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

Study on the Relationship Between Kinematic Viscosity, Density and Temperature of Lubricating Oil PAO

[1]Lijun Yang,[2]Yanshuang Wang,[3]Erqiang Wang,[4]Feilang Ning
[1234]Mechanical Manufacture and Automation
[1234]Tianjin University of Technology & Education
[1234]Tianjin, China

***Abstract*—Using the oil products kinematic viscosity tester and petroleum products density tester， the kinematic viscosities and densities of five PAO oils with different initial viscosity were measured in the range of 30°C~110°C. The relationship between viscosity, density and temperature of PAO oil was analyzed. The relation on viscosity-density-temperature of PAO oil was established. The results show that the viscosity and density of PAO lubricating oil decrease with the increase of temperature, and the higher the density of PAO oil, the higher the kinematic viscosity of PAO. The newly established viscosity-density-temperature formula can better describe the relationship between viscosity, density and temperature of PAO oil in the range of 30°C-110°C. This formula can be used to predict the viscosity of PAO oil in a certain range of temperature.**

Keywords:PAO; kinematic viscosity; density; temperature

I. INTRODUCTION

PAO oil is widely used in all fields of industry because of its comprehensive high quality performance. As a quality index of lubricating oil, viscosity has influences on oil film thickness, bearing capacity, mechanical efficiency and friction heat generation, etc, and has become an important factor affecting the service life of equipment. Therefore, it is of great significance to study the viscosity of lubricating oil.

Domestic scholars have conducted many researches on the viscosity of lubricating oil[1-3].Li Xinghu analyzed the effects of temperature and pressure, molecular weight and molecular structure on viscosity of lubricating oil[4].Li Yong analyzed the influence of constant bath temperature, viscometer viscosity constant, viscometer cleanliness, viscometer installation state, sample cleanliness and other aspects on the measurement results of lubricating oil kinematic viscosity[5].In 2016, Cui Jinlei studied the relationship between lubricating oil density and viscosity, and proposed a new viscosity pressure relation formula based on density to obtain viscosity[6]. Reference 7 introduces an applied research method for viscosity conversion of lubricating oil at different temperatures, which can realize the rapid calculation of viscosity index of oil with pour point greater than 50°C[7].

Abroad, the Soviet union scholars B.B.СОКОЛОВ studied the influence of viscosity-temperature characteristics of lubricating oil on power loss of automobile transmission system[8].Seeton C J studied the relationship between fluid viscosity and temperature[9].D.Knezevic proposed a mathematical model for the dynamic viscosity of mineral oil in a hydraulic system, varying with temperature and pressure[10].Bair S studied the variation of the viscosity of various lubricating oils with temperature and pressure[11].

At present, the research on lubricating oil viscosity mainly focuses on the influence factors of lubricating oil viscosity, as well as the empirical formulas of temperature-viscosity, temperature-density, temperature- pressure-viscosity.The relationship between viscosity-density-temperature of lubricating oil has not been studied.In this paper, the viscosity and density of PAO oil and the relationship between viscosity and temperature are studied. The viscosity-density-temperature model of PAO aviation lubricating oil was established.

II. EXPERIMENTAL DEVICES AND METHODS

The test samples were five PAO oil of different viscosity provided by Sinopec Lubricant Company Tianjin Branch.The kinematic viscosity at 40°C is:32mm^2/s, 48mm^2/s,68mm^2/s, 110mm^2/s,125mm^2/s.

In order to explore the relationship between kinematic viscosity, density and temperature of PAO oil, we first tested the kinematic viscosity and density of the above lubricating oil samples at different temperatures with petroleum product kinematic viscosity tester and petroleum product density tester.

A. Kinematic viscosity testing device and method

The measurement of kinematic viscosity is performed by SYP1003-6 petroleum products kinematic viscosity tester.Figure 1 is the device diagram of petroleum products kinematic viscometer, which is mainly composed of temperature control box, constant temperature cylinder, constant temperature medium, heater, agitator, stopwatch and viscometer.

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

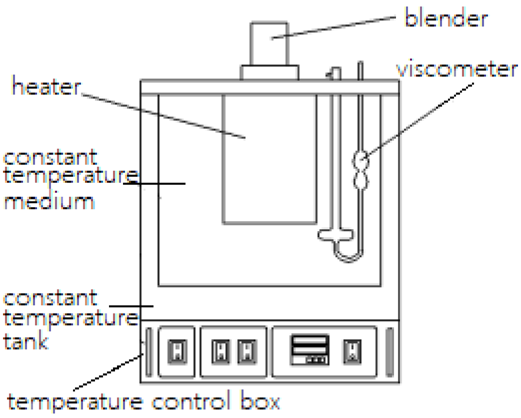

FIG. 1 Motion viscometer for petroleum products

During the test, pour the constant temperature medium into the constant temperature cylinder, turn on the heater and set the test temperature.When the temperature of the constant temperature medium reaches the test temperature, the viscometer loaded into the sample is placed vertically in the constant temperature medium for 15 minutes to measure the time of a certain amount of lubricating oil sample flowing through the capillary tube of the viscometer.Repeat the measurement 4 times, the kinematic viscosity of the sample at the set temperature can be obtained by multiplying the average value of the time obtained at least 3 times by the viscometer constant of the selected viscometer. The kinematic viscosity data of the lubricating oil measured by the above device is shown in Table 1.

TABLE I. KINEMATIC VISCOSITY OF PAO OILS AT DIFFERENT TEMPERATURES

Sample / Temperature	PAO （32mm²/s）	PAO （48mm²/s）	PAO （68mm²/s）	PAO （110mm²/s）	PAO （125mm²/s）
30°C	40.7	73.7	85.83	182.67	208.38
50°C	20.3	32.09	44	72.36	80.44
70°C	11.06	16.81	22.73	33.49	38.02
90°C	6.82	9.91	12.85	18.93	21.17
110°C	4.46	6.4	8.11	11.83	13.01

B. Density test device and method

The determination of the lube oil sample density is done by the petroleum product density tester.The structure of the density tester for petroleum products is shown in FIG. 2,

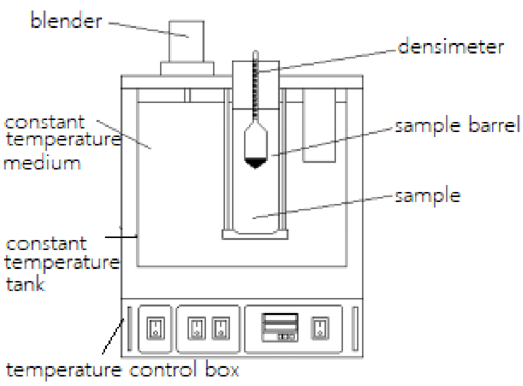

FIG. 2 Density tester for petroleum products

During the test, the constant temperature medium glycerol is poured into the constant temperature cylinder, and the constant temperature is set through the temperature control box.Pour the sample into the sample bucket, put the sample bucket into the constant temperature medium, make the liquid level of the sample lower than that of the constant temperature

which is mainly made up of a sample barrel of a constant temperature stirrer and a set of measuring range is composed of 600~650Kg/m^3, 650~700Kg/m^3, 700~750 Kg/m^3, 800~800Kg/m^3, 800~900Kg/m^3 , 900~950Kg/m^3,950~1000Kg/m^3 densitometer.

medium, and maintain the constant temperature for a certain time.When the temperature of the lubricating oil sample measured by the thermometer reaches the set temperature, select the appropriate densitometer and place it into the sample in the sample bucket.After the densitometer stabilizes, Read the scale on the densitometer that is tangent to the liquid level of the sample. This reading value is the density of the sample at this temperature.See Table 2

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

TABLE II. DENSITY OF POLYOLEFIN LUBRICANTS AT DIFFERENT TEMPERATURES(UNITS:Kg/m^3)

Temperature / Sample	30°C	50°C	70°C	90°C	110°C
PAO(32)	816.3	806.2	794.1	780.5	767.2
PAO(48)	822.6	812.3	800.2	787.8	774.1
PAO(68)	826.7	816.5	805.5	792.2	780.1
PAO(110)	830.2	818.3	806.1	795	782.3
PAO(125)	831.3	820.0	807.3	796.1	783.2

III. ANALYSIS OF TEST RESULTS

After collating the experimental data, the density-viscosity relationship of PAO lubricating oil at 30°C,50°C,70°C,90°C,110°C was obtained, as shown in FIG. 3

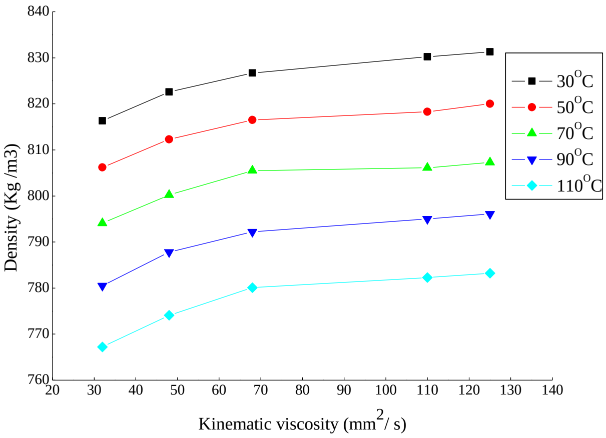

FIG. 3 Relationship between dynamic viscosity and temperature of lubricating oil with different viscosities

As can be seen from the figure, the density of lubricating oil with the same kinematic viscosity gradually decreases with the increase of temperature, and the trend of density reduction is approximately linearly correlated with the trend of temperature increase.At the same temperature, the lubricating oil with high kinematic viscosity has higher density, and with the increase of kinematic viscosity, the trend of density increase gradually decreases.

IV. DETERMINATION OF VISCOSITY-DENSITY-TEMPERATURE RELATIONSHIP

Use First Optimization software，regression analysis of the above experimental data was carried out by using Macquarie method.The fitting formula between kinematic viscosity density and temperature is obtained as follows:

$$\nu = p_1 + p_2 \times \left(\frac{1}{1+\frac{T}{p_3}-p_4} \right) + p_5 \times \left(\frac{1}{1+\frac{\rho}{p_6}-p_7} \right) + p_8 \times \left(\frac{1}{1+\frac{T}{p_3}-p_4} \right) \times \left(\frac{1}{1+\frac{\rho}{p_6}-p_7} \right) \quad (1)$$

In the formula:
T is temperature,ρ is the density of PAO oil at T:
p_1= -40.168;
p_2= 12.869;
p_3= 7.905;
p_4= -23.451;
p_5= -8.01868G10^2;
p_6= 7.741;
p_7= 1.09197G10^2;
p_8= 1.6955976G10^4;

Formula (1) reflects the relationship between PAO lubricating oil kinematic viscosity, density and temperature,Population correlation coefficient R= 0.99205,The relationship of the three is shown in Figure 4.

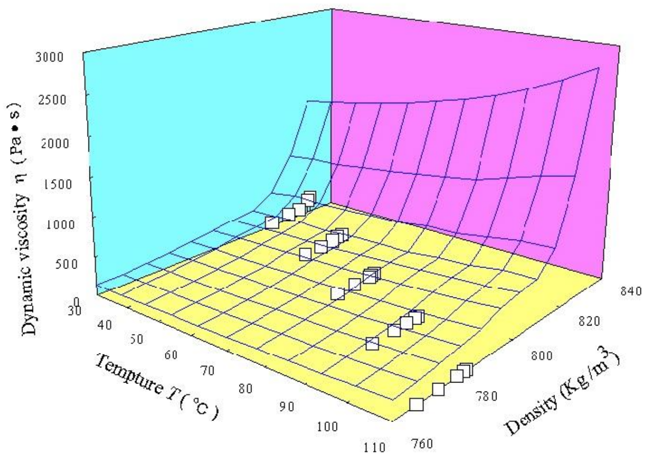

FIG. 4 Comparison of calculated and tested values of kinematic viscosity-density-temperature relationship

In the figure, the grid represents the predicted value of formula (1), and the white squares represent the test data points.

V. ERROR ANALYSIS

Table 3~7 shows the comparison between the calculated value and the test value of Formula (1) when the temperature is 30°C, 50°C, 70°C, 90°C and 110°C, respectively.

TABLE III. COMPARISON OF CALCULATED VALUES AND TEST VALUES(TEMPERATURE OF 30°C)

Density（Kg/m^3）	Test value（mm^2/s）	calculated value（mm^2/s）	relative error（%）
816.3	40.7	33.859	16.80
822.6	73.7	64.95	11.87
826.7	85.83	104.65	-21.93
830.2	182.67	173.8	4.86
831.3	208.38	211.63	-1.56

TABLE IV. COMPARISON OF CALCULATED VALUES AND TEST VALUES(TEMPERATURE OF 50°C)

Density（Kg/m^3）	Test value（mm^2/s）	calculated value（mm^2/s）	relative error（%）
806.2	20.3	22.288	-9.79
812.3	32.09	37.30	-16.24
816.5	44	52.71	-19.80
818.3	72.36	61.37	15.19
820	80.44	71.188	11.50

TABLE V. COMPARISON OF CALCULATED VALUES AND TEST VALUES(TEMPERATURE OF 70°C)

Density（Kg/m^3）	Test value（mm^2/s）	calculated value（mm^2/s）	relative error（%）
794.1	11.06	12.43	-12.39
800.2	16.81	20.96	-24.69
805.5	22.73	31.02	-36.47
806.1	33.49	32.37	3.34
807.3	38.02	35.24	7.31

TABLE VI. COMPARISON OF CALCULATED VALUES AND TEST VALUES(TEMPERATURE OF 90°C)

Density（Kg/m^3）	Test value（mm^2/s）	calculated value（mm^2/s）	relative error（%）
780.5	6.82	4.82	29.33
787.8	9.91	11.38	-14.83

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

792.2	12.85	16.35	-27.24
795	18.57	20.05	-7.97
796.1	20.17	21.64	-7.29

TABLE VII. COMPARISON OF CALCULATED VALUES AND TEST VALUES(TEMPERATURE OF 110°C)

Density（Kg/m^3）	Test value（mm^2/s）	calculated value（mm^2/s）	relative error（%）
767.2	4.46	-0.21	104.71
774.1	6.4	4.11	35.78
780.1	8.11	8.70	-7.27
782.3	11.83	10.63	10.14
783.2	13.01	11.47	11.84

It can be seen from the above table that the calculated value of viscosity-density- temperature relation is close to the experimental value.

VI. CONCLUSION

In this paper, the kinematic viscosity and density of PAO oil samples with different initial viscosities were measured at different temperatures and the experimental data were analyzed.A functional relationship between PAO oil viscosity-density-temperature was obtained by fitting test data.The following conclusions can be drawn:

1.The viscosity and density of lubricating oil decrease with the increase of temperature. At the same temperature, the density increases with the increase of kinematic viscosity, but the increase trend decreases gradually.

2.The equation of viscosity-density- temperature function is obtained.It can describe the relationship between viscosity density and temperature of PAO oil.The kinematic viscosity of PAO lubricating oil in the range of 30°C-110°C can be predicted using this relation.

REFERENCES

[1] Li Yong-cai. Application significance of lubricating oil viscosity and its influencing factors [J]. Wisco Technology,1985,(06):64-67+33

[2] Zhao Xiaohui. Experimental analysis of the influence of lubricating oil viscosity on power [J]. Rubber Technology and Equipment,1985,(01):53-54.

[3] Hao Jingtuan, YAO Ting, MA Yuhong, Yang Hongwei. Factors influencing the viscosity of aviation lubricating oil [J]. Guangzhou Chemical Industry,2014,(08):29-31+49.

[4] Li Xinghu, ZHAO Xiaojing. Analysis of influencing Factors of Lubricating Oil Viscosity [J]. Lubricating Oil,2009,(06):59-64.

[5] Li Yong, Yang Xiaofei, WANG Jian, ZHAO Yunqiang, LIU Yongping. Analysis of influencing factors for determination of kinematic viscosity of lubricating oil [J]. Experimental Science and Technology,2010,(04):16-19.

[6] Cui Jin-Lei, Yang Ping, LIU Xiao-ling, Yang Pei-an. Discussion on the new viscosity pressure relationship based on lubricating oil density [J]. Journal of Tribology,2016,(01):13-19.

[7] Wang Jin-fan, JIN Yong, CHENG Ye. Application study on viscosity conversion of lubricating oil at different temperature [J]. Lubricating Oil,2001,(01):45-48.

[8] В В. С О К О Л О В, dao-zhong zhang, Zhou Shiyang. The viscosity of the lubricating oil temperature characteristic of automobile transmission system [J]. The influence of power loss foreign cars, 1985, (4) : 43-45.

[9] Seeton C J. Viscosity–temperature correlation for liquids[J]. Tribology Letters, 2006, 22(1):67-78.

[10] D. Knezevic. Mathematical modeling of changing of dynamic viscosity, as a function of temperature and pressure, of mineral oils for hydraulic systems[J]. Facta Universitatis, 2006.

[11] Bair S. The Variation of Viscosity With Temperature and Pressure for Various Real Lubricants[J]. Journal of Tribology, 2001, 123(2):433-436.