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Technical tests on lubricating oils.

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Synopsis. The outstanding problems of lubricating oil testing are dealt with. After a general exposition of the various lubrication conditions, a description is given of the instruments used for the measurement of friction coefficients and wear; and finally the test results are given. The applicability of the four ball machine to the test of E.P. additives is also discussed.

Low temperature properties are dealt with and the advantage of good viscosity-temperature characteristics is particularly stressed. Test results from the I.G. cold cabinet are given, and the effects of viscosity at low temperatures and of solidification point are discussed. In the course of engine oil tests, the ring-sticking test is particularly emphasized and the effect of inhibitors is discussed. Finally it is reported on foam formation, oil thickening and oil consumption tests.

Technical tests on lubricating oils.

Up to a few decades ago, the choice of a lubricant for machine lubrication was of minor importance, but the swift development of automotive transport and aviation has forced the need for a closer attention to lubrication problems. In Germany, this question became particularly urgent during the last decade, mainly due to the development of the Luftwaffe, with the great demands involved both as regards quality and quantity. These demands have risen still further owing to the war. Engines were further improved, to combine maximum power with minimum weight. This resulted in higher bearing pressures and higher temperatures, i.e. an increased mechanical and thermal stress of the oil. Moreover there is the possibility of eliminating the oil cooler, which adds to air resistance, in order to step up the flying speed. This measure represents in turn yet an additional strain on the oil. If these requirements are to be met, the point should however not be neglected that the low temperature characteristics of the oil, i.e. cold starting, may in no case be affected; on the contrary they should be further improved, to meet present requirements. These contradicting and exacting demands are made not only on engine oils, but also on lubricants for different purposes, e.g. weapon oils. A machine-gun oil must assure adequate lubrication of the weapon even when it is hot as a result of use; on the other hand, the gun must be in firing order even at -50°C, as it is the case in high altitude flying. These two examples will suffice to show the demands which present technique makes on lubricants. If we consider the difficulties of raw material supplies both as regards quantity and grade, we can see that the problems confronting the oil chemist are to-day far from simple. To be able to solve these problems, he requires first of all facilities to test his products, on methods suited to practical requirements. There are numerous methods to test the various properties of lubricants, but none is quite satisfactory. The intensive work now carried out in various quarters on this subject gives rise to the hope that in the near future really faultless and practical test methods will be developed.

The object of this lecture is to outline the properties expected from lubricants and the possibilities of the technical experimental station in the investigation of lubricating oils.

In order to test lubricants, it is necessary first of all to understand clearly the tasks for which they must be suited. Primarily a lubricant has the purpose to reduce friction, secondly to prevent or lessen wear and thirdly to dissipate heat. We shall deal with the last named first. The cooling effect depends less on the choice of the lubricant than on the quantity of oil in circulation and on the design of the parts. For our purpose, it is therefore unnecessary to discuss this point any further. On the other hand stress must be laid on the antifriction and wear reducing effect of the oil, which we call lubricating capacity. Before using this expression it should be well understood that the processes of lubrication are still insufficiently known and no clear definition exists for the concept of lubricating capacity. I have mentioned boundary lubrication and for a better comprehension it is necessary briefly to elucidate the various lubrication conditions. This is best done by following the processes on a loaded plain bearing at varying speed. Fig. 1 shows the variation of the friction coefficient in a bearing in terms of the r.p.m., when three different oils of equal viscosity are used. At high speeds and otherwise equal conditions, the same coefficient of friction is found with the three oils. Bearing and shaft are separated by a comparatively thick oil film, capable of taking up the whole bearing pressure. The shaft "floats" on the oil, with a very slight relative eccentricity of shaft and bearing. If it were possible to increase the speed to infinity, the shaft would run concentrically in the bearing and in this case, the oil film thickness attains its maximum. If on the other hand the speed falls off, the shaft draws nearer to the bearing. At the same time the bearing friction coefficient drops till it reaches a turning point, a minimum, beyond which it increases to a maximum at zero speed, when the shaft rests directly on the bearing. The minimum point is of particular importance. To the right of this point, i.e. at high speeds, is the state of full lubrication, to which apply the laws of hydrodynamics, and in this region there is no wear. For the same mechanical conditions, i.e. the same superficial pressure, speed and bearing design, the friction coefficient μ depends solely on the viscosity; all liquids of equal viscosity, irrespective of their other chemical or physical properties, have therefore the same coefficient of friction. As they approach the minimum point the friction curves of the various oils diverge.

Here the lubricating capacity, which then manifests its effect completely in the region of boundary friction, becomes noticeable. In the state of boundary friction viscosity has no effect. In the region of mixed friction or partial lubrication, i.e. in the vicinity of the minimum, complete and boundary lubrication prevail together. In the state of boundary lubrication the shaft is so near to the bearing, that the metal surfaces are separated only by a few oil molecular layers. No consistent theory is available yet on this lubrication state; one of the best known of those is that the oil is adsorbed by the metal, is subject to an orientation effect the intensity of which varies with the composition of the lubricant as regards its polar components and its affinity to the metal, and produces a lubricating value which varies accordingly. This orientation effect exists also in the region of complete lubrication, but in the presence of the considerably thicker oil film its effect is negligible as compared to the laws of hydrodynamics.

In actual practice, the object will always be to work with very small friction coefficients in the region of complete lubrication, avoiding the minimum point for reasons of safety. This is quite possible. A convenient design of the bearings and particularly a suitable choice of the viscosity will permit operation in the most favourable region. The conditions of partial and boundary lubrication can, however, never be completely avoided. These occur on starting and stopping; all oscillatory and alternating motions such as those of the piston in the cylinder especially at the dead centres, lie in the region of boundary lubrication and cause wear. Thus we arrive at the concept of lubricating capacity of an oil; it is therefore necessary thoroughly to discuss its measurement.

The Experimental Station has a very simple instrument to measure the friction coefficient, illustrated in Fig. 2. It consists of a polished steel roller, which is slowly rotated over a worm gear by an electric motor. A fine chain is wound under and around the roller; at one end it is fastened to a lever and at the other it is loaded with a weight.Chain and roller are immersed in the oil which is in turn electrically heated. The roller should carry along with it the chain, with a force proportional to the friction coefficient of the oil film existing between roller and chain. The friction stresses can be measured on the scale and the friction coefficient calculated from them.

It seems rather surprising that a chain should be used as a test element. The reason is that the chain touches the roller at many very small points. This leads primarily to high specific surface pressures and prevents the appearance of a wedging effect, which might occur if a steel band or a bearing were used. These two conditions and the low rotational speed of the roller ensure that measurements are definitely within the boundary lubrication region and thus exclude the effect of viscosity.

With this instrument it is possible to demonstrate the well-known fact that animal and vegetable oils have considerably lower friction coefficients than mineral oils; also that additions of oleic acid likewise improve the lubricating capacity. Fig. 3 shows the effect of sulphur additions to a synthetic lubricant as a function of the temperature. It appears that particularly in the case of small quantities, sulphur is only effective at high temperatures. The higher chemical reactivity thus lowers the friction coefficient. It is well-known that this is one of the properties of sulphur: every machinist knows that it is possible to avoid seizure of bearings which are likely to get overheated, by adding flowers of sulphur to the oil.

Fig. 4 shows another practical example. This deals with tests on M.G. oils; other tests were also made on the M.G. itself. It was found that the hydrocarbon oil K permits only a low firing speed, and that the weapon jams after a few rounds. With a 5% addition of a sulphur compound to the same oil, a high firing speed was possible; misfiring occurred however when the weapon became hot after 2.000 rounds. This oil gave completely satisfactory results only after adding to it 10% of a sulphur compound. Similarly good results were also obtained with a mixture of oil K and E with 5% sulphur compound. As shown in this illustration, the same results were found also in the friction testing machine. Whereas the friction coefficient of pure oil is rather high and rises further as the temperature mounts, considerably lower figures were obtained at room temperature in the oils mixed with sulphur compounds. At about 60°C they still rise a little, until the sulphur effect becomes particularly noticeable, with the friction coefficients falling off at high temperature. The difference between sulphurised and pure oils increases at temperatures above 60°C. This explains why pure hydrocarbon oil caused the weapon to jam, whilst with 5% addition it was moderately satisfactory and with 10% addition it was fully satisfactory.

The example of the M.G. oil is a practical case which demonstrates the friction reducing effect of oil. In many cases however the importance of lessening the wear must be considered, as e.g.: in piston rings and cylinders, or in gears, or in slides etc. There may be a tendency to assume that an oil having a low friction coefficient gives also little wear; in other words that friction reduction and wear reduction imply one and the same characteristic. This assumption applies to some oils, but often it is the reverse, as shown by the typical instance of M.G. oils. The graph shows the friction coefficients and the wear of an iron pin immersed in oil. It is apparent that the oil having a maximum friction coefficient gives a minimum wear and vice versa. This example should prove that the indication of the friction coefficient is not sufficient to characterise the lubricating capacity of an oil. Wear tests must also be carried out.

For this purpose the Technical Experimental Station built an instrument (Fig. 5). It consists of two cylinders mounted on a shaft, with an electric motor which subjects them to a semi-rotary motion, through a reduction gear and a push rod. The cylinders are wound with polished and hardened steel bands, constituting the friction surfaces. The wear pieces in the shape of brass or iron cylindrical pins are held against the under side of the steel bands by means of a loaded lever having a reduction ratio of 2 : 1. Friction surface and wear piece are immersed in the test oil, which is kept at constant temperature on an electrically-heated oil bath. The shortening of the pin as a result of wear is measured at time intervals on the lever by means of a micrometric gauge.

Several oils were tested in this instrument. Fig. 6 shows the wear of a brass pin after 4½ hours at various temperatures and with different aero engine oils. It is evident that wear is very great at low temperatures, reaches a minimum between 90° and 120°C, and then increases again. The lubricating characteristics in the engine of three of these oils are known from operational experience. It was found that Aeroshell has fairly good wear characteristics, Rotring D is moderately good and oil A is poor. Rather surprisingly, this sequence is not found at high temperatures, but is found at about 50°C, with oil A presenting an exceptionally high degree of wear. Attempts were made to improve this oil by additives and by various treatments, to which it proved exceptionally sensitive (Fig. 7) - thus, at low temperatures, addition of 0.01% sulphur produces a considerable wear reduction. With larger additions the wear attains very high levels, apparently due to the corrosive action of sulphur.

A second test was carried out with oxidized oil (Fig. 8); again an improvement in the low temperature region is associated with worse results at high temperatures. The mixtures of the two compounds behave correspondingly. Oxidized oil and sulphur addition showed minimum wear. In this connection it should be mentioned that an oil aged in the engine improves rather than deteriorates. The use in the engine produces esters, which generally reduce the wear. This improvement of the oil progresses comparatively fast. After only a few hours a noticeable improvement of the wear behaviour can be ascertained.

Oleic acid was added in other tests (Fig. 9). Oil A was used, which was produced by a new process and gave therefore an altered wear curve. The oleic acid has a considerable effect covering the whole temperature range. The test results afford no conclusions on the practical behaviour of the oil, as it is impossible accurately to reproduce practical conditions in a test apparatus. These tests have shown that small variations of test conditions, e.g. temperature, often produce a change in the quality sequence of oils. It may be expected that a similar change occurs when passing from test instruments to practical conditions. It would therefore be risky to draw from these tests conclusions on the wear of pistons, cylinders and piston rings.

The measurement of friction coefficients and wear tests are not sufficient for the investigation of gear oils. Exceptionally high pressures develop on the tooth flanks, which in certain cases may lead to seizure of the metal surfaces. This is avoided by addition of certain chemically active substances, such as Chlorine, sulphur, phosphorus or lead compounds. These additives must have no corrosive action at normal operating temperatures; only when danger of seizure occurs, their action must manifest itself as a result of the high temperature produced, by developing salts which prevent metal contact and thus prevent seizure.

In order to test these properties of oils a Four Ball machine was developed similar to the one originally designed by Boerlage. Fig. 10 shows its constructional details. The four balls have a diameter of ½" and they are arranged in such a way that their centres form a tetrahedron. The three bottom balls are fitted in a bowl containing the oil. The top ball is fastened to the bottom end of the vertical shaft, which is rotated by an electric motor through a belt drive. The ball holder has an electric heater for tests at various temperatures. A thermocouple protruding from below in the oil between the balls is used to measure this temperature. The torque transmitted to the three bottom balls is measured by an indicator connected with the ball holder; it records the force transmitted at each moment and it suddenly reacts violently at the moment of seizure (view of four-ball machine, Figs. 11 and 12). The tests can be carried out with various methods. The following graphs illustrate tests in which a given weight was applied and then the time was noted between the start of the motor and the seizure of the balls. Thus the seizure delay is obtained as a function of the load. Several additives were tested in this way. Fig. 13 shows the effect of thioisobutanol, carbon tetrachloride and oleic acid as additives to a hydrocarbon oil TP 57. The two first compounds have a considerable effect, the seizure delay rising to 4 - 5 times that of the untreated oil, whereas oleic acid has little effect. Very good results were also obtained with a 10% addition of isobutenylmercaptane and trichlorethylene phosphate. 10% is rather a high proportion and naturally lower ones are desirable.

I have given you a short survey on the tests of the lubricating property of an oil. Summing up it can be said that this is mostly sufficient and that the problems involved are not so urgent. When lubrication difficulties arise, they are mainly in a region which has nothing to do with lubrication proper; they must however be accepted as undesirable accompaniments of the use of oil. I refer to starting difficulties, deposit formation, ring sticking, oil foaming, oil thickening, higher oil consumption etc.

Let us deal with starting characteristics. It is generally known that in the cold season thin winter oils are used instead of thick summer oils. The use of thin oil is limited by the minimum viscosity required for the lubrication of the warm engine. There are two reasons for this minimum viscosity: first to avoid excessive oil consumption, second to ensure operation in the region of fluid friction, even at high operating temperatures, in the lubrication of pistons, cylinder and bearings. These requirements can be met to a certain extent by specifying that a good oil must have good temperature viscosity characteristics. This is expressed either by the viscosity index (VI), by the pole height (Hp) or Walter's factor "m". Fig.15 shows the meaning of good viscosity temperature characteristics in practice. It shows the viscosity curves of three oils having the same viscosity at 100°C; owing to their different VI value however they present very widely different viscosities at lower temperatures and consequently behave very differently with respect to ease of starting an engine.

There is some connection between viscosity temperature characteristics and other physical properties, as shown in Fig. 16. Several analyses of natural oils showed that there is a close connection between VI and specific gravity, as well as boiling point. For the same viscosity, oils having a high viscosity index have a low specific gravity together with a high boiling point. Because a good viscosity index is very important, efforts were made to find substances capable of improving the temperature viscosity behaviour. These substances are voltolisation products of fatty oils, and of mineral products with an average molecular weight of 15,000, e.g. I.G. Oppanol mixture B.15.

Beside viscosity, the pour point is important for easy starting. Primarily, paraffin wax causes a stiffening of the oil mass at low temperature. Complete elimination of wax has, however, the disadvantage of reducing the VI of the oil and of reducing oxidation resistance. It is therefore inadvisable completely to remove the wax; on the other hand it is necessary for a lubricant to be sufficiently fluid at low temperatures in order that the flow in the oil pump may not be affected. "Paraflow" and PVO are substances which can lower the pour point of many oils, without affecting their other properties. (Fig. 17).

The purpose of lubricant testing is to find out the effect of these various substances in their practical use. Pour point and low temperature viscosity alone give no exhaustive data on the cold-starting properties of a lubricant. It is necessary for the tests to be as close as possible to practical conditions. An apparatus was developed which meets these requirements to a large extent (Fig.18). The interior of a cold chamber can be kept at a constantly low temperature by using dry ice and a heater with fan. Various instruments and machine parts can be mounted in this chamber and tests carried out on them; e.g. as illustrated a bearing ring with pins rotated by a motor. If an oil film between the two is cooled for a long time to a given temperature, the force required to break this thickened oil film is obtained by suddenly starting the shaft. This force is recorded continuously on an indicator drum. Fig. 19 shows the interior of the cold cupboard. Fig. 20 shows three curves obtained on this instrument; it appears that the force A required to break the solidified oil is of an entirely different order than force B due to viscosity. If we refer this force A to the size of the oil covered surface, we obtain a value in Kg/sq.cm. called adhesive strength, which serves well to identify the low temperature characteristic. This graph also shows a surprising behaviour of olive oil, which requires at the breaking moment a considerably greater force than the other two oils; beyond that it falls rapidly to a low level. Apparently the stearin crystals of olive oil form a very hard and resistant structure. These types of oil are exceptional also in another respect. Fig. 21 shows the importance of the length of time for which the oil covered bearing is subjected to low temperature. For instance in vegetable oils a gradual increase of the adhesion as a function of the cooling time can be observed, from which it may be inferred that the crystal structure is formed only gradually. On the other hand no alteration occurs in synthetic or mineral oils after an hour's cooling time, which was the duration of all tests illustrated in the following graphs. Fig. 22 shows the curve of adhesion in terms of temperature for five different oils. The behaviour of olive oil is remarkable; at low temperatures, when crystallization proceeds very fast, its adhesion is very high. This negative property of olive oil disappears if it is added in small quantities to a hydrocarbon oil, as it is shown in the curve of oil 1 + 5% olive oil. The comparison of this with that of oil 1 above shows that the olive oil addition increases the viscosity index from 106 to 113. Fig. 23 shows very clearly the importance of the viscosity index for cold starting. If we compare two oils, B and D, having nearly the same viscosity at 100°C, we find that oil D has a better start characteristic, although its solidification point (- 7°C) is much higher than that of oil B. This is due to the fact that oil B has considerably worse viscosity temperature characteristics, as expressed by the two viscosity index figures, 72 and 101. A comparison between oil A and C shows this phenomenon still more clearly. Oil A has the lowest viscosity of all the oils at 100°C and also has the lowest pour point; in this respect it is therefore the opposite of oil C which is the most viscous oil at 100°C and has the highest pour point. In spite of this, oil A is the worst by far as regards starting characteristics which in turn is due to the low viscosity index of 32.

As a result of this test the inference can be drawn that the pour point has little effect on starting. It plays however a prominent part whenever fluidity is important, as in the oil pump. As soon as the oil loses its fluidity, suddenly the quantity and pressure fall off. For tests of this kind a pump and pressure gauge were mounted in the I.G. cold box and the pressure at various temperatures was measured on different oils. Fig. 24 shows the effect of a pour point depressant. An addition of 0.5% PVO keeps the oil still fit for pumping at -15°C, a temperature at which the oil without additive could not be used.

Apart from the low temperature properties which have been discussed, the first requirement of a good engine lubricant is resistance to high temperatures. This includes first of all residue formation. At the prevailing high temperature the oil decomposes and forms carbon, which is deposited to a greater or less degree, particularly on the piston.

The most objectionable form of residue formation is when the oxidation products cause the piston rings to stick in their grooves. Seized piston rings can become very dangerous for the engine operation. They lead to overheating and possibly to piston seizure, thus damaging the whole engine. In flying operation this development is highly probable and particularly dangerous. In general it can be said that oils with exceptional lubricating capacity, e.g. fatty oils, are less resistant to high temperatures and more inclined to ring sticking than oils with lower lubricating capacity. A certain compromise must therefore be reached between these two properties. Successful attempts have been made to reduce the tendency to ring sticking. Oxidation "improvers" are now available, e.g. butylphenol-sulphide, small additions of which produce a considerable improvement of the oil. The demands made on oxidation inhibitors for motor and aero engine oils are many and considerable. They must retard oil ageing and remove the catalytic effect of some metals present in the engine; they must not be corrosive themselves nor affect negatively the action of other oil additives, such as V.I. improvers, pour point depressants and lubricating capacity improvers.

On Air Ministry instructions, the Technical Experimental Station has carried out for years oil tests on ring sticking. An air cooled BMW 9-cylinder engine was used, which had been converted to single cylinder for these tests. In order to shorten the duration of the test, the engine is run under more severe conditions, i.e. higher cylinder temperature, increased ignition advance and leaner mixture. With Rotring, a commercial aero engine oil used as a reference oil, it was possible to produce ring sticking after about 8 hours. This was indicated by a power drop and increased gas pressure in the crankcase. The effect of oxidation "improvers" could also be ascertained by this method. These vary in effect in different oils; they are particularly good in synthetic oils, where improvements of over 100% could be achieved in the running time.

Fig. 25 shows that the amount of additive used plays a great part. An increase up to 0.08 and 0.04% respectively in synthetic oils "M" and "N" increases the running time. Apparently there is an optimum, beyond which the effect decreases again, as it appears in oil "O" with inhibitor "p". An increase of the addition from 0.08 to 0.20% reduces the running time. Similar results appeared in the investigation of oil "P" with 0.02 - 0.04 and 0.06% of inhibitor "S_1". This exposition gives an idea of the extensive research work required to develop the best inhibitor in the best proportion for a given oil.

We should mention here that no conclusion can be drawn from laboratory ageing tests, as to the ring sticking characteristic of an oil in the engine. Fig. 25 shows that small variations of the inhibitor content produce considerable lengthening or shortening of the running time, whilst the tests do not vary at all. Ultimately recourse must be made to the engine test, which is the more annoying because not only does it require very large quantities of oil, but it is also very costly.

A problem which has caused some trouble, although its significance has only recently been appreciated, is foam formation. Foam appears in the presence of particles of carbon and metal, and especially of water. Whilst foam formation is common in motor and flying operations, none appears in test stand tests. The widely changing temperatures in the crankcase and oil sump cause a condensation of water; as a result of its being violently agitated with oil an emulsion is formed which separates as foam. Tests have shown that water is actually responsible for the foam formation; the injection of water in the carburettor produced considerable quantities of foam, which could not be obtained without these artificial methods. Experience shows that foam formation varies in different oils. It appears that special additives, e.g. voltolised fatty oils, reduce foam formation.

Another undesirable result of the ageing of lubricants is their thickening during operation. Fig. 26 shows the curve of viscosity at 100°C as a function of the running time in the BMW single-cylinder test engine. Five different oils were tested, namely synthetic oils 92 and 97 (both made from ethylene), Rotring D, which is a commercial mineral oil, LK 2200 which is a water soluble oil and which for the present is only considered as an experimental oil, and finally P 174 which is a paraffin basis synthetic oil. The marked viscosity increase in the two ethylene oils 92 and 97 is quite clear, whilst Rotring D and P 174 showed better characteristics in this respect. Thickening of LK 2200 was hardly noticeable. The worst aspect of oil thickening is primarily a deterioration in starting characteristics. Unfortunately, those oils which thicken considerably also show a deterioration in temperature-viscosity characteristics; thus, whilst in Rotring D, LK 2200 and P.174 the viscosity index even rises, in ethylene oils 92 and 97 it falls off from 105 to 98 and from 126 to 118. This process implies a further worsening of the starting characteristics. It is unfortunate that no means have been found as yet for overcoming this disadvantage.

Oil consumption must also be investigated. As a general rule, the thinner the oil at high temperature, the higher the consumption. For oils of equal viscosity the Noack vaporisation test is to some extent a guide to the consumption figure to be expected in practice, but in this case also the engine test is the safest, and a long test run is necessary to obtain reliable test figures and avoid excessive variations of the results.

Finally we should mention the behaviour of oils in the presence of the various materials with which they come into contact during use. It is agreed that a lubricant must have no corrosive effect on metals. To this we should add its behaviour towards packing material, leather, rubber, Buna etc. These materials must not be destroyed by contact with oil and must show no swelling. These properties must be expected in particular from oils to be used as brake and transmission fluids in vehicles or aircraft.

Gentlemen, I have given you a survey of the problems arising in the choice and test of oils. I hope I succeeded in presenting the most important questions and thus in stimulating you to further investigation.

Fig. 1 - Lubrication conditions in bearings for 3 oils of equal viscosity.

Fig. 2 - Friction testing machine.

Fig. 3 - Friction coefficients at different temperature.

Fig. 4 - Friction coefficient and wear.

Fig. 5 - Wear testing machine.

Fig. 6 - Aero engine oils in the wear testing machine.

Fig. 7 - Oils with additives in the wear testing machine.

Fig. 8 - Oxidised oil in the wear test machine.

Fig. 9 - Wear tests on oil A_2 and oleic acid addition.

Fig.10 - Four ball machine.

Fig.11 - ditto

Fig.12 - Ball holder for ditto.

Fig.13 - Engine oils with additives in the four ball machine.

Fig.14 - ditto

Fig.15 - Viscosity curves of oils with different V.I.

Fig.16 - V.I. density and boiling point.

Fig.17 - Pour point depressants.

Fig.18 - Cold box for oil testing.

Fig.19 - Ditto (Interior)

Fig.20 - Breaking-off curves of different oils.

Fig.21 - Start drag as a function of time.

Fig.22 - Start drag of various oils at low temperature.

Fig.23 - Adhesive strength in terms of temperature.

Fig.24 - Effect of a pour point depressant on the delivery pressure of an oil pump.

Fig.25 - Effect of inhibitors on the running time.

Fig.26 - Oil thickening as a function of running time.