, March 13, 1946. The retiring President, PROFESSOR F. H. GARNER, O.B.E., occupied the Chair during the first part of the meeting, being succeeded by SIR ANDREW AGNEW, C.B.E., the newly elected President.

THE SECRETARY read the notice convening the meeting.

The Minutes of the Thirty-second Annual General Meeting, held on March 14, 1945, and of the adjourned Annual General Meeting, held on December 12, 1945, which had been published in the *Journal*, were taken as read and were confirmed and signed.

THE PRESIDENT (Professor F. H. Garner) said he thought it might be of interest if he gave the meeting a very brief account of the present position of the Institute.

Two years ago the Committees of the Institute had been reorganized, and it had been made a rule that no member of the Council could be chairman of more than one committee. That rule had worked quite well, and each chairman found that on the whole the work of the committee over which he presided occupied a considerable amount of his time. He thought the members of the Institute should realize the importance of the work done by the chairmen of the committees and by the members of council.

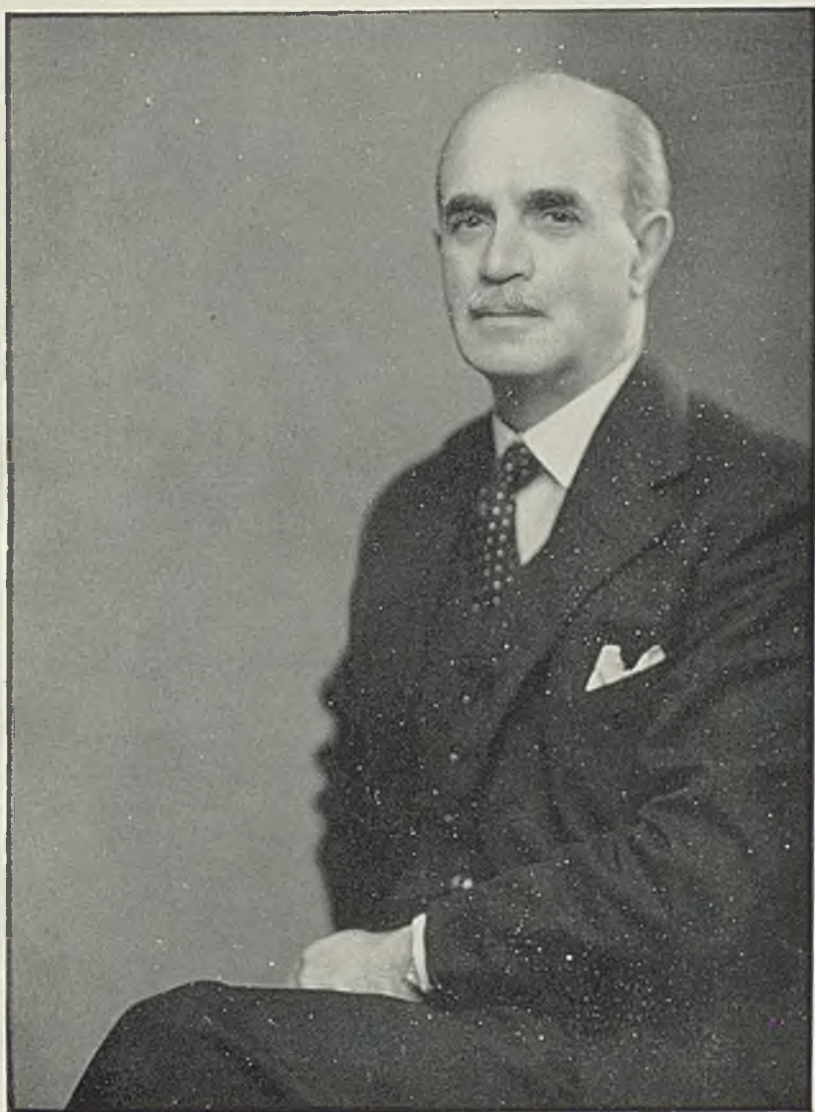
A new committee—the Education Committee—had recently been set up under the chairmanship of Mr. E. Thornton. That Committee proposed to confine its activities at first to the supervision of examinations, the passing of which would confer some recognition on those who entered the petroleum industry *via* the technical schools and colleges, particularly on the refining and laboratory sides. Education was specifically mentioned in the Memorandum of Association of the Institute as one of the objects for which the Institute was founded.

The Publication Committee, the Research Committee, and the Election Committee were equally important in connection with the objects for which the Institute was founded.

The Publication Committee had two Sub-Committees, the Abstract Sub-Committee and the Library Sub-Committee. The Abstract Sub-Committee dealt with the abstracts and with the volume entitled *Modern Petroleum Technology*, which was now in the press. It also was responsible for quinquennial *Review of Petroleum Technology*, covering briefly the progress made in petroleum technology during the war. The work of the Library Sub-Committee was of particular importance to the members, as it dealt with the matter of access to technical information. It had had a good deal of work to do in getting the Library into order, as part of the Library had been left in the Institute's former offices in the Adelphi.

The Research Committee had been engaged for a year and a half on its first project, hydrocarbon research, and would issue a report on the subject in due course.

The Standardization Committee was concerned with methods of test, and surprisingly was not specifically mentioned in the Memorandum of Association, as it was obviously an important part of the Institute's work.



SIR ANDREW AGNEW, C.B.E.
(PRESIDENT.)

[To face p. 292.]

There was a large number of committees of Council, and an attempt had been made to reduce the number, but their activities were so diversified that so far it had not been possible to do that.

Mr. Coxon had been appointed Chairman of Council, as Sir Andrew Agnew could not be expected to attend all the meetings of the Council. The choice was a particularly happy one, because there was a number of financial problems to be considered in the near future.

In considering who should be the next president of the Institute, the Council felt the time had come to select from a wider field than that of the members of the Council, and the choice had fallen on Sir Andrew Agnew. (*Applause.*) During Sir Andrew's chairmanship of the Petroleum Board, the petroleum industry had won fresh laurels for itself and, by its enterprise and perseverance, made substantial contributions to victory. The Institute was indeed fortunate in having for its next president such an outstanding leader of the petroleum industry and a man with such a charming personality as Sir Andrew Agnew. (*Applause.*)

Professor F. H. Garner then vacated the Chair, which was taken by Sir Andrew Agnew.

THE PRESIDENT (Sir Andrew Agnew), after thanking Professor Garner for the kind remarks he had made about him and the members for the way in which they had received those remarks, said that he was indeed happy to follow Professor Garner as president of the Institute and to find himself among so many of his old friends. He had known for a great many years a number of the members present that evening; some he had met abroad and others he had known in this country.

It was quite obvious to him, from what he had seen at the end of the Council meeting that day and also at the present meeting, that the Institute of Petroleum was a very live body. He was glad of that, because, in his experience of more than forty years in the oil industry, he thought it could be said of him that he was more a worker than a talker. Therefore the thought that he was to be President for a year of an Institute which was alive, and which obviously meant to keep alive, gave him very great pleasure indeed.

He appreciated very much the honour of being president of the Institute. His experience in the oil industry had been principally on the commercial side, but in the Institute he found himself in the Holy of Holies, amongst the men who made the whole petroleum industry possible.

Professor Garner had referred to the work of the Petroleum Board in a most appreciative way; he knew and was happy that the Board had done good work, not due to his own efforts but due to the people whom he had round him. He could honestly say, as he had done on many previous occasions, that a better lot of men than those who had to do with the affairs of the Petroleum Board did not exist anywhere in the Empire. They were second to none, and he was glad that he had worked amongst them.

He assured the members that he would do his best to serve the Institute during his year of office as president.

THE PRESIDENT then announced that the following had been elected Vice-Presidents of the Institute for the Session 1946-47: G. H. Coxon,

E. A. Evans, A. C. Hartley, Prof. V. C. Illing, J. S. Jackson and J. A. Oriel. That list of names seemed to him to be very suitable and admirable.

THE SECRETARY, announcing the result of the ballot for the election of the Council, said that 1,105 ballot papers had been distributed in the United Kingdom, of which 400 had been returned. The following had been elected: C. Chilvers, Dr. E. B. Evans, F. L. Garton, C. A. P. Southwell, H. C. Tett, A. Beeby Thompson and C. W. Wood.

THE PRESIDENT said he would ask Dr. Hanson to propose that the meeting be adjourned until such time as the Council might decide, of which due notice would be given. The reason for that motion was that it was not possible on the present occasion to present the accounts for the past year.

DR. T. K. HANSON moved:—

“That the meeting be adjourned until such time as the Council may decide, of which due notice will be given”.

MR. E. EVANS-JONES seconded the motion.

The motion was carried unanimously.