HIGH TEMPERATURE BREAKDOWN TESTS OF SOME VEGETABLE OIL ADDITANTS TO LUBRICATING OILS

By

J. E. BRYAN

A Thesis Submitted as Partial

Fulfillment for the Degree of

Master of Science

in

Chemical Engineering

APPROVED:

Professor in Charge

Head of the Department

Dean of Engineering

Chairman, Graduate Committee

Virginia Polytechnic Institute

Blacksburg, Virginia

1946

TABLE OF CONTENTS

DRAWINGS AND PLATES

I. INTRODUCTION

"Rapeseed oil or colza oil(3) is produced from seed grown largely in India and China and is in constant danger of admixtures of mustard, jamba, and ravison seed. The seed contains from 33 per cent to 45 per cent oil which is obtained both by expression and extraction methods. Cake from expression methods is a good cattle food, while that obtained by extraction is fit only for fertilizer. In this country "colza oil" denotes usually, an oil for burning, and is obtained from selected varieties of seeds. The technically refined oil when blown is used largely by lubricant manufacturers as flux in making rubber substitutes and when blown (with air) is now going into lacquer channels. Cold drawn or pressed oil is largely used as an edible oil in India and in Continental Europe.

"Of the total American imports, nearly one-half goes to one prominent lubricant manufacturing company which purchases the oil through its British office and has it processed to conform to its own specifications. The remainder is distributed throughout the American trade as described above. Lubricant buyers, as a rule, require that the oil shall conform to specifications which are understood here in the trade as Texas Company, Standard Oil Company, and Sinclair Refining Company. These specifications bear close resemblance but in general require that the oil shall be pure and unadulterated, the free fatty acids shall not exceed one per cent, the iodine value shall not be lower than 97 nor higher than 103 which is unduly low according to the standards suggested by the American Society for Testing Materials and other authorities who admit the purity of rapeseed oil with an iodine value as high as 105, the specific gravity shall be 212 to 240 seconds, Saybolt Standard Universal instrument at 100 deg. F., flash point less than 525 deg. F. open cup, pour test 0 deg. F.

"Fatty oils have a low coefficient of static friction and have high efficiencies. The blended oils give values intermediate between those of mineral and fatty oils. The "oiliness" factor of mineral lubricating oils is greatly increased by the addition of small proportions of fatty oils."

Sperm oil is generally conceded to have the highest lubricating properties of all the oils. However, its prohibitive cost makes its widespread use impractical. It is hoped that additions of rapeseed oil to mineral oil will impart some of the desirable lubricating characteristics of the fatty oils to the blend.

The object of this research is to investigate the lubricating properties of mineral-rapeseed oil mixtures, and to determine the economic feasibility of additions of rapeseed oil to commercial lubricating oils if improved lubricating properties are discovered.

II. LITERATURE REVIEW

Bodying of Rapeseed Oil[4] - "Rapeseed oil may be placed between the semi- and non-drying oils. At elevated temperatures, when air-blown, it thickens and finally gels, but it does not form a dry film as do the drying oils. In practice linseed and China wood oils are bodied to proper viscosity by heating; rapeseed oil is heated and air-blown.

"Before reporting the experimental results of this study, let us recall the fact that rapeseed oil is mainly composed of glycerides of saturated and unsaturated fatty acids. One analysis gives the following distribution of the acids gotten from the glycerides:

	%
Myristic	1.5
Stearic	1.6
Behenic	0.5
Lignoceric	2.4
Oleic	20.2
Erucic	57.2
Linolic	14.5
Linolenic	2.1

It will be seen that the unsaturated glycerides predominate.

Heat of Combustion. - "Since heat is generated in the blow, and since the degree of unsaturation decreases, as will be shown, it is evident that oxidation plays an important part in the changes experienced by the oil. If this is true, successive samples taken during the blowing period should show a progressive decrease in calorific value, unless such oxidized products are removed from the oil by the air.

The work reported was performed with an Emerson bomb calorimeter equipped with a Daniels adiabatic jacket. Proper corrections were introduced into the calculations. The numerical results are tabulated in column 1 of Table I.

"It is apparent that there is practically no change in the state of oxidation during the first few hours of blowing. At about the tenth hour there is evidence that the calorific value is diminishing. This time coincides very closely with the time at which the rise in temperature in the blow tank was noticed. It also appears that the rate of oxidation has reached a maximum at about the fifteenth hour, after which the rate decreases so that the change during the last seven hours is only seven per cent of the total change. There is also an indication that the maximum oxidation by blowing has been accomplished before the time of concluding the blow.

<u>Iodine Number.</u> - "The iodine numbers were determined with 0.3 to 0.5 gram samples of the oil dissolved in carbon tetrachloride, by the method of Hanus at a temperature of 22 deg. C.

The results are given in column 2 of Table I.

On account of the insolubility of the final samples in carbon tetrachloride, iodine values could not be obtained beyond the twenty-ninth hour.

<u>Acid Number.</u> - "All oils do not increase in acidity on drying. Tung oil, for instance, may show a decrease. But rapeseed oil is known to become more acid on blowing. This is undoubtedly due to partial hydrolysis of the glycerides. Indeed, this is supported by the fact that during the blowing irritating aldehyde and acid vapors, largely acrolein and "rapic" acid, are expelled from the oil, a proof of hydrolysis and

decomposition of free glycerol. The results are shown in column 3 of Table I.

Saponification Number. - "As the samples taken during the latter half of the blowing gave solutions, after saponification, which were entirely too dark in color to permit the ready use of indicators in titration of the excess alkali, a potentiometric titration was resorted to.

"Values checked well with those gotten by the usual method using phenolphthalein as indicator, on the earlier light-colored samples. The results are given in column 4 of Table I.

"It will be noted that the increase in saponification number is not to be accounted for by the increase in acidity alone, but is much greater. The former increases from 174 to 1944, the latter from 2.17 to 8.30. If we calculate the mean molecular weight of the acids from the saponification number, there is shown to be a decrease from 324 to 282 during the blowing period. It would thus appear that parts of the original acid chains have been disrupted, forming acids of smaller weight.

"This is not to be considered as in contradiction to the rise in molecular weight of the acids (and consequently of their glyceryl esters), which the calculation from the saponification numbers shows, is really due to the action of the saponifying base in depolymerising the complex acid groups of the glycerides.

Mean Molecular Weight.- "On account of the fact that blowing and heating rapeseed oil result in a variety of reactions, as oxidation, hydrolysis, saturation, polymerisation, and gelation, on a variety of different compounds, it is of course evident that we are here considering only an average, or mean molecular weight. Nevertheless, the changes in the values obtained should yield some information as to the preponderating reactions that are taking place. For instance, a large amount of polymerization should more than offset a moderate amount of hydrolysis.

"The method usually employed in such work has been the freezing point depression method, and the solvents used have been benzene and nitrobenzene. This has evoked considerable criticism, it being claimed that results obtained with benzene, particularly, are meaningless on account of its associating effect upon the dissolved oil (particularly upon the free fatty acids) and also on account of compound formation (solvation) in some cases.

"It would follow from both these causes that abnormally high values for molecular weights would be obtained, and further that the result obtained would be a function of the concentration of the solution.

"The results reported were obtained using nitrobenzene as solvent, the ratio of oil to solvent being kept practically constant throughout the series at about 10 per cent by weight. The results are shown in column 5 on Table I.

Specific Gravity. - "The Westphal balance was employed, and on account of the high viscosity of many of the samples, all gravities were taken at 40 deg. C., in terms of water at 4 deg. C. The results with the samples used in this study are given in column 6 of Table I.

Viscosity. - "Viscosities were measured with the Saybolt instrument. The values are expressed as time in minutes required for the outflow of 60 ml. from the oil tube. Here again a temperature of 40 deg. C.

was employed. The last samples, being gels at this temperature, did not flow.

The results are given in column 7 of Table I.

Index of Refraction. - "These indices were read on the Abbe instrument with the prism maintained at a constant temperature of 20 deg. C. It was thought that significant changes taking place during the first ten hours of the blow, which were not made evident in the above tests, might be indicated here. The results, however, show little change in refraction during the first nine or ten hours. The results are shown in column 8 of Table I."

TABLE I. - PHYSICAL AND CHEMICAL CONSTANTS OF BLOWN RAPESEED OIL

Time Blown (Hours)	1 Heat of Combustion (Cal./gram)	2 Iodine Number (Cg.I/gram)	3 Acid Number (Mg. KOH/gram)	4 Saponification Number (Mg. KOH/gram)	5 Molecular Weight	6 Specific Gravity at 40°/4° C.	7 Viscosity at 40° C. (Minutes)	8 Index of Refraction at 20° C.
1	9566	95.3	—	173	—	0.8999	3.9	1.4730
2	—	—	2.17	174	—	—	3.9	1.4730
3	9581	95.6	—	174	—	0.8999	3.97	1.4730
4	—	—	—	174	1036	—	4.0	1.4730
5	9556	96.1	2.22	—	—	0.9000	4.0	1.4730
6	—	—	2.17	173.8	—	—	4.0	1.4730
7	9560	96.1	2.23	—	—	0.9000	4.03	1.4730
8	—	—	2.19	174.0	—	—	4.08	1.4730
9	9551	95.7	2.23	—	—	0.9005	4.13	1.4730
10	9532	—	2.31	175.2	—	0.9009	4.17	1.4733
11	9509	95.1	2.40	—	1040	0.9018	4.27	1.4733
12	9463	91.2	2.62	177.4	1035	0.9044	4.77	1.4737
13	9407	89.8	3.10	179.1	1050	0.9080	5.43	1.4739
14	9357	84.3	4.31	—	1080	0.9135	7.25	1.4747
15	9277	79.9	5.08	180	1150	0.9204	10.88	1.4753
16	9230	76.8	5.75	—	1180	0.9242	16.27	1.4761
17	9171	74.7	6.04	182	1273	0.9300	17.55	1.4758
18	9128	72.8	6.66	—	1420	0.9340	24.5	1.4774
19	9106	70.4	6.82	184	1428	0.9377	32.5	1.4778
20	—	70.2	7.37	188	—	0.9405	42.7	1.4782
21	9049	68.3	—	188.9	1519	0.9430	58.8	1.4786
22	—	66.3	7.65	—	—	0.9460	81.3	1.4795
23	8986	65.2	—	193	1748	0.9480	109	1.4799
24	—	66.1	7.96	—	1807	0.949	158.5	1.4800
25	8981	64.1	—	194	—	0.951	250	1.4800
26	—	63.5	8.15	—	1992	0.952	345	1.4805
27	8965	63.7	—	195.3	2036	0.954	—	1.4806
28	—	64.0	8.23	197.1	—	0.955	—	1.4806
29	8955	—	—	197	2073	0.957	—	1.4806
30	—	—	8.30	—	—	—	—	1.4806
31	8945	—	—	198.9	2106	—	—	—
32	8940	—	—	—	—	—	—	1.4808

Results of Laboratory Tests[7] - "Fatty oils (rape, sperm and castor) give low coefficients of static friction and hence high efficiencies (calculated by the formula 100 - (p. plus 100) = efficiency) or high "oiliness" factors. The blended oil gives an intermediate value between the mineral and fatty oils.

"The "oiliness" factor of mineral lubricating oils is greatly increased by the addition of small proportions of fatty oils. A very small addition of rape oil, either pure or containing fatty acid, greatly reduces the frictional constants obtained with bayonne oil. As solid friction conditions are almost certain to exist when a machine is being set in motion, it is advisable to mix a little fatty oil, preferably one containing fatty acid, with the mineral oil to increase its oiliness, and hence reduce the friction and consequently the wear.

"With animal and vegetable oils, the decrease in viscosity with rise in temperature is not nearly so rapid as with mineral oils. This is characteristic and is one of the defects of mineral lubricating oils, since, at high temperatures due to the low viscosity, the lubricating viscous film cannot withstand much pressure before breaking down and giving way to solid friction conditions.

"The blended turbine oil, since it is composed mainly of mineral oil, gives the same type of viscosity curve as a mineral oil; namely, a high value of viscosity at low temperatures with a sudden drop to a very low value as the temperature is increased.

"The results of the tests carried out on the Boult machine and on the bearing friction machine where viscous friction conditions exist, may be summarized as follows:

(1) The friction depends on the viscosity of the oil.

(2) The more viscous the oil, the more easily does the viscous lubricating film form and vice versa.

(3) The lower the rubbing speed, the greater is the tendency for the viscous film to break down and vice versa.

(4) Within the speed and temperature ranges used in the tests, and provided the oil film temperature remains constant, the friction varies as the rubbing speed.

(5) A viscous lubricant will withstand a greater pressure before the film breaks down than will a non-viscous lubricant.

(6) The viscous film does not readily form at low speeds and high pressures.

(7) When fluid conditions are present, the friction decreases as the load increases, but only up to a certain load.

"In the case of a bearing subjected to very heavy loads or to low speeds or to a combination of these, a viscous lubricant should be used to ensure the formation of a viscous lubricating film.

"It is found by experiment and from practical experience that small bearings, and hence moderately high loads, cause less friction than large bearings with consequent low loads. Care must be taken, however, not to overload a bearing, otherwise there is the danger of the viscous film breaking down and giving way to semi-solid friction conditions with consequent greatly increased wear, and liability of the rubbing surfaces to seize."

<u>Data on Some Mineral and Fatty Oils</u>(6) - "Lubricating oils in the past consisted wholly of fatty oils such as olive, rape, castor, whale and sperm, but on the introduction of mineral oil as a commercial proposition shortly after 1870, the assets of the one began to be compared with the assets of the other, and it was quickly realised that the cheaper mineral lubricating oil was at least worthy of a trial. Of course, the scientific treatment of the crude oil was a little primitive in those days, as might be expected, but success which awaited the early efforts of the pioneers in the industry encouraged them to study their product and its applications, and before many years had passed mineral lubricating oil had become a serious competitor of the fatty oils for lubrication; and today it has almost entirely eclipsed them. This does not mean that fatty oils have disappeared from use, because they have not, and I hope to show shortly that they have a very definite use and value. One wonders, very naturally, whether this sudden rise to fame was due to the superior qualities of the mineral oil, or whether it was due to an advantage in price. Price no doubt has played its part, but in these days with thinking engineers in charge of expensive machinery, and much at stake, the cost of the lubricant is of secondary importance; it is quality which is demanded.

"Briefly, the advantages of mineral oils over fatty oils may be stated to be freedom from rancidity, gumminess, separation of foots, bacterial and enzyme growth, emulsification, drying on exposure to air, thickening and odour. At this stage it might be convenient to point out that in considering lubricants there are two aspects to bear in mind: -

1. Lubricating value.

2. Value as a lubricant.

The lubricating value is the power of a substance to reduce friction, and can be expressed in items of its coefficient of friction, provided we possess the means for determining it. The value of a body as a lubricant is much more important, and depends upon a number of factors. Primarily it must be capable of reducing friction and secondly it must have characteristics which permit its use for specific purposes with the minimum of inconvenience. An oil for use in a steam turbine must separate from water quickly; it must, as far as possible, be inert towards atmospheric conditions. Machines which operate over a wide range of temperature should use an oil whose viscosity variation with temperature is small. Many other examples could be given to illustrate my meaning. If an oil gums, acidifies, emulsifies, or behaves in some other undesirable manner, then its value as a lubricant is much reduced -- in fact, perhaps so far as to preclude its use altogether, in spite of the fact that it may be endowed with a perfect lubricating value.

"From the advantages of mineral oils over fatty oils it will be seen that not one word was said about friction reducing power. All the advantages named were such as would be considered in deciding upon the value as a lubricant. Mineral oils have, in the majority of cases, a better value as lubricants than have fatty oils, but it is generally conceded that fatty oils have better lubricating values, as may be seen in the curves showing the variation of efficiency of worm gears with temperature of oil.

"These curves are interesting insofar as they show a big difference between fatty oils and mineral oils. In each case, excepting for the moment sperm oil, fatty oils are superior to the mineral oils. It might be suggested that this difference is due to viscosity, but when one considers that castor oil is several times more viscous than rape or animal oil this thought will be immediately dispelled.

"Again, when we consider the mineral oils it will be observed that although the cylinder oils is very much more viscous than the others the efficiency at atmospheric temperature is practically the same in each case. The variation in viscosity with the temperature does vary with the three mineral oils, but not sufficiently to account for the variation in efficiency. It will be noted that with each oil the efficiency diminishes with increase in temperature except in the case of castor oil.

"What happens at temperatures higher than those shown on the curve need not concern us because worm gears very rarely work at high temperatures. It is clear that castor oil is the best lubricant for worm gears, and, in fact, we can almost say all types of pinion gears, provided of course there are not factors which would reduce its value as a lubricant for this purpose. I am thinking particularly of geared turbines on board ship where there is a risk of the introduction of water into the gear box, or where the turbine is lubricated with the same oil as the gears.

"It is significant how the efficiency of sperm oil falls off at a temperature of about 40 deg. C., whereas F.F.F. Cylinder oil falls off suddenly at about 75 deg. C. From these curves we can at least see the relative efficiencies of several oils for gear lubrication.

Before leaving the subject of gears, I wish to refer to the lubrication of motor-car gears, because it might be felt that the practice which is adopted therein might not fall into line with the above remarks. What has been said applies equally to this class of gear. The difficulty in the past has been that motor-car manufacturers have not, for one reason or another, made their gear-boxes and back axles oil-tight. The result has been that a lubricant has had to be supplied which would remain in the gear-box. Hence the resort to various types of grease. Nowadays motor manufacturers have realized the necessity for using an oil, and have therefore produced oil-tight boxes. The advice I give to you, then, is: use as thin a grease as possible, if it be not possible to use an oil of a suitable nature. Rape and sperm oils may be disqualified for the purpose because they both gum on exposure to air, and animal oil is not suitable by itself because it becomes rancid and acid, but as castor oil does not possess these objections, it is strongly recommended.

The work of Dr. Stanton is interesting, in that it shows the relative pressures which certain oils will withstand at atmospheric temperature. He designed a bearing on which the pressure distribution could be measured, also the actual thickness of the oil film at the point of highest pressure. With this apparatus he found that the maximum pressure obtainable with sperm oil was 1.44 tons per sq. inch, and with rape oil 1.38 tons per sq. inch. He then made an attempt to obtain still higher intensities of oil pressure by a further increase in the radius of the bearing. When using castor oil on this new bearing, he obtained a maximum pressure of 3.5 tons per sq. inch, and with F.F.F. Cylinder 2.8 tons per sq. inch.

"These experiments bring home to us the fact that the idea which was at one time prevalent that sperm oil was pre-eminently suitable for heavy bearings was false, and it confirms the still popular idea that there is no oil which is more suitable for hot bearings, and heavy bearings, than castor. For light bearings, or shafting in general, a comparatively thin mineral oil is used, because the loads are light; but in the case of reciprocating machinery, the viscosity of the oil must be considered more carefully and perhaps the method of application. On a locomotive, the oil is fed to the bearings through wool trimmings, and if perchance the trimmings become choked, trouble will ensue, thereby causing oil starvation. So in this case the oil must not merely be capable of giving efficient lubrication, but must syphon freely through the trimmings for considerable periods. The syphoning qualities of oils vary greatly, and the only means of ascertaining their suitability for this purpose is by actual experiment in the laboratory for a period of days.

SYPHONING TESTS

Oil	1st 24 hrs. CC.	Temp. Deg. F.	2nd 24 hrs. CC.	Temp. Deg. F.	3rd. 24 hrs. CC.	Temp. Deg. F.	4th 24 hrs. CC.	Temp. Deg. F.
A	170	68	187	74	170	71	180	69
B	165	68	165	74	160	71	167	69
C	187	68	180	74	160	71	165	69
D	165	68	153	74	130	71	120	69

"What might be said of loco practice might equally be said of all other systems where the oil is fed through wool trimmings. Many of the railway companies feel the necessity for fortifying the mineral oil with a fatty oil such as rape to increase its durability, just in the same way as motor manufacturers prefer the mineral oil containing castor, because castor oil, as has been shown above, will withstand the greatest pressure.

"There is no ready means for ascertaining the optimum amount of fatty oil in a lubricant for a given purpose. It is purely a matter of opinion, although laboratory experiments have been made to prove various ideas, but for my part I am content to base my judgment upon experience rather than on laboratory measurements.

"I regret there is not time to explain why fatty oils have the better lubricating value, but if anyone cares to refer to my book, "Lubricating and Allied Oils," reference will be found on the subject.

"Early in the paper I stated that the lubricating value is the power of a substance to reduce friction, and can be expressed in terms of its co-efficient of friction providing we possess the means for determining it. This proviso was made with due consideration of the fact that there are friction-testing machines. These machines have so far been disappointing, because they have not fulfilled the mission for which they were intended; namely, to give an engineer the necessary criterion of the behaviour of an oil in practice. I know that I can say without fear of contradiction that they have failed in their purpose. I am not going so far as to say that they have not had certain uses, but I do say that it is extremely difficult to reproduce running conditions on a laboratory scale. Therefore I am not an advocate of valuing lubricants, at present time, on friction-testing machines.

" Steam turbine practice might be taken to illustrate the limitation of friction-testing more clearly. On a high-speed machine of this character, large volumes of oil are flooded through the bearings, partly to overcome friction, partly to keep the journal floated, and partly to disseminate the heat transmitted to the bearings from the rotor. For this purpose a thin oil is used, with very little consideration for its lubricating value, for the only time at which the lubricating value is of importance is at the moment of starting when the shearing stress is applied, and if at this moment the oil film ruptures, wiping of the bearings might ensue. The thermal transference being more or less proportional to the viscosity of the oil it behoves one to use a thin oil on this account. Thermal transference must not be confused with specific heat, because the specific heat of all mineral oils per unit volume, is practically the same. It is important that the oil shall separate from water readily both when the oil is new and after it has been in service. The demulsification value looks after this point. Because mineral oils are sometimes referred to as "Paraffins," which means without affinity, it is frequently assumed that they are uninfluenced by atmospheric conditions. This belief is erroneous, for we know only too well that paraffin oils are influenced by the atmosphere, especially at elevated temperatures with the production of acid and solid decomposition products.

" These solid decomposition products occur in many phases of lubrication in addition to the steam turbine. We find them in the motor-car engine, both in the crank case and on the piston head, in the cylinder of steam engines, and in oil-cooled electrical transformers. They are referred to by various names, most common of which is "carbon." Unfortunately, the term is loosely applied, and gives rise to misunderstandings. The ultimate analysis of a so-called carbon from a petrol engine gave:-

	Per cent
Carbon	48.08
Hydrogen	4.67
Oxygen (by diff.)	13.35
Mineral matter	33.90
	100.00

From these figures it is obvious that the material was not "carbon" but an oxygen containing body impregnate with mineral matter, in this case road dust, and powdered iron formed by abrasion of the piston rings by the road dust. This isolated example can be made to serve our purpose to illustrate that the solid decomposition products are really formed by the oxidation of the oil. In fact, the process can be repeated on a laboratory scale by heating a quantity of oil, and passing air through it, when solid decomposition products are formed. The following ultimate analysis of a product so formed will show the similarity between that formed in the engine to that produced in the laboratory:

	Per cent
Carbon	70.20
Hydrogen	7.25
Oxygen (by diff.)	21.53
Mineral matter	1.02
	100.00

"If these two results are calculated on a mineral matter free basis it will be observed that the oxygen content in each is practically the same. Thus we see that if we can make a quantitative oxidation test we shall have a means of determining the propensity of an oil to form solid decomposition products when in use. Such a test is to be found in British Standard Specification 149 of "Insulating Oils."

"A word of warning is, without doubt, necessary at this stage. It might be thought that for all purposes the lower the oxidation value the better the oil. In transformers this is true, because the oil is merely serving the function of a cooling and insulating agent, and has not to reduce friction. Therefore the more inert it is the better. A lubricant adheres to the moving parts by virtue of certain chemical groups which possess forces which enable the lubricant to adhere to the metallic surfaces to withstand the applied pressure. If the oil be so purified as to render it inert its lubricating value would be seriously diminished, because, in the process of refining, the active groups are removed. Hence, one has to make a compromise between lubricating value and value as a lubricant. A good-class transformer oil has an oxidation value of less than 0.1 per cent, whereas a turbine oil would be considered to be quite good if it had an oxidation value of 0.7 per cent."

Adulterants of Mineral Oils[8]- "Some of the adulterants in common use are:

Rosin Oil. - "This is distilled from rosin, which in turn comes from turpentine. It can be refined readily until its color is such that it can be added to mineral oil without much danger of detection, except by a chemist. It has no lubricating value at all.

Cottonseed Oil and Maize Oil (Corn Oil). - "These are adulterants in lubricating oils, but hardly can be called that if used in cutting oil, as they have very great cooling power. All of these add to the weight and viscosity of the oil to which they are added, so only a comparatively small amount is needed to make a light oil correspond, in those two respects, to a heavier and more expensive one.

"To those who believe in using a clear mineral oil for all purposes of lubrication, the addition of lard, neatsfoot, sperm, rape or any of the other expensive and high-grade fixed oils appears to be adulteration. But to those who would possibly prefer the use of the latter oils, if they did not cost so much, it appears quite differently. The one original and never-to-be-forgotten lubricating oil is sperm oil, taken from the head of the sperm whale found in Southern waters. The arctic whale, which is not a sperm whale at all, gives an oil which is known as arctic sperm oil. Chemists cannot distinguish this from the other, but it sells for a considerably lower price because its color is different and it is not from the original source of sperm oil. It is of about the same specific gravity as the lightest of mineral oils, but it will successfully lubricate much heavier machinery than can be safely run with those light oils.

"Rape oil, on the other hand, has a specific gravity of 0.915, which is heavier than any mineral machinery oil. Yet it is a good loom oil when mixed with a considerable percentage of light mineral oil. Just now it is so high in price that not much will be used. Lard oil, which we make in this country in large quantities, is also extremely high, and will likely stay so as we progress as a manufacturing nation, the price being determined by the ratio of our demand for hogs to eat and to furnish oil for our machinery.

All the oils, except the mineral, have two features which the advocate of the use of mineral oils exclusively does not ever forget; they gum on exposure to the air and they cause spontaneous combustion. All seed oils have the same tendency, in greater or less degree, of oxidizing as linseed oil does. In paint this is a necessary attribute, as otherwise it would never dry; for lubricating purposes it is extremely undesirable. They can, however, be used mixed with mineral or sperm oil and not show this quality to an objectionable extent. Spontaneous combustion is due to the decomposition of oil or its oxidation when spread thinly over inflammable material such as cotton waste. Lard oil, or any other of the fixed oils for that matter, is therefore objectionable in a cotton or other textile mill because it is impossible to avoid getting it on the lint which fills the rooms. On the other hand, the mineral oils stain the goods, and it is impossible to avoid some lubricating oil falling on them. Vegetable oils will wash out, the mineral oils will not. The very clearest, "stainless" mineral oils make a colorless stain, but one that is apt to show as the goods age or when they are dyed. A mixture of 20 percent of animal or vegetable oil with a light, pale mineral oil will be stainless in the sense that it can be washed out, and since mineral oil can be loaded with as high as 50 or 60 percent of vegetable oils without endangering fire, it is possible in this way to get a satisfactory oil for textile mills. It should, however, be noted that there is no more agreement on these proportions than on many things that seemingly should have been settled long ago. At least one authority that should be reliable gives a mixture of 75 percent rape oil and 25 percent pale mineral oil as the one suitable oil. Sperm oil is like mineral oil in that it is not liable to spontaneous combustion and is not likely to gum to any objectionable extent. It is simply too expensive to use.

"Gumming of any of the vegetable oils can be reduced to an extent that makes them usable by the mixture of 30 or 40 percent mineral oil provided the latter is not so tarry as to have a tendency to gum on that account.

The Selection of Oil.(7) - "Now for the actual selection of oil for every-day use. First, it is safe to assume that the lighter the oil, the less the waste in friction, and the less the cost of power provided, the lower the expense due to wear and to hot boxes. It would be advisable to divide the different bearings about the shop into a number of classes, depending on the number of men employed and the class of work done. The lightest, high-speed mechanism should be put in the first class. The chances are that it will be found that a very light mineral oil, say of specific gravity of 0.879, will do the work without any mixture of other oils. If it does not seem to quite fill the bill, a small addition of sperm oil, even if it does cost something, ought to help. The exclusively mineral oil man would say use a little heavier oil, but if you do it is probably at the expense of a waste of power. At the quotations of 13½¢. for light mineral, and 90 ¢. for sperm, a mixture of 20 percent sperm and 80 percent mineral costs only 29 ¢. a gallon. This is not unreasonably high for light machinery which requires very small quantities. This oil, either the straight mineral or the mixture, will not stand any considerable pressure nor will it form much of a film at low speeds. Its film as it is allowed to flow out on metal is about one-fifth thousandth inch thick, which would make it likely that a one-half thousandth inch clearance, or the difference in diameter between the spindle and the bearing, will be sufficient. Anything which must run closer than that must depend on the metal of the bearing and what lubricant its pores can contain. For example, if it is to be a spindle for a high-speed sensitive drilling machine, it must either run in babbitt or bronze bearings, or it must depend on the openness of cast iron to absorb oil enough to keep it running.

"Having an oil for extremely light high-speed work, the next division may well be those numerous bearings which run slowly, have abundant clearance, can be easily lubricated, carry no appreciable load, and run at slow or moderate speeds. This includes many countershafts, most feed shafts, many machine spindles where the work is light, and in general all parts of mechanism where motion is transmitted rather than power. For such bearings a dark, medium-weight mineral oil is sufficient without admixture of animal or vegetable oil. It is possible that some of the cheaper adulterants may be used to advantage, though it would be better if men could be trained to be sparing of oil in cases where it is not needed in large quantities, rather than that the oil should be adulterated to save its cost.

"Another class of bearings comprises those of the spindles of slow-moving machines, like engine lathes, the slower shafts of planers and shapers, planer and shaper ways, etc. These require an oil that will not only work well if the speed is high enough to form a film (it is only in a few cases that it is), but can carry fairly heavy loads, say, above 70 lb. per sq. in.

"For these bearings the oil should be the lightest mineral oil that will answer at the highest speeds of these shafts, plus some other oil that will add the necessary greasiness for conditions when the film is broken down. Most of these bearings start up cold, after standing long enough so that the spindle settles down through the oil till it rests metal to metal on the bearing. Each time such a bearing starts up there is a short period, part of a revolution in many cases and several revolutions in others, when two metals are in practical contact and when cutting may easily be started, unless the oil has this quality of greasiness and the tendency to stick to the metals of both box and shaft. The mineral-oil man will say that he can obtain this by using an admixture of the more tarry or heavier bodied oils. He doubtless can do this, though the man on the other side of the fence will always say that he can obtain the same results with much less loss in friction by using the animal or vegetable oils, like sperm, rape, tallow, and lard, according to the price at which they are selling.

"For high speeds with considerable pressures, such as are found in electric motors, a still heavier mineral oil, say around 0.880 gravity, with the addition of a heavier bodied animal or vegetable oil, preferably sperm, makes a good combination. This oil, even if made up with sperm oil at the present price, should cost only a little over 30¢ per gal; not a prohibitive price if it produces the results expected."

<u>Wear Prevention by Means of Addition Agents.</u>[1] - "The wear-prevention qualities of lubricating oil can be multiplied as much as 17 times

by the addition of two groups of chemical agents, scientists of the Emeryville, California, laboratories of the Shell Development Company recently reported to the American Chemical Society.

"There are two major groups of agents," these research workers said, "which, when added to lubricating oil, are able considerably to reduce wear. These two groups have quite different functions.

"The first group consists of organic compounds whose molecules take the form of long threads which are able to attach themselves by chemical forces, arising from the special structure of the molecules, to the surface of the metal. These compounds greatly increase the tightness with which a film of oil is held between the moving metal surfaces, even under high loads.

"However, the favorable effect of such agents is lost unless the metal surfaces themselves are highly polished and maintain their high polish in service. Even the best polish attainable by mechanical means leaves the surface covered with microscopic irregularities or roughnesses, and it is in the removal of these that the second type of addition agent finds its usefulness.

"Addition agents of the second type have the property of combining, under the influence of the heat generated by the rubbing surfaces, with the surface layer of the metal to form low melting alloys. The result is that when the tiny hills on the surfaces become engaged with each other, isolated spots of very high temperature are produced at the points of contact which cause the surface layer of low-melting alloy to melt and flow just at those points where the hills come into contact.

"These chemical polishing agents are so chosen that the whole surface of the metal does not melt, nor even grow hot, but only the minute projecting roughnesses. In this way the surface of the metal is polished to a high degree while in motion and by virtue of its motion.

"Laboratory tests using highly sensitive apparatus, capable of reproducing wear measurements within an accuracy of 1 percent, have shown that the wear properties of a highly refined white oil, for example, can be improved ten times by the addition of the chemical polishing agents alone. When both polishing and 'film holding' agents are used this factor has been increased to 17 times."

Cause of Lubricating Oil Breakdown.[6] "Lubricating oil breakdown is caused by the tiny black powdery particles that flow in all long-used oil. The deterioration of lubricating oil shortening both the life of the oil and the life of the motors was explained before the meeting of the American Chemical Society recently by E. G. Larsen and F. A. Armfield of the Shell Development Company, Emeryville, California.

" Several things have been blamed for oil breakdown, they stated, including the heated metal of the engine, unburned gasoline, oxidation products of the oil itself, etc. The two researchers found the real culprits to be the tiny black powdery particles that float in all long-used oil. These act as catalysts, aiding the oil to contract an undesirable union with oxygen and then deteriorate.

" The black particles themselves are of diverse origin: microscopic bits of metal worn off the engine parts, dust from the air, and especially the chlorides of iron and bromine, which arise from the use of leaded gasoline.

" Practical moral of the story is the importance of having a good oil filter and seeing that it is always in good working order."

"An oil in an internal combustion engine has three distinct functions to perform: (1) To lubricate (a) reciprocating parts; (b) rotating parts. (2) To form a gas seal round the rings. (3) To conduct away heat generated by the shear it suffers in itself.

"It is not surprising, therefore, that the accompanying table shows conflicting requirements as regards viscosity, and that one is driven to the necessity of taking into account the average type of duty on which a vehicle is employed. In this table a plus indicates high viscosity and a minus low viscosity, while their number is a rough guide to the importance of viscosity with regard to the factors.

"Nevertheless, the balance is in favour of the use of thin oils, but bores, crank pins and journals must be very smooth and accurate, and clearances fine, if one is safely to take advantage of thin oils, and they must not be used in any engine in worn condition, but rather to delay their becoming so. Thin oils are preventive, not curative.

"Further, one must be willing to incur higher consumption and perhaps a less quiet engine. With these qualifications one can safely advise thin, clean, oily oil and plenty of it.

FACTORS INFLUENCED BY VISCOSITY

1. Cold starting	- - - -
2. Quiet running	+ +
3. Quick distribution of cylinder walls reducing wear due to "dry starting."	- - - -
4. Prevention of blow-by (hot).	+ + + +
5. Carbon formation in combustion space, piston head and under piston cover	- - -
6. Prevention of scoring of bearing and big ends due to road dust, etc., in oil or lack of good "finish."	+ + +
7. Petrol consumption	- -
8. Loss of oil by "mist" blown out of breather	+ +
9. Good pulling from cold	- -
10. Reduction of wear by corrosion under cold running for given quantity of oil reaching the cylinders	+ +
11. Heat generated in bearings and big ends at high speed, with consequent fatigue of white metal.	- -
12. Prevention of blow-by (cold).	+
13. Valve or ring sticking (for a given quantity of oil on the rings).	- -
14. Cylinder wear by abrasion, heavy duty	+
15. Heat generated in bearings and big ends, low speed, hard pulling	+
16. Cylinder wear by abrasion or scuffing (normal running with clean oil and air filter).	nil.
17. Average oil consumption.	+ + + +

III. EXPERIMENTAL

Purpose of the Investigation

The investigation was undertaken in an effort to determine the lubricating properties of mineral-rapeseed oil mixtures, and to determine the economic feasibility of additions of rapeseed oil to commercial lubricating oils.

Plan of the Investigation

The plan of the investigation:

Tests to be run on mixtures of S.A.E. #10 mineral oil and rapeseed oil and S.A.E. #50 mineral oil and rapeseed oil.

The tests to be conducted using a four-stroke cycle gasoline engine, preferably of not more than two cylinders.

The tests to be conducted in an effort to obtain the relative degree of bearing wear for each oil mixture used as a means of evaluating the lubricating properties of each oil mixture.

The oil mixtures to be used are 0, 25, 50, 75 and 100% rapeseed oil with both S.A.E. #10 and S.A.E. #50 mineral oils.

Tests to be conducted on each oil mixture for 24 and 72 hours at an oil temperature of 300°F ± 10°F.

The connecting-rod bearings used for each test to be tested metallographically in the Metallurgical Engineering Department to determine wear and corrosion.

The oil samples, both original and final, to be tested for A.P.I.

gravity, specific gravity, acid number and Saybolt viscosity.

A total of 18 runs will be made, using mixtures listed previously.

a. Nine will be of 24 hours' duration.

b. Nine will be of 72 hours' duration.

Materials

The following materials were used in the investigation:

Gasoline, Esso (One hundred and fifty gallons). Used as motor fuel. Standard Oil Company of New Jersey. Obtained from Christiansburg, Virginia, distributor.

Motor Oil, Essolube S.A.E. #10 (Five gallons). Used as a test oil. Standard Oil Company of New Jersey. Obtained from Christiansburg, Virginia, distributor.

Refined Rapeseed Oil (Ten gallons) Used as a test oil Murray Oil Products Company, Philadelphia, Pennsylvania

Motor Oil, Prestone (Ten quarts) Used as a test oil Manufactured by National Carbon Company, New York, New York. Obtained from Speedway Esso Station, Blacksburg, Virginia

Motor Oil, Quaker State, S.A.E. #10 (Six quarts) Used as a test oil. Quaker State Oil Refining Corporation, Oil City, Pennsylvania. Obtained from Blacksburg Motor Company, Blacksburg, Virginia.

Motor Oil, Esso No. 1 (Six quarts). Used as a test oil. Standard Oil Company of New Jersey. Obtained from Speedway Esso Station, Blacksburg, Virginia.

Castor Oil (Three quarts) Used as a test oil. Obtained from Chemical Engineering stockroom.

Kerosene (Five gallons) Used as cleaning solvent for motor parts. Obtained from Chemical Engineering stockroom.

Air (Thirty PSIG) Used for cooling motor cylinder head after motor cooling system was closed off in order to maintain 300°F oil pan temperature. Obtained from Nash Hytor Compressor in Chemical Engineering Department Laboratory.

Alkali Blue Indicator (Ten grams) Used as indicator in acid number determinations.
Manufactured by National Aniline and Chemical Co., Inc., New York, New York
Lot No. 3422 Schultz No. 536
Obtained from Fisher Scientific Company, Pittsburg, Pennsylvania

Sodium Hydroxide Pellets (Five pounds) Used to make titrating solution for acid number determinations.
Obtained from and manufactured by J. T. Baker Chemical Company, Phillipsburg, New Jersey
Lot No. 63043

Alcohol, Ethyl (95%) (One gallon) Scientific grade. Used in acid number determinations. Obtained from Chemistry Department stores.

Lagging, Asbestos Fiber. Used to lag motor. 85% magnesia. Obtained from Chemical Engineering stockroom.

Ether, Petroleum (One pound) Used as solvent in sludge test.
Manufactured by Coleman and Bell Company, Norwood, Ohio.
Lot No. 411162
Obtained from Chemistry Department stockroom.

Hexane, (One kilogram) Used as wash in sludge test
Manufactured by Eastman Kodak Co., Rochester, New York
Lot No. P1135
Obtained from Chemical Engineering stockroom

Apparatus

The following apparatus was used in the investigation:

Light Unit, Delco, Model 1271. (One). Used as test engine
Manufactured by Delco Appliance Division, General Motors Corporation, Rochester, New York.
Obtained from Agricultural Engineering Laboratory, Virginia Polytechnic Institute, Blacksburg, Virginia.

Bearings, Babbitt (Fourteen). Part No. 82826. Used as replacement test bearings.
Manufactured by Delco Appliance Division, General Motors Corporation, Rochester, New York.
Purchased from J. E. Mitchell Company, Baltimore, Maryland.

Heaters, Strip (Six). Used to heat oil pan of motor
Manufactured by General Electric Company, Schenectady, New York.
Cat. No. 2A24602
Volts: 230; Watts: 350
Obtained from General Electric Distributor, Roanoke, Virginia

Thermostat (One). Used to regulate oil pan temperature
Manufactured by General Electric Company, Schenectady, New York.
Cat. No. 4980281G126
Operating Unit No. CR2992-R1
Range 270-370°F
Obtained from General Electric Distributor, Roanoke, Virginia

Lampbank, 600 Watts. (One). Used to load generator.
Constructed with four 150 watt light bulbs in parallel.
Materials were available in Chemical Engineering stockroom.

Cement, Penn-Dixie. (Two bags). Used to make concrete block for motor support.
Obtained from Virginia Polytechnic Institute storage lot.

Gravel, Dolomite Native. (One-half inch). Used as aggregate in concrete block.
Obtained from Chemical Engineering storage.

Ammeter, D. C. (One). Used to determine current flowing in lampbank.
Range: 0-50 amperes
Manufactures by Jewell Electrical Instrument Company
Obtained from Electrical Engineering Department, Virginia Polytechnic Institute, Blacksburg, Virginia.

Piston Rings, Delco. (Three). Used as replacement rings
Obtained from McBryde Hall Shops, Virginia Polytechnic Institute, Blacksburg, Virginia.

Spark Plug (One). Used for ignition on motor.

Manufactured by A. C. Spark Plug Corporation, Flint, Michigan

Plug No. 73, 7/8" thread, 15/16" Hex. spark gap setting 0.025"

Obtained from Speedway Esso Station, Blacksburg, Virginia.

Hydrometers, A.P.I. (Four). Used to read A. P. I. Gravity

Range: 19-61

Obtained from Chemistry Department, Virginia Polytechnic Institute, Blacksburg, Virginia.

Viscosimeter, Saybolt Universal (One). Used to determine Saybolt Viscosity.

Obtained from Chemistry Department, Virginia Polytechnic Institute

Bottles, Ground-Glass Stoppered. (Eighteen). 250 ml. capacity. Used to run acid numbers.

Obtained from Chemistry Department, Virginia Polytechnic Institute

Burette (One.) 50 ml. capacity. Used to make titrations

Graduations: 0.1 ml.

Obtained from Chemical Engineering stockroom

Glassware, Assorted

Obtained from Chemical Engineering stockroom

Balance, Analytical (one.)

Obtained from Phipps & Bird Company, Richmond, Virginia

Batteries, Storage. (Three). Used as ignition source

Volts: 6

Plates: 15

No. A115

Obtained from Goodyear Electrosport Shop, Blacksburg, Virginia

<u>Thermometer</u> (One). Used to indicate oil pan temperature Manufactured by Western Electric Instrument Corporation, Newark, New Jersey.

Patent No. 1, 970, 219 B-4

Range: 50-500°F in graduations of 2°F

Obtained from Chemical Engineering stockroom

<u>Balance, Westphal.</u> (One). Used to read specific gravities of oils.

Obtained from Chemical Engineering stockroom.

<u>Methods of Procedure</u>

The following procedure was followed in making test runs on a Delco-Light Unit, Model 1271, which was used as a test engine.

<u>Assembling the Engine</u>.- The engine was first completely dismantled and cleaned.

Two holes were drilled and tapped for 3/8" pipe in the left side of the crankcase, into which a steam heating coil could be inserted.

A 3/8" copper coil was placed in the bottom of the oil pan of the motor, but was later removed when it was found that the desired oil pan temperature of 300°F. could not be maintained with the steam available for heating the coil.

The center of the base plate of the engine was drilled with a 3/4" drill to permit the oil drain pipe to pass through.

An 18" x 18" x 28", 1-4 mix, concrete motor stand block, with 5/8" anchor bolts for anchoring the base plate of the motor, was constructed on the balcony floor of the Unit Operations Laboratory. The block is located twelve feet from the east door of room #31 and two feet from the south wall of the Chemical Engineering building.

The motor-generator set was assembled on the concrete stand block. (See Plate No. 1.)

Six strip heaters (350 watts, each) were placed under the engine (See Dwg. No. 1.) in conjunction with a G.E. CR2992-R1 control thermostat. The bulb of the thermostat was inserted through one of the 3/8" tapped holes in the side of the crankcase previously used for the steam heating coil. The other hole was plugged with a 3/8" pipe plug.

A 600 watt lampbank was constructed with four 150 watt lamps in parallel in order to load the motor-generator set to 97% of its rated capacity of 620 watts. The generator was wired for power takeoff, and the motor for ignition.

The base of the motor and the air space between the crankcase and the outer shell were lagged with 2" asbestos (85% magnesia) lagging. (See Plate No. 1.)

A sheet metal strip was placed around the rim of the flywheel to eliminate the effect of the fan built into the flywheel to cool the motor head.

The lagging in the air space eliminated any possible cooling air to the engine head so three air jets (3-3/8" long, 7/8" Hex.) were installed in such a position that two of them directed cooling air on the engine head. Without this cooling air, the engine became overheated and, due to the excessive expansion of the engine head, stopped. The temper was taken out of the piston rings also.

The motor was started, and it was found, that with the above-mentioned modifications and changes of lagging, strip heaters, and

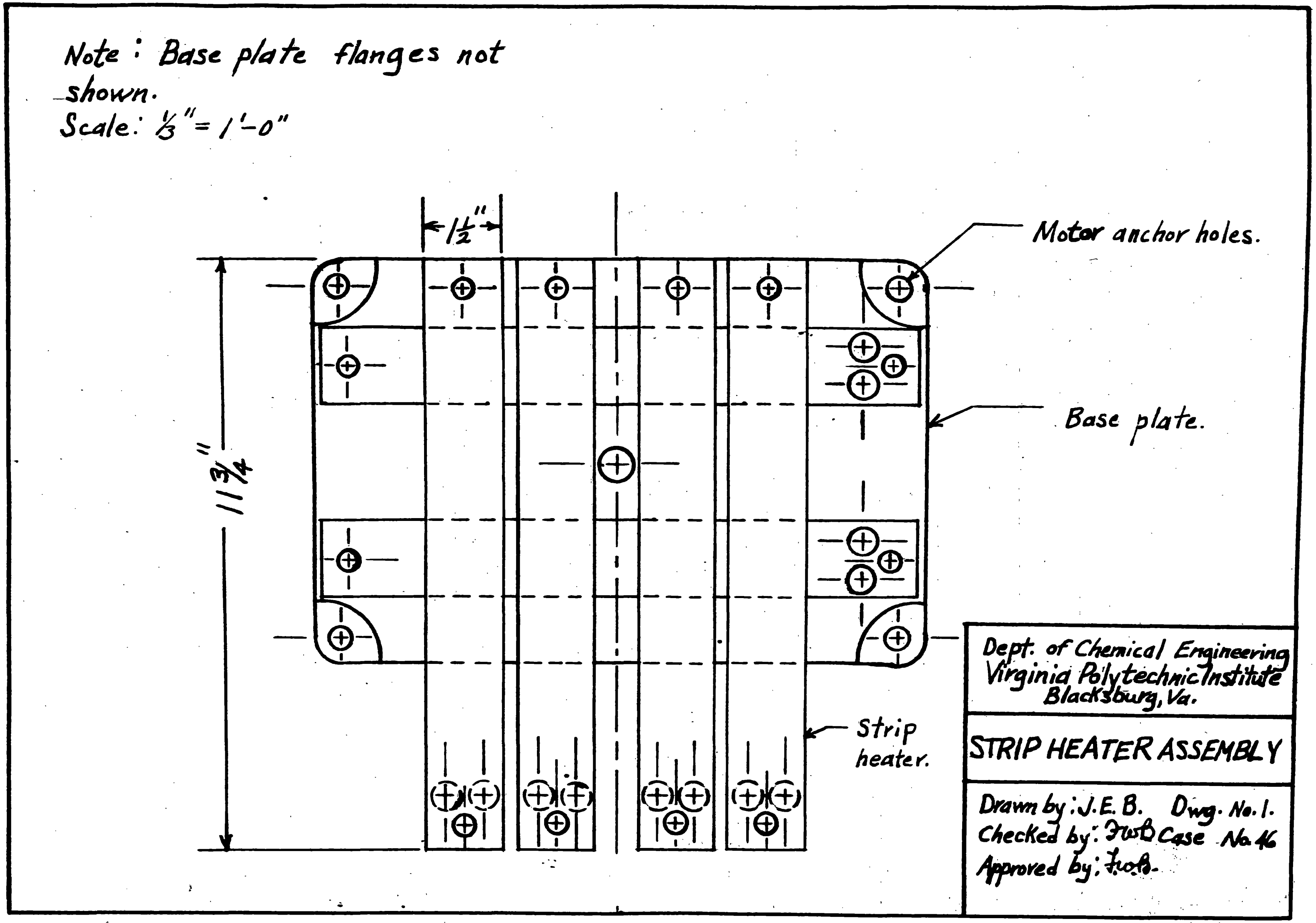

Note: Base plate flanges not shown.
Scale: 1/3" = 1'-0"
1½"
11¾"
Motor anchor holes.
Base plate.
Strip heater.
Dept. of Chemical Engineering
Virginia Polytechnic Institute
Blacksburg, Va.
STRIP HEATER ASSEMBLY
Drawn by: J.E.B.
Dwg. No. 1.
Checked by:
Case No. 46
Approved by:

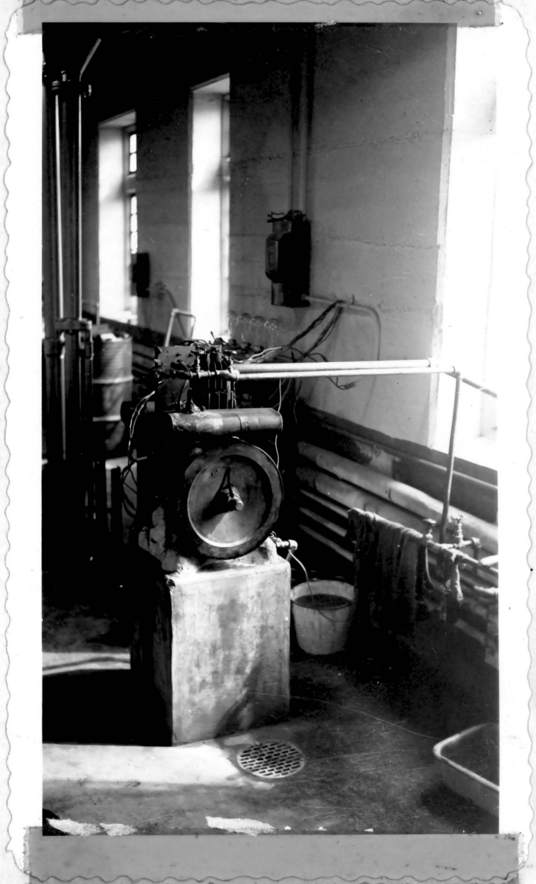
PLATE I

EQUIPMENT ASSEMBLY

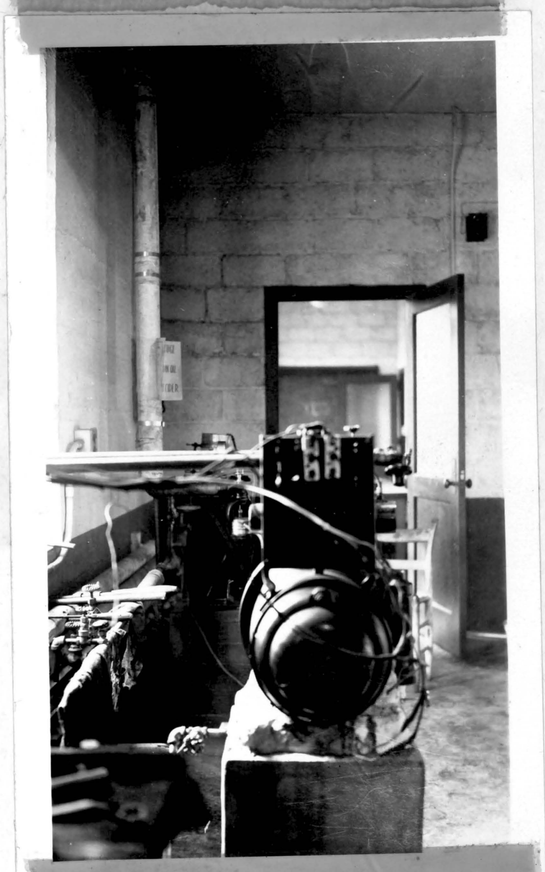
DELCO-LIGHT UNIT, MODEL 1271

A- Flywheel

B- Generator



FRONT VIEW



REAR VIEW

PLATE I.

EQUIPMENT ASSEMBLY

C - Air Jets
D - Flywheel
E - Lagging

RIGHT SIDE

LEFT SIDE

elimination of flywheel cooling, that the strip heaters would maintain an oil temperature of 304 12°F. with the motor-generator set in operation under test load conditions.

The finest adjustment possible on the control thermostat set the break-on point at 292°F. and the break-off point at 316°F., giving the average temperature of 304 12°F.

<u>Test Procedure.</u> - The crankcase face plate was removed and a new weighed bearing was inserted in the connecting rod assembly. The new bearing was polished with a paper towel prior to weighing in order to remove the oxide film and any grease or lint present.

Uniform bearing tightness throughout all runs was secured by tightening the connecting-rod nuts until the crankshaft could not be turned by hand and then backing the nuts off one-sixth of a turn.

The oil pan of the engine was thoroughly cleaned by flushing with kerosene and wiping dry with a cloth.

The engine was reassembled and two quarts of Prestone motor oil were poured into the crankcase.

The current was turned on to the strip heaters and when the oil pan temperature reached 300°F., the engine was started.

The Nash Hytor Compressor (30 PSIG) was started immediately afterward and the air valves which directed the cooling air on the engine head were fully opened.

The 600-watt resistance bank was switched on in order to load the generator. The generator has a rated load of 620 watts.

At the termination of the run (24 to 48 hours), the current to the strip heaters, the Hytor and the Delco engine were turned off.

The oil was drained from the engine into stoppered bottles and labeled for use in other determinations.

After the first five runs made at intervals of 45.0, 14.5, 24.0, 44.0, and 24.0 hours on Prestone, Prestone, Essolube #10, Essolube #10 and Prestone, respectively, it was decided to dismantle the engine at the end of each of the succeeding runs in order to clean the crankcase, piston, piston rings, and cylinder wall and to observe the extent of carbon deposits on the piston walls and ring grooves.

The piston rings were removed from the piston and cleaned of all carbon.

The bearing was removed from the connecting rod assembly, washed with kerosene, dried, polished with a clean cloth and weighed on an analytical balance.

The oil pan of the motor was flushed with kerosene, and wiped clean with a cloth.

The motor was reassembled and the foregoing test procedure was repeated on each succeeding run; i.e., on Prestone, Essolube #10, Essolube #10, Prestone, Essolube #10-25% Rapeseed, Rapeseed, Castor, Esso No. 1, Quaker State, Quaker State in the order listed for 14.5, 24.0, 44.25, 24.0, 6.0, 16.0, 16.0, 37.0, 41.5 and 35.5 hours respectively.

Analytical Procedure.-

A.P. I Gravity. - This test was run in the manner described in the United States Standard Tables for Petroleum Oils[3], using A.P. I.

hydrometers, range 19-61.

Acid Number. - This test was run according to the method of Holde(9).

Saybolt Viscosity. - This test was run according to A.S.T.M. specifications as set forth in A.S.T.M. Standards on Petroleum Products and Lubricants, September 1940.

Sludge Test. - Twenty cc. of oil and forty cc. of petroleum ether were agitated in 250 ml. ground glass stoppered bottles by shaking by hand for 60 seconds. Each bottle, with contents, was allowed to stand overnight before filtering through a double filter paper. The dilution of the oil with the petroleum ether made it possible to separate the finely divided carbon and resins from the more viscous oil by filtering through a double filter paper.

The first 60 ml. of the filtrate through the filter was not completely free from the finely divided carbon, but became more completely clarified as the carbon deposited on the filter paper and formed the true filter medium. Accordingly, the first filtrate obtained was filtered through the same filter a second time to obtain a higher degree of clarification.

The filter papers were dried in an oven for 25 hours at a temperature of 85°C. The filter papers were cooled and weighed on an analytical balance. Since there was a certain retention of oil by the filter paper, a blank, using new oil, was run in an identical manner to that used on the test samples and the weight so obtained on the blank was subtracted from the weights obtained on the test oils to ascertain the weight of sludge retained by the filter paper.

The filter papers were then washed with successive 10 ml. portions of hexane from a wash bottle to remove oil retained by the filter papers. The filter papers were then dried and weighed as before.

The weight of two new dry filter papers were subtracted from the weight obtained in order to determine the weight of oil free insolubles retained by the filter papers.

Data and Results. - The oils used, the duration of the runs, and the data and results recorded are presented in the following tables:

TABLE - II BREAKDOWN TEST DATA - PROPOSED TIME OF RUN: 48 HOURS

Oils Used		Esso No. 10	Esso No. 1	Quaker State	Prestone	Castor*	Quaker State
Time of Run (hrs.)		44.25	37.00	41.50	48.00		35.5
Bearing Weight (gms.)	(Initial	175.7642	175.7478	176.6054	175.6485		176.8936
	(Final	175.6430	175.4973	176.5113	175.4542		176.7943
	(Loss	0.1212	0.2505	0.0941	0.1943		0.0993
A.P.I. Gravity @ 60°F	(Initial	32.90	32.7	32.15	10.6		
	(Final	22.50	31.2	31.08	10.6		
	(Loss	10.40	1.5	1.07	0.0		
Specific Gravity @60°F	(Initial	0.8594	0.8605	0.8634	0.997		
	(Final	0.9180	0.8685	0.8691	0.997		
	(Increase	0.0586	0.0080	0.0057	0.0		
Acid Number	(Initial	0.0791	0.0790	0.0788	0.954		
	(Final	3.325	0.870	0.2380	1.670		
	(Increase	3.246	0.791	0.1592	0.716		
Saybolt Viscosity, S.U.S. Initial	(@ 100°F	208.5	290.0	247.6	300.0		
	(@ 130°F	105.0	150.0	127.0	---		
	(@ 210°F	48.5	59.5	51.7	62.7		
Saybolt Viscosity, S.U.S. Final	(@100° F	1511.0	268.8	323.0	412.0		
	(@ 130°F	641.6	154.3	156.6	209.7		
	(@ 210°F	118.0	61.5	55.3	76.7		
Increase, S.U.S.	(@ 100°F	1302.5	-21.2	75.4	112.0		
	(@ 130°F	536.6	4.3	29.6	---		
	(@ 210°F	69.5	2.0	3.6	14.0		
Sludge, gms/20cc.oil**		1.38	0.14	0.50	1.46		
Remarks		0.5 quart of oil remaining at end. Engine was gummed up	No gumming. 0.5 quart of oil remaining at time indicated	No gumming. 0.5 quart of oil remaining at time indicated	No gumming: 0.5 quart oil remaining at time indicated		Run was made to corroborate bearing data of previous Quaker State run

* Did not approach the proposed 48 hr. time
**Allowable error 0.1 gram

TABLE - III

BREAKDOWN TEST DATA - PROPOSED TIME OF RUN: 24 HOURS

Oils Used		Prestone	Prestone	Essolube #10	Rapeseed (Pure)	Castor (Pure)	Essolube #10/ 25% Rapeseed
Time of Run (hrs.)		14.60	24.00	24.00	16.00	16.00	6.00
Bearing Weight (gms.)	(Initial	176.4989	175.2640	172.4598	175.2490	175.8535	175.8535
	(Final	176.4287	175.1587	172.3239	174.9571	175.3029	175.6923
	(Loss	0.0702	0.1053	0.1359	0.2919	0.3339	0.1612
A.P.I. Gravity @ 60° F	(Initial	10.5	10.80	32.90	23.05	14.78	30.40
	(Final	—	10.99	25.50	17.00	10.99	27.09
	(Loss	—	0.49	7.40	6.05	3.79	3.31
Specific Gravity @ 60° F	(Initial	0.997	0.997	0.8594	0.9147	0.967	0.8728
	(Final	1.002	1.000	0.9003	0.9524	0.993	0.8912
	(Gain	0.005	0.003	0.0409	0.0377	0.026	0.0184
Acid Number	(Initial	0.954	0.954	0.0791	0.744	0.981	0.312
	(Final	0.949	0.952	3.175	0.714	1.200	1.527
	(Gain	*-0.005	-0.002	3.096	-0.030	0.219	1.216
Saybolt Viscosity S.U.S., Initial	(@ 100° F	300.0	300.0	208.5	271.5	1602.0	234.0
	(@ 130° F	—	—	105.0	158.0	661.0	122.0
	(@ 210° F	62.7	62.7	48.5	65.5	115.0	51.0
Saybolt Viscosity S.U.S., Final	(@ 100° F	380.0	384.0	542.0	2381.6	4668.0	398.8
	(@ 130° F	212.8	198.4	278.5	1120.0	1740.0	228.6
	(@ 210° F	69.0	70.7	73.3	263.5	330.0	73.6
Gain, S.U.S.	(@ 100° F	80.0	84.0	333.5	2110.1	3066.0	164.8
	(@ 130° F	—	—	173.5	962.0	1079.0	106.6
	(@ 210° F	6.3	8.0	24.8	198.0	115.0	22.6
Sludge, gms/20cc. oil**		0.90	0.93	0.83	1.75	—	0.82
Remarks		Run discontinued at time indicated due to severe knock in motor			Engine stopped due to gumming of oil at time indicated	Engine stopped due to gumming of oil at time indicated	Run was made with one piston ring in motor. Oil gummed.

* ± 0.005 is the range of experimental error

** Allowable error ± 0.1 gram

IV. DISCUSSION

Oils Tested in the Investigation. - The original plan of the investigation was not followed as it was found that the rapeseed oil which had been intended for admixture with the mineral oil had a very poor value as a lubricant. It gummed very rapidly and stopped the test unit in 16.0 hours as a result of gum formation on the piston and cylinder wall. Compared to Essolube #10, with which admixtures of rapeseed oil were to be made, this is a very poor lubricant as Essolube #10 was the only mineral oil tested which stopped the motor due to gum formation and the test unit ran for 44.25 hours with the mineral oil (no admixture of rapeseed) before stopping due to gum formation. The other mineral oils tested (Esso No. 1 and Quaker State) did not form sufficient gum in the motor to cause it to stop.

Castor oil was also run in the test engine and was found to have gum-forming properties similar to that of rapeseed as it also stopped the test engine in 16.0 hours due to gum formation.

It was decided to concentrate on testing some of the mineral oils to determine their breakdown characteristics under high temperature conditions (300°F.) in an effort to determine a satisfactory means of evaluating a lubricant under accelerated testing conditions.

Prestone motor oil, which is a non-petroleum oil, was tested also.

Oil Consumption. - In the discussion of oil consumption, only the oils which approached the maximum proposed time of 48 hours are considered.

The Prestone motor oil had the lowest oil consumption (1.5 quarts in 48.0 hours) of any of the oils tested. It was the only oil whose consumption was low enough to permit a complete 48-hour run.

The original plan of the investigation was to run tests for 24 and 72 hours, but because of oil consumption (below 500 ml., the engine was shut off), the time of the longest test had to be reduced to 48 hours.

Esso No. 1 and Quaker State proved to be slightly inferior to Prestone in the respect of oil consumption. All the runs which approached the 48.0 hour time were stopped when the oil quantity in the motor was 500±50 cc. Esso No. 1 and Quaker State oils reached this level in 37.0 and 41.5 hours respectively.

Loss in Bearing Weight.- In the case of rapeseed and castor oils, it is indicated, by the high bearing weight losses of 0.2919 and 0.3339 grams respectively in runs of 16.0 hours duration, that the extreme gumming of the oils resulted in a lack of lubrication and wiping of the bearings ensued. The bearing surfaces were discolored and it appeared that the oil film had broken down, and decomposition products had been ground into the metal bearing surface.

The only result completely at variance with expected data is that of Esso No. 1 oil. The high bearing weight loss of 0.2505 gram in 37.0 hours is probably due to the removal of some of the desirable lubricating constituents of the oil in the solvent refining processes used in treating this oil.

A duplicate run was made on Quaker State oil in an attempt to corroborate the original results. The first run showed a bearing weight loss of 0.0241 gram in 41.5 hours. This result compares favorably with the bearing weight loss of 0.0293 gram in the second run of 35.5 hours.

These two results would indicate that the values reported for bearing weight loss are reliable, that the results can be duplicated within narrow limits of differences, and that bearing weight loss is a satisfactory means of evaluating a lubricant.

A.P.I. Gravity.- The oils were allowed to stand for several weeks before testing for A.P.I. Gravity and when tested, the oils were poured into a 500 ml. graduate without being shaken first. It is probable that any decomposition products which would settle out of the oil would have done so during the standing period. Essolube #10 shows a decrease in A.P.I. Gravity of 10.40 in a run of 44.25 hours' duration. This difference is the greatest of any of the oils tested.

In the case of Essolube #10, the decomposition products evidently did not settle as evidenced by the fact that the oil became thicker causing the A.P.I. Gravity to decrease. This statement is also corroborated by the high sludge value of 1.33 grams in the same run of 44.25 hours.

The property of holding decomposition products in suspension is valuable to the car owner as these products will pass out of the automobile crankcase when the oil is drained rather than form a sludge in the oil pan. However, the quantity of decomposition products present makes Essolube #10 undesirable for long use as some of these products would undoubtedly settle out in the oil pan. This oil would be satisfactory if it were drained before sludging became too pronounced, or if an oil filter were used.

The effect of decomposition products on a motor is to obstruct oil lines and render the oil pump useless.

Specific Gravity.- Prestone motor oil has a specific gravity of 0.997. After the oil has been used for some time, foreign substances suspended in the oil may cause the specific gravity to become higher than that of water (greater than 1.00).

In internal combustion engines, this would cause any water which might be condensed in the oil pan to be floated on the oil. This situation is not so readily encountered with the low viscosity petroleum oils as they are of lower specific gravity.

Acid Number.- This test was conducted in an effort to ascertain the acid-forming tendencies of possible decomposition products of the various oils tested under high temperature (300°F.) conditions. Acid number is defined as the mg. of KOH required to neutralize 1.0 gm. of oil.

Of the oils tested, Essolube #10 showed an increase of 3.246 in acid number for a run of 44.25 hours' duration as compared to an acid number increase of 0.791 for Esso No. 1 oil for a run of 37.0 hours' duration. Since both of these oils had an original acid number of 0.079 and the Essolube #10 shows a much higher increase than the Esso No. 1, it would appear that the solvent refining treatment used on Esso No. 1 oil had removed the majority of the acid-forming constituents.

The presence of the acid-forming constituents in the Essolube #10 oil may account for the low bearing weight loss of 0.1212 gram in 44.25 hours, as they may possibly impart desirable lubricating characteristics to the oil insofar as wear prevention is concerned.

In view of the foregoing statements, the results obtained on the Quaker State oil may seem to be contradictory to what has been said, but it must be kept in mind that Quaker State is a paraffin base oil. This oil has a much lower percentage of asphaltenes than those from the Texas district. Crudes from the Bradford district of Pennsylvania where Quaker State oil originates, command an unit price of $2.30/bbl.* as compared to $0.63/bbl. from which Esso and Essolube oils originate. This premium price commanded for the Bradford crude, which is used primarily as a source of lubricating oils, is probably due to the lower percentage of unsaturates present in this oil and to its high stability while in use.

Prestone oil, being a non-petroleum oil and about which very little is known at the present time relative to its breakdown characteristics and decomposition products, little can be deduced from the fact that its acid number showed an increase of 0.718 in a run of 48.0 hours.

Saybolt Viscosity.- The Saybolt Viscosity increase may be considered to be an index of the gum-forming tendency of the oils tested, with the exception of Prestone. Prestone oil showed the high sludge value of 1.46 grams with the low increase in Saybolt Viscosity of 14 S.U.S. at the end of a 48-hour run.

In the case of rapeseed, castor, and Essolube - 25% rapeseed oil, gum formation evidently became so pronounced as to cause wiping of the bearings as evidenced by bearing weight losses of 0.2919, 0.3339 and 0.1612 gram respectively at run times of 16.0, 16.0, and 6.0 hours for the three oils, respectively. The bearing surfaces of the three bearings

* Kendall Refining Process Bulletin, Kendall Refining Co., Bradford, Pa. (1941)

used in these runs were discolored indicating that gum had been ground into the metal surface.

In the case of Essolube #10 oil, the oil evidently gummed on the piston and cylinder wall and caused the engine to stop before noticeable wiping of the bearing occurred as evidenced by the low bearing weight loss of 0.1212 gram in a run of 44.25 hours.

Sludge Test.- The values of sludge reported are those obtained before washing the filter papers with hexane. The hexane dissolved out not only the oil retained by the filter paper, but the resins and gums as well. Any material which would be retained on the filter paper after the hexane treatment, therefore, would not be a true measure of the gum and resins formed. Gumming material could be seen on the filter paper before washing with hexane, but this material was not in evidence after washing with hexane.

The primary reason for running this test was to determine the weight of gums, resins and carbon in the oil to ascertain the sludge-forming tendency of the oils.

The values of sludge formation are reasonable from the comparison of Esso No. 1 oil (sludge 0.14 gram in a run of 37.0 hours) and Essolube #10 oil (sludge 1.58 grams in a run of 44.25 hours). The Esso No. 1 oil is a solvent refined oil. Solvent refining removes the sludge-forming constitutents of the oil. These constituents are not removed from the Essolube #10 oil which would account for the higher value of sludge formation.

Castor oil could not be tested for sludge as it is immiscible with petroleum ether.

V. CONCLUSIONS

Using a Delco-Light Unit, Model 1271, equipped with Delco No. 82526 babbitt bearings, operating the unit at an average r.p.m. of 1000 ± 20, drawing 600 watts of the 620 watts rated capacity of the generator, and with the oil temperature of 304 ± 12°F., the following conclusions may be drawn:

1. The test equipment used provides a satisfactory method of evaluating lubricating oils according to breakdown characteristics and friction prevention under accelerated conditions.

2. The bearing weight loss obtained from using vegetable oils in the test unit varied from 0.01825 to 0.02085 gm/hour for rapeseed and castor oil, respectively. This result shows a greater degree of bearing wear than that exhibited by the mineral oils tested which varied from 0.00227 to 0.00677 gm/ hour.

3. The vegetable oils used, and the mixture of 25% vegetable and 75% mineral oil were not as satisfactory for the purpose of continuous, uninterrupted operation as the non-mineral and mineral oils as they formed decomposition products on the cylinder wall of the engine and caused it to stall due to friction.

4. The vegetable and vegetable-mineral oil mixture showed higher sludge-forming properties than did the mineral oils tested. The sludge-forming rate varied from 0.1095 gm/ hour to 0.1368 gm/ hour for rapeseed and 25% rapeseed-75% mineral oils respectively while the mineral oils varied from 0.00378 gm/hour to 0.0312 gm/ hour.

5. The vegetable oils showed greater tendency to become of higher viscosity during use than did the mineral oils. The Saybolt Viscosity increase, @ 210° F., varied from 7.2 S.U.S. per hour to 12.5 S.U.S. per hour for castor and rapeseed oil respectively while the mineral oils varied from 0.0 S. U. S. per hour to 1.57 S. U. S. per hour.

VI. SUMMARY

HIGH TEMPERATURE BREAKDOWN TESTS OF SOME VEGETABLE OIL ADDITANTS TO LUBRICATING OILS

This investigation was undertaken in an effort to determine the lubricating properties of mineral-rapeseed oil mixtures and to determine the economic feasibility of additions of rapeseed oil to commercial lubricating oils.

The lubricating properties of the various oil mixtures were determined by bearing weight loss, A.P.I. Gravity difference, specific gravity difference, acid number difference, and Saybolt Viscosity difference in the original and final oil. A sludge test was run on the final oil also.

Test Equipment. - The test engine used was a Delco-Light Unit, Model 1271, equipped with Delco No. 82526 babbitt bearings, operating the unit at an average r.p.m. of 1000 ± 20, drawing 600 watts of the 620 watts rated capacity of the generator, and with the oil temperature of 304 ± 12° F.

The oil pan temperature was maintained by placing six 350 watt, 230 volt strip heaters under the engine crankcase and lagging the base of the motor and the crankcase ventilating ducts with 2" (85% magnesia) asbestos lagging.

Oils Tested in the Investigation. - The rapeseed oil which was intended for admixture with Essolube #10 mineral oil gummed very rapidly and stopped the test unit in 16.0 hours.

Esselube #10 was the only mineral oil tested which stopped the test engine due to gum formation, and the test unit ran for 44.25 hours before stopping. The other mineral oils tested (Esso No. 1 and Quaker State) did not form sufficient gum in the motor to cause it to stop. Prestone, a non-petroleum oil, also did not form sufficient gum to stop the test unit.

Castor oil stopped the test unit in 16.0 hours as a result of gum formation.

Results. - The test equipment used provided a satisfactory method of evaluating lubricating oils under accelerated conditions.

Bearing weight loss was found to be higher when vegetable oils were used in the test unit than when mineral oils were used.

Vegetable oils had a greater tendency to form decomposition products than did the mineral oils.

Vegetable oils had a greater tendency to form sludge in the motor and to become of higher viscosity than did the mineral oils.

RECOMMENDATIONS AND LIMITATIONS

Mechanical.- A permanent tachometer should be installed on the test unit in order to obtain the actual revolutions of the motor during a test run. The runs could then be based on the actual revolutions of the motor instead of a specified time.

The test unit is now limited by the fact that the runs must be based on a specified run time while the r.p.m. does not remain constant.

An auxiliary tank should be attached to the oil pan in order to have a sufficient quantity of oil available to continue test runs to 72 hours.

At present, test runs must be stopped at 48 hours or less due to oil consumption. It is inadvisable to run the motor with less than 500 cc. of oil in the oil pan.

Testing.- Further tests should be conducted on one oil, in small increments of time or revolutions, to determine whether or not a straight-line function exists for oil breakdown and bearing wear.

At present, only three sets of data are available for this determination and more are required.

Further tests should be conducted on the solvent refined oils to determine the extent of the deleterious effect of the various solvent refining processes on friction reducing power.

There are possibilities for more work using other substances than vegetable oils for admixture with mineral oil to enhance the lubricating properties of the mineral oil.

VIII. BIBLIOGRAPHY

1. Anon. Oiling Oil-Wear Prevention by Means of Addition Agents. Scientific American 163, 264, (1940)

2. Anon. Thin vs. Thick Oils. Automobile Engineer 29, 382, (1939)

3. Anon. United States Standard Tables for Petroleum Oils. Natl. Bur. Standards Tech. Paper (1916)

4. Austin, M. F. Growing Market for Vegetable Oils in Paint and Varnish Industries. Chem. & Met. 33, 104, (1926)

5. Caldwell, B. P. and Price, R. B. Bodying of Rapeseed Oil. Ind. Eng. Chem. 23, 1463-6, (1931)

6. Evans, E. A. Lubricating and Allied Oils. Petroleum World, London, 23, 133-4, 136, 138-9, (1926)

7. Fish, E. H. Properties and Selection of Lubricating Oils. American Machinist 42, 197-200, (1915)

8. Griffin, R. C. "Technical Methods of Analysis". p. 739, 741. McGraw-Hill Book Co., New York. 1927. 2nd ed.

9. Holde, D. "The Examination of Hydrocarbon Oils and Saponifiable Fats and Waxes." p. 69, Wiley., 1922. 2nd ed.

10. Thomson, A.S.T. and Caldwell, P.S. The Lubricating Properties of Mineral, Vegetable, and Fatty Oils. Journal Royal Technical College (Glasgow) 2, 490-502, (1931)

11. Thone, F. Cause of Lubricating Oil Breakdown. Science Digest 12, 95, (1942)

VIII. ACKNOWLEDGEMENTS

The author wishes to express his gratitude to all members of the Chemical Engineering Department for their aid during the investigation.

In particular the author wishes to thank Dr. F. C. Vilbrandt and Professor F. W. Bull for their many helpful aids and criticisms.

The author also wishes to thank Professor W. A. Murray and Mr. M. A. Price for their aid during the construction of the test unit.