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Report No. 572

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INVESTIGATION OF THE PUMPABILITY OF OILS.

Synopsis:

The conditions under which 10 different engine oils were subjected to pumping tests, corresponded largely to those prevailing in a cold engine. The results obtained indicated that the quantity pumped from a vessel during a certain interval largely depended on the solidifying point, while no relation with the viscosity obtained by extrapolation, could be established. Investigation of the rate at which the oil pumped out returns to the oil sump showed no connection between that rate and either the point of solidification or with the viscosity. A relationship between practical conditions and viscosity appears to exist as long as the viscosity is not that derived by extrapolation, but that measured on the cold engine: a further condition being that such measurement takes place at various shear rates.

1) Object of the Tests:

The Testing Station received instructions from the OKH to follow up a line of research and development under the following terms of reference: "To determine a new numerical factor by means of which the behaviour of engine and gear drive oils at low temperatures, could be defined".

2) General Survey of the Field to be Investigated.

"Behaviour at low temperatures" is nothing more than a collective term applied to ease of starting, pumping, circulation/etc. And as none of these properties affect one another it is necessary to investigate them singly. Starting resistance is satisfactorily determined by the break away tests in the I.G. cold chamber, the results obtained easily bearing comparison with actual practice. The factors governing ease of pumping are less well understood, and the tests serve to investigate the pumping of engine oils at low temperatures more closely and also to correlate the results with the various coefficients at present in use.

The apparatus built was based on the following considerations: the reason why the pumpability of engine oils at lower temperatures requires any investigation at all, is that every now and then an engine run in winter will suffer damage to its bearings, pistons and cylinders immediately on starting, owing to the lack of oil in all those parts which require lubrication. Even as the engine is starting the oil contained in it will be pumped, either completely or partly, to the lubricated parts. On account of its high viscosity, however, the oil will not flow back and will stick to the internal walls of the engine. The pump will, therefore, run dry very quickly and cease delivery: the latter will start again as soon as the oil flows back to the oil sump, a process which is quickened by the running of the engine and the temperature increase caused by it. The time interval during which no delivery of oil takes place, is particularly critical and it seems obvious to consider that oil best which keeps the time interval a minimum. In order to be considered "pumpable" an oil must meet two demands: a minimum quantity of oil must be delivered right from the moment the starter is operated: and this amount of oil must return to the sump within an acceptable space of time. The test must therefore show what portion of a certain quantity of oil can be pumped within a given period as well as the rate at which the oil thus pumped will return to the sump. The apparatus described below was used to find out these properties at cold temperature.

3) Apparatus Employed

A complete oil pump system of the type used in motor cars, and equipped with a cam shaft and an oil filter, was made available for the tests by the Daimler-Benz works at Gaggenau. The system, complete with oil container, was installed in the I.G. refrigerator. (cf "Luftwissen" vol.9 No.1 Page 19,1942) All the parts which come into direct contact with the oil were placed in the cold chamber of the tank, thus acquiring the temperature produced in it. The driven end of the pump projects from the top of the chamber and the cam shaft in the chamber was rotated at 60 rpm. through a V-belt drive. The pump could also be operated at a speed of 720 rpm.although this speed was not employed during any of the tests described below. As usual, low temperatures were obtained with the use of carbon dioxide "snow", and were kept at a constant level by an electrical heating apparatus, itself electrically controlled. In order to perform the various measurement two different pieces of apparatus had to be installed in the working space of the cold chamber. The first one of them was intended to show the amount of oil that could be taken from a vessel of given dimensions at low temperatures, while the other was to produce information about the manner in which the oil returned to the vessel after pumping.

a) The former apparatus is illustrated on Sheet 1. The pump is immersed in the oil so that the suction filter is at a depth of 7 cms. below the surface, the pump proper being ~~above the~~ surface: an arrangement which is somewhat similar to an actual engine installation. In this case the oil filter was left out, it had been found that the working pressures in these tests are in any case invariably those at which the by-pass valve opens, thus cutting out the filter. The oil, therefore, is forced from the pump immediately into a pipe line 700 mm long and 10 mm int. diameter and hence through a nozzle of 8 mm.diameter into a calibrated vessel. The nozzle diameter is the deciding factor in the test. The nozzle must be such that it is equivalent to all the oil exits in an engine: rough calculations showed that a cross-sectional area of 0.5 sq. cm. was required, resulting in a nozzle diameter of 8 mm. A pumping trial was made at + 50°C so as to test the accuracy of this result at 720 rpm. using oil of a viscosity of approximately 60 centistokes, the trial resulting in an oil pressure of 2.5 atmospheres which roughly corresponds to pressures observed in practice at that speed. In effect, then, the nozzle and pipe line adopted in the apparatus offer approximately the same resistance as all the lubricating channels in an engine.

b) In the second apparatus (sheet 2) the filter was included in the pipe circuit, and the oil was pumped back into the container from which it was pumped in the first place. In order to impede the flow of the oil to some extent during its return to the sump, it was pumped up an inclined plane, and then once again reached the suction pipe after passing through a screen. The object of this was to imitate actual engine conditions as nearly as possible. The total length of the pipe line was 1600 mm, its diameter (internal) 10 mm and that of the nozzle was 8 mm.

The arrangement of both thermometers and the thermocouples in each apparatus is clear from sheets 1 and 2.

4) Methods of Test

a) Measurement of Quantity Pumped

The oil sump was filled with 3 litres of oil, this quantity being adhered to throughout all tests, and the pump was run for a short time at room temperature to free both pump and pipe line. The cold chamber was then cooled to the experimental temperature which was kept constant for 6-10 hours (the time varying with the temperature chosen). For the temperature to be uniform unusually low temperatures require a longer time being taken over this cooling than do higher temperatures. Before the test begins the temperature is checked on the thermocouple, on the two thermometers immersed in the oil on either side of the suction pipe, and the temperature of the air too, is obtained. In accordance with an assumed starting time of 5 mins., the pump was set rotating at 60 rpm. the oil pressure being measured at 15 secs. intervals during the run and the amount of oil pumped in those 5 mins being measured by weighing. Without renewing the oil, the test was then repeated at various temperatures.

b) Tests on the Flow Behaviour of the Oil Pumped

4 litres of oil were used to completely fill the whole system, and in order to remove all air from the pipe and filter, the pump was run at room temperature at a speed of 720 rpm. for a few minutes. After that, the test proper started at 60 rpm. uniform speed, the oil system being cooled throughout. The temperature (thermometers in oil, and thermocouples) and the oil pressure were measured at certain intervals. The test terminated if and when the pressure suddenly dropped almost to 0, air bubbles appeared and delivery practically ceased. The temperatures at that point, and the highest oil pressure attained were then noted.

The following oils were investigated:

TABLE I

Oil No.	Viscosity C.S. at °C 20	38	99	V.I.	B	C	Spec.Grav. gs/cm³	Solidification Point °C
1	268.40	87.97	8.75	69	3.80	2.26	0.906	0
2	456.10	149.10	13.56	97	3.48	1.91	0.880	-12
3	58.12	172.30	13.66	78	3.65	2.21	0.911	-18
4	330.00	105.80	9.98	75	3.73	2.20	0.905	-19
5	282.00	96.93	10.22	91	3.59	1.96	0.877	-26
6	189.10	68.85	8.28	91	3.62	1.89	0.885	-41
7	394.30	130.20	12.25	92	3.54	1.96	0.883	-14
8	1086.50	275.10	17.10	71	3.70	2.43	0.911	-20
9	179.30	66.14	7.99	88	3.65	1.91	0.873	-26
10	317.10	109.00	10.97	85	3.63	2.05	0.902	-25

RESULTS

a) Determination of Quantity Delivered.

The tests show that within the temperature range employed, delivery usually ceases after 1-3 minutes, the oil pressure rising quickly after the first few revolutions, and then falling slowly. As soon as air bubbles appeared the pressure dropped to almost zero and delivery of oil practically ceased: while the quantity of oil forced through the system under high pressure during the first few minutes, in an uninterrupted stream, is hardly increased by the subsequent delivery of occasional small amounts of oil. Delivery actually stopped before the specified pumping period of 5 mins. had elapsed, although there was still sufficient oil left in the container. This leads to the conclusion that responsibility for the small quantity of oil delivered does not lie with the low capacity of the pump, but the fact that some part of the suction funnel of the pump has freed itself from contact with the oil, formed a crater-like depression on the oil surface thus permitting air to enter. This depression can actually be observed with the naked eye - the pump itself and all its parts on the suction side were completely air-tight, and no leaks were noticed at any time.

Diagrams 3 and 4 illustrate the results of these tests, while diagrams 5 and 6 show the curves for the highest pressures observed during the tests. The greatest amount which can be taken from the oil container with the pump employed is 2.6 litres, and the lower limit adopted, for a pumping time of 5 minutes, was 1 litre. Exactly what quantity of oil should represent the minimum used for starting is a matter of opinion: the amount of oil absorbed in the lubricated parts is comparatively small, so that 1 litre of oil will probably suffice. Compared with the quantity which it is possible to pump (at room temperature), this represents 38%: the investigation is, however, intended also to cover the case where the amount dealt with is 2 litres (= 76%). If that temperature is derived from the graphs on sheets 3 and 4, at which quantities of 1 litre, and 2 litres respectively, can just be pumped - hereafter referred to as critical temperature (see table 2) - its relation to the solidifying point is as shown in diagram 8 (sheet 7). This relationship is quite clear, no matter whether the critical temperature is based on deliveries of 1 or 2 litres. For the critical temperatures based on a delivery of 1 litre the viscosities were obtained by extrapolation and incorporated in the graph. Oil No.1 is an example of an oil which fails even at a high temperature when its extrapolated viscosity is still very low, while oil No. 6 behaves in the opposite way: despite its high extrapolated viscosity and due to its low solidifying point, the oil is still differently pumpable at low temperatures. It is clear, therefore, that in these tests the point of solidification is the deciding factor, whereas the extrapolated viscosity is of practically no consequence - a result which is not new and was mentioned in Report No.269 (1934).

The graphs on sheets 5 and 6 are indications of the maximum pressures observed during the 5 minutes of pumping - the maximum pressure of 50 atmospheres measurable on the manometer being frequently exceeded. The pressures show an approximately linear decrease as the temperature rises. With a delivery of 1 litre as basis, the pressures corresponding to the critical temperatures obtained from sheets 3 and 4 can be read off from sheets 5 and 6 (table 2). Diagram 9 (Sheet 7) shows the pressures thus obtained for the different oils, in ascending order of magnitude: comparison with the viscosities (by extrapolation) shows that there is a certain, though not very satisfactory, connection between the two.

TABLE 2

Oil No.	Critical Temp. (°C) based on delivery of 1 ltr.	2 ltrs.	Extrapol. Viscosity for crital temp. 1 ltre. cs	Oil Pressure at critical temp 1 ltre. atmos.	Point of Solidification °C
1	-3.5	- 0.5	2300	4.0	0
2	-13.0	-10.0	12000	21.0	-12
3	-17.3	-13.3	37000	31.5	-18
4	-22.0	-17.7	34000	33.0	-19
5	-25.0	-20.7	30000	45.0	-26
6	-46.0	-28.0	550000	>50.0	-41
7	-14.8	-11.4	11500	20.5	-15
8	-21.0	-15.0	210000	43.0	-20
9	-26.0	-20.0	17000	32.0	-26
10	-24.4	-20.2	33000	45.5	-25

Strangely enough the oil pressure is seen to increase as the solidifying point falls. This apparent contradiction can be explained as follows: the oils tested all have approximately the same viscosity, and a low point of solidification is always coupled with high viscosity, and vice versa. High viscosity, in its turn, causes high oil pressures, and as failure during the pump tests is widely influenced by the solidifying temperature, the latter can be said to directly affect the oil pressure measured at the critical temperature.

Judging by the results so far obtained, the following conclusion can be drawn: on the suction side of the pump where the oil flows owing to its own weight, the solidifying point is the deciding factor. On the delivery side of the pump where the movement of the oil is involuntary and takes place at greater speed, the point of solidification loses its importance, while the viscosity - roughly determinable by extrapolation - gains in significance. The suction side of the pump, however, and hence the solidification point are of great importance to the quantity delivered, while the behaviour of the oil on the delivery side can be of little import, except perhaps when it is desired to determine the mechanical work necessary for pumping: the higher the oil pressure, the greater is the amount of work to be done by the starter. In the tests dealt with in this report, the mechanical work done was not measured, but various signs of high starting torque, like slipping of the belt, were noticed in conjunction with high pressures: for instance, oil No.6 makes very high demands on the starting power of the engine. It is doubtful whether a starter is capable of developing enough power to overcome the combined resistance of the pump, bearings and pistons, and thus start the engine. Rather it is believed that the sunction end will free itself from contact with the oil surface after a few minutes, whereupon the pressure will fall, when the mechanical power required will be sufficiently low to make starting possible.

b) Tests on the Flow of the Pumped Oil

The results are shown in table 3.

Oil No.	1		3		8		9		10	
	Separate Tests	Average	Separate Tests	Average	Separate Tests	Average	Separate Tests	Average	Separate Tests	Average
Uninterrupted delivery up to °C	-9.2 -8.2 -10.0	-9.1	-18.2 -[illegible]3.0 -17.5 -17.5	-17.3	<-16.0 <-20.0 *)	<-20.0	-17.6 -16.9 -17.5	-17.3	-11.5 -12.1	-11.8
Oil Pressure at end of Test atmospheres.	6.8 6.5 6.8	6.7	26.0 31.0 25.0 26.5	27.1	>38.0 >50.0	>50.0	8.8 8.3 8.9	8.7	11.0 11.8	11.4
Extrapolated viscosity at end of test.	4 000		35 000		>170 000		5 000		7 000	
Solidification Point.	0		-18		-20		-26		-25	

*) Belt slipping

These experiments give an indication of the way the oil flows, once it has passed the pump and is on its way back to the oil container. Some oils lose their stiffness, on stirring, pumping etc. and in consequence their flow is more satisfactory than before. Oil No. 1 belongs to that category flowing sufficiently well at -9°C, although it has a solidification point of 0°C. The reason for this is not an excessive heating effect produced by pumping, but the following: the crystal structure which causes the high solidification point is destroyed by pumping, and the flow of such an oil is therefore more in accordance with the extrapolated viscosity (in the case of oil No.1 this is still very low at the solidification temperature), whether or not a change in the flow behaviour of the oil is produced by pumping obviously depends to a large extent on the type of crystal structure composing it. Any oils whose temperature falls to the point of solidification without precipitating solid particles, flow sufficiently well almost down to the point of solidification: an example of this is oil No.8. The few tests carried out so far do not allow a general ruling to be pronounced, and the question of flow of oils after pumping obviously requires further investigation.

On the strength of these results, the question arises whether a new factor is required at all. As far as one can judge from the outcome of the tests carried out, it seems possible satisfactorily to define the quantity delivered in terms of the solidification point, and the viscosity may serve to define the subsequent flow of the oil: the viscosity, however, must be that obtained by measurement, not by extrapolation, and this must not only embrace measurement at different temperatures, but particularly at widely different shearing velocities as great differences in that respect are met with in practice. At low temperatures, engine oils are not ideal Newtonian fluids in which the viscosity is independent of the shear speed, as proved by the following simple test in the Schwaigen viscometer. If a load of 3.0 kg. is employed instead of one of 0.9 kg. the peripheral speed is not three-and-one-third times as great (3/0.9), as might be expected from Newton's law, but it is much higher, indicating a lower viscosity. As shown on Sheet 8, the change in the measured viscosity thus effected varies from one oil to another, and produces a change in the order of merit if the oils. In fact measurements at higher loads are more in accord with the extrapolated viscosity than those at low loads, and the shear speeds in the tests illustrated on sheet 8 lie between 4.2 and 1100 $\frac{cm/sec.}{cm.}$ These velocities are still very high, and for the investigation of the flow, for instance, they would have to be considerably lower, presumably resulting in further re-arrangement of the oils in a new order of merit. These tests show, then, that by employing different shear speeds, the measured viscosities vary very much indeed. Presumably they would enable valuable conclusions to be drawn regarding the behaviour of the lubricants at low temperatures in actual practice. And they also show that any measurement of viscosities of low temperatures is really pointless when no data about the shear speeds is available.

DESCRIPTION

Fig. 1 Measurement of the Quantity Pumped at low temperatures.

Figs.2&3 Flow of Oil after Pumping: Apparatus used total length of pipes 1.6 metres "trennwand" - screen.

Figs.4&5 Quantity Pumped/Temperature of Oil
Ordinate: delivery during 5 mins.

Figs.6&7 Max. Oil Pressure/Temperature of Oil

Fig. 8 Critical Temperature for 1 and 2 litres, point of solidification and extrapolated viscosity - comparative curves.

Fig. 9 Oil Pressure at Critical Temperature, points of solidification and extrapolated viscosity - comparative curves.

Fig. 10 Schwaigen Viscometer: Viscosity at -20°C, employing 2 different loads, as compared with extrapolated viscosity
X axis no. of oil.

The temperature noted on the graph represent the points of solidification.

________ Viscosity with normal load, 0.9 kg. torque 3.6 cm.kg.

— — — — — — Viscosity with load of 3.0 kg. torque 12 cm.kg.

------------- Viscosity by extrapolation.

(Oil No. 1 could not be measured).