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Research Article

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A Tribology Study on the Effect of Physical and Mechanical Properties of Multi-Grade Engine Oils on their Deviation in Viscosity Index

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Abstract The deviation in viscosity index of multi-grade engine oils is essential in determining the ideal physical and mechanical properties of a lubricant fluid at different temperatures. The experiment takes into account three different multi-grade engine oils (Valvoline 20W50, Castrol Magnatec 15W40, Total Quartz 7000 10W40) of varying viscosity grades and properties. A capillary tube viscometer – with known viscometer constant and calibration set at 40°C and 100°C – was used to measure the flowing time of the liquid under controlled conditions. The flowing time was measured for 3 trials per lubricant and their average was used for subsequent calculations. The viscosity of the oils with known density were calculated through the product of the density, viscometer constant, and flowing time in the capillary, with a fixed volume of 7 ml. The investigation produced results in agreement with theory (within error) and were reliable due to repeatability of trials and the adequate control of variables outside the scope of the methodology. The experimental results were correlated with the physical and mechanical properties of the engine oils. These properties include the viscosity grades, density, flash point, and pour point. A clear positive relationship was established between the "W" winter viscosity grades of the oils and the deviation in viscosity index. Although, the density of the oils also showed a generally increasing trend with the deviation in viscosity index, its association with the flash point and pour point did not seem to be significant.

Keywords viscosity grade, density, flash point, pour point, viscosity index

Introduction

Multi-grade engine oils provide the suitable fluid film protection in various flow and temperature conditions. Through a reduction in frictional forces exerted on moving parts of the engine, they act as a lubricant to increase power output and efficiency. The engine oils have to endure cold starting temperatures as low as 35°C, circulate in internal combustion engines at 110°C, and channel through the ring belt area at conditions around 185°C [1]. Therefore, The Society of Automotive Engineers (SAE) viscosity grades are segregated into two distinct sets – the "W" winter grades and the "non-W" high temperature viscosity grades. While, the "W" winter viscosity grades serve to define the viscosity of the engine oil under cold starting temperatures, the "non-W" viscosity grades describe the viscosity of the engine oil at high temperatures.

Viscosity Index refers to the rate of change of the viscosity of engine oil with temperature. There is a decrease in viscosity with an increase in temperature due to the persistent decrease in the cohesive forces between liquid molecules. The deviation in this viscosity index would be calculated at temperatures 40°C and 100°C – the calibration set on the capillary tube viscometer. Therefore, information about this deviation in viscosity index of different engine oils would benefit their manufacturers as it would inform them about how the properties of their engine oils influence the viscosity thus, enabling them to make optimal modifications by reducing or increasing the presence of certain elements to provide more consistency in the viscosity of the oil at different temperatures.

The process of viscosity determination is used to calculate the viscosity of lubricant samples with the use of a capillary tube viscometer. When the liquid travels in a particular direction – with the liquid's velocity maintaining a gradient about the direction rectangular to that of flow – an internal frictional force is generated along the sides of the hypothetical plane parallel to the movement. This flow property of the lubricant oil can be expressed in terms of its viscosity [2]. The pressure exerted due to the internal frictional force on the parallel plane is called the shear stress. The velocity gradient about the direction rectangular to that of flow is called the shear velocity [3]. A liquid whose shear velocity is proportional to its shear stress is called a Newtonian fluid – which are used in this investigation.

The analysis of different physical and mechanical properties of the lubricant is essential. The kinematic viscosity would be calculated, which is the ratio of dynamic viscosity to that of density [4]. The density of the oil refers to its mass per unit volume and affects the space between the particles thus, it would have an impact on the change in viscosity on an increase in temperature. The flash point of the oil is the temperature at which the vapor over the liquid will ignite under exposure to a source of heat while, the pour point refers to the lowest temperature at which the oil is capable of flowing under gravity thus, these values would be a factor in the change in viscosity due to the abrupt change in temperature of the capillary tube viscometer [5]. The deviation in viscosity index of the multi-grade engine oils would be analysed with respect to the viscosity grade of the engine oil, density, flash point, and pour point of each lubricant.

Materials and Methods

The following samples of engine oils were used for the experimental analysis, as shown in Table 1. They were initially weighed using an electronic weighing scale, with each oil's volume set at 50 ml with the help of a measuring cylinder. The density was calculated as follows:

$$\text{Density of Engine Oil (g/ml)} = \frac{\text{Mass (g)}}{\text{Volume (ml)}}$$

This value would be further used for analysis as well as calculation of the viscosity. The information and grades of the engine oils are certified by SAE and taken from their specifications.

Table 1: Specifications of Multi-Grade Engine Oils Used

Engine Oil and Viscosity Grade	Density (g/cm^3)	Flash Point (°C)	Pour Point (°C)
Valvoline 20W50	0.811	256	-33
Castrol Magnatec 15W40	0.744	203	-36
Total Quartz 7000 10W40	0.777	232	-24

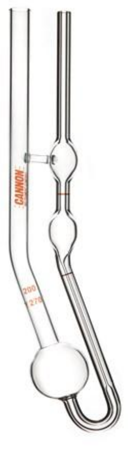

Figure 1: Cannon-Fenske Routine

The Cannon-Fenske Routine was used as the capillary tube in the viscometer. The tube had graduations to measure the flowed time of the liquid through the volume, which was set at 7 ml, with the nominal overall length of 250 mm. The 300-unit size was chosen due to the suitable viscosity ranges of the engine oils. The Cannon-Fenske Routine was cleaned with ethanol before every trial in order to eliminate the influence of other measurements and produce accurate results. The required volume of the engine oil was measured using a syringe, with an absolute uncertainty of $\pm$ 5 ml, to transfer the oil into the Cannon-Fenske Routine.

Figure 2: Capillary Tube Viscometer

The capillary tube viscometer was used in order to vary the temperature, whose calibration was set at 40°C and 100°C, thus, being able to determine the flowing time of the liquid under controlled conditions. The least count of the temperature scale of the capillary tube viscometer was 0.01°C. Since the capillary tube viscometer is a digital instrument with high accuracy, the systematic error in the viscometer would be equal to its least count, therefore, it would be $\pm$ 0.01°C. The viscosity of each engine oil was measured at 40°C for 3 trials and was repeated at 100°C, to provide reliable data through repeatability. The deviation in viscosity index was compared using this experimental data. A stopwatch was used to record the flowing time of the liquid in the 7 ml range.

In order to measure the viscosity of Newtonian fluids – in this case, lubricant engine oils – using a capillary tube viscometer, downflowing time of the liquid, t(s), and the viscometer constant, K (m^2s^2), are required quantities to firstly, calculate the kinematic viscosity, v (m^2/s).

$$\mathrm{v} = \mathrm{Kt}$$

Further, the viscosity, η ($m^2gs^{-1}cm^{-3}$), is calculated through the product of the kinematic viscosity, v (m^2/s), and the density of the engine oil, ρ (g/cm^3):

$$\eta = v\rho$$
$$\eta = Kt\rho$$

The viscometer constant, K (m^2s^2), varies for different temperatures thus, they will vary for 40°C and 100°C.

The percentage change in the viscosity with temperature would be the determinant of the deviation in viscosity index of the lubricant engine oil.

Results & Discussion

The flowing time of the lubricant engine oil was measured at 2 temperatures – 40°C and 100°C. The experimental raw data for the temperature 40°C has been recorded in Table 2.

Table 2: Flowing Time of Engine Oil at 40°C

Trial	**Flowing Time at 40°C ($\pm$ 0.005 s)**		
	Valvoline 20W50	**Total Quartz 7000 10W40**	**Castrol Magnatec 15W40**
1	727.24	387.14	460.49
2	713.65	383.64	462.11
3	722.82	392.03	466.55
Mean Average	721.237	387.603	463.050

The experimental raw data for the temperature 100°C has been recorded in Table 3.

Table 3: Flowing Time of Engine Oil at 100°C

Trial	Flowing Time at 100°C (± 0.005 s)		
	Valvoline 20W50	**Total Quartz 7000 10W40**	**Castrol Magnatec 15W40**
1	75.92	66.36	66.25
2	73.62	63.19	61.11
3	72.98	61.42	60.11
Mean Average	74.173	63.657	62.490

The calibration of the capillary tube viscometer was set at 40°C and 100°C.The viscometer constant, K(m^2/s^2), at 40°C is 2.644×10^{-7} m^2/s^2 and at 100°C is 2.631×10^{-7} m^2/s^2.

The viscometer constant at 100°C was calculated using the following equation due to the coefficient of thermal expansion:

$$C_{100} = C_{40}\times 0.995$$

As mathematically derived above, the viscosity of the engine oil, η($m^2gs^{-1}cm^{-3}$), is equal to the product of the viscometer constant,K(m^2/s^2), flowing time, t(s), and density of oil ρ (g/mL). This can be represented using the following equation [6]:

$$\eta = Kt\rho$$

The processed data in the form of the viscosity of engine oil for the lubricants at 40°Cis calculated and recorded in Table 4.

Table 4: Viscosity of Engine Oil at 40°C

Multi-Grade Engine Oil	Viscometer Constant (m^2s^{-2})	Average Flowing Time (s)	Density (g/mL)	Viscosity of Engine Oil at 40°C ($m^2gs^{-1}cm^{-3}$)
Valvoline 20W50	2.644×10^{-7}	721.237	0.811	0.000155
Total Quartz 7000 10W40	2.644×10^{-7}	387.603	0.777	0.000080
Castrol Magnatec 15W40	2.644×10^{-7}	463.050	0.744	0.000091

The processed data in the form of the viscosity of engine oil for the lubricants at 100°Cis calculated and recorded in Table 5.

Table 5: Viscosity of Engine Oil at 100°C

Multi-Grade Engine Oil	Viscometer Constant (m^2s^{-2})	Average Flowing Time (s)	Density (g/mL)	Viscosity of Engine Oil at 100°C ($m^2gs^{-1}cm^{-3}$)
Valvoline 20W50	2.631×10^{-7}	74.173	0.811	0.000016
Total Quartz 7000 10W40	2.631×10^{-7}	63.657	0.777	0.000013
Castrol Magnatec 15W40	2.631×10^{-7}	62.490	0.744	0.000012

The percentage change in the viscosity of the multi-grade engine oil with a change in temperature is calculated using the following equation:

$$\text{Percentage Change} = \frac{|\eta_2-\eta_1|}{T_2-T_1}$$

This has been calculated and represented in Table 6.

Table 6: Processed Data

Multi-Grade Engine Oil	Viscosity of Engine Oil at 40°C ($m^2gs^{-1}cm^{-3}$)	Viscosity of Engine Oil at 100°C ($m^2gs^{-1}cm^{-3}$)	Temperature Difference (°C)	Percentage Change
Valvoline 20W50	0.000155	0.000016	60	0.000232
Total Quartz 7000 10W40	0.000080	0.000013	60	0.000112
Castrol Magnatec 15W40	0.000091	0.000012	60	0.000132

The processed data in Table 6 display the percentage change in the viscosity of the 3 engine oils for a temperature change of 60°C. The density of Valvoline 20W50 is the greatest (0.811 g/cm^3), which correlates with it having the highest viscosity at both 40°C and 100°C, as a result, giving the largest percentage change in the viscosity index. Although, the higher viscosity is due to the particular grade of the engine oil and does not correlate with the density, the higher percentage change in the viscosity index may be a function of the larger mass of particles in the engine oil per unit volume, which increased the fluid's internal resistance to flow – essentially making it thicker. The results of the investigation also denote the positive relationship between the "W" winter grades of the multi-grade engine oils and the percentage change of its viscosity with temperature. This indicates that the higher the viscosity of the lubricant, the greater the percentage change of its viscosity would be with a change in temperature. This is due to the mechanical property of the viscosity grade of engine oils as thicker oils tend to comprise of a greater proportion of chemical elements with unfilled valence shells that are more reactive in nature such as Potassium (K) and Magnesium (Mg) therefore, they show higher deviation while stabilizing in the new conditions of thermal expansion leading to a greater percentage change in viscosity index. In addition, although the physical properties of flash point and pour point are accurate determinants of the viscosity of engine oils, as seen through the correlation between Table 1 and Table 6, there may not necessarily be a relationship with its deviation in viscosity index.

Conclusion

The experiment was conducted using apparatus with a low systematic error in order to provide accurate readings. The flowing time was measured for 3 trials per engine oil to ensure repeatability and precise measurements, which further facilitated the calculation of the percentage change in the viscosity of the multi-grade engine oil with accuracy. The results of the experiment were in agreement with theory (within error) and external variables outside the scope of its procedure were adequately controlled. There is a positive correlation between the "W" winter viscosity grades – a mechanical property of lubricants – and the deviation in viscosity index due to the presence of reactive elements. The density may not necessarily correlate with the viscosity however, it does have a positive association with the percentage change in the quantity over temperature due to larger mass of particles per unit volume. Lastly, the physical properties of flash point and pour point show no trend with the deviation in viscosity index of the 3 multi-grade engine oils.

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References

[1]. Mohammed, A., Al, A. (2008). Viscosity Index Improvement of Lubricating Oil Fraction (SAE-30). *Iraqi Journal of Chemical and Petroleum Engineering,* 9(3): 51-57.

[2]. Nedic, B., Peric, S., Vuruna, M. (2009). Monitoring Physical and Chemical Characteristics of Oil for Lubrication. *Tribology in Industry,* 31(3): 59-66.

[3]. Jaudon, C., Jackson, R., Gallagher, T. (2016). The Effect of High Viscosity Index on Fuel Economy with Bio-Derived Hydraulic Oils. *Tribology and Lubrication Technology,* 72(4): 20-23.

[4]. Epelle, E.,Otaru A., Zubair, Y., Okolie, J. (2017). Improving the Viscosity Index of Used Lubricating Oil by Solvent Extraction. *International Research Journal of Engineering and Technology,* 4(12): 1581-1585.

[5]. Karim, A., Al-Salihi, K., Ahmed, N. (2015). Influence of EPDM viscosity index improvers on Kurdistan manufacturing oils. *International Journal of Scientific and Engineering Research,* 6(8): 638-643.

[6]. Stanciu, Ioana. (2014). Methods of Determination of Viscosity Index for Sunflower Oils. *International Journal of Scientific Research,* 3(11): 55-56.