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ENGINEERING EXPERIMENT STATION SERIES

VOLUME 4 NUMBER 2

COMPARATIVE TESTS OF CYLINDER OILS

BY

M. P. WEINBACH

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
June, 1913

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INTRODUCTION.

The cylinder oil tests described in the following pages are to be regarded as a continuation of Vol. 2, No. 2 of the Engineering Experiment Station Series: "Friction and Lubrication Testing Apparatus" by Mr. A. E. Flowers, formerly Assistant Professor of Electrical Engineering, University of Missouri. This bulletin was a report on the oil testing apparatus devised by him, and which has been used to test and compare the lubricating values of the samples of cylinder oils reported in the present bulletin.

It is generally agreed among operating engineers, that the present specifications based on the chemical and physical constants of an oil (the specific gravity, flash and fire tests, viscosity, acidity, per cent animal and vegetable fat, etc.), do not give sufficient information as to their value as a friction and wear reducing agent. Even these chemical and physical constants are very often not supplied to the purchaser, with the result that the operating engineer finds himself in a difficult position when he has to choose between a certain number of oils of different costs, different compositions and of different and also unknown lubricating values.

It was this difficulty experienced in the selection of a proper cylinder oil to be used at the Light and Heat Station of the University of Missouri, that has led the Engineering Experiment Station to develop an apparatus for the testing of the lubricating value of cylinder oils under conditions identical to every-day practice.

Nine samples of cylinder oils, designated by the first nine letters of our alphabet, were tested; the results of these tests are given in the following pages.

PHYSICAL PROPERTIES.

Color and Consistency. The color and consistency of the oils tested are given below:

Oil	Color	Consistency
A	Dark brown	Thick
B	Dark green	Thick
C	Dark	Thick
D	Brown	Thick
E	Dark brown	Thick

F	Brown	Thick
G	Reddish brown	Limpid, flows easily
H	Black	Thick
I	Reddish	Clear, flows easily

Specific Gravity. The specific gravity or the weight per unit volume of the oils at different temperatures was determined by using a direct reading hydrometer, and their comparative values are shown in Figure 1, where the specific gravity is plotted as a function of the temperature.

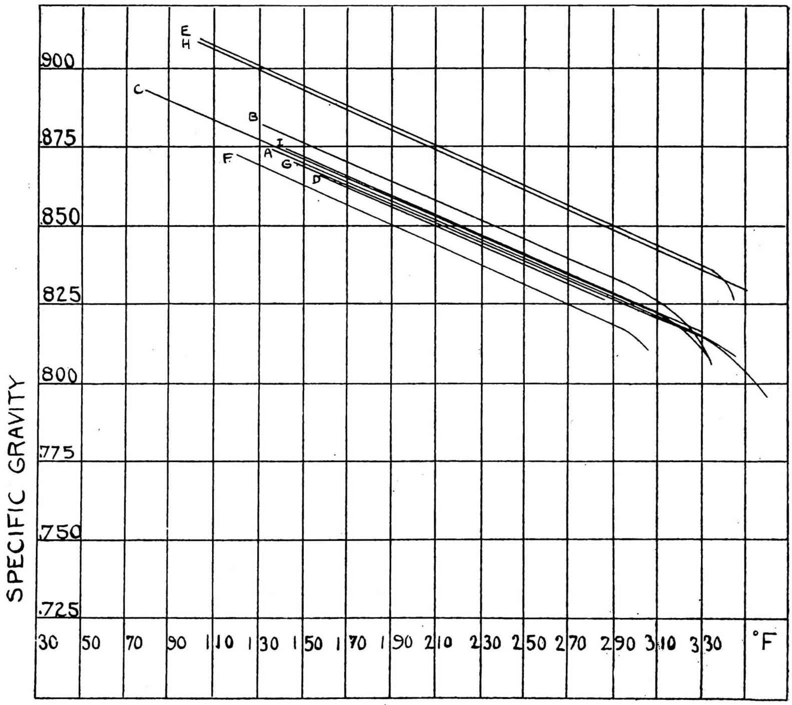

Fig. 1

From these curves we can readily see that as to their comparative heaviness at the temperature of boiling water (212°F) the oils tested rank as follows:

TABLE 1.

Oil	Sp. Gr.
E	.875
H	.873
B	.857
A	.855
I	.855
C	.855
G	.851
D	.849
F	.844

It is to be noted the oils A, C and I, though entirely different as to color and consistency have the same specific gravity throughout the range of temperatures under which they have been tested.

Flash and Fire Tests. The open flash point is the temperature at which the oil flashes under atmospheric pressure when a flame is brought near its surface. This was determined in the usual manner by nearly filling a tin cup with a sample of oil and heating it gradually over a sand bath and passing over the surface of the oil a lighted match until the oil starting to vaporize, the vapor ignites with a flash.

By repeating this test till the surface of the oil catches fire, we obtain the fire point or fire temperature.

It is generally inferred that the flash point being more or less an indication of the temperature at which an oil begins to decompose, would naturally indicate whether an oil is suitable or not for high temperature work. But it is also more or less evident that the flash and fire temperature is very much different at the various pressures in the cylinder as compared with the flash and fire temperature at atmospheric pressure because in the cylinder, the oil being, so to say, intimately mixed with steam, its chemical composition might be somewhat changed. The open flash and fire temperatures are given, as are all the other physical and chemical constants, as a possible and probable means of identifying the oils.

According to their flash points the oils ranks as follows:

TABLE 2.

Oil	Flash Temp.	Fire Temp.	Difference
D	568° F.	616° F.	48° F
F	568°	605°	37°
C	559°	606°	47°

B	553°	602°	49°
G	546°	610°	64°
A	533°	602°	69°
I	493°	564°	71°
E	487°	519°	32°
H	478°	514°	36°

It should be noted from the above table, that with the exception of oils D, C, A, I, E and H, which occupy the same rank in the flash and fire points, oil B is the fourth in the flash point and ranks the sixth in the fire test; oil F stands the second in the flash and the fourth in the fire test, while oil G is the fifth in the flash and second in the fire test. There is no apparent reason for these oils to behave in this manner.

Viscosity. The viscosity or the resistance of the oils to flow at various temperatures was measured by means of a "home made" electric viscosimeter.

This viscosimeter was made of a copper cup, fitted at its bottom with a standard nozzle, and around which was wound a resistance unit of german silver wire, the turns and layers of resistance wire being properly insulated from each other and from the cup.

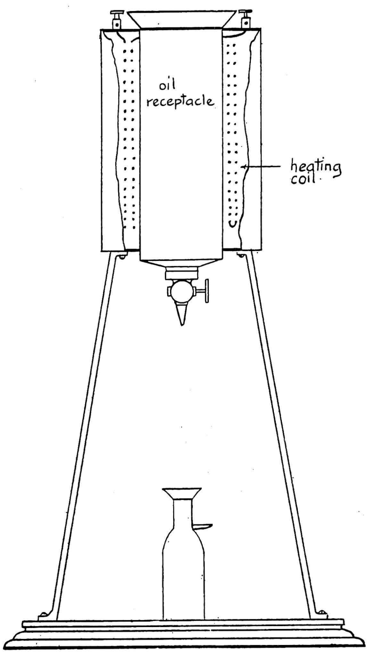

Fig. 2.

A maximum electric current of of 1.5 amperes was allowed to flow through the resistance unit, and the heat generated was sufficient to bring the oil in the cup to a temperature of 400° F in about 8 minutes. The control of temperature was obtained by varying the current in the resistance unit by means of suitable rheostat.

A sketch of this viscosimeter is shown in Figure 2.

The comparative viscosity of the oils tested are given in the following table for temperatures of 212° F, and 327.8° F (corresponding to 100 pounds steam pressure), the viscosity of water at 25° C (77° F) being taken as unity.

TABLE 3.

Oil	Viscosity At 212° F	Viscosity At 327.8° F
C	4.00	1.50
A	3.18	1.37
F	2.94	1.46
B	2.88	1.42
I	2.80	1.44
D	2.62	1.37
H	2.60	1.44
E	2.40	1.25
G	2.32	1.25

It is easily seen from the above table that at higher temperatures, the viscosity of all the oils tested approach the viscosity of water, and also that the oils do not rank in the same order for the higher temperature as they do for the temperature of 212°F.

CHEMICAL CONSTANTS OF THE OILS.

The determination of the acidity, saponification number, iodine absorption number, and per cent animal and vegetable fats were determined in the Dairy Research Laboratory by Mr. H. F. Yancey through the courtesy of Mr. L. S. Palmer, Dairy Chemist.

Acidity. The method used to determine the acidity is the one given by Allen†, and is as follows:

Weigh about 15 grams of oil into a 200 c c. Erlenmeyer flask. Add 50 c. c. of 95 per cent alcohol which has been neutralized with a weak solution of caustic solution using phenolphthalein as indicator, and heat to boiling. Agitate the flask thoroughly in order to dissolve the free acids as completely as possible. Decant the solution through a filter, and collect the filtrate in an Erlenmeyer flask. Repeat this operation six or seven times in order to get all of the free acid into the filtrate. Titrate hot with tenth normal alkali,‡ agitating thoroughly until the pink color persists after vigorous shaking.

The results are expressed either as percentage oleic acid or as acid value, that is, the number of milligrams of potassium hydroxide required to neutralize the free acids contained in one gram of oil tested.

It was found necessary to filter off the alcoholic solution from

†Allen, Commercial Organic Analysis, 3d Ed.

‡One cubic centimeter of tenth normal alkali is equal to 0.0282 grams of oleic acid.

the insoluble oil, because the dark color of the oil obscured the endpoint of the titration.

Saponification Number. The saponification number is the number of milligrams of potassium hydroxide required to saponify one gram of oil.

The method used for its determination is the official method, as given in Bulletin No. 107 (revised) U. S. Dept. of Agriculture, and is as follows:

Preparation of reagents:

1. Alcoholic Potash Solution.—Dissolve 40 grams of chemically pure potassium hydroxide in one liter of 95 per cent redistilled alcohol. The solution must be clear and the potassium hydroxide free from carbonates.

2. Standard Acid Solution.—Prepare accurately half normal solution of hydrochloric acid.

3. Indicator.—Dissolve 1 gram of phenophthalein in 100 c.c. of 95 per cent alcohol.

Determination:

Weigh about 10 grams of oil into a 300 c. c. Erlenmeyer flask. Run in 50 c. c. of the alcoholic potash solution, put on steam bath, and connect with reflux condenser. Allow to remain on steam bath for three hours with occasional shaking. Filter through paper, and wash unsaponifiable matter with hot alcohol until one drop of the filtrate from the filter shows no alkalinity to phenophthalein. Titrate the hot filtrate against half normal hydrochloric acid using phenolphthalein as indicator.

Conduct two or three blank experiments to determine the amount of alkali added to each sample in terms of the acid. To obtain the saponification number subtract the number of cubic centimeters of hydrochloric acid to neutralize the excess alkali after saponification from the number of cubic centimeters necessary to neutralize the 50 c. c. added; multiply the result by 28.06 (the number of milligrams of potassium hydroxide equivalent to 1 c. c. half normal acid) and divide by the number of grams of oil in the sample.

The unsaponifiable matter in the oils tested had to be separated from the solution, because its presence obscured the end point of the titration.

Iodine Absorption Number. The method used for the determination of the iodine absorption number of the oils is the Hübl official method as given in Bulletin No. 107 (revised) U. S. Dept. of Agriculture.

Preparation of Reagents:

1. Hübl's Iodin Solution.—Dissolve 26 grams of pure iodin

in 500 c. c. of 95 per cent alcohol. Dissolve 30 grams of mercuric chlorid in 500 c. c. of 95 per cent alcohol. Filter the latter solution if necessary, and mix the two solutions. Let the mixed solutions stand twelve hours before using.

2. Decinormal Sodium Thiosulphate Solution.—Dissolve 24.8 gr. of chemically pure sodium thiosulphate, freshly pulverized as finely as possible and dried between filter or blotting paper, and dilute with water to 1 liter at the temperature at which the titration is to be made.

3. Starch Paste.—Boil 1 gram of starch in 200 c. c. of distilled water for 10 minutes and cool to room temperature.

4. Solution of Potassium Iodid.—Dissolve 150 grams of potassium iodid in water to make up 1 liter.

5. Decinormal Potassium Bichromate.—Dissolve 4.9083 grams of chemically pure potassium bichromate in distilled water and bring the volume up to 1 liter at the temperature at which the titrations are to be made. The bichromate solution should be checked against pure iron.

Determination:

1. Standardizing the Sodium Thiosulphate Solution.—Place 20 c. c. of the potassium bichromate solution, to which has been added 10 c. c. of the solution of potassium iodid, in a glass stoppered flask. Add to this 5 c. c. of strong hyrochloric acid. Allow the solution of sodium thiosulphate to flow slowly into the flask until the yellow color of the liquid has almost disappeared. Add a few drops of the starch paste, and with constant shaking continue to add the sodium thiosulphate solution until the blue color just disappears.

2. Weigh about one half gram of the oil on a small watch crystal; heat and mix thoroughly; pour into another watch crystal and allow to cool. Introduce the watch crystal (containing the oil) into a wide-mouth 16 ounce bottle with ground glass stopper.

3. Absorption of Iodin.—Dissolve the oil in the bottle in 10 c. c. of chloroform. After complete solution has taken place, add 40 or 50 c. c. of the iodin solution. Place the bottle in a dark place and allow to stand, with occasional shaking, for eight hours. This time must be closely adhered to in order to get good results. The excess of iodin should be at least twice as much as is absorbed.

4. Titration of the Unabsorbed Iodin.—Add 20 c. c. of the potassium iodid solution and shake thoroughly, then add 100 c. c. of distilled water to the contents of the bottle, washing down any free iodin that may be noted on the stopper. Titrate the iodin with the sodium thiosulphate solution which is added gradually, with constant shaking, until the yellow color of the solution has almost

disappeared. Add a few drops of starch paste and continue the titration until the blue color has entirely disappeared. Toward the end of the reaction, stopper the bottle and shake violently, so that any iodin remaining in solution in the chloroform may be taken up by the potassium iodid solution.

5. Standardizing the Iodin Solution by Thiosulphate Solution.—At the time of adding the iodin solution to the oil employ two bottles of the same size as those used for the operations described under paragraph 3, 4, and 5, the extra bottle being used for standardizing the iodin solution, no oil being present. The blank experiments for standardizing must be made each time the iodin solution is used. Great care must be taken that the temperature of the solution does not change during the time of the operation, as alcohol has a very high coefficient of expansion, and a slight change of temperature makes an appreciable difference in the strength of the solution.

Per cent of Animal and Vegetable Oils. According to Sherman's Organic Analysis pp. 147 and 192, if any oil has a low saponification number and also a low iodin number, it may safely be assumed that the oil in question is composed of a large percentage of mineral oil and a correspondingly small percentage of animal and vegetable fats, and if such is the case, the percent fatty oils can be estimated with sufficient accuracy for most purposes from the saponification number, since fatty oils which are likely to be present in mixed lubricants do not vary greatly in their saponification number.

In estimating the percent animal and vegetable fats present in the oils tested a saponification number of 190 was used.

The following table shows the results of the above described tests:

TABLE 4.

Oil	Free acid value	Free oleic acid	Saponif. number	Iodine number	Animal and vegetable fats
B	trace	trace	8.5	14.56	4.47
A	.133	.097	12.2	15.32	6.42
G	.125	.087	14.3	14.32	7.52
I	.575	.405	17.1	11.36	9.08
D	.238	.169	18.4	13.70	9.25
F	.098	.073	21.0	12.80	11.05
C	.176	.127	25.2	12.21	13.26
E	.367	.280	34.9	16.37	18.38
H	.362	.254	35.8	15.90	18.84

The above table shows that all oils tested have a very low acid value, also low saponifications and iodin numbers. Naturally these facts indicate the high percentage of mineral oil and the low percentage of animal and vegetable oil.*

FRICTION TESTS.

The following description of the friction testing apparatus is given by Mr. A. E. Flowers, who designed it, in Vol. 2, No. 2 of the Engineering Experiment Station Series:

"The method of measurement (of the friction coefficient) . . . was to measure electrically the input to a motor and to subtract the motor losses. The motor was provided with a crank disk and connecting rod, driving two pistons fastened on the opposite ends of a piston rod with a steam space, and a pocket for collecting condensation between pistons." . . . Two Detroit one pint lubricators "connected to steam pipes entering the cylinder near the ends, just inside the inner portions of the cylinder" fed the oil to the cylinder. "The use of two pistons with a steam space between them prevents the steam from doing any work itself or having work done on it. Each end of the connecting rod was fitted with Hess-Bright ball bearings so that its friction is negligible compared with that of the pistons." . . . . "The cylinder bore is 5 inches and each piston has 3 standard type, cast iron piston rings, the width of each being .2175 inches. These rings gave a pressure of about 3.23 pounds per inch of circumference and 14.92 pounds per square inch after being worked to a fit. As the cylinder ends are open, only one face of the piston is subjected to steam pressure and temperature, the other face being subject to conditions corresponding to those of the exhaust of a non-condensing engine."

This method of measuring the friction coefficient in a steam cylinder by means of an electric motor is not entirely new. Mr. F. C. Wagner has used it in making friction tests of a locomotive slide valve. (Proc. A. S· M. E. Vol. XXI, 1900, p. 242.)

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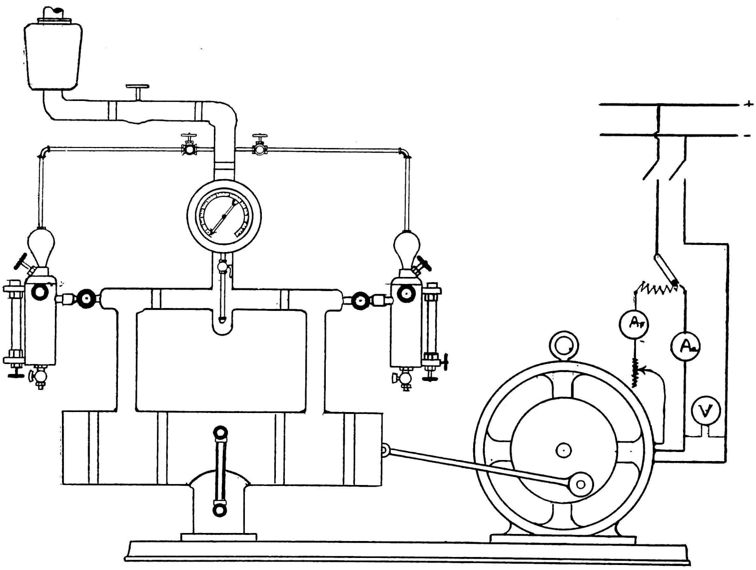
*For more detailed information on the chemical analysis of cylinder oils see A. C. Wright, The Analysis of Oils; Stillman, Engineering Chemistry; A. H. Gill, Oil Analysis; Sherman's Organic Analysis.

The following sketch shows diagramatically the testing apparatus above described.



APPARATUS FOR MAKING LUBRICATION TESTS.

Fig. 3.

The steam, after passing through a steam separator and reducing valve, is admitted into the cylinder, the steam pressure being obtained by means of an Ashcroft standard gauge.

The motor supplying the motive power was an Interpole motor made by the Electro-Dynamic Co. of Bayonne, N. J., and rated V. 110—H. P. ½—R. P. M. 400-1600 and throughout all the tests was run on constant supplied voltage of 90 volts and with a constant excitation of .300 amperes, the speed of the motor varying slightly from 620 revolutions per minute under various steam pressures in the cylinder, and various conditions of oil feed thus giving an approximate piston speed in the cylinder of about 520 feet per minute.

This motor has been carefully calibrated for losses by Mr. Flowers before and recalibrated by the writer after the tests were made, the difference in results being of no consequence.

Each of the oils has been tested under varying pressures up to or a little over 100 pounds per square inch steam pressure, and with three different conditions of feed, namely 10, 20 and 30 seconds to the drop, that is six, three and two drops to the minute. The feed of the oil was maintained as far as possible constant during each test.

The following readings were taken:

Voltage supplied to the motor, constant at 90 volts.

Field current of the motor, constant at .300 amperes.

Armature current of the motor, variable, depending upon kind of oil used, feed, and steam pressure.

Oil feed, in seconds to the drop.

Steam pressure in pounds to the square inch, gauge.

The temperature of the rubbing surfaces, by means of thermometers in "pockets" within 1-16 of an inch of the inner cylinder wall and opposite the mid stroke position.

Calculations.. The calculations were made as follows:

Let **E** = voltage supplied to the motor armature.

I = armature current for any reading during a test.

R = resistance of the armature of motor at the working temperature.

L = friction and iron losses of the motor corrected for armature reactions occuring for an armature current (I).

Then

EI = power supplied to the motor armature in watts.

$EI - (I^2R + L)$ = watts power output of the motor, supplied to the cylinder to overcome the friction. In terms of horse power this amounts to

$$\frac{EI - (I^2R + L)}{746} \text{ Horse Power.}$$

If **F** = drag force and

V = speed of piston in feet per minute, then

$$H.\ P. = \frac{F \times V}{33000}$$

Hence the drag force $F = 33000 \dfrac{EI - (I^2R + L)}{746V}$

Now if **f** = friction coefficient, and

P = normal pressure exerted on the cylinder walls,

$$f = \frac{F}{P} = 33000 \frac{EI - (I^2R + L)}{746\, V\, P}$$

Results. The results of the friction tests above described are shown graphically in the following nine plates, Figs. 4 to 12 inclusive, each plate representing the variation of the friction coefficient of one oil with the steam pressure in pounds per square inch, and also with the corresponding temperature in degrees Fahrenheit. The three curves on each plate are for three different conditions of feed, the upper curve being for a feed of 30 seconds to the drop, (or 2 drops to the minute), the middle curve for a feed of 20 seconds to the drop (or 3 drops to the minute), and the lower curve for a feed of 10 seconds to the drop (or 6 drops to the minute). Each of these curves is a composite curve of at least three different sets of observations under similar conditions of feed. For some oils as many as six different sets of observations were taken to check and thus insure uniform results.

An analysis of the curves shows that for most of the oils tested, the friction coefficient decreases with increase of the quantity of oil supplied, and also a decrease in the friction coefficient under the three different conditions of feed with increase of steam pressure, the friction coefficient becoming more or less constant with higher steam pressures.

This last statement is especially true for oils A, B, E, and G, as seen from curves Figs. 4, 5, 8 and 10.

The other oils behave in a rather peculiar manner. Thus for oil C the above statement is true only for feeds of 10 and 20 seconds to the drop, while for a feed of 30 seconds to the drop, with the exception of a slight decrease up to 50 pounds per square inch of steam pressure, the friction coefficient is almost constant at .0640.

A similar but more pronounced result was obtained for oils F and H, the coefficient of friction being .0660 and about .0510 for the two oils respectively at feeds of 30 seconds to the drop for each oil.

A still more pronounced result of a similar nature was obtained for oil D, for which the friction coefficient is constant at about .0600 and .0560 for 30 and 20 seconds to the drop respectively.

The results for oil I are still more peculiar in as much, that while the friction coefficient for a feed of 30 seconds to the drop decreases with the steam pressure as it does for the other oils at higher feeds, the friction coefficient for feeds of 10 and 20 seconds to the drop apparently increases with the steam pressure, as seen from the curves in Fig 12.

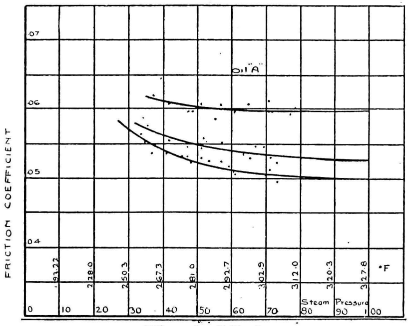


Fig. 4, Oil A.

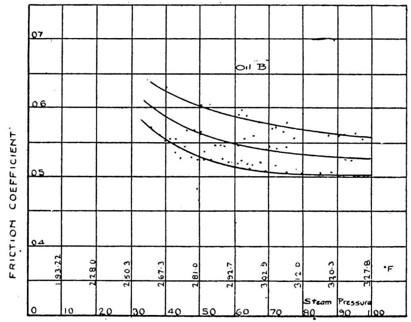


Fig. 5, Oil B.

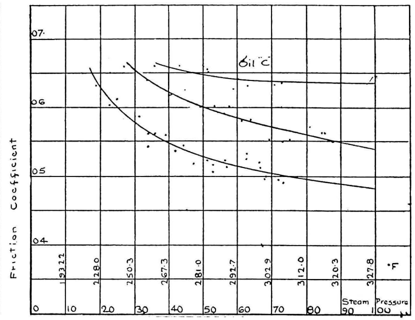


Fig. 6, Oil C.

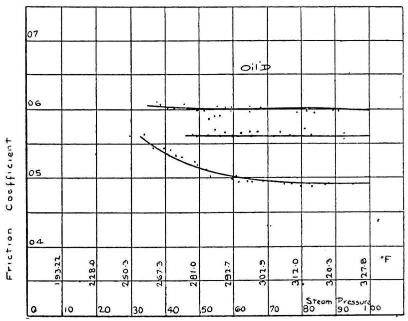


Fig. 7, Oil D

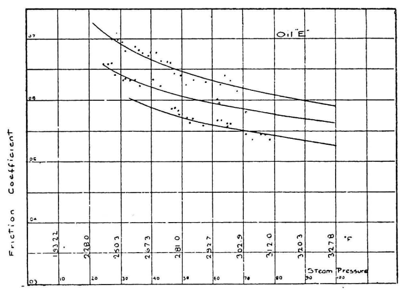


Fig. 8, Oil E.

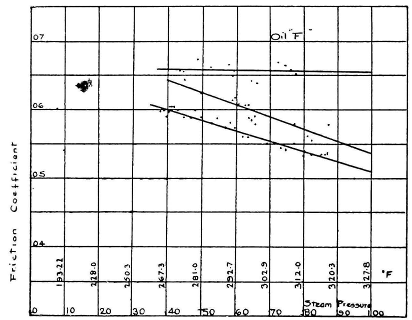


Fig. 9, Oil F.

VARIATION OF THE FRICTION COEFFICIENT WITH STEAM PRESSURE AND TEMPERATURE.

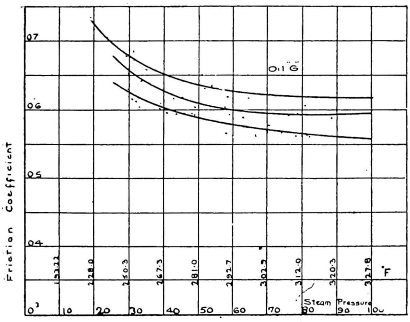


Fig. 10, Oil G.

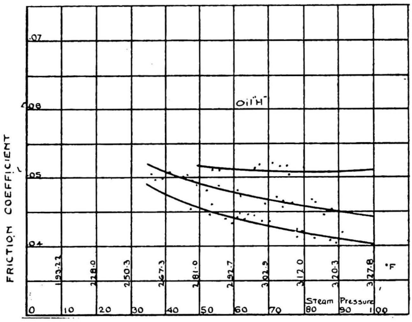


Fig. 11, Oil H.

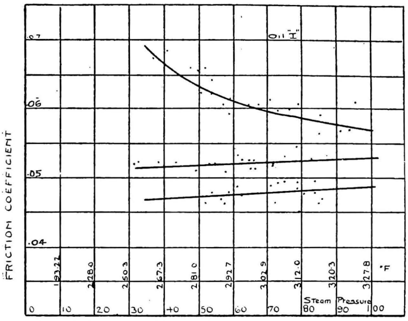


Fig. 12, Oil I.

VARIATION OF THE FRICTION COEFFICIENT WITH STEAM PRESSURE AND TEMPERATURE

According to the value of friction coefficient, based on the same feed in seconds to the drop and for the same steam pressure, the oils rank as shown in the following tables:

TABLE 5.

Steam Pressure, 60 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0439	H	.0472	H	.0510
I	.0474	I	.0520	B	.0588
D	.0500	A	.0539	D	.0600
C	.0511	B	.0550	A	.0600
A	.0511	D	.0560	I	.0610
B	.0517	C	.0582	G	.0626
E	.0560	E	.0596	E	.0632
F	.0570	G	.0598	C	.0640
G	.0572	F	.0608	F	.0660

TABLE 6.

Steam Pressure, 80 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0418	H	.0452	H	.0510
I	.0480	I	.0523	B	.0569
D	.0490	A	.0529	I	.0585
C	.0493	B	.0533	A	.0598
A	.0500	D	.0560	D	.0600
B	.0505	C	.0567	E	.0608
E	.0540	F	.0573	G	.0618
F	.0540	E	.0580	C	.0640
G	.0560	G	.0590	F	.0660

TABLE 7.

Steam Pressure, 100 Pounds per Square Inch, Gauge.

Feed 6 drops per minute		Feed 3 drops per minute		Feed 2 drops per minute	
Oil	Coef. of frict.	Oil	Coef. of frict.	Oil	Coef. of frict.
H	.0404	H	.0438	H	.0510
I	.0485	B	.0525	B	.0558
C	.0485	A	.0526	I	.0567
D	.0490	I	.0528	E	.0591
A	.0495	F	.0535	A	.0598
B	.0502	C	.0542	D	.0600
F	.0510	E	.0572	G	.0618
E	.0528	D	.0560	C	.0640
G	.0560	G	.0590	F	.0660

It appeared to writer that a comparison of the lubricating qualities of the oils on the basis of the same rate of feed in drops per minute, is not entirely reasonable on account of the fact that different oils have different size drops. Therefore even though the feed in number of drops per minute is the same, the quantity by volume admitted into the cylinder will not be same, and as a consequence the comparison is not a true one.

The friction coefficients of the oils should be compared on the basis of the same quantity by volume and with that end in view experiments were carried out to determine the size in cubic centimeters of the drops of the oils tested under the same conditions of feed in drops per minute, and at the same temperature of the oil in the lubricator as under the actual conditions of the friction tests described in the previous pages.

Size of Drops. The apparatus used to determine the size of the drops of the oils, was a lubricating cup, detached for this purpose from the friction testing apparatus, fitted with a graduated glass tube (a) filled with hot water, whereby the oil was warmed up to the proper temperature, and by means of which sufficient pressure was obtained to force the oil from the lubricating cup into another graduated glass tube (b), partially filled with water. The apparatus is shown in Fig. 13.

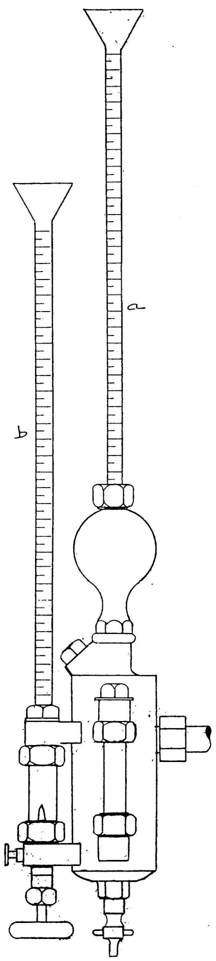


Fig. 13.

After adjusting the rate of feed to the required number of drops per minute, a certain counted number of drops of oil was let into the graduated glass tube (b) and their combined volume in cubic centimeters read.

The volume of the water in tube (a) which displaced the oil was also read, and as it is equal to the volume of oil displaced, the average value of these two volumes, namely that of the oil and that of the water displacing the oil divided by the number of drops, gave the size of the drop in cubic centimeters.

The average size of the drops of the oils, as measured by the above described method, is given in the following table:

TABLE 8.

Oil	Size of drops
A	.3124 c. c
B	.2423
C	.2142
D	.1911
E	.1653
F	.1482
G	.1418
H	.1184
I	.0722

From the size of drops, as given in the above table, and the rate of feed in drops per minute, the quantity of oil admitted into the cylinder for various rates of feed was calculated and the results embodied in the following curve (Fig. 14), where the volume per minute is plotted as a function of the rate of feed in seconds to the drop.

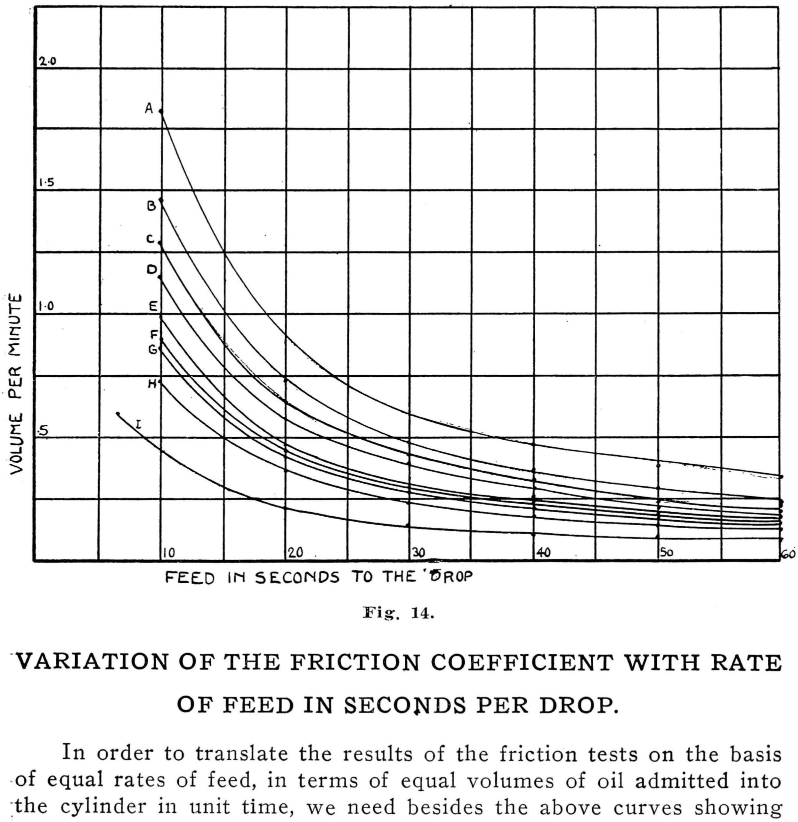


Fig. 14.

VARIATION OF THE FRICTION COEFFICIENT WITH RATE OF FEED IN SECONDS PER DROP.

In order to translate the results of the friction tests on the basis of equal rates of feed, in terms of equal volumes of oil admitted into the cylinder in unit time, we need besides the above curves showing the variation of the volume of oil with the rate of feed, also curves showing the variation of the friction coefficient with the rate of feed in seconds to the drop, or drops per minute.

Accordingly the following curves, Figs. 15 to 23, showing the friction coefficient as a function of the rate of feed in seconds to drop for constant pressure, were obtained from the friction coefficient curves plotted against steam pressure.

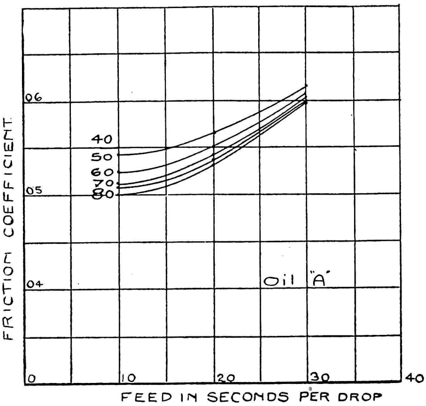


Fig. 15, Oil A.

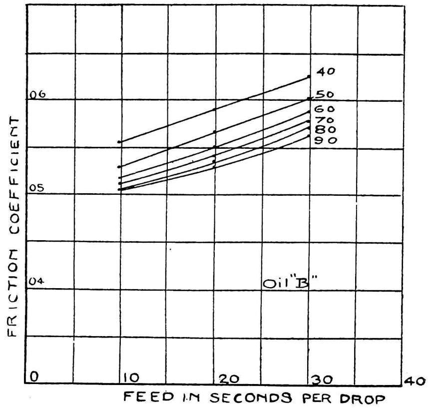


Fig. 16, Oil B.

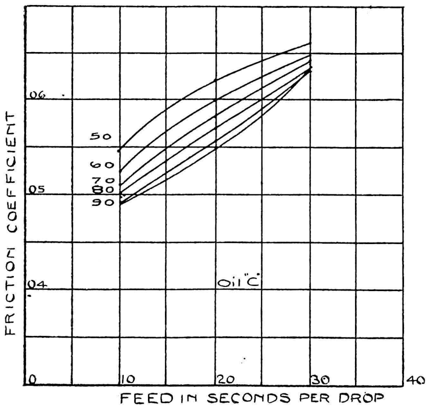


Fig. 17, Oil C.

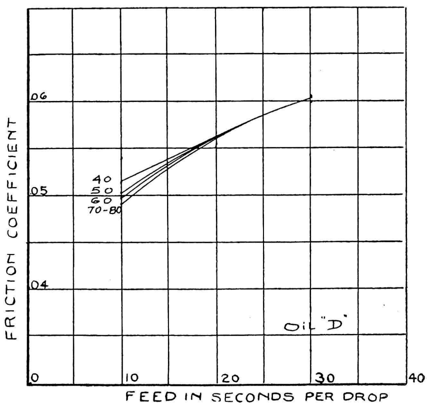


Fig. 18, Oil D.

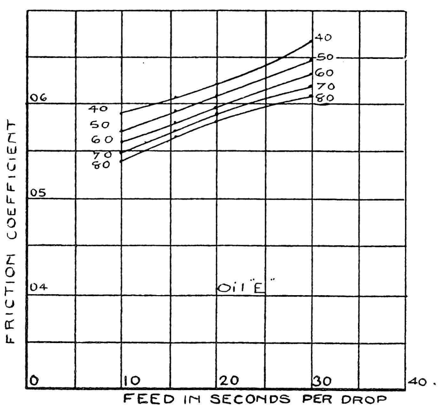


Fig. 19, Oil E.

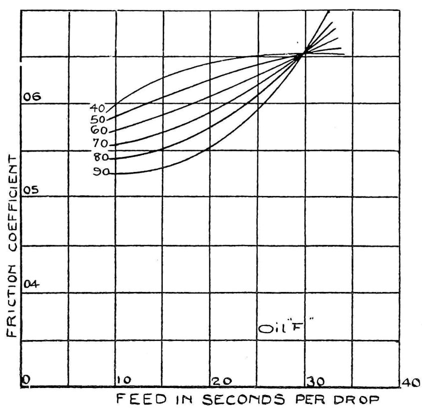


Fig. 20, Oil F.

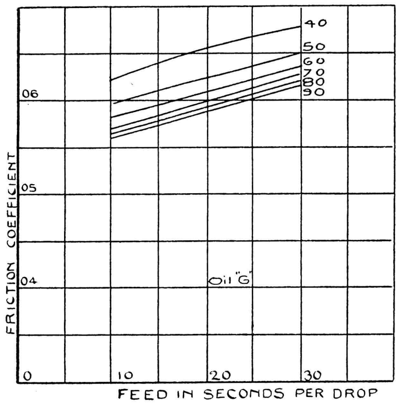


Fig. 21, Oil G.

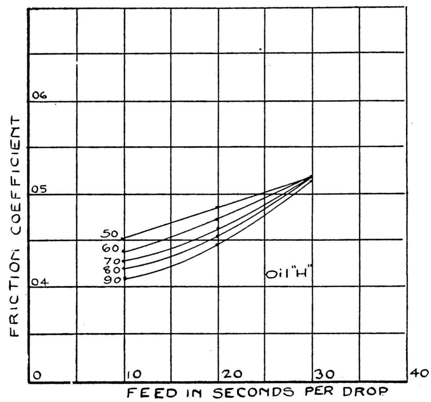


Fig. 22, Oil H.

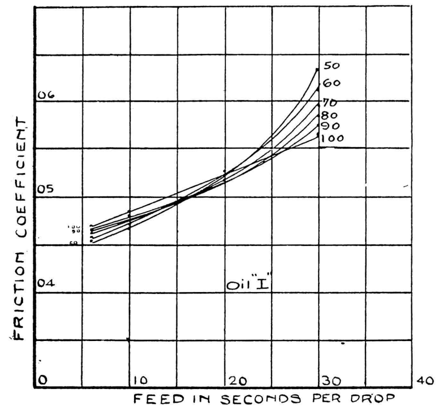


Fig. 23, Oil I.

VARIATION OF THE FRICTION COEFFICIENT WITH THE OIL FEED IN SECONDS PER DROP

These curves show certain peculiarities of the oils that are well worth some attention. Thus oils H and D while differing in many respects, have a more or less identical peculiarity, namely that the friction coefficient attains a constant value at a certain rate of feed, irrespective of the steam pressure. Oil H, has a constant friction cofficient of .0520 at a feed of 2 drops per minute and oil D, a constant friction coefficient of .0560 at about 3 drops per minute.

Similarly oil F attains a constant friction coefficient of .0655 at a feed of 2 drops per minute, while the point of constant friction coefficient is not so well defined for oil I. However, these last two oils differ from oils D and H in the fact that for feeds higher than the feed for constant friction, the friction coefficient is higher for higher steam pressures and lower for lower steam pressures, the reverse being true for lower rates of feed beyond that for the constant friction coefficient value.

These rather curious results were not obtained for the other oils tested.

A quantity of .60 cubic centimeters of oil, corresponding to 2 drops per minute for oil A, was arbitrarily chosen as a standard for which the friction coefficient of the oils should be compared on the basis of equal volumes of oil admitted into the cylinder per minute.

From the curves of figure 14 we find, that in order to supply this quantity of oil per minute, the various oils tested would have to be fed at the following rates:

TABLE 9.

Volume of Oil Admitted into the Cylinder per Minute = .60 c c.

Oil	Rate of feed seconds per drop.
A	30
B	24
C	21
D	19
E	16
F	15
G	14
H	12
I	7

Using these rates of feed and the curves showing the relation between the friction coefficient and the rate of feed in seconds to the drop, (figs. 15 to 23), we can then find the corresponding friction coefficient of the oils for various steam pressures at a constant feed of .60 cubic centimeters per minute.

The following table shows the comparative values of the friction coefficient on this basis:

TABLE 10.

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "A" 30 sec. per drop	Oil "B" 24 sec. per drop	Oil "C" 21 sec. per drop
40	0.0613	0.0601	0.0625
50	.0607	.0580	.0600
60	.0600	.0562	.0590
70	.0600	.0552	.0570
80	.0600	.0545	.0557
90	——	.0540	.0550
100	.0590	.0535	.0540

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "D" 19 sec. per drop	Oil "E" 16 sec. per drop	Oil "F" 15 sec. per drop
40	——	0.0608	0.0630
50	0.0557	.0593	.0609
60	.0555	.0581	.0587
70	.0555	.0575	.0570
80	.0555	.0569	.0552
90	.0555	——	.0532
100	.0555	.0555	.0512

Steam Pressure, pounds per sq. inch, gauge	Friction Coefficient for 0.60 c c. of Oil per minute.		
	Oil "G" 14 sec. per drop	Oil "H" 12 sec. per drop	Oil "I" 7 sec. per drop
40	0.0608	——	——
50	.0592	0.0460	0.0460
60	.0582	.0444	.0462
70	.0578	.0432	.0468
80	——	.0424	.0470
90	.0572	.0415	.0472
100	.0571	.0410	.0475

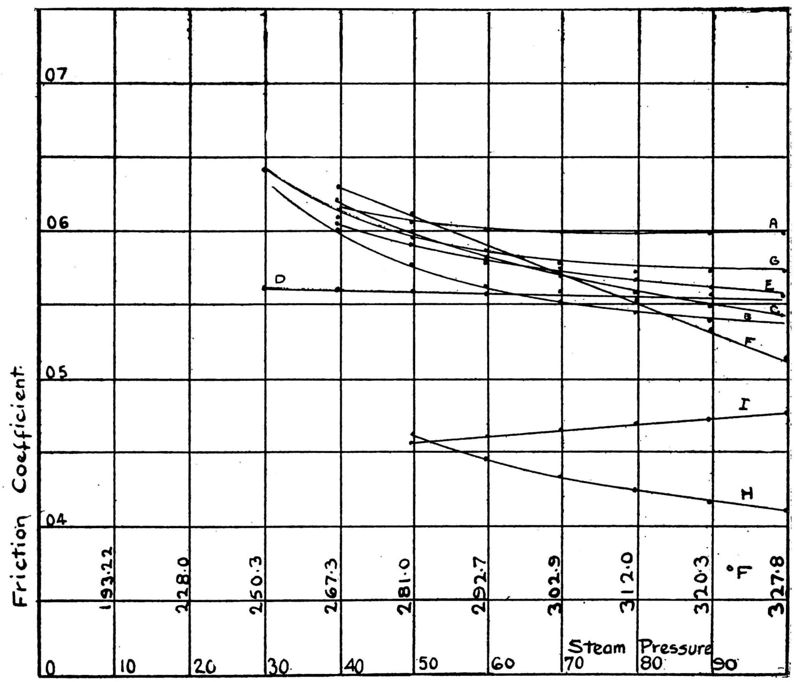


Fig. 24.

These results are also shown graphically in fig. 24. From these curves we can readily see that on the basis of the same quantity of .60 cubic centimeters of oil admitted into the cylinder per minute, the oils tested rank as follows for a steam pressure of 100 pounds per square inch.

TABLE 11

No.	Oil	Frict. Coeff.
1	H	.0410
2	I	.0475
3	F	.0512
4	B	.0535
5	C	.0540
6	E	.0555
7	D	.0555
8	G	.0571
9	A	.0590

MONEY VALUE OF THE OILS TESTED.

The question that the operating engineer frequently asks himself is whether a proposed change of cylinder oils would be profitable, in other words, whether the cost of operation would thereby be reduced and to what extent this change of oils will affect the operating expenses.

At present, in the absence of reliable information on the lubricating values of cylinder oils, the method generally followed by operating engineers is, after comparing the market prices, to buy a certain brand of oil at the best rate obtainable, try it for a certain time on his engine and if it does not produce any ill effects after a reasonable time, to continue to use it, assuming it to be a good oil. But the question whether he has gained by this change or not, whether the operating expenses have been decreased or actually increased is not at all settled.

According to a paper on "The Theory of Finances of Lubrication" presented before the American Society of Mechanical Engineers by the late Professor Robert H. Thurston,* it is absolutely necessary to ascertain every item of expense affected by the proposed change.

These items of expense are classified by Prof. Thurston as follows:

(1) "The cost of power produced, only to be wasted by that of friction."

*A. S M. E. Vol. VI, 1885, pp. 437-

(2) "The expense incurred in wear and tear of the running parts, and in the replacement of parts destroyed, either by direct strains, or by gradual tear due to such exceptional resistances as are the effect of excessive friction."

(3) "The casual, indirect and often unperceived yet none the less serious losses throughout the system which are not included in the above."

(4) "The cost of the lubricating material applied for the purpose of ameliorating these losses."

The first item depends largely upon the cost and character of the fuel, type and size of the engine, the locality where the plant is situated, interest on the capital invested, depreciation, wages and insurance. The actual cost of producing one horse power per year may be as low as $30.00 and as high as $120.00 and in the following pages $80.00 was assumed as a fair estimate of the cost of production per horse power per annum.

The second and third items of expense cannot be estimated in dollars and cents with any degree of accuracy as they depend upon variable and generally unforeseen circumstances. As a rule these two items are included in the first item of expense as depreciation, and as a consequence their value, whatever it might be, is included in our assumed $80.00 per horse power per year.

If a proposed change in cylinder oil is desirable from the standpoint of economy, the money values of the oils should be determined by not only comparing the quantities and the cost of these quantities of oils used for a specified time, but also the other expenses incurred by using one oil instead of another.

In view of these briefly discussed considerations, the oils tested have been compared as to their money value assuming them to be used on a 70 horse power engine, and the results are given below:

Size of engine..............70 H. P.............13 x 13

Cylinder circumference .... $\pi \times 13 = 40.82$ in.

Ring diameter .... 13.25 in.

Ring circumference .... $\pi \times 13.25 = 41.65$ in.

Spring tension 3 pounds per inch circumference.

Tension per ring ....3 x 41.65 = 124.95 pounds

Tension for the 3 rings.............................373.85 pounds

Weight of piston ....110.00 pounds

Weight of piston rod .... 18.00 pounds

Total normal pressure ....510.85 pounds

Speed of engine ....275 revolutions per minute

$$\text{Piston speed} \ldots\ldots \frac{275 \times 2 \times 13}{12} = 596 \text{ feet per minute}$$

Steam pressure 100 pounds per sq. in. gauge.
Horse power loss in the cylinder due to friction:

$$\text{H. P.} = \frac{510.85 \times 596}{33000} \times \text{friction coefficient}$$

H. P. loss in the cylinder = 9.23 x friction coefficient.
Quantity of oil in gallons per year of 360 days = 136.86 x s x d
where s = size of the oil drop in cubic centimeters.
d = drops of oil admitted into the cylinder per minute.
hence s x d = volume of oil in c c. admitted into the cylinder per minute.

TABLE 12.

Rate of Feed = .60 c c. per minute.—Steam pressure = 100 pounds per sq. inch.

Oil	Gallons per year	Cost of Oil per Gal., cents	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
H	82	45	$36.90	.378	$29.40	$66.30
I	82	38	31.16	.438	35.00	66.16
F	82	48	39.36	.473	37.80	77.16
D	82	45	36.90	.512	41.00	77.90
C	82	59.5	48.79	.498	39.90	88.69
B	82	60	49.20	.494	39.50	88.70
E	82	60	49.20	.512	41.00	90.20
A	82	60	49.20	.545	43.50	92.70
G	82	65	53.30	.527	42.20	95.50

TABLE 13.

Rate of Feed = 2 drops per minute—Steam Pressure = 100 pounds per sq. inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	19.15	$ 7.75	.523	$42.00	$49.75
H	30.10	15.18	.469	37.50	52.68
F	39.96	18.85	.602	48.20	67.05
D	52.00	23.40	.550	44.00	67.40
G	37.90	24.60	.567	45.35	69.95
B	65.60	39.40	.514	41.20	80.60
C	57.50	34.20	.582	46.50	80.70
E	43.80	26.30	.544	43.50	89.80
A	82.00	49.20	.550	44.00	93.20

TABLE 14.

Rate of Feed = 3 drops per minute.—Steam pressure = 100 pounds per square inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	29.80	$11.52	.487	$39.00	$50.52
H	48.80	22.98	.405	32.40	55.38
F	61.00	28.80	.494	39.50	68.30
D	72.40	32.60	.516	41.30	73.90
E	62.50	37.50	.525	42.00	79.50
G	57.00	37.00	.544	43.50	80.50
C	86.80	51.64	.498	39.90	91.50
B	100.00	60.00	.484	38.90	98.90
A	123.00	73.75	.485	38.90	112.65

TABLE 15.

Rate of Feed = 6 drops per minute.—Steam pressure = 100 pounds per square inch.

Oil	Gallons per year	Cost of oil per year	H. P. loss	Cost of power loss	Total cost of friction
I	61.60	$33.40	.446	$35.60	$69.00
H	98.50	43.50	.373	29.80	73.30
F	123.00	59.00	.470	37.60	96.60
D	157.40	70.80	.452	35.90	106.70
G	116.20	75.60	.516	41.30	116.90
E	134.00	80.50	.488	39.10	119.60
C	174.00	103.50	.446	35.60	139.10
B	192.80	115.10	.462	36.90	152.00
A	249.00	149.00	.456	36.50	185.50

From the above tables, it is readily seen that from whatever standpoint we consider the oils, either on the basis of equal volumes of oil or equal rates in drops per minute, oils I and H rank higher than the other oils tested. These oils have in their favor, besides a low cost also a low friction coefficient and also a small drop as compared with the other oils, which when the comparison is made on the basis of equal rates of feed in drops per minute, is a deciding factor in their favor.

But besides the cost of the oil and the cost of the power loss due to friction, or a combination of the two, there is the actual behaviour of the oil in the engine which must be given some consideration. Thus, the oil may get gummy, or it may not distribute well over the surfaces to be lubricated, or it may contain a comparatively large amount of free acid or animal and vegetable fats, which to be sure reduce friction, but under the action of the high temperature in the cylinder will give off free acid that will attack the cylinder and in time corrode it.

Referring to table 4 we notice that oil H has the largest saponification number in comparison with the other oils, indicating that it is more apt to become gummy in the cylinder; it has also the largest per cent of animal and vegetable fats, similarly indicating that it will give off more free acid to corrode the cylinder.

As to oil I, we find that it has the largest free acid value (per cent oleic acid), besides having too small a drop, which in this instance may be considered a disadvantage, for on the basis of the same volume admitted into the cylinder, this oil will have to be fed at a pretty high rate, as compared with the other oils, and on the basis of equal rates of feed, the film of oil may not be sufficiently thick, especially as the viscosity of the oil decreases at higher temperature, and though the friction is decreased, it is decreased at the expense of the more rapid wear of the rubbing surfaces.

Oil F is the third in rank on the basis of cost. It has a low free acid value also a lower per cent animal and vegetable fat, which gives it a decided advantage over oils I and H.

Oil D does not differ very much from oil F, especially when the comparison is made on the basis of equal volumes and equal rates of two drops per minute. It is true that with two drops per minute, the necessary quantity of oil D is quite a good deal larger than the corresponding quantity of oil F on account of the difference in the size of the drops, but the friction coefficient of oil D is correspondingly smaller, resulting in a smaller amunt of power loss. Similarly, oil D contains a larger amount of free acid compared with oil F, but F has a larger per cent of animal and vegetable fats. All things considered then, there is not apparently much choice between these two oils for the rates of feed mentioned.

The other oils tested, although they have low acid values and low percent of animal and vegetable fats to their advantage, have correspondingly larger friction coefficients resulting in larger power loss, besides the higher cost and large size drops with increase in quantity for equal rates of feed, which is decidedly against them.

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