

THE CONTAMINATION, DETERIORATION, AND DECOMPOSITION OF LUBRICATING OILS IN SERVICE.*

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1. INTRODUCTORY REMARKS.

MANY fallacious beliefs still exist in the minds of a number of oil users, as exemplified by the oft-heard remark "All oils are the same." Engineers, however, realize that different types of oils are required for different services, and have always shown an earnest desire to obtain a better understanding of the influence on lubrication of design and operating factors. The author's object in writing this paper is to assist users to obtain a better comprehension of the composition and deterioration of lubricating oils, so far as our present knowledge will permit, and to indicate the type of deterioration to be expected in the operation of the more common items of equipment found in plants on the Reef.

An attempt has been made to treat the subject from the operating engineer's point of view by reducing reference to chemical terms to the minimum, but it will be appreciated that to understand the changes which might take place in an oil, it is necessary to have some knowledge of the chemical composition and structure of oils.

The author is well aware of the shortcomings of this paper, as all possible failures cannot be predicted and many will require separate investigation. He hopes, however, that it will assist engineers to get a clearer view of possible difficulties and their solution.

2. CHEMICAL COMPOSITION AND STRUCTURE OF MINERAL LUBRICATING OILS.

Crude petroleum oils consist of compounds of carbon and hydrogen (known as hydrocarbons) which are combined in an infinite number of different ways. A study of these possible combinations embraces practically the whole field of organic chemistry, and the segregation of separate hydrocarbons in their pure state has proved a most difficult task for research chemists. Thus, whilst our knowledge of the exact structure and composition of hydrocarbons is limited, petroleum chemists have succeeded in classifying or grouping hydrocarbon structures.

Simple cases illustrating members of each family of the four basic hydrocarbon series are shown in Fig. 1. Fig. 1 (A) is one member of the paraffin hydrocarbon series in which, it will be noted, there are four bonds to each carbon atom and one to each hydrogen atom, in accordance with the well-known chemical law of valence. All bonds are satisfied and the hydrocarbon is said to be saturated. The chain can be extended or

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as they are essential for the initiation of combustion (rapid oxidation) of hydrocarbon fuels in diesel engines.

The extent to which oil is atomized, split up, or aerated, will naturally affect the rate of oxidation by exposing a larger surface of the oil to the oxygen in the atmosphere.

All ferrous metals when in a finely divided state appear to increase the rate of ageing of an oil; alloyed steels often more so than iron which is chemically pure. Some non-ferrous metals, such as lead, copper, brass, phosphor bronze, and nickel, can act as catalysts in promoting rapid oxidation, and the presence of finely divided carbon and dust can have a detrimental effect on the life of the oil. It appears that suspended solids accelerate oxidation by acting as oxygen-carrying agents.

It should be stressed that, although all the metals mentioned may act as catalysts, it does not follow that the oil will react chemically with these metals.

The presence of an alkali hastens oxidation, but pure water has little effect. Many bacteria have been known to accelerate oxidation, which is also promoted by galvanic currents, leakage electric currents, and silent electric discharges.

The foregoing stresses the importance of reducing impurities to the minimum if the maximum life is desired from oils in use.

(iii) *Products of Oxidation.*—The products of oxidation of mineral lubricating oils are chemically known as peroxides, alcohols, ketones, aldehydes, and organic acids. Small amounts of volatile acids are also formed, but it will be seen from the above that not all oxidation products are acid in character. The acids that are formed are not all soluble in water, but some ionize and exhibit the properties of weak acids.

The products of oxidation can be divided into those products soluble in the oil at operating temperatures and those insoluble. The former will sometimes precipitate from the oil in cooling coils or other places where the oil is allowed to cool down and rest: the latter precipitate at operating temperatures.

Here a paradox arises. Too drastic or too careful refining (which completely removes resinous or asphaltic substances) may make an oil oxidize more slowly: but products more acidic in character may be formed during use. Therefore, it will be appreciated why the proper selection of crudes, and the experience of the refiner often count for more than laboratory tests.

(iv) *Test for Acidity.*—The extent of ageing which has taken place in a used oil is usually measured by the change in such properties as carbon residue, viscosity, colour, demulsibility, etc., and by testing for acidity. This latter item has been somewhat overstressed in recent times, because acidity in oils is not always harmful, and tests have shown that there is no direct relation between acidity and sludge.

The method most commonly used for testing acidity is the neutralization of the acids by potassium hydroxide. The number of milligrams of potassium hydroxide required to neutralize the acids in one gram of oil is known as the Neutralization Number. Objections have been raised to this method of testing for oxidation products on the grounds that, as previously mentioned, not all deterioration products are acid in character.

Some acid products are volatile. Water-soluble and insoluble acids are measured, but some investigators consider that only the former cause sludge deposition.

In spite of these drawbacks, the neutralization test remains one of the most simple, readily available means of testing for deterioration products, but the foregoing indicates that too much reliance must not be placed on the results obtained by its use.

(B) *Polymerization.*

Polymerization is the chemical capacity of two or more similar molecules to combine and form a larger molecule of more complicated structure, but having a multiple of the original molecular weight.

Many unsaturated hydrocarbons are capable of polymerization at normal temperatures, but in refined lubricating oils it is usually the oxygenated molecules which combine. One way in which oxidized hydrocarbons can polymerize is illustrated in Fig. 3.

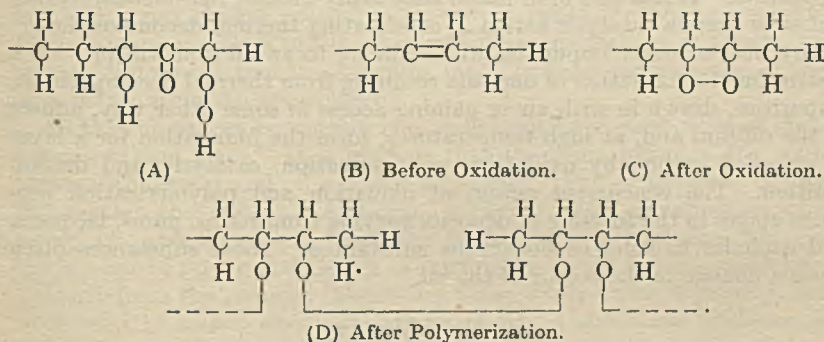


FIG. 3.

OXIDATION AND POLYMERIZATION.

Fig. 3 (B) shows a simple hydrocarbon side-chain before oxidation; Fig. 3 (C) after oxidation to form a peroxide; and Fig. 3 (D) shows the joining together or polymerization of the oxidized hydrocarbons.

Not all oxidation products will polymerize, but when this does take place it results in a small increase in viscosity and a precipitation of some of the polymerized hydrocarbons which have increased in molecular weight and become insoluble in the oil.

Heat, metallic catalysts, and finely divided solids in suspension, as well as electrical phenomena, accelerate polymerization.

(C) *Thermal Decomposition.*

When lubricating oils are subjected to heat the nature of the products formed depends on the constitution of the hydrocarbon and the conditions of pyrolysis. The thermal stability of the cyclic hydrocarbons is generally higher than the chain products which usually form the side-chains in lubricating oils.

High temperatures can cause a rupture of the chain. The splitting off of hydrogen also takes place, and is termed dehydrogenation. As the

elimination of hydrogen proceeds, the proportion of carbon in any molecule is increased, and products more carbonaceous in character are formed.

Deposits of so-called *carbon* taken from various types of prime movers have shown the presence of considerable quantities of combined oxygen, and there appears to be no doubt that oxidation plays a large part in the formation of *carbon* deposits. That the deposits do not consist of chemically pure carbon is emphasized by Gurwitsch.^{1*} Talking of the decomposition of petroleum by pyrolysis, he states: "Direct splitting up of a hydrocarbon molecule into pure elements is excluded. . . . Pure carbon may be regarded as a final product which can hardly be attained by the highest degree of heat which it is possible to employ."

It is important to remember that the thermal stability of hydrocarbons decreases with increased molecular weight. This means that the higher-viscosity oils are likely to yield more deposits from pyrogenetic decomposition.

Pressure reduces the temperature necessary for pyrolysis and polymerization. It has also been found that many metals, non-metals, oxides, and salts exert a catalytic action in accelerating thermal decomposition.

Any dust or other impurities which adhere to an oil film will provide a matrix for the formation of deposits resulting from thermal decomposition. Impurities, drawn in with air or gaining access in some other way, adhere to the oil film and, at high temperatures, form the foundation for a layer of so-called carbon by oxidation, polymerization, catalysis, and decomposition. The concurrent action of oxidation and polymerization produces stages in the forming of deposits varying from resins, gums, lacquers, and asphalts to solid carbonaceous substances. These substances often cause a change in the colour of the oil.

(D) *Emulsification.*

The phenomenon of emulsification may be simply explained by imagining drops of, say, water in a mass of oil (water in oil emulsion). Under normal conditions, with a pure mineral oil and water, the drops of water will coalesce and separate from the oil on standing. With a persistent emulsion, however, as the globules of water approach each other the interfacial film between the globules prevents coalescence. In some cases this may be due mainly to electrostatic repulsion, which prevents collision of the approaching droplets. In other instances additional factors, such as the nature of the interfacial film and the presence of impurities, will stabilize the emulsion.

Powdered solids stabilize emulsions by requiring to be expelled at the interface. The powder must be driven into one liquid or the other, but the necessary increase in free energy required is not always available, thus the tendency will be to retard a rupture of the interface and coalescence of the internal phase.

The dispersion of one liquid in another is of two types. Either the oil or the water can be the "internal" phase and is dispersed as separate droplets in a continuous "external" phase of the other. Water-oil emulsions are the more common type.

* Numbered references are tabulated at end of paper.

The interfacial tension of water and hydrocarbon oils is diminished if there is acid in the oil and alkali in the water. Thus, oils which have oxidized to form acids will emulsify more readily than the same oil when new. Impurities in the water, such as sodium and calcium chlorides, will reduce the surface tension and assist the formation of emulsions.

Considering only high-grade well-refined mineral oils, it will be seen from the foregoing remarks that the service conditions which may bring about emulsification, provided water is present, are :—

(a) Ageing of the oil to form soluble acids, resins, or asphaltic matter by oxidation, thermal decomposition, etc.

(b) Impurities in solution in the water.

(c) Dust, dirt, carbon, or metallic particles when in a finely divided state.

(d) The presence of other substances which act as emulsifying agents.

If water intrusion can be prevented, there is no danger of emulsification, but this is not always possible with certain prime movers and machines. Water may gain access to the oil in circulation by leakage at glands, seals, or bad joints, from broken oil-cooling pipes, or from condensation of steam or moisture from the atmosphere.

All the substances previously mentioned can be present without emulsification taking place. It is obvious that the more intimate the contact between the water and oil, *i.e.*, the more finely divided the state of either, the greater the danger. Agitation, spraying, and pulverization of the water, oil, and impurities assist the formation of emulsions. Therefore, the lay-out of piping and design of settling tanks are important factors.

Apart from the reduced lubricating value when water is present, emulsions tend to collect and hold impurities which accelerate oxidation and sludge formation. An emulsion of oil and water may have the appearance of a milky-white solution, or of a mass of foam with a honeycomb structure; it can have a creamy consistency, or it may be a black slimy gelatinous mass with many intermediate varieties according to circumstances.

(E) *Electrolysis and Electrical Phenomena.*

A broad definition of electrolysis is the resolution of compounds into their elements, or groups of elements, under the action of a current of electricity. The ionic theory of electrolysis assumes the establishment of positively and negatively charged ions, known as cations and anions, in the electrolyte. Experimental evidence indicates that, with saturated oils, conduction of an electrical current is of an ionic nature. The source of the ions is not definitely known, but experiments show that impurities are the main cause of conductivity rather than the molecules in the oil itself. This suggests that oil is not an electrolyte, but impurities dissolved in the oil materially affect its electrical characteristics.

In Michie's experiments on insulating oils he was unable to cause the oil to deposit any precipitate merely by an electrical stress, but he found that the deposits in oil-cooled transformers are products of oxidation of petroleum.

The experiments of Hovorka and Antony² have shown that in bearings

or other machine parts in which two dissimilar metals are separated by oil, the whole set-up can act as a galvanic cell. One of the metals may, because of its electrolytic solution pressure, dissolve in the oil and form a conducting solution. The metals may then act as electrodes, and oxidation of the oil may take place at their surfaces, resulting in chemical reaction between the metals and the oxidation products. Thus it may be possible that the electrode potential so produced is responsible, directly or indirectly, for corrosion which takes place in some bearing combinations. The above experimenters found that with a cadmium-silver-oil-steel combination a potential of up to 0.6 volt could be produced. However, the voltage did not appear until the oil temperature reached 200° F., the conductivity of the oil increased with temperature.

The galvanic currents just mentioned have not presented any lubricating problems in the majority of bearings, and the author has found little evidence in practice to support this theory as a general cause of bearing failure.

Leakage currents due to dynamic electrical leakage, magnetic induction, or static charges present greater practical hazards to be guarded against. Dynamic leakage currents through bearings can occur with electric traction systems where the return current flows through the axles and wheels to the rails. A failure of the collector-ring or brush-gear will divert current through the bearings. An earth fault on any electric machine may, in certain circumstances, cause current to flow through bearings. For instance, if the frame of a three-phase motor is not well earthed, a fault in the stator winding may cause current to seek a path to earth through the bearings and shaft.

Leakage currents due to magnetic induction can be caused in a number of ways. With D.C. machines, if the positive and negative commutator leads are brought out on opposite sides of the bearing pedestal they act as a single turn to produce a magnetic flux linking the shaft, bearing pedestal, and bed-plate. Series and interpole leads can cause unbalance and magnetization of the shaft. Unbalanced magnetic fields in A.C. and D.C. machines may produce shaft currents.

Static charges due to friction drives or belts can cause bearing currents.

If a shaft current is produced in any of the above ways, it might, if of sufficient strength, arc through the oil film and cause pittings of the shaft and bearing. The effect of shaft currents passing through the oil film in a bearing is to accelerate polymerization and oxidation and cause thermal decomposition. The oil darkens in colour, increases in acidity, and deposits a chocolate-coloured precipitate in the oil system. Arcing also causes small particles of metal to flake off and contaminate the oil.

The measures adopted to prevent bearing currents are either to fit an earth collector-ring and brush-gear or to insulate one bearing. In the latter case care must be taken to ensure that handrails, oil- or water-cooling pipes, etc., do not "short" the insulation.

(F) *Corrosion of Metals.*

Practice has shown that highly polished metals can remain in contact with straight mineral oils in service for extended periods without showing any signs of corrosion.

It has already been mentioned (Section 3 (A)) that acidity due to oxidation is not always harmful and, in fact, a measurement of this acidity is not a definite indication of corrosive possibilities. The acids resulting from the oxidation of straight mineral oils are very weak and normally do not attack metals. However, at elevated temperatures (in the neighbourhood of 300° F.) corrosion of certain metals can take place; with lead, zinc, copper, and cadmium-silver trouble might develop. It is only in certain plants—*e.g.*, internal-combustion engine crankcases—that temperatures exceeding 250° F. are met. Davis, Lincoln, and Silbey³ have shown that the oxidation products from some mineral oils, particularly the highly paraffinic type, are corrosive on the copper-lead and cadmium-silver bearings often used in I.C. engines. Curiously enough, babbitt or white-metal bearings, which may contain copper or lead, are not affected in the same way.

Corrosion is very likely to occur if water or moisture is present in oils. This might take place in two ways. Firstly, it has been suggested that a form of electrolytic corrosion takes place by the water dissolving acids or metal salts to form an electrolyte. Secondly, when the oil drains off polished parts they may be left exposed to the rusting action of any moisture which may be present.

If there is sulphur as an impurity in an internal-combustion engine fuel the lubricant can become contaminated with corrosive sulphur compounds.

As opposed to straight mineral oils, compounded oils, which consist of mineral oils blended with a small percentage of an animal or vegetable oil, will oxidize to form free fatty acids. These acids will attack metals to form metallic soaps; lead is dissolved, and with lead-bronze bearings failure could result. The free fatty acids might also attack copper and brass parts to form verdigris.

With the introduction of extreme pressure (inhibited) oils, corrosion troubles were experienced; but to-day manufacturers and oil suppliers alike are alert to these possibilities, and troubles of this nature have been overcome to a point where their occurrence is now almost unknown.

(G) *Paints and Pipe-Jointing Compounds, etc.*

The oil reservoirs on most machines are painted internally to avoid rusting and the loosening of moulding sand that might remain after cleaning or shot blasting the inner surfaces of castings. Manufacturers are well acquainted with the type of paint which should be used, and so in most cases no trouble is encountered. However, cases are on record where, through the use of unsuitable paints, the lubricating oil has become severely contaminated, particularly where lead or zinc base paints and compounded oils were involved.

Most fluid pipe-jointing compounds contain a drying oil similar to linseed, and if care is not taken to apply such products sparingly, the lubricating oil may become contaminated with a sufficient quantity to accelerate oxidation or form an emulsion with water. The complete removal of all anti-rust paints or greases in the case of new plants is important.

(H) Foaming and Vaporization.

When minutes bubbles of air are trapped in oil which is undergoing rapid circulation, there is a tendency towards foaming. This is usually the result of some mechanical fault, and may be due to any one or several of the following. An air-leak in the pump-suction line; uncovering of the pump suction due to too low an oil level or by the creation of a vortex due to the particular lay-out of the suction branch. Air may be occluded by incorrect pipe lay-out causing the oil to fall an excessive height or cascade in the system; by too high a rate of oil circulation or discharge from by-pass valves. The incorrect adjustment of nozzles feeding oil to gears may cause undue splashing. Inadequate venting and draining of bearings, etc., will accentuate foaming.

The cure for any of the foregoing troubles is self-evident, but the cause of aeration is not always obvious. For example, the addition of too much new oil to the oil in service may cause foaming due to the higher surface tension of the new oil. Therefore, it is good practice not to add more than 10 per cent. of new oil to a system at any one time. Foaming sometimes results from oil temperatures being too low, and the raising of the temperature to that of normal working by reducing the water-flow to coolers or bearings will, in these specific instances, reduce aeration.

Foaming sometimes occurs after overhaul of certain units, such as aircraft engines, due to the use and incomplete removal of special cleaning fluids.

Excessive foaming reduces the oil pressure and, where governors or relays are being operated by the oil, erratic functioning might result. Foaming is also objectionable because it not only increases the surface of the oil exposed to oxidation, but is responsible for mist formation, which is often erroneously taken for vaporization. As most lubricating oils will not vaporize under a temperature of 350–400° F. it will be appreciated that as the average plant operates with oil temperatures well below these figures, the extent of vaporization will usually be negligible. The oil mist escaping from breathers will often deposit on high-temperature machine parts, such as turbine steam casings, indicating that vaporization, which involves condensation to bring about deposition, is not taking place.

(I) Mixing of Lubricants.

When some users of lubricating oils are told that it is not safe to mix certain different lubricants, they are apt to think it a "salesman's catchphrase" to prevent the user changing to another oil. There are sound reasons for the proffering of such advice. Dealing first with straight mineral oils, it has been shown that certain oxidized hydrocarbons remain soluble in the oil at operating temperatures. If another oil of a different type is introduced in large quantities, it can happen that the oxidized hydrocarbons in solution will not be soluble in the new type of oil, with the result that there may be a sudden precipitation of these oxidation products. Therefore, in those items of equipment in which a sudden accumulation of deposits is dangerous—for example, turbines and internal-combustion engines—there is every reason to be cautious. In other units, such as splash-lubricated gear-boxes, etc., where the system can hold an

accumulation of sediment without the danger of blockage of feed, conditions would be less hazardous.

It is a common experience, when changing from one compounded to another compounded steam-cylinder oil, to find a steam engine groan and the valve gear clatter; dry spots on the valve faces and cylinder walls are sometimes evident. It appears that the oil being introduced gradually displaces the film of old oil adsorbed on the metal, and it is most probably during this transition period that dry spots occur.

Finally, the reason for discouraging the mixing of different inhibited oils (see later), which contain chemical additives, should be obvious. Here there is the distinct possibility of chemical reaction between the chemicals used as additives or inhibitors in different oils of this type. Thus, when next you are changing the oil in the differential of your car and a garage-man asks what brand of Hypoid gear oil you are using, don't prevaricate and think he is indulging in subterfuge, but remember that it shows he is earnest in his endeavours to assist you.

(J) "*Sludge*" and *Deposits*.

The possible constituents of any deposit are beyond description because, apart from the products of deterioration and decomposition of lubricating oils, extrinsic impurities, such as metallic particles and oxides, soaps of metals, dust, fuel, products of incomplete combustion, and other substances (some of which are mentioned later when specific items of plant are discussed), invariably form part of any deposit.

In addition to contaminating impurities, deposits may consist of precipitated oxidized or polymerized hydrocarbons; thermal decomposition may yield resinous, gummy or asphaltic materials, or an accretion of a dry, coke-like mass with many intermediate varieties of reddish-brown, shiny-black, or liver-like deposits. Emulsified materials may be present, resulting in a creamy sediment or a black, slimy, gelatinous mass. Electrical effects may have produced a chocolate-coloured or muddy precipitate. Two or more of the aforementioned types of impurities may be present, so that the appearance of any deposit is not an infallible guide to its origin.

4. MODERN TREND—INHIBITED OILS.

Constant increase in the severity of conditions encountered in internal-combustion engines, turbines, gears, and bearings, etc., led many research workers to seek ways and means of overcoming the disabilities of straight mineral oils. New methods of refining brought about marked advances in the resistance to oxidation and thermal decomposition of mineral oils. In the wake of progress came other problems. Mechanical skill and science produced better metals and means of manufacture, thereby imposing greater strain on the film of oil which takes within itself all motion and wear. Piston-ring sticking and gear galling were but a few of the troubles encountered, but research chemists were not long in discovering effective additives to overcome these problems.

The modern trend is towards an extension of the field of application of such inhibited oils. The number of additives which have been patented is legion. Therefore, no attempt will be made to describe them.

Among the classes of additives or inhibitors appear pour-point depressants, oiliness carriers and extreme-pressure materials, viscosity-characteristic improvers, oxidation inhibitors, colour improvers, anti-ring-sticking, and sludge-dispersing additives. Any one inhibitor or additive may be uni- or multi-functional.

It would be a retrogressive step to shun the developments which are taking place, although it often requires a daring person to be first in the field to use any new product.

5. CONTAMINATION, DETERIORATION, AND DECOMPOSITION EXPECTED IN DIFFERENT TYPES OF PLANTS.

Before dealing with specific items under this heading it should be stressed that it is assumed only high-grade oils suitable for the service intended in each case are considered. Inferior quality oils will deteriorate and decompose at a more rapid rate than properly refined lubricants.

(I) *Air Compressors—Reciprocating.*

(i) *Cylinder Lubrication.*—The formation of deposits in cylinders and on valves of air compressors has been the subject of much debate, owing to the possibility of explosions. A comprehensive paper on this subject was read to the South African Institution of Engineers by the late J. A. Vaughan,⁴ but, in the light of knowledge gained since this paper was presented, several theories require slight revision.

The formation of deposits on air-compressor valves, etc., is due primarily to oxidation and thermal decomposition. There are, however, several contributory factors which accentuate the formation of so-called *carbon* deposits, the most important being :

- (1) Impurities in the intake air.
- (2) Overfeeding of lubricating oil.
- (3) Operating temperatures.

Dust and other solid particles in the air are the most objectionable. It is considered by some engineers that a spark can be caused by the piston striking such impurities, but, whilst this is possible, in the author's opinion it is not likely to happen unless large particles accidentally gain access to the cylinder. Broken internal parts are more likely sources of this means of ignition. The principal danger with dust and impurities in the air is that they lodge on oil-wet surfaces and cause the valves or piston-rings to leak. Impurities adhere to the oil film and form a paste, which, by oxidation, polymerization, catalysis, and thermal decomposition, eventually becomes baked into a hard deposit. A portion of such a deposit may break off and cause a valve or piston-ring to stick.

The increase in temperature resulting from a leaky valve or piston was fully dealt with by Vaughan. Suffice to say that recompression of leakage air is the main cause of temperature rise.

If an excessive quantity of oil is fed to a cylinder it will lodge in valve-pockets, the discharge pipe, and receiver, and thereby increase the formation of deposits, since it is responsible for oil-covered surfaces that readily collect impurities. The resulting thicker film of oil on the cylinder wall

is not as effectively cooled by the circulating water as the thin film which exists with the correct rate of feed, thus increasing the tendency to form deposits.

With double-acting reciprocating compressors the crankcase is separated from the cylinders, and lubrication of the latter is effected by means of mechanical lubricators. Here, by simple adjustment, the feed to the cylinders is readily controlled. In the case of single-acting trunk-type piston compressors, oil consumption is governed by the mechanical condition of the piston, piston-rings, cylinder, and bearings. With force-feed oil circulation, worn bearings, or an excessively high oil pressure due to incorrect adjustment of the by-pass valve, excessive oil might be thrown on to the cylinder walls. It often happens that the piston-rings cannot control the extra quantity, and excess oil reaches the piston head and valves. Overfilling of the crankcase will cause the connecting-rods to dip and splash extra oil on to the cylinder walls.

Among the cases of explosions in trunk-type compressors which have come to the author's notice, the cause of deposits in one compressor was found to be excessive oil due to the unloader valve creating a partial vacuum in the cylinder. Therefore, it is advisable in the case of trunk-type compressors on which the unloader closes the inlet valve, to operate such units "loaded" as much as possible.

Defective cooling due to failure of the water supply or scaled jackets will naturally increase the overall operating temperature and assist in the formation of deposits, but the writer is not aware of any cases of explosion due to this cause alone.

In most instances of explosions investigated by the author signs of valve leaks were evident by burnt deposits and either burnt or "blued" valve faces.

An interesting case of an explosion in a 3500-c.f.m., twin-cylinder, double-acting, single-stage compressor operating to 50 lb. per sq. inch was recently investigated, and the available evidence provides an example of the troubles, pointed out by Vaughan, likely to result from the use of high-flash-point heavy oils for air-compressor cylinder lubrication. Before dealing with this case it will be as well to discuss the modern interpretation of the significance of flash point, the generation of combustible gases or vapours, and the probable means of ignition of this volatile matter in air compressors.

(ii) *Flash Point in Relation to Explosions.*—Contrary to the impression of many, the flash test is not indicative of the limiting safe temperature for the use of an oil.

The flash point is the temperature at which a definite volume of oil, when heated in standardized apparatus, will give off vapour in sufficient quantity to flash momentarily when a small *test flame* is applied. It should be noted that complete evaporation does not take place at the flash point, and the mere act of heating oil to the temperature spoken of as its "flash point" does not result in ignition or flash. It is *necessary* to apply the *test flame* just above the oil surface.

In practice, the author has often seen portable air compressors which, whilst operating on an oil with a flash point of 390° F., have continuous discharge air temperatures of about 420° F., and no trouble has occurred.

(iii) *Generation of Combustible Vapour-Air Mixtures.*—Carbonaceous deposits on the valves are the chief source of danger, because if leakage of air occurs the valve will become overheated and the deposit may begin to emit vapours at 120–150° F. below the flash point. The generation of vapours is now no longer a function of the flash point. Oil vapours can be derived from the deposit and any free oil, regardless of the flash point of the original oil. This may be due to the porous nature of deposit exposing a greater surface of oil to heat, vaporization being further accelerated by the high velocity of hot air through the leak.

The products of thermal decomposition may be lighter volatile hydrocarbons (methane gas is the lightest member of the Paraffin series—Section 2). Thus, inflammable oil vapour or gas-oil mixtures can be generated.

Feeding oil to the cylinders in excessive quantities may cause any accumulations of oil in the cylinder to be splashed and atomized by the motion of the piston. Apart from excess oil accentuating the growth of deposits, the objectionable condition of atomized oil in suspension in the air is produced. It is known that there are upper and lower limits of explosibility of oil vapour-air mixtures. These limits, however, need not be discussed, because whilst they are confined to a narrow range, experience has shown that explosive mixtures can sometimes exist in the valve chambers, etc., of air compressors.

The mere existence of an explosive mixture alone is insufficient to cause trouble, but given the means of ignition the danger obviously arises.

(iv) *Possible Means of Ignition.*—The reasons for abnormally high temperatures have been discussed and the possibility of a spark being struck by the piston or valve fouling some material brought in with the air or a broken ring, etc., has been mentioned.

When there is a leakage at one of the valves, the consequent wire drawing of the already compressed air as it leaks back into the cylinder may result in overheating to such an extent as to cause any deposit on the valve to become incandescent. It is considered that these hot glowing deposits, fanned by the high velocity of the air, are the most probable means of ignition.

Vaughan, in his paper, mentioned “spontaneous ignition” of the volatile matter, and quoted figures for the “ignition temperature” of methane. It is considered that, where glowing deposits exist, firing and not spontaneous ignition of oily material in the deposit first takes place. The mechanism of spontaneous combustion (as in diesel engines) requires that each particle of combustible substance absorbs heat until its temperature is raised to a point where it ignites spontaneously without the application of any external source of ignition.

It is most unlikely that the temperatures reached in compressors with leaky valves, but no glowing deposits, will approach the “spontaneous ignition” temperature of the volatile gases or vapours resulting from low-flash-point oils, but there is a distinct possibility of spontaneous ignition with high-flash-point oils. The reason is explained in the following section :—

(v) *Disadvantage of High-Flash-Point Oils.*—Flash point does not vary directly with the viscosity, but, generally, it may be said that the flash point of uncontaminated heavy oils is higher than that of light oils.

Recent researches are providing more proof of the phenomenon that, in general, the more complex and more viscous an oil is, the lower is its spontaneous ignition temperature. Sortman, Beaty, and Heron⁵ quote the following spontaneous ignition temperatures using the open crucible method :—

Cetane, $(\text{CH}_3(\text{CH}_2)_{14}\text{CH}_3$	455° F.
Pentane, $\text{CH}_3(\text{CH}_2)_3\text{CH}_3$	785° F.
Toluene, $\text{C}_6\text{H}_5\text{CH}_3$	1165° F.
Benzene, C_6H_6	1205° F.

It will be seen from the above that the heavier and more complex the hydrocarbon the lower the spontaneous ignition temperature, but the type of hydrocarbon also has a bearing on the spontaneous ignition temperature. An increase in pressure reduces the spontaneous ignition temperature. This is clearly demonstrated in a paper entitled "The Inflammation of Hydrocarbon Air Mixtures," by Townend and MacCormac.⁶

Therefore, it will be seen that the factors to be watched, and which accrue from the use of high-flash-point oils, may be summarized as follows :—

(a) High-flash-point oils are high-viscosity oils which, by their very nature, accumulate more impurities from the intake air, form thicker films on valves, etc., and yield more deposits on thermal decomposition.

(b) Speaking generally, the spontaneous ignition temperatures of petroleum products are in inverse relationship to the flash points. Therefore, high-flash-point oils will often have the lowest spontaneous ignition temperatures.

(vi) *A Case in Point.*—The explosion in the twin-cylinder, double-acting, single-stage, 3500-c.f.m. 50-lb.-per-sq.-inch compressor previously mentioned differed from others investigated by the writer in the following respects :—

(a) A lubricating oil with a flash point (Cleveland Open Cup Test) of over 500° F. was in use, whereas in other cases the average flash point of the oils in use was about 390° F.

(b) The deposits on the discharge valves, whilst more than usual, were oily with no signs of overheating on any valves.

(c) The highest recorded temperature before the explosion was 420° F. This temperature is not high for single-stage units.

(d) Liquid oil was found in the cylinder, valve ports, etc., indicating that no previous burning to any extent, if at all, had occurred.

The conclusion to be drawn from these facts is that ignition was by spontaneous combustion: the inflammable air-oil mixture probably being provided by atomization of the oil due to the piston motion.

The compressor was not damaged mechanically and, after cleaning, a low-flash-point (390° F.) oil was introduced. The compressor is still operating at periods with a discharge air temperature up to 420° F., but, whereas previously the valves had to be cleaned every two weeks before the change over to the lighter oil, the deposits have now been reduced to

practically nil, and valve-cleaning is only necessary once every three months.

Explosions of the type under discussion are not confined to air compressors. Fig. 4 shows the result of an explosion in a winding engine, the details of which are given later under winding engines.

(vii) *Compressor and Vacuum Pump Crankcase Oils.*—The oils in circulation in these crankcases are not subjected to high temperatures, and gradual deterioration results chiefly from oxidation and polymerization. The oils do become contaminated with dust and metallic particles and, where the unit operates intermittently, moisture gains access by condensation from the atmosphere. Water contamination can also result from broken oil-cooler pipes if these are fitted.

In passing, a typical experience of a remote cause of trouble may prove of interest. The lubricating oil in the crankcase of a trunk piston vacuum pump was thickening up very rapidly. On investigation it was found that timbers in the vacuum tank had been coated with a paint containing linseed oil. Before the paint dried the tank was recommissioned. The linseed oil, which emulsified with the water in the tank, was carried with moisture over the barometric leg into the vacuum pump cylinders. Here it contaminated the oil on the cylinder walls, and so gained access to the crankcase. Water and linseed oil were found in the crankcase oil. More careful treatment of the timbers eliminated this trouble.

(II) *Crushers—Gyratory.*

The oil in circulation in these units is not subjected to severe oxidizing conditions, but slow oxidation and polymerization will take place over a period of time. Thermal decomposition is unlikely at the temperatures encountered.

Severe contamination with dust and metallic particles is the chief danger to be guarded against. With crushers fitted with water seals the ingress of water has presented many problems.

The danger in this instance is emulsification of the water and oil, which takes place due to the presence of finely divided dust particles (Section 3 (D)). Emulsions of this type are usually black and slimy in appearance.

(III) *Electrical Plant.*

The oils in the bearings or circulatory systems of electrical machines are subjected to oxidation in varying degrees, depending on the intimacy of contact with air; polymerization resulting from oxidation as well as the possible effects of electrolysis and thermal decomposition if bearing currents occur (Section 3 (E)).

Dust, water, and metallic particles can contaminate the oil, and core sand and inferior paints have also caused trouble.

(IV) *Gear-Boxes.*

Because of the variety of types and sizes of gear-boxes in use for a multitude of services, the possible contaminants are numerous. Dust, moisture, metallic particles, and oxides are common impurities found in varying quantities in most gear-boxes. Contamination with grease from

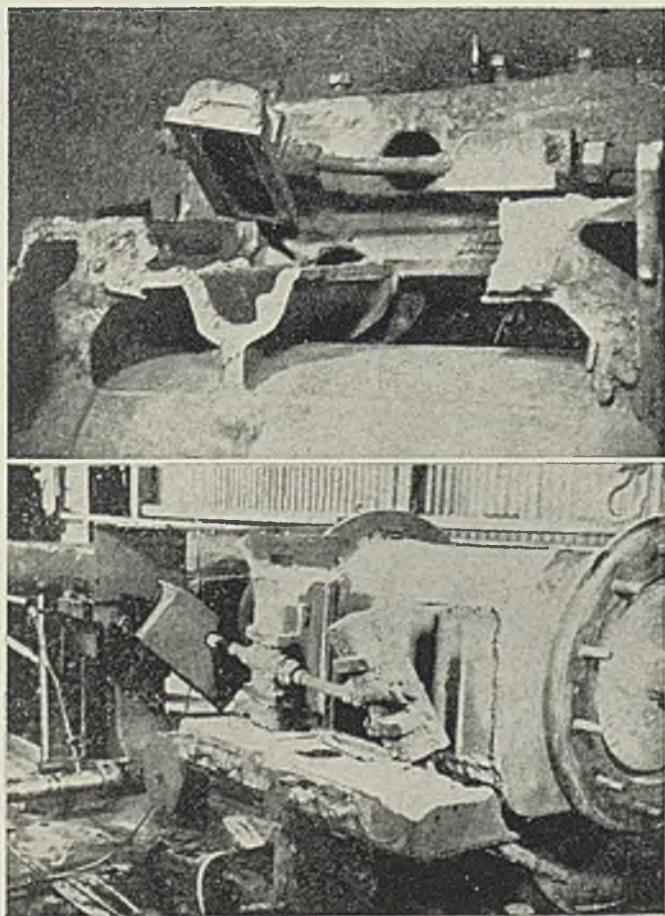


FIG. 4.

grease-lubricated bearings is a regular occurrence, and deposits resembling "pitch" often result from this cause.

In any gear-box the oil is churned and sprayed into a fine mist, so that a large surface is exposed to oxygen in the atmosphere. The resulting oxidation, followed by polymerization, is the main cause of the slimy deposits found in the sumps of gear-boxes, but the quantity increases with the increase of the impurities mentioned above; emulsification often occurs with badly deteriorated oils and condensed moisture.

Inhibited oils are used in a number of gear-boxes where extreme pressures are encountered, and the deterioration of these lubricants depends largely on service conditions and the type of oil and additive involved. Compounded oils will oxidize more readily than straight mineral oils, and corrosion troubles (Section 3 (F)) might occur due to the fatty acids formed by oxidation of the compounding, but the author has not personally experienced any corrosion troubles due to this cause.

Provided the correct type and grade of oil is applied by the proper method and the gears are not grossly overloaded, spalling, galling, and wear of tooth contours have been found to be due to faults in machining, misalignment, or incorrect heat treatment. A discussion of such failures together with the phenomenon of pitting (primarily due to skin stresses) is beyond the scope of this paper.

(V) *Hydraulic Systems.*

The derivation of the word hydraulic makes its application to systems employing oil a misnomer. Dr. Hele-Shaw suggested the term "Elaulic" where oil is employed, but the former term has gained such universal adoption that its use will be continued in this section.

In hydraulic systems the oil generally circulates in a completely enclosed system. However, if the by-pass pipe from the control valve does not remain full, but drains, or if this pipe is led in above the oil in the main sump, some spraying and aeration can occur. The main objection to aeration is that it causes "chattering" or erratic operation due to compression and expansion of entrained air.

Moisture gains access to the main oil sump by condensation from the atmosphere during "breathing," and this often gives the oil a cloudy appearance. Rust, resulting from the presence of water, might contaminate the oil, and soapy emulsions could form if impurities be present to any large extent.

Mineral oil dissolves natural rubber, and if U packings or flexible pipes are used, they should be made of synthetic rubber.

Generally, the straight mineral oils used in the majority of hydraulic systems do not deteriorate rapidly, and oxidation, etc., is not severe.

(VI) *Internal-Combustion Engines.*

(a) *General.*—With the exception of some horizontal and very large double-acting vertical units, the lubricating oil in the crankcase of internal-combustion engines must lubricate both bearings and cylinders. It is subjected to very severe conditions, and contamination, deterioration, and decomposition are likely to be more pronounced than in other services.

Dealing with cylinder-head deposits, these are affected by

- (1) Engine design, operating temperatures, speed, and load.
- (2) Impurities in the intake air. (See Section 5 (I).)
- (3) Amount of oil passing the piston. This is a function of design and mechanical condition. The more oil passing the piston the greater the deposits. (See Section 5 (I).)
- (4) The air-fuel mixture ratio and the efficiency of combustion.

Incomplete combustion of the fuel due to the wrong mixture or some mechanical fault—*e.g.*, spark- or valve-timing—will yield gummy deposits, which act as binders and accentuate carbonaceous deposits and ring-sticking.

Ring-sticking is experienced more with diesel or compression-ignition engines than with petrol engines, but lacquers or varnishes on the piston skirts and ring grooves are common to both types. Lacquer or varnish formation is affected by a number of factors, but appears to be most closely connected with piston temperatures. Piston-head temperatures can be up to (and even above) 550° F. and, as most of the heat passes through the ring lands to the cylinder walls and water-jacket, more trouble is expected at this part. However, there appears to be an optimum temperature at which some varnishes form, as they are often found on cooler parts of the engine, such as piston skirt below the gudgeon pin or on valve stems, etc.

The oil on the cylinder wall in the combustion chamber is subjected to direct contact with dirt in the intake air, fuel on the suction stroke, or during injection and flame during combustion. No oil can stand exposure to flame without some thermal decomposition taking place, but the cooling water prevents the thin film of oil on the cylinder wall from being violently decomposed. These factors, coupled with oxidation, etc., which takes place chiefly in the crankcase, yield deposits which vary from lacquers, resins, or gums to hard carbonaceous deposits.

All piston-rings leak to a certain extent, but if blowby is excessive, any dirt, deposits, soot, or liquid fuel will be carried through the ring grooves and accentuate ring-sticking.

The lubricating oil in the crankcase of any engine is split up into a finely divided atomized state by being thrown and splashed about in the crankcase. Oxidizing conditions are thus produced, and thermal decomposition might result from the oil being thrown on to the hot underside of the piston. Contamination with water results from condensation, blowby (water is a product of combustion), and leaks in the cooling system. Nitrogen oxides, carbon di- and monoxide, and perhaps sulphur and lead compounds are other products of combustion which contaminate the crankcase oil by blowby or working past the piston with the oil returning to the sump.

Soot from combustion can be drawn down with the oil by the scraper rings, dust gains access through the crankcase breather, and metallic particles and oxides result from wear and rusting.

The possible catalytic effect of such impurities has been mentioned, and deterioration of any oil will be accelerated by their presence. Emulsification can take place with water due either to badly oxidized oil or the

presence of finely divided solids (Section 3 (D)). Emulsification of a charge of new oil occurred after overhaul of a stationary diesel engine when red-lead was used for the oil-pipe joints, and water gained access to the sump through the push-rod opening from a leaky water-pipe gasket or one cylinder head. The red-lead acted as an emulsifying agent, and the resulting emulsion could be literally shovelled out of the crankcase.

(b) *Petrol Engines*.—In addition to all the above contaminants, dilution with liquid fuel results from incomplete combustion when starting from cold or due to cold operation, too rich a mixture, incorrect timing, or improper functioning or operation of the choke.

The percentage of dilution depends on operating conditions; for example, if a car is operated on long runs and becomes comparatively hot, a large portion of the contaminating petrol would evaporate, and fairly stable conditions would be reached with very low dilution. However, where vehicles are operated for short runs only, such as from door-to-door delivery, dilution may be high.

In view of all the aforementioned facts, is it not common sense in normal times that frequent draining be recommended? It is much better than waiting for, say, 10,000 miles to see what will happen, as then the repair bill might be ten times or more the cost of the lubricating oil. Granted, failure might not occur, but the possibilities are there and should be guarded against.

(c) *Paraffin Engines*.—The percentage dilution in these engines is always higher than in petrol units, and more frequent draining is necessary. Owing to the higher boiling points of power paraffins, they cannot always be successfully removed from lubricating oils, and attempts at reclamation should not be made without prior advice and proper laboratory facilities.

(d) *Diesel and Compression Ignition Engines*.—With these engines more difficulty is experienced in maintaining complete combustion under all load conditions, and consequently more "soot" or finely divided carbon is found in the lubricating oil. Fuel dilution occurs, and ring-sticking is more severe.

These factors, coupled with the possible presence of the general contaminants previously mentioned, usually make the successful reclamation of lubricating oils from these engines a difficult task. To avoid ring-sticking and crankcase deposits of finely divided carbon, inhibited oils (which dissolve lacquers or gums and take finely divided carbon into quasi-colloidal solution) are being used more and more.

(e) *Gas Engines*.—The additional contaminants found in these engines are coke dust, tar (if coal is used), and sulphur compounds. Moisture from scrubbers may be carried over with the gas, and this, together with sulphur compounds, can produce corrosion and also react with the unsaturated oil constituents.

Ring-sticking due to tarry substances is a common occurrence unless the gas is absolutely clean and dry. Special oils are often used to counteract these effects.

(VII) *Refrigerators.*

The number of different refrigerants used presents problems which are peculiar to this type of machine. All refrigerator oils should have a low

cold test to avoid any oil that might be carried over to the cooler pipes and expansion valve from congealing and retarding heat transfer or interfering with the proper functioning of the valve.

Water might gain access through cooling-water leakage, air left in the system, leaky glands, or by allowing moisture to contaminate the oil or refrigerant before its introduction to the compressor. This is the chief contaminant to be guarded against, because, apart from the possibility of freezing on expansion valves, etc., it will cause trouble in other directions.

Ammonia, the most commonly used refrigerant, is partly miscible with oil. In the presence of water it forms ammonium hydroxide, which promotes emulsification. Speaking generally, as air is not usually present in the system, no oxidation of the oil should take place, but, if this were to happen, oxidation could result, but any acids formed would probably be neutralized by the ammonia.

Carbon dioxide has practically no effect on oils, but, in the presence of water, corrosion might take place. Sulphur dioxide is partly miscible in oil. In the presence of water, sulphurous acid can form and attack the oil, with resultant "sludge," unless specially refined "water-white" or "off-white" oils are used. The presence of sulphurous or sulphuric acids will naturally cause severe corrosion of metals.

Many chlorine compounds, such as methyl chloride, Freon, etc., are used as refrigerants, and they are completely miscible with the oil. They are apt to react with ordinary oils, and special "water-white" or "off-white" refrigerator oils are necessary to avoid gummy deposits.

If water gains access to a system in which copper pipes, etc., are included in the construction and chlorinated refrigerants are being used, an electrolytic action (ionization) will take place and result in copper plating of the internal parts. Lubricating oils were blamed for this trouble, but proper dehydration of circuits has eliminated this problem. Copper plating is often accompanied by a deposit of fine powder (copper chloride) on filters. Absolute alcohol is sometimes added to a system to lower the freezing point of any moisture present, but, as it is difficult to keep alcohol dry, it should not be used indiscriminately, and it is preferable, particularly where chlorinated refrigerants are used, to dehydrate the system by heating or by the use of special dehydrating cartridges.

Scale from pipes and metal particles from wear can contaminate the oil and, if air is present, copper oxide, an active catalyst, can result. The use of natural-rubber gaskets which are dissolved by mineral oils has caused trouble. Although compressor temperatures can be high, thermal decomposition is not expected, particularly if air is not present.

(VIII) *Steam Engines.*

(a) *General Cylinder Deposits.*—Under normal steaming conditions, such as with power-plant units, there is very little oxygen present, as only a small percentage of air is mixed with the steam. However, temperatures are high, and a certain amount of oxidation, polymerization, and thermal decomposition takes place, but the amount of deposit in steam-engine cylinders resulting from these causes is normally very small.

The analysis of steam-cylinder deposits has shown that impurities in steam can play a large part in deposit formation. The impurities which

can be carried over with steam, particularly when boilers prime, include iron oxide, alumina, metallic carbonates, sulphates, phosphates, and chlorides, most of which come from impure feed-water. Any chemicals used for treating feed-water can also be carried over—*e.g.*, lime and soda. Iron oxides and scale formed in pipes by the action of steam may become loosened, due to expansion and contraction of the pipes or by vibration.

If lubricating oil is fed to the cylinders in excessive quantities or applied by a method which permits of accumulations of oil in parts of the engine, deposits will be increased.

(b) *Locomotives and Winding Engines.*—These engines are not steaming continuously, and additional factors enter into the problem of cylinder deposits.

When locomotives are coasting or drifting with a closed regulator, hot dusty gas from the smokebox can be drawn back through the blast pipe into the cylinders. This results in heavy deposits, unless “snifter” or anti-vacuum and by-pass valves are fitted. On smaller engines employing hydrostatic lubricators sufficient steam to break any vacuum is fed with the oil, but on larger locomotives steam is injected to the exhaust (French practice) or a breath of steam is fed to the steam chest. By this expedient locomotive cylinder deposits have been considerably reduced.

Conditions are more severe with winding engines on which the valve gear is brought over to reverse for braking. The more modern hoists are fitted with by-pass and relief-valve arrangements, but, nevertheless, in most cases air is drawn into the cylinders when the valve gear is reversed. In the presence of hot air most steam-cylinder oils, although entirely suitable for steam-cylinder and valve lubrication under normal steaming conditions, will oxidize and help to build deposits. When recompression of hot air is taking place, thermal decomposition of the oil is most likely. To lubricate a steam cylinder under conditions of high steam pressure and comparatively high temperatures a heavy-bodied oil is necessary. It has been shown (Sections 3 (C) and 5 (I)) that the heavier-bodied oils yield more deposits than light oils on decomposition.

It will be evident that if air and deposits are present, there is the same potential danger of explosions in winding engines as in air compressors. Fig. 4 shows the result of an explosion in a winding engine, and records show that a similar accident occurred in 1924 with a similar winder on an East Reef mine. There seems little doubt that explosions occurred in both instances, as soot was found on the internal parts of cylinders and valve chests.

The experience gained from locomotive practice suggests that the best way of reducing deposits in winders is to reduce the amount of air present by the admission of a breath of steam to the exhaust. After repair of the hoist shown in Fig. 4, a $\frac{1}{4}$ -in. steam pipe was fitted to the exhaust pipes, as shown in Fig. 5, and the maximum speed was reduced. After over two years of operation at the reduced speed and with steam fed to the exhaust during running, deposits have been considerably reduced.

No novelty is claimed for this idea, which has been in use on a number of hoist engines for some time, but the advantages to be gained by its adoption are not always understood. Circumstances will alter cases, but, generally speaking, the steam in the exhaust pipe will destroy any vacuum,

and so avoid dust or other matter being drawn into the cylinders; the effect of the latent heat of any moisture in the cylinders will result in cooler running; the reduction of air will retard oxidation of the oil, all of which will reduce deposits.

Apart from these considerations, it is interesting to note the influence of moisture on the ignition of vapours. When conducting flash tests, a very small percentage of moisture present will make it difficult to ignite

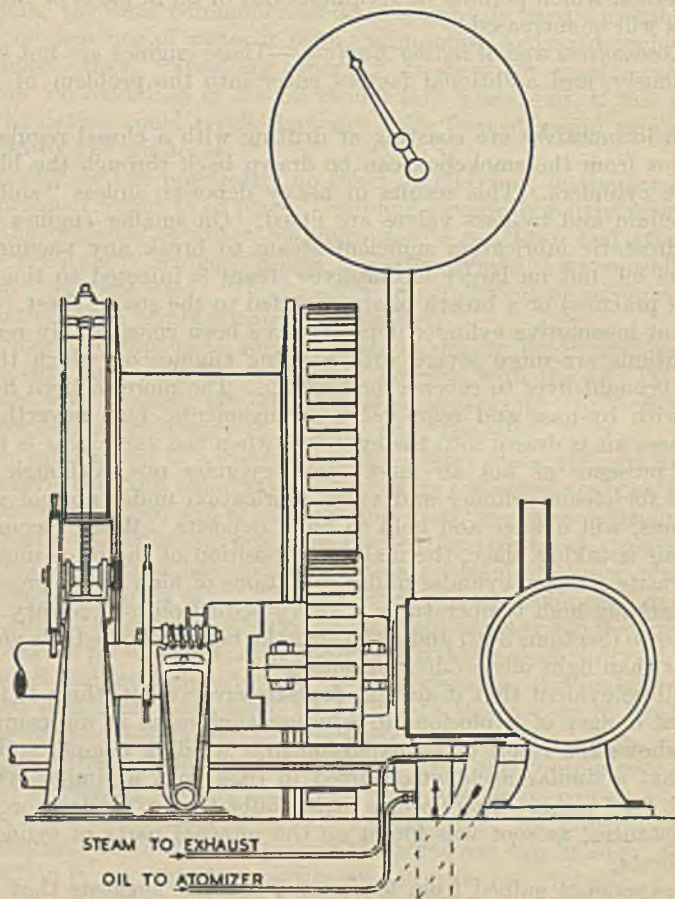


FIG. 5.

any vapours with an open flame. The spontaneous ignition temperature of oils is raised by the presence of moisture. It would seem, then, that admission of steam to the exhaust of winding engines whilst running against reverse should play an important part in preventing explosions.

In the case of winding engines lubricated by means of atomizers in the steam-inlet pipe, as in Fig. 5 (the most efficient and economical method under normal conditions), when the engine is running against reverse no steam will flow through the inlet pipe, but oil will be fed to the atomizer.

This oil has no carrier (*i.e.*, steam) to convey it into the engine, and so it will accumulate in the steam pipe. When steam is again admitted to the engine this accumulation of oil is picked up, and overfeeding for a short period results. This might be a factor in deposit formation, but its significance can only be judged from a knowledge of pipe lay-out, and actual observations and study of operating conditions.

(c) *Crankcase Oils—Enclosed Crankcase Engines.*—The oil in circulation in the crankcases of steam engines of this type—*e.g.*, vertical sets and steam wagons—is usually a straight mineral oil which is highly resistant to oxidation and emulsification. However, where compounded steam-cylinder oils are being used for cylinder lubrication, intrusion of this oil and water, which gain access by adhering to piston-rods and working past the cylinder and crankcase glands (generally in the form of an emulsion), adversely affect the stability of the crankcase oil. Over-feeding of cylinder oil has often been the cause of severe emulsification of the crankcase oil. In the same way, swabbing of piston-rods, which is often unnecessary, can result in excessive quantities of cylinder oil reaching the crankcase.

Due to the spraying of the oil in the crankcase, oxidation will slowly progress, and is accelerated by the presence of cylinder oil and water. Excessive spraying and churning of crankcase oil can be reduced by not overfilling and the avoidance of high circulating-oil pressures.

Some of the impurities carried over with steam (see (a) cylinder deposits) can gain access to the crankcase with condensed steam, and might act as emulsifying agents. Therefore, the purity and dryness of the steam are factors which should be watched. In some instances, where the piston-rod travel is small, the intrusion of cylinder oil and water can be avoided by fitting an "umbrella" collar to the piston-rod so that these contaminants drop clear of the crankcase gland. Where operating conditions permit the use of straight mineral cylinder oils, the danger of emulsification of the crankcase oil will be diminished.

The fitment of automatic "goose-neck" water-drains on the crankcase will also assist by reducing the amount of water present in the crankcase at any time. Crankcase oils will also become contaminated with dust and metallic particles.

(IX) *Steam Turbines.*

The oil in circulation in a turbine generally serves to lubricate and cool the bearings and to operate the governor mechanism. The latter service requires oil at high pressures, and the discharge from pressure control and by-pass valves are frequent sources of aeration. The occlusion of air might also result from one or more of the causes mentioned under foaming (Section 3 (I)).

These conditions promote oxidation, which is accelerated by the presence of metallic particles and oxides, dust, and water. Metallic particles and oxides result from wear and rust. Other impurities might come over with the steam. Water can gain access to the oil by steam leaks at glands playing on to bearings (frequently due to incorrect adjustment of the gland steam pressure); leaks from water-sealed glands; condensation from the atmosphere and leaks in oil coolers.

A small amount of water in solution will often cause the oil to become

cloudy when a machine is taken out of service and cools. The oil clears on heating, and there is little danger under these conditions. The risk occurs when oil has become badly oxidized and contaminated with impurities and intrusion of water takes place; the result might be a persistent emulsion and deposition of "sludge." Apart from the danger of coking screens and oil pipes, emulsions can carry solids in suspension, and scored parts might result.

Thermal decomposition is unlikely unless high temperatures are encountered in the governor mechanism. Electric leakage currents (Section 3 (E)) can produce deposits, which, together with oxidation, polymerization, emulsification, and contamination with impurities, are the main causes of deposits in turbine systems.

Speaking generally, a rise in acidity (as measured by the neutralization number (Section 3 (V)) will often be accompanied by an increase in sludge formation. There is no direct relation, as the quantity of deposit formed depends on the type of oxidation products and the extent of polymerization, contamination, etc. However, the neutralization number is frequently used for assessing the condition of the oil, and the question is often asked "What is a safe limit for the neutralization number of turbine oils?" The answer is, that it is the rate of change in acidity, read in conjunction with other factors, that is important rather than the actual neutralization number alone.

Considering, for illustrative purposes, the hypothetical case shown in Fig. 6; the neutralization number is shown as having increased progressively over 24,000 hours of operation. This is accompanied by a rise but not a corresponding increase in sludge deposition. If the neutralization number suddenly increased, as shown by *AB*, to a value of, say, 2, there would be more cause for concern than if it reached this value by progressively increasing over a further period of, say, 8000 hours. If the assumed rapid increase *AB* occurred when a comparatively large amount of new oil (curve *CD*) was being added to the system (which could be due to excessive oil being removed by the centrifuge in an emulsified state), conditions would be more serious, because it would indicate that the new oil is being "poisoned." In these circumstances it might be more economical to drain, clean the system, and refill with new oil, rather than attempt to restore conditions by the addition of large quantities of new oil as make-up.

It must be appreciated that each turbine offers a separate problem, due to the wide variations in size, rate of oil circulation, temperatures, and the rate of contamination. Therefore, the maximum values shown in Fig. 6 are not to be taken as upper limits. The amount of water removed in a given period indicates whether any given machine might be prone to emulsification troubles, and this factor is then compared with the Steam Emulsion Number (or Demulsification Number BSS-489-1933, or R.L. Emulsion Test ⁷) and the Neutralization Number. If large quantities of water are shown to be gaining access, a high acidity or poor demulsibility test is more dangerous than when smaller amounts of water are present. Of course, a sudden intrusion of water due to a broken cooler pipe, etc., cannot be predicted, but can very often be prevented by proper maintenance.

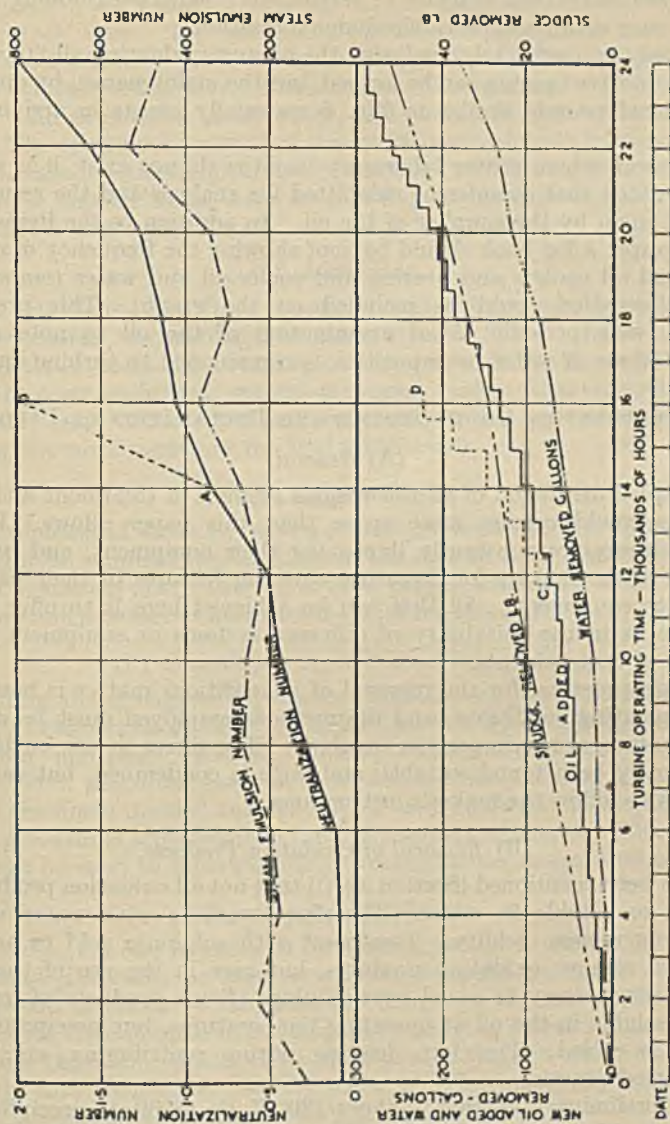


FIG. 6.

Large concerns can, by using drained oil for less onerous services, conveniently keep to low acidity and demulsibility values, but with smaller operators the cost of a new charge of oil is an item demanding careful consideration. In this connection, whilst a neutralization number of 1 is often considered a limiting figure, experience has shown that by a proper comprehension of operating conditions, coupled with periodic analysis of the oil to show the *progressive rate of increase* in deterioration, values of 3

and higher have been reached in service over periods extending beyond fifteen years with no appreciable sludge formation.

It is only by completely analysing the oil and evaluating all factors that an authoritative opinion can be formed, but the maintenance, by operators, of graphical records similar to Fig. 6 materially assists in arriving at a decision.

In general, where proper laboratory facilities do not exist, it is strongly recommended that samples be submitted for analysis and the results pronounced upon by the supplier of the oil. In addition to the items shown on the graph, a log book should be kept showing the frequency of cleaning filters and oil coolers and bearing and cooler-oil and water temperatures (this information could be included on the graph). This procedure, together with periodic visual examination of the oil to note unusual accumulations of water or impurities, is commended to turbine operators.

6. TREATMENT OF OIL IN SERVICE AND RECLAMATION OF USED OIL.

(A) *General.*

A detailed discussion of all the various systems of treatment and makes of filters would require more space than this paper allows. Further, manufacturers are constantly improving their equipment, and users are referred to the makers for literature covering features of their particular system or equipment. All that can be achieved here is to offer general guidance as to the suitability of different systems or equipment for the removal of contaminants.

No single method for the removal of adventitious matter is best suited to all operating conditions, and the methods employed must be matched to the nature of the impurities involved. The filters in use on the Reef have mostly been found suitable, and none is condemned, but care must be taken to follow the maker's instructions.

(B) *Removal of Oxidation Products.*

It has been mentioned (Section 3 (A)) that not all oxidation products are harmful or soluble in water. Therefore, washing with water will not necessarily remove acidity. Treatment with sulphuric acid or activated clays will remove oxidation products, but care in the use of these substances is necessary to avoid over-refining. Some products of oxidation remain soluble in the oil at operating temperatures, but precipitate when the oil is cooled. Therefore, heating during centrifuging, etc., is not always good practice.

After preliminary heating to about 180° F. (to facilitate precipitation of solid impurities) a period of rest from ten days onwards for the entire charge of oil will allow many oxidation products to precipitate when the oil cools and remains undisturbed. Followed by centrifuging or filtering, this method is known as "*Batch Treatment*," and is recommended for turbines and other units holding reasonably large charges of oil.

(C) *Sweetening.*

The removal from the lowest point in a system of several gallons of oil per shift, day, or week, depending on the size of unit and probable rate of

contamination, will assist in reducing the amount of contaminants present at any given time. The treatment of this withdrawn oil in a simple gravity filter for subsequent use as make-up oil, together with new oil to give the correct sump level, is known as "sweetening." Filtering will remove solid impurities, most water, and probably some oxidation products. The continued removal of the worst contaminants by this method always assists in extending the life of the oil. Sweetening is often recommended for smaller units, such as gear-box oils, compressor, diesel, and steam-engine crankcase oils, etc.

(D) *Emulsions.*

Some emulsions—*e.g.*, from crushers—might prove very persistent and difficult to break in centrifugal or other types of filters. In such cases it will sometimes be found advantageous to drive off the water by heating the oil in a steam-heated, conical-bottomed tank. After evaporation of the water, most of the dust and other impurities will settle out, thus reducing the work necessary for final purification.

(E) *Dehydration.*

After removal of water by, say, a centrifugal separator, further dehydration might be required, particularly in the case of refrigerator lubricating oils and insulating oils. The use of filter presses employing dried blotting-paper or similar material has proved useful for this purpose.

(F) *Coagulation of Colloidal Carbon, Etc.*

Oils from diesel engines invariably contain very finely divided soot or carbon. Coagulation of this "colloidal" carbon by means of solutions of tri-sodium phosphate, sodium silicate, sodium carbonate, proprietary powders, etc., will often assist in those cases where the filter alone cannot remove the finely divided carbon. Final treatment should include means for the removal of any chemicals used as coagulating agents. Electrostatic filters can be used to separate finely divided matter in suspension in oil.

(G) *Removal of Diluents.*

Petrol dilution can be reduced by heating the oil to about 300° F., but this should preferably be done at a lower temperature under vacuum or with the aid of steam to minimize the danger of thermal decomposition. Many filters are equipped with means for removing petrol dilution.

Because the boiling points of the fuels used in paraffin and diesel engines are high, and sometimes overlap those of lubricating oils, removal by heating is impracticable with the ordinary run of filters.

(H) *Oil Colour.*

Darkening of an oil in service or lack of colour in a reclaimed oil does not necessarily imply that the lubricant is unfit for further service. For example, a very small amount of colloidal carbon in diesel lubricating oils can appreciably blacken the oil, yet not adversely affect its lubricating value. On the other hand, the kind and quantity of contaminants causing discoloration may be of a decidedly injurious nature. In cases of doubt a complete laboratory examination is recommended.

(1) *Types of Filters.*

Some makes of filters incorporate several of the systems of purification mentioned below, and the remarks that follow are not intended to refer to any specific make.

(i) *Gravity Filters.*—These filters remove impurities by screening, precipitation, filtration, and in some cases by washing with water. Screening through gauze, etc., removes the coarser particles. The finest gauzes will pass particles up to 0.002 and 0.003 inch, and to avoid choking, coarser gauzes are generally necessary, and a 0.01-inch mesh is commonly used. Precipitation is accelerated by heating (180° F.), but care must be taken, particularly with water-bottom filters, to avoid convection currents which might retard precipitation. Filtering is accomplished by passing the oil through felt, cotton, wool, or cloth. With the latter, particles as small as 0.001 inch can be removed by a properly designed unit. As previously mentioned, water-washing will not remove all acidity or deterioration products and, as the oil rises through the water in drops which hold impurities inside the globule of oil, the fine particles are not removed. A water bottom is often provided in gravity filters to ensure even heat distribution. Gravity filters do not remove fuel dilution, colloids, very fine solid impurities, and generally will not restore original colour to the oil.

(ii) *Centrifugal Filters.*—These remove impurities by accelerated gravity, and the rate of flow through the filter determines the rate of removal of solids. Centrifugal separators will remove abrasive impurities, insoluble sludge, and water. Colloidal carbon is not removed unless the oil is previously treated with a coagulating agent. Simple emulsions can often be broken, but soluble sludge and fuel dilution are not removed, and the colour of the oil is not always restored, as this depends on the nature of the contaminants. Centrifugal separators can operate as “clarifiers” or “purifiers.” When set up as “clarifiers” they remove solid impurities mainly, and little, if any, water. Maker’s instructions should be followed carefully, because the author has often found these units set up as “clarifiers” where they should be run as “purifiers.”

(iii) *Clay Filters.*—The adsorptive effect of activated clay on solids (including colloidal materials) and oxidation and deterioration products is utilized in all reclaimers of this type. As a general rule, these filters are very effective and remove most extrinsic impurities and deterioration products as well as restoring colour to the oil. This is a function of the type and quantity of clay, amount of oil being treated, and the time and temperature of contact. The original colour will not always be restored, but an improvement over the untreated oil colour is usually expected, and the best results are obtained through excluding air by the admission of an inert gas or steam during the process. Fuel dilution (petrol) and water are generally removed during the heating and agitating stage of the process. Here a word of warning is necessary. There seems no need to exceed a temperature of 300° F. because, whilst higher temperatures might increase the avidity of the clay, there is a danger of thermal decomposition. Clay filters usually adversely affect inhibited oils.

(iv) *Edge-Type Filters.*—These may be of the metal or paper-disc type.

The metal type can be made to remove particles as small as 0.001 inch. The paper-disc type is effective in removing sludge and all abrasive particles, including colloidal substances, and so the colour of the oil is usually restored. Petrol dilution is removed by special vacuum attachments, and there is no danger of thermal decomposition. Soluble oxidation products, which are not always harmful, are not removed by the ordinary paper-disc type, but some makes employ a filter-bed of activated material which removes oxidation and deterioration products. Generally, paper-disc-type edge filters will not handle large quantities of water, because the filter discs swell and restrict the flow. Preliminary settling and separation of water before treatment will overcome this disability.

(v) *Filter Presses*.—As the oil has to permeate through the filter material, sludge and all abrasive particles and colloids are removed. Soluble oxidation products and petrol dilution are not extracted, but moisture is effectively removed if dried blotting-paper or similar material is used.

(vi) *Magnetic Filters*.—These filters consist of powerful magnets used in conjunction with a series of metal baffles. They remove only magnetic particles.

It is regretted that it is impossible in a short paper to deal completely with this kaleidoscopic subject, but it is hoped that the main points of interest have been included.

In conclusion, the author wishes to thank those engineers whose willing co-operation has made possible many of the investigations mentioned in this paper. He is also indebted to Mr. E. May for the loan of the negative of Fig. 4.

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DISCUSSION.

THE PRESIDENT: Gentlemen, we have listened to a summary of a most interesting paper, containing many practical points, which you will agree forms a valuable contribution to the records of the Institution.

I shall confine myself to one point; it is a matter that concerns the regulations. One of these calls for a thermometer marked with a red line showing the maximum temperature at which an air compressor may be permitted to discharge. The regulations carefully avoid giving any indication as to where this red line should be placed. The author has suggested the lines along which one might proceed in fixing this line, but perhaps in his reply he would give some further practical information to enable those concerned to comply with the regulations on a rational basis in this respect. We thank Mr. Pomeroy very much for his most valuable paper, and I ask you to express your appreciation in the usual way.

I have pleasure in calling on Mr. Whittingham to open the discussion on the paper.

MR. R. R. WHITTINGHAM (Visitor): Mr. Pomeroy has undertaken to cover the very broad field of abstruse petroleum chemistry in the limited time at his disposal,

and in my opinion has made an excellent job of it. Accordingly, my comments will be, more or less, in the nature of amplification, as I believe that some of his points are deserving of further elaboration.

I am not so sure that the laws of valence are so "well known" as the author assumes. Undoubtedly they are to the organic chemist, but most of us here to-night are not chemists. In any event, it may not be amiss to define valence as a measure of the combining power of atoms. Hydrogen, with a valence of 1, is taken as a standard; oxygen is 2; nitrogen is 3; and carbon is usually 4. I think it should be emphasized that saturated hydrocarbons are chemically more stable than unsaturated ones because all valence bonds are satisfied. Unsaturated hydrocarbons exhibit a marked tendency to combine with other elements, especially oxygen, nitrogen, sulphur, chlorine, and bromine. As Mr. Pomeroy very properly remarks, the true composition of the heavier hydrocarbons, comprising the principal constituents of lubricating oils, is not well known. It seems that more chemical research has been expended on the lighter burning fractions which are the primary products of petroleum refining, whilst those of higher boiling points have been comparatively neglected. However, there is ample evidence that certain unsaturated hydrocarbons are valuable constituents of lubricating oils in providing oiliness and film strength. White oils—*i.e.*, liquid paraffins—are notoriously poor lubricants, with their unsaturates removed by severe acid treatment. On the contrary, black oils, consisting largely of asphaltic residual material, are rich in lubricating value, although entirely unsuited for use in enclosed systems of high-grade machinery. Therefore, it is the responsibility of the oil refiner to utilize treatments which will remove, so far as possible, the oxygenated compounds and the more highly reactive of the unsaturated hydrocarbons, which produce gumming and carbonization in service, while eliminating a minimum of the more stable unsaturated hydrocarbons, whose presence in the finished product is a definite asset.

Of course, the petroleum refiner should resist the temptation to carry destructive distillation too far. "Cracking" of the heavier hydrocarbons can be employed to an extent whereby the natural yield of petrol, burning oils, and paraffin wax will be greatly increased, at the expense of the lubricating oils in both quantity and quality.

To the average engineer, all deposits precipitated in enclosed oiling systems are, for want of a better name, called sludge. The author has defined both the soluble and insoluble products of oxidation in chemical terms, and, as you will recall, these are generally of an asphaltic, gummy, or resinous nature. Obviously, they are highly objectionable, and I think it is appropriate to stress some of the means which can be taken to control oxidation.

Heat is undoubtedly lubricating oil's worst enemy. The amount of oxidation which occurs at ordinary temperatures with good mineral oils is practically nil. Lubricating oils can be kept in storage for indefinite periods, even in containers open to the air, with no deleterious effect. However, when lubricating oil is circulated and agitated in the presence of air, oxidation increases out of all proportion to increase in temperature. Data published in the *Journal of the Society of Automotive Engineers*, following tests recently conducted with the Underwood oxidation apparatus by the United States Naval Engineering Experiment Station, Annapolis, Maryland, disclosed that a good quality straight mineral motor oil in the S.A.E. 30 viscosity range, gave a viscosity increase of 5.05 per cent. after 30 hours' continuous use at 250° F., but 152.6 per cent. increase, following the same period of operation at 325° F. On the basis of the same comparison of time and temperature:—

Neutralization No. increased from 0.20 to 6.65.

Carbon Residue increased from 0.08 to 1.75 per cent.

Naphtha Insoluble increased from 0.01 to 2.90 per cent.

Chloroform Soluble increased from nil to 2.30 per cent.

This report is significant in confirming the theory that operating temperatures above 300° F. deteriorate oil very rapidly.

In internal-combustion-engine operation, either petrol, oil, or diesel, ideal crank-case temperatures lie within the range of 120–150° F. Such moderate temperatures are not always attainable, but every effort should be made to keep them as low as possible. Proper mechanical maintenance, with special attention to the cooling system and ignition timing, on spark-ignition engines; avoidance of overloading;

and an adequate supply of oil in circulation, are important in keeping temperatures down. Even in one's motor car, a sump half full of oil is called upon to circulate twice as often and absorb and radiate twice as much heat by volume, compared with its full capacity. We should not forget that in any such engine the oiling system is an essential part of the cooling system, and is depended on to dissipate a not inconsiderable portion of the waste heat generated. A stabilized crankcase temperature ultimately results from an equilibrium established between heat input from the engine and heat removal from the oil-pan.

The author, in touching on the causes of lubricant deterioration in gear-boxes, ignores this important factor of heat. Admittedly, in large spur- and helical-gear units, such as are employed for winder and tube mill drives, temperatures above, say, 140° F. are uncommon, both because tooth loading in this type of gearing is usually moderate and ample heat radiation is obtained with the relatively large exposed area of the casing. But worm-gears are another story, and in my experience these are much more susceptible to lubrication difficulties. I do not agree with the author's implication that the admixture of dust, moisture, metal particles, and grease is the root of the trouble—at least, in so far as worm-gears are concerned.

Fully enclosed worm-gears permit of the entrance of little dust. In this dry climate, and at normal operating temperatures, atmospheric condensation is negligible. With properly adjusted and lubricated worm-gears, metallic abrasion is also negligible.

Due to the more severe conditions of tooth engagement and the higher proportion of total loss represented by tooth friction, industrial worm-gears operate at somewhat higher temperatures than enclosed spur, helical, and bevel gears, but the maximum running temperatures should not exceed 100° F. above the ambient temperature. Assuming that a worm-gear is not overloaded, overheating is invariably due to the use of an oil of incoherent viscosity, or overfilling, or both. From my observation, a marked tendency exists in South Africa to use oils for worm-gear lubrication which are too heavy, often in disregard of the manufacturers' specific recommendation. Excessively heavy oils produce churning losses; churning losses raise the running temperature; elevated temperatures accelerate oxidation; oxidation has the effect of thickening the oil; the thickened oil further increases the churning losses; and so we enter upon a vicious circle, involving heat and more heat, which may ultimately result in the failure of an expensive worm-gear.

I find the author's comments on the cylinder lubrication of reciprocating air compressors and the influence which the formation of deposits bears on the possibility of explosions particularly interesting. In devoting a considerable portion of his paper to this one subject, he apparently considers it of major importance. It seems to me that he is over-emphasizing this danger.

One of the largest manufacturers of air compressors has placed on record that of all the thousands of units he has in operation under all conceivable conditions, he knows of but three explosions in the past ten years. The Compressed Air Society, New York City, states that explosions are "very infrequent occurrences."

In "Lubricants and Lubrication," by James I. Clower, and published by the McGraw-Hill Book Co., the following statement appears:—

"Contrary to the generally accepted opinion, the characteristics of the oil have very little to do with air-compressor fires and explosions. Most authorities hold that some faulty condition of operation, or installation, *must* exist before fires and explosions can occur. When such conditions do exist and fires and explosions take place, it is always found that the operating temperatures have exceeded the flash point of any oil."

This brings us to the question of flash point. I quite agree that the use of high-flash-point, high-viscosity oils is indefensible. Oils of this type are invariably blends containing a substantial portion of filtered cylinder stock and a comparatively light-bodied distillate. The tendency exists for the light-bodied distillate to vaporize and leave the heavy-bodied cylinder stock as a residue to form deposits by acting as a binder for dust, worn metal particles, and other impurities. It is also true that the spontaneous ignition temperatures of low-viscosity oils are higher than those of heavy-viscosity oils. For example, paraffin ignites spontaneously in air at a lower temperature than petrol.

For these reasons a proper compressor oil, for discharge pressures under 150 lb. gauge, should be a straight-run distillate of approximately 300 secs. S.U.V. at 100° F. The flash point of such an oil is of little consequence, as any high-quality oil of this type and in this viscosity range will have a flash point amply high, not to prevent fires and explosions, but to obviate excessive evaporation which might leave the cylinder walls in an unprotected state. Incidentally, no direct relationship exists between the volatility of an oil and its flash point, but it is generally true that as the flash point falls, volatility increases.

The principal cause of consumption in air compressors is *not* evaporation and burning, but rather the scouring of the oil from the cylinder wall by air—an action over which the flash point of the oil has no control whatsoever.

In the case of the air-compressor explosion investigated and cited by the author, it is significant that the effect was not serious enough to produce any mechanical damage, and with the introduction of the correct type of oil, deposits were practically eliminated. I am not prepared to deny that spontaneous combustion can, and probably has, caused explosions, nor that carbonaceous deposits on discharge valves are blameless, but the fact remains that in spite of all the carelessness and ignorance existing in this world, air-compressor explosions are few and far between. In view of extensive lubrication recommendations published by manufacturers of air compressors and the technical service freely available from the various oil companies, there seems no more excuse for getting the wrong oil into an air compressor cylinder than there would be for employing turbine oil in a steam-engine cylinder. Therefore, I submit that in air compressors, operated with a reasonable degree of care and intelligence, explosions are not only infrequent, they are impossible.

The few explosions which have taken place could have been prevented by careful attention to the following procedure:—

- (1) Proper installation.
- (2) Draw the intake air from as clean and cool a location as possible through an efficient filter.
- (3) Establish an ample supply of cooling water from a source that is not likely to fail.
- (4) Maintain good mechanical condition with periodic inspection and cleaning.
- (5) Occasionally feed a soapy water solution through the regular lubricator for several hours to remove any cylinder deposits. The oil feed should be restored before the compressor is shut down to avoid rusting. Never use paraffin oil, or other volatile solvents, for cleaning cylinders, valves, piping, intercoolers, or receivers.
- (6) Use a high-quality oil corresponding to the specification of the compressor manufacturer, or one recommended by a reliable oil company.
- (7) Feed the oil sparingly. Inspection of both the suction and discharge valves and of the cylinder walls will assist in adjusting the lubricator. If these parts appear dry and rusted, more oil should be fed. If excess oil has accumulated in ports and clearance spaces, the feed should be reduced.

The author has neglected to make any mention of lubrication problems involved in the operation of rock drills. This omission is to be regretted in view of the large number of units, upwards of 20,000, owned in the mining industry, representing an investment of at least £1,000,000 and involving an annual expenditure of over £600,000 for spares alone. I am sympathetic to Mr. Pomeroy's problem of time and space limitation in the preparation of his paper, but I trust that a brief comment on this important subject will be appropriate and acceptable.

Modern rock drills demand lubricants that have been specially designed and manufactured for this rigorous service, if efficient and economical operation is to be had. Higher drilling speeds and decreased weights obtained by the use of alloy steels, and lighter and faster moving parts, impose heavier burdens, which can only be offset by correct lubrication. Rock drills are particularly sensitive to oil of the proper viscosity. If the oil is too heavy it cannot penetrate close clearances and distribute over all working parts. Also, excessively heavy oils produce sluggish valve action with a corresponding reduction in drilling speed. If the oil is too light it cannot effectively seal the piston and valve assembly against leakage of air; nor will it provide so good a protective film against rust and corrosion.

To control rust and corrosion in rock drills a percentage of saponifiable oil, which may be any one of several animal or vegetable oils, is added to a straight mineral oil. This provides desirable emulsifying properties to combat rusting effects of water, and also increases film strength to some extent. We know that fixed oils and fats oxidize more readily than mineral oils, and the degree to which they absorb oxygen classifies them as drying, semi-drying, and non-drying oils. Blown rape-seed oil—a semi-drying oil—is popular as an emulsifying agent in rock-drill lubricants. Some rock-drill manufacturers consider it suspect and condemn its use as being responsible for the formation of gummy, varnish-like deposits to retard valve action and act as a matrix for abrasive particles. I personally believe that animal oils of low free fatty acid content and falling in the non-drying class, are preferable as compounds in rock-drill oils to prevent objectionable deposits.

In the early part of his paper, the author devoted some space to the subject of foaming. His remarks applied entirely to enclosed circulation systems. However, this condition also is found in air-line oilers and lubricators of rock drills, although not always recognized. A rich, creamy emulsion, observed in an air-line oiler, may have all the appearance of an ideal lubricant and yet contain only 10 per cent. of oil by volume. Obviously, such a highly aerated mixture is practically worthless. This type of foaming is caused by the oil being too heavily compounded with saponifiable material. Only enough should be incorporated to provide a comparatively short-lived emulsion, which is perfectly satisfactory in preventing rusting. In the air stream each minute globule of water is coated with a film of oil, so that the oil will reach the metallic surfaces first. There will then exist a surface of oil which, although of lower surface tension, is in close alliance with the metal and cannot be displaced by the water.

Under the heading of "Corrosion of Metals," the author's reference to corrosion of cadmium-silver bearings, by oils of the highly paraffinic type, produces a nostalgic recollection of the historic feud which developed in the United States some years ago between General Motors and the petroleum industry. Happily, this is now an almost forgotten incident, but at the time, no punches were pulled—a Pontiac was called a Pontiac, and some of the oil companies were called names which bore no resemblance to their corporate titles.

Anyhow, the story is that after the 1935 model Pontiac got into the hands of the public, an epidemic of connecting-rod bearing failures developed with this particular engine. At about the same time, a number of the larger refining companies introduced a new line of solvent-extracted motor oils, supported by elaborate advertising campaigns. When investigation revealed that the Pontiac engine gave no trouble with ordinary cheap naphthenic oils, but shed its big end rod bearings with the greatest ease when the highly refined oils were used, obviously something had to be done and done quickly. Meanwhile, General Motors' dealers had become very sceptical of the new oils, and lost no opportunity to criticize and disparage them to their customers. It was all very embarrassing.

Some of the oil companies proceeded to purchase Pontiac engines for dynamometer test in their mechanical laboratories. In due course announcement was made to the effect that the Pontiac lubricating system was poorly designed, in that the oil pump was under capacity; the bearings were improperly grooved; oil bleed was abnormal; and crankcase temperatures far too high. This report did not improve the *entente cordiale* to any great extent, notwithstanding that it was also admitted that many of the highly refined oils exhibit a greater tendency to corrosion of cadmium-silver and copper-lead bearings than do some of the less highly refined oils. In any event, on subsequent production, General Motors revised the original design by omitting an annular groove in the rod liners; increasing the oil pressure; and changing the bearing material to tin-base babbitt. The Pontiac engine was now out of trouble, and the petroleum industry had apparently won the argument.

My purpose in resurrecting this account, of what is probably the most famous case of bearing corrosion extant, is to provide irrefutable evidence that certain types of even straight mineral oils do have a deleterious effect on some bearing materials under conditions of high operating temperature. Compounded oils containing chemical additives, in the form of oxidation inhibitors, detergents, and film-strength improvers, can be even worse offenders in this respect—but that is another story. Permit me to reiterate that heat is oil's worst enemy, and was largely the cause of Pontiac's difficulties, when crank-pin bearing temperatures actually reached 402° F.

Prior to the war, tin was one of the predominant constituents used in bearing alloys. The United Nations were deprived of practically all the active world tin supply, with the loss of the Dutch East Indies. Therefore, many bearings which have been babbitted with tin-base alloys must now resort to various tin-substitute materials. The United States Naval Engineering Experiment Station rates bearing materials in the following order of merit, as regards resistance to corrosion :—

- (1) Tin-base babbitt.
- (2) Arsenic lead-base babbitt.
- (3) Lead-base babbitt.
- (4) Alkali hardened lead.
- (5) Copper-lead alloy.
- (6) Cadmium-silver alloy.
- (7) Cadmium-nickel alloy.

Please note that copper-lead and cadmium-silver alloys are at the bottom of the list.

Bearing alloys, which have a tendency to corrode at elevated temperatures, should be lubricated with low-corrosive oils. In any case, adequate cooling of the lubricating oil is of paramount importance to impede oxidation, and thereby diminish bearing corrosion and possible failure.

In these critical days of scarcities and high costs, the reclamation and re-use of many types of lubricating oils are naturally receiving greater attention. I am glad that the author examined this phase of his general subject quite thoroughly, as it is of very pertinent interest. I agree that opportunity exists to satisfactorily and economically recover substantial quantities of valuable lubricants. This is particularly true of bearing oils which have been employed in steam engines, steam turbines, rotary compressors, gyratory crushers, ice machines, etc., when, due to various factors, including moderate operating temperatures, contamination and deterioration is less severe than in internal-combustion-engine service. The statement has been publicized for years that oil does not wear out, and it has even been said that refined oil is better than new. This contention is open to some dispute. The latest theory is that good-quality virgin oils contain certain natural oxidation inhibitors, which are ultimately consumed, particularly in high-temperature service. It is known positively that the beneficial effect of oxidation inhibitors, in the form of chemical additives, in compounded motor oils, becomes progressively less the longer the oil is continued in use. Therefore, if we are prepared to accept the idea that perchance oil *does* wear out, we should be more meticulous in maintaining proper draining periods, and not expect the best results from reclaimed motor oils, which are possibly deficient in both oxidation resistance and oiliness.

The subject is so fascinating and at the same time so inexhaustible that even in touching the high spots, it is difficult to keep one's remarks within a reasonable time limit. I have enjoyed Mr. Pomeroy's paper very much, and compliment him on his valuable contribution to the available data on this important subject.

MR. G. W. BOND (Visitor) : We have had the privilege of listening to a most interesting and instructive paper by Mr. Pomeroy, one of the greatest experts on oil in this country.

As the author has rightly pointed out, the chemistry of petroleum oils is, unfortunately, most complex and difficult to understand, even by the chemist, unless he has made a specialized study of the subject.

With regard to Mr. Pomeroy's statement that the fatty acids present in deteriorated compounded oils (*i.e.*, mineral oils mixed with vegetable oils) will attack metals with the formation of metallic soaps, I would qualify that statement as far as steel is concerned. The work of Garlick,¹ Donath,² and Archbutt and Deely³ has shown that the corrosive effect of fatty acids depends to a large extent on whether the lubricated surface comes into contact with moisture and oxygen, and that pure fatty acids are without action on most metals. In a paper read before this Institution in 1935,⁴ I drew attention to a possible case of corrosion of steel roller bearings in rotary converters by the action of fatty acids present in a certain grease. In this particular case moisture was present and iron soaps were definitely formed. Even the organic acids derived from the deterioration of straight mineral oils will attack metals (in

the presence of air and moisture), as is shown by the corrosion of the lids which sometimes takes place in the case of those transformers unequipped with conservators or means of "breathing."

In connection with the permissible limits for acidity in turbine and transformer oils, the chemist is frequently asked to recommend a safe limit for acidity (*i.e.*, neutralization number). As Mr. Pomeroy points out, it is the *rate of increase in acidity* rather than the actual amount that is important, read in conjunction, of course, with other factors such as demulsification numbers, rise in bearing temperature, viscosity, and amount of sludge formation. The statement applies more particularly to turbine oils, but even in the case of transformer oils it is difficult to set a limit, so many factors being involved. The figure of 1.0 mg. KOH per gram oil is generally given as the permissible limit of acidity in transformer oils; many examples, however, could be given of cases where much higher acidities have developed, unaccompanied by sludge formation, and with no apparent effect on insulating materials.

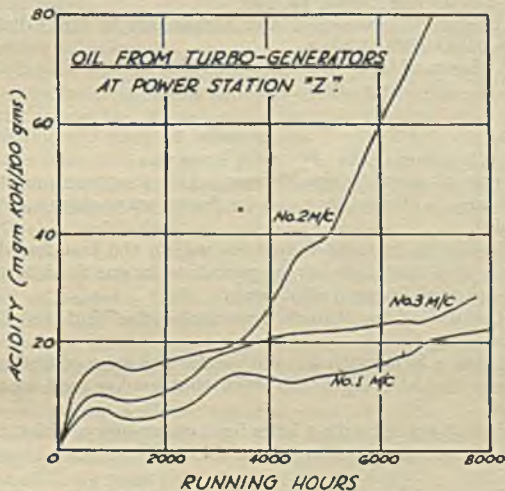


FIG. 7.

Mr. Pomeroy emphasizes the importance of regular acidity determinations, in order that acidity curves may be drawn with the object of throwing light on the performance of the oil in each machine. Some typical acidity curves from one of our stations (Fig. 7), illustrate the importance of carrying out acidity determination at very frequent intervals.

The author advocates—and quite rightly too, in my opinion—that regular routine determinations should be made not only of acidity, but of the demulsification numbers, percentage sludge, and water removed, and the exact amount of oil added to "top up," etc. In making such a proposal he shows no little courage, for it is the experience of most chemists (I refer to no particular concern) that it is a matter of extreme difficulty to get certain engineers to agree to even a regular acidity determination, let alone all the other determinations advocated by Mr. Pomeroy.

I am sure, however, that Mr. Pomeroy has succeeded in convincing all of us of the necessity of carrying out all these tests as a matter of routine.

I may mention that at all the Commission's stations, monthly tests are carried out on all turbine oils for acidity and viscosity, while quarterly samples are sent to Head Office for complete analysis. Quarterly acidity tests are also carried out on transformer oils, and acidity curves are plotted to illustrate the behaviour of the oil in each machine, and the progressive increase in acidity is thus readily followed.

I would mention that, as far as used oils are concerned, considerable difficulty is experienced in the determination of the "end point" of the titration, if either B.E.S.A. or A.S.T.M. methods (designed for new oils) be followed.

The indicator recommended, namely, phenolphthalein, is useless in the case of badly deteriorated or dark-coloured oils. In connection with this difficulty, Miss J. Freeland⁶ has pointed out that for such oils the "Alkali-blue method," carried out under strict conditions, is most suitable for the routine testing of used oils, but that for more exact determinations, an electrometric titration is the only solution. In connection with the purification of turbine oils, it would appear, at least in my reading of it, that Mr. Pomeroy does not altogether ascribe to the very recent tendency to regard centrifuging as doing more harm than good to the turbine oils. I should like to have Mr. Pomeroy's opinion on this problem, if it be not too "leading" a question.

In conclusion, I would once again repeat that we are grateful to Mr. Pomeroy for such an instructive paper.

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Mr. W. E. GOODAY (Visitor): I am grateful to your Council for allowing me to contribute to the discussion of Mr. Pomeroy's paper.

His subject is one of growing significance. His treatment of it displays a grasp of its complexities and, so far as they can be drawn up to-day, a clear-sighted exposition of its principles.

Technical developments in most industries within the last few decades have been so copious and so rapid that it behoves specialists in one field to take heed of what another says in respect of his own allotment.

This paper is brimful of uncommon technical sense that can be translated into useful practice.

I have tried to pick a bone with the author for the sake of illumination and entertainment, but I can find nothing in his work that evokes sufficient disagreement for that purpose.

Thus, I must content myself with a little light embroidery, which I ask Mr. Pomeroy and his audience to accept, in lieu of ponderous argument or pyrotechnical controversy.

The paper's title includes the terms: "deterioration" and "decomposition." These words stir one's memory to a realization that it is due to its remarkable stability and comparative inertness—apart from availability and scope for physical variety—that the petroleum product has gained ascendancy over its predecessors, the animal and vegetable oils and fats.

In truth, few words in the paper need be changed were its title altered to: "The purity, stability, and inertness of mineral lubricating oils in service."

Under many operating conditions decomposition of oil does not occur at all and deterioration is due mainly to contamination.

In this connection, care in handling and storage of all lubricants is a necessary precaution.

The opening words are a great disappointment to me; they read: "Many fallacious beliefs still exist in the minds of a number of oil users . . ." Having myself let off some effervescence entitled "Fallacies Concerning Lubricants," I thought I had dealt death to those delusions and that, like Mr. Bunbury, they were "quite exploded"!

That oils may be refined too drastically was confirmed on a large scale by results observed in the performance of early solvent-treated products as compared with the behaviour of oils then going through the orthodox treatment with sulphuric acid and caustic soda.

The precipitation of solid decomposition products was delayed and diminished by the more stringent treatment, but this ostensible boon was wrought at the cost of unforeseen increases in the growth of acidity/time ratios.

Again, experience since 1923 with those uppish cousins of the lubricants—insulating oils, manufactured to meet B.S.I. specifications—has resulted in a preference for

Class B oils with a Michie test of 0.8 per cent. in place of Class A oils with the lower limit of 0.1 per cent.

Whereas proneness to throw down solid decomposition products was lessened by intense refining, the rate of increase of soluble and, therefore, invisible petroleum acids rose; but now I think it is fair to assume that through the flexibility of solvent treatment a satisfactory balance is attained.

Mr. Pomeroy says: "Water-soluble and insoluble acids are measured, but some investigators consider that only the former cause sludge deposition." I suggest that it is not quite accurate to say that any acid causes "sludge." Acid making and the precipitation of solids are, I feel, concomitant symptoms of partial decomposition. In all probability, the oil-soluble acids that cannot be washed out with water help to maintain in solution oxidized bodies that, deprived of those solvents, would be precipitated.

An important aspect of Mr. Pomeroy's paper is its help in our steps towards the conservation of lubricants.

That measure, so urgent at the present time, has been studied by the Oil Advisory Panel of the Chamber of Mines.

The Panel's Memorandum on Conservation was issued by the Chamber in July 1942, and it has since been reprinted in England by the Institute of Petroleum. I am glad to pay tribute to Mr. Pomeroy for his assistance in preparing that Memorandum.

I am sorry to find that in a technical paper where he should use terms, each with the least number of meanings, the author rejects Dr. Hele Shaw's unequivocal and precise "elaulic" and stretches "hydraulic" (himself admitting it to be a misnomer) to cover oil, thus upholding a verbal inexactitude.

And then, that term of easy virtue, "sludge," embracing emulsions, precipitates, carbonaceous deposits and whatnot. "Sludge!" Robert Browning used it in describing a doubtful character: "Mr. Sludge, the medium"; but it is the extreme, comprehensive use of it that I object to.

I think Mr. Pomeroy is nearly converted to my view for, at least on one occasion, he drapes the term with quotes. I wish it could be draped with crape and cast out from our technical glossary.

Concerning colour, it can well be repeated that this is an incidental and not a critical quality. The few exceptions to that assertion—namely, "non-staining" textile oils, slab oils in bakeries, desirable transparency of coolants for some metal-working operations and, we may add, the tasteless, odourless, colourless, alimentary lubricant (liquid paraffin of the pharmacy)—do not fall exclusively within the field of lubrication; they admit considerations of process or of prejudice.

Colour may provide an indication of the efficacy of filtration but certainly not of lubrication, although it is thought that the ingredients imparting colour to an oil are amongst those that are helpful in boundary conditions of lubrication.

It is conceded that in a large organization where reclaimed oil may be distributed to a number of users, the receipt of filtered oil to which the colour of new oil has been restored, may stife criticism. It would surely be better, where possible, to advise the individual user of the facts, enlist his understanding and to eliminate, where it is superfluous, the employment of filtering clays.

One cannot summarize this excellent paper in a couple of paragraphs, but to the student in search of a mnemonic to embody the factors that affect the life of a lubricating oil, I offer this simple keepsake: ATTWIT, which stands for:—

Air—source of oxygen.

Temperature—hastens chemical change.

Turbulence—increases area of contact with air and other contaminants.

Water—ingredient of emulsions and carrier of impurities.

Impurities—catalysts, direct chemical reagents and promoters of emulsion.

Treatment—lengthens life of oil.

These headings might be put up as homely finger-posts to the careful consideration and appropriate elucidation that Mr. Pomeroy has given us in his paper.

I believe the author and the Institution of Certificated Engineers have contributed a useful chapter of technical service to the engineering community in preparing and in publishing this comprehensive and thoughtful paper.

Mr. E. B. PRIVETT (Associate Member) : Mr. President, gentlemen, I have listened with great interest to Mr. Pomeroy's paper. I would like to state a case in connection with a turbine gear that gave a particular amount of trouble. It happened about three years ago in England at a large ironworks outside Nottingham—a concern that should have known better. The trouble was with a bronze worm-wheel driven by a worm at 3000 r.p.m., the ratio being about 1 to 6. All the worm-wheel had to do was to drive the governor gear, the tachometer, and the oil pump. Numerous people had been to this particular machine and checked the alignments and everything else mechanical, but very little attention had been paid to the lubrication system.

The machine had been in use for about seven years, and before I was sent there they had changed the worm-wheel during the previous four months on an average of once every six weeks. Within six weeks of a new wheel being fitted, the teeth had worn to about $\frac{1}{4}$ in. thick. The steel worm was in absolutely perfect condition; I could find nothing mechanically wrong with it or the running of the turbine. A larger oil jet had been fitted with no beneficial result. I put on a new worm-wheel and tried to locate the trouble. I found the oil was in very bad condition, and on enquiry it was ascertained that the oil had been in the tank of the totally enclosed system for seven years, it had never been cleaned and had just been topped up from time to time, so we had to dismantle and clean everything out. There was a great accumulation of this so-called sludge everywhere; in this case it was a very smooth brown-coloured sludge. When we drained the oil out—the tank held about 300 gallons—we first got 22 gallons of water and then what looked like oil. After all the oil had been taken out, there was still about six to seven inches of sludge. The oil entering the tank from the turbine had to pass through a two-stage gauze filter, which was completely choked and the oil had been flowing over the sides and cascading down into the oil tank itself. We took the oil that we considered might be useful again and passed it through an activated clay filter, put it back in the oil tank, topped it up with fresh oil of the same make and the same viscosity, and the machine was put into use again. The only changes made were, the new worm-wheel had been put on and the oil system thoroughly cleaned, and from that day onwards—I was there about a year afterwards—there was no trouble whatsoever. I believe to this day the same worm-wheel is on the machine and giving no trouble. Although it is obvious where the trouble lay, I would like Mr. Pomeroy's opinion as to what was the technical cause of the worm-wheel wearing like that. The worm was in perfect condition, and it was only the bronze worm-wheel that was wearing.

There was no electrical equipment on the machine—the 2000-H.P. turbine was direct coupled to an L.P. blower and, in my opinion, the probable original cause of the deterioration of the oil was the effect of neglect in adjusting the H.P. and L.P. gland steam, with consequent overheating of the oil in the bearing housings and condensation of moisture therein.

Mr. W. E. M. PALLISER (Member) : Mr. President and gentlemen, I feel sure that Mr. Pomeroy's paper is one of those which many of us will put aside for future reference. It is full of valuable information, and once again proves the axiom : "Each man to his job." Oil is so completely essential to the proper functioning of practically every form of mechanical contrivance that we take it for granted. We give little thought to the enormous amount of work involved in producing oils to meet specific requirements. I was particularly interested in that part of the paper dealing with Refrigeration. It recalled an experience I had some years ago, when I had to investigate and report on certain refrigeration plant and get it working. I took the precaution to charge up the compressor with oil having a low cold test, and at that time thought it was the only precaution I had to take. All went well for a short time, until a seizure occurred. The ammonia liquid had got past the pistons into the crankcase, causing the oil to saponify, and naturally in that frothy condition the oil pump would not function. I enlisted the co-operation of Mr. Pomeroy's predecessor, but, instead of being sympathetic, he regarded it more as a joke. However, after following his advice, we had no more trouble.

As recently as four months ago I was in trouble again. This time it was a very large refrigeration plant, and every precaution had been taken to charge up the compressor with the particular grade and type of oil recommended by the makers. The condensed ammonia liquid would not feed back to the low-pressure side, and

we came to the conclusion that there was some obstruction in the pipe-line. We passed a wire through it and found no obstruction. I was baffled for a time, but, nevertheless, suspected the oil, as a sample I had tapped out of one part of the plant congealed at a very much higher temperature than the working temperature of the plant. I called in Mr. Pomeroy, and after investigating and eliminating every possible cause of the trouble, we found that one of the shiftsmen had been using ordinary bearing oil in the hand oil-priming pump. This bearing oil had a freezing temperature very much higher than the working temperature of the plant, and naturally as soon as it passed to the low-temperature side, it congealed and caused a temporary obstruction in the ammonia liquid pipe-line.

DRILLING.

By M. C. SEAMARK.

THIS section is written in the hope that it will give to technologists who are interested in other branches of the Petroleum Industry some idea of the methods employed in drilling the wells by which petroleum is produced.

SOURCE OF PETROLEUM.

Crude petroleum is found at various depths ranging from "shallow" wells of say 500 feet to "deep" wells of the order of 13,000 feet deep. It will undoubtedly be found at still greater depths by the introduction of improved drilling technique, and when the price of oil justifies the additional cost of deeper wells.

DESCRIPTION OF AN OIL WELL.

In general terms an oil-well is similar to any other borehole drilled for the purpose of producing water, brine, or other fluids, or for testing for minerals.

The depth of an oil-well is controlled by the depth at which oil is found, the deepest well drilled for oil to date being 15,004 feet deep. The world's deepest producing well—a gas well—produced from 13,475 feet.

The diameter of a well varies, but as a general statement a deep well has a diameter at the surface of about 18 inches, which diameter is reduced progressively to about 6 inches at the bottom.

As drilling proceeds, subsurface waters or formations of a caving nature are often encountered. To exclude such water from the well and to hold back the caving formations, the well is lined with steel tubes known as casing. The number of "strings" of casing and their diameter is controlled by local conditions and by the depth to which the well is to be drilled. A typical casing programme for a deep well is :

15 inch diameter casing to about	500 feet.
11 " " " "	4000 "
8 " " " "	7000 "
6 " " " "	the oil horizon.

When underground conditions in a field are known the starting diameter and number of casing strings can be reduced.

Oil-well casing is usually made of solid drawn steel tubes with screwed and socketed joints. It is made in various weights or wall thicknesses to suit the conditions under which it is used; a normal wall thickness ranges from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick.

The casing may be subjected to high internal pressure due to the pressure of the oil, and to high external pressures exerted by underground water or by cavings which must be sealed off and held back by the casing.

To ensure against failures, the casing is tested hydraulically at the mills to a pressure higher than any which will be encountered in the well.

In cases where the oil is struck at high pressures or where it is essential that all upper water shows must be permanently sealed off or segregated from each other, each string of casing is cemented in place. In low-pressure wells the upper section of the smaller diameter casing, the "oil

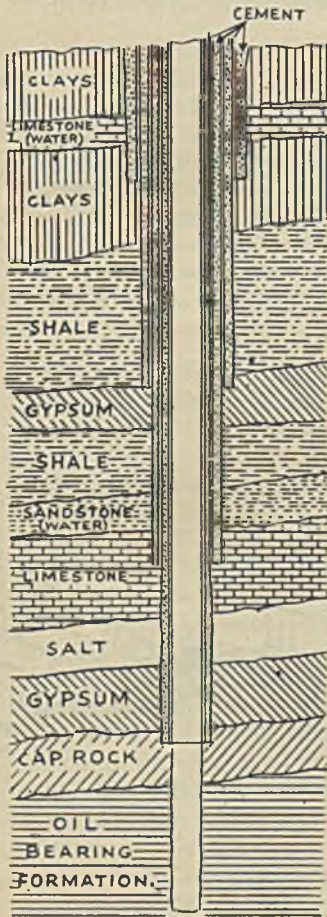


FIG. 1.

SECTION OF WELL.

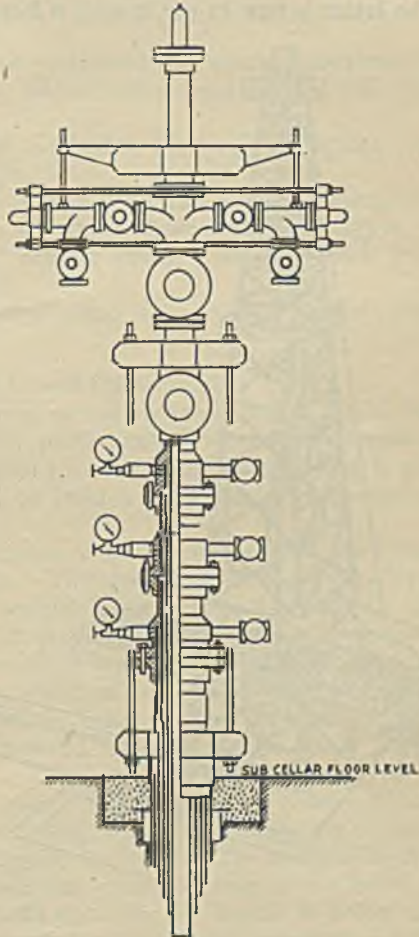


FIG. 2.

WELL HEAD.

string," is sometimes removed as a measure of economy, but in wells in which gas or oil under a high pressure is expected, each string of casing extends to the surface. The section of a completed oil-well (Fig. 1) therefore somewhat resembles a telescope, the eye-piece end being the bottom of the well and the large end the top of the well. The necessary valves and fittings, known as the "Christmas Tree," for closing-in or

controlling the production, are attached to the inner or "oil string" of casing (Fig. 2, Well Head).

SYSTEMS OF DRILLING.

There are two main systems employed in drilling oil-wells: (1) the rotary or mud-flush system, and (2) the cable-tool or percussion system. The latter is now in use in only a few oil-fields where local conditions are

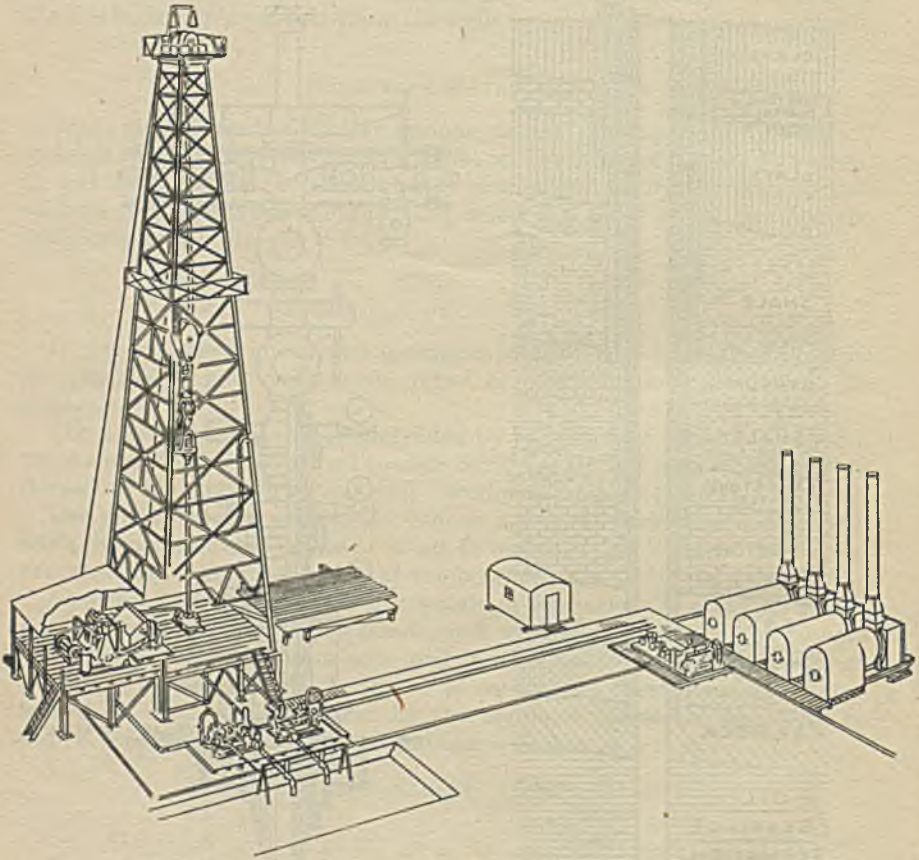


FIG. 3.
LAYOUT OF GEAR.

suitable to it, particularly where the wells are shallow and the formation is hard and not of a caving nature. The rotary system, due to developments over the past twenty years, has now come into general use. Its main advantages are ability to drill faster and deeper than other systems except in quartz and rocks of similar hardness.

The rotary or mud-flush system requires much more equipment than the cable-tool system. For a deep well in which no complications are expected the main items consist of:

- (1) A steel derrick usually 136 feet high by 26 feet base with a load capacity of about 300 tons and fitted with a crown block.
- (2) The draw-works by which the drill pipe and casing are raised or lowered.
- (3) The rotary table which rotates the drill pipe.
- (4) Slush pumps.
- (5) Power unit.
- (6) Drill pipe, kelley, bits, swivel, travelling block, fishing tools, etc.

For a large outfit (Fig. 3) the above equipment will weigh approximately 350 tons. In addition, the casing, which will remain in the well, will possibly amount to 300 tons.

For shallow wells the equipment is similar, although of lighter construction and of a more portable type.

With the rotary system the hole is drilled by the rotating action of a cutting head. This cutting head, of which there are many types, is attached to the lower end of the "drilling string" which extends from the bottom of the well to the surface.

Starting from the bottom the drilling string is made up of the following items :

- (1) The drilling bit of a type to suit the formation.
- (2) Drill collars. These consist of hollow steel bars of 20-30 feet length, each fitted with a coarse pitch tapered threaded connection. Three to four of these are coupled together, their object being to add weight to the drilling bit and to form a rigid section immediately above it.
- (3) The drill pipe. This consists of heavy solid-drawn steel pipe usually made in 30 foot lengths. The sizes in general use vary from $3\frac{1}{2}$ to $6\frac{1}{2}$ inches diameter with weights ranging from 13 to 26 lbs. per foot. To enable each length of drill pipe to be quickly and easily coupled together, the ends are fitted with a male and female tool-joint. These consist of a heavy coupling, one end of which is screwed permanently on to the drill pipe, the other end having a coarse pitch tapered thread. The coarse tapered threads can be made up or broken down very quickly.
- (4) The kelley or "grief" stem. This consists of a hollow bar, about 5 inches square and 38 feet long, by which the drilling string is rotated. Its length must be slightly longer than the sections of drill pipe, because as drilling proceeds the square section of the kelley is lowered through the rotary table until its full length is below the table. The drilling string is then raised, the kelley removed, a fresh length of drill pipe is coupled up and the kelley is replaced. The drilling string is then lowered until the bit touches the bottom of the well. The kelley now extends above the rotary table a distance equal to the length of drill pipe last inserted, and drilling can then proceed for a distance equal to the length of the kelley.

The kelley, working in a square hole in the rotary table, enables the necessary rotation to be applied, and also allows the whole string of drill pipe to be lowered as drilling proceeds. The drilling string is suspended

on a roller-bearing swivel, which in turn is suspended from a heavy travelling block. The derrick is fitted with a set of sheaves (crown block), over which is run a wire line usually of 1 to $1\frac{1}{4}$ inches diameter, to make, with the travelling block, a set of heavy block-and-tackle. The line is then led to a drum, to which the power is applied for withdrawing the drilling string or for lowering it under control of a brake.

With the above equipment the drilling string can be rotated and raised or lowered as required as drilling proceeds.

The next essential operation is to remove by a continuous process the debris formed by the action of drilling; this is accomplished by the use of a mud-flush circulation.

The circuit of this mud-laden fluid, which, for normal drilling, ranges around 1.25 specific gravity, begins at the slush-pumps, which are of the duplex reciprocating type, either direct steam driven or belt driven from a steam engine or other type of power unit. The amount of fluid to be handled by the pumps varies with the size of hole being drilled, but a pump capable of delivering 600 gallons per minute against a pressure of 600 lbs. per square inch and absorbing 300 H.P. will meet most conditions. The pumps are often duplicated to provide a standby.

Various forms of power are used for drilling. Steam, because of its flexibility, is generally used where water and cheap fuel are available, but electric motors and I.C. engines are also used. The introduction of a fluid coupling, by which a high degree of flexibility and speed control can be obtained, has brought the diesel engine into increasing favour. The horse-power required for a deep-drilling outfit ranges around 600, but may exceed 1000. Adequate pump capacity in volume and pressure is essential for successful drilling.

From the pump discharge the fluid is conveyed through a 40 foot length of $2\frac{1}{2}$ -inch high-pressure flexible hose, which is coupled to the rotary swivel, down through the kelley, drill pipe, and drill collars, and through the drilling bit, returning via the annulus between the outside of the drill pipe and the walls of the well to the surface. The uses of this mud-fluid flush are fourfold: to keep the drilling bit cool and clean, to flush away the debris as it is drilled and to convey it to the surface, and to plaster the walls of the well so as to prevent caving, and in some cases to seal off water shows.

When the debris-laden fluid reaches the surface, the coarser particles are separated from the fluid by screening or settling, and the "good" mud is recycled in a continuous process.

In many cases when no difficulties are encountered a mud prepared from local clays or shales makes a suitable drilling fluid, but in wells in which caving persists, and where high-pressure water- or gas-shows have to be passed, or where considerable beds of salt are penetrated, the mud fluid is specially treated to suit the conditions. To hold back high pressures the mud may have to be "weighted" with barytes or similar material to increase its specific gravity; it may have to be treated with a saturated brine solution to prevent leaching out of salt zones while they are being drilled; and when drilling through porous sands it is often necessary to prepare a mud fluid with a low permeability factor—i.e., one which leaves on the walls of the well a thin and impervious sheath which seals the

pores in the formation, and so prevents a thick mud sheath being built up due to the expression of water from the mud fluid into the formation.

The rate of drilling varies with the formations to be penetrated, the diameter of the hole, and with the type of bit which must be used. For the softer rocks a "drag" type of bit is used; this consists of a multi-bladed bit, the cutting action of which is similar to the normal flat drill used in drilling metals (Fig. 4). In suitable formations consisting of soft shales or other unconsolidated beds as much as 1500 feet can be drilled in 8 hours. Drag bits are easily rebuilt by the application of hard facing material. When drilling through hard formations such as limestone or consolidated and well-cemented sandstone, rock bits are in general use (Fig. 5). These consist of a series of circular-toothed cutters running on ball or roller bearings and mounted in a suitable body. The penetration speed again depends on the hardness and abrasive quality of the rock, and varies from 1 to upwards of 10 feet per hour.

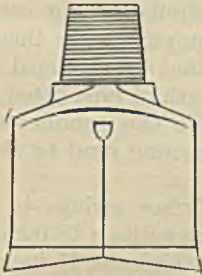


FIG. 4.
DRAG BIT.

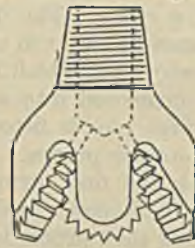


FIG. 5.
ROCK BIT.

The footage drilled before a bit must be replaced is also variable, an average figure being about 500 feet. These rock bits can also be rebuilt by tipping the teeth with hard-facing material, when a further footage of about 80 per cent. of that obtained from a new bit can be drilled.

In extreme cases, a total footage of 2 feet per bit with a penetration speed of 6 inches per hour is all that can be obtained.

When a drilling bit becomes worn to the extent that the drilling speed falls off, the whole string of drill pipe must be withdrawn in order to replace the worn bit by a new one. To save time, when the drill pipe is being withdrawn it is uncoupled in "stands" of three 30-foot lengths, these 90-foot "stands" being racked upright in the derrick.

The speed of rotation and the weight applied to the bit are dependent on the formations and the type of bit in use. In soft formations speeds up to 500 r.p.m. have been used, but it is largely a question of opinion as to whether such high rotation speeds are necessary or advisable. In hard rock the speed of rotation may have to be reduced to as low as 30 r.p.m.

The weight applied on the bit is controlled by the rate at which the line is fed off from the winding drum of the draw-works. At a depth of 5000 feet the drilling string may weigh 30 tons. Of this 30 tons only from 2 tons to, say, 8 tons should be carried by the bit, the balance of 28 to

22 tons must therefore be carried by the travelling block under control of the brake on the draw-works. Recording weight indicators are available which show at all times the weight applied at the bit. The most suitable bit-loading for any given formation is generally found by trial, and when this has been ascertained the drilling string is lowered at a rate which allows the correct weight to be carried by the bit at all times.

DRILLING THE WELL.

To give a general idea of the work involved in drilling an oil-well, we will assume that the well is to be drilled to 8000 feet, and that when oil is struck it will be under a pressure when closed in of the order of 3000 lbs. per square inch.

In the first place, a cellar varying from 10 to 25 feet deep and about 15 feet square is excavated and lined with concrete; the purpose of this cellar is to provide space for the well-head fittings, etc., below the derrick floor. Alternatively, a steel sub-structure of similar height can be used instead of a cellar. The derrick and other equipment are then erected, and mud storage either in open pits or in steel tanks is arranged.

A conductor box, which is merely a short length of pipe fitted with side outlets, is cemented into a small sub-cellar. To this conductor box the mud-discharge pipe is fitted to convey the returning mud to the suction tanks of the slush pumps.

Assuming the first string of casing—the surface string—is to be 15 inches outside diameter, drilling would commence with an 18-inch-diameter bit. Drilling then proceeds until the depth at which the 15-inch casing is to be set is reached. The 15-inch casing, fitted with a shoe to protect the bottom end, and a non-return valve (float collar), is then inserted, each length of approximately 30 feet being screwed into the lower length, which is supported in clamps (known as a spider) at the surface while the added length is being screwed in. Each joint of casing is screwed "home" by heavy power-operated tongs. Accurate measurements are taken while the casing is being inserted, as a check to ensure that the casing reaches to within a few feet of the bottom of the well and is not held up by any obstruction. If necessary, a "make-up" length is added at the top of the string of casing to bring the top of the casing to the correct height at the surface.

To hold back any water-shows which may have been penetrated, and to anchor the casing securely in the ground, the casing is cemented in place. Cementing is carried out by pumping down inside the casing a pre-determined quantity of neat cement slurry, usually of a specific gravity of 1.8. As the cement is pumped in, an equal volume of the mud fluid is displaced by the cement, and when the total quantity of cement, which is generally equal to the volume of the annular space between the outside of the casing and the inside of the drilled hole, has been placed, a cementing plug—a short piston fitted with U rubbers (Fig. 6), and fitting inside the casing—is placed on top of the column of cement. Mud fluid is then pumped in on top of the cement plug, driving the cement ahead of it past the non-return valve and up the annular space to the surface. When the piston (cementing plug) reaches the non-return valve, no more mud can

be pumped in, nor can the cement which has been placed in position return into the casing. The cement is then allowed to set for about 48 hours.

Drilling then proceeds with a bit about $\frac{1}{8}$ inch less in diameter than the inside diameter of the casing last cemented. The cementing plug and the float-shoe, which are made of drillable material, are drilled out. To test the soundness of the cementing job the hole is deepened to about 5 feet below the shoe of the casing, and the fluid level is bailed down. If after standing for a period there is no change in the fluid level, this proves there is no leakage past the shoe or through the casing joints. Alternatively, or in addition to this test, a hydraulic pressure is applied at the surface of the casing. If the necessary pressure can be held, it proves

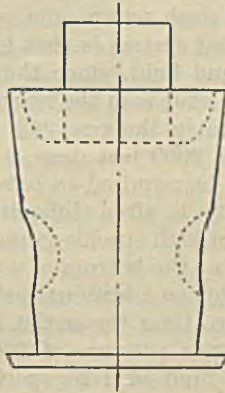


FIG. 6.
CEMENTING PLUG.

that no leakage is taking place around the casing shoe and so up into the formation.

The well is then deepened until the depth at which the next and smaller string of casing is to be landed, when the same cementing procedure is carried out.

After the last or oil string of casing is cemented the well is prepared for "drilling in." If oil under only low pressure is expected, or if the pressure will not be in excess of the static pressure developed by the column of mud fluid in the well, no special precautions other than pressure tests of the casing and well-head fittings are necessary. When the oil-bearing horizon has been drilled through or into for a distance which is considered advisable, the drill pipe is withdrawn and the production is "brought in." This is done by either bailing down the mud fluid or displacing it with a fluid of a lower specific gravity, until the oil can overcome the static head and flow into the well. The well is then ready for production.

PRESSURE DRILLING.

In cases where oil or gas under high pressure is expected, or in some cases where the pressure conditions are unknown and might not be held

under control by even a long column of drilling mud of high specific gravity, pressure drilling may have to be used. Pressure drilling is a method by which drilling can be carried on while the well is under a pressure at the surface. To enable this to be done a special gland (a blowout preventer) which will enable the drill pipe to be passed through it and rotated under pressure is fitted to the well-head above a master gate-valve. Side outlet valves are also arranged to take the returns from the well to the pump suction. In one method of pressure drilling, the pressure of the returning circulation is allowed to fall to atmospheric pressure before being again picked up by the slush pump and re-circulated down the well. In another system, known as the closed system, the returning fluid is passed through suitable closed containers. In these containers the debris is screened from the fluid, and the fluid is led direct to the suction inlet of the slush pumps and recycled into the well. The chief advantage of the closed system is that less power is required at the pumps for recycling the mud fluid, since the pressure is not allowed to fall to atmospheric pressure as it is in the normal open system.

If the oil or gas pressure in the reservoir rock is, say, 5500 lbs. per square inch and the well is 8000 feet deep, a column of drilling fluid of 1.60 specific gravity would be required to balance the pressure. As mud fluid of 1.60 specific gravity is often difficult to pump, due to its high viscosity, the use of fluids of high specific gravity often leads to trouble.

The same static pressure at the bottom of a well can be obtained by the use of a lighter mud fluid plus an additional pressure, which can be applied by the slush pumps by throttling the outlet from the well-head. Thus, to balance the same reservoir pressure of 5500 lbs. per square inch an 8000-foot column of mud fluid of 1.25 specific gravity giving a static pressure of about 4300 lbs. per square inch, plus an added pump pressure of about 1200 lbs. per square inch, will give the same static pressure as the column of the heavier mud fluid.

Another feature of pressure drilling is that, as the pump pressure is easily controllable and may be reduced or increased as desired, so the pressure at the bottom of the well can be controlled to within very fine limits, even though the specific gravity of the column of mud fluid may vary.

To prevent the drill pipe being blown out through the blowout preventer by the pressure in the well, some form of snubbing gear must be used. The drill pipe must also be fitted with a non-return valve at the lower end, to prevent the pressure in the well escaping upwards through the drill pipe when running it into or pulling it out of the well.

After drilling is completed and the drilling string has been pulled out, the pump pressure is released and the well "comes in" under control without further assistance.

The foregoing is a brief description of the work involved if everything goes according to plan. Many complications are likely to arise, however, and these must be avoided if possible.

CROOKED HOLES.

With the rotary system there is a tendency for the hole to go crooked, particularly where the strata are inclined and alternate between hard and

soft layers. When drilling through such zones, the weight on the bit is reduced, in order to avoid any "crowding" and to ensure that the drilling string hangs by its own weight in a vertical position. The drill collars assist in maintaining a straight hole, because with their added weight close to the bit the greater part of the drill-pipe sections can be kept in tension, so avoiding any tendency to buckle and wobble during rotation.

Wells are usually tested for verticality at frequent intervals of from 250 to 500 feet. The method employed is to lower an inclinometer through the drilling string until it comes to rest on a stop arranged at the bottom of the lower drill collar. The inclinometer is normally inserted at the end of a "run" and just before the drill pipe would in any case have to be withdrawn; it is then recovered and the inclination noted when the bit is removed.

The simplest forms of inclinometers give only the degrees the hole deviates from vertical, but other more complicated types show also the compass direction to which the well may incline. In exceptional cases, and where the deviation exceeds a given allowable, say 5° , the well may have to be plugged back with cement and redrilled from the position where excessive deviation started.

For many reasons it is important that a well should be practically vertical. For instance, a deviation of only 5° if cumulative over say 5000 feet will place the bottom of a well 437 feet away from a position vertically below the starting point. The depth below the surface will also be 4980 feet instead of 5000 feet. As the geology of an oil-field, in so far as detail is concerned, is based on the information obtained from the well logs, it is essential to know the correct depth, and any deviation and direction of deviation of all wells. Crooked wells, especially those which have left and have later come back to vertical—*i.e.*, a "dog-legged" hole—are a source of trouble and expense. They cause excessive wear on the drill pipe during the drilling of the well, and are sometimes the cause of prolonged fishing jobs. It is often found impossible to insert the casing, and reaming or other attempts to straighten the well must be resorted to. In the later stages of the life of a well, when its production may have to be pumped, a crooked well causes excessive wear on the pump tubing and the rods which operate the pump.

Directional drilling—*i.e.*, a method by which the direction and deviation are controlled—is often employed. Its chief objectives are to "offset" a well which if continued vertically would not reach its target. Wells are sometimes located on the sea-shore, in order to reach an oil horizon a short distance out to sea. Similarly, oil- and gas-wells which have got out of control have been "killed" by drilling a directionally controlled well from which the "wild" well can be sealed off by pumping in heavy mud fluid.

CAVING.

Caving zones and sections in which the formations tend to squeeze into the well are often the source of serious trouble. Caving can sometimes be prevented by the use of the correct type of mud fluid, but once a bad cave has occurred it is not easy to correct the trouble, or to overcome the difficulties arising through it.

The drilling debris is carried from the well by the returning mud circulation, the carrying capacity being a function of the viscosity of the fluid and the velocity of the flow-stream. If excessive caving occurs, the area of the annulus outside the drill pipe is increased, and therefore the velocity of the circulating fluid over this zone is decreased. As soon as the speed is reduced below a critical point, the debris can no longer be carried upwards in the flow-stream, but settles around the bottom of the "funnel" caused by the cave. In extremely bad cases the cave must be filled up with cement and a new hole drilled through it before drilling can proceed.

Similar conditions can arise due to the leaching out of salt zones, but here again a mud fluid made of a saturated brine solution will prevent the leaching if the remedy is applied soon enough.

"Squeezing" formations are extremely difficult to overcome. They can in some cases be held back by using a mud fluid of high specific gravity or by pressure drilling, but it is sometimes necessary to keep reaming out the well and to insert casing to shut off the zone as soon as possible.

Some formations containing bentonite have a tendency to swell on coming in contact with water. The result is similar to that experienced due to squeezing formations; a drilling fluid with an oil instead of a water base is often effective in preventing the swelling.

FISHING.

Fishing jobs, although at one time quite common, are gradually being reduced by the introduction of better material and improved methods. The most common is probably due to the drill pipe twisting off. If there are no other complications, such as, for instance, the top of the lost section falling over into a cave or becoming stuck due to the drilling debris settling around it, the lost section is easily recovered by a suitable fishing tool. In some cases, however, the drill pipe must be "backed off" or cut in sections before it can be removed; it may have to be trepanned over in order to remove the obstruction which is holding it, or lubricated with a charge of oil before it can be pulled free.

The cutters of rock-bits sometimes become detached from the body and must be recovered before drilling can proceed. Fishing operations range from the simpler ones which can be dealt with in an hour or two to the more difficult and complicated ones which sometimes result in the loss of the well, or which, even if the "fish" could eventually be recovered, would be more expensive than drilling another well.

CORING.

In areas in which little information is available regarding the underground conditions, and in fact in any well in virgin territory, every effort is made to ensure that no oil horizons are inadvertently passed through. Confirmation of geological evidence is also obtained whenever possible, in order that such information can be applied to other wells to be drilled.

When drilling in unknown areas it is also essential that the well is at all times in a condition to cope with unforeseen difficulties which may arise, such as the striking of high-pressure gas, oil, or water.

Cores probably provide the most convincing and satisfactory evidence, so far as the recognition of geological horizons is concerned. They are obtained by using a special core-bit (Fig. 7), the form of which enables a core of the formation to be recovered and brought to the surface. The size of these cores varies according to the diameter of the hole being drilled, that obtained from a 10-inch-diameter core-bit being about 5 inches diameter. The length is dependent on the formation being cored and on the length of the core barrel. As a rule cores of 10-20 feet can be taken at one "run," the percentage of core recovered averaging about 80 per cent. of the amount actually cored.

The examination of these cores provides valuable information as to the oil or water content, porosity, and composition of the rock, all of which may have a bearing on the future development of the oil-field.

Small cores about $1\frac{1}{2}$ inches long by $\frac{1}{2}$ inch diameter can be taken from the side of the well after drilling. This is accomplished by a tool which has a small tube fixed to a hinged holder. The tool with the holder contracted is run into the well on the drill pipe. When the desired depth is reached, the holder is forced outwards by hydraulic pressure applied to the drill pipe at the surface, and after the holder contacts the wall of the hole the weight of the drill pipe is applied. This weight causes the holder to roll on its hinge-pin, so forcing the core tube into the side of the wall. On the drill pipe being raised the core tube returns to its original position, having extracted a small core of the formation. This method can only be used in fairly soft formations, but it provides a means of obtaining a core from zones which have already been drilled.

PILOT HOLE.

In many exploration wells where it is desired to feel ahead, and yet have the well in a safe condition, a pilot hole is sometimes drilled ahead of the full-sized hole. The pilot hole is usually about three-quarters the diameter of the full sized hole and may be drilled ahead for say 50 to 100 feet. It is large enough to enable the necessary cores to be taken, or for other tests to be carried out. The advantage of a pilot hole is that if oil is struck, the hole can be reamed out to the correct depth, leaving a shoulder on which the casing can be landed. Tests for production can be carried out with greater safety in a pilot hole, and if necessary it can be plugged more easily. If the evidence from the pilot hole is of no importance, it is drilled out to the full diameter and another pilot hole carried on ahead. If water or other undesirable conditions are encountered, they can more easily be plugged off in a pilot hole than in a full-sized hole.

PACKER TESTS.

Although core evidence is very useful, it is sometimes necessary to test a certain horizon to prove whether it contains and will produce oil. Such tests are known as packer tests. As explained elsewhere in this article, the weight of a long column of mud fluid exerts a considerable pressure at the bottom of a well, and this pressure may be far in excess of the pressure of the oil in its reservoir. It follows then that this oil cannot make its presence known by flowing into the well against a much higher pressure.

In order to create a zone of low pressure opposite a suspected oil horizon, and so enable the oil to flow from the reservoir, the lower section of the well where the oil is expected is isolated from the upper section.

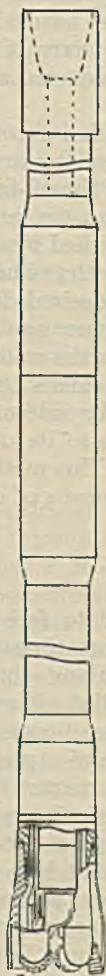


FIG. 7.
CORE BIT AND BARREL.

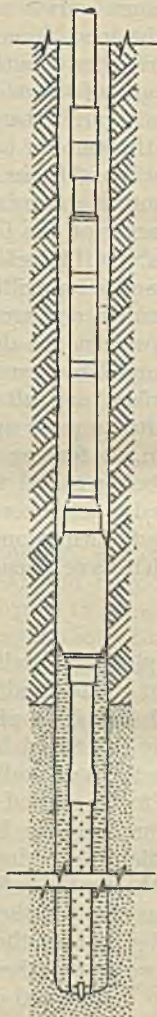


FIG. 8.
FORMATION TESTER.

To enable this to be done, a formation tester is employed (Fig. 8). This consists of a tool comprising a massive rubber sleeve slightly smaller in diameter than the hole being drilled and a suitable valve mechanism which can be operated from the surface. The tool is run into the well on the drill pipe with the valve closed, and with an anchor pipe of the correct length attached to the bottom end. When the anchor pipe reaches the

bottom of the well, the upper and telescopic part of the tool is lowered a few inches, so expanding the rubber sleeve and forming a seal with the wall of the well. At this stage the mud fluid in the well completely fills the annular space outside the drill pipe, and extends up inside the formation tester to below the closed valve. The whole of the inside of the drill pipe is empty, and therefore at atmospheric pressure. On opening the valve the comparatively small volume of mud fluid below the rubber sleeve is released into and rises a short distance up inside the drill pipe. The zone below the rubber sleeve, being separated from the static head of the column of mud fluid above it, is under practically the same pressure as any fluid which is contained in the horizon being tested; any fluid can therefore flow from the formation and up into the drill pipe. The fluid will rise in the drill pipe to a height at which the head of fluid balances the pressure in the formation which is being tested. The rate at which the fluid rises, and also the pressure, can be measured, and from these figures an estimate can be made of the well's production and pressure conditions. The fluid can also be sampled in order to know whether it is oil or water; it may be only gas.

When the test is completed—after about one to four hours—the valve is closed and the drill pipe and packer are withdrawn, thus bringing to the surface a sample of the fluid produced. From the information obtained from these tests a decision can be made as to whether the production is sufficient to justify the completion of the well at that point, or whether drilling should continue to explore the possibility of deeper horizons.

SHOOTING.

Some rocks, although containing oil, are so compact and "tight" that the oil cannot move freely through the small pores or cracks which contain the oil. In such cases the well is often "shot" in order to shatter the rock, and so form drainage channels through which the oil can travel towards the well.

The size of the explosive charge and the method of firing it depends on the conditions in the well; a charge of 100 to 400 lbs. of liquid nitroglycerine or blasting gelatine is commonly used. The charge is packed into containers of about 10 feet long, each container being lowered into the well on a steel cable fitted with a self-releasing hook and placed opposite the zone to be shot. The upper container is fitted with a primer and detonator, which in turn are connected with a clockwork time-bomb. After the whole charge and the time-bomb are in position, tamping is placed above the time-bomb. This tamping may consist of oil or water, or in some cases gravel is used and is poured into the well. At the pre-arranged time the time-bomb fires the charge, shattering the rock, and so opening up new drainage channels. The debris is afterwards cleaned out and the well put on production.

ACID TREATMENT.

Another method of opening channels, and so enabling freer movement of the oil, is acid treatment. This is effective only in rocks which contain

a high proportion of calcium carbonate which is soluble in hydrochloric acid. It is very effective in limestone and in some sandstones in which either the sand-grains or the cementing material is calcareous.

Commercial hydrochloric acid, diluted with an equal quantity of water and mixed with an inhibitor to prevent the acid attacking the casing, is placed in the well, and is forced into the small cracks or pores in the rock by pump pressure. The pressure is then released, and the spent acid is allowed to return into the well. The well is then cleaned out, and the formation thoroughly washed by pumping in water to remove any sludge which remains in the pores or cracks.

Great increases in production are often obtained either by shooting or acid treatment, or even by a combination of both methods.

ELECTRICAL LOGGING.

The term "electrical logging" is applied to the practice of obtaining information from an open hole by measuring the resistivity of the surrounding rock formation. This has a two-fold purpose. First, when a porous sandstone is encountered the resistivity indicates whether its contents are oil or water, and, secondly, the resistivity log enables correlation to be effected between a number of wells by matching zones of high and low resistance and the interval between them. In a field of known conditions, the depth at which to set a casing or "oil string" may be decided from the electric log.

Briefly the usual method is to lower three electrodes on separate conductors. These hang above one another in the drilling mud or water, and can be raised or lowered by a winch at the surface. The relative position of the hanging electrodes is determined in relation to the diameter of the hole. The cable carrying the lowest electrode is connected to a source of electric supply at the surface, the other pole of this supply being grounded in the vicinity of the well. When the circuit is closed the current flowing from the lowest electrode creates a difference of potential between the other two electrodes due to ohmic effect. The cables carrying these two electrodes are connected to a potentiometer at the surface where variations in the induced potential are measured. As the intensity of the current and the distances between the three electrodes are known factors, the apparent resistivity of the surrounding formation can be computed from the variations of potential as recorded on the potentiometer. The interpretation of these readings and the problem of calculating the real resistivity is complicated to the extent that account must be taken of the diameter of the well, the thickness of the bed being measured and the resistivity of the mud (or water) in the well.

When once a suitable and comparable interpretation has been arrived at, future wells can then be drilled without taking cores, and an electrical log is made after the well has been drilled, but before the casing is inserted.

Although possibly not quite as satisfactory and positive as the evidence obtained by the examination of cores, the electrical logging method is much quicker, and is coming into general use where conditions are favourable to its use.

The foregoing is intended to give only a brief and general description of the work involved, and of some of the tools and methods which are employed in drilling oil-wells, and in obtaining data from the underground conditions encountered. The subject is one which cannot be dealt with in detail in an article of this description, but it is hoped that it has given the reader a general idea on a subject about which little is known by those not directly associated with the industry.

OBITUARY.

MR. CHRISTOPHER DALLEY.

PRESIDENT OF THE INSTITUTE OF PETROLEUM, 1942-1944.

It is with deep regret that we announce the death, on 28th January, 1944, of Mr. Christopher Dalley, President of the Institute from 1942 to 1944.

Christopher Dalley was born at the School House, Liss, Hampshire, on 5th May, 1883. He was one of a family of seven children, and the third son of Albert Dalley, a schoolmaster. At an early age he began to absorb knowledge and develop a love for reading. And his early life in the country at Liss gave him a deep acquaintance with natural history which remained a very real part of his mental background. He maintained this interest to the end by his hobbies of gardening and interest in British birds.

At the age of 13 he won a scholarship at Churcher's College, Petersfield—actually the first open scholar of the school. At school he did particularly well in natural science and was no mean athlete.

In 1900 he was awarded a school-leaving exhibition coupled with a County Council studentship at the Hartley University College, Southampton, in which Institution he remained till 1902. As a student he took an active and successful part in all College activities.

At the age of 19 he started his professional career with the firm of Messrs. Dick, Kerr & Co. He stayed in this post for three years, being engaged in the erection of electric plant of many kinds.

He joined the British Westinghouse Company in 1905, and until 1910 was occupied as an erecting engineer on projects that took him all over the country. In these formative years he acquired a notable experience in mechanical and electrical engineering and a wide general knowledge of his subject.

The most significant move in his career occurred in 1914, when he joined the (then) Anglo-Persian Oil Co. At the very beginning of the modern scientific development in oil-fields, pipe-lines, refineries, and transport, Dalley's vigorous intelligence had the fullest scope. Almost day by day new problems were put to him, urgent developments had to be improvised, rapidly increasing staff to be engaged and directed and encouraged. His life was as full as even he could have wished. And all through these eventful years he never lost equilibrium and poise, nothing ever really upset him, his constant good humour always saved him in the successive and sudden problems that followed one another in a grim succession.

Electrification in the petroleum industry may be described as the pole star of Dalley's technical career.

Many of his old colleagues will remember the work he did on the Persian pipe-line system; on Fields electrification; at Abadan Refinery; tank farms



CHRISTOPHER DALLEY.
1883-1944.

[To face p. 150.]

and jetties and plant; at Llandarcy Refinery, Docks, and Installations. In those full years there were very few men whose fingers were closer and tighter on the pulse of our Industry.

And in the closing period of a life all too short when Dalley was appointed joint Managing Director of the British Controlled Oil Fields, Ltd., and later of the Trinidad Petroleum Company he brought to bear not only his unrivalled technical knowledge, but a flair for administration and the control of men that were of the highest order.

In no way did he spare himself. He visited the overseas territories of his Companies on many occasions and, as at home, endeared himself to all his colleagues.

Elsewhere the writer has tried to point out the peculiarly human characteristics of our late President. In closing this brief account, he would wish once more to stress this aspect of Dalley's make-up.

A. E. D.

MR. TWEED writes :—

When the writer of these personal notes received news of the death of Christopher Dalley, he looked at the empty chair, and some words, long forgotten, came to his mind : "*Vaunteth not itself, is not puffed up. Doth not behave itself unseemly, seeketh not her own, is not easily provoked. . . . Rejoiceth not in iniquity, but rejoiceth in the truth.*"

That was Christopher Dalley. Whether he was bowling first ball to open a new cricket ground for the local staff in Trinidad, or taking the Chair at a Luncheon of the Institute of Petroleum in London, surrounded by distinguished guests, Christopher Dalley was just the same—his own genial, kindly, knowledgeable self.

The writer received the following from Trinidad : "The whole staff down to the coloured domestic servants in Trinidad felt the death of Mr. Dalley keenly. They remembered his visits."

His sense of humour was a great delight to all his friends, but in the last two years he was undoubtedly carrying on his mind the possibility of the fate which eventually overtook him. What courage! One of his last acts was to hand his secretary the article recently published entitled "The Application of Electricity to the Winning of Petroleum," with the words, "Keep it safely; that will show them what I have done." He kept on working to the last. On the Thursday afternoon of 27th January he attended his office in London as usual, and on the following morning he died before breakfast.

Of his technical achievements other persons are writing, but the departure of this lovable personality has left an irreplaceable blank in the lives of many of us, and especially of his older friends.

The honour that he valued more than any was his election as President of the Institute of Petroleum. This meant more to him than any other honour or financial gain that he might have attained. He put great energy into furthering the objects of the Institute of Petroleum in the last two years, and especially in acquiring the new premises in Portland Place. When the new premises were opened on 17th February, Christopher Dalley was not there in person, but he was there in spirit. On that occasion the speeches made by his two old friends, Lt.-Col. Auld and Dr. Dunstan,

received by the audience with reverence, were a fine memorial to a man whose life was devoted to the oil industry.

A sigh of real and deep regret went round the world through every oil-field where his numerous friends were working when the news reached them that Christopher Dalley had passed over.

R. R. T.

MR. COLIN SPEARING writes :—

Christopher Dalley came to the petroleum industry at the beginning of the last war, and to those who worked with him in the early nineteen twenties he will be especially remembered as a most kindly and approachable person, invariably helpful to his staff.

He brought to the industry a wide knowledge of general engineering, particularly electrical practice as applied to colliery work, consequently the handling of large quantities of materials offered no novelty to him. He applied his knowledge and experience successfully to many problems which were encountered in the development of the Anglo-Persian oil-fields, and in several instances, particularly oil-field electrification and the adoption of turbo-driven centrifugal oil-pumps on the main Persian pipe-line, he may rightly be regarded as a pioneer.

Dalley was among the foremost in the rapidly developing petroleum industry to appreciate the scope for employment of the University engineer and chemist at a period when many could see little that required trained technologists; as a result many young University graduates owe a debt of gratitude to Dalley for the encouragement and help given to them in overcoming the inevitable prejudice which arose from their employment in the petroleum industry in the early 1920's.

C. E. S.

MR. A. C. HEARN writes :—

My own recollection of Christopher Dalley, dating from some 24 years ago, covers a period when, as our respective duties often brought us together, I was able to appreciate the particularly valuable part he played in the evolution of oil technology. He was quick, far-seeing, ingenious and remarkably well-balanced; indeed, a better and more competent colleague it would have been hard to find. That would have been a sufficient equipment for most men. But he contributed much more to the common fund than his wide technical competence, for his large tolerance, his genial good nature and his strong sense of "fair play" were natural solvents to many difficulties that were human, and not technical, in character. His heart and brain were well mated and by virtue of their happy conjunction his memory will be specially cherished by all those, who, like myself, were once privileged to call him both colleague and friend.

A. C. H.

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Geology and Development.

563. **Huntington Beach Oil-Field. Old Field Portion.** J. T. Carriel. *Calif. Oil Fields*, Jan.-June 1942, 28 (1), 7.—Huntington Beach Oil-Field, Orange County, is the sixth largest in California, judged on total production. It has been divided by development and structural conditions into a number of areas, which in turn have been grouped under two headings—Old Field (north-east of Palm Avenue and its extension) and New Field (south-west of Palm Avenue and its extension). This report concerns primarily the Old Field, but it includes also an historical and production description of the entire field.

The Old Field consists of a monoclinical limb of a central structure to the south, the original form of which is not clearly revealed. Except in the case of one sand body, the oil is prevented from migrating farther by a series of faults extending along and through the southern limits of the producing wells.

Production for the entire Huntington Beach oil-field amounted to 308,332,859 bbl. of oil to 1st September, 1942, and at that time average daily production from 683 wells was 39,697 bbl. of oil and 32,695,000 cub. ft. of gas. All the oil has desirable characteristics.

Possibilities of future development are encouraging, and it is believed that investigation of the area between the Old and New Field will connect the segments of the major structure, and so make possible a complete study of the whole field. Deeper production could be obtained from the Old Field and extensions of areas made.

H. B. M.

564. East Coalinga Extension Oil-Field. E. J. Kaplow. *Calif. Oil Fields*. Jan.-June 1942, 28 (1), 15.—The East Coalinga Extension field is in Fresno County, California, on the west side of the San Joaquin Valley. It was discovered in 1938, and is rather an unusual type of reservoir for California. The report embodies a history of the field from December 1937, when drilling was started at the discovery well, to the end of 1942, by which time practically all locations which could be drilled under existing agreements had been completed. Throughout this period conservative drilling and production practices were followed, practically all wells being drilled with large steam rotary outfit, using rock-bits. Chemically treated mud was used as circulating medium, with very careful control of properties such as viscosity, water loss, and weight. This prevented difficulty in handling oil sand pressures, which tended to be high throughout.

The Gatchell sand which forms the reservoir in this field is considered an excellent example of the stratigraphic trap. Much of it is massive, with little or no evidence of bedding, but some of it is quite platy. Permeability of the sand decreases with depth, and in one well which was subjected to exhaustive tests it was found that permeabilities perpendicular to the bedding averaged 62% of permeabilities parallel to the bedding. Water conditions differ from those of most Californian fields in that there is practical absence of intermediate water.

In July 1942 production averaged 8554 bbl. of oil per day in the Amerada area and 16,717 bbl./day in the Gatchell area.

H. B. M.

565.* Problem of Oil Supply Assumes Growing Urgency. Anon. *World Petrol.*, September 1943, 14 (10), 50.—Over the years the price curve and the curve of drilling have moved together; when prices fell, drilling slumped temporarily.

According to Heroy, from the beginning of 1937 to the end of 1942 discoveries, extensions, and revisions added 14,916,007,000 bbl. to the U.S.A. proved reserves. Withdrawals during those years amounted to 7,896,614,000 bbl. At the beginning of 1943, the known reserve was estimated to be slightly over 20,000,000,000 bbl. In the past few years the amount of the annual additions has been decreasing, and the volume of discoveries in particular is falling off. Various obstacles have caused well drilling to fall sharply, and while 30,000 wells were drilled in 1941, only 18,000 were drilled in 1942. The wildcat completions fell slightly, but the quantity of reserves added through wildcatting was only about one-third of that found by fewer wells in 1940, and less than one-sixth of what it had been in 1937. It became clear that oil was being produced faster than it was being found.

It is agreed that much oil remains to be found in U.S.A., but the cost of finding the undiscovered accumulations is rising as it becomes necessary to drill more difficult and less favourable areas and to go to greater depths. Fixing of prices has greatly curtailed exploratory activity.

It has been estimated that the average maximum efficient producing capacity of the known fields is 4,421,500 bbl./day, 4,212,000 bbl./day, and 4,022,500 bbl./day for the years 1943, 1944, and 1945, respectively, while the average minimum essential requirements will be 4,100,000 bbl./day (1943), 4,400,000 bbl./day (1944), and 4,400,000 bbl./day (1945). The requirement figures are believed to be decidedly conservative.

261 new fields were found in 1942, with an average estimated reserve of only 1,200,000 bbl./field, and 4500 wildcats were asked for in 1943, compared with 3000 drilled in 1942. The 1943 figure was later raised to 5200 wildcats, but only 1503 were drilled in the first half of 1943. However, the ratio of producers to dry wildcats in 1943 has been higher than in 1942, and in a few areas, notably in West Texas, the fields promise to be of first-rate importance.

In the first half of 1943, California was the only important area with a substantial increase in drilling, and there a small oil price increase was allowed early in the year. Only 11,600 development wells were asked for in 1943, and in the first half of the year completions were ahead of schedule.

Various diagrams present data on wildcatting, total completions, crude production and demand, crude stocks, crude prices and military and aviation gasoline requirements. G. D. H.

566.* South-east Georgia—North Florida Area Getting Big Exploration Plan. D. L. Carroll. *Oil Wkly.*, 13.12.43, 112 (2), 46.—Some 8,000,000 acres in 35 counties are under option or lease in Southern Georgia and adjacent parts of Florida. Geological and geophysical parties have been active, and particular interest has been shown in the area east, south and west of the Okofenokee swamp. The Georgia play is not related to the activity in Central Florida, which has given a discovery in Collier County.

The geology of the Georgia-Florida boundary region is very promising, and the presence of gas and oil is confirmed by non-commercial wells, surface shows, and gas-seeps. Shows have been found in the Hawthorn (Miocene), Wilcox (Eocene), and Tuscaloosa-Eutaw (Upper Cretaceous).

The sedimentary rocks of Southern Georgia are dominantly marine, typically of coastal-plain types. They rest on basement granites, gneisses, and schists, and dip south and south-east, thickening towards the centre of the basin near the Florida border. On the Atlantic edge of the basin the beds are 5000 ft. thick, and in south-western Georgia 7000 ft. These beds contain many overlaps. It is possible that there are buried basement ridges. Truncated Palaeozoic and Mesozoic beds lie below the Tuscaloosa-Eutaw in Florida.

A generalized cross-section and a stratigraphical column are included, and tentative correlations with beds in the oil-bearing regions farther west are suggested.

G. D. H.

567.* November Completions Highest in 1943 but Total Far Under Last Year. Anon. *Oil Wkly.*, 13.12.43, 112 (2), 64.—An average of 422 well completions per week was achieved in U.S.A. in November, compared with 386 per week in October, 385 per week in September, and 398 per week in August. Up to the end of November 1943, completions totalled 17,211, against 19,895 in the corresponding period of 1942. Compared with the first eleven months of 1942, completions were down in Louisiana (39.4%), Pennsylvania (35.4%), New Mexico (31.8%), Indiana (28.5%), and Texas (20.1%). There were increases in the number of completions in California (79.2%), Kentucky (150.3%), Wyoming (16.8%), Arkansas (13.9%), and Oklahoma (4.0%).

877 oil-wells and 119 gas-wells were completed in November. There were 499 dry holes.

A table gives by States and districts a summary of the drilling results in November 1943 and during the first eleven months of 1943. G. D. H.

568.* Canadian Oil Production Remains Steady. Anon. *Oil Wkly.*, 13.12.43, 112 (2), 68.—In the first nine months of 1943 the Canadian oil production averaged 835,552 brl./month. The corresponding figures for 1941 and 1942 were 844,486 brl./month and 863,567 brl./month, respectively. Turner Valley limestone wells provide over 93% of the output. G. D. H.

569.* New Gas Sand Found in Northern Mexico. Anon. *Oil Wkly.*, 13.12.43, 112 (2), 68.—A new and deeper pay has been found in the Carrizo at 3672-3680 ft. in the Chiltipin gas-field of north-eastern Nuevo Leon, Mexico. The previous gas production was from the Mount Selman at 2780 ft. G. D. H.

570.* Fluorographic Analysis of Soil Samples Used in Search for Oil Deposits. E. H. Short. *Oil Gas J.*, 16.12.43, 42 (32), 51.—Fluorographic analysis is being employed in the search for new petroleum reserves on the Gulf Coast. In the development of the method it was found that all soil samples, regardless of location, contained easily detectable evidence of free hydrocarbons, thus eliminating such criteria as a significant

factor in oil-reconnaissance surveys based on soil inspection. It was also found that an acid-solvent treatment of the samples removed all free hydrocarbons, leaving a fixed hydrocarbon which was consistently found in soil which had been subjected to reservoir leakage over millions of years.

The fluorographic technique makes use of specially designed photographic equipment combined with ultra-violet light apparatus. This combination permits the recording of fluorescence from several hundred samples at a time.

Samples are taken on a grid, preliminary surveys using 440 yd. spacing. Approximately 1 oz. of soil is taken from a depth of 4 ft. The soil is dehydrated and pulverized before fine screening. The fine material is next acid-solvent treated to remove all free hydrocarbons. The samples are then placed in open-end capsules on a tray holding 110 capsules.

The time required to photograph the fluorescence is about 90 minutes. The film is darkened in proportion to the intensity of the emitted radiation, and a densitometer is used to measure the degree of film darkening. To allow for the fact that all soil contains fluorescent inorganic substances, the fluorescent quality of all soils is used as an average background, and this is subtracted from the density reading of each sample to give positive and negative values for the fixed hydrocarbons. Since calcium gives as much fluorescence as the fixed hydrocarbons, this must be removed to prevent its masking the hydrocarbons.

An example of the application of fluorographic analysis in the Hitchcock area, Texas, is described. G. D. H.

571.* Summary of Operations, November 1943. Anon. *Oil Gas J.*, 16.12.43, 42 (32), 99.—1732 wells were completed in November 1943, compared with 1636 in October. 958 were oil-wells, and 182 gas-wells. There was a drop in the number of completions in Illinois, but most other areas showed rises.

A table summarizes the results of completions in November 1943 by States and districts, and gives the footage, numbers of drilling rigs, and the completions in different depth ranges. G. D. H.

572.* Wildcat Completions. Anon. *Oil Gas J.*, 16.12.43, 42 (32), 99.—An important Mississippi lime discovery was made in the week ended 11th December, 1943, in Clay County, North Central Texas. The well, which is 4½ ml. west of Bollovue, produced 1980 brl. of oil per day with 48 brl. of water from 6253–6283 ft. The Ellonburger at 6706–6795 ft. was dry. 7 ml. north of Anson, Jones County, West Central Texas, the Hardy pool was opened with a flow of 154 brl./day from the Canyon at 3690–3706 ft.

Three new pays were discovered and an extension made in South-west Texas.

Twelve oil discoveries and three gas discoveries were made out of 72 wildcats completed in the week ended 11th December, 1943. The results of the wildcat completions in that week are tabulated by States and districts, together with cumulative totals for 1943. G. D. H.

573.* Crude Oil Output Declines Slightly in Week. Anon. *Oil Wkly.*, 27.12.43, 112 (4), 52.—In the week ended 25th December, 1943, the U.S.A. crude output of 4,381,687 brl./day was 8126 brl./day below the figure for the previous week. Wyoming showed a decline of 7400 brl./day, while Kentucky, Kansas, Pennsylvania, Indiana, Colorado, and Montana also had declines. Illinois had an increase of 10,700 brl./day, California 5550 brl./day, Arkansas 2350 brl./day, and Oklahoma 1700 brl./day.

G. D. H.

574.* New Del Bonita Well Makes Good Flow. Anon. *Oil Wkly.*, 27.12.43, 112 (4), 53.—Del Bonita 1 is being finished as a dual completion. It is flowing clean 37-gravity oil by heads, and is expected to yield 400 brl./day when both pays are acidized. The depth is 4700 ft. G. D. H.

575.* New Fields of Southern Alberta Plains Important. Anon. *Oil Wkly.*, 27.12.43, 112 (4), 53.—In the past season seismograph work in Alberta has been on a scale never before known in that province.

Taber-Province 17–18b is the biggest Canadian well outside Turner Valley, and it swabbed 500 brl./day from 37 ft. of oil sand at 3141 ft. Taber-Province 1, the previous

best Alberta well outside Turner Valley, gave 406 bbl. in its best day. It is now shut in. Drilling at Tabor is cheap, and presents no serious difficulties.

Pacific Oil Co.'s No. 1 at Del Bonita has 4700 ft. of 37-gravity oil in the hole, and an upper oil-zone has not yet been tested. The well is flowing by heads. It is a direct west offset of the discovery well, which has been making 20 bbl./day for years.

Pincher Creek was the scene of some of the earliest drilling in Alberta, and although good shows have been obtained, commercial production has been lacking. A new well is under way. G. D. H.

576.* Prince Edward Island Well Making Progress. Anon. *Oil Wkly.*, 27.12.43, 112 (4), 53.—The wildcat which is 8 ml. off-shore from Prince Edward Island has reached a depth of over 2800 ft. The test may go to 15,000 ft., and is on a structure which was seismographed. An earlier test in 1927 was 1½ ml. nearer shore. This location, now known to be well down structure, was abandoned at a depth of 5970 ft., because of the inability to complete with the equipment in use. G. D. H.

577.* Crude Oil Output Again Sets Record in October. Anon. *Oil Wkly.*, 27.12.43, 112 (4), 54.—In October the U.S. crude production averaged 4,403,000 bbl./day, 56,000 bbl./day more than in September, and 515,000 bbl./day more than in October 1942. In the first ten months of 1943, 1,234,378,000 bbl. was produced, compared with 1,149,781,000 bbl. in the same period of 1942.

The demand was 4,324,000 bbl./day in October, 64,000 bbl./day less than in September. The October runs to stills averaged 4,162,000 bbl./day, against 4,203,000 bbl./day in September. In October the gasoline yield rose from 38.1% to 38.6%, and the residual fuel-oil yield fell from 29.0% to 26.9%. G. D. H.

578.* Florida Looms as Area for Future Exploration. R. Roaves. *Oil Wkly.*, 3.1.44, 112 (5), 8.—Millions of acres have been leased in the South-eastern States of U.S.A., and a small amount of oil has been found in Florida.

Florida has a sedimentary series ranging from 5000 ft. to more than 15,000 ft. in thickness. The rocks consist of about 75% of limestone and other calcareous rocks, with 25% of sandstones and shales. The formations range, pre-Palaeozoic to Recent in age, but are mainly Cretaceous and Tertiary. About 100 wells have been or are being drilled in Florida, spread over 39 counties. The first producer is the State's deepest well (11,626 ft.) near Sunniland, Collier County. Most of the tests are in the north-west of the State and on the Gulf of Mexico side.

In the extreme west of the State, Miocene marls and sands outcrop, and to the east and south are Pliocene and Pleistocene sands and clays. Between the Ocklocknee and Suwannee rivers, Ocala (Eocene) limestone outcrops. The dominant structural feature of eastern Florida is described as an arch trending south-south-east, and forming the axis of the peninsula. This is a continuation of the broad anticlinal region of south-central Georgia. A large high occurs in eastern Levy County (Ocala uplift), and there is a smaller one near Live Oak. Ocala beds outcrop in the core of the Ocala uplift. To the south, in the Brooksville area, the Tampa limestone (Miocene) rests directly on the Ocala.

In the north-eastern part of the State, Miocene and post-Miocene sands and clays are at the surface. Unconsolidated sands mask the solid geology in the Daytona area, but to the west are Miocene and Pliocene sands, clays and limestones. Pleistocene marls and sands occur in the Kissimmee valley, with unconsolidated Pleistocene and Pliocene beds in the west of the Kissimmee area. In the Gulf coast area of south Florida Miocene beds are present, sometimes with a thin cover of Pliocene and Pleistocene. Pleistocene shell marls form the surface beds in the Miami area, with the Ocala limestone probably 300 ft. below sea-level in the north, and dipping south and south-east until it is 670 ft. below sea-level at Fort Pierce.

Accurate knowledge of the subsurface geology of Florida is fragmentary, and confined to the shallower formations.

A list is given of the wells drilled since 1900, with the location, depth and date, and a map and two well logs are included. G. D. H.

579.* British Dominion Company Has Best Turner Valley Well. Anon. *Oil Wkly.*, 3.1.44, 112 (5), 47.—British Dominion No. 5 at the north end of the Turner Valley

field had yielded 130,000 bbl. of crude in five months up to the end of November 1943. On a current production basis Homo-Millarville 14, which produced a little over 100,000 bbl. in nine months after completion in February 1943, is the second best well in the field. British Dominion 7 met the Cardium sand at 3520 ft., and is probably 400 ft. higher on structure than the nearest well. G. D. H.

580.* Chinese Government Pushing Oil Development. Anon. *Oil Wkly.*, 3.1.44, 112 (5), 47.—There are indications that extensive exploration and test-drilling campaigns are under way in the Urumchi area of Sinkiang Province, in the extreme north-west of China. Oil has been known in this region for many years, and has been bailed from pits by hand. G. D. H.

581.* 34 Drilling Operations at Turner Valley. Anon. *Oil Wkly.*, 3.1.44, 112 (5), 47.—On 18th December, 1943, 34 drilling operations were proceeding in the Turner Valley field. Foothills 13, at 10,155 ft., was testing the Upper Porous formation. The average daily production from 202 wells was 26,084 bbl. on 14th December, 2500 bbl./day better than in the preceding week. G. D. H.

582.* New Field Opened in Athabaska Area. Anon. *Oil Wkly.*, 3.1.44, 112 (5), 47.—A wildcat on a large structure near Fort Assinaboine, in the Athabaska district, has opened a new field, but cold weather has delayed the carrying out of a production test. G. D. H.

583.* Taber Field Production Halted. Anon. *Oil Wkly.*, 3.1.44, 112 (5), 47.—Lack of outlet for the 20-gravity crude has caused the closing down of all producing wells in the Taber field. A wildcat has been spudded at Crow Indian Lake, nearby. G. D. H.

584.* Wildcat Hits Richest Vermilion Pay. Anon. *Oil Wkly.*, 3.1.44, 112 (5), 47.—Apex Oil Company's No. 1, 7 ml. south-west of the Vermilion field, is reported to have encountered the richest pay-sand yet discovered in the area. G. D. H.

585.* December Wildcat Successes May Indicate Better Holes Ahead. D. L. Carroll. *Oil Wkly.*, 17.1.44, 112 (7), 37.—45 oil discoveries were made in U.S.A. in December 1943, 28 being new fields, 8 new pays, and 9 field extensions. In addition 2 new distillate pays, 6 new gas-fields, and 3 new gas-pays were found. 21 of the oil discoveries were in Texas, 4 in Kansas, 2 each in Michigan and Oklahoma, and 1 each in Illinois, California, Florida, Indiana, Kentucky, Louisiana and Wyoming. In addition, 3 new pays and 6 extensions were found in Illinois.

During 1943, 643 discoveries were made, 145 being extensions. Exclusive of extensions there were 519 successes in 1942. 3370 wildcats were drilled in 1943, 263 more than in 1942.

The Wynn field of Clay County, Texas, was completed in the Mississippi lime for 1998 bbl./day from a 93-ft. producing zone. The well was plugged back to 6454 ft., from the Ellenburger topped at 6706 ft. 3½ ml. north-east of the Thalia field in Wilbarger County, North Texas, a new field was opened by a 941-bbl. well completed in two thin pays in the Gunsight limestone (Pennsylvanian).

Heavy oil and water have been pumped from a well near Sunniland, Collier County, Florida. The oil yield is about 77 bbl./day.

In Wyoming the Gebo Dome field of Hot Springs County was opened by a producer in the Embar limestone at 4735–4742 ft. The well flowed 180 bbl./hr. The structure is a broad faulted dome with 800 ft. of closure. The reserves are estimated at 4,000,000 bbl. at least, and the Madison has not yet been tested. The two Michigan finds were marked by small wells in the Dundee and Traverse limestones. In the Grooley area of Kern County, California, a 303-bbl. well in the Vedder sand (Miocene) opened a small field at a depth of 11,600 ft.

A 355-bbl. well was completed in a small anticline in Pottawatomie County, Oklahoma. The Stowell field of Chambers County, Texas Gulf Coast, was extended 1 ml. north by a 349-bbl. Frio sand-well. The structure is on a fault-line, and the reserves are at least 6,000,000 bbl.

The successful wildcats in December 1943 are listed with the locality, field, depth, producing horizon, type of structure, and other information, while tables give by States and districts the results of wildcatting in December and during 1943, and compare the 1942 and 1943 wildcat totals in different categories. G. D. H.

586.* Better Oil Supply Is Seen for Brazil. Anon. *Oil Wkly.*, 17.1.44, 112 (7), 51.—Oil exploration continues in Brazil, and some promising strikes have been reported. Efforts are being concentrated on the Bahia-Alagoas region, where a recent 6000-ft. well found four promising pay-zones. Geological and geophysical work and coring are being carried out in the western part of Acre Territory. G. D. H.

587.* Taber Field Wildcat Is At Coring Depth. Anon. *Oil Wkly.*, 17.1.44, 112 (7), 51.—Mid-Continent Oil and Gas Limited's No. 3 well has been cored below 3163 ft. on approaching the Taber sand. The Ellis sand is 60 ft. deeper. No. 1 was $\frac{3}{4}$ ml. east of No. 3. This was off-structure and failed. G. D. H.

588.* Twenty Parties Assigned to Field Projects in U.S.G.S. Expanded Program. Anon. *Oil Gas J.*, 20.1.44, 42 (37), 20.—20 U.S.G.S. parties are in the field searching for potential oil-producing structures. The programme will include both regional stratigraphic studies and areal structural investigations.

Approximately \$380,000 has been allotted to the search.

A summary is given of the specific projects in California, the Rocky Mountain, Mid-Continent, Mid-South, Gulf Coast, Appalachian, Michigan, and Northern Great Plains areas.

The tar-sands of California and elsewhere are to be studied with the objective of using them to produce war-time fuel, and a search for further tar-sand deposits is to be made in Oklahoma. G. D. H.

589.* Wildcat Completions and Discoveries. Anon. *Oil Gas J.*, 20.1.44, 42 (37), 83.—In the week ended 15th January, 1944, 7 wildcats in U.S.A. were completed as oil-wells, 3 being in new pays, 4 as gas wells, 1 as a distillate well. 3 of the discoveries were on the Texas Lower Gulf Coast, 1 being a new pay-zone in the Rooke field. In Bee County, oil was found 3 ml. west of the Pettus field, and in Jim Wells County the discovery was $3\frac{1}{2}$ ml. south-east of the Seeligson field, the pay being 7221 ft. deep. In South-west Texas a new pay was found at a depth of 4428 ft. in the Cadona field, Duval County, while a new gas sand was opened in the Lopeno field, Zapata County, at 2752–2770 ft.

A table gives by States and districts the results of wildcatting in U.S.A. during the week ended 15th January, 1944, with cumulative totals for 1944. G. D. H.

590.* Active Exploration Is Under Way in Colombia. Anon. *Oil Wkly.*, 24.1.44, 112 (8), 41.—Exploratory campaigns of various types are under way in Colombia in the Caqueta region of the Llanos, north of El Banco, around San Pedro de Arimona, as far east as the Cosar river, and on the Caraballo tract. G. D. H.

591.* Another 10,000-Barrel Well in Poza Rica Field. Anon. *Oil Wkly.*, 24.1.44, 112 (8), 41.—A new well with an initial production of 10,000 brl./day and a high gas-drive is reported in the Poza Rica field. G. D. H.

592.* Production Declines for Year in New Zealand. Anon. *Oil Wkly.*, 24.1.44, 112 (8), 41.—In 1942 wells in New Zealand produced 77,716 brl. of oil. The production was considerably less than that in 1943. The Moturoa field is reported to have a potential of 150 brl./month.

Several deep wildcats were drilled in 1942, the deepest being abandoned at 10,925 ft. G. D. H.

593.* Taber Field Extension Opens New Pay in Ellis. Anon. *Oil Wkly.*, 24.1.44, 112 (8), 41.—2 ml. south of previous production in the Taber field a well has opened a new pay in the Ellis sand. This well will test both the Taber and Ellis sands. A

previous outpost well had found saturation in both these sands. All the other Taber wells produce from the Taber sand. G. D. H.

594.* Two-Thirds of Alberta Activity in Turner Valley. Anon. *Oil Wkly.*, 24.1.44, 112 (8), 41.—20 of the 29 drilling operations under way in Alberta at the end of the first week in January were in the Turner Valley field.

The average daily production of all the Alberta wells in the first week in January was 22,887 bbl., 2650 bbl./day more than in the preceding week. G. D. H.

Drilling.

595.* Mechanical Causes of Casing Failure and Practices for Their Control. L. O'Donnell and W. S. Crake. *Oil Gas J.*, 16.12.43, 42 (32), 46.—The paper deals first with causes of failure and then gives recommendations on how to use casing in different circumstances. Wear of casing by drill-pipe is a most predominant cause of failure. To reduce wear, it is quite essential, when drilling oil-wells, to use rubber protectors on the drill-pipe operating inside casing. The use of sufficient rubber protectors greatly increases the contact area, and also permits abrasive materials to be cushioned by the rubber, thus materially reducing the wear on the casing string and on the drill-pipe. Each joint of drill-pipe operating inside of casing should have at least one rubber protector installed on it, spaced about 2 ft. from the tool joint. Rubber protectors can be sufficiently worn to the point where they provide no protection, so it is also advisable to check the outside diameter of the protectors periodically to insure that they are at a minimum of $\frac{1}{4}$ -in. larger in diameter than the tool joints on the drill-pipe. Due to wear, it is highly probable that a large proportion of surface strings on deep wells, which are not exposed to high internal pressures or collapse forces under normal drilling conditions, would fail in collapse if emptied, or from bursting if excessively high pressure were imposed thereon.

In order to provide greater resistance to wear, a better grade of casing is sometimes mistakenly used. Within the range of hardness obtainable in casing, one grade will not last against abrasion appreciably better than another, and an increase in grade to prevent wear is wasted expenditure. Use of additional thickness of metal is a much more suitable method of providing additional wear resistance, but the best method of reducing wear is to have the surface casing set vertical.

Failure may also occur by poor support or high and faulty structural loading. These points are elaborated. Compressional loads should always be avoided.

A. H. N.

596.* Cementing Casing through Troublesome Zones. W. A. Sawdon. *Petrol. Engr.*, January 1944, 15 (4), 152.—Troublesome zones frequently present such a hazard to further drilling that casing must be set and cemented before the well can be drilled to completion. Even the cementing of casing through zones where circulation is being lost is sometimes a problem, because the best drilling mud, no matter how well prepared and conditioned, is usually unable to prevent loss of fluids into the formation while drilling under these conditions, and thus cannot build a mud-cake on the wall of the thief-zone to prevent loss of slurry while the cement is being forced up behind the casing. When gas-zones are encountered in the troublesome area, the problem becomes even more difficult. This was the case in a well recently drilled in the Ventura Avonue field, California, in which gel cement was employed.

The paper gives full details of the cement characteristics and method employed, which resulted in successfully shutting off the thief formation. A. H. N.

597.* Gamma Ray Logging in East Texas. J. I. P. Campbell. *Petrol. Engr.*, January 1944, 15 (4), 156.—The basis of Gamma ray logging is explained. Radioactivity, which is the basis of the survey, is the change of one element into another by disintegration, these changes leaving the element as a newer element of lower atomic weight. So it continues in a declining action until the end product is reached. This end product is lead, and is non-radioactive. While the elements are disintegrating, rays are emanating from them (alpha, beta, and gamma), the most powerful of which is the gamma ray. Gamma rays are electro-magnetic waves, similar to light-waves, but having a shorter wave-length and extremely high penetrating power. They will

penetrate casing, cement, fluid, and the instrument of survey. When the gamma rays penetrate the surveying instrument, they ionize a gas and permit the flow of a current to the central electrode. One ten-trillionth of an ampere is the order of magnitude of the current. Because it is so minute, it is amplified within the instrument, sent to the surface by a single conductor cable, where it is further amplified and recorded. The number of gamma rays penetrating the instrument at any instant cause increases or decreases in the intensity of the current in the ionization chamber. These changes in intensity are recorded, and so become available for interpretation. Sands, for example, are of low intensity because they are weakly radioactive. Shales are high in radioactive intensities. Other sedimentary formations are correspondingly interpreted either through experience or by local conditions. Its use, then, in oil-well information is logical. All terrestrial formations have some measurable amount of radioactivity, therefore any sediment can be surveyed, whether it is sand, lime, shale, salt, anhydrite, potash, coal, bentonite, or another mixture. There is no formation that cannot be surveyed and interpreted. This "nutshell" information on radioactivity is applied and interpreted as a tool for workover operations in the East Texas field.

Three typical logs are given and briefly interpreted.

A. H. N.

598.* **What it Costs to Drill.** W. K. Powell. *Petrol. Engr.* January 1944, 15 (4), 181.—An accounting method used for estimating costs of drilling wells is given. In conclusion it is stated that the cost of drilling can be determined within reasonable bounds through modern cost accounting, provided the operation is such that essential time data from similar operations can be procured. Thus, through the application of a history of costs, the direct expense/day, the overhead/day, the drilling equipment depreciation expense/day, the drill-pipe cost/day or /foot all become available for use in prognosticating the cost of future wells. Likewise, there is available daily the material necessary to determine the most effective drilling practices and the information to point the way to improved operations.

A. H. N.

Production.

599.* **Prime-Mover Requirements For Pumping Installations.** J. Zaba. *Oil Gas J.*, 16.12.43, 42 (32), 56-58.—Gas engines and their ratings, together with water requirements for cooling purposes, are briefly discussed. In selecting a gas engine, an economic balance must be arrived at in regard to three factors—fuel economy, initial investment, and possible overload of engine. Increase in fuel consumption at light loads and higher investment in larger engines present an argument in favour of using engines loaded closely to their rating. On the other hand, cost of keeping in good repair a severely loaded engine may be prohibitive, and this usually becomes the factor governing the selection. A decision on the selection of the size of the engine should be based on consideration of these three factors. A.P.I. specifications are discussed.

The type of loading encountered in oil-well pumping necessitates use of "application factor" in selecting the electric motor for powering of a pumping installation. The governing factor of rating of a motor is its temperature rise due to operation. This heat depends primarily on power peaks and minima, not on the average current. Rating of a motor operating under constant loading cannot, therefore, be applied to oil-well pumping conditions. The following formula has been presented for horse-power rating of a general purpose pumping motor:—

$$\text{Horse-power rating} = \frac{K \times B \times L \times 1.5}{T}$$

where K = kilowatt hours/barrel fluid/1000 ft. of lift, B = barrels fluid/day, L = lift in thousands of feet, T = pumping time in hours/day.

Factor of 1.5 includes the application factor and motor efficiency and converts kilowatts into horse-power. Factor K has been found, from a large number of tests, to average close to 0.4 kw-hr./brl. of fluid/1000 ft. of lift.

A. H. N.

600.* **Pressure Maintenance in Wertz Field Provides Sustained Production.** N. Williams. *Oil Gas J.*, 16.12.43, 42 (32), 60.—As far as is known, this project is unique. While providing for the preservation of reservoir pressure, and control and utilization of

the hydrostatic drive, the operation also effects sustained daily production at higher rates, variable within limits according to needs. As proof, reservoir pressure is now actually being increased, although oil withdrawals have for some time been sustained at a rate substantially above that at which it is calculated the water is advancing. A volumetric balance has been maintained between oil withdrawn and gas injected, and by this it will be possible to realize maximum ultimate oil recovery and depletion of the reservoir in a much shorter time than would otherwise be required. Early in the development it was proposed to initiate production practices that would insure maximum utilization and conservation of the energy of the hydrostatic drive in expediting the most advantageous recovery of the reserves. With this in view, a thorough study of reservoir behaviour and subsurface pressure reaction to various rates of flow was undertaken. The study revealed that the hydrostatic head alone would not permit a fluid withdrawal rate of more than approximately 3300 brl. daily without depletion of reservoir pressures, and if greater withdrawals were desired the energy supplied by the hydrostatic head would have to be supplemented by return to the formation of sufficient gas to displace the volume of fluid withdrawn in excess of the 3300 brl. daily. The volume of gas required to displace a barrel of oil under existing reservoir conditions was calculated at approximately 1400 cu. ft. Consequently, by returning to the formation this volume of gas for each barrel of oil produced over 3300 brl. daily, theoretically, daily withdrawals can be sustained at any rate desired without decline of pressure. Also, by returning a greater volume of gas, the pressure can be increased. Since the volume of gas produced from the Tensleep formation is not sufficient, gas from the shallower horizons is drawn on to make up any deficiency in volume needed to maintain volumetric balance in the reservoir.

Characteristics of the geological structure, formation characteristics, together with properties of the crude and production rates are given. The treatment and injection of the gas are discussed in some detail. Plant operation is semi-automatic, and ordinarily only one man is needed on each shift. Operation of the project is joint between the production and gasoline departments. With the exception of the regulation of the flow of individual wells in the field, which is handled by a resident production engineer, all gauging and handling of crude oil are done by operators at the plant. Obviously, man-power requirements are minimum. All electric controls are located at a central point outdoors. An electrically operated emergency shut-down system has been provided. Switches are placed at three convenient points in the plant and yard. Pulling any one of these cuts off the fuel to the boilers quenches the boiler fire-boxes with steam, shorts the magnetos on the engines, shuts off the incoming gas, and turns all production through the separators direct to storage, instead of through the plant.

A. H. N.

601.* Plastic Plugging is Ingenious Innovation for Shut-Offs. D. L. Carroll. *Oil Wkly*, 27.12.43, 112 (4), 14-15.—In bottom-hole plugging-back to shut off water, the plastic is dumped from a special bailer equipped with a trigger valve which opens on reaching the bottom. Adequate pressure for inducing penetration of the plastic into the formation is supplied by the weight of a column of water above the bailer in the hole. The height of the water column is controlled according to the requirements of each specific job and the amount of penetration desired. The plastic is prepared in such a way that it remains in liquid condition at ordinary temperatures, but changes to a non-elastic solid when heated. The necessary heat for this change is provided by the temperature at the plugging depth. The higher the temperature, the shorter is the setting time. In wells plugged with plastic at the East Texas field, bottom-hole temperatures averaged approximately 145°, and the setting time averaged 12 hours. More recently, plastic plugging in the South Houton field has been done with bottom-hole temperatures at approximately 150°, and setting time was found to be slightly more than 11 hours. It is estimated, on the basis of field and laboratory experience, that at 200° the setting time would be no more than 2 or 3 hours.

The viscosity of the liquid is about that of S.A.E. 30 motor oil. Plastic plugging is controllable to such a fine degree that success has been attained on as little as 3 ft. of exposed formation section, shutting off water that had been entering the hole from only a few inches of the rock wall. Only 1 or 2 gal. of plugging material have been used on some of these small-scale shut-offs. On the other hand, more than 30 gal.

have frequently been used on bigger jobs. Cost of a normal plastic plugging job is approximately \$300.00, including the use of up to 30 gal. of plastic. Extra costs, for electric logs that may be requested and for special tubing crews or materials, may amount to perhaps \$600.00 more. A complete job, then, properly performed, cost the operator \$800 or \$900.

A. H. N.

602.* Oil-Field Operation with Co-operative Engineering Committees. V. E. Cottingham. *Oil Wkly*, 27.12.43, 112 (4), 16.—The working of a co-operative engineering committee and the information it supplies are described. One of the most important functions of such a committee is the compilation of all general engineering and statistical data for the field as a unit. Through monthly and annual reports, the operator may see the relationship of his lease to all other leases in the field. Good conservation practices in the production of oil are based chiefly on two things: (1) the proper completion of wells, and (2) the efficient rate of withdrawals from the individual well and from the reservoir as a unit. In order to accomplish this objective in a field where there is a large diversified leasehold ownership, each operator should see the picture as a whole. These data are especially desirable when going before the oil-regulatory authorities for changes in allowables and corrective measures, designed to prevent physical waste. In those fields in which co-operative engineering committees are employed, the more technical engineering projects are carried on by the individual operator. Such projects as bottom-hole sampling, core analyses, productivity indexes, permeability, and saturation tests, and many others, could be carried on under the auspices of committee engineers. At present, however, the more highly technical projects are left to the initiative of the individual operator. Many of the major companies have their own laboratories and technical staffs for carrying on this specialized type of engineering. This same service is also available to independent operators through consulting engineering firms. In fact, many of the major companies draw heavily on this type of specialized service.

There are a number of fields in Texas in which the leasehold interests are small, and the company engineers as individuals exchange data with one another, much in the manner that oil scouts exchange information. In a number of these fields the picture as a whole is practically as complete as in those fields in which engineering committees operate. However, where the leasehold interests are large, this simple arrangement for acquiring engineering and other data for the field as a unit does not work. Should a large number of the producers in a field undertake to carry on the more common types of petroleum-engineering work individually, there would be a duplication of specialized man-power, engineering, and automotive equipment for acquiring the information. The data so acquired would still have to be assembled and compiled before it could be translated into its fullest meaning for the individual lease or the field as a whole, to say nothing of the added cost.

A. H. N.

603. Determining Probability of Success of Secondary-Recovery Operations. Part 6. W. A. Hoath. *Oil Wkly*, 27.12.43, 112 (4), 26.—*Paper Presented before American Petroleum Institute.*—After a brief discussion on the meaning of viscosity and its units, its influence on production in the light of recent research is discussed. It appears that to a given economic limit of water-oil or gas-oil ratio, the more viscous oils will yield less recovery than the less viscous oils, other conditions being equal. The magnitude of such difference has not been evaluated in field experience. In general, within the small range of viscosities in which secondary-recovery operations have been conducted, other factors—such as geological and sedimentation characteristics, and water and oil saturations of the reservoir—have more weight in determining the amount of recoverable oil than viscosity alone. The influence of viscosity of the oil in governing the rate of fluid travel, and therefore the flood life and development investment, will by far outweigh the influence of viscosity on residual saturation in determining the economic success of water-flooding of the shallow, less permeable reservoirs. In the deeper reservoirs, where the well-spacing may be controlled by the spacing of existing wells, the additional permissible pressure that can be carried at the sand-face due to the greater depth will tend to overcome the effect of viscosity on fluid flow and enable injection of satisfactory volumes of water. As gas drive in depleted reservoirs is essentially an oil “dragging” rather than “pushing” process, viscosity will only slightly affect the volume of gas that can be injected into the sand, and the economics

of recovery will be definitely affected by the gas-oil ratios required in removal of oils of varying viscosity.

A. H. N.

604.* Dually Completed Oil and Gas Wells. L. L. Jordan and A. Crowell. *Petrol. Engr.*, January 1944, 15 (4), 85-86.—More than \$2,250,000 and 6700 tons of steel are the initial saving effected by the first 37 dually completed oil- and gas-wells in Arkansas. 32 of these 37 dual completions are in the Dorcheat-Macedonia field of Columbia County. This field, which is under an extensive development programme, has already proved a reserve of 90,000,000 brls. of oil and distillate and more than 400,000,000,000 cu. ft. of natural gas. There are 66 producing well-bores in the field, 21 of which are located on 1160 acres and operate as a unit, whereas 2 are on 40-acre units, and the remaining 43 are in the centre of 80-acre units. The deeper pool—Smackover limestone—which is found at a depth of approximately 8600-8800 ft. subsea, accounts for two-thirds of the reserve mentioned, the remainder being credited to the upper productive pools—Cotton Valley sandstone—which is found from 6500 to 8200 ft. subsea. Details of the pools are given.

The general programme of well completion in the Dorcheat-Macedonia area has been to drill the entire hole by rotary, cement 100-400 ft. of 13 $\frac{3}{8}$ -in. surface pipe with 200-375 sacks, 2200-4100 ft. of 9 $\frac{1}{2}$ -in. intermediate casing with 1000-1800 sacks, the oil-string of 5 $\frac{1}{2}$ -in. casing through the producing smackover with 1000-2500 sacks, and complete the tubular equipment with 2-in. tubing. Both single and double separations are in use, while the general practice is to use wooden storage tanks. That dual completions have been successful is reflected in a brief *résumé* of operations at a well completed more than a year ago, and as yet there has been no evidence of packer leaks. From the *résumé* it appears that dual completion in Arkansas has become comparatively simple.

A. H. N.

605.* Correlation of Polished-Rod Acceleration and Well-Load. K. N. Mills. *Petrol. Engr.*, January 1944, 15 (4), 95.—The effect of the polished-rod acceleration on the force required to reciprocate the rods would be very simple if the entire mass being accelerated were attached directly to the polished rod. This is not the case, however, as in an oil-well the static weight of the well is distributed over a space of several thousand feet, and this distribution of mass introduces a time lag which must be considered if a useful solution to the problem is to be attained. This time lag will tend to reduce the magnitude of the dynamic forces acting on the system. An equation in general form is developed on these ideas. From this equation it is apparent that, considering the rod-string only, the magnitude of the difference between the true acceleration factor and the apparent acceleration factor (acceleration factor based on the maximum rate of acceleration at the surface) will depend on the rate of change of the surface acceleration. If the rate of change is rapid, the difference between the true and apparent acceleration factors will be greater than it would be if the rate of change were less rapid. The contribution of the fluid load to the dynamic forces is less susceptible to analysis than the part played by the rods. Pump dynamograph cards, which are load-space records taken between the rod-string and the pump, indicate that the fluid load either is not accelerated or is accelerated at a uniform rate. After the fluid load has been assumed by the rod-string, and the rod-string is attempting to set the fluid in motion, an increased load will be imposed on the rod-string. As the rod-string is elastic, it will stretch when this increased load is imposed on it, and this stretch will temporarily decrease the rate of motion imparted to the fluid by the rod-string. As this decrease in the rate of motion occurs near the time of maximum acceleration, it tends to decrease the rate of acceleration imparted to the fluid by the rod-string at that instant. As this energy will gradually be released to the fluid at a later instant when the rate of acceleration is decreasing, it will tend to promote a constant rate of fluid acceleration. During the early stage of this cycle of events the tubing is contracting, and it is imparting some energy to the fluid. This event also occurs near the instant of maximum acceleration, and tends to decrease the dynamic effect of the fluid load on the rod load. The velocities of stress transmission in oil and steel are different—about 1:4. This further complicates the problem.

Typical well dynamometer cards are analysed.

A. H. N.

606.* Time As a Factor in Economics of Oil-Field Exploitation. L. C. Uron. *Petrol. Engr*, January 1944, 15 (4), 116.—In this article it has been shown that time is a factor of primary importance in planning the exploitation of an oil-producing property. Wells must be drilled at a suitable time in relation to surrounding development, otherwise the owner of the tract on which they are situated will suffer an irreparable loss. In gas-drive fields, later drilled wells characteristically display small initial and ultimate recoveries than do the early wells in the same locality. In water-drive fields the later drilled wells suffer a loss in ultimate recovery, but not necessarily in the initial rate of production. Those conclusions apply particularly to uninfluenced, competitive fields, and may be modified to some extent by proration practices and by application of the pressure-maintenance method of exploitation. Delay in development may also occasion additional loss as a result of deferred realization of profit on oil and gas production. The market demand and selling price of oil may dictate the exploitation programme, compelling a slower rate of development than other considerations might require. Lack of available capital for rapid early development of producing properties is responsible for delay with many operators.

Determination of the economic life of an oil-producing property is an important problem that confronts every oil producer. This problem presents both physical and economic factors, some of which are intangible or susceptible only of approximate determination. Higher oil prices, reduction in production cost, and application of more efficient recovery methods will operate to extend the economic life of oil-producing properties. For every oil-producing property there is a certain optimum rate of production that will result in maximum profit, but this is not usually the rate at which maximum recovery will be achieved. A technically satisfactory means of determining the most efficient rate of oil production under a given set of conditions remains to be determined. It is believed that rates of production prescribed by proration authorities often fail to coincide with the optimum rate for most profitable operation.

A. H. N.

607.* Wellhead Pressure Reduced by Subsurface Regulation. J. O. Farmer. *Petrol. Engr*, January 1944, 15 (4), 160.—Because the maximum pressure reduction that can be effected by single-stage regulation is 1500 lb./sq. in., the reduction of subsurface pressures exceeding 3000 lb./sq. in. to safe flowing pressures within non-freezing limits requires two or more regulators. The well discussed was completed with perforations at 9350 ft. depth. The shut-in pressure at the surface was approximately 5650 lb./sq. in., which required a total pressure reduction of 4200 lb./sq. in. for safe workable limits in which hydrates would not form in the flow-lines. Three 2½-in. sub-surface regulators with ¾-in. Kennametal valves and valve seats were installed at depths of 6250, 5000, and 3750 ft. The regulators were set in the conventional manner by means of an ordinary steel measuring line. The regulator set at a depth of 6250 ft. was adjusted to accommodate a pressure differential of 1500 lb./sq. in., the regulator at 5000 ft. was set for a differential of 1400 lb./sq. in., and the regulator at 3750 ft. was set for a differential of 1300 lb./sq. in. After opening the wellhead connections for the desired rate of flow, the flowing pressure on the tubing stabilized at 900 lb./sq. in., and since then the well has flowed almost continuously to supply fuel for a drilling rig. The well has produced without interruption, and its general behaviour has stimulated that of a low-pressure flowing well. The flow rate is varied by changing the surface choke. Freezing is eliminated completely.

The critical problem in making such an installation lies in selecting proper depths for each regulator, so that the upstream temperature of the flow-stream at each regulator is high enough to permit each pressure reduction without the formation of hydrates. Previous experience in setting bottom-hole chokes and regulators has established the fact that from 500 to 1000 ft. of vertical travel in the flow-stream is adequate to equalize the temperature of the hydrocarbon fluid with the surrounding formation after its temperature has been reduced by a subsurface control. The calculation used for the well is given.

A. H. N.

608.* Fundamentals of Petroleum Reservoir Behaviour. Part 2. Anon. *Oil Wkly*, 17.1.44, 112 (7), 12-15.—This forms the second instalment of a long paper published in a booklet form by the Reservoir Development and Operation Committee of Standard Oil Co. (New Jersey) Affiliated Companies, and of Humble Oil & Refining Co. The

nature of oil reservoirs themselves, of reservoir fluids and their distributions, and of flow of these fluids are outlined. The mechanics of fluid-flow through a porous medium may be divided broadly into two types: (1) homogeneous, or single-phase flow, and (2) heterogeneous, or multiphase flow. Homogeneous flow is the flow of a single fluid, and is illustrated by the flow of water through clean sand or by dead oil-flow. The mechanics and laws governing this type of flow may be summed up by the statement that the rate of fluid flow is directly proportional to the permeability of the sand and the pressure drop or gradient imposed, and inversely proportional to the viscosity of the fluid. The condition of homogeneous flow has only limited application, however, in the usual reservoir, since both the release of gas from solution in the reservoir due to decline of pressure as production proceeds, and the influx of either gas-cap gas or water into the oil-sand creates a heterogeneous (that is, two or more fluids) flow system. It is the latter type of flow, therefore, which largely governs oil recovery in most fields. Heterogeneous flow is briefly studied in general terms.

Since oil in itself has no inherent energy, it can be appreciated that recovery of oil from sand is a process involving displacement of the oil by either gas or water. There are three major mechanisms by which oil may be displaced: (1) With no free gas present and no water influx, simple release of pressure will cause gas to evolve from solution, and will result in expulsion of some of the oil and most of the gas from the sand, leaving a large amount of dead oil—that is, oil with no gas remaining in solution, in the sand. This recovery process is known as dissolved gas drive, and is the least efficient mechanism. (2) With a free gas-cap present, but no water influx, utilization of displacement action by the free gas expanding downwards will drive oil out of the sand-body. This process is known as gas-cap drive, and can yield very high oil recovery. (3) Displacement of oil by water rising from below, or water drive. This is usually the most efficient natural oil recovery mechanism. Action of gravitational forces, sometimes listed as a separate recovery mechanism, may have an important bearing on the relative efficiencies of the three drives. The influence of gravity is to favour both gravitational segregation of oil and the gas which has been released from solution, and the segregation of oil and water, and thus the maintenance of a reasonably sharp interface between the two fluids. Another phase of such segregation permits, under certain conditions, the gravity drainage of considerable quantities of oil to low points in a structure from which it may be recovered by pumping, even after exhaustion of the driving energy of gas.

In practice, probably all oil reservoirs are controlled by more than one type of these drives simultaneously.

A. H. N.

609.* Determining Probability of Success of Secondary-Recovery Operations. Part 10. W. B. Borwald, *Oil Wkly*, 17.1.44, 112 (7), 16. *Paper Presented before American Petroleum Institute.*—Secondary oil production today is governed almost entirely by economic factors. In the mind of the average petroleum engineer there is no question, from an engineering standpoint, as to the possibility of recovering additional oil from numerous oil reservoirs by the application of known secondary-recovery operations. The important question to the owner of all properties, as well as to the engineer, is whether secondary-recovery operations will be feasible and desirable from an economic standpoint. Numerous economic factors are involved in determining the feasibility and desirability of secondary oil production from an economic standpoint, and each one may, and usually does, affect individual owners or properties differently. Because of the wide variety of factors that must be considered, and the variable effect of individual factors in individual cases, only an over-all or general consideration of these factors is important industrially. Most economic factors affecting secondary recovery of oil also affect primary oil production and, to a large extent in the industry as a whole, secondary oil production may, and apparently does, depend on general economic conditions in the primary production of oil. Thus it becomes important in any general consideration of the economics of secondary recovery of oil to consider also many economic factors that ordinarily are considered only in relation to the primary production of oil.

As a basis for a general treatment of the economics of secondary recovery, consideration of individual factors has been grouped under two general sub-divisions: Preliminary Economic Study and Investigation, and Final Economic Analyses. Under these headings numerous factors that have some bearing on the economics of secondary oil

recovery are analysed in a general way, in an effort to present and describe the criteria that usually determine the economic feasibility and desirability of such operations. Few statistics are considered, except in a general way, and an effort is made to show in conclusion that in view of current economic conditions, there is an apparent lack of incentive to engage in secondary-oil-recovery operations, although many prospects might be considered economically feasible.

A. H. N.

610. Patents on Drilling and Production. J. E. Brantly. U.S.P. 2,334,746, 23.11.43. Appl. 12.11.40. Collapsible whipstock.

J. E. Brantly. U.S.P. 2,334,747, 23.11.43. Appl. 12.11.40. Vibrating head whipstock.

C. M. O'Leary. U.S.P. 2,334,788, 23.11.43. Appl. 12.8.40. Hydraulic bore-cleaner and cement shoe.

J. E. Gosline, W. R. Postlewaito, and W. G. Miller. U.S.P. 2,334,920, 23.11.43. Appl. 16.9.40. Method for testing wells.

J. E. Gasline, W. R. Postlewaito, and W. G. Miller. U.S.P. 2,334,921, 23.11.43. Appl. 16.9.40. Apparatus for testing wells.

J. Johnson. U.S.P. 2,334,931, 23.11.43. Appl. 17.3.41. Gun perforator and firing device therefor.

G. W. Miller and W. L. Kimsey. U.S.P. 2,334,943, 23.11.43. Appl. 1.3.41. Well-pumping device.

W. J. Opocensky. U.S.P. 2,334,950, 23.11.43. Appl. 27.4.42. Inclination indicating instrument.

A. A. Tauben. U.S.P. 2,334,964, 23.11.43. Appl. 17.6.42. Perforating gun.

W. St. Maur Elmore Crake. U.S.P. 2,334,992, 23.11.43. Appl. 8.10.40. Floating drilling barge.

F. A. Reed. U.S.P. 2,335,025, 23.11.43. Appl. 27.10.41. Oil-well packer.

T. F. Ford and A. G. Loomis. U.S.P. 2,335,146, 23.11.43. Appl. 20.6.39. Well-drilling fluid.

H. Allen. U.S.P. 2,337,221, 21.12.43. Appl. 7.11.38. Wellhead.

G. L. Adams and R. G. Barlow. U.S.P. 2,337,291, 21.12.43. Appl. 23.8.38. Apparatus for separating the constituents of petroleum emulsions.

H. T. Kennedy. U.S.P. 2,337,295, 21.12.43. Appl. 9.7.40. Treating oil- and gas-wells for improvement of production thereof.

H. T. Kennedy and A. J. Toplitz. U.S.P. 2,337,296, 21.12.43. Appl. 6.11.41. Drilling fluid.

L. E. Tomlinson. U.S.P. 2,337,429, 21.12.43. Appl. 29.3.41. Gravel packing-valve.

L. W. Blau. U.S.P. 2,337,442, 21.12.43. Appl. 19.8.40. Well logging.

J. J. Heigl. U.S.P. 2,337,465, 21.12.43. Appl. 26.10.40. Well logging by examining drilling mud for oil-show.

W. St. Maur Elmore Crake. U.S.P. 2,337,711, 28.12.43. Appl. 12.11.41. Screw joint for sucker-rods and the like.

C. C. Koeln. U.S.P. 2,337,720, 28.12.43. Appl. 15.3.43. Removable drilling bit.

E. Burns and F. C. Boyd. U.S.P. 2,337,733, 28.12.43. Appl. 22.10.40. Liner hanger.

M. O. Johnston. U.S.P. 2,337,752, 28.12.43. Appl. 16.12.40. Means of testing wells.

D. Erickson. U.S.P. 2,337,805, 28.12.43. Appl. 8.11.41. Pump-rod shield.

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- W. T. Caldwell. U.S.P. 2,338,093, 4.1.44. Appl. 28.6.41. Kelly rod and drive bushing thereof.
- A. D. Garrison. U.S.P. 2,338,174, 4.1.44. Appl. 1.7.39. Treatment of drilling mud.
- K. L. Vonder Aho and H. C. Zweifel. U.S.P. 2,338,217, 4.1.44. Appl. 14.12.40. Production of petroleum.
- L. H. Flett. U.S.P. 2,338,282, 4.1.44. Appl. 20.5.39. Method of treating wells.
- W. E. Rombert. U.S.P. 2,338,300, 4.1.44. Appl. 7.9.42. Well pump.
- N. C. Coates. U.S.P. 2,338,317, 4.1.44. Appl. 9.1.41. Portable derrick.
- G. Green. U.S.P. 2,338,326, 4.1.44. Appl. 18.3.40. Retractable pack-off device.
- G. F. Nicolson and R. K. Hertel. U.S.P. 2,338,349, Appl. 9.1.42. Drilling hook.
- A. J. Parrish. U.S.P. 2,338,351, 4.1.44. Appl. 3.8.40. Boring machine.
- O. W. Williams and L. E. Brown. U.S.P. 2,338,369, 4.1.44. Appl. 11.11.37. Well-tester.
- M. C. Wilson. U.S.P. 2,338,370, 4.1.44. Appl. 29.7.40. Cement retainer.
- K. A. Wright. U.S.P. 2,338,372, 4.1.44. Appl. 19.8.39. Method for conditioning well-bores.
- B. W. Sewell. U.S.P. 2,338,670, 4.1.44. Appl. 26.3.42. Retractable hard formation bit.

A. H. N.

Transport and Storage.

- 611.* Rate-of-Flow Chart Devised for Natural-Gas Pipe Lines.** G. W. Carpenter. *Oil Gas J.*, 23.12.43, **42** (33), 52.—A nomograph for solution of the orifice-meter equation, $Q = CV\sqrt{hP}$, with illustrative examples. C. G. G.

Crude Petroleum.

- 612.* World Production will Set Another Record this Year.** J. P. O'Donnell. *Oil Gas J.*, 27.1.44, **42** (38), 143.—It is estimated that the world's crude-oil production in 1943 was 2,248,405,000 bbl., an increase of 197,454,000 bbl. over the 1942 figure, and that the 1944 production will represent an increase of 10% on the 1943 figure. Major gains are expected in the U.S., Venezuela, U.S.S.R., Columbia, and Iran, while decreases are probable in Central Europe. It is expected that in future the proportion of the U.S.A. production to the world's production will decline to some degree. A table is given showing the estimated production in 1942 and 1943 in the major producing countries, and a graph showing the growth in the world's and the U.S.A. production since 1914. C. L. G.

Gas.

- 613.* Liquefied Petroleum Gas Demand Rises 19 Per Cent. Despite War Restrictions.** G. G. Oberfell. *Oil Gas J.*, 23.12.43, **42** (33), 16.—The marketed production of l.p.g. for fuel and miscellaneous purposes is estimated to have increased to 635 million gals. in 1943, an increase of 19% over 1942 figures.

Synthetic rubber and aviation gasoline production increased enormously, and absorbed greatly augmented quantities of butanes, but this offtake is excluded from the estimate given above, for security and other reasons.

Among industrial users there has been a considerable switch-over from butanes to propane, owing to the priority demands for butanes. Notable increases in propane consumption have occurred in the shipbuilding industry, where it is used for metal-cutting, heating of plates, pipes and rivets, for forging, etc.; also in the glass industry, for furnace heating. The quantities distributed as fuel gas by the public utility companies, and blended into motor fuel, have also increased.

The increased demand for l.p.g. has necessitated additional provision for production and transport. The steps taken to meet these needs are briefly described.

C. G. G.

Cracking.

614.* **Recent Developments in Thermofor Catalytic Cracking.** T. P. Simpson, L. P. Evans, C. V. Hornberg, and J. W. Payne. *Chem. Met. Engng.*, December 1943, 50 (12), 108-110. *Paper Presented before American Petroleum Institute.*—The "bead" catalyst is described. It is unique in shape, and is outstanding with respect to both physical ruggedness and catalytic activity. This catalyst derives its name from the fact that it is produced in the form of small spherical particles resembling translucent glass beads. The phenomenal ruggedness and resistance to attrition which this catalyst possesses can be demonstrated in many ways. An individual bead with a diameter of $\frac{1}{8}$ in. will support an average load of about 200 lb., and a mass of beads in a column will support a load of about 3000 lb./sq. in. before crushing. In a jet test, where the beads are carried in an air-stream at a velocity of 100 ft./sec. and impinged against a vertical steel plate, they show no breakage and only 3% wear after passing through 90,000 cycles.

Recent catalyst developments have made it possible to design reactors of high throughput capacity which require no baffle system for obtaining intimate contact between oil vapours and catalyst. The elimination of internal baffling increases the effective volume of the reaction zone, and permits wide flexibility with respect to space velocity. All the recent commercial T.C.C. reactors are of this improved type. As an added feature of flexibility, the reactors can be adapted to countercurrent or concurrent flow.

Catalyst feed in continuous-flow system is used. The kilns used are briefly described, together with the utilization of heat of regeneration.

The chief result of these improvements is the ability to use a wide variety of charging stocks other than gas-oils which are well suited for aviation production. Improvements in motor fuel, as distinct from aviation fuel, are also discussed.

Reviewing these various developments, it is evident that the T.C.C. process now offers the unique possibility of utilizing substantially all crude distillate fractions to produce high-octane aviation base stock and useful by-products, with little or no auxiliary processing other than fractionation. A. H. N.

615.* **Cracking Technology. Part 9. Reactions of Sulphur Compounds during Cracking.** C. R. Wagner. *Oil Gas J.*, 2.12.43, 42 (30), 69.—Sulphur compounds in cracking stocks vary with the cracking conditions and the nature of the sulphur compounds. Oil containing mercaptans and straight-chain sulphur compounds easily break down to give H_2S . Tables are given showing (1) the distribution of the sulphur in the products from pressure distillations at 95 p.s.i. with different charging stocks, and (2) the results obtained with an Illinois crude petroleum, containing 0.23% sulphur, processed in a modern combination high-pressure cracking plant. Comparing the results of (2) with (1), the loss to H_2S is greater in proportion to the sulphur content of the charge than was found at the low pressure and temperature. The percentage of the total sulphur appearing in the fuel is also very much higher, as would be expected from the more favourable conditions for polymerization. When stocks from certain crudes containing high percentages of thiophene-type sulphur compounds are cracked, the distillates have high sulphur contents and there is less tendency for sulphur to concentrate in the residual fuel oil. Nitrogen compounds in crude petroleum are complex, and under cracking conditions decompose to pyrrole derivatives and simpler nitrogen compounds. The author has observed crystals of ammonium salts and the odour of acetamide in connection with the Burton cracking stills. W. H. C.

616.* **Cracking Technology. Part 10. Today's Cracking Equipment in the Post-War Era.** C. R. Wagner. *Oil Gas J.*, 9.12.43, 42 (31), 64.—In the final paper of the series the author gives his views on the trends in post-war refining. He considers that aviation fuel will be made by catalytic cracking or alkylation or both processes. Motor fuels are considered from the viewpoint of types of hydrocarbon components in relation to engine performance. Processes for the manufacture are discussed. Large percentages of olefins in the lighter fractions of fuels improve performance, but if present over the whole of the boiling range give low lead susceptibility and poor performance. High percentages of *iso*-paraffins, naphthenes, and aromatics in the heavier half of a fuel give high anti-knock values and good lead susceptibility.

An ideal fuel should contain a light end, such as that obtained by low-pressure, high-temperature, thermal cracking, and a heavy fraction containing *iso*-paraffins, alkyl benzenes, and branched-chain naphthenes. The products from reforming, gas-reversion, polyforming or high-pressure, high-temperature gas-oil operations, when fractionated to 200–250° F., provide a fairly satisfactory light ends source. The heavy fractions can be produced by catalytic cracking and alkylation, and produce directly the desired constituents, although the light fractions in the product are less desirable than the light fractions from severe thermal cracking operations. In most straight-run gasolines more than 50% distills above 250° F., and this heavy portion is usually subjected to a reforming operation.

Reforming is practised to destroy *n*-paraffins, but other and more useful components are also attacked. One method of avoiding this, which would produce suitable components, and which is deemed worthy of wider study, is by the precise fractionation of the heavier fractions referred to, so that the *n*-paraffins from *n*-octane to *n*-dodecane are removed in cuts containing 50–70% of the paraffins. These could be subjected to reforming, the remainder of the gasoline, consisting of *iso*-paraffins, alkyl aromatics, and naphthenes, being excellent constituents for the gasoline heavy ends. The portion of cracked or reformed gasoline boiling from 250° to 400° F. (about 25% of the total) containing relatively large percentages of olefins is considered worthy of wide study to convert it into more satisfactory heavy ends of the gasoline. Methods of attacking this problem are discussed: Solvent extraction appears too expensive, but other ways of promise are: (1) dehydrogenation of the olefins, using a catalyst which would not attack the aromatics present, (2) cracking under high-pressure, high-temperature conditions with large quantities of recycled C3 and C4 gases, (3) by dehydrogenation of the olefins to alkyl-aromatics by a process such as the Phillips' cycloversion method.

W. H. C.

Polymerization and Alkylation.

617.* Barco Runs of Codimer Unit by Remote Control. Anon. *Oil Gas J.*, 9.12.43, 42 (31), 56.—A U.O.P. non-selective H_3PO_4 polymerization plant at the Barco Refinery, Wichita, Kans., formerly processing gases from a pressure distillate stabilizer, has been converted for selective codimer (*iso*-octane) operation. The charge gases from the pressure distillate stabilizer contain 36–41% olefins and 4–6% *iso*-paraffins, are compressed to 275 p.s.i. and passed to the polymerizing stabilizer operating with overhead held at 116° F. which removes the C₃ and lighter hydrocarbons, and the bottoms are stripped at 225–227° F. The bottoms are washed with very dilute caustic at 160–180° F., settled and heated to 275° F., and pumped at 500 p.s.i. through two catalyst chambers, in series. Cold C₄ streams from the overhead of the codimer stripper pumped to the middle of the catalyst chambers reduce any temperature rise due to the exothermic reaction and maintain the temperature of the codimer and unreacted C₄ fractions at 310° F. The stabilizer charge contains 50–51% olefins and up to 17% *iso*-paraffins, is passed, via a heat exchanger heated by the recycle gas-oil from the cracking unit, to the codimer stabilizer operated at 370–380° F., and is reduced to 4 p.s.i. vapour pressure. The vaporized light fractions pass up the tower, and the codimer is knocked back by the reflux drawn from the overhead accumulator. Quench oil is pumped from this accumulator to the quenching section of the catalyst chambers. Conversion of codimer averages 96% of the olefins charged, the octane value is 91. The sulphur content of the charge to the caustic washer is 0.35–0.3%. The plant is operated by remote control.

W. H. C.

Refining and Refinery Plant.

618.* Complex Heat Transfer Solved by Electrical Analogy. Anon. *Chem. Met. Engng.*, December 1943, 50 (12), 111.—The paper describes systems of electrical resistances and capacities which are used to solve complex heat-transfer problems by analogy. Briefly, the equipment consists of a source of direct-current power, a network of resistances and capacitances, and the necessary instruments for reading the results of the tests. The flow of electricity is comparable to the flow of heat; for example, electricity flows from a point of higher to a point of lower voltage, at a rate proportional to the voltage difference, while the flow of heat is from a point of higher

to a point of lower temperature, at a rate proportional to the temperature difference. The resistance of the flow-path to the flow of either heat or electricity depends on the character of the material of the path, and on the area and length of the path, so that the rate of flow depends both on these factors and on the driving force (potential or temperature drop) causing the flow. Finally, when the flow of either heat or electricity is not constant, net changes in the energy stores in the material of the path take place and the "capacity" of the material comes into play. Just as electricity is stored in quantity, depending on the potential, and the geometry and character of the material of the path, so heat is also stored in quantity, depending on the temperature, weight, and heat capacity of the material. The problem is put into a simple mathematical form to illustrate this picture of the processes. Examples are given of the multi-dimensional form of the problems encountered.

A. H. N.

619.* Socony-Vacuum Codimer Unit Built Almost Entirely from Used Materials. J. P. O'Donnell. *Oil Gas J.*, 2.12.43, **42** (30), 58-59.—Several petroleum companies, by the exchange of information and operating experiences, have facilitated the design of this plant. Preliminary studies completed, search was made for available material. After securing the equipment, design was started, and by ingenious adaptation or modification of the available material each part was made to fulfil a definite function in the system. From the beginning of erection to coming on stream the time taken was only six weeks. The plant is briefly described as consisting of: (1) Facilities for collecting butane from all debutanizers, (2) Butane depropanizer set, (3) Desulphurizing set, including caustic wash, water wash, coalescer, and regenerator, (4) Butane-butylene feed accumulator, (5) Catalyst reactor for 900 p.s.i. working pressure, (6) High-pressure pumps for feed, recycle, and quench, (7) High-pressure preheaters, (8) Codimer debutanizer set, (9) Gasoline repressuring system.

W. H. C.

620.* Predicting Flow-Friction Data for Sludges. J. D. Parent. *Chem. Met. Engng.*, January 1944, **51** (1), 101-103.—The author takes the Fanning equation for viscous flow, *i.e.*

$$f = \frac{16}{Re} = \frac{H}{L} \cdot \frac{gD}{2u^2}$$

and Poiseuille's equation

$$\frac{H}{L} = \frac{32\mu}{\rho g D^3}$$

and evaluates an apparent viscosity

$$\mu' = \frac{H}{L} \cdot \frac{\rho g D^3}{32u}$$

which he then uses to obtain a line on the friction factor chart for sludges identical with that of ordinary fluids. Further, μ' is also calculated by using the formula derived by Buckingham for ideal Bingham flow, and charts are given for design purposes. For the turbulent regime the work of Babbit and Caldwell is recommended.

A. H. N.

621.* Filtration in the Chemical Process Industries. Anon. *Chem. Met. Engng.*, January 1944, **51** (1), 117-124. A comprehensive report is presented by the editors of the *Chem. Met. Engng J.* on filtration. Since the main object in filtration is to secure a balance between speed of separation and quality of product, theoretical considerations usually begin by relating the liquor flow to filtering conditions. In simple form it is stated that the instantaneous rate of flow of liquor through a filtering medium is directly proportional to the pressure drop across the medium and inversely proportional to filtrate viscosity and resistance to flow offered by the medium, plus the cake which may have been built up. This relation can be expressed by a form of Poiseuille's equation as follows:

$$\frac{dV}{Ad\theta} = \frac{P}{\mu\alpha(\bar{W}/A + r)}$$

This equation is written on the basis that cake formation results in capillary flow of the filtrate. V is the volume of filtrate, θ the time, A the area of filtering surface, P

the total pressure drop across the filter medium and cake, μ the viscosity of the filtrate, α the average specific cake resistance, W the weight of dry cake solid, and r the resistance of a unit area of filter medium plus pressure drop in pipe-lines and other minor resistances. The average specific cake resistance, α , is a constant depending on the type and condition of slurry filtered, and is directly proportional to the total pressure P raised to the s power times another constant, α' , where s is the cake compressibility. This may be written as follows:—

$$\alpha = \alpha' P^s.$$

The exponent s may vary from 0 in the case of incompressible cake, to 1 for highly compressible cakes, but it is usually between 0.1 and 0.8 for slurries met in industrial filtration. The variables are discussed in some detail.

In selecting a filtering medium there must be balance between quality of filtrate and rate of filtration. On the one extreme is a fine-woven medium which gives a clear filtrate but tends to plug, while at the other extreme there is open fabric which allows rapid filtration but "bleeds" the finer particles. In the latter case the initial filtrate is frequently recycled until a cake has been formed which becomes the filter medium, the fabric acting only as a holder.

Details of a number of industrial filters, with particulars of their material of construction and operation, are given. A. H. N.

622. Economics of Combustion. E. L. Donniss. *Refiner*, January 1944, 23 (1), 23-31.—The paper deals at first with general principles of heat and fuel economics. A brief review of the physics and chemistry involved is then given, followed by a study of design principles.

The rate at which combustion takes place in a furnace is affected by many factors. In practice those that are most important are the intimacy or degree of complete mixture of the fuel and air upon entering the combustion space, and the temperature not only of the combustion space, but also of the flame propagated. When a homogeneous mixture of gas and air that contains exactly the correct amount of oxygen for complete combustion is ignited, the rate of ignition is maximum. The rate of ignition is retarded almost equally by a deficiency or an excess of oxygen carried in the air. The ultimate temperature of the products of combustion (flame) is likewise depressed by either excess air or deficiency in air. It is common in practice always to supply through burners excess air to be certain that oxidation or combustion will be complete and all energy released in the furnace. The amount of excess air required by a burner to assure this is a direct measure of the degree of mixing provided by the burner. Especially does this become important when high unit heat releases are desired. The important gas law pertaining to burner and furnace relationship is: "The volume a gas assumes is in direct proportion to the absolute pressure and inversely proportionate to the absolute temperature." As absolute furnace pressures encountered in industry are so nearly constant, the effect of pressure on volume may be disregarded. Therefore, when the reaction of combustion of a gas is speeded up, the temperature of the combustion gases will rise, as all the heat is liberated nearer the burner, and the combustion gases will expand closer to the burner, tending by expansion to spread over the furnace nearer to the front or burner wall, but this heat distribution can be governed. With increased combustion speeds it will be seen that much higher heat releases can be secured in a furnace than is possible where secondary combustion takes place.

Heat is transmitted by conduction, by convection, and by radiation. The laws governing each—particularly of radiation—are given.

Because one burner produces products of combustion at a higher temperature than another, it does not follow that wall or tube surface temperatures will be higher, nor that the amount of heat absorbed/unit area of tube surface will be increased over the maximum unit area absorption in the case of the lower-temperature flame. A burner that produces a lower-temperature flame does so for one or both of the following reasons: (a) Poor mixing of air and gas at the burner, resulting in air and gas strata entering the furnace and consequent delayed complete combustion. (b) Employment of excess air.

Design principles conclude the paper.

A. H. N.

623. Compressed Air Institute Urges More Complete Use of Compressor Auxiliaries. Anon. *Refiner*, January 1944, 23 (1), 32-34.—As a rule, practically every compressor requires an air receiver of ample size, and, in addition, most compressed-air plants should use after-coolers. An approved and efficient air-filter should always be installed in the suction, and, in addition to this, a great many protective instruments in the way of gauges, thermometers, relief valves, suitable drains, etc., should be installed when necessary. The air receiver not only absorbs pulsations in the discharge of the compressor, but also acts as a reservoir for the storage of compressed air, furnishing some reserve capacity to compensate for instantaneous demands in excess of the compressor capacity. It also acts as a condenser for some of the moisture present in the air or gas as it comes from the compressor, and to collect such condensation as may pass the after-cooler, keeping same from entering the distribution system. Receivers are also necessary to supply uniform pressure for governing instruments. If governors are connected to the discharge line, the pulsations therein will result in unstable operation.

There is almost always a chance of water and other vapours condensing in the line after compression. It is to force this precipitation by lowering the temperature of the air before it enters the discharge line that after-coolers are employed. They are installed near the compressor, to condense the moisture before it has a chance to enter the line, and should be installed with an automatic trap to dispose of the condensation as it occurs. After-coolers are of the shell-and-tube type, and depend for satisfactory performance on the use of the coldest water available. Obviously, unless the after-cooler is of liberal size, cooling will be incomplete, which means that the maximum amount of water will not be removed from the air. After-coolers also present an element of safety in every compressor plant. In case any carbon accumulating on the walls of the discharge pipe should become incandescent and start to burn (which condition might occur with careless operation, e.g., use of too much oil of inferior quality, and, in addition, leakage of valve and piston), the fire is promptly quenched as soon as it enters the after-cooler, and no harm occurs.

Other protective devices are further discussed in the paper.

A. H. N.

624. Maintaining Required Clearances in Centrifugal Pumps. E. Sterrett. *Refiner*, January 1944, 23 (1), 39-40.—The wear in a centrifugal pump which affects the output of the unit is not, except where the unit is handling a fluid in which there is considerable grit or abrasive, located in the impeller or runner, but instead occurs in the clearances between static and rotating portions of the design on the suction side of each stage. This clearance is between surfaces of greater diameter than obtained on the other side of the impeller, due to the fact that sufficient port aperture must be left around the shaft to permit the fluid from one stage to enter axially, and thus be boosted to the discharge pressure of the next stage. Except in a few designs, the clearance between that portion of the impeller which forms the outer wall of the suction tube and that of the adjoining portion of the pump-case is not itself a portion of the case, due to difficulty of manufacture and need for providing a surface of high abrasion resistance, whereas the characteristic most desired in the pump body is close-grained resistance against the pressures generated. A wear- or packing-ring, usually of the same material as the impellers, is fitted to a recess within the pump body, with clearance as designed between the inner face of this ring and the closure portion of the impeller body. Of relatively small section, this ring is subjected only to compression in its seat, and must offer only such clearance as is demanded by running characteristics of the pump, as added clearance at that point permits the recirculation of pressured fluid and accelerated wear between the closely placed metal faces.

Repair of wear by rebuilding is described with photographic illustration.

A. H. N.

625.* Practical Alignment Chart for Fluid Flow in Pipe-Lines. P. Meyer. *J. Inst. Petrol.*, February 1944, 30 (242), 52-56.—An alignment chart is given to solve the general equation for flow of oil and gas. $Q = 34.5 \frac{D^5 P}{\sqrt{GLF}}$, where Q = cu. ft./hr. flowing

fluid, D = actual pipe diameter in inches, P = pressure drop, lb./sq. in., between inlet and outlet, G = specific gravity or density of flowing fluid (water 1.0), L = length

of pipe-line in feet, F = the fanning friction factor. For gas the equation takes the specific form :—

$$Q = \text{Constant} \sqrt{\frac{D^5(P_1^2 - P_2^2)}{GTLF}}$$

where T is absolute temperature and Q is measured under specified standard conditions. A. H. N.

Chemistry and Physics of Petroleum.

626. Foreign Processes for the Conversion of Methane to Hydrogen and Carbon Monoxide. H. Heinemann. *Refiner*, January 1944, 23 (1), 35-36.—A summary of German methods is presented. In the presence of catalysts, the whole problem is greatly simplified, because temperatures for the reaction between methane and water are reduced to about 760° C. Russel and Hanks use at this temperature a catalyst consisting of alumina or oxides or rare earths impregnated with finely divided nickel or cobalt. The search for a suitable catalyst is concentrated on finding an active and physically stable mass of long life which is not easily poisoned by such by-products as are formed in the course of the reaction. One method of preparation is to impregnate an aluminous cement with nickel or cobalt nitrates and to calcine the mixture. The oxides are then reduced by means of hydrogen. The powder obtained is then mixed with black nickel oxide, formed into cubes, and heated to 1000° C. in a hydrogen atmosphere. Other catalysts proposed consist nearly always of nickel or cobalt associated with alkaline earths, or oxides of rare earths, the mixtures being calcined at temperatures below those at which the elements fuse. In a European industrial process the procedure is based on the decomposition of methane in the presence of oxygen and water. The first reaction delivers the heat necessary for the decomposition of methane. The methane, oxygen, and water are heated in a series of heat exchangers and passed over a catalyst consisting of activated nickel on a refractory support. Less than 1% of methane remains in the effluent.

Japanese practices and papers are briefly discussed. References up to 1941 are given. The work of Ogawa and his associates is given in slightly more detailed form than that of the others—the works of Tutumi, Coura and Huzdmura, Ogura and Nagai, and Lotteri are mentioned. A. H. N.

627. The Thermodynamics and Molecular Structure of Benzene and its Methyl Derivatives. K. S. Pitzer and D. W. Scott. *J. Amer. chem. Soc.*, 1943, 65, 803-829.—With the determination of the barriers to internal rotation as one of their main objects, the authors have carried out thermodynamic measurements on the three xylenes (and on benzene and toluene when the required information could not be found in the literature). The quantities measured were: the melting points and vapour pressures; the heats of fusion and vaporization; and the heat capacity of solid, liquid, and gas in appropriate ranges from 15° to 470° K. Evidence of the beginning of rotation of methyl groups is afforded by the appearance of a hump in the heat capacity curve for *m*-xylene near 50° K. and a more gradual one in the curve for *p*-xylene near 100° K.

The composition of the equilibrium mixture of the xylenes was determined by measurement of (i) the refractive index and (ii) the depression of the freezing point of pure *p*-xylene on addition of the unknown. The reaction 2 Toluene = Benzene + Xylene was also investigated, and the equilibrium constant found to lie between 0.15 and 0.22 at 323° K. Anhydrous aluminium bromide and hydrogen bromide was found to be a more effective catalyst in these reactions than the chlorides.

By considering the lines appearing in the infra-red and Raman spectra of liquid benzene in violation of the simple selection rules, the authors have assigned reasonable values to the twenty fundamental vibration frequencies. The spectra of the simpler deuterated benzenes were also considered.

A modification of the Teller-Rodlich product rule appropriate for methyl substitution was used to assign values for the fundamental vibration of toluene, all three xylenes and mesitylene. Some assignments are reasonably certain, other somewhat arbitrary.

Attention is directed to the striking behaviour of the 1000 cm^{-1} line in the Raman spectra of benzene derivatives which are substituted in only 1 : 3 : 5-positions. Corres-

ponding effects are observed when the trigonal positions are all similarly substituted. It is suggested that the Raman spectra might be used to determine the position of substituents in favourable cases.

Using the assigned frequencies, the vibrational entropy and heat-capacity contributions were calculated and the corresponding quantities for internal rotation of methyl groups obtained. The results indicated relatively free rotation of methyl groups in toluene, *m*- and *p*-xylene, but about a 2000-cal. potential barrier for *o*-xylene. These results are shown to be reasonable in terms of steric effect.

Based on these results calculations were made for the free energy function ($H^0 - F^0_T$)/ T , the heat content, and the heat capacity over the range 298–1500° K.

The equilibrium composition of the xylenes, and also of the benzene-toluene-xylene reaction, were calculated over the same range of temperature. The *meta*-compound was shown to have the lowest energy of the xylenes, and it is suggested that *meta* orientation of identical or similar groups may be generally the most stable.

C. F. M.

628. The Pressure-Volume-Temperature Relations of 2:2-Dimethylbutane. W. A. Felsing and G. M. Watson. *J. Amer. chem. Soc.*, 1943, **65**, 1889–1891.—The results of determinations of the specific volumes of 2:2-dimethylbutane at temperatures ranging from 100° to 275° C. and at pressures of from 10 to 300 atmospheres are presented tabularly and graphically.

C. F. M.

629. The Volume of Mixing and the Thermodynamic Functions of Benzene-Carbon Tetrachloride Mixture. S. E. Wood and J. P. Brusio. *J. Amer. chem. Soc.*, 1943, **65**, 1891–1895.—The increase in volume on mixing benzene and carbon tetrachloride at constant pressure has been measured from 15° to 75° C. The changes of the thermodynamic functions on mixing at constant volume have been calculated from the changes on mixing at constant pressure at 25, 40, and 70° C.

C. F. M.

630. Fluorine Derivatives of Acetophenone and Ethylbenzene. J. H. Simons and D. F. Herman. *J. Amer. chem. Soc.*, 1943, **65**, 2064–2066.—Two new modifications of fluorination technique are described. In the first a replacement reaction on an aliphatic chloride is accomplished using active silver fluoride in anhydrous hydrogen fluoride as solvent. The second replaces hydrogen atoms of an organic compound by solution of the latter in liquid hydrogen fluoride.

E. H. W.

631. Studies on Some *t*-Butyl Homologues of Naphthalene. F. C. Whitmore and W. H. James. *J. Amer. chem. Soc.*, 1943, **65**, 2088–2090.—The synthesis of mono-*t*-butyl naphthalene with 45% yield is described, and the product compared with the 2-*t*-butylnaphthalene reported by Bromby *et al.* (*J. Chem. Soc.*, 1943, 144.) The same reaction also gave di-*t*-butylnaphthalene (yield 41%). *t*-Butyl naphthalene was also prepared by dehydrogenation of *t*-butyltetralin and by the reaction between *iso*-butylene and naphthalene, but the yields were lower in each case. *t*-Butyl-naphthalene and bromine or phosphorus pentachloride gave halogenated products of undetermined structure. Oxidation of *t*-butyl-naphthalene gave 2-*t*-butyl-1:4-naphthoquinone. This paper reports the preliminary results of an investigation, unavoidably terminated, on the synthesis, halogenation, and oxidation of some *t*-butyl-homologues of naphthalene.

E. H. W.

632. Restricted Rotation in Aryl Olefins. VII. A New Synthesis of Hindered β -Substituted- β -Arylacrylic Acids. R. Adams and C. W. Theobald. *J. Amer. chem. Soc.*, 1943, **65**, 2208–2211.—Arylacrylic acids with restricted rotation and having various β -substituents may be prepared by addition reactions of di-ortho-substituted phenylpropionic acids.

E. H. W.

633. Magnetic Measurements on Some Catalytically Active Substances. H. M. Morris and P. W. Selwood. *J. Amer. chem. Soc.*, 1943, **65**, 2245–2252.—Magnetic susceptibility experiments over a range of temperature and field strength have been made on a series of nickel-activated copper hydrogenation catalysts, on nickel supported on

magnesia, and on a catalyst derived from ammonian nickel molybdate. The environment and behaviour of the nickel in these catalysts are discussed in view of the results. It was shown that hydrogen sulphide and carbon monoxide affected only a small fraction of the nickel atoms; apparently those on the surface of the active micro-crystals were poisoned.
E. H. W.

634. Hydrocarbons in the Gasoline Fraction of Seven Representative Crudes, Including all the Distillate to 102° C. and the Aromatics to 160° C. A. F. Forziato, C. B. Willingham, B. J. Mair, and F. D. Rossini. *Bur. Stand. J. Res. Wash.*, 1944, **32** (1), 11.—This paper is the second report of an investigation on the analysis of the gasoline fraction of representative crudes carried out by A.P.I. Research Project 6.

Samples were selected to cover the largest possible range in composition, and were drawn from Oklahoma, Texas, Pasadena, Michigan, and California. The seven samples were analysed by the methods of fractional adsorption and distillation described in the first report (*Proc. Amer. Petrol. Inst.*, 1942, **23** (3), 7).

It is concluded that: (1) the gasoline fraction of different crudes may be characterized by specifying the relative amounts of the five hydrocarbon classes: *n*-paraffins, *iso*-paraffins, alkyl cyclopentanes, alkyl cyclohexanes, aromatics; (2) the gasolines from different crudes are composed of the same hydrocarbons, the differences from one crude to another being essentially in the relative amounts of the foregoing five classes of hydrocarbons; (3) within each hydrocarbon class the individual hydrocarbons occur in approximately the same proportion in different naphthas; (4) it appears possible to predict the order of magnitude of the amounts of the individual hydrocarbons, paraffins, and naphthenes, 40–102° C., and aromatics to 160° C., in an appropriate fraction of a given naphtha when there are known the relative amounts of the foregoing five classes of hydrocarbons, or alternatively, for each class, the amount of one of the main components of that class.
C. G. G.

Analysis and Testing.

635. The Electron Tube. W. D. Cockrell. *Refiner*, January 1944, **23** (1), 14–18.—Every true electron tube is a rectifier—composed of at least two elements or electrodes enclosed in a vacuum envelope made either of glass or of metal. One of the two principal elements of each tube is called a “cathode.” The cathode is made of special materials, and is heated, usually by a small electric heater, to release electrons—those fundamental particles of negative electric current. If the other principal tube element, called “anode,” is connected to a power source so that it is positive with respect to the cathode, the anode will attract the electrons from the cathode. But if conditions are reversed, and the cathode is positive and the anode negative, no electron flow will take place, because the anode is so made that it will prevent the loss of electrons. Thus, we get the one-way valve action of rectification; the electron flow (or the negative current flow, if one likes to think of the normal current from positive to negative) can move in but one direction through the tube—viz., from cathode to anode.

As the stream of electrons is of infinitesimal mass, its control is relatively simple. The control element added to the electron tube for this purpose is called a “grid,” which is usually a spiral or grate of fine wires placed between the cathode and the anode. If the grid is held at a negative potential with respect to the cathode, it tends to repel the electrons passing by it on their way to the anode, thus cutting down the flow of current, or possibly preventing it altogether. So long as the grid is negative, it pushes the negative electrons away, and thus collects no electrons to itself. No electrons means no current, and no current—even with a large impressed voltage—means no power. Thus an economic control is effected.

The paper describes in simple terms the phototubes, high-vacuum tubes, gas-filled tubes, up to high-power ignitron.
A. H. N.

636.* Asphaltization Tests for Lubricating Oils. J. Faust. *Oil Gas J.*, 20.1.44, **42**, (37), 29.—During investigations on the oxidation characteristics of lubricating oils two types of oil have been observed: (1) nonasphaltizing oils—e.g., overhead distillates or certain Mid-continent oils which retain their fluidity but tend to form oil-

insoluble hard granular sludge; and (2) rapidly asphaltizing oils—*e.g.*, blends of bright stocks and neutral oils which exhibit a large increase in viscosity and tend to form an oil-soluble sludge. The mechanism of the oxidation process is the concomitant formation of the two types of sludge, the oil-soluble material formed from the bright stock which cements the hard, carbonaceous, oil-insoluble material from the neutral oil preventing its precipitation. This composite sludge is the primary cause of the asphaltization. The asphaltization test is carried out in the Indiana oxidation apparatus, modified only by the introduction of metals; the temperature of the apparatus and the flow of air passing through it are maintained at respectively 341° F. and 10 litres per hour. Cd-Ag alloy, as used in bearings, has been found to give the most accurate results. The effect of metals and various alloys, on a Pennsylvanian Motor oil S.A.E. 20 tested, is shown by the time in hours required for asphaltization: The sample (without metals present) 360; with: steel 350, copper 260, Cu-Pb 210, Cd-Ag 140, Cu + Cd-Ag 126, Cu-Pb + Cd-Ag 96. The most suitable method of following the reaction is by the increase on viscosity at definite intervals of time. The correlation of increase in viscosity of the oil and its asphaltization tendency is illustrated by a table:—

Time of test hours.	Saybolt viscosity at 80° F. of an S.A.E. 20 Pennsylvanian oil tested with Cd-Ag bearings. seconds.
24	565
48	675
72	1050
96	1900
120	4550
140	barely moving
168	solid.

A graph shows that the critical point at which the oil acquires a sudden extraordinary increase in viscosity occurs after about 120 hours. The oil at this point, while gel-like, still possesses some mobility; after 140 hours it is nearly gone, and then it changes to a semi-solid, plastic asphalt. The time at which the oil barely moves is recorded as the asphaltization time in hours, or the asphaltization index of the oil. The procedure for the test is given in detail, and discussion is made on the following: Factors influencing asphaltization of lubricating oils: (1) influence of initial viscosity; (2) effect of colour; (3) effect of refining methods. The term nonasphaltizing oils is described as a designation for oils found to withstand the operating conditions of the test for 400 hours. The period of 400 hours was adopted as the limit because subjecting the oil to longer periods of catalytic oxidation would deteriorate it beyond the point of any practical consideration. It has been established that it is the residual oil hydrocarbons which cause the formation of the cementing sludge leading to the asphaltization of lubricating oils.

W. H. C.

637.* **Standardization Committee.** Anon. *J. Inst. Petrol.*, February 1944, 30 (242), 25-51.—An extensive report by the various Sub-Committees on the work done during 1942-1943 is given. Trend of future work is indicated in each case. A. H. N.

638.* **Some Ideas About Correlation of Test-Engine Results.** T. P. Sands, C. J. Livingstone and W. A. Gruso. *J. Inst. Petrol.*, March 1944, 30 (243), 68-75. General principles of correlating tests with practice, the history of such correlation in petrol and lubricating oil testing and the methods adopted in wartime, with their possible inapplicability in peace time, are given. An interesting suggestion is made for adopting one engine in which all important factors can be made variable to wide degree, and testing oils for different uses by varying these factors rather than adopting very many different engines, each with limited but different factors operating.

A. H. N.

Gas, Diesel, and Fuel Oils.

639.* **Future for Diesel Engines.** A. L. Foster. *Oil Gas J.*, 9.12.43, 42 (31), 34.—The paper surveys the possible trends, both in diesel engine development and in refining, to meet the demands of both gasoline and diesel fuels in the future.

In general, the best stocks for thermal cracking stocks for high-octane fuels are also the most efficient diesel fuels, and in consequence of the enormous demands for the former, the diesel oil available is the recycle gas-oil from such cracking operations, which has deteriorated in diesel fuel qualities, especially the cetane value. The recycle gas-oils from catalytic cracking for aviation gasoline are superior to those from thermal cracking operations, in that they contain less olefins and more aromatics and have intermediate cetane values. The recycle gas-oils from a Houdry catalytic plant have a cetane value of 46, compared with 35 for the recycle gas-oil from a thermal operation. A method which has not received the consideration it merits is the employment of chemicals with low-cetane value diesel fuels to improve the ignition qualities.

A table is given showing the cetane number improvement affected by different additives.

Chemical	Cetane No. raw fuel	Increase by 0.5% wt. additive	Additive cost per gal. fuel
Amyl thionitrite	52	13-14	—
Ethyl thionitrite	52	13	—
Amyl nitrite	54	9.5	7.50 cents.
Amyl nitrate	56	9.0	—
Butyl nitrate	56	8.75	—
Sulphur (elementary)	50	7.5	0.07 cents.
Diamyl disulphide	50	7.5	—
Tetranitromethane	42	7	—
Diethyl disulphide	—	3.5	—

It is in the interest of diesel-engine manufacturers in co-operation with refiners to institute extensive research on methods for improving of diesel oils, so that the diesel cycle may retain for industry its inherent advantage of efficiency. W. H. C.

Lubricants and Lubrication.

640.* New Test Engine Shows Great Flexibility. A. L. Foster. *Oil Gas J.*, 23.12.43, 42 (33), 39.—A new test engine designed by the research laboratories of the Gulf Oil Corporation, primarily for the testing of lubricants, consists of a two-cylinder 90°-V unit with a single-throw crankshaft, so designed that mechanical hold-up of oil in the crankcase and sump is reduced to a minimum. Recovery of the used lubricant is virtually complete, and the sump is quickly detachable for cleaning and inspection.

Either C.I. or spark-ignition cylinder units may be used on the crankcase assembly. Oil from the cylinder walls may be collected separately from the sump oil, and there is provision for the collection of piston and valve-stem blow-by samples. Cylinder jackets and manifolds are provided for the control of atmospheric temperature, humidity, etc., so that flying conditions may be simulated.

In operating the engine, speeds of 4000 r.p.m. are attainable. The set-up may be used as a single-cylinder unit, the counterbalancing being such that the use of permanent dummy pistons is avoided. Operating as a single-cylinder unit, speeds of 2500 r.p.m. are practicable. Using standard Chevrolet or Plymouth parts, the h.p. developed is 27-30.

It is considered that the engine shows sufficient flexibility to form the basis for a standard unit for lubricating oil testing. C. G. G.

641.* Questions on Technology. Lubricating Oil Classification Systems. W. L. Nelson. *Oil Gas J.*, 20.1.44, 42 (37), 53.—Only two numbering systems for lubricating oils are widely used—*i.e.*, the Society of Automotive Engineers (S.A.E.) viscosity-number system, and the Bureau of Ships number system. The advantage of the S.A.E. system, is its extreme simplicity. It is based on viscosity, but involves viscosity in some degree because viscosities are given at two temperatures. The Bureau of Ships classification, N.B.S. 431, entitled "Lubricating Oils," consists of a series of numbers of four digits each, and a tabulation of complete specifications for all the oils that have been assigned numbers. The first digit shows the kind of oil, and the last three digits are used to show the numerical value of the viscosity at a temperature specified according to the type of oil under examination. The significance of the

specification can be illustrated by comparison of the Bureau of Ships oils with the corresponding S.A.E. oils:—

S.A.E.	Bureau of Ships.
10W	1042
10	2110
20W	1047
20	3050 or 9170
30	3065 or 9250
40	3380 or 9370
50	3100
60	3120 or 1120
70	1150

W. H. C.

642. Practical Examination of Lubricating Greases. Part I. Analysis. M. W. Wobber. *Petroleum*, February 1944, 7 (2), 18–20.—The only standard method of analysis of grease at present available for reference is A.S.T.M. Designation D128–40. Up to the present the I.P. has only published standard methods for individual tests. Certain of the standard methods of analysis and testing are critically reviewed.

Suggestions are offered to fill the need for quicker and simpler methods of examination, than those provided by the standard methods, and suitable for routine examination and works control.

Much useful information in regard to presence and nature of fillers, impurities, and additives, if such are present, and also in regard to the type of oil and of fatty material used, can be obtained by a trained observer from visual examination, sense of touch, and odour. Observation of the ash and of the effect produced by dropping a little of the grease into boiling water will often give an indicating of the soap base used.

For the rapid examination of light-coloured greases, except those of aluminium or other weak base, a method based on direct extraction in a Soxhlet or Stevens apparatus, preferably using acetone as solvent, is proposed. Procedure for extraction, which takes about 3 hours for limo-base and 6 hours for soda-base greases, and special precautions to be observed are described. The residue in the thimble is used for the determination of soap content, and may be further extracted with a mixture of toluene and butyl alcohol if fillers are present, or if further examination of the soap is required.

The acetone extract is used for determination of free fatty acid, neutral fat, and mineral oil plus unsaponifiable content, and for examination of the oil. If extraction of soap is suspected, a reasonably accurate correction may be applied from determination of the ash content of part of the extract.

Suggestions are also offered for the rapid examination of fillers, extreme pressure additives, colloidal graphite, rubber and latex addition, glycerine content and impurities, if such are present in the grease under examination.

R. A. E.

Special Products.

643.* Two Shell-Developed Processes Aid in the Production of Toluene. J. P. O'Donnell. *Oil Gas J.*, 16.12.43, 42 (32), 43.—At the outbreak of war, the U.S.A. were dependent on the coal-tar industry for their entire production of toluene—some 20 million gals. annually. It was estimated that demands would rise to more than 100 million gals. These demands have been met by resorting to petroleum as a source material.

The production of toluene from petroleum has been effected by isolation of such toluene as exists in crudes, together with that produced by synthetic operations on suitable fractions. Two processes have been developed by the Shell Development Co. and put into operation by the Shell Oil Co., Inc.

The first process consists in a hydroforming treatment of a suitable fraction to yield a product of 40–60% aromatics, of which at least 15–20% is toluene. The product is then treated by the Shell "extractive distillation" process to yield nitration grade toluene.

The second process consists in the isomerization of a fraction which yields a product of boiling range 200–250° F., rich in methyl cyclohexane. Catalytic dehydrogenation of this product is followed by extractive distillation of the toluene produced. The

dehydrogenation is carried out under non-cracking conditions, and the catalyst remains active for months.

By combining synthetic and extraction operations, the Shell Oil Co. is now producing far more toluene than the entire coal-tar industry. C. G. G.

644.* Halogenated Hydroxydiphenyl Methanes as Disinfectants. A. R. Cade. *Soap*, Feb. 1944, 20 (2), 111.—The alkali salts of 2 : 2'-dihydroxy-5 : 5'-dichlorodiphenyl methane (known as G.4) or of 2 : 2'-dihydroxy-3 : 5 : 6 : 3' : 5' : 6'-hexachlorodiphenyl methane (known as G.11) have been found the most effective disinfectants from a wide range of compounds of this type. G.4 and G.11 are colourless solids of melting point 176° and 164° C., respectively, practically odourless, poorly soluble in water and mineral oils, but readily soluble in alcohols, ketones, many fatty acids, and esters. The sodium salts are soluble and possess high germicidal powers (phenol coefficients over 100). G.11 is more active against the gram-positive types of organism (e.g., *Staphylococcus aureus*) and G.4 against the gram negative type (e.g., *Eberthella typhi*). G.4 is relatively non-toxic and, for most people, non-irritant to the skin, and should be of value in household disinfectants. C. L. G.

645. Pyrethrum Aerosol. Anon. *Soap*, Feb. 1944, 20 (2), 115.—A short summary is given of an article by H. A. Z. Monro in the *Annual Report of the Entomological Society of Ontario*, describing the results of tests on a pyrethrum aerosol containing 1% pyrethrins and 2% sesame oil in dichlorodifluoromethane. At a dosage of 2-12 oz. per 1000 cu. ft. the aerosol controls flying Indian meal moths, but not the different stages of the insect when penetration of web, grain, etc., is required. At the rate of 1 lb. per 4000 cu. ft. the aerosol is highly effective against the German cockroach in heavily infested rooms. C. L. G.

646. Activated Pyrethrum Mosquito Spray. A. R. McGouran and J. H. Fales. *Soap*, Feb. 1944, 20 (2), 117.—Tests have been carried out in a Peet Grady chamber on *Aedes Aegypti* using 6 c.c. of a solution of pyrethrins in kerosine containing as activators sesame oil and isobutyl undecylencamide. It was found that *Aedes Aegypti* is less resistant to pyrethrum than the house-fly, but that activators are less effective. A solution containing 0.033 mgm./ml. pyrethrins gives a kill of 54%, the addition of 0.19 mgm. of isobutylundecylencamide and of 3.0 mgm. sesame oil respectively increasing the kill to 62% and 76%. The dosage used is equivalent to one U.S. fluid oz. per 1000 cu. ft. C. L. G.

647. Pyrethrum Synergists. W. A. Gersdarrf and S. I. Gertler. *Soap*, Feb. 1944, 20 (2), 123.—Tests have been carried out on house-flies with solutions in kerosine of 0.5 mgm./m. litre of pyrethrins containing as activators various N-substituted piperonylamides and benzamides. The most effective activator was NN-diethyl piperonylamide, 1.6 mgm./m. litre increasing the kill from 18% to 50% and giving 100% knock-down. A solution of 2 mgm./m. litre of this compound and 0.5 mgm. pyrethrins is equivalent to a solution containing 2 mgm. pyrethrins. C. L. G.

648.* Properties and Utilization of Petroleum Waxes. C. G. Gray. *J. Inst. Petrol.*, March 1944, 30 (243), 57-67.—The waxy materials derived from petroleum are classified into three main groups: (1) the paraffin-wax group; (2) the petrolatum group; and (3) the petroleum resin group. This classification is based mainly on crystal size, consistency, and method of manufacture. Each group is treated separately. The properties required in the manufacture of candles, nightlights, tapers, waxed paper, and polish materials are given in some detail and other uses are briefly treated. A. H. N.

649. Solvents for Dry Cleaning. Properties of the Chlorinated Hydrocarbons. O. C. Cossna. *Chem. Tr. J.*, 31.3.44, 114, 331-333 (*Canad. Chem. and Process Ind.*, January 1944).—In the early days of dry cleaning with benzene, benzole, or solvent naphtha (1910-1920) little attempt was made to recover the solvent, but between 1920 and 1930 special products such as Stoddard solvent were brought out, and it became general

practice to purify the solvent by filtration with vacuum distillation or treatment with activated charcoal and caustic soda, thus improving the quality of the work. In 1930 the non-flammable chlorinated hydrocarbon solvents were introduced, their expensive nature requiring complete recovery equipment, and their corrosive properties the use of special equipment.

Methods now in use for solvent recovery from air include adsorption methods using activated carbon, mainly for the larger units and condensation over water-cooled coils, chiefly for the smaller units. The dirty solvent is recovered by filtration through metal screens or cloth bags, using filter aid and distillation.

The solvents generally used include carbon tetrachloride, perchlorethylene, and trichloroethylene, while ethylene dichloride, methylene chloride, and chloroform are used mixed with other solvents, owing to their attack on cellulose acetate fabrics. In decreasing order of grease removal, the solvents rank as follows: trichloroethylene, carbon tetrachloride, perchlorethylene, chloroform, and methylene chloride. All wet the fabrics well and suspend insoluble impurities, except with moist cotton goods and in the presence of static electricity. The solvents may undergo thermal decomposition, the unsaturated compounds oxidation, particularly in light and at increased temperature, with the formation of acids and the saturated compounds hydrolysis, particularly in the presence of metals and at higher temperatures. In the absence of moisture and light, carbon tetrachloride is stable to 1100° F., perchlorethylene to 290° F., trichloroethylene to 250° F., ethylene dichloride to 275° F., and chloroform to 250° F. and methylene chloride to 300° F.

C. L. G.

650. Ethylene in Wheat Storage. Anon. *Chem. Tr. J.*, 31.3.44, 114, 345.—The U.S.A. Department of Agriculture and the Department of Milling Industry at Kansas State College report that the bin burning of moist wheat in storage can be retarded by blowing ethylene, at a concentration of 1 part in 10,000 of air, into the bin. In tests the temperature of the wheat remained below 103° F., untreated wheat rising to 110° F., resulting in considerable damage. Ethylene also hastens the ageing process through which wheat must go before a satisfactory baking flour can be produced. It improves the volume, texture, and colour of the bread. Similar experiments are being carried out on corn.

C. L. G.

Detonation and Engines.

651. Diesel Engines Underground. (V.) Effect of Sulphur Content of Fuel on Composition of Exhaust Gas. L. B. Berger, M. A. Elliott, J. C. Holtz and H. H. Schrenk. U.S. Bur. Mines. Report of Investigations No. 3713, June 1943.—In previous studies of exhaust gases in this series, fuels used were in general conformity with specifications recommended by diesel-engine manufacturers. Toxic or objectionable gases determined were carbon monoxide, carbon dioxide, oxides of nitrogen, and aldehydes. Sulphur dioxide and sulphur trioxide were not determined. This report embodies results of tests carried out on a high-sulphur fuel (2.4%) to determine the effect on exhaust-gas composition on operation with a fuel of this type.

It is established that the ratio of sulphur dioxide to sulphur trioxide in the exhaust gas varies at different operating conditions, and that high temperature during combustion favours the formation of sulphur dioxide and the dissociation of sulphur trioxide. Practically all the sulphur in the fuel on passing through the engine appears as sulphur dioxide or trioxide in the exhaust gas.

Test results are correlated with similar data obtained on a fuel of low sulphur content, and are assessed in connection with the use of diesel engines in underground working places. It is concluded that the sulphur content of diesel fuels in such circumstances should be limited to 0.3–0.4%. A greater percentage of sulphur in the fuel would imply the need for ventilation in excess of that required to dilute to permissible limits the other toxic or objectionable constituents of the exhaust.

H. B. M.

652. Intake Systems for Aircraft Engines. C. T. Doman. *J. Soc. Aut. Engrs*, 1943, 51 (9), 335–343.—The effect of modifications on aircraft engine intake systems is illustrated by experiments on a small air-cooled in-line horizontally opposed 4½ in. × 3½ in. engine with overhead valves.

The engine was designed to allow for an eventual increase in cylinder bore, and the

valve sizes were varied to obtain the maximum permissible inlet valve size without choking the exhaust valve opening or weakening the bridge metal between the two valves.

Experiments showed that no increase in power resulted from increases in exhaust valve size up to $\frac{1}{4}$ in., and no decrease occurred with a smaller valve size. An increase in inlet valve size showed an increase in power. This, however, caused a weakening of the bridge metal between the guides.

During tests, an alteration in the inlet port design which caused a restriction in flow of the inlet gases was found to cut down the power output by 10% per cylinder. This was due to the addition of metal for strengthening the bridge section just inside the valve openings. The writer makes the suggestion that inlet port design is probably one of the most critical factors in its effect on power outputs.

The article also deals with some problems of valve lifter design, and in particular that of valve-spring design. The chief points are the reduction of the heat flow to the valve-spring by good location of parts and the use of a spring metal that will not "tire" with prolonged high temperature or life.

In dealing with camshaft design, mention is made of the false motion given to the valve-lifters by lack of sufficient camshaft stiffness. It is suggested that the maximum permissible diameter camshaft with a large centre hole for lightness would give improved results.

The position of the carburettor and intake pipes is discussed at length. The position of the carburettor as cast integral with the oil-pan gave good induction heating, and also acted as an oil cooler. The use of long individual distribution pipes gave good supercharging effect. The article shows how a system with either one or two carburettors in any position could be operated very satisfactorily up to 3000 revolutions per minute by a runner-type manifold acting as a balance pipe, comparable to a ring-main system. This system gave decreased power at low speeds, but was advantageous above 2700 revolutions per minute. The mixture distribution, however, in this system showed greater variation than normally obtains, and the system was unstable in cold temperature operation.

The article concludes with some observations on multi-cylinder distribution, from which it appears that the runner-type manifold does not give such satisfactory results as might be expected. The same system with dual carburettors and individual distribution pipes gave a 4% increase in power output. Also with regard to the firing order of cylinders it was found that new firing orders to give smoother running could be used, without loss of power, if a balanced manifold system was used. It is felt that further useful work could be done in this field of exploration.

C. J. B.

Coal and Shale.

653.* The Science of Coal to Oil Conversion. I. General Considerations. W. D. Spencer. *Petroleum*, February 1944, 7 (2), 25-28.—Reference is made to the small production of home-produced hydrocarbon oils in relation to imports into U.K., to synthetic oil developments in Germany, and to the recent decision of the U.S. to sponsor experimental work on the production of oil from coal.

The compositions of some typical solid fuels and of typical petroleum products are shown, and the general principles involved in conversion of coal to oil outlined.

As regards low-temperature carbonization, the effects of coal composition and process temperature on yields are discussed, and methods of calculating the assay tar yield from the analysis of the coal presented.

An outline is given of the theory and operation of the hydrogenation process as applied to coal, and the effects of the source of hydrogen on the oil yield per ton of coal and thermal efficiency of the process are discussed.

An outline is also given of the Fischer-Tropsch process, together with general information on the effects of variation of temperature, pressure, gas composition, and catalyst on the properties of the oil produced. A summary shows the oil-yields per ton of coal obtainable by the three processes, together with an indication of the range of suitable coals for each process. This table includes a combination Carbonization-Fischer Tropsch process, and shows variations in yields with source of hydrogen where applicable.

R. A. E.

654. Complete Coal Gasification. Progress by Gas Research Board. Anon. *Chem. Tr. J.*, 31.3.44, 114, 336.—In an address to the Southern Association of Gas Engineers, E. V. Evans outlined the work of the Gas Research Board on the total conversion of coal into gas. Of several processes investigated in the laboratory, two have been selected for further developments.

The first is the carbonization of coal in hydrogen with the production of methane and utilizing the heat of reaction for the carbonization step, which is stopped when half the charge has disappeared, so that the residue can be gasified in steam and oxygen to provide the hydrogen. The caking of coal presents one difficulty, as it passes through a plastic stage, but a yield of primary tar is given which is suitable for conversion into motor spirit, etc., by the hydrogen produced in the process. The second process involves the gasification of coal in steam and oxygen, and the subsequent enrichment of the gas by methane produced catalytically from carbon monoxide and hydrogen. Caking difficulties are likely to be less troublesome in this process, but deterioration of the catalyst is a problem.

It is hoped that if the coal can be completely converted into gaseous and liquid products, much of the present handling and transport of coal could be replaced by long-distance transmission of gas under pressure, the use of which would lead to the disappearance of atmospheric pollution.

C. L. G.

BOOK REVIEW.

The Chemical Background for Engine Research. *Frontiers in Chemistry.* Vol. II, 1943. Editors, R. E. Burk and Oliver Grummitt. Interscience Publishers, Inc., 215, Fourth Avenue, New York.

This book is the second volume of *Frontiers in Chemistry*, and is based on a series of twelve lectures at Western Reserve University by E. F. Fiock, F. D. Rossini, F. C. Whitmore, G. Von Elbe, Bernard Lewis, and O. Beeck.

The first five authors deal with hydrocarbons and their combustion in engines, and the last named with lubrication. The book is edited by R. E. Burk and Oliver Grummitt.

Fiock, of the National Bureau of Standards, gives a survey of combustion research and, after an historical survey, describes more recent work on stationary and explosion flames. In the historical survey, Robert Boyle is credited with work on flame and combustion in 1630, when he was less than 5 years old, and Hooke, who was one of the brilliant contemporaries of Boyle, and was employed by him, is described as one of his pupils. The explosion-flame section is illustrated with high-speed photographs of explosion in soap bubbles and in closed and open tubes. Later Fiock deals with flame in engine cylinders summarizing the work of Boyd of General Motors Corporation and of the National Advisory Committee for Aeronautics. This section is particularly valuable, and also deals briefly with combustion in compression ignition engines. In conclusion he points out that not a great deal is actually known of the highly complex mechanism by which chemical energy, latent in the combustible mixtures, is transformed into usable mechanical energy. He also points out that there are a number of important problems awaiting solution, and puts the question, can materials be found which will absorb or prevent the omission of a portion of the radiation which represents a large part of the heat loss, and thus retain more energy for useful work?

Rossini, in a section on the "Chemical Thermodynamics of Hydrocarbons," describes the evaluation of entropies and heat of formation and of free energies of formation. The best values for heats and free energies of formation for a number of important hydrocarbons are given.

F. C. Whitmore gives a review of the various methods used in the synthesis of hydrocarbons, together with a brief account of industrial hydrocarbon synthesis.

G. Von Elbe and Bernard Lewis, in two separate sections, describe the kinetics of flame and combustion, and the experimental side of combustion research in engines.

In the former section an account is given of the application of the chain-reaction theory to slow and rapid combustion of simple fuel gases such as hydrogen and carbon monoxide, and he points out the difficulty of the subject when applied to chemically complex fuels, such as paraffin hydrocarbons. One of his conclusions is the factual basis on which to build a complete kinetic treatment appears to be still too meagre. Lewis describes the quartz-covered combustion chamber, designed by General Motors Research Corporation, together with the work of Lewis and Von Elbe using their pressure indicator. In this section an account is also given of the spectroscopic investigation of combustion in engines, and of combustion under knocking conditions, including lead susceptibility. A proposed rational method of rating fuels based on the determination of fuels and engine characteristics separately, is discussed, but again it is pointed out that a number of other variables require investigation before this method can be considered in practice.

In the last chapter, O. Beek gives an account of "Some Physicochemical Aspects of Lubrication," but the work described is primarily limited to the work of one laboratory only, so this article does not present the broader view-point given in the other articles. A general discussion, however, is given on such subjects as ring-sticking and the cause of engine deposits, including detergency, and on boundary lubrication. Much of the work described, however, has not appeared before, or has not been presented together, and the whole range of mechanical tests of lubricants is discussed. Beek points out that the lectures were based on a series of laboratory experiments intended to contribute to an understanding of the many complex factors in engine lubrication. In such a short article it is naturally not possible to present a complete survey and, in general, laboratory tests are described with incidental reference only to the correlation of the results of laboratory tests with full scale practice.

"The Chemical Background for Engine Research" is a most timely publication, and should stimulate the formulation of research programmes into this frontier of research on combustion in engines which has such potentialities in the direction of greater overall efficiency in the utilisation of fuels. F. H. GARNER.

BOOKS RECEIVED.

- B.S.S. No. 430 : 1944. Solid Drawn Steel Air Receivers.** Pp. 9. British Standards Institution, 28, Victoria Street, London, S.W.1. Price 2s. net.
- B.S.S. No. 1157 : 1944. Tapping Drill Sizes.** Pp. 28. British Standards Institution, 28, Victoria Street, London, S.W.1. Price 2s. net.
- Analysis of Oil Production in near-depleted Mexia-Powell Fault-Line Fields of Texas.** H. B. Hill and R. K. Guthrie. U.S. Bureau of Mines Report of Investigations No. 3712. Pp. 83.
- Survey of Subsurface Brine-Disposal Systems in Western Kansas Oil Fields.** U.S. Bureau of Mines Report of Investigations No. 3719, August 1943. Pp. 20.



INSTITUTE NOTES.

MAY, 1944.

NEW MEMBERS.

The following elections have been made by the Council in accordance with the By-Laws, Sect. IV, para. 7.

Elections are subject to confirmation in accordance with the By-Laws, Sect. IV, Paras. 9 and 10.

Transferred to Fellow.

JENKIN, James Edmund E.

As Members.

BREWER, Charles D.	KEMPTON, William J. H.
COLLINS, Charles H.	SANDERS, Harold W. F.
JOHNSON, Christopher H.	SELLERS, Ernest S.
JOHNSON, Wilfred	STURGESS, Herbert L.

Transferred to Members.

ALLCARD, Harry G.	McKEE, John L.
JACKSON, George G.	NEWTON, Ernest J.
JEWELL, John C.	KIERNAN, Herbert S.

As Associate Members.

COOPER, David W.	MURRAY, George
EVANS, Ifor Wyn	RAIT, Frank P.
JENKINS, Colin Rees	SHELBRooke, George E.
KENYON, Arthur J. F.	TAYLOR, Alec.
McNAMARA, Francis T.	THOMAS, David W.

Transferred to Associate Member.

WAELE, J. P. A. de

As Students.

McGRATH, Leonard.	STERN, Hans K.
SEDLEY, Walter T.	

APPLICATIONS FOR MEMBERSHIP.

The following have applied for admission to the Institute. In accordance with the By-Laws, the proposals will not be considered until the lapse of at least one month after the publication of this *Journal*, during which time any Fellow, Member, or Associate Member may communicate by letter to the Secretary, for the confidential information of the Council, any particulars he may possess respecting the qualifications or suitability of the candidate.

The object of this information is to assist the Council in grading the candidate according to the class of membership.

The names of candidates' proposers and seconders are given in parentheses.

Membership.

- EVANS, Vincent, Process Superintendent, National Oil Refineries, Ltd.
(*R. B. Southall ; E. Thornton.*)
- HARRISON, Dennis Murland, Administrative Officer, Shell-Mex and B.P., Ltd.
(*A. E. Hope ; H. W. Clark.*)
- PEACE, George, Group Officer, Indian Army Ordnance Corps Laboratories.
(*C. O. Tattersall ; J. L. McKee.*)
- SNOW, Sydney Frederick, Company Director, Messrs. Gaunt & Hickman, Ltd.
(*Percy H. Snow ; William Blackwell.*)

PARLIAMENTARY AND SCIENTIFIC COMMITTEE REPORT ON SCIENTIFIC RESEARCH AND THE UNIVERSITIES.

SUMMARY OF PROPOSALS.

1. If Britain is to maintain her position in the post-war world and carry out her plans for reconstruction and social betterment, scientific research and the application of scientific knowledge should be promoted on a far bolder and more imaginative scale than in 1919-39. This applies equally to fundamental, industrial, agricultural, veterinary, medical, and other allied research.
2. There should accordingly be proportional expansion of the supply of scientific personnel.
3. This in turn calls for expansion at the universities, and technical colleges, and an all-round improvement in the teaching of science and scientific principles at all stages of education for the whole school population of the country.
4. As a first step there should be an effective organisation of the demobilisation of the large number of scientific people now on war work or in the Services to enable them to complete their training and to guide them into positions where their previous training and their war experience will be of special value. It is hoped that this will be adequately covered by the Committees under Lord Hankey, but the maximum assistance will be required from Government and private enterprise.
5. The universities should prepare for a rapid growth in the number of students of science and technology. This will call for an expansion of existing universities, and possibly the development of some existing establishments into new universities.
6. State Bursaries and Engineering Cadetships should be continued after the war is over and developed to cover sciences not hitherto included, and the recommendations of the Norwood Committee on this point generously implemented.

7. Materials and finance should be made available for the expansion of research schools in the universities. The number and value and scope of the post-graduate grants awarded by the D.S.I.R. also need to be considerably increased; more post-doctoral fellowships are also required.

8. University staffs, stipends and buildings should all be increased. A capital sum of £10,000,000 will be required for buildings and equipment spread over the first five post-war years, as well as adequate priority for the work and materials involved.

9. The present annual Treasury grant to the universities of approximately £2½ millions p.a. should be increased to £6 or £7 millions p.a.

10. The freedom, independence and diversity of the universities should not be prejudiced in any circumstances, but to ensure the best use of the increased funds, and to avoid wasteful overlapping, they should set up a suitable Universities' Advisory Council.

11. The recent assurance of the Government that they recognise the need for increasing the provision for technical education is most welcome and it is hoped that this proposal for a revision and expansion of the £12,000,000 scheme of development mooted before the war will be put into effect without delay. The provision of adequate facilities for part-time technical study and training should also be increased.

12. There is a need for greater assistance to promising young people already engaged in industry to enable them to take full or part-time courses.

13. Courses in "laboratory arts" should be instituted in order that there shall be an adequate supply of properly trained laboratory technicians, and young people should be encouraged by the provision of grants to enrol in such courses. The status and remuneration of laboratory technicians require improvement.

14. The supply and training of technical teachers requires urgent investigation.

15. There should be a considerable increase in the Parliamentary Grants-in-Aid to the Royal Society for Scientific Investigations and Publications.

October, 1943.

ARTHUR W. EASTLAKE,
ASHLEY CARTER,
Joint Honorary Secretaries.

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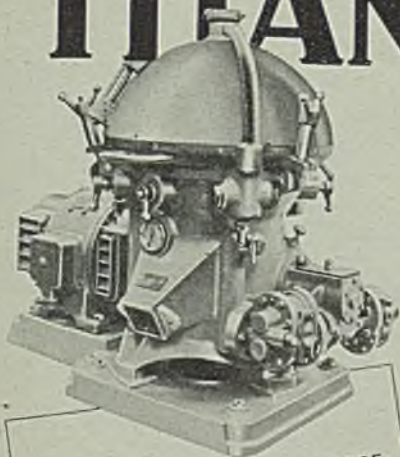
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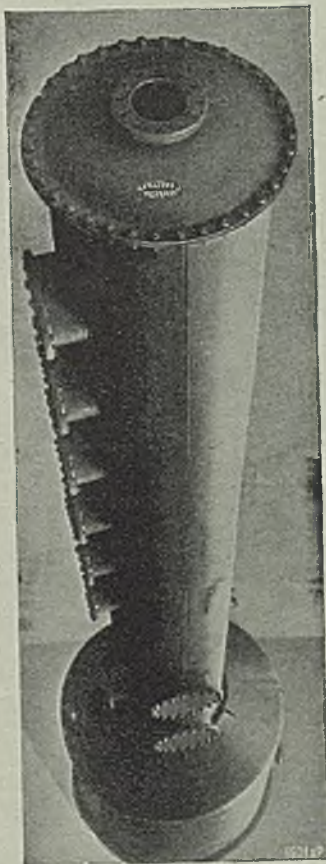
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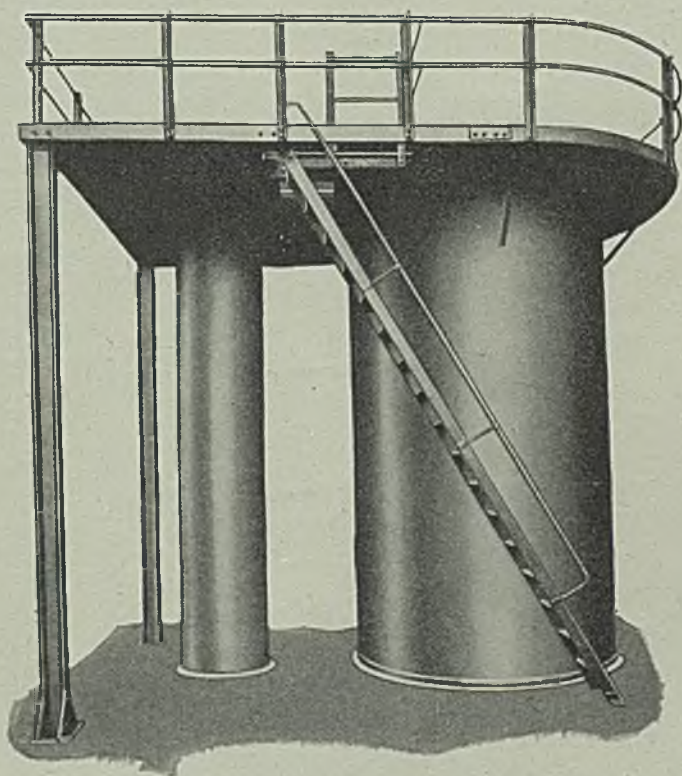


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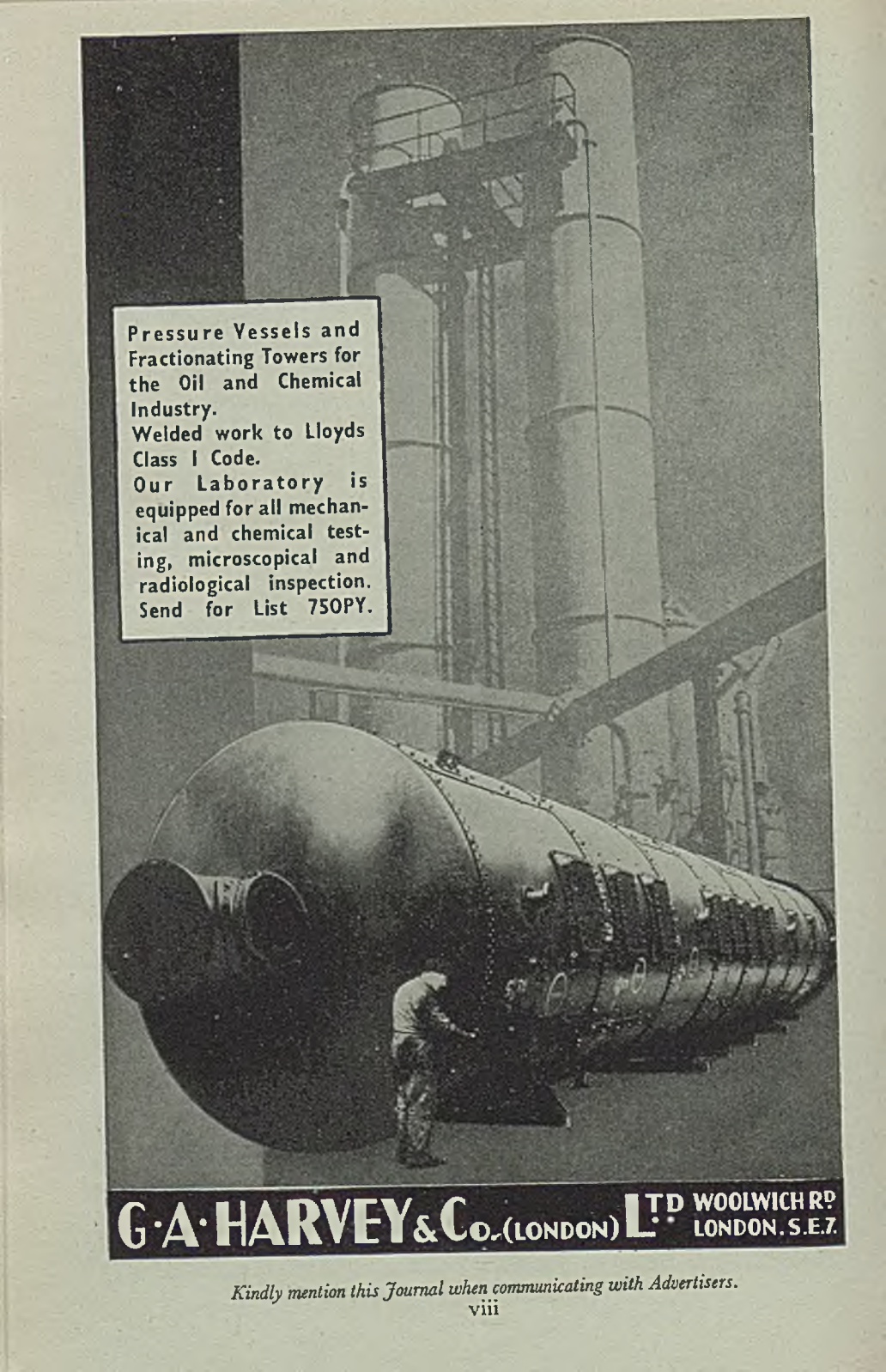
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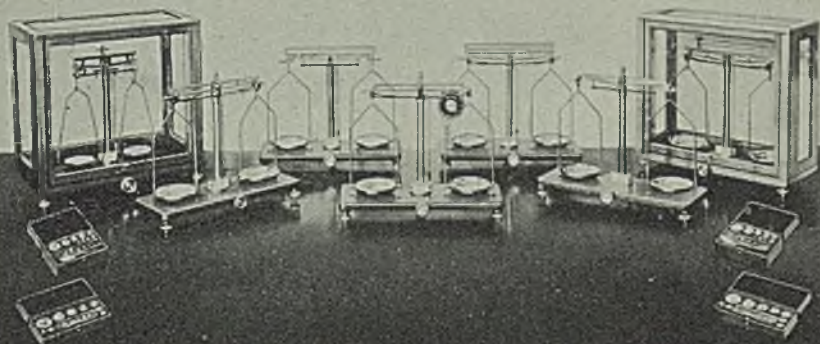
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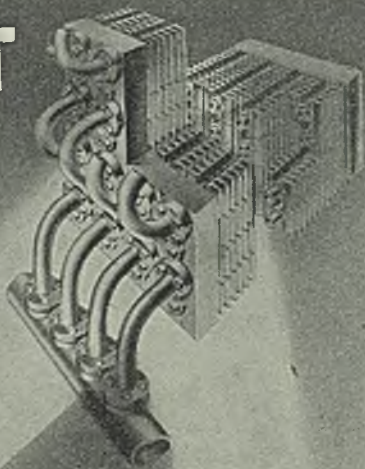
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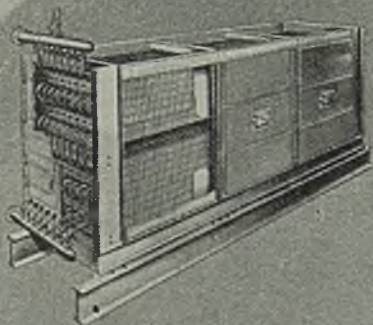
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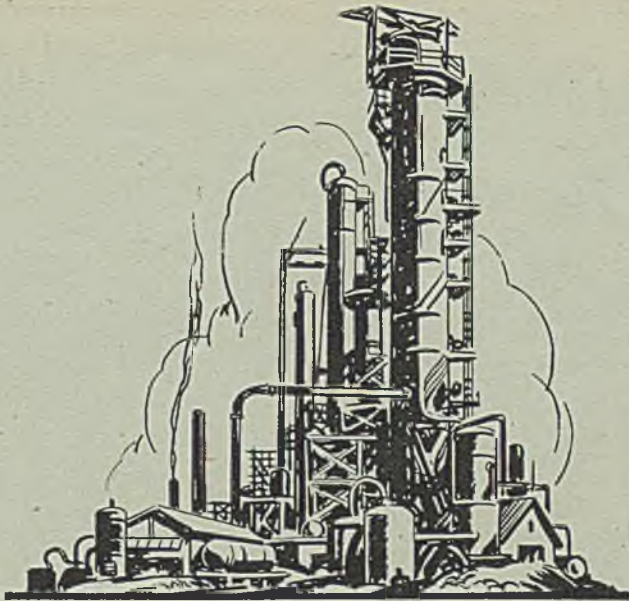
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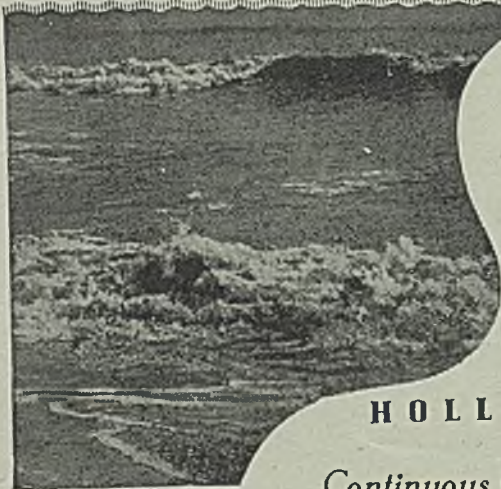


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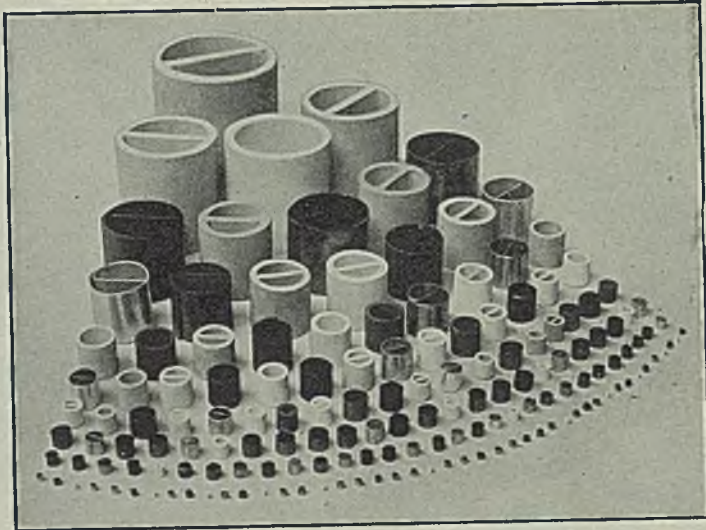
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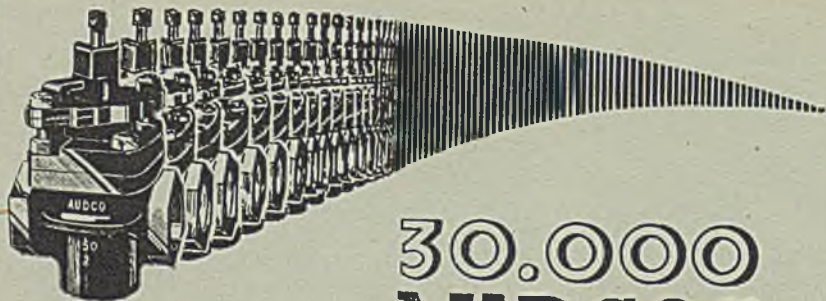
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