Study on Prediction of Viscosity of Automobile Lubricants at Different Temperatures

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ABSTRACT - Viscosity is one of the most important rheological properties of lubricating oils. This study investigated the trend of viscosity variation with temperature for automobile lubricants. Commercial lubricating oil performance was examined for several different base oils.The complicating factor is that oil's viscosity varies with changes in temperature: thinner when hot and thicker when cold. Two classes of lubricants as well as the different grades of lubricants for Petrol Automotive Engines and their individual resistance to temperature were investigated. Three different lubricating oils were used and laboratory analyses were carried out for each of them relating their temperature with viscosity for the different grades at different ranges of temperature. The Comparisons of both lubricants were made as regards some of the quality control tests carried out on them, their viscosity, and the simultaneous dependence of their viscosity on temperature. By using MATLAB, an empirical model was developed from the experimental data's which resulted in a Quadratic equation for each grade of oil relating their temperature with viscosity at different ranges of temperature. Thus, from this an experimental conclusion can be drawn of which class and grade of oil best fits petrol automotive engines.

Keywords: Lubricant, oil, viscosity, temperature, petrol automotive engine.

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1.0INTRODUCTION

Reducing friction and wear-related mechanical failures in moving mechanical systems has gained increased attention in recent years, as a result of friction's adverse impacts on efficiency, durability, and environmental compatibility [4]. Hence, the search continues for novel materials, coatings, and lubricants (both liquid and solid) that can potentially reduce friction and wear. One of the most effective ways to control friction is to use a lubricant in liquid and/or solid forms. The lubricants may be liquid (such as motor oil and hydraulic oil) or semi-solid or solid; such as grease, even dry in the form of graphite or molybdenum disulfide. They are divided into two basic categories: Petroleum-based and Synthetic-based lubricants. The difference in these categories is the base fluid in which they are made from [9]. Lubricating oils are made as a result of blending base oils; performance enhancing additives and some other special ingredients which when put together in an appropriate concentration ensures that the finished lubricants performed the required function and meet the equipment's requirement [6]. A very important property of lubricating oil is viscosity- the quantitative measure of a fluid's resistance to flow. It is one of the most important rheological properties of lubricating oils [1], [11]. Viscosity is classified into two categories: Dynamic or Absolute Viscosity and Kinematic Viscosity.

Some mechanized equipment such as cars, heavy-duty machines, generating set break down due to the fact that the right lubricating oil is not used to service them. Automotive applications dominate, but other industrial, marine, and metal working applications are also big consumers of lubricants [6]. Liquid lubricants reduce friction by preventing sliding contact interfaces from severe or more frequent metal-to-metal contacts or by forming a low-shear, high-durability boundary film on rubbing surfaces [4], [11]. They are generally composed of a majority of base oil plus a variety of additives to impart desirable characteristics. Although generally lubricants are based on one type of base oil, mixtures of the base oils also are used to meet performance requirements. Lubricating oils contain 90% base oil (most often petroleum fractions, called mineral oils) and less than 10% additives [5]. Additives deliver reduced friction and

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wear, increased viscosity, improved viscosity index, resistance to corrosion and oxidation, aging, contamination, etc. A large number of additives are used to impart performance characteristics to the lubricants. Diesel engine was used to evaluate lube oil performance and engine friction at conditions typical for a fired engine and also used to predict the effects of lube oil formulations on the engine friction of the same engine [7].

The standard system for developing engine oil viscosity is the SAE viscosity classification system developed by the Society of Automotive Engineers (SAE). The society (SAE) has divided oils into grades. Each grade lays down broad limits for viscosity. This system assigns an SAE grade number to a specified viscosity range as measured at a specified temperature-the higher the viscosity, the higher the grade number. SAE grade numbers indicate only viscosity and not the type or quality of oil or the service for which it is intended. Some oils with polymers added to them, have high viscosity indices and are therefore referred to as multi-grade oils [2]. Mono- grades of oil are formulated to meet the requirements of only one SAE viscosity grade classification which makes its usefulness limited within a temperature range. A monograde engine oil, as defined by SAE, cannot use a polymeric. SAE has established eleven viscosity grades, of which six are considered Winter-grades and given a W designation, non-'W' grades are intended primarily for warm weather use. The 11 viscosity grades are 0W, 5W,10W, 15W, 20W, 25W, 20, 30, 40, 50, and 60. These numbers are often referred to as the "weight" of motor oil, and mono-grade motor oils are often called "straight-weight" oils [6]. Based on the coldest temperature the oil passes at, that oil is graded as SAE viscosity grade 0w, 5w, 10w, 15w, 20w, or 25w. The lower the viscosity grade, the lower the temperature the oil can pass. For example, if an oil passes at the specifications for 10w and 5w, but fails for 0w, then that oil must be labeled as an SAE 5W. That oil cannot be labeled as either 0W or 10W [8]. Multi-Grades of oil are formulated to meet the requirements of more than one SAE viscosity grade classification; this means they can be used over a wider temperature range than single-grade oils. Multi-grade oil is identified by two SAE grade designations, for example, an SAE 15W50 designation indicates that an oil acts like a 15W oil at cold temperatures and a 50 grade oil at normal operating temperatures.

The temperature range the oil is exposed to in most vehicles can be wide, ranging from cold temperatures in the winter before the vehicle is started up, to hot operating temperatures when the vehicle is fully warmed up in hot weather [6]. Specific oil will have high viscosity when cold and a lower viscosity at the engine's operating temperature. The difference in viscosities for most single grade oil is too large between the extremes of temperature. To bring the difference in viscosities closer together, special polymer additives called viscosity index improvers, (VIIs) are added to the oil. The viscosity of multi-grade oil still varies logarithmically with temperature, but the slope representing the change is lessened. This slope representing the change with temperature depends on the nature and amount of the additives to the base oil [8]. Also, if oil does not contain any VIIs, and can pass as multi-grade, that oil can be labeled with either of two SAE viscosity grades. For example, very simple multi-grade oil that can easily make with modern base oil without any VII is a 20W-20. This oil can be labeled as 20W-20, 20W, or 20 [3]. Viscosity index (VI) is an arbitrary measure for the change of viscosity with variations in temperature. The rate of change in viscosity with temperature can be expressed in terms of viscosity index (VI). A small reduction in viscosity coupled with a large temperature changes indicates a high viscosity index [9]. The lower the VI, the greater the change of viscosity of the oil with temperature and vice versa. It is used to characterize viscosity changes with relation to temperature in lubricating oil [10]. Automotive lubricants are one example where lubrication is needed at both high and low temperatures. However, for cooling applications, such as metal working or quenching, a low VI is better because of the lower viscosity (better heat transfer) at operating temperatures. Viscosity (kinematic) is measured according to ASTM D 445 [9] and it is a measurement of the time taken for a known volume of oil to flow under gravity through a calibrated glass capillary viscometer. Kinematic viscosity is measured at 40 degrees C. and 100 degrees C in order to have standard reporting temperatures. It is essentially the ratio of the viscosity to the density of the oil being tested. The viscosity index of synthetic oils ranges from 80 to over 400. The viscosity index is calculated by the following formula (equation 1):

$$VI = \frac{L - U}{L - H} \times 10 \qquad (1)$$

Where, VI = viscosity index
U = the kinematic viscosity of oil of interest
L and H are the kinematic viscosity of the reference oils

Some of the major tests carried out on the properties of lubricant are as approved by the American Society for Testing and Materials (ASTM) are as follows (ASTM, 2005):

The pour point of oil is defined as the lowest temperature at which a lubricant will flow. It is frequently and erroneously used as the oil viscosity selection criteria.

The total acid number (TAN) which is a measurement of acidity that is determined by the amount of potassium hydroxide in milligrams that is needed to neutralize the acids in one gram of oil. It is an important quality measurement of crude oil,

Total Base Number (TBN) is a measure of a lubricants reserve alkalinity. It is measured in milligrams of potassium hydroxide per gram (mg/KOH/g)

The flash point of a lubricant is the lowest temperature at which it can vaporize to form an ignitable mixture in air. Measuring a flash point requires an ignition source. At the flash point, the vapor may cease to burn when the source of ignition is removed.

This study determined and compared the kinematic viscosity of three (3) different types of oils of the same brand (at varying temperatures). And develop an empirical model from the experimental data's for each grade of oil which could be relatively useful in predicting viscosity at different temperatures. Samples of both Natural Base Stock (Monograde and Multigrade) and Synthetic Base Stock of lubricant were bought from a commercial dealer's outlet and proper quality control tests were carried out on the samples.

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2.0 METHODOLOGY

2.1 Materials and Experimental Procedure

The samples used in this experiment were gotten from a specified producer/dealer The experiment was based on their superior engine oils for petrol engines, with samples consisting of a mono-grade and multi-grade of the natural/mineral type of lubricant and also the synthetic blend of lubricant which are;

SAMPLE A: A commercial mono-grade based mineral oil with additive dopage for general application in engines operating under mild condition of service.

SAMPLE B: A commercial technologically advanced super multi-grade anti sludge mineral **oil** for all petrol engines, no matter the severity of operating conditions or season.

SAMPLE C: Commercial synthetic based multi-grade oil developed to meet the most severe operating conditions of all petrol engines. The oil is suited for extended drain intervals and is also adapted for multi-valved and turbo-charged engines.

The procedure employed in the experiment involved carrying out some of the general quality control tests on the different grades and types of automotive lubricants of a specified producer/dealer. Of importance amongst the tests was the viscosity test showing the viscosity's simultaneous dependence on temperature at different temperature ranges of 40°C, 60°C, 80°C, and 100°C which resulted in experimental data's. An empirical model useful in the prediction of viscosity at different temperatures for different grades and types of oil for the specified producer/dealer was subsequently introduced in the study.

2.2 Quality Control Test Methods

Some of the quality control test methods carried out on the three (3) samples are detailed below:

Colour
Method: ASTM D-1500
Equipment: Lovibond Petroleum Oils Comparator.

Total Base Number (TBN)
Method: ASTM D-2896
Unit: Mg KOH/g
Equipment: Burette, 250ml beakers, Magnetic Stirrers, Erlenmeyer flasks, Analytical balance.

The TBN was calculated from the equation (2)

$$TBN = \frac{A \ X \ N \ X \ 56.1}{W} \qquad (2)$$

Where A = Volume of acid used
N = Normality of perchloric acid; $HClO_4$ = 0.09792880575
W = Weight of sample.

Pour Point
Method: ASTM D-97
Equipment: Pour Point Tester

Kinematic Viscosity
Method: ASTM D-455, 1S0-3104, IP-71
Units: Centistokes
Equipment: Thermostatic bath that can provide a uniform temperature, precision

thermometer, Viscometer,
propipette bulb and stop watch.
Record average of the two readings which do not differ by more than 0.35% of their measurements.

Density
Method: Calibration prior to use
Unit: Kilogram per litre / cubic meter (kg/m^3)
Equipment: DMA 38 Automatic Density Meter,
2ml Syringe
Reagents: Acetone, N-Hexane

Water Content of Oil
Method: Crackle.
Equipment: 100ml burette, Measuring cylinder,
Hotplate and Thermometer.

Open Cup Flash Point (Cleveland)
Method: ASTM D-92, IP-36, ISO-2592
Unit: Degrees Centigrade (°C)
Equipment: Cleveland open cup flash tester comprising of hot plate, open cup, thermometer (ASTM 8C / IP 6C) and butane gas line.

3.0 RESULTS

Comparison of the three (3) samples was made as regards some of the general Quality Control Tests carried out on them such as; Specific Gravity, Pour Point Flash Point and Water Content. Table 1 shows their respective values with the three samples.

3.1 Viscosity Variation With Temperature

The test of importance (Viscosity) was carried out using a viscosity bath and suitable viscometers for each sample at 4 different temperatures (40^{o}C, 60^{o}C, 80^{o}C and 100^{o}C). Table 2 shows the simultaneous dependence of their viscosity on temperature.

Table 1 Comparison of Samples

Tests	Monograde Sample A	Multigrade Sample B	Synthetic Sample C
Density (kg/m^3)	895.0	890.7	877.5
Pour point (°C)	-6	-8	-25
Flash Point (°C)	250	232	228
Water Content	Negative	Negative	Negative

Table 2 Viscosity Dependence on Temperature

Temp (°C)	Viscosity(Centistokes)		
	Monograde Sample A	Multigrade Sample B	Synthetic Sample C
40	153.1	143.1	135.5
60	56.60	56.88	57.61
80	26.69	28.25	30.06
100	14.95	16.61	18.06

3.2 Empirical Modeling

An empirical model was developed from the experimental data's using MATLAB which resulted in a Quadratic equation for each grade of oil which could be relatively useful in predicting viscosity at different temperatures. Table 3 shows the three equations for the three different grades. Plot of graphs of viscosity against temperature was drawn for the three samples containing both the experimental values and predicted values as shown in Figures 1, 2, and 3. Fig1 shows the overview of containing both the experimental values and predicted values of viscosity–temperature dependence in mono-grade oils. Fig 2 shows the overview of containing both the experimental values and predicted values of viscosity–temperature dependence in multigrade oils. Fig 3 shows the overview of containing both the experimental values and predicted values of viscosity–temperature dependence in Synthetic Oils.

Table 3: Empirical Modeling Equations

Grade	Equation ($Ax^2 + Bx + C$)
Monograde Sample A	$0.0530x^2 - 9.6383x + 451.4510$
Multigrade Sample B	$0.0466x^2 - 8.5663x + 409.1400$
Synthetic Sample C	$0.0412x^2 - 7.6647x + 374.4595$

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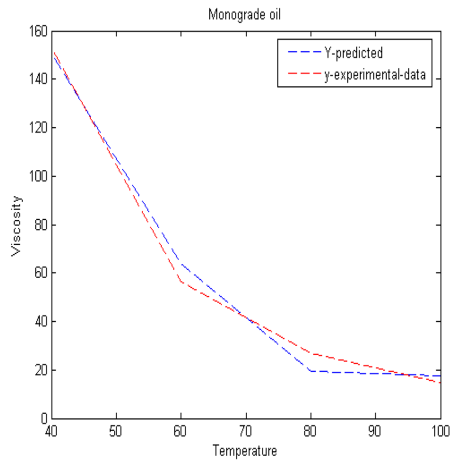

Figure 1: Variation of viscosity against temperature for Monograde Oil

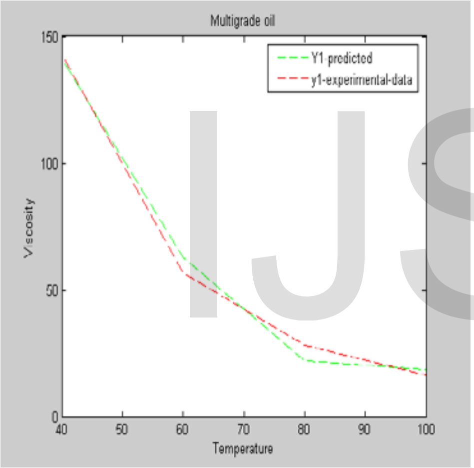

Figure 2: Variation of viscosity against temperature for Multigrade Oil

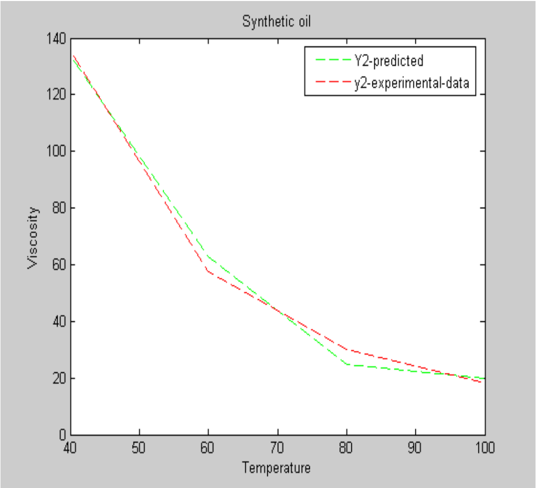

Figure 3: Variation of viscosity against temperature for Synthetic Oil

4.0 DISCUSSION OF RESULT

Kinematic viscosity as a function of temperature of three different synthetic, mono-grades and multi-grades oils was considered. It was obvious that Mono-grade oils have low resistance to increasing temperature, followed by Multi-grade oils while Synthetic Oils has the highest resistance to increasing temperature (Figures 1 to 3). It is also obvious that density (From Table 1) is not the ruling or determinative factor influencing viscosity. This effect can be explained by partially different chemical composition of individual oils Decrease in oil viscosity with increasing temperature was expected and corresponds with conclusions reported in literature. It is obvious that dependence is far to be linear. The reason can be explained as an effect of chemical processes occurring in the oil. It was observed that the reduction in viscosity for the mono-grade type of oil was rapid followed by the multi-grade for the natural/mineral type of oil, after which came the synthetic blend, showing that the synthetic blend had the highest resistance to temperature amongst all. A mathematical model gotten from the experimental data is proposed for better prediction of lubricant formulation and usage at different temperature ranges. A limitation was observed in the graphs as it was noticed, that the empirical model evaluation of viscosities varied from the experimental values obtained by range of value;

- (± 2 to 7 cSt), for Monograde oil
- (± 2 to 6 cSt), for Multigrade oil
- (± 2 to 5 cSt), for Synthetic oil

The variation was due to the fact that the number of experimental values used in deriving the

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model was small (the more the number of values, the lesser the error).

5.0 CONCLUSION

Three different lubricating oils were investigated for the variation of their viscosity with temperature changes in this study. Based on the Specific Gravity, Pour Point Flash Point, Water Content and Viscosity obtained for the three lubricants, the synthetic blend remained the best in terms of its light weight compared to other samples. It also had higher flash point, good pour point value, and the highest resistance to temperature compared to others. All this could be attributed to the stable chemical compositions and highly uniform molecular chains of synthetic base stocks and is therefore recommended for petrol engines over a wider range of temperature above the mineral blend. Comparisons of both lubricants are made as regards some of the quality control tests carried out on them, their viscosity, and the simultaneous dependence of their viscosity on temperature was recorded and compared resulting in experimental data in which a mathematical model obtained is used to propose a better prediction of lubricant formulation and usage at different temperature ranges. This variation as can be seen on the graph, comparing the empirical data's to the experimental data's was due to the fact that, the number of experimental values used in deriving the model was small as more number of experimental values lessens the error difference. In order to eliminate the slight limitation involved in the development of the empirical model, it's highly recommended that the viscosity variation with temperature be carried out over a wider range of temperatures in order to reduce the error difference.

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