Research on Viscosity-Temperature Characteristics of PAO Oil and Ester Oil

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***Abstract*: To study the viscosity-temperature characteristics of PAO oil and ester oil and find its different. The viscosities of PAO oil and ester oil at the temperatures from -30 ℃ to 150 ℃ are measured by SYP1003 kinematical viscosity instrument. The curves of viscosity versus temperature are presented based on the least square method. The viscosity-temperature expressions using the Walther-ASTM model are established. The expression better forecast the viscosities value and can be used in practice. Experiment results show that the viscosity of the two lubricating oils decreases when temperature increasing. The viscosity-temperature characteristics of the two types of lubricating oils are better and the viscosity decrease slowly in high temperatures than those in low temperatures. The experimental data show that the viscosity-temperature characteristic of ester oil is better than PAO oil. As the temperature goes up, the viscosity discrepancies between the two types of oils are smaller and smaller. When the temperature up to 150 ℃, the viscosity of the two lubricating oils tends to be the same. In order to keep the viscosity and temperature characteristics of the oil in use, the usage temperature of the two kinds of lubricating oil is above 30 ℃.**

Keywords:Llubricating oil, viscosity-temperature characteristic, viscosity-temperature model

I. INTRODUCTION

Viscosity is one of the important physical and chemical indexes when choosing lubricating oil. Different working conditions need to use different viscosity lubricating oil. The higher the viscosity, the thicker the oil film and the better the friction performance. But too high viscosity increases friction resistance. On the contrary, too low viscosity is not enough to form oil film, which increases the mechanical loss.Viscosity directly affects the degree of wear, failure of friction surface, loss of friction power and working efficiency [1-2]. Temperature is an important external factor affecting the viscosity characteristics of lubricating oil. The working temperature of lubricating oil varies greatly under different working conditions. Sometimes, it is necessary to maintain good lubrication effect in a wide temperature range, which requires good viscosity-temperature characteristics of lubricating oil [3-4]. In China, Bian Sen, Fei Yiwei et al. [5] studied the unique physical and chemical properties of PAO oil and ester oil due to different chemical composition. Fei Yiwei, Guo Feng et al.[6] analyzed the characteristics of PAO (polyalkene) and ester synthetic aviation lubricating base oil, and focused on their high temperature decay mechanism. Shi Chengfei, Fu Hongrui et al.[7] studied the influence of ester oil on the viscosity-temperature property of PAO oil.Wang Zhifang, Liu Yifei et al. [8] analyzed the fitting errors of different fitting methods for the viscosity-temperature characteristic model of lubricating oil. In foreign countries, Rozga P. [9] has made experimental research on the streamer propagation of synthetic ester under lightning impulse voltage, Karthik R [10] and others have studied the insulation performance of ester oil and analyzed its insulation technology stability, Martins R C [11] has studied the influence of PAO oil and ester oil on the efficiency and corrosion of gears, and revithi B [12] has studied the insulation characteristics and changes of ester oil. In the current study, there is no study comparing the viscosity-temperature characteristics of ester oil and PAO oil in a widerange of temperature span. In practice, dueto the working temperature of lubricating oil sometimes changes greatly, it is necessary to understand the viscosity-temperature characteristics of oil in a wide range of temperature. The purpose of this paper is to study the viscosity change of ester oil and PAO oil with temperature,andto give the viscosity-temperature curveand Walther-ASTM viscosity-temperature model.

II MATERIAL AND METHODS

1. Testing

A. samples and test conditions

The experimental oil is PAO oil and ester oil. PAO oil is made of α olefin from ethylene through polymerization, and then further polymerized and hydrogenated. PAO oil has the characteristics of good oxidation thermal stability, low temperature fluidity and low volatility. The ester oil has a low freezing point, strong anti-oxidation ability, and excellent anti-wear, anti scratch and anti-wear properties.The test temperature range of this experiment is - 30 ℃ to 150 ℃, take a temperature value every 20 ℃, test the kinematic viscosity of the oil sample under the corresponding temperature, and get 10 groups of experimental values.

B. test device

The device used in this experiment is syp-1003 petroleum product kinematic viscosity tester, which is mainly composed of glass capillary viscometer, constant temperature sleeve, constant temperature medium, mercury in glass thermometer, heater, mixer, temperature control box, etc., as shown in Figure 1.

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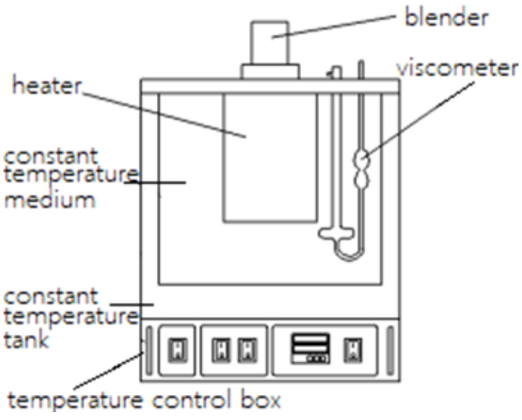

Fig 1 SYP1003 kinematical viscosity instrument

When the measuring temperature is higher than 100 ℃, glycerol shall be used as the constant temperature medium, and when the measuring temperature is lower than 0 ℃, anhydrous ethanol shall be used as the constant temperature medium.

The glass capillary viscometer used shall be verified in accordance with the verification regulation of JJG155 capillary viscometer, and the corresponding constant shall be determined. According to the test temperature, a suitable viscometer should be selected to measure the kinematic viscosity of the oil sample. In order to ensure the laminar flow of lubricating oil in the capillary, the flow time of the sample shall not be less than 200 seconds, and that of the viscometer with an inner diameter of 0.4 mm shall not be less than 350 seconds.

C. test method

Set the required test temperature on the experimental device and heat the constant temperature bath. After heating, observe the mercury thermometer and fine tune the temperature of the experimental device. Select a suitable viscometer, use the ear ball to suck the oil sample into the viscometer and put it into the constant temperature bath for heating 10-15 min. Use the ear ball to suck the oil sample liquid level above the upper mark of the viscometer and release it. When the liquid level reaches the upper mark, start timing, when it reaches the lower mark, end timing, and measure four times under each temperature value. When the interval time is less than 200 s, the viscometer with smaller inner diameter shall be replaced and remeasured.

The viscosity of the oil sample at each temperature was measured four times by the above experimental device and method. In order to reduce the random error, the data whose error exceeds ± 0.5% of the arithmetic mean should be eliminated. Then take the arithmetic mean of the flow time of not less than two times as the average flow time of the sample $\bar{t}$. The product of the average flow time $\bar{t}$ and the viscometer constant c is the kinematic viscosity v_θ ,The unit is mm^2/s . That is: $v_\theta = c \times \bar{t}$ .The kinematic viscosity of PAO oil and ester oil is shown in Table 1.

2. test data processing and analysis

The viscosity curve of PAO oil and ester oil with temperature is shown in Figure 2:

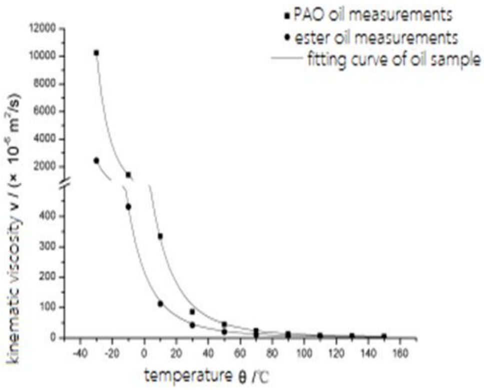

Fig 2 The viscosities of PAO oil and ester oil at different temperatures

It can be seen from the figure that the kinematic viscosity of both oils decreases with the increase of this temperature. This is because the increase of temperature makes the molecular vibration of lubricating oil strengthen, the distance between molecules increase, so the intermolecular force weakens, the cohesion decreases, the internal friction of oil decreases, and finally the viscosity of lubricating oil decreases. Figure 2 shows that the viscosity changes rapidly at low temperature and tends to be gentle when it drops to a certain temperature. Compared with the viscosity-temperature curve, it is found that the viscosity difference between PAO oil and ester oil is smaller and smaller as the temperature increases, and the curve of ester oil is smoother than that of PAO oil, which shows that the viscosity-temperature characteristic of ester oil is better than that of PAO oil. The molecular chain of PAO oil belongs to isoalkanes with multiple comb like side chains on the straight alkane skeleton, and the straight alkane skeleton determines the viscosity-temperature characteristics of PAO oil. Because of its long chain ester functional group, the longer the main chain, the better the viscosity-temperature property and the higher the viscosity index. The bigger the viscosity index of oil is, the better the viscosity property is. In general, the viscosity index of PAO oil is more than 120, while that of ester oil is more than 150.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 06, June-2020

Table 1 The viscosities of PAO oil and ester oil

Temperature (℃)	-30	-10	10	30	50	70	90	110	130	150
PAO oil viscosity (mm^2/s)	1024.6	1402.01	333.59	105.83	44	22.73	12.85	8.11	5.64	3.94
Ester oil viscosity (mm^2/s)	2426.28	431.9	111.9	41.6	19.72	11.003	6.84	4.46	3.27	2.49
Viscosity difference (mm^2/s)	7819.72	970.11	221.69	44.23	24.28	11.727	6.01	3.65	2.37	1.45

3. Establishment of Walter-ASTM viscosity-temperature model

The Walther-ASTM relation can be approximately written as:

$$\lg\lg(v+0.6)=A-B\lg(\theta+273) \quad (1)$$

Where, v is kinematic viscosity, unit is mm^2/s θ is the relative temperature, unit is ℃. A、B is a constant. The least square method is used to fit the experimental data, and the set of experimental data points is $\{(\theta_i,v_i)\}(i=1,2,\ldots,n)$, θ_i is the experimental temperature, v_i is the kinematic viscosity of the lubricating oil. From formula (1), we can get the formula:

$$v = f(\theta_i)=10^{10^{A-B\lg(\theta_i+273)}}-0.6 \ldots(2)$$

By substituting the experimental temperature θ_i into the formula (2), the calculated value of the kinematic viscosity $f(\theta_i)$ of the lubricating oil at the temperature θ_i can be obtained.

When the least square method is used to estimate the parameters, the sum of the square deviation between the experimental kinematic viscosity v_i and the calculated value $f(\theta)$ is required to be the minimum.

$$\sum_{i=1}^{N}\left[v_i-f(\theta_i)\right]^2=\sum_{i=1}^{n}\left[v_i-\left(10^{10^{A-B\lg(\theta_i+273)}}-0.6\right)\right]^2\rightarrow\min \quad (3)$$

The following can be obtained by partial derivation:

$$\begin{cases}\dfrac{\partial}{\partial A}\sum_{i=1}^{n}\left[v_i-\left(10^{10^{A-B\lg(\theta_i+273)}}-0.6\right)\right]^2=0\\ \dfrac{\partial}{\partial B}\sum_{i=1}^{n}\left[v_i-\left(10^{10^{A-B\lg(\theta_i+273)}}-0.6\right)\right]^2=0\end{cases} \quad (4)$$

The obtained parameters A and B are brought into formula (1).It is the obtained Walther-ASTM viscosity -temperature model, and its viscosity-temperature equation is as follows:

For PAO oil:

$$\lg\lg(v+0.6)=8.31773-3.23117\lg(\theta+273)\ldots(5)$$

For ester oil:

$$\lg\lg(v+0.6)=8.87527-3.49345\lg(\theta+273)\ldots(6)$$

The viscosity-temperature curve of PAO oil and ester oil is shown in Figure 2. Table 2 shows the calculated values and relative errors of PAO oil and ester oil under Walther-ASTM viscosity-temperature model. It can be seen that the fitting error of Walther-ASTM viscosity-temperature model is larger at low temperature and smaller at high temperature.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 06, June-2020

Table 2 The calculation value of PAO oil and ester oil viscosities and the relative error

	PAO oil		Ester oil	
Temperature/℃	Calculated kinematic viscosity $/(mm^2/s)$	relative error/%	Calculated kinematic viscosity $/(mm^2/s)$	relative error/%
-30	11706.9206	12.4723	3002.3842	19.1882
-10	1415.0325	0.9203	433.9151	0.4644
10	305.9602	9.0305	109.5789	2.1182
30	98.0716	7.9110	40.0160	3.9584
50	41.2863	6.5730	18.7534	5.1544
70	21.0705	7.8761	10.4446	5.3463
90	12.3520	4.0316	6.5744	4.0403
110	8.0170	1.1608	4.5235	1.4042
130	5.6158	0.4304	3.3262	1.6899
150	4.1702	5.5219	2.5733	3.2373

III Conclusion

1. The viscosity-temperature characteristics of PAO oil and ester oil are better at higher temperature and worse at lower temperature. With the increase of temperature, the viscosity difference between PAO oil and ester oil becomes smaller and smaller, and tends to be the same when the temperature exceeds 150 ℃.
2. When the temperature is lower than 10 ℃, the viscosity of PAO oil and ester oil increases rapidly, and the increase range of PAO oil is larger than that of ester oil, indicating that the viscosity-temperature characteristics of ester oil is better than that of PAO oil at low temperature.
3. In order to make the viscosity-temperature characteristics of oil better, the applicable
temperature of ester oil and PAO oil is about 30℃

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