Viscosity Index Improver for Engine Oils: An Experimental Study

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Abstract

Engine oils are widely used for lubrication purposes in automobile and related industries. Viscosity Index (*VI*) improver has found its largest commercial applications as additives to engine oils. Examples are power steering fluid, aircraft piston engine oils, modern internal-combustion engines, turbine engine oils (stationary and aircraft), and industrial gear oils. Viscosity Index improvers are added in the lube oils to reach the desired Viscosity Index (*VI*). The enhancement of *VI* of lube oils (Servoneum 100, Servopress 68, Servomesh SP 220, and Servocut 335) by the addition of viscosity index improvers (Methylmethacrylate (MMA), Polybutadiene rubber (PBR), and Polyisoprene-cis) has been studied. *VI* of blended oils, made from the lube oils (Servoneum 100, Servopress 68, Servomesh SP 220, and Servocut 335) by the addition of MMA, PBR, and Polyisoprene-cis, has shown the potential to reach the maximum value. It has been found that the occurrence of maximum *VI* depends on the lube oil used and the type and concentration of viscosity index improver.

Keywords

Lube oil;
Methylmethacrylate;
Polybutadiene rubber;
Polyisoprene-cis;
VI improvers;
Viscosity index.

1. Introduction

The exponential rise of vehicles on roads has led to the simplicity in transportation, commutation, and several other means. For the smooth operations of these vehicles, the wear and tear of the engines should be minimum or negligible. Maintenance of these engines depends upon several factors, such as use of good fuels, proper lubrication, and time to time maintenance. With advancement in technology, the engine modification should be adopted properly. The fact has been well established that lubrication of the engine plays a significant role in its life. Lubrication oil provides the smoothness of the engine [9, 7]. Many types of lube oils are available, which can be used affectively in order to provide the desired lubrication. However, the stringent environment regulation adopted by environment agencies has led to the development of lubricating oil [3, 10]. This leads the researchers around the globe to develop such lubricating oils, which can perform in severe operational conditions. They have good oxidation stability, superior low-temperature performance, low volatility, low carbon forming tendency, viscosity stability, and improved additive response [2]. Synthetic lubricants are produced via chemical synthesis. A chemical

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could be blended with the lube oils to change some specific properties. One of the important parameters is viscosity index [4]. Viscosity of liquids is much greater than that of gases at the same temperature. It is an essential requirement that the engine lube oil must have low enough viscosity at low temperature and high enough viscosity at high temperature for the smooth operation of engine. Therefore, the viscosity changes with temperature must be minimum. The comparison of kinematic viscosity of the fluid to that of two reference fluids at 40^0C and 100^0C is generally adopted. Viscosity index improvers can be regarded as the key to high performance of multi-grade oil [6, 8]. They are generally oil-soluble polymers. The addition of these soluble polymers can enhance the viscosity of the oil. Oils containing *VI* improver can achieve viscosity index up to 150 [5]. The viscosity of engine oils increases with increase in temperature because engine oils include additives developed to reduce changes in viscosity [1]. As the number of polymers increases with the increase in concentration of *VI* improvers (polymers), the viscosity index of the oil also increases.

Ahmed et al. [5] reported that effectiveness of the prepared compounds became pronounced by increasing either the molecular weight of copolymer (140,000-236,000) or alkyl chain length (C_8-C_{12}). The preparation of copolymers was evaluated as *VI* improvers for lube oils (SAE 30). Estrification of acrylic acid was performed with alkyl chain length alcohols (octyl, decyl, octadecyl, tetradecyl, and hexadecyl) (C_8 to C_{16}) and confirmed by FTIR spectrometry. Then, copolymers were tested for solubility and molecular weight was determined by Gel Permeation Chromatography.

The viscosity index is determined according to the ASTMD-2270-87 formula:

$$VI = 100 \times [(L - U)/(L - H)] \tag{1}$$

Values of L and H are obtained from the tables of ASTM D-2270-87, where the basic kinematic viscosity at 100^0C is equal to or more than 2cSt and less than 70cSt. When the basic kinematic viscosity at 100^0C is above 70cSt, the values of L and H are calculated as follows:

$$L = 0.8353\, Y^2 + 14.67\, Y - 216 \tag{2}$$

$$H = 0.1684\, Y^2 + 11.85\, Y - 97 \tag{3}$$

If the measured viscosity at 100^0C is not listed in the tables, within the range of 2–70cSt, the corresponding values of L and H can be obtained by linear interpolation. When the calculated VI is above 100cSt, it has to be recalculated as follows

$$YN = H/U \tag{4}$$

$$N = (\log H - \log U)/\log Y \tag{5}$$

$$VI = [\,(e^N) - 1]/(0.00715) + 100 \tag{6}$$

Ghosh et al. [11] used the polymethacrylate, olefin copolymer, and hydrogenated styrene-isoprene copolymer as viscosity modifiers in lubricants with polymer concentrations of 0.5 to 4%w/w in five high-viscosity indices and one medium-viscosity index using Bosch injector shear rig and ASTM D-3945 method. The effect of mineral oil (base stock) viscosity and its composition were studied. It was found that there was no correlation between shear stability index values based on kinematic viscosities and those based on high temperature, high shear viscosities.

2. Experimental Section

2.1. Material

The lube oils (Servoneum 100, Servocut 335, Servopress 68, and Servomesh SP 220) were obtained from Indian Oil Corporation Limited, Panipat, and viscosity index improvers (PBR, MMA, and Polyisoprene-cis) were obtained from Sigma, Loba Chemie, and Aldrich, respectively.

2.2. Method

200ml of lube oil was put in a glass beaker. Electrically operated magnetic stirrer produced by Heidolph, Germany, was used for blending the lube oil at 500rpm and 30^0C in order to avoid foaming. The viscosity index improver was then added to the lube oil by taking necessary precautions. Each sample was blended for about 1h, which was enough for proper sample formation. After blending, the prepared sample oil was tested for the kinematic viscosity measurement at 40^0C and 100^0C, which were determined by Redwood viscometer no. 1 [13]. For each kinematic viscosity measurement, the sample oil was kept at constant temperature for 30min in order to attain the thermodynamic equilibrium. The temperature of the sample oil was maintained constant with the help of K – type controller. The flow time was measured with electronic stop-watch with precision of ±0.1sec. The efflux time was repeated at least 3 times for each concentration. The uncertainty of values was within ±0.005mm²/s. The kinematic viscosities were measured by using calibrated Redwood viscometer no. 1. The calibration was done using standard oils whose kinematic viscosities were reported in literature.

2.3. Equations [12]

When the temperature attains the standard temperatures (*i.e.*, 40^0C & 100^0C), the orifice of the viscometer is unsealed and the efflux time is noted for 50mL of the sample. This efflux time is put into Eq. 7 and the kinematic viscosity is calculated as υ in mm^2/s:

$$\upsilon = At - B/t \quad (7)$$

where, A is instrument calibration constant, B is instrumental type constant depending on the capillary diameter, and t is an efflux time in seconds.

Viscosity index is calculated by the following equations. When the kinematic viscosity is above $70mm^2/s$ at 100°C, the values of υ_L, υ_D, and υ_H are calculated as follows:

$$\upsilon_L = 0.8353\,\upsilon_Y{}^2 + 14.67\ \upsilon_Y - 216 \quad (8)$$

$$\upsilon_D = 0.6669\,\upsilon_Y{}^2 + 2.82\ \upsilon_Y - 119 \quad (9)$$

$$\upsilon_H = 0.1684\ \upsilon_Y{}^2 + 2.82\ \upsilon_Y - 97 \quad (10)$$

where υ_Y is the kinematic viscosity in mm^2/s at 100°C for the petroleum product whose viscosity index is to be calculated, υ_H is the kinematic viscosity in mm^2/s at 40°C of a petroleum product of viscosity index 100 having the same kinematic viscosity at 100°C as the petroleum product whose viscosity index is to be calculated, and υ_L is the kinematic viscosity in mm^2/s at 40°C of a petroleum product of viscosity index zero (0) having the same kinematic viscosity at 100°C as the petroleum product whose viscosity index is to be calculated. By using values of υ_L, υ_D, and υ_H, the viscosity index of the petroleum product is calculated as follows:

$$VI = 100\ \times [(\upsilon_L - \ \upsilon_U)/(\upsilon_L - \ \upsilon_H)] \quad (11)$$

where υ_U is the kinematic viscosity in mm^2/s at 40°C of the petroleum product whose viscosity index is to be calculated.

For petroleum products of viscosity index 100 or greater, *VI* is calculated by the following equation:

$$VI = [\ (e^N) - \ 1]/0.00715 + \ 100 \quad (12)$$

Where N is the power required to raise the kinematic viscosity of the oil at 100°C to make it equal to the ratios of the υ_H and υ_U kinematic viscosities at 40°C.

$$N = (\log \upsilon_H - \ \log \upsilon_U)/\log \upsilon_Y \quad (13)$$

Similarly, υ_U and υ_Y are the measured kinematic viscosities at 40°C and 100°C, respectively, for the liquid whose viscosity index has to be found, while υ_H is the kinematic viscosity at 40°C for a liquid of viscosity index 100, which has the same kinematic viscosity at 100°C as the liquid whose viscosity index has to be found.

3. Results and Discussions

3.1. Effect of concentration of *VI* improver on *VI* of blended oil

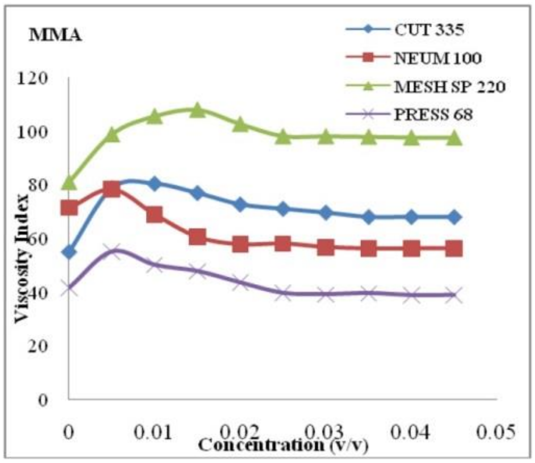

Figure 1. Variation of viscosity index of lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 with concentration of MMA

Figs. 1, 2, and 3 show the variations of *VI* for blended oils made from lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 by the addition of MMA, PBR, and Polyisoprene-cis, respectively, with the concentrations of MMA and PBR expressed in v/v % and Polyisoprene-cis in w/w %.

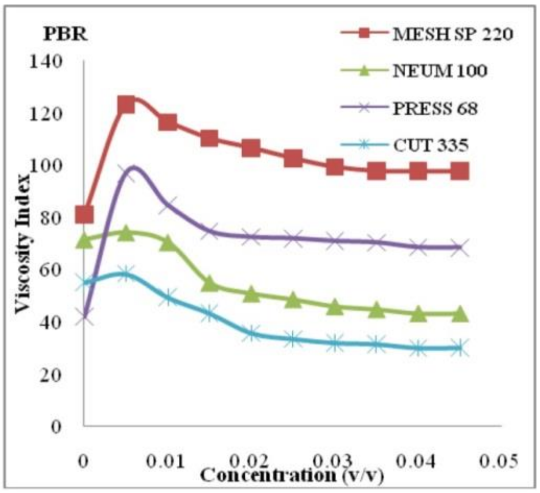

Figure 2. Variation of viscosity index of lube oils Servomesh SP 220, Servoneum 100, Servopress 68, and Servocut 335 with concentration of PBR

These figures depict the effectiveness of MMA/PBR/Polyisoprene-cis for different lube oils. The concentrations of MMA/PBR/Polyisoprene-cis vary in the range of 0 to 4.5v/v%. From this figure, it can be seen that *VI* of the blended oil made from lube oil Servocut 335 and MMA/PBR/Polyisoprene-cis reaches the maximum with increase in the concentration of MMA/PBR/Polyisoprene-cis. The similar curves are obtained for lube oils Servoneum 100, Servomesh SP 220, and Servopress 68. It can be seen from these figures that the maximum *VI* is obtained at different concentrations of MMA/PBR/Polyisoprene-cis. These concentrations are 1, 0.5, 1.5, and 0.5 v/v% for MMA; 0.5, 0.5, 0.5, and 0.5 v/v% for PBR; and 0.5, 0.5, 1, and 0.5 wt./wt.% for Polyisoprene-cis for lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68, respectively. The maximum possible *VI*s of blended oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 by addition of MMA, PBR, and Polyisoprene-cis are 80, 78, 108, and 55; 58, 74, 123, and 97; and 72, 78, 113, and 100, respectively. These figures are helpful in selecting the lube oil for producing multi-grade engine oils of desired viscosity index by the addition of MMA, PBR, and Polyisoprene-cis.

Figs. 4 and 5 are plots of *VI*, $(\upsilon_L - \upsilon_U)$ and $(\upsilon_L - \upsilon_H)$, for lube oil Servomesh SP 220 versus concentrations of PBR and MMA. It can be seen from the figures that with increase in the concentration of *VI* improver, $(\upsilon_L - \upsilon_U)$ first increases and then decreases, but $(\upsilon_L - \upsilon_H)$ increases monotonically. By definition, *VI* is the ratio of $(\upsilon_L - \upsilon_U)$ to $(\upsilon_L - \upsilon_H)$. Therefore, *VI* of blended oils reaches maxima with increase in the concentration of *VI* improver.

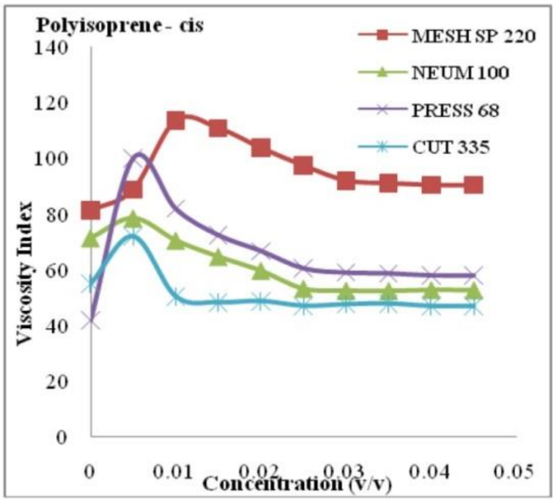

Figure 3. Variation of viscosity index of lube oils Servomesh SP 220, Servoneum 100, Servopress 68, and Servocut 335 with concentration of Polyisoprene-cis

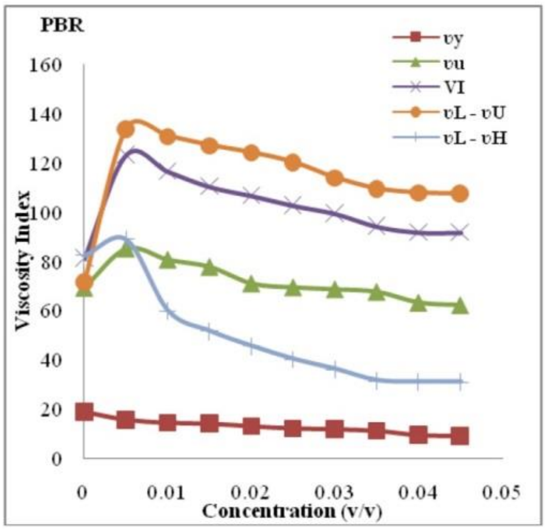

Figure 4. Variation of viscosity index and kinematic viscosity of lube oil Servomesh SP 220 with concentration of PBR

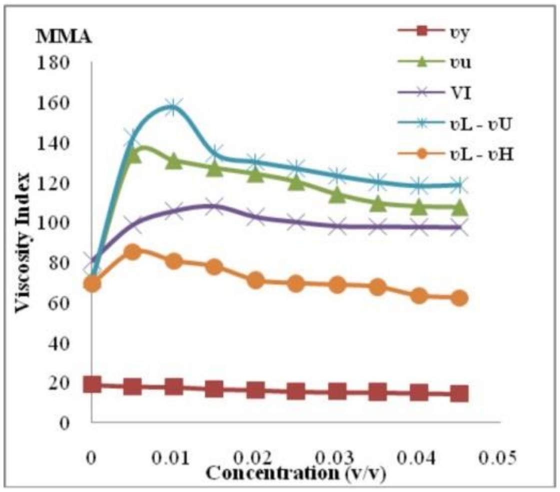

Figure 5. Variation of viscosity index and kinematic viscosity of lube oil Servomesh SP 220 with concentration of MMA

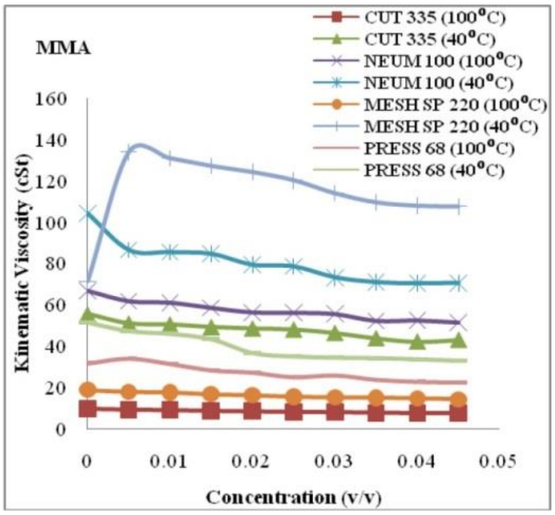

Figure 7. Variation of kinematic viscosity of lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 with concentration of MMA at 40 and 100^{0}C

3.2. Effect of concentration of *VI* improver on kinematic viscosity of blended oil

Fig. 6 is a plot of kinematic viscosity of blended oils, made from lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 by addition of PBR at 40^{0}C and 100^{0}C versus concentration of PBR. This figure indicates that the kinematic viscosity of blended oils decreases with increase in the concentration of PBR. It also indicates that the rate of change of kinematic viscosity of a blended oil, made from a lube oil by addition of PBR, at 40^{0}C with concentration of PBR is higher than its value at 100^{0}C.

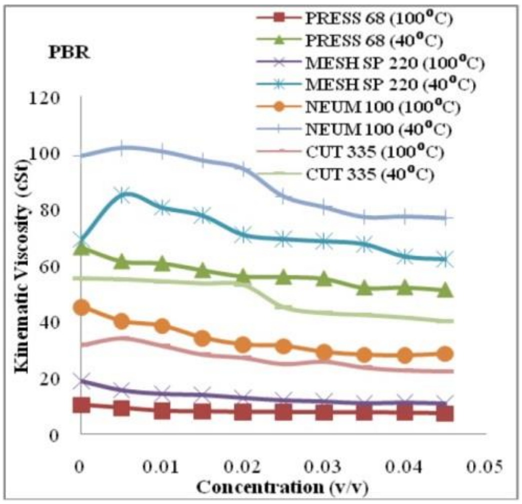

Figure 6. Variation of kinematic viscosity of lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 with concentration of PBR at 40 and 100^{0}C

Fig. 7 is a plot of kinematic viscosity of blended oils, made from lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 by addition of MMA, at 40^{0}C and 100^{0}C, versus concentration of MMA. This figure indicates that the kinematic viscosity of blended oils decreases with increase in the concentration of MMA. It also indicates that the rate of change of kinematic viscosity of a blended oil, made from a lube oil by addition of MMA, at 40^{0}C with concentration of MMA is higher than its value at 100^{0}C.

Fig. 8 is a plot of kinematic viscosity of blended oils, made from lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 by addition of Polyisoprene-cis, at 40^{0}C and 100^{0}C versus concentration of Polyisoprene-cis. This figure indicates that the kinematic viscosity of blended oils decreases with increase in the concentration of Polyisoprene-cis.

It also indicates that the rate of change of kinematic viscosity of a blended oil, made from a lube oil by addition of Polyisoprene-cis, at 40^{0}C with concentration of Polyisoprene-cis is higher than its value at 100^{0}C. Hence, the difference in kinematic viscosities of blended oil at 40^{0}C and 100^{0}C increases with increase in the concentrations of MMA, PBR, and Polyisoprene-cis for all lube oils. The variation of the kinematic viscosity at 100^{0}C should be considered in the formulation of desired oil.

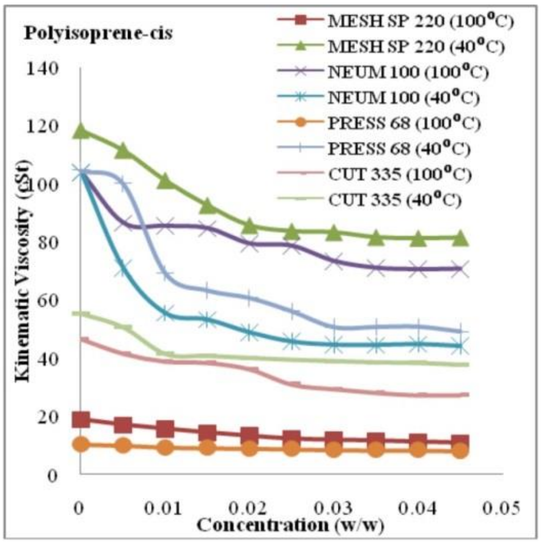

Figure 8. Variation of kinematic viscosity of lube oils Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 with concentration of Polyisoprene-cis at 40 and 100^0C

4. Conclusions

The conclusions drawn from the research study are as follows:

1. The maximum *VI*s of blended oils made from Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 were found to be 80, 78, 108, and 55 at 1, 0.5, 1.5, and 0.5v/v% of MMA, respectively.

2. The maximum *VI*s of blended oils made from Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 were found to be 58, 74, 123, and 97 at 0.5, 0.5, 0.5, and 0.5v/v% of PBR, respectively.

3. The maximum *VI*s of blended oils made from Servocut 335, Servoneum 100, Servomesh SP 220, and Servopress 68 were found to be 72, 78, 113, and 100 at 0.5, 0.5, 1, and 0.5w/w% of Polyisoprene-cis, respectively.

4. The difference in the kinematic viscosities of blended oils at 40^0C and 100^0C is found to increase with increase in the concentrations of MMA, PBR, and Polyisoprene-cis for all lube oils.

5. *VI* of blended oils, made from the lube oils Servoneum 100, Servopress 68, Servomesh SP 220, and Servocut 335 with these particular *VI* improvers, i.e., MMA, PBR, and Polyisoprene-cis, has not been considered so far.

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