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Comparative Efficiency of Lubricants.

BY MR. J. VEITCH WILSON.

READ

Tuesday, March 23, 1915,

THE NEW PREMISES, MINORIES, TOWER HILL.

CHAIRMAN: MR. F. M. TIMPSON (Member of Council).

THE question which we are to consider this evening is that of the relative efficiency in reducing friction of various lubricants, mainly, from my point of view, as between mineral or hydrocarbon oils, on one hand, and fatty, *i.e.*, animal or vegetable oils on the other.

Since friction must play an important part in the consideration of our subject, it is desirable that, although we are all more or less familiar with the various ways in which it manifests itself, we should devote a little attention to the nature of friction and to its more immediate effects.

According to the lexicographers, friction is the resistance which occurs between two bodies when we attempt to move one over the other. Numerous explanations have been offered as to the nature and origin of this resistance, and among the more notable of these we find—

Inequalities in the surfaces in contact.
Cohesion due to pressure.
Attraction between two masses.
Magnetic or electrical force.
Internal motion of the particles in the materials used as lubricants.

I am not competent, and I shall not attempt to discuss the relative probabilities of these suggestions, but I cannot fail to observe that actual contact or close contiguity is an important factor in the efficiency of each. It seems, therefore, to follow that, whatever value may attach to the several forces which have been referred to, the introduction of some material film which will separate the surfaces and which may, perhaps, even to some extent act as a non-conductor, must reduce friction, whatever may be its origin.

But apart from its immediate cause, although (probably) affected thereby, it is found that friction varies in intensity according to the materials between which it occurs and to the condition, in regard to smoothness of the opposed surfaces.

Dealing with the latter condition first, it is common knowledge that if two pieces of glass with perfectly smooth and clean surfaces are firmly pressed together it is difficult to separate them.

A somewhat similar condition may occur in mechanical practice, although I do not think that engineers have frequently to complain of such perfect bearings. That it may be an occasion for trouble, has, however, been impressed on me by several engineering friends who have explained that journals and bearings may be worn so smooth that it is impossible for oil to find its way between them. Some of these friends have also told me that when the journal got into this condition they tapped it over gently with a rasp to make pockets for the lubricant, a somewhat drastic remedy it seems to me.

We return now to consider farther the manner in and the degree to which friction is affected by the materials and conditions in which it is produced, and at this point we may classify friction as:—

1st. Rolling friction, as in the case of the road wheels of a vehicle, an essential condition in the case of railway locomotives and road motor vehicles.

2nd. Sliding friction, as in the revolution of a journal on its bearing or of the table of a planing machine.

3rd. Solid friction, as between the dry surfaces of solid bodies.

4th. Liquid friction as in the case of a lubricated bearing.

With the first of these—"Rolling Friction"— we are not at present concerned.

The second, sliding friction, will be considered conjointly with No. 4, fluid friction.

The third only calls for mention to permit of the introduction of an oft quoted table showing the results of certain experiments carried out by George Rennie, an eminent engineer and son of the still more famous John Rennie, the architect of Waterloo and Southwark Bridges.

Mr. George Rennie determined co-efficients of friction by sliding a block of one material over an inclined plane of the other and noting the angle of motion. (1)

TABLE A.

GEORGE RENNIE—CO-EFFICIENT OF FRICTION FOR ORDINARY BODIES.

Steel on Ice	·014
Ice on ice	·028
Hard wood on hard wood...	·13
Brass on wrought iron	·135
Yellow deal on deal	·35
Soft steel on soft steel	·146
Leather on iron	·25
Granite on granite...	·30
Sandstone on sandstone	·36
Woollen cloth on cloth	·43

I give also a table showing the results of experiments, carried out on the same method, by the famous French physicist, General Morin.

TABLE B.

MORIN.—FRICTION OF REST AND OF MOTION.

	Rest.	Motion.
Wood on wood—dry	·50	·36
,, ,, —soaped	·36	·14
,, ,, —greased	·19	·07
Wood on metal—dry	·60	·42
,, ,, —greased	·63	·45
Metal on metal—dry	·18	·18
,, ,, —oiled	·12	·07

(1) Chambers' Encyclopædia.

I have suggested that "Sliding Friction" and "Liquid Friction" may be considered together. To prevent misunderstanding let me say here that, for convenience, I use the expression "Liquid Friction," perhaps incorrectly, to denote the use of oil or some similar unguent in contradiction to "Solid Friction," not, as I understand the expression is sometimes used, as indicating the friction of water or other liquid in passing through a tube, or the friction of the hull of a ship in passing through water.

As regards the essential principles of lubrication in relation to friction, we need not be astonished to find that in this, as in other spheres, doctors differ, but, after consideration of many theories promulgated by various eminent authorities, I think that we may accept the following formulæ as expressing the leading factors which dominate friction:—

1st. Friction is dependent upon the total weight or pressure, *i.e.* (where the surface is constant), upon load per square inch, a statement which seems to require no qualification.

2nd. Friction is independent of surface or area in respect that, under constant load, the pressure per unit surface increases as the bearing area is reduced or diminishes as it is extended.

3rd. Friction is nearly independent of velocity, which must be qualified by the consideration that, although the co-efficient of friction may even be slightly reduced as speed increases, the total amount of friction per unit of time increases with the velocity.

As it would not be fair of me to withhold from you the opinions of authorities better qualified than I profess to be to deal with this subject, even although their conclusions should not in every respect support the theories which I have enumerated, I give you the following quotations:—

1st. From Mr. John Bourne, the famous old shipbuilder and engineer, who, in his "Catechism of the Steam Engine" says:—

"Friction is the resistance experienced when one body is rubbed upon another body, and is supposed to be the result of the natural attraction which bodies have for one another, and of the interlocking of the impalpable asperities upon the surfaces of all bodies, and these combined agencies produce such internal motions among the particles of a rubbing surface as to generate heat, which heat will always be of equivalent value to the power expended in overcoming the friction. It is found that as much power is expended in heating a pound of water one degree by friction, as would raise a pound weight 772 feet high; and this measure of power is consequently termed the mechanical equivalent of the heat. The friction of smooth rubbing substances is less when the composition of those substances is different, than when it is the same, the particles being supposed to interlock less when the opposite prominences or asperities are not coincident."

"Friction does not increase with the extent of rubbing surface. So long as there is no violent heating or abrasion, it is simply in the proportion of the pressure keeping the surfaces together, or nearly so. It is, therefore, an obvious advantage to have the bearing surfaces of steam engines as large as possible, as there is no increase of friction by extending the surface, while there is a great increase in the durability."

"Friction does not increase with the velocity at all, if the friction over a given amount of surface be considered;* but it increases as the velocity, if the comparison be made with the time during which the friction acts. Thus the friction of each stroke of a piston is the same, whether it makes 20 strokes in the minute or 40: in the latter case, however, there are twice the number of strokes made, so that, although the friction per stroke is the same, the friction per minute is doubled. The friction, therefore, of any machine per hour varies as the velocity, though the friction per revolution remains, at all ordinary velocities, the same. Of excessive velocities we have not sufficient experience to enable us to state with confidence whether the same law continues to operate among them."

"The nature of the unguent, proper for different bearings, appears to depend in a great measure upon the amount of the pressure to which the bearings are subjected—the hardest unguents being best where the pressure is greatest. The function of lubricating substances is to prevent the rubbing surfaces from coming into con-

*This statement refers only to the friction of solids, and not of liquids, which comes under a different law.

tact, whereby abrasion would be produced, and unguents are effectual in this respect in the proportion of their viscidity; but if the viscidity of the unguent be greater than what suffices to keep the surfaces asunder, an additional resistance will be occasioned; and the nature of the unguent selected should always have reference, therefore, to the size of the rubbing surfaces, or to the pressure per square inch upon them. With oil, the friction appears to be a minimum when the pressure on the surface of a bearing is about 90 lbs. per square inch. The friction from too small a surface increases twice as rapidly as the friction from too large a surface, added to which, the bearing, when the surface is too small, wears rapidly away."

2nd. I next refer to Mr. Beauchamp Tower, whose report upon the long series of experiments which he undertook on behalf of the Institution of Mechanical Engineers may be fairly regarded as among the "classics" on the subject. Mr. Tower says:—

"The theory of liquid friction is that it is independent of the pressure per unit of surface, is directly dependent on the extent of surface, and increases as the square of the velocity. The results of these experiments seem to show that the friction of a perfectly lubricated journal follows the laws of liquid friction much more closely than those of solid friction. They show that under these circumstances the friction is nearly independent of the pressure per square inch, and that it increases with the velocity, though at a rate not nearly so rapid as the square of the velocity."

There would appear to be a remarkable difference between these two authorities in some of their statements, but a little consideration may help us to reconcile them.

The most important point of divergence occurs between Mr. Bourne's statement that—

"friction does not increase with velocity at all if the friction over a given amount of surface be considered."

and Mr. Tower's equally direct statement that—

"it (friction) increases with the velocity, though at a rate not nearly so rapid as the square of the velocity."

I take it that the explanation of the apparent discrepancy is that while Mr. Bourne is speaking of absolute co-efficient of friction, Mr. Tower is referring to the amount of friction developed in a given time. This seems to be borne out by reference to some of his tables—I take, at random, the first, which deals with olive oil. This shows that at a temperature of 90° Fahrenheit, with 100 lbs. load per square inch, the nominal friction resistance per square inch of bearing was 0·36 at 100 r.p.m., and 0·89 at 450 r.p.m., thus showing an increase of 0·53 in friction in the period of one minute. But the journal was four inches in diameter by six inches long, with chord of the arc of contact = 3·92 inches. We have thus a rubbing surface of $3·92 \times 6 = 23\frac{1}{2}$ sq. inches. In the first test we find therefore that the total surface over which friction occurred was $23\frac{1}{2} \times 100$ revs. = 2,350 sq. inches, while, in the second test, we have $23\frac{1}{2} \times 450$ revs. = 10,575. If we now divide the total friction developed at each velocity by the number of square inches over which the friction was generated we find—

for 100 r.p.m., $0·36 \div 2,350 = 0·000153$, and
for 450 r.p.m., $0·89 \div 10,575 = 0·000085$

as the actual friction per sq. inch of surface covered, showing that the friction per unit space is very much less at the higher than at the lower speed.

Having now, in some fashion, ascertained the general opinions held with regard to the inherent properties of friction, we shall, in the next place, consider the means available for overcoming these.

In doing this I depart from chronological order and deal first with what is probably the latest method of reducing friction, viz., "ball" or "roller" bearings, which indirectly throws some light upon all older methods. "Balls" and "rollers" may in fact be regarded as a system of mechanical lubrication since they introduce a moving agent between two surfaces, those of the journal and the bearing, which would otherwise be in direct contact and rubbing on one another.

Another instance of a mechanical arrangement for the reduction of friction is to be seen in the "penny in the slot" weighing machines which are found on many railway stations and other places of popular resort. In these the spindles of the operative parts are carried on the peripheries of two loose discs or wheels which revolve freely with the spindles and thus eliminate the slight friction which would occur if the spindles were carried on ordinary fixed bearings.

Now it seems to me that these balls or rollers or free discs embody the whole principle of lubrication by interposing a yielding medium between surfaces which would otherwise be in actual contact and rubbing one on the other.

I have seen several demonstrations of the value of ball bearings, one, which struck me very much at the time, was probably seen by many of you. It was exhibited a few years ago by the Hoffmann Manufacturing Co., Ltd., at some of the motor shows at "Olympia." It consisted of two bearings, each fitted with a pendulum with a load of about one ton. One was fitted with balls, the other with a plain bearing. To the end of each journal a crank handle was attached, and visitors were invited to turn them. The journal with the ball bearing was easily turned by the finger and thumb, while, according to the physical strength of the individual, it took one or both hands and violent exertion to start the plain bearing, although when started it was kept going with moderate effort.

I have been induced to devote so much attention to this form of mechanical lubrication as it appears to me to illustrate in a visible manner the principle which is equally in operation when oils or greases, which are more popularly regarded as lubricants, are used. It is now generally conceded that all matter consists of agglomerations of atoms held together either in a liquid or a solid condition by some inherent power of attraction. It is also understood that, even in the case of such homogeneous solid materials as iron or steel, the component atoms have the power, and, under certain conditions, such as electrical influences, do actually change their relative positions. It is therefore more easy to understand that, in the case of more mobile substances, which we call liquids, similar movements of atoms may occur, and that, when a film of oil or grease is introduced between a moving and a stationary surface, the film may be divided into a number of thinner films, the outer films in contact with metal on one side and with the next film of oil on the inner side, each inner film rolling or sliding between the two adjacent films till the centre film is found at rest.

If this theory of the behaviour of films is correct it is evident that it offers a key to the value of different bodies as lubricants and a guide to the selection of suitable lubricants for different purposes and conditions.

Let us now endeavour to apply this principle to the three different classes of material which are generally regarded as available as lubricants. These are:—

1st. Solid lubricants as graphite or sulphur.
2nd. Semi-solid lubricants as suet, tallow or grease.
3rd. Fluid lubricants—animal, vegetable, or mineral oils.

1st. Judged by the suggested test the solid lubricants offer least advantage, as, from their nature, they are not likely to resolve themselves readily into a series of sliding or rolling films, but are rather likely to attach themselves intimately to the opposed surfaces simply transferring the rubbing surface from the metal itself to that of the material with which it is coated. It is true that graphite or sulphur may, by filling up the interstices in the journal and bearing, produce a perfectly smooth surface on these, but we have already seen that an absolutely smooth surface is inimical to successful lubrication.

2nd. Semi-solid substances, such as suet, tallow, or grease, can only be regarded as lubricants to the extent that they may be, more or less readily, converted into oil. They offer the advantage that, as heat is required to liquify them, they act as a store of lubricating material, but, at the same time, they have the disadvantage that they only provide lubrication when a certain amount of heat, which it is the object of lubrication to prevent, has been developed on the bearing.

3rd. Liquid oils seem to possess all the important properties which are required in a true and efficient lubricant. They may be easily applied in a variety of ways, and whether the bearing is hot or cold, the supply can be exactly adjusted to the requirements of the bearing and can be shut off when not wanted. When liberally applied in a constant stream they serve not only as lubricants, but act as cooling agents in carrying off the heat generated in the bearing from which they also remove any metallic or other particles which, if suffered to remain and accumulate upon the bearing, might be the cause of trouble.

We now approach that aspect of the subject which provided the motive which suggested the production of this paper, viz., an attempt to discriminate, in regard to their value as lubricants, between animal, vegetable, and mineral oils.

When I originally undertook to deal with the question I had hoped to arrange for a comprehensive series of experiments on a very efficient testing apparatus designed by my colleague, Mr. A. J. Dodd, in conjunction with the Admiralty experts.

It is an objection common to the majority of testing apparatus, that, on account of their small size and their general departure from practical arrangements, they do not reproduce actual working conditions. The Dodd machine, as you will see from the photographs which I exhibit, is in reality a miniature propeller shaft working, as nearly as possible, under the conditions which occur in actual practice. The machine consists essentially of a shaft 3 inches in diameter with a thrust collar $7\frac{1}{2}$ inches in diameter, and a horse-shoe bearing, the whole exactly reproducing a single section one-fourth size of the thrust block of H.M. Battle Cruiser *Royal Sovereign*, and run at four times the speed of that ship's shaft in order to reproduce the same surface speed as that of the original.

The machine is driven by an electric motor on the shaft itself, to which power is transmitted through a meter which indicates the voltage and the amperage (the pressure and the current) of the power absorbed in driving the apparatus. The mechanical pressure, or load, representing the thrust of the propeller, is applied by a bell crank overhanging the shaft. One end of this crank terminates in a hardened steel point which fits into a cup-shaped orifice in a floating disc, with ball bearings, in which the end of the shaft is received. End friction is thus entirely eliminated at this point. The other arm of the bell crank connects with a powerful spring balance by which the pressure on the shaft is regulated. The machine is normally run at 560 r.p.m. with a load of 100 lbs. per sq. inch.

Our purpose had been, as I have said, to undertake an exhaustive series of experiments with this apparatus, testing standard oils of the three great classes, animal, vegetable and mineral, in a pure condition and mixtures of mineral oils with various percentages of the fatty oils.

A few preliminary tests, to which I shall refer later, had been carried out when war was declared. This unfortunate occurrence imposed a severe strain upon the resources, and especially upon the technical staff of the Belvedere works, and as each test occupies a whole day and calls for the continuous attention of a skilled observer, it has been found impossible to complete the series.

Under these circumstances, and in order to fulfil my promise to you, I have been under the necessity of utilizing information obtained from two series of tests undertaken many years ago, under my own observation, some particulars of which have already been submitted to you in a paper on marine lubrication which I read before you in 1910. I propose also to avail myself of data from Mr. Beauchamp Tower's elaborate investigations and experiments, and, finally, I hope to find some confirmatory evidence in support of my arguments in the incomplete series of tests made at Belvedere.

The first series of tests to which I refer was undertaken by myself personally, both as regards the ordinary laboratory tests and the mechanical or frictional tests.

The tests were made somewhere about the middle seventies of last century. The apparatus used was an Ingram and Stapfer oil tester (Fig. 1). Numerous oils were tested, but I can at present only find my reports on a few pure oils, which, however, will serve to illustrate one of the principles which I wish to emphasize this evening, viz., the statement made by Mr. Bourne in the last paragraph which I quoted from him (see page 94) that "if the viscidity of the unguent be greater than what suffices to keep the surfaces asunder, an additional resistance will be occasioned."

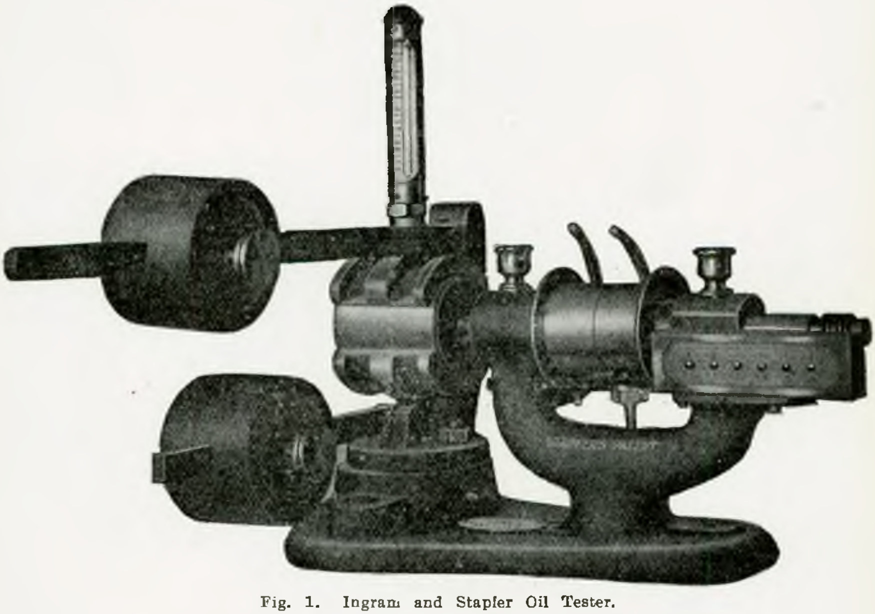


Fig. 1. Ingram and Stapfer Oil Tester.
By the courtesy of Messrs. W. H. Bailey & Co., Ltd., Salford.

Each test lasted ninety minutes. Each oil was tested two or three times, before breakfast, in the forenoon, and in the afternoon, sufficient time being given between each test to allow the bearing to cool down to the normal atmospheric temperature. The apparatus was fitted up in an engineer's shop—the works of John Norman & Co., Pulteney Street, Glasgow, and was subject to variation in speed of the machinery in the shop which was affected by the load on the engine when a big job was in hand. This accounts, in part, but not wholly, for the variation shown in the table (A) in the total number of revolu-

TABLE—C.

AVERAGE DATA FROM TESTS MADE BY THE AUTHOR ON AN INGRAM & STAPFER OIL TESTER.

Oils.	Specific Gravity at 60° Fah.	Viscosity. Sperm Oil at 70° F. taken as Unity.			Time required to attain Max. Temp	Maximum and Constant Temp.	Number of Tests of 90 min. each.	Total Duration of Tests of each Oil.	Total Revolutions during Tests.	Average Revolutions per minute.	Remarks.
		at 70° F.	at 120° F.	at 180° F.							
Sperm ..	880	100	45	28	27 min.	134° F.	3	270 min.	430,971	1596	The variation in the Total and average number of Revolutions was due partly to difference in the time required to attain full speed coinciding with maximum temperature, and partly to variation in the speed of the engine from which driving power was obtained.
Lard	917	223	79	38	29 ,,	147 ,,	2	180 ,,	292,389	1624	
Animal ..	920	218	81	39	33 ,,	144 ,,	3	270 ,,	414,214	1534	
Olive	916	213	75	36	32 ,,	145 ,,	3	270 ,,	416,342	1542	
Rape	916	250	88	41	42 ,,	153 ,,	3	270 ,,	411,645	1524	
Castor .	963	2500	390	90	50 ,,	162 ,,	2	180 ,,	227,623	1264	
Refined Rosin	990	—	—	—	90 ,,	157 ,,	2	180 ,,	281,425	1563	

tions for each test and in the average number per minute. As, however, each of the values given in the table is the average result of all the tests of each oil, I think that the effect of variation in engine speed may be largely discounted, and the greater part may be safely attributed to the greater or less viscidity of the oils.

The points calling for special attention in this table are:—

(1) The viscosity of the oil at 70° fahr., sperm oil being taken as unity.

(2) The time required to attain maximum temperature.

(3) The maximum and constant temperature.

The principal deductions to be drawn from the results shown are that, in a very consistent manner, the temperature developed on the bearing and the time taken to attain constant temperature, closely accord with the viscosity of the oil. The low average r.p.m. for castor oil and for rosin oil was doubtless due to the high viscosity of these oils which is responsible also for the long time required to attain maximum temperature.

Incidentally I ought to explain that in conducting these tests I had other evidence before me that the variation in the speed of the tester was not wholly, or even mainly, due to the speed of the shop. I was enabled to satisfy myself on this point by the fact that the belt driving the tester was loose and "slip" was visible for a longer or shorter period in starting with every oil except sperm.

The second series of tests was undertaken in 1886-1887, conjointly by Mr. T. J. Pullin, of Burton-on-Trent and myself.

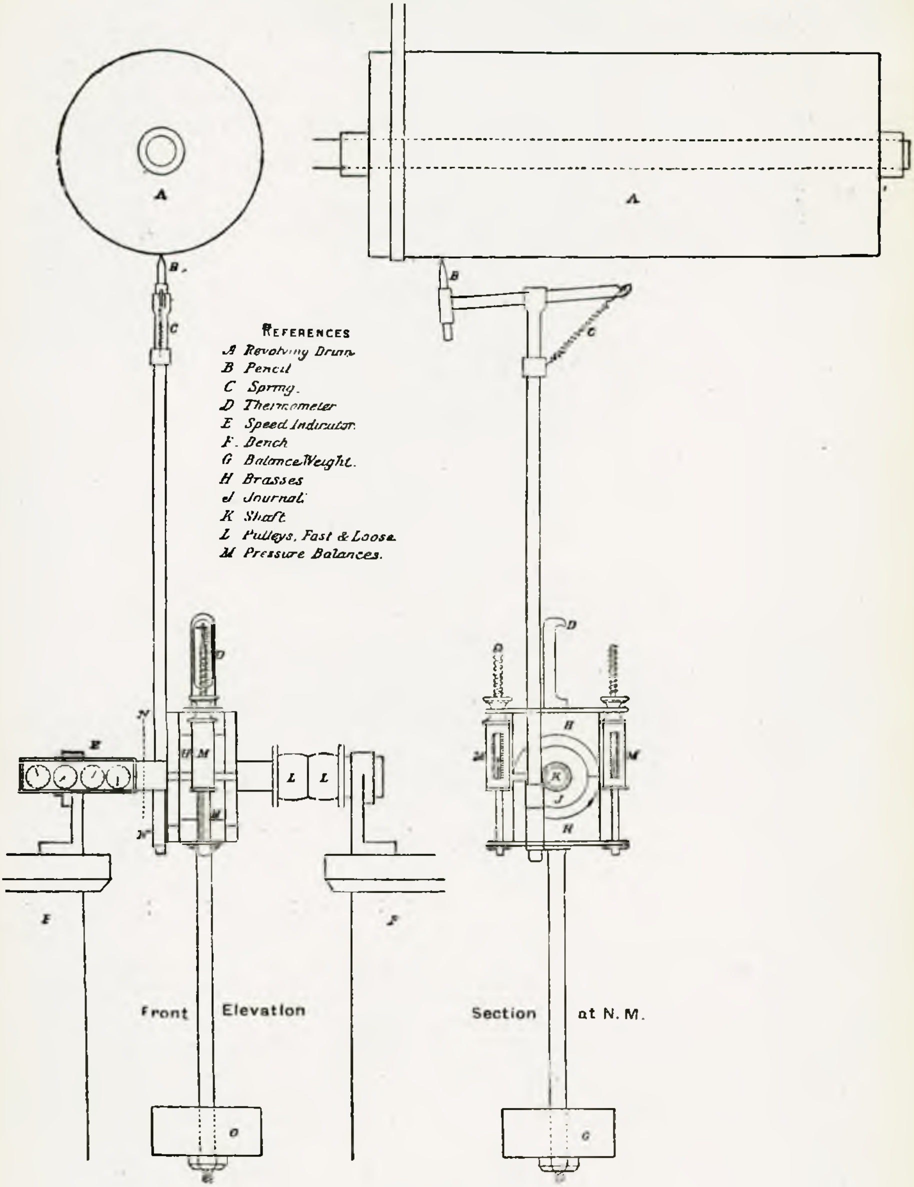
Consideration of the results obtained from my first series of tests had shown me that something more was wanted to determine the lubricative value of an oil than merely the temperature developed on a bearing during its use.

The other necessary factor was evidently that of the power required to drive the machine.

It had also occurred to me, in contemplating my earlier tests, that the reason why different oils developed and maintained different constant temperatures in use might be due to the fact that for each bearing, and subject to the conditions of load and speed, a suitable viscosity of oil was required, the temperature of the bearing continuing to rise till this had been attained.

Mr. Pullin, who took much interest in lubrication, had designed an apparatus, a cross between the Ingram & Stapfer and the "Thurston," fitted with an appliance which enabled him not only to measure, but automatically to record, the working resistance of each oil. I arranged with Mr. Pullin for a joint series of experiments to determine the correctness or otherwise of the theories which we had been discussing. I undertook to make the laboratory tests before and after the mechanical tests for which he was responsible.

His apparatus is shown in Fig. 2.



Scale ½ in to an inch

Fig. 2 T. J. Pullin's Autographic Dynometric Oil Tester.

The additional facts to be elicited by the enquiry were:—

(a) The resistance developed by each oil, and (b) the viscosity of the oil at constant working temperature.

The results of our joint investigations are shown in table B.

TABLE—D.

SHOWING THE PHYSICAL AND FRICTIONAL PROPERTIES OF VARIOUS STANDARD OILS COMMONLY USED FOR LUBRICATION.

Determinations by Messrs. T. J. PULLIN and J. VEITCH WILSON.

	DESCRIPTION.	Specific Grav. at 60° Fahr.	Flash Point Fah.	Average Viscosity at				Normal working		Visc'ty at working temp.
				60° F.	70° F.	120° F.	212° F.	Drag.	Temp' Fah.	
		1.	2.	3.	4.	5.	6.	7.	8.	9.
Water (distilled) ..		1,000	—	21	21	20½	boils.	—	—	—
Sperm (refined) ..	Southern ..	881	482	51	44½	30	24	18	189	25
,, ,, ..	Arctic	878	490	52	45	31	24½	18·5	194	25
Olive	Gallipoli	916	457	97	79	38	26	26·5	202	26½
,, ...	Smyrna	917	418	107	84	39	26	25	198	25½
,, ...	Saffi	915	430	89½	72	37	25½	26	202	26
Neatsfoot	British	916	458	108	83	40	26	27	208	26½
Lard Oil	Prime American ..	916	525	100	80	39	26	27·5	210	26½
Tallow Oil.. ..	British	914	456	109	87	40	28	27	204	26½
Refined Rape Oil..	"Special" ..	916	535	116	93½	43	27	32	214	27
,, ,, ..	German	914	498	114	88½	42	27	32	213	27
,, ,, ..	English	918	506	100	82	40	27	28	207	27
Castor Oil	French 1st ..	964	526	—	974	143	33	41	232	31½
Tallow (solid) ..	British	—	502	solid	solid	43	27	—	—	—

NOTE.—The viscosities given in this Table were determined by Coleman's Viscosimeter.

The interesting items in this table are the viscosities of the various oils at normal temperatures, and the normal working drag and temperature and the viscosity of each oil at the latter. I regret that the comparative results are not quite so consistent as one might have desired, but I give them as they occurred, without any attempt at correction, and, if allowance be made for error on the part of the observer, who, in the case of the mechanical tests, was not a scientific man, but an ordinary warehouseman, the results may be accepted as generally satisfactory. It will be observed that, in respect to working drag and temperature in relation to viscosity, the theory which I suggested in an earlier part of this paper is fully justified, as the drag and working temperature seem to adjust themselves very uniformly to the viscosity, while, although still subject to slight irregularities, it will be seen that all the oils were reduced to *practical uniformity* at their respective working temperatures.

This again bears out the correctness of Mr. Bourne's remark that "extra viscidity means extra resistance," as it throws upon the bearing the necessity for developing a higher temperature, at the expense of extra power, in order to reduce the lubricant to a suitable body.

In none of the foregoing tests are any particulars given of the behaviour of mineral oils, but, although I cannot at present find the records of tests made some forty years ago, I included several of the standard mineral oils of that period in my earlier experiments, and found that, as far as temperature was concerned, which was positively determined, and in regard to slip, which was a matter of personal observation, they seemed to behave similarly to fatty oils of corresponding viscosity.

It was, however, clearly demonstrated that whereas the few drops of fatty oil which were allowed for each test were never approximately exhausted during the period of the test, the mineral oils barely lasted out till the end of the test, while some of the lighter grades were visibly exhausted before the test was completed, in some cases with detriment to the bearings.

I now avail myself of Mr. Beauchamp Tower's valuable and interesting series of experiments, probably constituting the most exhaustive and instructive enquiry which has ever been undertaken in connection with the subject.*

Mr. Beauchamp Tower's experiments were made upon a cylindrical journal 6 ins. long by 4 ins. diameter, at speeds

* Reports upon friction experiments by Mr. Beauchamp Tower—Transactions of the Institution of Mechanical Engineers, 1st Report, November, 1883; 2nd Report, January, 1885; 3rd Report, May, 1888; 4th and last Report, March, 1891.

varying from 100 to 450 r.p.m., and loads of from 100 lbs. to 625 lbs. per square inch. From the numerous tables in which the results which Mr. Tower obtained are recorded, I have made the abstract shown in table C in which I give only the figures obtained at a load of 100 lbs. per square inch, as most nearly agreeing with the conditions under which the results shown in the other tables in this paper were obtained.

TABLE—E.

MR. BEAUCHAMP TOWER.—ABSTRACT OF EXPERIMENTS SHOWING FRICTION DEVELOPED BY DIFFERENT OILS ON A STEEL JOURNAL, 6 INCHES LONG × 4 INCHES DIAMETER, RUNNING AT VARIOUS SPEEDS AT A TEMPERATURE OF 90° FAHR. GUN-METAL BEARING, ARC OF CONTACT 3·92 INCHES, NOMINAL LOAD 100 LBS. PER SQUARE INCH.

Oil.	Spec. Grav. at 60° Fah.	Viscosity. at 70° Fah.	Viscosity. at 120° Fah.	Nomical Frictional Resistance per sq. in. of Bearing. 100 rev. 105 feet per min.	150 rev. 157 feet per min.	200 rev. 209 feet per min.	250 rev. 262 feet per min.	300 rev. 314 feet per min.	350 rev. 366 feet per min.	400 rev. 419 feet per min.	450 rev. 471 feet per min.
				lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Sperm	880/885	100	45	·25	·30	·38	·44	·51	·57	·61	·64
Rape	913/5	250	88	·28	·36	·42	·50	·58	·62	·66	·71
Lard	916	225/230	80	·35	·42	·50	·60	·67	·76	·81	·90
Olive	916	215/220	75	·36	·45	·55	·68	·69	·77	·82	·89
Mineral	905/910	200/225	55/65	·33	·42	·49	·56	·62	·68	·73	seized
Mineral Grease	—	—	—	·54	·76	·94	1·09	1·23	1·33	1·42	1·51

It is stated that the tests were made at a temperature of 90° fahr., but it is not shown that steps were taken to keep the bearing at this temperature or to take account of any variation, and, failing this, it is possible that some part of the reduction observed in friction may have been due to increased temperature.

No particulars are given regarding the physical properties of the oils used in testing. I have therefore added, in the columns headed specific gravity and viscosity, these average particulars of genuine specimens of the oils named. But, as all oils are subject to some variation in these respects, it must be remembered in studying this table that the particulars may not accurately represent the samples dealt with. These remarks apply particularly to the mineral oil as this includes grades varying in respect to viscosity from something lighter than sperm oil to something two or three times heavier than rape oil. As Mr. Tower, in reply to a question of mine upon this point, said that the "mineral oil" was that generally used in the shop, I have assumed that it may have been such a cheap mineral oil of moderate body as is frequently used in an engineer's shop in which more oil is wasted on the floor than is used on the machinery.

Subject to these explanations, this brief abstract of Mr. Tower's experiments is interesting and useful. The most important result for our purpose consists in the fact that while all the fatty oils lasted out the full period of the test and, for aught we know, might have lasted longer, the mineral oil "gave in" at 450 r.p.m., either because the oil was exhausted or because the oil was insufficient for the work, a striking corroboration as it seems to me of the failure of mineral oils which I had found in my own experiments.

Finally, we turn to the incomplete series of Belvedere experiments which had, as I have explained to you, for their purpose an attempt to determine directly the relative value as lubricants of fatty and of mineral oils—our intention was to select typical specimens of each class, and, after determining the physical properties of each, especially their viscosity at various temperatures, to test each oil in its pure state and subsequently to prepare and test mixtures of the various oils in order to ascertain the effect, if any, of the addition of fatty oils to mineral oils, in the reduction of friction.

All that the untoward circumstances have permitted us to do has been to test three standard mineral oils and a few of the leading fatty oils, and the results are shown in the following table:—

TABLE—F.

SHOWING RESULTS OBTAINED IN PRELIMINARY EXPERIMENTS ON THE "DODD" FRICTION TESTER FROM VARIOUS ANIMAL, VEGETABLE AND MINERAL OILS.

Description of Oils Tested.	Specific Gravity at 60° F.	Viscosity		Results after 8 hours running.			
		at 70° F.	at 140° F.	Pressure per sq. inch.	Temperature of bearing.	Viscosity at temp. of bearing.	Driving power B.T.U.
Sperm	880	100	37·8	100 lbs.	175° F.	30·9	5·75
Olive	916	217	56·4	100 lbs.	167° F.	31·8	7·50
Refined Rape ..	916	250	65·9	100 lbs.	177° F.	40·8	?
Castor	963	2,500 (?)	212·0	100 lbs.	190° F.	55·5	9·75
Heavy Pale Mineral..	912	775	84·0	65 lbs.	182° F.	54·6	8·00
Heavy Red	954	?	190·0	65 lbs.	210° F.	63·0	9·00
Vaseline Cylinder Oil	894	?	350·0	65 lbs.	230° F.	69·0	8·50

On account of continued pressure upon the staff at the Belvedere Works, it has been impossible to carry out the projected experiments, but the particulars given above have been compiled from a number of preliminary tests which were undertaken with a view to calibrate the tester in view of the contemplated investigation.

The results are not complete nor are they wholly concordant, but they show in a general way the superiority of fatty over mineral oils.

I exceedingly regret the imperfect and perfunctory manner in which I have fulfilled the very agreeable duty which you did me the honour of laying upon me. We have, all of us, suffered more or less through personal loss of some relatives or friends or in dislocation of business through the criminal megalomania of the greatest criminal of Europe—of the world, and, had it not been my desire to avoid responsibility for adding to the many troubles which already beset my good friend, your Honorary Secretary, I should have preferred to postpone the fulfilment of my task till, under happier conditions, I could have performed it with greater satisfaction to you and perhaps with some credit to myself. I thank you for the patient way in which you have dealt with my short-comings, and I trust that I may yet have an opportunity of redeeming my promise more successfully under more auspicious circumstances.

DISCUSSION.

The HON. SECRETARY: Mr. Wilson has prepared this paper and kept tryst with us to-night at much inconvenience and under many disadvantages, so that we are very much indebted to him for a most interesting paper, which could only be got from one of his experience. He has indicated some features that are generally known, but others may be new to us. The references to the oil being carried between the surface of the journal and the bearings and to the journal and the bearing surface being too smooth, are details open to discussion. There are many other points in the paper which should lead to discussion, and we have an opportunity of asking Mr. Wilson questions on the subject before us.

Mr. WARREN: I would like to ask Mr. Wilson a question. It is generallly recognised that mineral oils are better than animal oils on account of viscosity, but Mr. Wilson distinctly states that vegetable oils are an improvement. I am speaking rather from the factory than from the marine point of view, and from that point of view the mineral oil may come in better, as we have a distinct method for keeping the bearings cool. Has Mr. Wilson any idea how finely powdered graphite acts? There is a tendency when graphite is used for it to set on the lower bearings, so that it fills up the inequalities on the surface between the bearings and the journal. Perhaps these few remarks may induce discussion on the subject.

The CHAIRMAN: If there are any items which require explanation I hope members will mention them, so that we may have an opportunity of discussing them. Perhaps, in the meantime, Mr. Wilson would kindly answer the question with reference to the graphite.

Mr. VEITCH WILSON: Mr. Warren has raised two or three important questions in regard to the matter under consideration. He suggests that, on account of their viscosity, mineral oils are better lubricants than animal oils. He informs us that, in the case of the plant in which he is interested, special arrangements are provided for keeping the bearings cool, which has a very important effect on the result, and he asks whether I can offer any opinion regarding the value of graphite as a lubricant.

I shall attempt to deal with these points seriatim.

As regards the respective value, as lubricants, of mineral oils and of animal or vegetable oils, I did not think that any question could be raised as, during my fifty years' active connection with the oil trade and continual intercourse with men in all trades, both land and marine, in which lubricants are used, I have never met anyone who hesitated to express the opinion that in respect to their power of reducing friction, fatty oils, animal or vegetable, are superior to mineral oils. Under certain conditions, arising in connection with steam cylinders, steam turbines, ring bearings with bath lubrication, and some textile machinery, in which, through exposure to steam, to moisture or to the action of the atmosphere, fatty oils may develop acid, may be oxidised or may produce saponaceous compounds, the lubricative advantages of fatty oils may be surrendered in favour of mineral oils which are not affected by the conditions mentioned, but the only people whom I have met who advocate the universal superiority of mineral oils were those who are wholly and exclusively interested in their production.

As far as I am concerned I think that sufficient justification for the attitude which I assume, will be found in the friction tables which are given in my paper. If I am asked to offer reasons for the superiority which fatty oils possess over mineral oils, I would suggest:

(*a*) that fatty oils have greater surface tension, *i.e.*, that they have the power of being, by pressure or otherwise, reduced to a finer film than mineral oils without being ruptured.

(*b*) that, in regard to viscosity, which Mr. Warren regards as one of the points in which mineral oils are superior to fatty oils, the former are inferior to fatty oils in respect that mineral oils are affected by heat to a much greater extent than fatty oils, and rapidly and to a great extent lose their body as the temperature rises.

This disadvantage may be wholly or partly overcome in Mr. Warren's case if his cooling arrangements enable him to maintain a constant temperature on his bearings.

I may add that numerous cases have come before me in which, when pure mineral oils have failed to give satisfaction, the addition of a small percentage 5, 10 or 15 per cent., of animal or vegetable oil has given perfectly satisfactory results.

As regards the value of graphite as a lubricant, it is commonly supposed that it should improve lubrication, but reports which I have received from some who have tried it rather point in the contrary direction. Some advocates of graphite, including Dr. Atcheson's Company, maintain that it is a very fine thing and that means of incorporating what is supposed to be graphite, in a deflocculated form, in oil has been discovered. But the question as to whether it is or is not really graphite has been raised and it is also questionable whether the improvement claimed is due to superior lubricating properties or to some improvement in the surfaces of the bearings.

One of the series of practical experiments to which I refer was conducted in our own works at Belvedere, with graphite and with various kinds of oils, and the results were unsatisfactory. I do not want to emphasize this too much, and I should like to investigate it further. The surfaces may have been improved, but we were not induced to adopt graphite. I may add that we had recently given us, in confidence, a long series of reports upon a number of experiments conducted by an eminent firm of continental engineers. They were interested in the graphite question and made extensive tests, taking ordinary shop oils, and although I cannot recall the figures I remember that the outcome was that they found that they did better with ordinary cheap oils than with graphite, and by using their own oil a little more liberally they got better results. I am sorry that this is all the information I have at present.

(Mr. Veitch Wilson then exhibited two large photographs of the "Dodd" testing apparatus to which he had referred in the course of his paper. These photographs, which are reproduced below, were fully described by Mr. J. J. Paton, Head Engineer

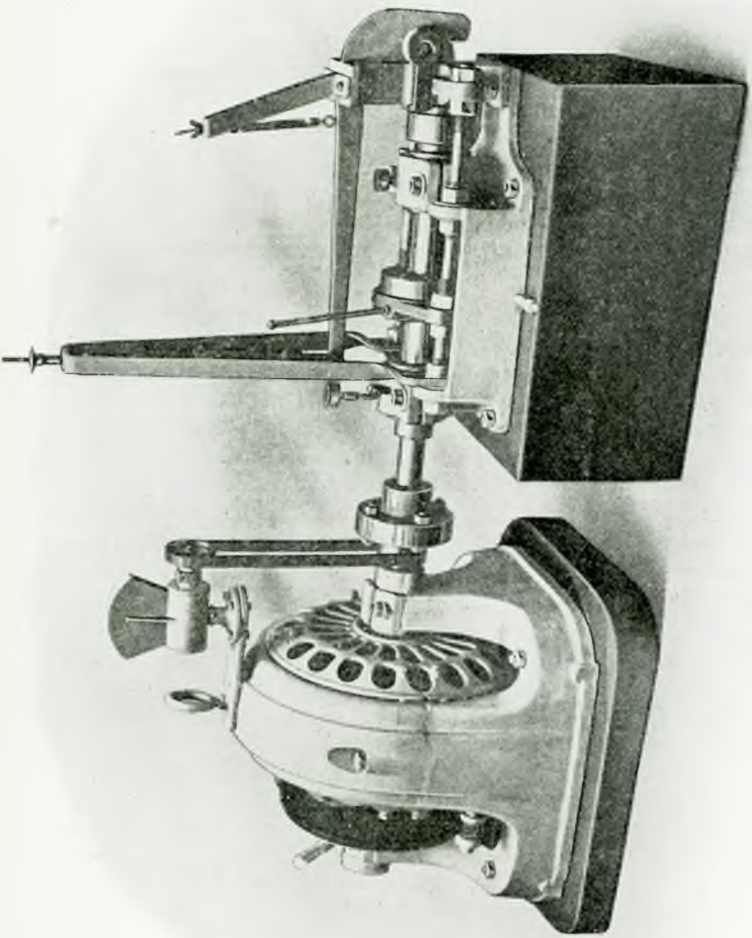


Fig. 3. Mr. A. J. Dodd's Friction Tester (Front View).

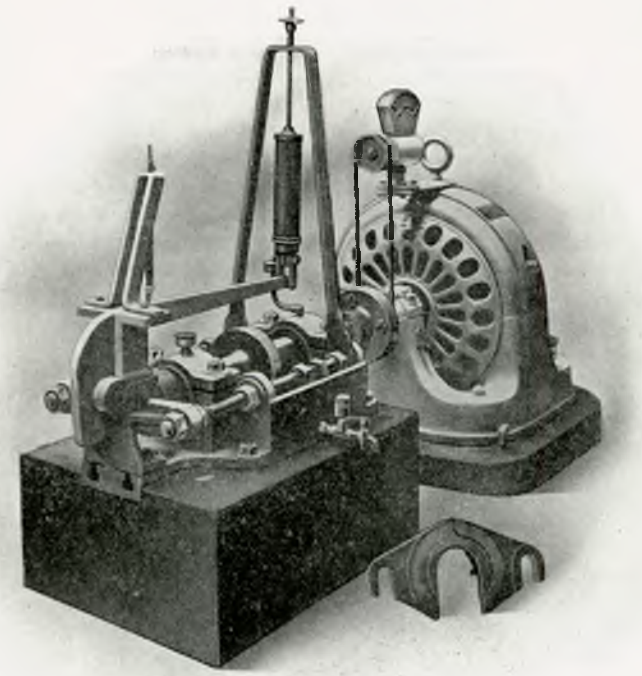


Fig. 4. Mr. A. J. Dodd's Friction Tester (End View).

of the Belvedere Works, who answered numerous questions regarding them. Mr. Paton explained that they endeavour to get the comparative tests made, as nearly as possible, under the same conditions, using about a pint of oil in each test. The result of these tests pointed to an improvement by the introduction of fatty oil with the mineral oil as the mineral oil alone only seemed to hold good for moderate temperatures, being unsatisfactory for higher temperatures. He supposed that the addition of fatty oil to the mineral oil gave greater unctuousity.)

Mr. J. Clark: We always listen to Mr. Wilson's papers with great interest, as we know he is a great authority on oils, and I think I am right in saying that he advocates a compound oil. It has been mentioned with the comparative tests that the compound oils broke down under certain conditions. Mr. Wilson has given us a table of Mr. Beauchamp Tower's results which confirms this. At the same time, it is perhaps necessary to consider some of the results given in this table. The viscosity of olive oil is given as 215/220 at 70° Fahrenheit and 75 at 120° Fahrenheit respectively; taking frictional resistance from the table at 100 revolutions per minute, the frictional resistance is given as ·36, carried on to 450 revolutions per minute it is ·89. The mineral oil in the table comes next; it starts with a lower normal frictional resistance and maintains that lower rate up to 400 revolutions, then at 450 the bearing has seized. It is unsatisfactory, one must admit, that there is no reason given why the bearing then seized. Why should a mineral oil maintain itself up to 400 revolutions and then at 50 revolutions more the bearing seizes? There are many things to cause a bearing to seize, but one of the last things blamed is the oil. The inference in this instance is to the opposite. I should like to ask a question regarding the proper lubrication of ball bearings. Some makers advocate greases, others oil. Mr. Wilson has referred to tests that he was unfortunately unable to complete in time to give us the results to-night, but, if I am not trespassing, I might suggest that perhaps he may be induced to give us these tests later on, because from what has been said they are evidently of very great use in connection with oils. Then, with regard to Mr. Wilson's remarks about the waste of oil, I do not think anyone will deny there is a considerable amount of oil wasted, but I hope that there is not anyone here present who will agree that more oil is wasted on the floor than is put on the machinery. In such a case somebody ought to get into trouble.

Mr. Veitch Wilson: Mr. Clark has called attention to Beauchamp Tower's experiment, made some thirty years ago. As far as I can now remember I was present at some of the meetings when he presented his reports, and I took some part in the discussion upon the subject, but, as I have explained in my paper, Mr. Tower gave no particulars of the oils which he used, which is unfortunate. Mr. Clark calls attention to the fact that no explanation is offered why mineral oil which, apparently, continue to give satisfactory results up to 400 r.p.m. should have seized at 450 r.p.m. It may, of course, have seized at some point not stated between 400 and 450, but I think that the explanation is, and I called attention to it in discussing the paper, that, as no special arrangements were made to maintain a constant temperature and no note seems to have been taken of the temperature of the bearing, the temperature was unsuspectedly rising with the speed of the journal and the body of the oil was being proportionately reduced by the increasing temperature till somewhere between 400 and 450 r.p.m. the film of oil was ruptured, metallic contact ensued, and the bearing seized. In the course of my own experiments in 1875 I had a similar experience. My tests included mineral oils, although particulars of these are not given in the table on page 100. I observed, however, that mineral oils in regard to temperature developed, and the frictional resistance behaved very much like fatty oils of the same viscosity, but while in no case were the fatty oils exhausted by the end of my tests, the mineral oils invariably showed signs of exhaustion before the tests were completed and in the case of some of the lighter oils having about the same viscosity of sperm oil, the bearing began to whistle and smoke within half-an-hour, and the brasses were found to be fired and scored, although the fatty oils all ran normally till the end of the test.

Mr. Clark also refers to acidity. This is a point upon which I have not touched as I think that we have heard sufficient of acids and their effect upon bearings and know how to avoid them.

As regards ball bearings, the firm of Hoffman recommend grease, but I think that, on the whole, the users of ball bearings prefer a compound oil, and I think that it is best. Grease acts as a packing, and prevents grit, moisture or other matter from getting into the bearing, but I think that, if the bearings are oil tight, oil will give better results.

With regard to the waste of oil on the floor, I may perhaps be permitted to justify my statement by saying that I had my information from the head of a well-known firm of engineers in Glasgow, Messrs. Clarkson, who once said to me "I know the advantage of using better oils, but three-fourths of the stuff goes on the floor and the cheapest oil is good enough for that."

The Chairman: There used to be great stress laid on the use of graphite; evidently graphite is very useful in reducing friction, and, if we could get some definite tests it would be very interesting. I have used graphite myself many times in connection with ball bearings, in the same way as I have used sulphur. But according to what Mr. Wilson has said, graphite is not good used in large quantities. He also pointed out that fatty substances have to be reduced to oil before they are lubricants. This opens up another feature for review.

Mr. Veitch Wilson: In reply to the Chairman's remarks regarding the use of graphite, I take this opportunity of saying, in addition to what I have already said this evening, that, as greases may carry particles of lime or of other hard substances, which may damage the delicate surfaces of the balls, such semi-solid lubricants ought to be carefully avoided, and the same remark applies especially to all lubricants, whether in the form of grease or oil, into the composition of which graphite enters.

A Member: There is one more point I should like to mention with reference to the remarks about vegetable and mineral oils. I think the point is that mineral oil does not last, it breaks up more rapidly. If anybody takes the trouble to look at mineral oil and apply heat, he will see, if he look at it, that it breaks like glass when it goes on the journal, the apparent body of the oil is rapidly lost; and if you want the oil so thick that it requires heat to thin it, does not this reduce its effectiveness? Is this a characteristic of the action of the mineral oil, or of certain compound oils.

Mr. Veitch Wilson: I entirely endorse the remarks which have been made by the last speaker. I would only add, in reference to his concluding remark, that the addition of fatty oil to mineral oil seems to exert a softening influence upon the latter, may even be supposed to grease the molecules of the mineral oil and to reduce their internal friction. Or it may be that the mineral oil serves as a vehicle for the distribution of the fatty oil while the fatty oil does the lubrication. It is a strange thing, well known to those who have given attention to the matter, that, if we mix, say equal quantities or any other proportions of a mineral oil and a fatty oil of known viscosities, the viscosity of the mixture is lower than the arithmetical mean of the viscosities of the separate oils, which seems to support my theory that the internal friction of the mixture has been reduced.

The Chairman: I believe there is a division of opinions as regards mineral and vegetable oils, and I think that Mr. Wilson recommends a mixed oil for internal combustion motors. We also find as regards lubrication that hydrocarbons or mineral oils are generally preferred in extreme heat. It is more the efficiency of lubrication that Mr. Wilson has brought before us to-night, and unfortunately he is not able to give us the tests he hoped to give. If no further remarks are forthcoming, I will ask Mr. Wilson to give us a few concluding remarks.

Mr. Veitch Wilson: The Chairman has raised the very important question of the use of mineral oils in internal combustion engines. You cannot very well test lubricants in your engine on the bench, but we have another means of comparison altogether. If a man is going to Brooklands, he sends for a gallon or two of cheap oil for use on the road, but, directly he gets on the track he uses compound oil. Aviators have even been using castor oil, an expensive oil, and one difficult to introduce to the engine. They use compound oils when they want to get the best result out of their machines, and cheap oils when they are jogging along in the ordinary way and do not want high results. I was recently discussing internal combustion engines with the Managing Director of a well known firm of makers of gas and oil engines when he disagreed and said: "You and I belong to different schools, you have your ideas and I have mine." I thought I had more information and said that I knew cases in which gas engine makers, who do not use compound oil regularly, take it for their trials and show engines. But, if an engine wants feeding give it compound oil. I have heard this from a good many people whose names I am not at liberty to quote. I discovered on a recent visit to one of these continental makers, that he had changed his view as to the mechanical effects of the introduction of a mineral oil for lubrication for internal combustion engines and had adopted compound oils. A 10 per cent. mixture has been used with satisfactory results where a mineral oil has failed. I give this as an example, not as a dogmatic assertion.

A vote of thanks was then proposed and passed to Mr. Veitch Wilson for his very interesting paper, and also to the Chairman for presiding.