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Petroleum and Lubrication.

BY E. A. EVANS, F.C.S., M.I.P.T.

READ

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CHAIRMAN: MR. J. B. HARVEY (Member of Council).

IT has long been assumed that petroleum is a modern creation, but this is by no means the case; in fact it was known some 3,000 years before Christ. Excavators in Assyria have found excellently preserved walls cemented with bitumen, which have stood probably 35 centuries. According to the latest translations of the Bible we are told that the burning of Sodom and Gomorrah was due to the ignition of the oil pools, and that Lot's wife was not really converted into a pillar of salt, but fell into a bitumen pit and became covered with bitumen. Baku is always associated with the fire-worshippers, who for thousands of years have made pilgrimages to the eternal fires, which are nothing more than the burning of natural gas or petroleum.

It is to the Romans that we are indebted for the earliest record of petroleum being used as an illuminating agent. The oil was obtained from Agrigentum, Sicily, which was used in the lamps in the Temple of Jupiter.

Marco Polo described the Baku oil industry as he found it in the twelfth century. He states " There was a great fountain of oil from which 100 shiploads might be taken at one time. The oil was used for burning, and for this purpose was sought by people even at great distances."

About the year 1400 a concession was made for the collection of petroleum near Miano in Italy, and about 1,600 wells were bored at Modena, and in the early part of the 19th century, Genoa was lighted by oil from Amiano.

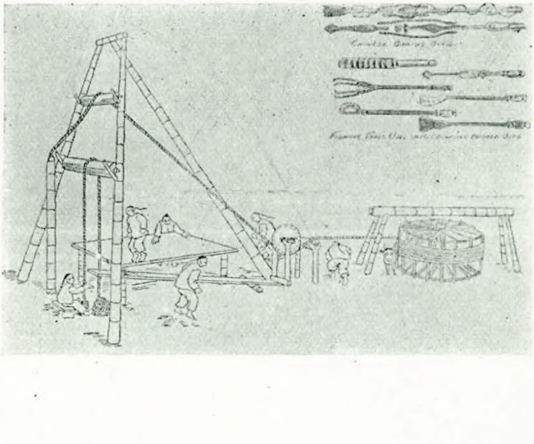
The first occasion on which petroleum distillation was practised on a large scale was at Prague in 1810, although Shale Oil was certainly being obtained in England in the seventeenth century, of course by a process of distillation of Shale. The process was patented and the oil was sold as "Betton's British Oil" to cure rheumatism.

The modern petroleum industry commenced in 1850, when the famous patent was granted to James Young, whose attention was drawn to a viscous substance oozing into a coal mine at Alfreton in Derbyshire, by Lord Playfair. This substance was subsequently found to be petroleum. It is interesting to note that when the British Government recently commenced oil operations in this country, bore-holes were put down at Alfreton.

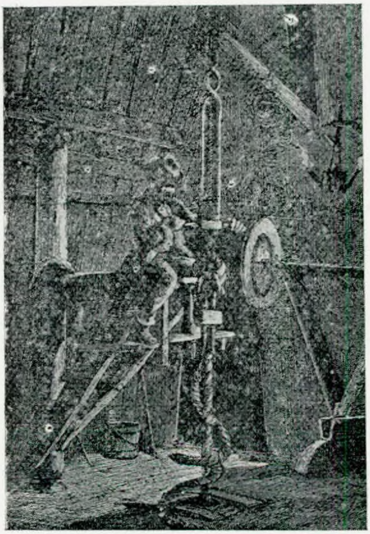
In 1859 Colonel Drake tapped an oil-bearing stratum at a depth of 69½ feet at Oil Creek, Pennsylvania. It is from this time that the industry began to make headway.

Needless to say, the discovery of oil in days gone by was simple, because its presence was indicated by seepages and oil pools, but nowadays systematic prospecting is undertaken by trained geologists and mining engineers, whose work is often extremely arduous and self-sacrificing. In the endeavour to locate oil, it is highly desirable, from almost every point of view, that systematic prospecting should be undertaken, because the so-called "wild catting" occurs and damage to the oil field, and frequently involves heavy financial expenditure.

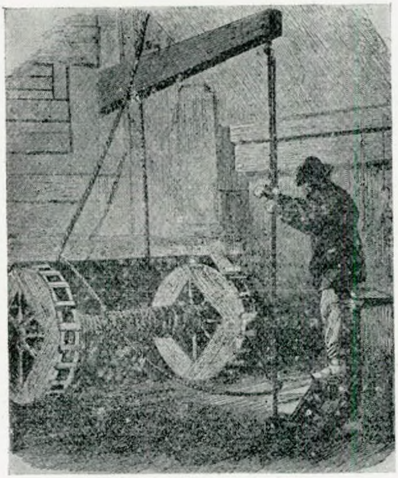
When there is good reason to believe that oil is present in some particular region, drilling operations are commenced.



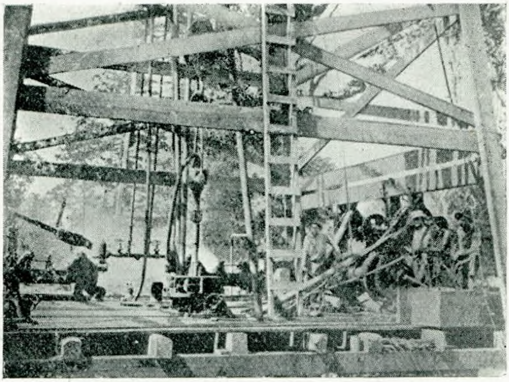
This illustration shows how the Chinese bored an oil well. The first thing to be done is to erect a derrick, and then to provide suitable drilling tools and means to operate them. The system here depicted is what is called the " percussion method," *i.e.*, to allow a heavy tool to fall and break the rock. Although this method used by the Chinese was very crude, yet in principle it is the one which is used at the present day.



By the year 1860 the method of drilling appears to have advanced, but whether the time taken to secure the prize had been reduced is a little doubtful, for, as you see, the drilling was done entirely by hand,



but in 1870 the mechanical devices had been somewhat improved. The construction of the bull wheels is interesting.



This photograph shows a modern rotary drill fitted with up-to-date steam power, although electrical power is now being adopted in some cases with marked advantage, but there are cases where its use is not applicable.

In passing, one is interested to see the various types of bits which are used in the " percussion " system, but this illustration gives no indication as to the sizes of the bits used.

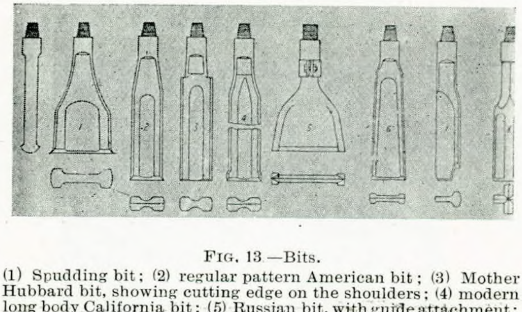


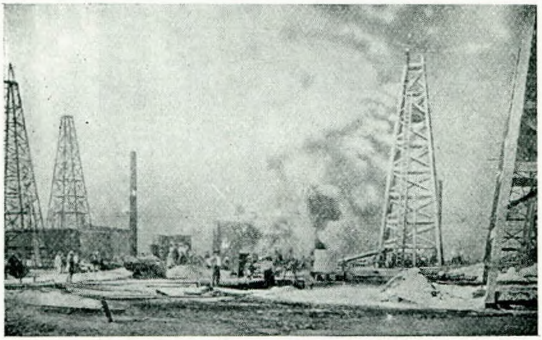
FIG. 13.—Bits.

(1) Spudding bit; (2) regular pattern American bit; (3) Mother Hubbard bit, showing cutting edge on the shoulders; (4) modern long body California bit; (5) Russian bit, with guide attachment; (6) regular Canadian tapered bit; (7) eccentric bit as used with pole tools (Canadian), also with cable tools to a limited extent in California: (8) star bit, favoured by the Rumanian and Russian fields for trimming or rounding a hole, but only used to a limited extent.

From this photograph you will see that they are very formidable implements.

One of the unfortunate economic conditions which has occurred in the oil fields is the overcrowding of the wells. This is especially the case at Baku, owing to the leasing of small properties to many lessees. This photograph shows the congestion which occurs, and gives some indication of the inconvenience to successful operations, storage and transport, and the very grave risks which would arise in the event of fire, which I regret to say is not uncommon. Obviously the ignition of an oil well or storage tank is a very serious consideration for those about the well, and incidentally for those who have their money invested

in that particular region. It is stated that a newspaper can be read 16 miles away if the fire occurs at night. It is also stated that owing to the large volume of smoke emitted, one cannot see at all! "It's all in the state of mind," as the poet said.



When an oil well ceases to flow, it may be due to:—

(1) All the oil having been withdrawn.

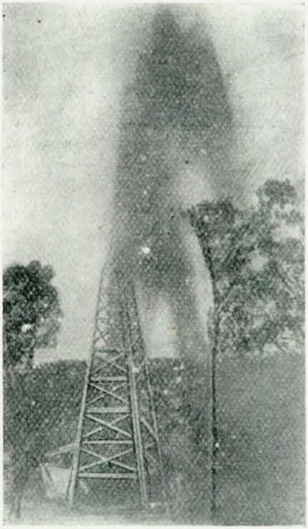
(2) Separation of paraffin wax in the pipe or stratum.

(3) Choking of oil-ways by debris.

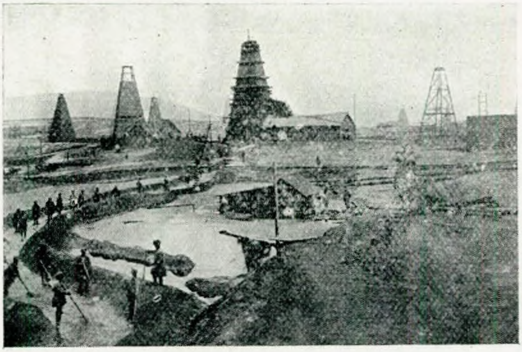
If it be due to the two latter, various methods have been adopted to enable the oil to re-flow, one of which is the introduction of a high explosive such as nitroglycerol into the bore hole, which dislodges the paraffin wax or the debris, as the case may be, with explosive violence, and is manifested by a sudden roar, an expulsion of debris and oil, which is shot sometimes several hundred feet into the air, and if care is not exercised, the death of the operator: and, of course, the oil in the well commences to flow again.

The photograph might easily also depict a gusher. A gusher is a well which emits its oil under great pressure, which may be hurled several hundred feet into the air.

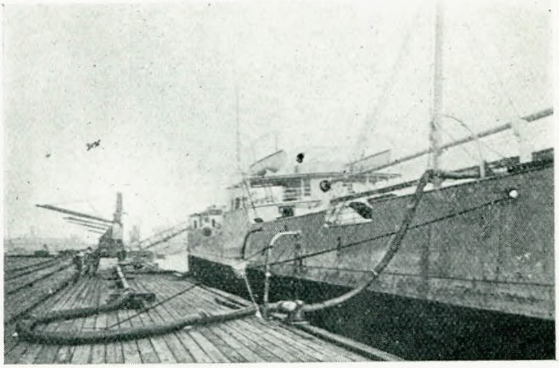
To allow a gusher to flow unchecked would result in considerable financial loss, in spite of the earth reservoirs which may be hurriedly constructed to collect the oil. To check the flow, valves are fitted to the mouth of the well, which in its turn is attached to a pipe through which the oil is conveyed to the refinery, which may be hundreds of miles away.



In Pennsylvania alone there are approximately 25,000 miles of pipe line. Usually the pipes are placed below ground to protect them from cold, but in this picture they are above ground, because they are conveying an oil free from wax. The oil may be either stored in tanks or barrels.

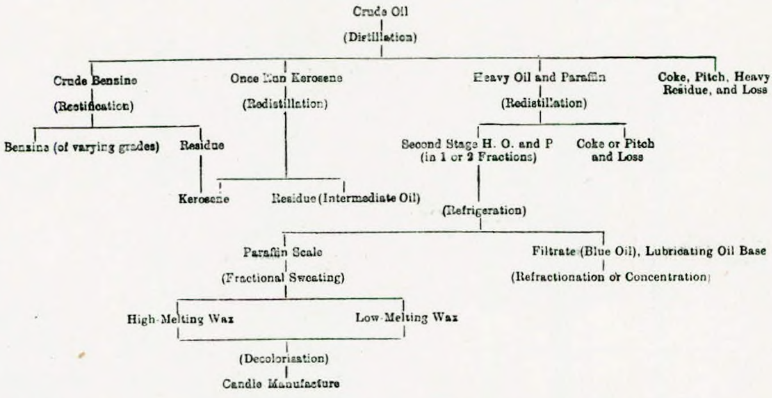


The crude oil may be treated in its country of origin or may be shipped to foreign refineries. The ease with which the oil is handled is very remarkable.



At the refinery the oil is led into stills, where a continuous distillation is carried on.

The exact method of effecting this need not concern us now. Suffice it to say that by distillation a resolution into various fractions is effected. Some sort of scheme for the distillation is recognised, but when one considers the very large varieties of crude oil, it is obvious that such a system must be very elastic.



The petrols can frequently be sufficiently purified by distillation, but the kerosene may contain constituents which are objectionable in oil lamps. Some kerosenes burn with a smoky flame

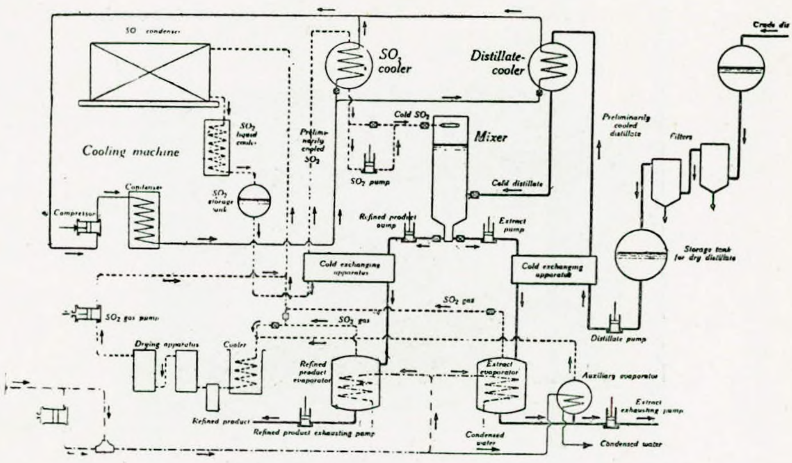


FIG. 109.—Scheme of a refining plant on the Edeleanu process.

and it has been found that this is largely due to the presence of aromatic hydrocarbons. For the ordinary wick type of lamp, they are removed by treating the kerosene with liquid sulphur dioxide. At atmospheric temperatures and pressure, sulphur dioxide is a gas, therefore the treatment must take place either under pressure or reduced temperature, or both. The diagram shows the general scheme of treatment.

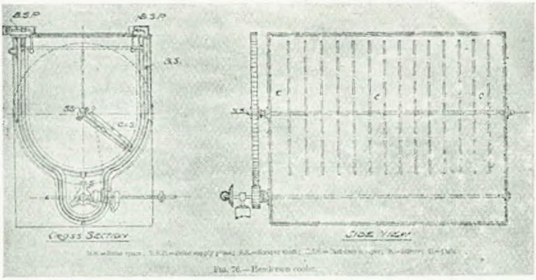
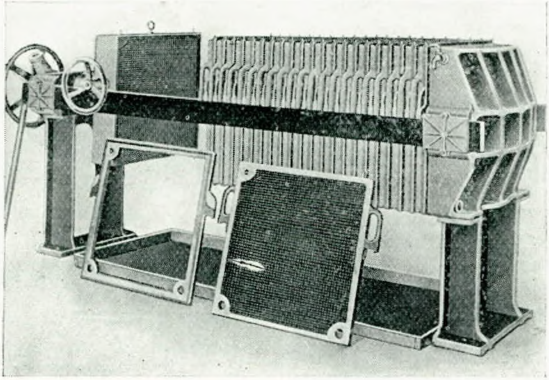


Fig. 76.—[illegible] cooler.

The lubricating oil fraction may contain paraffin wax. If it does, it is extracted by various operations, one of which consists of cooling the oil in an apparatus, which contains a number of revolving scrapers to remove the wax from the sides of the vessel as it crystallises. Then it is passed through a filter press which removes the separated wax. The oil is forced through the press under pressure and the wax collects on the plates, which are covered with some filtering medium such as hessian.



The filtered oil may then be violently agitated with strong sulphuric acid, the acid allowed to settle and removed, then the oil is subsequently washed with water, with caustic soda solution, and finally with water. This process sounds very simple, and is quoted in the literature as if it were perfectly straightforward, but as soon as you commence to wash, troublesome emulsions may result, which are very difficult to break.

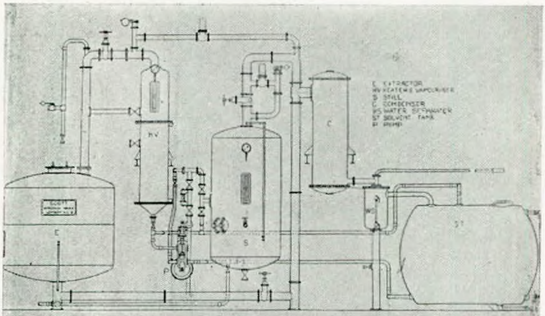


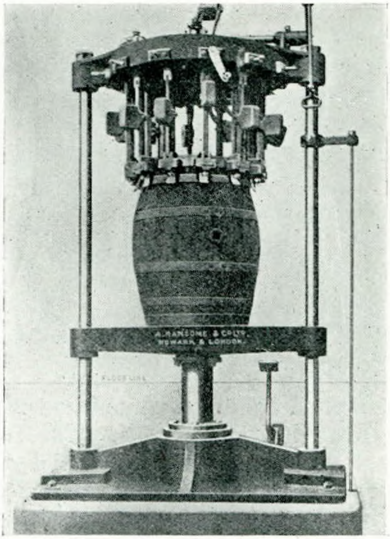
Fig. 93.—Scott extractor.

Some oils will respond to physical methods of purification, such as filtration through fullers earth. The fullers earth removes certain constituents by what is called *ad*sorption, not *ab*sorption. The fullers earth can be reclaimed four or five times, by extracting the adhering oil, and then burning it to destroy the adsorbed material.

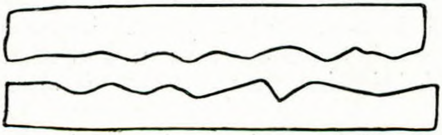
The oil from various crudes or fractions may be separately treated or blended to give any desired results according to the dictates of the market, and the oil so produced is packed in barrels, the coopering of which is a serious operation in any oil works.

Let us pause for a few moments to consider the underlying principles of lubrication. What is a lubricant? Why do we use one? Surely it is to reduce friction. But what is friction? To understand lubrication we must first of all answer these questions.

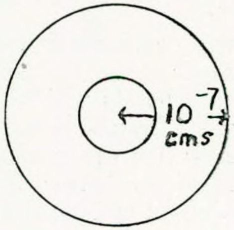
Friction, as we all know, is manifested in the amount of energy which is required to move one body resting on another body. But manifestation is a result, not a cause. If you place a piece of roughly filed metal on another roughly filed piece of metal and try to move the other piece, a resistance is felt, and when movement is effected, a jerky motion is introduced. This is due to the crests on one face fitting into the dips on the other face. Now if you file the two surfaces with a fine file you remove the crests to a very large extent, but not wholly. Suppose you continue the operation of smoothing the surfaces, you will finally obtain a tolerably smooth surface, but still the little dips and crests will exist and, in consequence, friction.

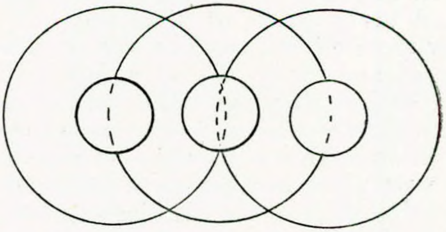


You will naturally say, "Yes, this is all right as far as it goes, but suppose you give the faces of the metal an exceedingly high polish, friction still exists." True it does, and this is where real friction is to be found. In the other case it was really hindrance and not friction.



In order to understand real friction, we must consider the tiny particles called "molecules" which compose all substances. Each molecule possesses an attractive force. If this attractive force did not exist, there could be no such thing as liquids and solids, because it is that attractive force which keeps the molecules sufficiently closely packed that we can see and handle them. This force is sometimes called "cohesion." The distance to which this attraction is perceptible is known as the radius of molecular action. It is estimated that the distance is about 10^{-7} cm. Forces of this character may be imperceptible at distances of a few thousandths of an inch, but they are enormous in the small spaces in which they are operative. Such a conception is naturally very difficult, but it becomes easier if we consider a parallel case—that of adhesion between surfaces in contact. This is also caused by attraction, effective only over such short distances that the slight irregularities of even smooth surfaces prevent it from acting. Yet copper can be polished to such a degree that a cube of it can support eleven other such cubes merely by adhesion. This means that one





square cm. of surface carries a copper prism one cm. square and 11 cms. long, which accordingly weighs 98 grms. Yet a slightly insufficient polish, or the presence of some particles of polishing material, renders this attractive force inoperative.

Friction then is the attractive force possessed by molecules on one surface—I say "on one surface" advisedly—re-acting with the attractive force of the molecules on another surface, provided the two surfaces come sufficiently close to be within the radius of molecular action. If the surfaces come to rest under such conditions, adhesion or seizing results, and the only way to part them is to apply a force greater than the molecular force of attraction. Those who have endeavoured to separate two pieces of metal which have seized together will know how great this force really is.

Your attention was called to the fact that it is only the molecules on the surface which concern us when dealing with friction. The molecules in the interior are completely surrounded by other molecules, but those on the surface are not completely surrounded. This being so, there are lines of force extending away from the surface which are capable of attracting molecules at the surface of some other body which is brought within the radius of attraction. Obviously the molecules away from the surface attract only each other, but of course they exert an inward pull upon those on the surface. Hence the surface is always under a certain tension, and the energy at the surface is called surface energy.

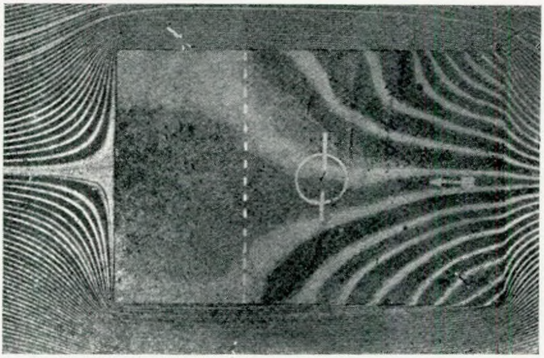
This brings us to the consideration of what is commonly called oiliness. Oiliness is generally regarded as some obscure property possessed by lubricants which enables them to lubricate, but which has never been satisfactorily defined or measured. Although oiliness has never been explained, we know that some lubricants lubricate better than others. I believe that oiliness can be explained and proved by molecular physics.

We have just seen how molecules of one substance attract each other and are capable of attracting the molecules of another. Now if an oil be placed on the surface of a piece of metal, the distances between the oil molecules and the metal molecules will be less than the radius of attraction of each; therefore they will adhere to each other by a force equal to the power of attraction. This is why the oil remains on the surface. Suppose we place another piece of metal upon the oil film, the exposed surface of the oil film will adhere to its surface, the result being two metal surfaces separated by a film of oil but held towards each other by the attractive forces of the two sides of the oil film.

The molecules in the body of the oil are held together by a definite force of attraction, or if we care to express it in another way, by a definite pressure. It is evident that if a certain force is holding the molecules together, a greater force than this would have to be applied if they are to be separated. Suppose a film of oil is interposed between two metal surfaces, the thickness of the film will depend upon the pressure exerted upon the metal; if the pressure be increased, the oil will be squeezed out at the edges, and in consequence the thickness of the film will be reduced. By the continual addition of pressure the film will become thinner and thinner, until a stage is reached when there is only a single layer of oil molecules. Having now reached a stage at which the oil molecules cannot slide over each other in their efforts to escape, the only alternative left to them is to separate from each other or, in other words, to rupture the film. But the molecules are held together by a certain force, and before the molecules will separate, a greater force than this must be applied. The pressure which has been applied to reduce the film to one molecule thick has only been sufficient to overcome the friction exerted by the oil molecules sliding over each other, which is proportional to the viscosity of the oil. As you can imagine, this is not very great.

Here it should be mentioned that the viscosity of the oil increases with the pressure, so that the resistance increases directly as the pressure is applied. But the pressure required to rupture the film is amazingly great. Even for a very inefficient lubricant such as water it is equal to 10,500 atmospheres.

When one speaks of the pressure on a bearing, it is generally calculated upon the projected area of the bearing and not upon the actual area upon which the pressure is being exerted; in fact it is a very difficult matter to ascertain what the maximum pressure on a bearing really is for this very reason, although the research which I am doing will enable us, I believe, to measure this accurately.



This photograph shows a film of oil passing a bearing. You will observe that it is made to enter in fine streams which spread out as they approach the zone of highest pressure. By measuring the minimum and maximum width of the stream line the pressure can be calculated. How the oil escapes is very clearly seen.

Very briefly I want to refer to another consideration with regard to oil films, and that is the constitution of the film itself. Those of you who have studied organic chemistry, even in its most elementary stages, will know that organic substances are composed mainly of carbon, hydrogen and oxygen, and that these elements are combined together in groups $CH_3\cdot$ methyl $\cdot CO\cdot$ ketone $\cdot COOH$ carboxyl $CH_3\cdot CH_2\cdot$ ethyl $\cdot OH$ hydroxyl etc., and the groups are bound together to form a substance. The various organic substances are, roughly speaking, made up of several combinations of these groups arranged in specific formations.

$CH_3\cdot COOH$ (acetic acid.) $CH_3\cdot CH_2\cdot CH_2\cdot CH_3\,CH_2\cdot CH_3$ (hexane) $(C_6\,H_{14})$ etc.

It is reasonable to assume that these groups are arranged in the molecule in some sort of order and that some of the groups are more active than others. If this be so, it is highly probable that the molecule seats itself in some definite way when it comes in contact with another substance. From experiments made by floating oil on water we believe that such is the case. The water attracts a portion of the oil molecule, and the remainder of the molecule is attracted by the other oil molecules. The least active portions arrange themselves upon the surface, whereas the more active portions are drawn down on to the surface of the water or the metal.

Substance.	Formula.	Cross Section sq. cm.	$\sqrt{\text{Cross Section}}$ cm.	Length cm.
Palmitic Acid ..	$C_{15}\,H_{31}\,COOH$	21×10^{-16}	$4{\cdot}6 \times 10^{-8}$	24×10^{-8}
Stearic Acid ..	$C_{17}\,H_{35}\,COOH$	22×10^{-16}	$4{\cdot}7 \times 10^{-8}$	25×10^{-8}
Tristearin ..	$(C_{18}\,H_{35}\,O_2)_3\,C_3\,H_5$	66×10^{-16}	$8{\cdot}1 \times 10^{-8}$	25×10^{-8}
Oleic Acid ..	$C_{17}\,H_{33}\,COOH$	46×10^{-16}	$6{\cdot}8 \times 10^{-8}$	11×10^{-8}
Triolein	$(C_{18}\,H_{33}\,O_2)_3\,C_3\,H_5$	126×10^{-16}	$11{\cdot}2 \times 10^{-8}$	13×10^{-8}
Cetyl Palmitate ..	$C_{15}H_{31}\,COO\,C_{16}\,H_{33}$	23×10^{-16}	$4{\cdot}8 \times 10^{-8}$	41×10^{-8}

By measuring the dimensions of the molecules of a number of substances floating on water, some very interesting data has been obtained.

The molecule of tristearin has the same length as stearic acid, but three times the cross section, while the hydrocarbon chains are packed side by side and are erect upon the surface. The active group in this case is the carboxyl.

The parent hydrocarbon of stearic acid is:—

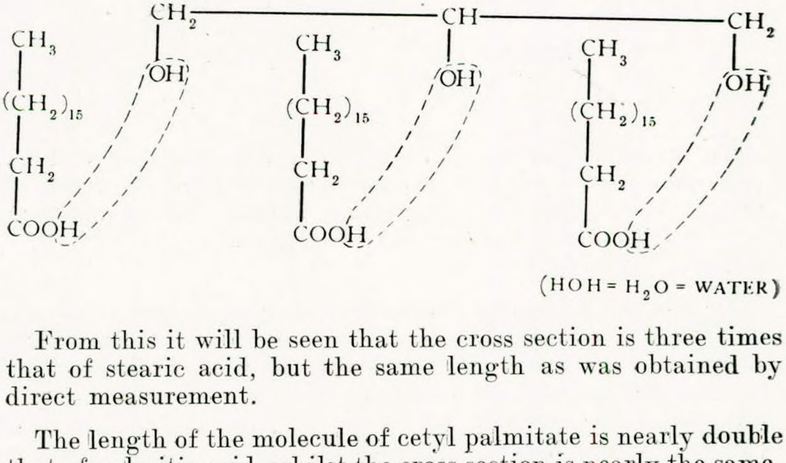
$$C_{17}\,H_{36} \text{ or } CH_3\,(CH_2)_{15}\,CH_3$$

and stearic acid differs from this merely by the replacement of one of the hydrogen atoms in the end methyl group by a carboxyl group. Thus:—

$$C_{17}\,H_{35}\,COOH \text{ or } CH_3\,(CH_2)_{15}\,CH_2{\cdot}COOH$$

If this were arranged vertically instead of horizontally, we could picture how it would sit upon a metal surface and obtain a mental conception of its cross section and length.

Tristearin is one of the principal constituents of animal fat. It is composed of three molecules of stearic acid and one of glycerol, commonly called glycerine. The stearic acid and the glycerol when they combine part with three molecules of water, thus:—

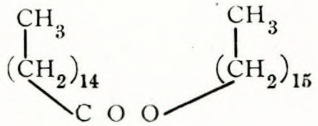


(HOH = H_2O = WATER)

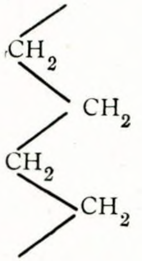
From this it will be seen that the cross section is three times that of stearic acid, but the same length as was obtained by direct measurement.

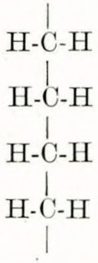
The length of the molecule of cetyl palmitate is nearly double that of palmitic acid, whilst the cross section is nearly the same. From this fact it would appear as if the molecule were arranged vertically with the carboxyl group in the middle and having a methyl group at each end, but from other considerations, we can assume that this is not so, but that the two hydrocarbon chains are placed vertically above it.

Even when we have solved the mystery of oiliness, lubrication problems will not cease. The friction-reducing power of an oil is important, but what is the use of having an oily oil which will not withstand the effect of heat in a Diesel engine, or will not separate from water in a steam turbine, or deposits carbon in a steam cylinder? However good the lubricating value of an oil may be, its value as a lubricant will be seriously impaired if it will not meet the inherent characteristics of the device to be lubricated.



and that the chains are arranged thus :—





To judge the value of a lubricant, a wise engineer will seek the opinion of a chemist, who in order to give it carries out certain prescribed tests to ascertain whether the oil meets the specification which has received the approval of the engineer by practical experience.

Confession is good for the soul. I suppose there is no commodity—except patent medicines—about which the user knows so little as lubricants. Consequently, it is an industry which lends itself to bluff and unscrupulousness. Therefore in your own interests I strongly advise you to deal only with those oil companies who have a competent technical staff. If I were the secretary of the Chemists' Trade Union I should insist upon every oil company having a chemist.

"You can fool some men all the time."

"You can fool all men some of the time."

"But you cannot fool all men all the time."

Believe me, no oil company can function properly without a chemist. By a chemist, I do not merely mean a glorified lab. boy. I mean someone who understands the industry, and is capable of giving you what you want, and not something which he wants you to have.

That is one side of the picture, but there is another. You provide a specification for an oil (excluding transformer oil for the moment). How do you know you are getting what you want? You reply, "The oil meets the specification." But there is hardly a specification which comes through my hands which I am not able to satisfy and yet satisfy it with an oil which will not suit you. If I can do this thing knowingly, what is there to prevent someone else from doing it unknowingly?

What about the user's chemist? He may know something about oil, he may not—he is probably a specialist in another branch of the science. If he does not, teach him. The mere fact of teaching him will secure his company's confidence.

A little while ago a certain firm reported that their chemist had examined a sample of oil and found it to be no better than any other. Later this firm tried the oil and found it to be far superior. Another firm said the oil was useless for the job, on the advice of their chemist. That chemist, of course, did not know that the oil was being used in the very engines for which he condemned it, and is working perfectly. One of the reasons why I wrote my book entitled "Lubricating and Allied Oils" was to supply information to enable a chemist to examine the oil and to report upon it, and the engineer to have sufficient knowledge of the subject to appreciate it.

Let us consider two oils which appear to be very similar on paper and compare the results in a Diesel engine under exactly similar conditions.

	A	B
Flash Point (closed)	408°F.	410°F.
Flash Point (open)	430°F.	440°F.
Fire Point	484°F.	515°F.
Vapourisation Point ...	245°F.	265°F.
Viscosity at 60°F.	*843	1060
,, 80°F.	435	525
,, 100°F.	246	291
,, 200°F.	49	54
,, 250°F. ...	39	42
Specific Gravity at 60°F. ...	0·872	0·878

* Redwood seconds.

	A	B
Hours run	1720	3001½
Units generated	166308	334810
Load factor, per cent.	64	74
Oil per 100 running hours	16·6 gallons	5·3 gallons
Oil per 1,000 units	1·74 gallons	0·48 gallons

There are differences, but are these differences sufficient to create the impression that the oils are materially different? Surely they are not, but the consumption in B is very much less than in A. There must, of course, be some very definite reason for this, and yet the difference is not revealed in the specification. The difference lies in the constitution of the oil which is not revealed by the physical data.

	A	B
Water from L. P.	0·074%	0·049%
,, ,, H. P.	0·083%	0·073%
,, ,, Blast Bottle	—	0·063%
Used Oil	0·02%	0·0078%

	C
Water from Inter Cooler	0·426%
Deposit from Inter Cooler	0·235%
Water from Blast Bottle	0·181%

These figures are interesting in that they give the acidity of various water samples from the air compressor. It will be seen that the acidities produced with B are less than the acidities with A. Again, the tendency for the oil to produce acid is not revealed in the specification and yet in a Diesel engine lubrication is an important factor, especially when considering the life of the copper coils and the valves.

No. 1.

Specific Gravity at 60°F.	0·891
Flash Point Closed	395°F.
,, ,, Open	405°F.
Viscosity at 70°	750 secs.
,, 140°	104 ,,

No. 2.

Specific Gravity at 60°	0·880
Flash Point Closed	420°
Viscosity at 70°	617 secs.
,, 140°	110 ,,

No. 3.

Specific Gravity at 60°	0·880
Flash Point Open	420°
Viscosity at 70°	604 secs.
,, 140°	99 ,,

These three oils have very similar specifications, but in the engine test it was found that No. 1 was satisfactory, No. 2 carbonised badly and caused scoring of the cylinder, and No. 3 was too thin and allowed wear. The consumptions were as follows:—

No. 1	111 gallons.
No. 2	107 ,,
No. 3	114 ,,

In these specifications no mention is made of the propensity of the oil to carbonise, nor of its liability to form acids when in use. Yet it must be acknowledged that some laboratory test should be available. It is available, and is shown in the diagram. Briefly the test consists of passing purified air for 45 hours through a known quantity of the oil heated to 150°C. and allowing the air to impinge upon copper foil. The solid material which forms in the oil is separated and weighed. The amount of this solid which is produced varies with the different classes of oil and is, in large measure, proportional to the propensity of the oil to carbonise when in use. Concurrently, acids are generated in the oil which can be collected and estimated, but it is by no means certain that this is directly proportional to the liability of the oil to produce acid in an air compressor. More work is required to be done to satisfy this point.

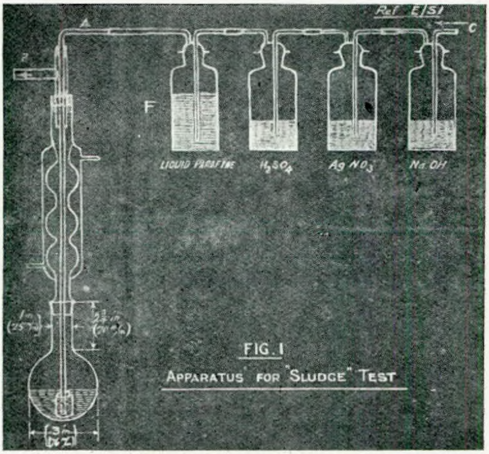


FIG. I

APPARATUS FOR "SLUDGE" TEST

Unfortunately nobody knows what it is in an oil which gives rise to carbonisation, although we know how to reduce the rate and the amount of carbonisation. It has been thought for some years that the unsaturated hydrocarbons present in the oil are responsible for it. If this view be correct, then we can ascertain the carbonisation value by measuring the extent of the unsaturation by the iodine method.

No.	Sludge.	Hübl.
1	Nil.	1·08
2	0·35	10·6
3	0·35	9·6
4	0·36	2·6
5	0·35	12·8
6	0·6	18·5
7	0·7	10·9
8	0·7	5·9
9	0·7	15·5
10	0·8	13·8
11	0.9	12·8
12	1·2	13·9

From these figures it is evident that there is no concordance between the sludge or carbonisation value and the iodine figures.

I particularly bring this to your notice because there is a very strong feeling at the present moment that the iodine absorption is all-important, whereas I have taken the opposite view. The so-called carbon which forms in a turbine oil is really an oxidation product of the oil or, if we care to call it so, "carbon." It is as much unlike carbon as most "carbon" deposits are. Deposits in turbines are often very interesting, especially if they accumulate rapidly. Needless to say, the oil is frequently condemned without a moment's hesitation.

Let us take a concrete case of the turbine whose bearings became badly worn and blackened, and the oil developed black "carbon." A sample of oil was drawn from the sump tank, when a considerable amount of water was discovered. This sample consisted of oil, black deposit and water. The three portions were separated and examined individually.

The acidity of the oil was only 0·0098%. Hence the blackening of the bearing could not be due to corrosion. The analysis of the water is as follows:—

	Grains Per Gallon.
Magnesium Carbonate	2·499
Magnesium Sulphate	0·235
Calcium Sulphate	7·616
Sodium Sulphate	0·235
Sodium Chloride	15·470
Difference	3·225
Total Solids	29·400

The sodium chloride content is exceptionally high, and as this turbine was working in a ship, it was reasonable to suppose that the water was in some measure sea water, but the amount of magnesium and calcium salts indicate that it was not wholly sea water but was contaminated by boiler water. The boilers had evidently primed.

The black deposit was found to consist of copper oxide, silica, iron oxide, calcium and magnesium salts. There was no oxidised oil present. The deposit was, in fact, an emulsion of iron oxide, oil, and water, contaminated with the other substances.

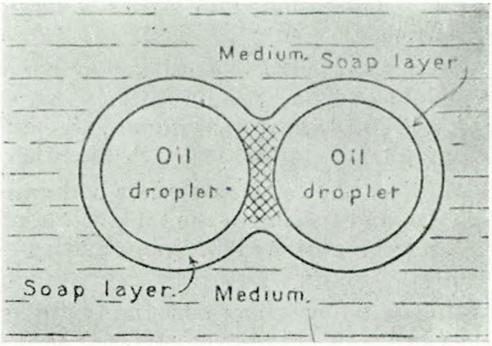
Priming had taken place and salt water had gained entrance during the voyage, and rusting of the tank had taken place, due to the water, and the rust had become churned with the oil and emulsified it.

The blackening of the bearings was simply due to the deposition of the iron oxide from the emulsion.

Having used the term "emulsion" in connection with turbine lubrication, it would be very improper on my part to pass over this important phenomenon without an explanation of it. For turbine lubrication it is highly desirable that the oil should separate readily from water.

The power of an oil to form an emulsion with water may be due to several conditions. Stable emulsions can be made, using emulsifying agents which are known not to have any marked effect on the surface tension of water. This is important because it was believed that soaps and other substances which would reduce the surface tension of the water were cheifly responsible for the production of emulsions, whereas now it is known that colloidal ferric oxide (iron oxide), which has practically no effect on the surface tension of water is an excellent emulsifier. It has been assumed that the emulsifying power of a solid substance depends solely on the size of the particles constituting it. This, however, is not the case, for if basic sulphates, Oxford clay, etc., which will form emulsions when hydrated, be dried and very finely powdered, no emulsion results. Not only then does the emulsifying action of insoluble particles depend only on the fineness of division, but must be of such a nature and in such a state that it can and does form a coherent film around the globules of oil.

In oils as supplied to the user the possibilities of the presence of inorganic suspensions are remote, but the presence of organic colloids is almost assured, and it is chiefly to them that emulsification is attributable. In order to obtain a non-emulsifiable oil, the colloids have to be removed or rendered innocuous. The colloids may be present as soaps, asphaltic substances, or even



certain varieties of paraffin wax. That other emulsifying agents may be also present is not denied, but further evidence of their presence and influence is wanted.

Non-emulsifiable oils when stored in wooden barrels, which have been treated with glue, and left exposed to the weather are liable to revert into emulsifiable oils, due to the rain softening the glue, and becoming dispersed in the oil. The trouble is aggravated if the oil should be acid or alkaline, as acid and alkali-albumins are very effective emulsifying agents.

Many cases of a good non-emulsifiable oil having emulsified badly when in use have come to my notice, and almost invariably I have found it to be due to the natural production of acid in the oil by oxidation, and this free fatty acid combining with alkalies or alkaline earths carried over from the boiler into the turbine or crank chamber and forming soaps.

The subject of priming is worthy of mention, because engineers are often loth to acknowledge its happening, and because it is often a contribution to lubrication troubles. Priming, as you all know, is the ejection of liquid water from the boiler into the steam pipe and onwards. When this takes place, the dissolved solids in the water also pass over. But these solids can be carried from the boiler mechanically by the steam. When the water in the boiler boils a certain amount of spray is formed of liquid water. This may be carried on to the superheater where the liquid water is properly vapourised and the solids are left in suspension in the steam and are carried along through the velocity of the steam.

These solids may finally find their way through the glands when the turbine is making water and into the oil. Emulsions might result immediately, or troublesome deposits might occur due to the oxidation product of the oil remaining in suspension as colloidal particles. These particles are electrically charged and are capable of precipitation when they come in contact with an oppositely charged body. That the coagulating power of different substances should differ from each other is to be expected, and it has been found to be the case as is shown in the following table.

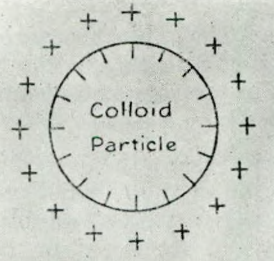


FIG. 50.—Illustrates the electric "double-layer". The positive charges are situated upon the molecules of the medium.

Salt.	Minimal concentration in Gram-atoms of Cation per litre.	Atomic precipitating power of the Cation.
HCl	6·00	0·16
$LiCl$	0·913	1·1
$NaCl$	0·153	6·1
Na_2SO_4	0·176	5·7
KCl	0·021	47·5
K_2SO_4	0·025	39·7
$CaCl_2$	0·0041	245
$ZnSO_4$	0·0756	13·2
Al_2Cl_6	0·0044	227
$CuSO_4$	0·0098	102

The CHAIRMAN: I am sure we have all been most interested in hearing Mr. Evans read his paper, in which he has given us the history of oil from the earliest times, and we have learned that information acquired by us as students was not always true. It has been instructive to hear how they obtained oil in early days in China. Also Mr. Evans' explanation of the attraction of the oil molecules by the molecules of metal during lubrication is very helpful to engineers. I will call upon Mr. Chaloner to open the discussion.

Mr. J. L. CHALONER: The subject to-night is a most interesting one and I have listened to Mr. Evans with great pleasure, not only owing to his reputation as a chemist, but also for the instructive manner in which he has dealt with his subject.

I fully endorse his views as to the desirability of the engineer enlisting the co-operation of the chemist, yet for a harmonious understanding it will be essential to establish a more practical base of measurement than suggested by the lecturer. Engineers consider 4/1,000th of an inch as a very fine clearance, and hence to know that the molecular attraction or cohesion acts at a distance of only 10^{-7} cm. will strain their imaginative powers beyond the practical limit with regard to the size, motion or even function of the molecules.

If such a knowledge is the basis of a clear understanding of the problem of lubrication, one can hardly wonder at the scope for "bluff and unscrupulousness" hinted at by the lecturer.

There are, however, many interesting practical problems connected with lubrication, of which one or two occurred to me while listening to Mr. Evans.

The formation of explosive vapour and the possibility of its subsequent ignition raise the question of an appropriate test for inclusion in a practical specification.

Again, what constitutes a practical specification? The Diesel Engine Users' Association have with their report on this matter indicated the difficulties to be encountered, and have suggested as the best solution a very general specification.

It indicates that there is very little to choose between all first class grades of oil on the market.

Besides, even if the chief knows what the cold test, the viscosity, the flash, the carbon test should be, he is not in the position to check the specification data himself.

There are no handy and simple tests, and a few hints from a chemist would be most valuable.

Take, for instance, the sludge which is found at the bottom of the cylinder liner or in the crank pit. Could a simple test be made to show the percentage of lubricating oil and fuel oil? Whether it is unburnt or partially burnt, whether it is faulty lubricant or faulty adjustment of the valve gear? A guide of this nature would facilitate a remedy being found much more rapidly.

Lubricating oils are mainly selected for the satisfaction they have given in practice. The motorship is coming to the front very rapidly, and with it the lubrication problem requires a practical settlement.

May I suggest to the Council of the Institute that we should enlist the co-operation of the members in charge of oil engine plants.

Reports should be issued by the engineers based on a set of questions drafted by the Council or a special committee. The data would be collected, analysed and reconstructed with a view to publishing periodical reports, private or public, for the specific benefit of the members. Much of practical guidance could be gleaned from such reports, provided they are built up on reliable and impartial data.

Whilst Mr. Evans has no doubt kept a certain amount of information "up his sleeve," I think that he has been exceedingly frank and fair in his paper. Our thanks are due to him for his valuable contribution.

Mr. D. M. Smart: I should like to ask Mr. Evans whether there is any simple but reliable test whereby the marine engineer could distinguish any oil supplied to him from doubtful sources. Is there any test which would tell him whether he was being given cylinder oil, Diesel oil, turbine oil, or other oil? He has to rely at present on the honesty of the people who are supplying him with oil. I know of instances in connection with the taking over of some of the German ships, where the engineers have been at a loss to determine the exact nature of the oil handed over to them, as there has been no chemist available to assist them.

Mr. W. McLaren: I was particularly interested in Mr. Evans' account of the commercial development of the oil industry, because there is a little village near my home in Scotland where the shale oil workings are being developed at present. As regards the demands for a reliable means of testing oil supplied to the engineer, in the early days one could rely upon the name of the supplier as a guarantee of quality, though there is no doubt that there have always been oils which were not good for the safe running of machinery. On the question of measurement of bearing friction I agree with Mr. Evans that it is a very difficult problem, but apart from any assistance which reliable measurements of this friction would afford, the sea-going engineer knows from experience that he can often reduce the friction in a troublesome bearing by increasing the clearance which has been allowed in the shops.

Mr. F. O. Beckett: The question of hot bearings may arise sometimes as the result of not putting the oil in the right place. We have inverted vertical engines at sea, and horizontal engines on land. If you follow the path of the shaft during its rotation you will find that you are introducing the oil at the point of least resistance, in the case of the horizontal engine. If you take the inverted engine you find that you are putting the oil into the place of greatest resistance. In one ship in which I served I had the oil-holes altered, and put them in at the side instead of the top of the bearings. The same thing applies to the cross-head. As the lecturer has pointed out, the point of contact takes place in a bearing only along a fine line. If you divide the 360° of the shaft section into parts according to the surface pressure, it is just that fine line of contact where the greatest pressure takes place.

The lecturer has referred to the deposits found in the sumps of turbines. I was looking at some turbine blades recently which had become very badly scored. Would it be possible that minute pieces of the blades are carried away by the steam? Often you will find that in high speed turbines the scoring action at the periphery is enormous, and the minute particles which come away are quite a consideration. On the Metropolitan Railway the atmosphere is very metallic. The Company expends over a ton of metal per week on brake blocks, and you can understand where the metal is going!

In conclusion I should like to congratulate the Institute on having secured such an able lecturer on such an engrossing subject.

The Chairman: As it is getting late, I will call upon Mr. Evans to reply to the previous speakers.

Mr. Evans: It is very kind of Mr. Chaloner to make such appreciative remarks. He raised the question of explosive mixtures in air compressors. This was dealt with at some length in a paper which I read in January, 1917, before the Diesel Engine Users' Association. Up to that time it was thought that explosions in air compressors were due to oil-fog, and after an explosion at Smithfield in 1918 this theory was repeated. There was no suggestion as to how the oil-fog ignited. Not feeling satisfied with the explanation, I set to work to find out more about what actually occurred. I was able to form fresh conclusions from conditions which I examined, and I showed that certain substances could be formed due to decomposition of the oil, which would explode by just the heat of the hand. If these substances are formed with certain types of oil, they simply act as a detonator for the remainder of the charge. One has to consider not only the oil charge igniting, but also the amount of gas which is in the air compressor. That is to say, there is a minimum and a maximum concentration of oil vapour which is necessary—there are limits between which an explosion will take place. If you refer to the paper you will see there is a curve showing these limits.

I was very glad to hear Mr. Chaloner's suggestion regarding the co-operation of the engineer and the chemist in laying down a specification. What I should like to know is why some shipping companies buy an oil which contains 5% of rape while others specify 25%. It is quite evident that there must be one specification which would be suitable to both, if the idiosyncracies of the buyers could be disposed of. One hears arguments in favour of the higher percentage; on the other hand one hears of engineers who do with very much less.

Mr. Chaloner asked whether it is possible to lay down a definite carbon test. I have heard people say that it is possible, but I am very sceptical. Mr. Chaloner also suggests that I (like himself) am not going to tell you everything. I do not agree with him; I am certain that if you give me a week I shall be pleased to come here and tell you all I know.

The question of pressures on bearings has been raised. I have been led to believe that a bearing is not circular. It is only a very limited area which is carrying the pressure somewhere between "6 o'clock" and "7 o'clock" on the circumference.

Mr. Smart asked whether there is any simple test to ascertain whether an oil is a cylinder oil or other quality. Unfortunately there is not, but fortunately the different oils have distinct characteristics; steam cylinder oil is black and thick, engine oil is fairly viscous, while a turbine oil is very much thinner. If you want to gauge it more than that, the Michell viscometer can be used. There are many people who get quite good results with it, and that will enable you to tell pretty closely what class of oil you are getting.

With regard to Mr. McLaren's remarks, I could not quite follow his statement that when you ease a bearing you increase the speed.

Mr. McLaren: It is often the case that if you ease a bearing with a hammer or a spanner you will find you are making two or three more revolutions than before the bearing was eased.

Mr. Evans: You mean that in other words you are reducing the pressure on the bearing?

Mr. McLaren: Yes.

Mr. Evans: Then does not that indicate that you are greatly reducing the friction?

Mr. McLaren: You must be having a greater amount of oil flowing round than before.

Mr. Evans: Yes, if you are reducing the pressure a little, because the viscosity of the oil is greater under pressure. If you are getting greater pressure and the same volume of oil you are getting fluid friction. Referring to Mr. Beckett's statement regarding the ton of iron per week, which apparently goes into the underground atmosphere from the railway brake-blocks. I shall fancy I am at Wells, taking the waters, when I travel by Underground again!

I thank you for the interest and attention which you have given to my lecture.

A Member: I should like to propose a vote of thanks to Mr. Evans for his very interesting lecture. He has cleared up quite a number of points about which I have previously had no information, and he has made me keen to study the subject. It is not studied with much keenness by the average marine engineer, though it is highly important.

Mr. F. O. Beckett: I have great pleasure in seconding this vote of thanks. In so doing I must thank the lecturer for pointing out the cause of explosions from lubricating oils. I recollect an explosion which was caused by a fitter forgetting to take liners out of a bearing. The oil exploded, and a manhole cover was sent 40 feet into the air. The engineer who was injured in this accident had undergone no less than three similar accidents from the same cause, and had actually grown three successive skins on his face! In many cases with air receivers I have had occasion to call attention to greasy deposits forming a source of danger in this respect.

Notes.

THE Lloyd's Register Scholarship of £100 per annum, available for three years, has been awarded to David H. Alexander, apprentice with Messrs. Harland and Wolff, Belfast. He stood 1st in the examination held in June, 1922. He was 2nd in the examination of 1921.

One of our Graduates, Sydney P. Smith, serving in the works of the General Steam Navigation Company, won the shield and gold medallion in the competition for "good work and conduct" awarded by the London Association of Foremen Engineers.

The examination for Student Graduates has resulted in the following passes. To the candidates who failed to pass in all subjects, an opportunity will be given in the course of next examination to take the subjects in which they have failed.

Newcastle: Cyril Gallon, Frank Hamilton, Henry W. Howey, Thos. B. Lowes, R. Pearson, Fred. L. Turnbull, Percy B. Wells.

Aberdeen: H. Duthie, Frank Jamieson, A. A. Mair, D. Murray, C. Simpson, Wm. Symon, F. G. S. Teunon, John Will.

Henry W. Howey stands 1st in Theoretical Mechanics, Applied Mechanics, English and Composition, Electrical Engineering. Cyril Gallon 1st in Mathematics and Geometry. C. Simpson 1st in Machine Construction and Drawing. W. Mitchell (Aberdeen), who failed to pass in all subjects, 1st in Heat and Heat Engines.

Review of Books presented to the Library.

STEAM TURBINES (WM. J. GOUDIE) (*Longmans*).—This 2nd edition of this work, which has been revised, is a very thorough and complete exposition of this subject, of which the author is a master. The book is at once a work of practical reference, and a very searching demonstration of the theory of turbines. The many theoretical problems dealt with in mathematical form have now been subjected to the test of extended practice, and much that was conjectural, as is the case with any new idea, has been modified and perfected in service, so that this latest volume presents what is perhaps as thorough a demonstration of this subject as the student can expect.

NATURE NOTES FOR OCEAN VOYAGERS, by *A. Carpenter and Sir D. Wilson Barker*.—This is an entertaining little book, apparently designed to be of interest to those who have their business in deep waters, and it deals briefly with many items of interest among the fauna and flora of the sea. There are many illustrations, and the various matters dealt with are full of interest. The treatment is light, and the references rather brief, but this will not prevent the book being an entertaining companion on a voyage for anyone interested in natural phenomena.

THE TRANSACTIONS OF THE LIVERPOOL ENGINEERING SOCIETY for 1921, have been received with thanks, and the papers contained, which cover a wide range of subjects, including "Ship Construction and Repairs," "Water Power Problems," and "The Construction of Oil Fuel Depots," contain a wealth of practical experience of which our members will be able to avail themselves with advantage.

THE INSTITUTION OF MECHANICAL ENGINEERS have kindly sent us a copy of their 1921 Transactions, and the subjects dealt with are almost without exception of the greatest importance to Marine Engineers. Mention need only be made here of "The Theory of Internal Combustion Engines with relation to Thermal Efficiency," "The Economy of Steam Engines," "The Low Temperature Carbonisation of Coal," "Liquid, Powdered, and Colloidal Fuels," "Machinery of Floating Docks," and "Power Transmission by Oil" among others for our members to realise what a valuable series of papers this volume contains.

———o———

Election of Members.

Members elected at a meeting of the Council held on 14th August, 1922.

Members.

Henry Acton, 13, Brunswick Square, Kirkdale, Liverpool.
Leonard John Campey, 25, Achilles Street, New Cross, S.E.14.

Edmund Henry Hope Cann, 20, Howrah Road, Salkhia, India.
John Charles Coleman, "Algoma," Ormiston Park, Knock, Belfast.
Sidney George Colinese, 46, Newton Road, Faversham, Kent.
Charles Edward Gee, 5, Exchange Chambers, Cardiff.
Herbert R. Gilbert, 103, Tower Street, Brightlingsea, Essex.
Sidney Hall, 88, Albert Road, Ilford, Essex.
Thomas William Hayhurst, 143, Cairo Street, Sunderland.
John Mathieson, 33, High Street, Forres, Morayshire.
Walter Thomas Pinnock, 13, Stamford Hill, N.16.
Frank Shapley, The Gables, Hayes Lane, Alderley Edge, Cheshire.
William Simpson, 2, Rundle Road, Aigburth, Liverpool.
Alexander Thomson, 9, Kirkwood Street, Ibrox, Glasgow.
Alexander Thomson, "Keirallan," St. Meddans Street, Troon, N.B.

Associate-Members.

Alexander Graham, Tigh-Na-Bruaich, Keppel Harbour, Singapore.
William Grocock, 53, Shirlock Road, Hampstead, N.W.3.
Sidney George Herbert, 86, Battle Road, Belvedere, Kent.
Joseph James Teasdale, Park Terrace, Hall-Bank-Gate, Brampton, Carlisle.

Associates.

David Alexander Fotheringham, 18, Alexandra Park Road, Muswell Hill, N.10.
Frank Edward Hardcastle, 31, Howitt Road, Hampstead, N.W.3 (and Alice Buildings, Hornby Road, Bombay).
William Frank Norman, 23, Blisset Street, Greenwich, S.E.10.

Graduates.

Douglas Henry King, 23, Glebe Road, Hornsey, N.8.
Cyril Walter Jones, 96, Peacock Street, Gravesend, Kent.
William Alfred Jones, 22, Louvaine Road, St. John's Hill, Clapham Junction, S.W.11.

Transfers:—

From Associate to Associate-Member.

J. L. Rutherford, 19, Claremont Road, E.7.

From Graduate to Associate.

Howard Kenneth Sankey, R.N. Barracks, Portsmouth.