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EFFECTS OF TEMPERATURE ON THE PRESSURE VISCOSITY RELATIONSHIPS OF 4 TYPES OF MINERAL OILS

by

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TITLE: EFFECTS OF TEMPERATURE ON THE PRESSURE VISCOSITY RELATIONSHIPS OF 4 TYPES OF MINERAL OILS

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SUMMARY This article describes the basic principles of added weight load type high pressure capillary tube pressure viscosity meters. It gives the pressure viscosity relationships for No.10 machine oil, No.25 transformer oil, No.20 machine oil, and No.20 turbine oil at different temperatures. The highest measured pressure was 0.1 GPa. The measurement temperatures were 13°C, 40°C, and 100°C. The results of the measurments clearly show that the pressure viscosity coefficients a for these 4 types of mineral oil are lessened as they follow along with raises in temperature.

KEY TERMS Pressure Viscosity Relationship, Viscosity Measurement, Mineral Oil Character

Fluids under high pressure will very greatly increase their viscosity. This phenomenon was know to people early on. As far as the rheological properties of lubricating oil under high pressure are concerned, they have been an important topic of research in lubricating oil engineering circles in recent years, both inside China and abroad. Moreover, one of the important contents of the research was nothing else than the status of the viscosity of lubricating oil following along with changes in pressure--pressure viscosity characteristics. Elastic fluid dynamics lubrication theory is one type of new lubrication theory which has been developing in the last few years, and there is a need to carry out research on elastic fluid dynamic lubrication. It is necessary to know the pressure viscosity characteristics of lubricating oils. In the lubrication of machinery parts, the oil film pressure for such high secondary contact locations as gears, cams, shaft bearings, and so on, are capable of generally exceeding 0.5 GPa. However, the tooth surface contact pressures of railroad train rear axle hyperbolic gear wheels are capable of reaching 2~3 GPa. Under pressure this high, lubricating oil viscosities will produce huge changes. There are some lubricating oils that will be pressurized into becoming solid crystals. As a result of this, as far as the design calculation concepts of secondary friction lubrication are concerned, it is necessary to make radical changes. In high pressure hydraulic systems, when hydraulic system operating pressures reach 35 MPa, the hydraulic fluid viscosity changes will be more than double. Because of this, at this time, hydraulic fluid pressure viscosity characteristics must also be considered. To sum up, research on oil product pressure viscosity characteristics is absolutely necessary.

Research work on pressure viscosity characteristics of lubricating oils outside of China began to develop relatively early. In conjunction with this, a large amount of work has already been carried out. For example, in 1953, the American Society of Mechanical Engineers (ASME) published research reports[1] on the pressure viscosity characteristics of over 40 types of lubricating agents. Another example would be West Germany's Hannowei (phonetic, possible Hannover) Research Institute which also used numerous types of methods to carry out large amounts of test research. However, as far as the properties of the lubricating oils were concerned, it was not possible to use the foreign test data holus bolus. Our country needs to carry out testing research on the pressure viscosity characteristics of lubricating oil produced in our country. In this regard, our country has only just now begun to take steps. In this article, the authors, on a high pressure capillary tube pressure viscosity instrument, which they test manufactured themselves, carried out test research on the 28
pressure viscosity relationships of 4 types of mineral oil at different temperatures. In conjunction with this, they carried out correlations of pressure viscosity relationships at different temperatures.

(I) Operating Principles of the Experimental Device

At the present time, outside of China, one finds the following several types of methods in experimental research on the pressure viscosity relationships of lubricating oils: the weight drop method, the capillary tube method, supersonic wave methods, and light interference methods. Among these, the capillary tube method has the advantages that its pressure measurement and shear rate ranges are both relatively wide and approach closer to the actual operating conditions at various types of part lubrication positions. Because of this, we designed, and, in conjunction, opted for the use of the capillary tube methods. What is shown in the Fig. is a schematic diagram of the NY-1 model high pressure capillary tube pressure viscosity instrument's operating principles. This pressure viscosity instrument has already been produced by the Hebei Province Cangzhou experimental machine plant. The method of testing is as shown below:

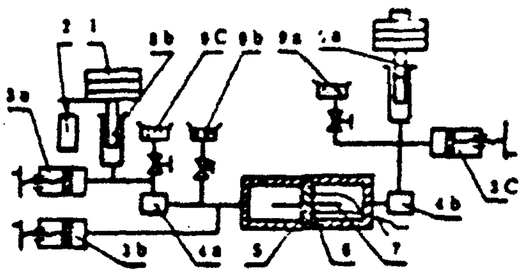

Diagram of the Operating Principles of the NY-1 Model High Pressure Capillary Tube Pressure Viscosity Instrument 1. Weights 2. Positional Displacement Sensor 3. Pressurized Oil Cylinder 4. Oil Separator 5. Elastic Slab 6. Strain Slab 7. Capillary Tube 8. Pressure Elevating Piston 9. Oil Cup

Take the test oil insertion oil cup 9b, and, take the pressure elevation oil insertion oil cups 9a and 9c. Respectively making use of the pressurization oil cylinders 3b, 3a, and 3c, one takes the test oil and the pressure elevation oil and injects them into the oil pipeline system. The oil separators 4a and 4b are used in order to take the experimental oil and the pressure elevation oil and separte them. In this way, carrying out tests on any type of oil product, in no case will there be an effect on the pressure elevation results. On the pressure elevation pistons 8a and 8b, one adds the same amount of weights, using the oil pressurization cylinders 3a, 3b, and 3c to elevate the pressure. This causes the weights on the two ends and the pressure elevating pistons 8a and 8b to float together at the same time. At this time, the pressure in the pipeline system, that is, the pressure produced by the weights on the pressure elevating pistons, is also nothing else than the basic test pressure. When the pressure elevating pistons at the two ends both float, the two ends are placed in a state of equilibrium. At that time, one again takes another small weight and adds it to the weights at the right end. This then causes the total of the weights on the right end to be greater than the total of the weights on the left end. The right end pipeline system pressure is greater than the left end pipeline system pressure.

At this time, the experimental oil will flow through the capillary tube 7 and move from the right end pipeline toward the left end pipeline. The right end pressure elevation piston will drop down. The left end pressure elevation piston will rise up. From strain slab 6, it is possible to measure, during the process of the flow movement, the pressure differential between the two ends of the capillary tube. From the position displacement sensor 2, it is possible to indirectly measure the volume and speed of flow through the capillary tube. One uses an X-Y function recording instrument to simultaneously record the pressure differential between the two ends of the capillary tube and the volume and flow speed through the capillary tube. In this way, under conditions of laminar flow, from Poiseuille equations, it is then possible to solve for the viscosity value of the test oil under those conditions. Altering the weights elevating the pressure, it is then possible to obtain different basic pressures. Under different basic pressures, one respectively carries out the testing. It is then possible to obtain the relationships between viscosity and changes in pressure--pressure viscosity relationships. The test oil temperature is controled by a thermostat. It is possible to carry out tests at any temperature from 10°C to 150°C.

(II) Test Results and Analysis

These tests carried out studies of experimental measurements on the pressure viscosity relationships for 4 types of mineral oil at different temperatures. The tested oil products were No.10 machine oil, No.25 transformer oil, No.20 machine oil, and No.20 turbine oil. The test temperatures were 13°C, 40°C, and 100°C. The highest pressure tested was 0.1 GPa. Table 1 - Table 12 present the pressure viscosity relationship data, at different temperatures, for 4 types of mineral oil. In these are included actual test measurements and numerical values on linear curves drawn up by the law of least squares. In conjunction with this, it gives the corresponding errors between the two when at different basic pressures. Table 18 gives values for the pressure viscosity coefficient a on the corresponding drawn up linear curves for Table 1 – Table 12. For calculation methods of test results, see [2(unclear)]. τ_R is the shear stress on the inside walls of the capillary tube.

(τ_R = 1.167 × 10⁴ N/m²) 13℃

(1) 基础压力(MPa)	0	6	16	26	36	46
(2) 实测粘度(cP)	40.[illegible]	52.10	58.96	68.83	78.68	92.9[illegible]
(3) 拟合直线上粘度(cP)	42.16	46.33	56.38	66.40	79.17	93.31
(4) 相对误差(%)	10.5	11.2	4.4	3.0	-0.6	-1.5
(5) 基础压力(MPa)	56	66	76	86	93	100
(6) 实测粘度(cP)	101.46	122.40	145.49	179.30	237.03	283.00
(7) 拟合直线上粘度(cP)	112.35	133.84	159.44	189.91	226.28	242.08
(8) 相对误差(%)	-9.7	-8.5	-8.7	-5.6	13.6	17.63

Table 1 No.10 Machine Oil Pressure Viscosity Data (1) Basic Pressure (2) Actually Measured Viscosity (3) Viscosities Off Drawn Up Linear Curves (4) Relative Error (5) Basic Pressure (6) Actually Measured Viscosity (7) Viscosities Off Drawn Up Linear Curves (8) Relative Error

(τ_R = 1.167 × 10³ N/m²) 40℃

(1) 基础压力(MPa)	0	6	16	26	36	46
(2) 实测粘度(cP)	14.0	16.1	17.3	19.0	21.5	24.7
(3) 拟合直线上粘度(cP)	14.6	15.6	17.5	19.6	22.0	24.6
(4) 相对误差(%)	-2.7	-2.6	-1.1	-3.1	-2.3	0.4
(5) 基础压力(MPa)	56	66	76	86	03	100
(6) 实测粘度(cP)	28.9	31.0	35.0	38.0	41.6	42.9
(7) 拟合直线上粘度(cP)	27.6	30.9	34.7	38.8	43.5	43.6
(8) 相对误差(%)	4.7	0.3	0.9	-2.1	-4.4	-5.9

Table 2 No.10 Machine Oil Pressure Viscosity Data (1) Basic Pressure (2) Actually Measured Viscosity (3) Viscosities Off Drawn Up Linear Curves (4) Relative Error (5) Basic Pressure (6) Actually Measured Viscosity (7) Viscosities Off Drawn Up Linear Curves (8) Relative Error

($\tau_g = 1.167 \times 10^3$ N/m^2) 100℃

① 基础压力(MPa)	0	6	16	26	36	46
② 实测粘度(cP)	3.43	3.71	4.36	4.90	5.44	6.07
③ 拟合直线上粘度(cP)	3.67	3.91	4.32	4.79	5.30	5.88
④ 相对误差(%)	-6.0	-4.9	-0.9	4.2	2.6	3.2
⑤ 基础压力(MPa)	56	66	76	86	96	100
⑥ 实测粘度(cP)	6.70	7.48	8.38	8.91	9.31	9.62
⑦ 拟合直线上粘度(cP)	6.31	7.21	7.99	8.83	9.80	10.21
⑧ 相对误差(%)	3.8	3.7	4.9	0.7	-5.0	-6.8

Table 3 No.10 Machine Oil Pressure Viscosity Data (1) Basic Pressure (2) Actually Measured Viscosity (3) Viscosities Off Drawn Up Linear Curves (4) Relative Error (5) Basic Pressure (6) Actually Measured Viscosity (7) Viscosities Off Drawn Up Linear Curves (8) Relative Error

($\tau_g = 1.167 \times 10^3$ N/m^2) 15℃

① 基础压力(MPa)	0	6	16	26	36	46
② 实测粘度(cP)	39.10	43.92	49.71	58.20	66.28	78.08
③ 拟合直线上粘度(cP)	37.63	41.36	48.93	57.61	67.83	79.86
④ 相对误差(%)	3.3	5.7	1.6	1.0	-2.3	-1.3
⑤ 基础压力(MPa)	56	66	76	86	93	100
⑥ 实测粘度(cP)	89.48	105.27	123.42	155.02	193.47	195.00
⑦ 拟合直线上粘度(cP)	94.03	110.71	130.33	153.47	180.69	192.87
⑧ 相对误差(%)	-4.6	-4.9	-5.3	1.4	7.1	3.1

Table 4 No.25 Transformer Oil Pressure Viscosity Data (1) Basic Pressure (2) Actually Measured Viscosity (3) Viscosities Off Drawn Up Linear Curves (4) Relative Error (5) Basic Pressure (6) Actually Measured Viscosity (7) Viscosities Off Drawn Up Linear Curves (8) Relative Error

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($\tau_g = 1.167 \times 10^3$ N/m^2) 40℃

① 基础压力(MPa)	0	6	16	26	36	46
② 实测粘度(cP)	11.0	11.9	13.8	16.3	17.8	20.4
③ 拟合直线上粘度(cP)	11.2	12.1	13.7	15.6	17.7	20.1
④ 相对误差(%)	-1.8	-1.7	0.7	4.3	0.6	1.5
⑤ 基础压力(MPa)	56	66	76	86	93	100
⑥ 实测粘度(cP)	22.6	25.0	28.4	33.7	38.6	39.2
⑦ 拟合直线上粘度(cP)	22.8	25.0	29.4	33.4	37.0	39.9
⑧ 相对误差(%)	-0.9	-3.3	-3.4	0.3	1.8	-1.8

Table 5 No.25 Transformer Oil Pressure Viscosity Data (1) Basic Pressure (2) Actually Measured Viscosity (3) Viscosities Off Drawn Up Linear Curves (4) Relative Error (5) Basic Pressure (6) Actually Measured Viscosity (7) Viscosities Off Drawn Up Linear Curves (8) Relative Error

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($r_g = 1.167 \times 10^3$ N/m^2) 100℃

(1) 基础压力 (MPa)	0	6	16	20	30	40
(2) 实测粘度 (cP)	4.80	5.12	5.49	6.19	6.74	7.68
(3) 拟合直线上粘度 (cP)	4.62	4.93	5.55	6.23	6.90	7.84
(4) 相对误差 (%)	3.9	3.4	−1.1	−0.6	−3.0	−2.0
(5) 基础压力 (MPa)	56	68	76	80	92	100
(6) 实测粘度 (cP)	8.73	9.60	11.00	12.40	14.20	14.80
(7) 拟合直线上粘度 (cP)	8.79	9.86	11.08	12.41	13.92	14.58
(8) 相对误差 (%)	−0.7	−3.3	−0.8	−0.1	2.0	1.5

Table 12 No.20 Turbine Oil Pressure Viscosity Data (1) Basic Pressure (2) Actually Measured Viscosity (3) Viscosities Off Drawn Up Linear Curves (4) Relative Error (5) Basic Pressure (6) Actually Measured Viscosity (7) Viscosities Off Drawn Up Linear Curves (8) Relative Error

(1) 油样种类	(2) 10号机械油			(3) 25号变压器油			(4) 20号机械油			(5) 20号汽轮机油		
(6) 测试温度 (°C)	13	40	100	13	40	100	13	40	100	13	40	100
(7) 测试剪切率 r_g (×10^3 N/m^2)		1.167			1.167		2.334	1.167	1.167	2.334	1.167	1.167
(8) 压粘系数 α (×10^{-8} Pa^{-1})	1.730	1.138	1.023	1.063	1.270	1.140	2.032	1.490	1.160	1.864	1.417	1.149

Table 13 Pressure Viscosity Coefficient Table (1) Oil Sample Type (2) No.10 Machine Oil (3) No.25 Transformer Oil (4) No.20 Machine Oil (5) No.20 Turbine Oil (6) Test Temperature (7) Test Shear Rate (8) Pressure Viscosity Coefficient

The drawing up of the linear curves from the least squares method is carried out at the single logrithmic coordinate ($\ln\eta - P$). As a result of this, the values on the linear curves which are drawn up satisfy the Barus equation $\eta = \eta_0 e^{\alpha P}$. In this equation, is the dynamic viscosity at any basic pressure. η_0 is the dynamic viscosity under normal pressure. a is the pressure viscosity coefficient. P is the basic pressure. From the relative errors in the table, it is possible to see that the largest relative error is 17.68%. However, the majority of relative errors are under 10%. Because of this, it is possible to say that these 4 types of mineral oil, in the pressure range 0~0.1 GPa, at the 3 types of temperatures tested, have pressure viscosity relationships which are basically in agreement with the Bavus equation. The relative error values in the table also possess a certain scattered character. The explanation for this is that there is a certain error which also exists in the testing system itself.

(III) Conclusions

As far as the pressure viscosity relationships which these tests on 4 types of mineral oils at 3 types of temperature conditions have measured are concerned, they clearly demonstrate that the authors' test manufactured NY-1 Model high pressure capillary tube pressure viscosity instrument is reliable.

The test results clearly show that the pressure viscosity relationships for these 4 types of mineral oils measured at 3 types of temperature conditions are basically in agreement with the Barus equation.

Looking from the point of view of the 4 types of mineral oils which have already been measured, the larger the viscosity of mineral lubricating oils is, the larger their pressure viscosity coefficient a also is.

The pressure viscosity coefficient a for these 4 types of mineral oils follows along with elevations in temperature by becoming smaller.

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