Measurement and Analysis of Silicone Oil Characteristics and Viscosity-Temperature Index

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Abstract. This paper introduces the shear resistance, viscous-temperature characteristics and thermal expansion characteristics of silicone oil. According to the physical and chemical properties of silicone oil, the viscosity of silicone oil is tested through experiments, and the viscous-temperature characteristic curve of the sample is obtained. The degree of the decrease of the viscosity of silicone oil with the increase of the temperature of silicone oil is quantified. It is important to study the calculation method of slip difference of silicone oil fan clutch and the surface temperature of the shell.

1. Introduction
There are organic groups such as methyl and ethyl in the molecular structure formula of silicone oil [1]. According to the different molecular structure of silicone oil, there are methyl silicone oil, methyl hydrogen silicone oil, ethyl silicone oil, phenyl silicone oil and so on; according to different application occasions, there are insulating oil, brake oil, damping silicone oil, etc.[2]. Among them, all the organic groups are methyl, which is called methyl silicone oil. Methyl silicone oil is widely used in industry. In industry, in order to make silicone oil products suitable for various special properties, methyl silicone oil can be modified by replacing part of its methyl group with other groups. Silicone oil belongs to high polymer. The special properties of silicone oil include: (1) shear resistance of silicone oil: the viscosity of silicone oil increases with the increase of molecular weight of silicone oil, Methyl silicone oil has very strong shear resistance, which is much better than general mineral oil. The viscosity of low molecular weight silicone oil is little affected by shear rate. At room temperature, even at a high shear rate, the low molecular weight silicone oil still behaves as Newtonian fluid[3]. The viscosity stability of silicone oil is very good, and it can adapt to severe shear conditions and keep the viscosity stable; (2) viscosity-temperature characteristics of silicone oil: when the temperature of silicone oil increases, its viscosity decreases. On the contrary, when the temperature of silicone oil decreases, its viscosity increases. The smaller the viscosity of silicone oil, the better the fluidity. In addition, the viscous-temperature index is used to evaluate the viscous-temperature characteristics of liquids; (3) thermal expansion characteristics of silicone oil: the density of silicone oil is affected by its own temperature. Generally speaking, temperature is inversely proportional to density[4].

For a clutch filled with silicone oil of different viscosity, the greater the viscosity of silicone oil, the smaller the slip rate, but the viscosity of silicone oil cannot be too large, otherwise it will affect the fluidity of silicone oil, and then affect the transmission efficiency of the clutch. In 1997, Wei Chengguan et al.[5] studied the influence of silicone oil viscosity and silicone oil quantity on the
performance of silicone oil fan clutch. It was pointed out that low viscosity silicone oil should be preferentially used on the premise of ensuring the torque transfer capability of the clutch. In 2003, Liu Liang et al.[6] considered the influence of silicone oil viscous-temperature characteristics and other factors, studied the hydro-viscous coupling, and analyzed its torque characteristics. In 2008, Zhang Rongbo[4] carried out an experimental study on the viscous-temperature characteristics of methyl silicone oil, measured its dynamic viscosity at different temperatures, and finally processed the experimental data with Origin software, obtained the viscous-temperature curve and viscous-temperature index of the methyl silicone oil sample.

Quantifying the degree of silicone oil viscosity decreasing with the increase of silicone oil temperature is of great guiding significance to the study of calculation methods of slip difference and shell surface temperature of silicone oil fan clutch. According to the physical and chemical properties of silicone oil, the viscosity of silicone oil is tested through experiments, and the viscous-temperature characteristic curve of the sample is obtained, which deepens the understanding of the working mechanism of silicone oil fan clutch, so as to better guide the development and design of silicone oil fan clutch.

2. Testing equipment and testing principle

LVDV-II+PRO digital viscometer and TC-502D constant temperature bath will be used in the actual measurement of silicone oil viscosity. The working principle of LVDV-II+PRO digital viscometer is briefly analyzed. The rotor immersed in silicone oil is simplified into two parts: cylinder end surface and cylinder surface. In the cylindrical coordinate system shown in figure 1, the torques transmitted by the end element $dA$ and the cylindrical element $dA'$ are [7]:

$$dT_{disk} = r\tau_{\theta}dA = r\mu_r\left(\frac{1}{r}\frac{\partial u_r}{\partial \theta} + \frac{\partial u_\theta}{\partial z}\right)dA$$  

$$dT_{cylinder} = r\tau_{\phi}dA' = r\mu_r\left(\frac{\partial u_\phi}{\partial r} + \frac{1}{r}\frac{\partial u_r}{\partial \phi} - \frac{u_\phi}{r}\right)dA'$$

In the formula, $u_r$, $u_\theta$, $u_z$ are respectively the radial, circumferential and axial flow velocities of silicone oil and are respectively calculated.

It is approximated that the flow of silicone oil is symmetrical, that is, the flow velocity is independent of the rotation angle, so the above formula can be simplified as follows:

$$dT_{disk} = r\mu_r\frac{\partial u_\theta}{\partial z}dA$$

Figure 1. Cylindrical coordinate system
When silicone oil flows between the active disk and the driven disk, as shown in Figure 2. Assuming that its circumferential velocity is linearly distributed along the Z axis, it can be obtained:

\[
d T_{\text{disk}} = r \mu \left( \frac{\partial u_\theta}{\partial r} - \frac{u_\theta}{r} \right) dA'
\]

(4)

Formula (5) is integrated. Considering that only the rotor rotates, the beaker holding the silicone oil sample is fixed. Assuming that \( \omega_z = 0 \), the torque \( T_{\text{disk}} \) transmitted by the disc oil film with radius \( R_1 \) is as follows:

\[
T_{\text{disk}} = \frac{1}{2} \pi \mu_1 \omega_1 R_1^2
\]

(6)

Suppose two cylinders with radii of \( r_1 \) and \( r_2 \) are sleeved together, rotated at angular speed \( \omega_1, \omega_2 \), filled with silicone oil, and the oil film width is \( L \), which is shown in Figure 3. If the Z axis coincides with the rotating axis, the angular velocity of the liquid at the radius \( r \) of the oil film is \( \omega \), and the linear velocity is \( u_\theta \), then, we can get this:

\[
u_\theta = \omega r
\]

(7)

\[
\frac{du_\theta}{dr} = r \frac{d\omega}{dr} + \omega
\]

(8)

Formula (8) is substituted for formula (4), and the viscous torque of the liquid is known as:
Formula (9) is deformed to obtain formula (10).

$$d\omega = \frac{T_{cylinder}}{2\pi L\mu_s} \times \frac{dr}{r^3}$$

(Formula 10)

Formula (10) is integrated, and the torsion acting on the wall of inner and outer cylinders is obtained as:

$$T_{cylinder} = \frac{4\pi L\mu_s (\omega_1 - \omega_2) r_1^2 r_2^2}{r_2^2 - r_1^2}$$

(Formula 11)

According to formula (6) and formula (11), the formula of silicone oil viscosity is obtained as follows:

$$\mu_s = \frac{T}{8\pi^2 L r_1^2 n}$$

(Formula 12)

Once the type of the rotor is determined, the radius \( r_1 \) of the rotor and the depth \( L \) of the silicone oil immersion are also determined. Then the viscosity of the silicone oil can be calculated according to formula (12), when the rotor speed is also selected, which is the working principle of LVDV-II+PRO digital viscometer for testing the viscosity of silicone oil.

3. Testing and result analysis

Referring to the instrument use specifications, the silicone oil viscosity is measured in the following test steps according to the relevant method of silicone oil viscosity test [8-9]:

① Start the constant temperature bath, place the beaker containing the tested silicone oil in a constant temperature bath, and keep it constant to the specified temperature;

② Open the LVDV-II+P viscometer, zero the instrument, first clean the viscometer rotor with alcohol cotton, and then dip the viscometer rotor into the groove of the rotor to the groove of the rotor rod;

③ After reaching the required temperature, start the rotor motor and select the appropriate rotor speed so that the torque percentage during the test is between 10% and 100%, and read the viscosity value after stable;

④ After the test, close the thermostatic bath and viscometer, pour the sample into the sample cup, and clean the viscometer rotor with alcohol cotton. The test average value is fitted exponentially in Origin software according to the formula \( \mu_s = \mu_0 e^{-A(T_s - T_0)} \) as shown in figure 4.
Dynamic viscosity (cP) vs Temperature (°C)

(a) 8000cP viscosity-temperature curve
(b) 14800cP viscosity-temperature curve

Figure 4. The viscosity-temperature curve of the silicone oil obtained by fitted

For other viscosity silicone oils, the viscosity-temperature characteristic curve and the viscosity-temperature index can be tested in the same manner. Quantifying the degree of silicone oil viscosity decreasing with the increase of silicone oil temperature is of great guiding significance to the study of calculation methods of slip difference and shell surface temperature of silicone oil fan clutch.

4. Conclusion
Silicone oil has shear resistance, viscosity temperature characteristics and thermal expansion characteristics. According to the physicochemical properties of silicon oil, the viscosity of two silicon oils is designed and tested experimentally, and the viscosity temperature characteristic curve and viscosity index of these two silicon oils are obtained. The degree of the viscosity of silicon oil decreased with the temperature of silicon oil is calculated. Because the degree of the viscosity of silicone oil decreased with the temperature of Silicon oil plays an important role in calculating the slip difference of silicon oil fan clutch and the surface temperature of the shell, the research in this paper is of great significance to the study of slip difference of silicon oil fan clutch and surface temperature of shell.

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