To Study of Chain Length on Viscosity and Tribological Characteristics of Lubricants Condition

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Abstract - Polyisobutylene (PIB) is blended in mineral oil N150 in varying proportions of 2, 4, 6, 8,and 10 percentage to increase the viscosity index (VI) of the oil. This is the first successful attempt to calculate Viscosity from the structural parameters and rheological properties of mineral oil and the same is verified with the experimental results. First the specific volume of the lubricant blend is calculated form molecular weight and vander Waals volume. Then the viscosity has been calculated using specific volume, structural factor and friction factor. The calculated viscosity is then verified by the experimental viscosity and errors have been calculated. Several tribological tests using standard ASTM D 4172B and other stipulated conditions have been performed to assess the behavior of friction and wear of increased VIoil blends. It has been found that the viscosity increases were of the oil by addition of PIB and maximum increase in viscosity index is 14.37% for 10% blend. The calculated viscosity form structural and rheological parameters have maximum error of 8%. The tribological test shows that anti-friction and anti-wear properties of the lubricant enhanced by addition of PIB in N150 and for anti-wear performances 6% PIB in blend results minimum wear observed in this study.

Index Terms - Tribological Tests, - Polyisobutylene (PIB), vander Waals volume, viscosity index (VI).

I. INTRODUCTION

Some mechanical equipment needs lubrication, primary purpose is to reduce friction and wear. If these friction and wear is not controlled it can lead to inefficiencies, damage, and ultimately to equipment seizure [1]. Lubricants oil used in industry are formulated oils and comprise base stocks and performance additives. A slight alteration in base stock or additives can result in significant changes in lubricant performances; this emphasizes the need for a better understanding of lubricants. Viscosity is the prime factor for the lubricants' selection and influences physico-chemical properties which in turn affects its tribological performance. The lubricant molecules and the chain length have a profound influence on its viscosity. The lubricant viscosity increases with increase in macromolecule length, branch content, and branch length. The proper design of lubricant molecules can aid in formation of boundary films which can enhance the anti-wear and anti-friction properties. The viscosity can be measured by several types of viscometers, but it can also be calculated theoretically within reasonable errors from its structural parameters. Once all the structural parameters are known then the mathematical model can be formulated for a particular group of blends which can be used to predict viscosity of any branch content, chain length and temperature.

A lubricantis a substance introduced to reduce friction between surfaces in relative motion, and ultimately reduces the heat generated [2]. The property of reducing friction is known as lubricity. Almost all commercial lubricants are formulated oils that, they comprise base stocks and performance additives [1]. When present in the proper concentration, these components impart the formulated lubricant properties necessary to perform effectively in the intended application. In addition to performing the principle functions of lubrication, the lubricant also performs other functions such as cooling, containments suspension, corrosion protection, and power transfer; the lubricant must also fulfill additional functions that are unique to the application. The amount of additives in a lubricant can range between 1 to 25 %, or more, [1].

A lubricant's quality can depend upon the type of base oil used and refining and/or production method used to produce the base oil [3]. Lubricants base oil is used according to the specific requirements of service conditions e.g. within the engine oils, some base oil types work better for gasoline than for heavy-duty diesel application. All the additives react differently with different base oils; this is a good reason to formulate for specific applications by using different types of base oils. The base stocks used to formulate lubricants are generally of mineral (petroleum) or synthetic origin.

Approximately 95 percent of the current lubricant market share is comprised of conventional (mineral-based) oils. Mineral stocks are refined by a number of processes of selection from the crude oil barrel. They are of paraffinic, naphthenic and of aromatic types. Most favored are paraffinic crudes, which give a good, yield of high Viscosity Index (HV) stocks, although they also contain a lot of wax [1]. In certain applications, naphthenic crudes are preferred because they quality medium viscosity index

(MVI) and low viscosity index (LVI). Aromatic mineral oil is least preferred [1].

Synthetics can be made from petroleum or vegetable oil and are "tailor made" for the job they are expected to do. Synthetic processes enable molecules to be built from simpler substances to give the precise or desired oil properties required. Their viscosity indexes (VI) and flash points, however, are higher and their pour points are considerably lower. This makes them valuable blending components when compounding oils for extreme service at both high and low temperatures. The main disadvantage of synthetics is that they are inherently more expensive than mineral oils, and are in limited supply. Esters suffer the further disadvantage of greater seal-swelling tendencies than hydrocarbons so caution need to be exercised in using them in applications where they may contact elastomers designed for use only with mineral oils.

II. LUBRICANTS AND ADDITIVES

All metal surfaces, irrespective of their finish, contain ridges, valleys, asperities, and depressions. When two metal surfaces come in contact, they experience friction, and friction results in wear which leads to failure of the mechanical component hence it is said that all the mechanical component must be lubricated to decrease wear, energy consumption and increase service life of the component.

A. Lubricant selection criteria

A lubricant must possess the appropriate properties necessary to perform in a particular application. Desirable properties include the following:

(I). Viscosity (II) Fluidity Range (III) Viscosity-temperature Relationship (Viscosity Index) (IV) Low-temperature Fluidity (V) Oxidation Stability Inhibited (VI) Hydrolytic Stability (VII) Thermal Stability (VIII) Mineral Oil Compatibility (IX) Additive Solvency (X) Volatility (XI) Rust Control Inhibited (XII) Boundary Lubrication (XIII) Fire Resistance (XIV) Elastomer Compatibility, Especially with Buna Rubber (XV) Relative Cost.

B. Lubricants Classification

Lubricants are categorized by their service conditions, base stocks, additives and other useful features. The American Petroleum institute (API) has categorized base oils by their sulfur content, level of saturates, and Viscosity Index (VI). The first three groups are refined from petroleum crude oil. Group IV base oils are full synthetic (polyalphaolefin) oils. Group V is for all other base oils not included in Groups I through IV. Before all the additives are added to the mixture, lubricating oils begin as one or more of these five API groups.

C. Refinery Flow Process

The mineral oil is processed from the petroleum crude oil. There are several steps involved in the production of lubricants. Figure 2.1 shows the block diagram of the processes involve in conversion of petroleum crude oil in to useful finished products. The red arrows in the Figure 2.1 shows the specific processes involves in the production of the mineral oil in refineries. Distillation under atmospheric pressure removes the gases (propane, butane, etc.), gasoline fraction, and distillate fuel components, leaving a “lube oil fraction” containing the lube oil and asphalt. Further distillation under vacuum yields “neutral distillates” and an asphalt residue. Simple treatment with sulfuric acid, lime and clay turns the distillates into acceptable Low Viscosity Index stocks. For High Viscosity Index and Medium Viscosity Index stocks, some form of solvent extraction is necessary to remove colored, unstable and low-VI components.

III. THEORETICAL MODEL

A. Molecular Model

For applying the theoretical model for volume and viscosity calculation we first need to know the chemical composition of the mineral oil which we are using in this study. As we have already discussed that mineral base oil is the compound of paraffinic, naphthenic and aromatic in certain proportions but exact molecular structure is unknown. We are using data of molecular NMR, CHNS analyzer and GPC results extensively for approximating molecular structure. Table 3.1 shows the terminal groups and their percentages in the mineral oil N150 in NMR analysis. Table 3.1 gives there are 29.30% of terminal HCH_3 and 62.70% terminal HCH2 groups which accounts for 92% of total weight hence N150 have 92% paraffinic groups [31]. Table 3.2 gives the GPC analysis which shows number average molecular weight Mn and weight average molecular weight Mw.

Table 3.1 Molecular NMR analysis

Terminal groups	% of total weight
HCH_3	29.30
HCH_2	62.70

Hnaph	08.60

Table 3.2 GPC analysis

Sample Name	**Mn**	**Mw**
N150	495.0	521.0
PIB	2482	3971

Molecular weight of terminal CH3 groups in N150 = 145

Number of terminal CH3 groups = 9

Similarly for CH_2 groups

Total molecular weight of terminal CH_2 groups= 310

Number of CH_2 groups = 21

Hence it is evident from the above results there are 9 terminals CH_3 and 21 terminal CH_2 groups present in the mineral oil N150. Since N150 is 92% saturated paraffinic base oil hence it must have linear chain. Figure 3.2 gives the approximated molecular structure of N150.

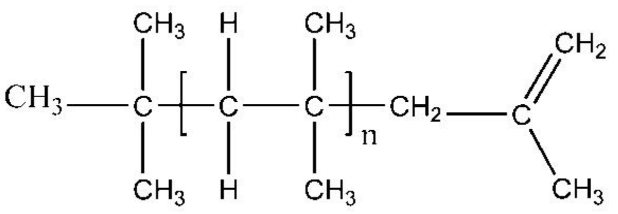

Figure 3.1 molecular structure of PIB.

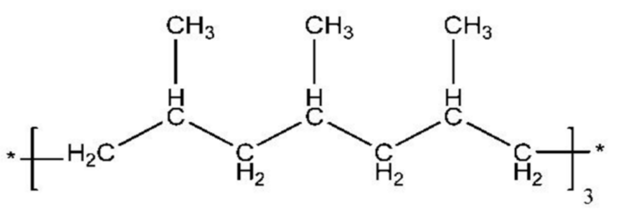

Figure 3.2 approximated molecular structure of N150 oil.

Figure 3.1 shows the molecular structure of the Polyisobutylene, it is evident from the PIB molecular structure that it has double bond at one end. The Pi bond of this double bond is weaker and hence it must break and make bond with any of the terminal methyl group of the mineral oil N150. Figure 3.3 shows the blend of PIB and mineral oil. The prime assumption in this bonding is that one PIB will attach to only one N150 since percentages of PIB is very less as compared to mineral oil in the blend. The alkyl length shows the number of carbon atoms in the backbone of PIB polymer. The pedant group represent which type of polymer is attached to the mineral oil. The degree of polymerization is the number of repeating units of the mineral oil.

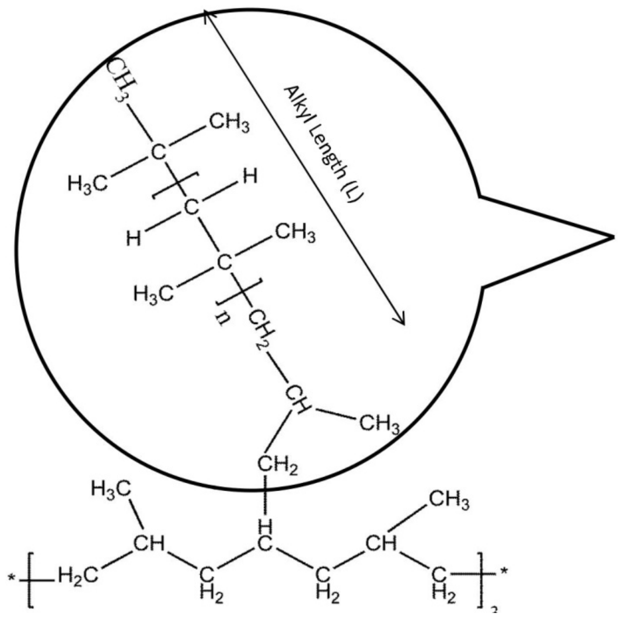

Figure 3.3 General Molecular structure of N 150+PIB depicting alkyl length(L), pedant group (J), and Degree of polymerization(DP).

IV. EXPERIMENTAL SETUP

A. Materials

- Synthesis of Polyisobutylene (PIB)

Liquid monomer of isobutylene was passed through neutral alumina column to remove the inhibitor from isobutylene. The isobutylene and catalyst (benzyl peroxide) were then used in the ratio of 1:10 for polymerization. 10 grams of isobutylene was then taken in 100 ml three necked flask in the presence of DMF (dimethyl formaide) and perched with nitrogen for 15 minutes at C to remove the oxygen from the flask. After 15 minutes one gram of benzyl peroxide was added and the solution was heated while continuous nitrogen perching for 1 hour to complete polymerization. The reaction mixture was poured in 100 ml methanol in a beaker to precipitate the polymer. After complete precipitation, polymer was separated from solvent. Liquid polyisobutylene was taken out from the flask. The as obtained PIB was characterized for its physic-chemical properties. We failed to synthesize polyisobutylene of smaller chain length, the synthesized PIB was blended in mineral oil but it settled after a week hence we have to buy the PIB.

- Mineral Base oil

A Group I mineral oil N-150 was obtained from IOCL refinery. The N-150 being medium viscosity base oil finds its application in development of various grades of industrial lubricants. The base oil was characterized for its physico-chemical properties using ASTM D standard test procedures.

B. Preparation of lubricant blends

The lubricant blends were prepared by mixing PIB in varying concentration in the mineral oil. The mineral oil and PIB were weighted according to their weight fraction in the beaker. The sample is then sonicated using ultrasonic bath till a clear homogeneous solution was obtained. The ultrasonic bath converts electrical oscillation to mechanical vibration.

- Experimental Details

This ultrasonic vibration blends the sample in 4 hours. The sample temperature increases around above the room temperature during sonication due to the mechanical vibration. The PIB was blended in 2%, 4%, 6%, 8% and 10% by weight to prepare the lubricant blends. Figure 4.1 shows the digital image for the mineral oil, PIB and the 6% blends of PIB in mineral oil.

Figure 4.1 The base oil (N150), additive (PIB) and the blend used in the study.

C. Characterization of Lubricants

The base oil, additive and the lubricant blends were characterized using various analytical techniques to determine the chemical constituents, structure and molecular mass of the components. The chemical characterization techniques such as CHNS, GPC and NMR were extensively used to determine the chemical composition and other relevant information about the lubricant and additives.

The viscosity of the lubricant blends was determined using Stabinger viscometer. The change in viscosity with the concentration of additive and the influence of temperature on the viscosity of the lubricant was efficiently studied over a wide range of temperature.

The lubricant blends were later characterized for their tribo-performance on a four ball tribo-tester. The influence of operating parameter such as load, speed and temperature on the tribo-performance of the lubricant blend was investigated. Also the influence of additive concentration on the tribo-performance of the lubricant blends was analyzed.

D. Tribo-performance investigation

The tribo-performance of lubricant blends has been performed on a four-ball tribo tester. The experiments have been performed as per standard ASTM D: 4172B procedure. Further, simulation tests were performed to determine the influence of operating condition and the concentration of the additive on the antifriction and anti-wear behavior of the lubricant blends. The wear-scars developed on the used test specimens were later investigated through the optical chromatic microscope.

- Four ball tribo-tester

The four-ball tribo-tester as shown in figure 4.2, utilizes a tetrahedral geometry in which the top ball forms a sliding contact with the bottom three balls.

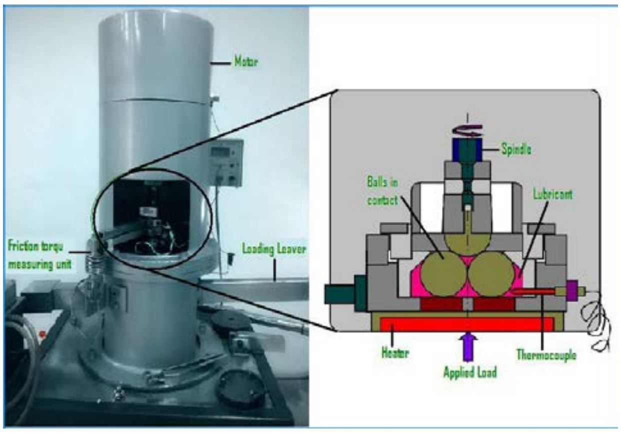

Figure 4.2 Four ball tribo-tester.

The bottom three balls are immersed in the lubricating oil to be tested. The top ball is held into the chuck and rotated at a desired speed with the help of an electric motor. The bottom three balls are held fixed in position against each other in a steel cup by means of a clamping ring and locking nut.

The cup assembly is supported on the load lever with the help of a disk resting on a thrust bearing thus allowing automatic alignment of the three bottom balls against the top ball. The lubricant samples were filled in the cup and the load was applied through the loading lever. The resistive rotational torque acting on the spindle was continuously measured and converted into frictional force. The anti-wear behavior of the lubricant sample is reported in terms of wear scar diameter (WSD) obtained on the balls. The WSD was measured at the end of the tests with the help of optical microscope.

The experiments were performed on standard steel ball specimens fabricated using AISI Standard Steel No. E-52100. The balls are of 12.7mm diameter and possess hardness of Rockwell C 64-66.

E. Experimental Procedure

The tribological tests for the assessment of friction and wear behavior of PIB and mineral oil blend were performed under fully flooded EHL conditions on a four-ball. Experiments were performed as per the standard ASTM D: 4172B procedure and simulated load, speed and temperature conditions on the four ball tribo-tester. The ASTM D: 4172B procedure is a generalized procedure to assess the wear performance of lubricating oils under severe loading conditions of 392N. In most of the cases under such severe loading the surfaces were out extensively and therefore the lubricating capabilities of lubricant and additive cannot be assessed. Hence, in the present case along with the ASTM D: 4172B procedure the experiments were also performed under simulated conditions. The test parameters employed for the four ball tests are as given in Table 4.1.

Table 4.1 the test parameters employed for the four ball tests.

Test parameter	**Characteristic values**	
	ASTM D: 4172B	**Simulated Conditons**
Load, N	392	98,196
Speed, RPM	1200	600, 1800
Lubricant temperature, ^{0}C	75	25, 50
Test duration, min.	60	60

V. RESULTS AND DISCUSSION

The theoretical model presented in chapter 3 has been used to predict the viscosity of the lubricant blends. The information required for the solution of the model parameters were obtained experimentally using chemical characterization techniques. The theoretical results thus, obtained were validated using experimental data obtained through the viscometer. Further, to have an insight on the significance of the additive on the tribological performance, various experiments were performed on four ball tribo-tester. This section deals with the results obtained from the theoretical and experimental procedures followed.

A. Physico-chemical characterization

The physico-chemical property of base oil is given in table 5.1 from the table it is clearly observed that the N-150 base oil is medium viscosity grade oil with a low temperature viscosity of 33.72 mm2/s.

Table 5.1: Physico-Chemical Properties of N150.

Properties		**Method**	**Result**
Density @	C (g/ml)	ASTM D 4052	0.843
K.V @	C (mm^{2}/s)	ASTM D 445	33.72
K.V @	0C (mm^{2}/s)	ASTM D 445	5.56
Viscosity Index		ASTM D 2270	115
Total Acid Number (mg KOH/g)		ASTM D 664	0.002
Pour Point (^{0}C)		ASTM D 97	-21

The base oil as such has a high VI of 115 suitable to be used in the formulations of industrial lubricants.

The PIB was obtained from M/s. KUNTAL organics LLP. The physico-chemical characteristic of PIB is given in Table 5.2. The PIB being a polymer has a higher viscosity value of 4500-4900 mm2/s at 100°C. Further the additive also contains some small traces of sulphur which has got a very good lubricity property.

Table 5.2: Physico-Chemical Properties of PIB.

Properties		**Test Method**	**PIB**
K.V@	**C (mm^2/s)**	ASTM D445	4500-4900
Acid value (mgKOH/g)		ASTM D974	0.01 max
Flash Point ^{0}C		ASTM D92	Min 250
Total Sulphur (Wt-ppm)		ASTM D2785	Max 1.0
Water (Wt-ppm)		ASTM D6304	Max 40

B. The Model parameters

Table 5.3 lists the lubricant type, and structures, specific volume, and viscosity for all of the fluids tested. The molecular structure information is listed according to the general mineral oil blend diagram in figure 6. Column 1 shows the sample name M.O (mineral oil) and its blend. Ø represent percentage of molecules of mineral oil containing PIB pedant group. Where L represents the chain length of pedant group and J represents pedant group. Z represents the number of carbon atoms in the backbone of mineral oil. Specific volume and viscosity column gives the measured specific volume and viscosity from the viscometer.

Table 5.3 Molecular structure, Sp. volume, and viscosity of the lubricant and blend examined in this study.

Molecular structure					**Sp. Volume**	**Viscosity**
Sample	**Ø**	**L**	**J**	**Z**		
M.O	0	0	0	21	1.153668	33.72
M.O+2%PIB	2	45	PIB	21	1.151277	39.486
M.O+4%PIB	4	45	PIB	21	1.150350	46.631
M.O+6%PIB	6	45	PIB	21	1.149954	55.701
M.O+8%PIB	8	45	PIB	21	1.149557	66.569
M.O+10%PIB	10	45	PIB	21	1.148633	78.752

C. Volume Variation with Branch Contents

]Table 5.4 lists the masses and van der Waals volumes of functional monomers. The monomer types include pure mineral oil and blend functional monomer. The mass of the monomeric constituents are summations of the atomic masses of the constituents. The van der Waals volume of the monomers listed in the table 5.4.

Table 5.4 molecular masses and Van der Waals volume of blend monomeric constituents

Monomer	**g/mol)**	**)**
Mineral oil	420.0	524.920

Table 5.5 lists the species specific molecular packing factor values (x, j) for the blends studied in this contribution equation (3.5).

Table 5.5 Molecular packing factors for the blend constituent studied in this work

Molecular Packing Of Monomers		
Monomer	x	j
Mineral oil	1.54	0
PIB blend	1.674	-0.2

D. Viscosity Variation Structure

Table 5.6 lists the structural parameters of the Berry and Fox equation, monomeric friction coefficients. The radii of gyration are calculated by using Flory Exponent [32]. The monomeric friction factors are calculated form the measured volume, viscosity, and radii of gyration. The data from the Table 5.6 shows monomeric friction factor which increases when the polymer is added into the mineral oil.

Table 5.6 functional monomers' viscosity-molecular structured parameters for the Berry and Fox equation

Monomer	(m.Pa . s)
Mineral oil	-6.4168
PIB blend	-5.0681

E. Viscosity Variation with Temperature

Among the Vogel, Reynods, and Walther's equation used in this study it is observed that the Walther's equation gives accurate relationship with minor adjustment with constant.

Figure 5.1 depicts the viscosity-temperature relationship of the different blend and their percentage of branch contents, the graph is plotted form to temperature. Fig 5.1 is the representation of Walther's equation of temperature and viscosity relationships which has been plotted by using matlab software. Table 5.7 depicts the viscosity index increase with increase in branch content of PIB. For pure mineral oil the viscosity is 106.726 and it increase to 121.237, a total of 13.60% increase in VI for branch content 10%.

Volume is calculated by using equation form 3.1 to 3.6, equation 3.5 is used fit the data of specific volume measured for the monomer using specific packing factor values (x,j) in an empirically derived equation. Table 5.8 gives the specific volume which is calculated theoretically and experimentally.

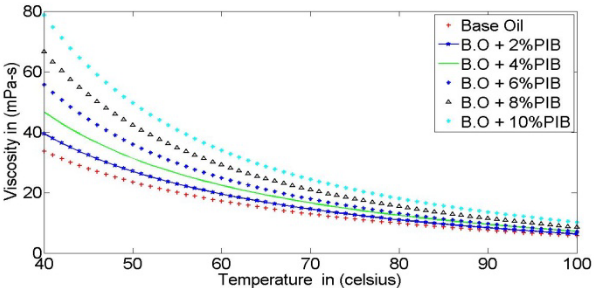

Figure 5.1 Fig 5.1 viscosity Temperature Relationship.

Table 5.7 Increase of Viscosity Index with increase of branch content of PIB.

Lubricant Sample			**VI**
Mineral Oil	33.72	5.6633	106.726
M.O+2%PIB	39.486	6.299	107.279
M.O+4%PIB	46.631	7.1618	112.874
M.O+6%PIB	55.701	8.1905	116.799
M.O+8%PIB	66.569	9.4083	120.018
M.O+10%PIB	78.752	10.673	121.237

Table 5.8 theoretical and experimental values of sp. volume.

Sample	**Sp. Volume**	**Sp. Volume**
	(theoretical)	**(Experimental)**
Mineral Oil	1.15368	1.15367
M.O+2%PIB	1.15255	1.15128
M.O+4%PIB	1.15143	1.15035
M.O+6%PIB	1.1503	1.14995
M.O+8%PIB	1.1491	1.14956
M.O+10%PIB	1.14805	1.14863

Table 5.9 gives the viscosity and intermediate steps in viscosity calculation. After the specific volume is calculated by the equation 3.7 to 3.12 is used in calculation of viscosity. Table 5.10 shows the error percentage in calculation of viscosity by structural approach.

F. Tribo-performance of PIB polymer fluids

The tribological performance behavior of PIB polymer and base oil has been experimentally carried out under variation of speed, temperature, and load. The tribo-performance of the lubricant blends reveals that there is significant reduction in friction for the successive increase of branch content of PIB in mineral oil. The friction is higher in case of base oil and decreases with the increase in concentration of PIB polymer, and the wear first decreases and then increases when increase of PIB in the blend.

- Effect of Load

The effect of load on mineral oil blend was investigated through varying load from 98 N to 392 N. Figure 5.2, 5.3 and 5.4 shows that the co-efficient of friction decreases as the percentage of PIB in lubricant oil increases.

Table 5.9 Important values for theoretical viscosity.

Sample	Xc	volume	F(X)		
Mineral Oil	5.60E-15	1.153679	87163023	3.83E-7	33.40
M.O+2%PIB	5.60E-15	1.152553	68465069	5.4634E-7	37.41
M.O+4%PIB	5.60E-15	1.151427	64295124	7.0968E-7	45.62
M.O+6%PIB	5.60E-15	1.15030	62380304	8.7302E-7	54.45
M.O+8%PIB	5.60E-15	1.14911	61207148	1.03636E-6	63.43
M.O+10%PIB	5.60E-15	1.14805	60364557	1.1997E-6	72.42

Table 5.10 Error in theoretical and experimental viscosity.

Lubricant	Viscosity	Viscosity	Error %
Sample	**(theoretical)**	**(Experimental)**	
Mineral Oil	33.40	33.72	0.9489
M.O+2%PIB	37.41	39.486	5.2501
M.O+4%PIB	45.62	46.631	2.1681
M.O+6%PIB	54.45	55.701	2.2450
M.O+8%PIB	63.43	66.569	4.7154
M.O+10%PIB	72.42	78.752	8.0404

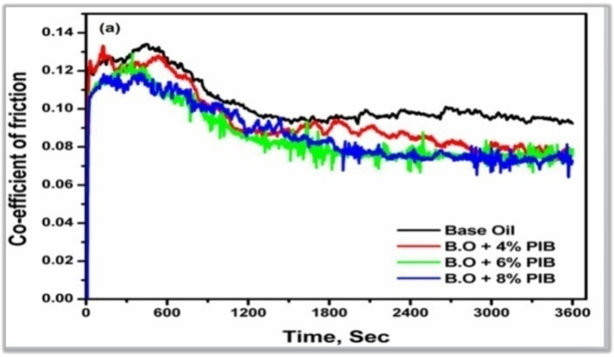

Figure 5.2 Co-efficient of Friction behavior of samples for 98N load.

- Effect of Temperature

The effect of temperature on mineral oil and PIB blended lubricating oil were investigated through varying temperature from 250 C to 750 C. It is observed from figure 5.6, 5.7 and 5.8 that the co-efficient of friction decreases gradually with increasing percentage of branch content in blend which is less than that of mineral oil. The average of coefficient of friction at different temperature is shown in the Table 5.12.

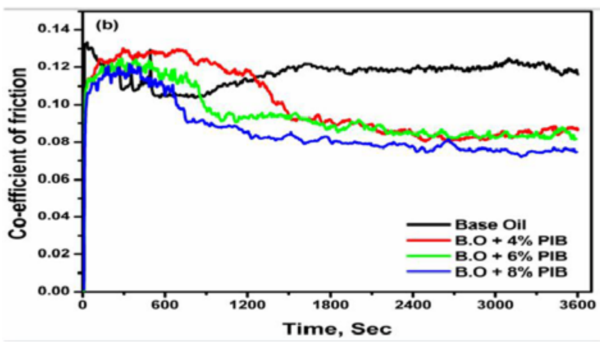

Figure 5.3 Co-efficient of Friction behavior of samples for 196N load.

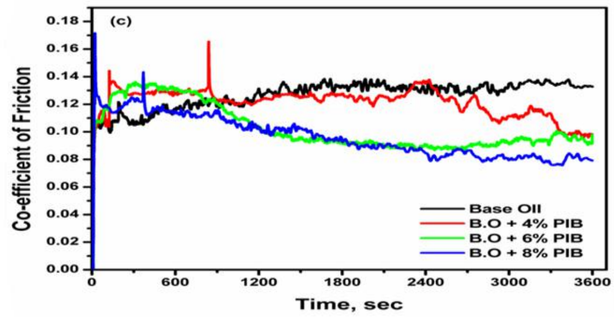

Figure Co-efficient of Friction behavior of samples for 392N load.

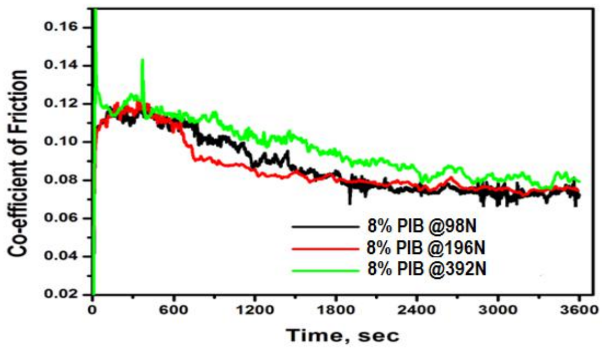

Figure 5.5 Co-efficient of friction of 8%PIB at 98, 196,392 N loads.

Table 5.11 gives the average coefficient of friction data of the graphs drawn for different loads.

Table 5.11 average of all COF at different loads

Load, (N)	C.O.F of M.O	C.O.F of	C.O.F of	C.O.F of
		M.O + 4 % PIB	M.O + 6 % PIB	M.O + 8 % PIB
98	0.11612	0.07955	0.7722	0.07743
196	0.11928	0.0867	0.08178	0.07861
392	0.13289	0.09777	0.09148	0.0791

Table 5.12 average of COF at different temperature

Temperature	C.O.F of M.O	C.O.F of	C.O.F of	C.O.F of
^{0}C		M.O + 4 % PIB	M.O + 6 % PIB	M.O + 8 % PIB
25	0.11928	0.07955	0.07722	0.07719
50	0.12231	0.08562	0.07994	0.07868
75	0.13289	0.09777	0.09148	0.0791

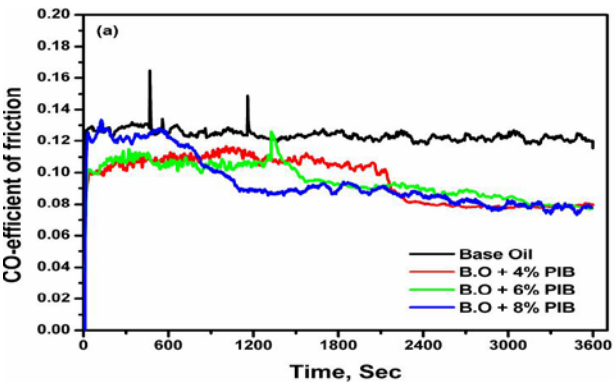

Figure 5.6 Co-efficient of Friction behavior of samples for 250C Temperature.

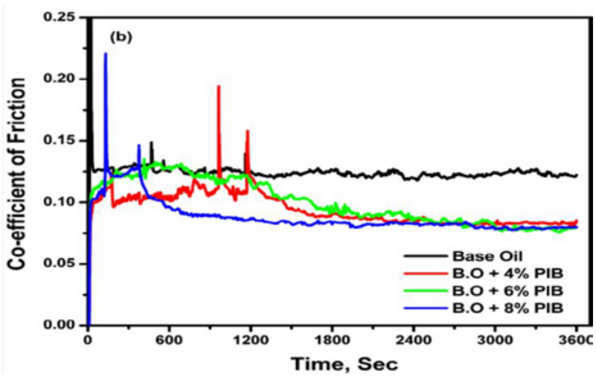

Figure 5.7 Co-efficient of Friction behavior of samples for 50^{0}C Temperature.

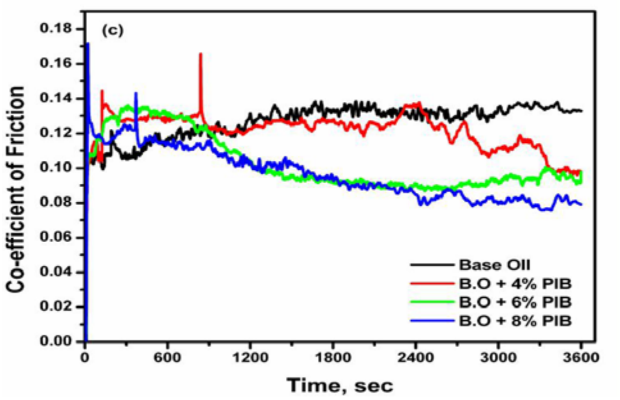

Figure 5.8 Co-efficient of Friction behavior of samples for 75^{0}C Temperature.

Figure 5.9 show that the increase of branch content in mineral oil decreases the co-efficient of friction. The fig shows the COF behavior of 8% PIB in mineral oil at temperature of 250C, 500C, and 750C versus time.

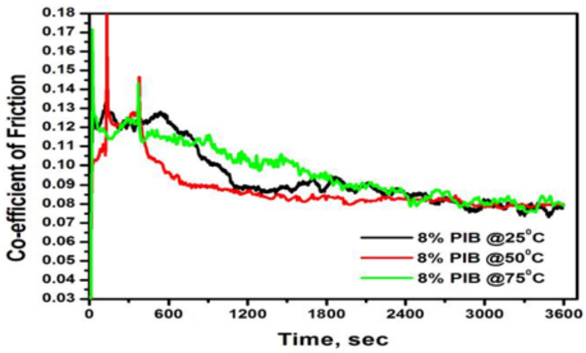

Figure 5.9 Co-efficient of friction of 8%PIB at 25, 50,750C Temperature.

- Effect of Speed

The effect of speed on mineral oil and PIB blend was investigated through varying speed from 600 rpm to 1800 rpm. It is observed from figure 5.10, 5.11, 5.12 that the co-efficient of friction decreases slightly with increasing percentage of branch content in blend which is less than that of that of mineral oil.

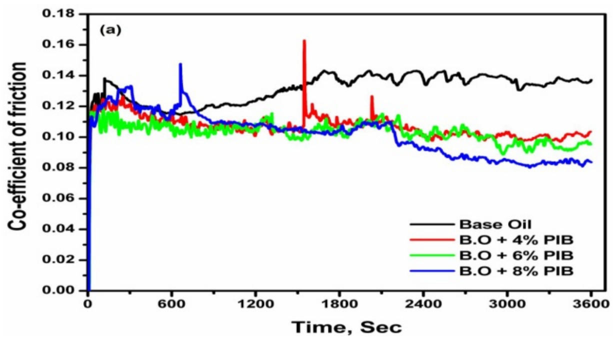

Figure 5.10 Co-efficient of Friction behavior of samples for 600 RPM.

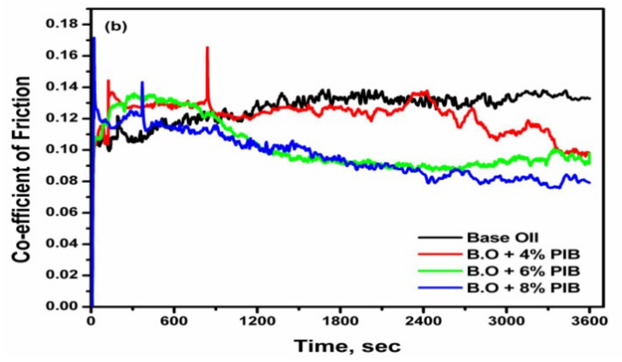

Figure5.1 1 Co-efficient of Friction behavior of samples for 1200 RPM.

Table 5.13 average of COF for different speed.

Speed (RPM)	C.O.F of	C.O.F of	C.O.F of	C.O.F of
	M.O	M.O + 4 %	M.O + 6 %	M.O + 8 %
		PIB	PIB	PIB
600	0.13127	0.094361	0.09529	0.07843
1200	0.13289	0.09777	0.09148	0.0791
1800	0.13476	0.12398	0.11931	0.1166

Figure 5.12 shows co-efficient of friction increases with increase with rpm, between 600 and 1200 rpm there is very slight increase in coefficient of friction but at 1800 rpm it shows significant increase in co-efficient of friction the theory behind this is that at high rpm the temperature of the oil increase and shear thinning takes place which leads to the exposer of more asperities in contact so increasing the co-efficient of friction.

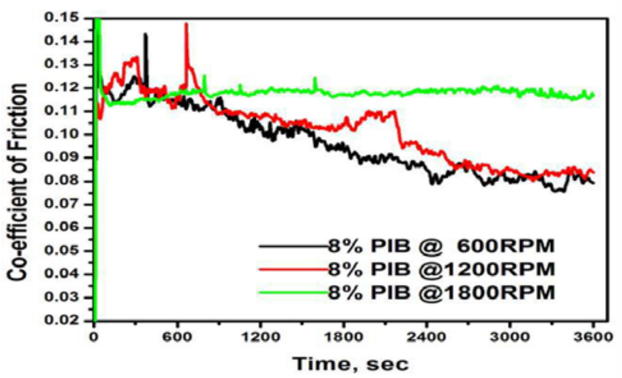

Figure 5.12 Co-efficient of friction of 8%PIB at 600, 1200, 1800 RPM.

F. Wear behavior of blended PIB in mineral base oil at different concentration

Our type of lubrication falls under mixed lubrication and EHL region. In this region the there are two predominant theory associated for the wear.

It is evident from the figure 5.13, 5.14, 5.15 that the Wear Scar Diameter (WSD) of the PIB blend in mineral oil is less than that of the pure mineral oils.

- Effect of Speed

Wear is directly proportional to speed (RPM), at low rpm wear is less as we can see from Figure 5.14 that the wear between 600 and 1200 rpm the slope is very less but between 1200 and 1800 rpm the slope increases rapidly.

Table 5.14 tabulated values of WSD for speed variation of samples

Speed	Base Oil	B.O+4%PIB	B.O+6%PIB	B.O+8%PIB
600	0.0891	0.8383	0.7645	0.80511
1200	0.9193	0.8943	0.8273	0.87118
1800	1.311	1.14	1.1311	1.2115

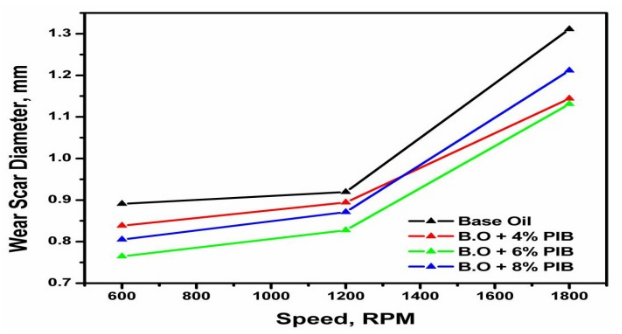

Figure 5.13 Wear Scar Diameter for the speed variation.

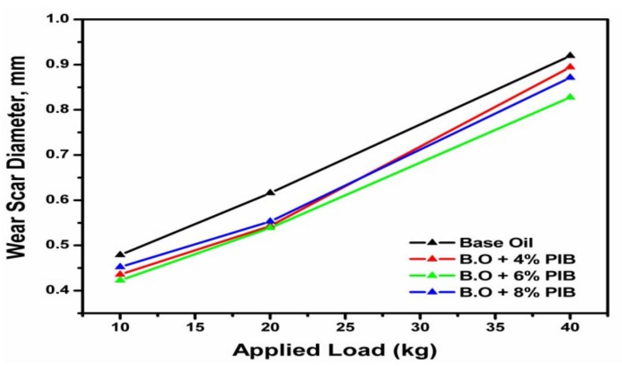

Figure 5.14 Wear Scar Diameter for the load variation.

- Effect of Load

Wear is directly proportional to the applied load as the load increases the wear also increases. The slope form 98 N to 392 N loads for mineral oil is almost constant but it increases gradually form 98 N to 392 N for blended oil.

As the normal load increases the lubricant squeezed out and more asperities comes in contact and the wear increases. It is evident from Figure 5.15 that the wear blended oil is less than that of pure mineral oil.

Table 5.15 tabulated values of WSD with Load variation of samples

Load	B.O+4%PIB	B.O+6%PIB	B.O+8%PIB
98	0.4355	0.4226	0.4521
196	0.543	0.5388	0.5532
392	0.8943	0.8273	0.87118

- Effect of temperature

The wear is directly proportional to the rise in temperature. The slope of lines remains almost similar throughout the test temperature. The test was carried out from temp of 250C to 750C and it is evident from Figure 5.15 that the performance of blend is better than that of the pure mineral oil.

Table 5.16 tabulated values of WSD for temperature variation of samples.

Temperature ^{0}C	Base Oil	B.O+4%PIB	B.O+6%PIB	B.O+8%PIB
25	0.8668	0.7097	0.7051	0.73112
50	0.8985	0.7801	0.7735	0.79885
75	0.9193	0.8943	0.8273	0.87118

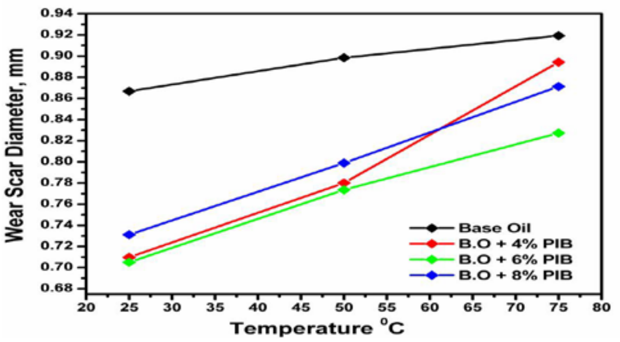

Figure 1.15 Wear Scar Diameter for the Temperature variation.

After the four ball tribo-tester the balls are taken out and observed under optical microscope and the wear scar diameter (WSD) is measured. Figure 5.17 shows the WSD of the sample studied in this work.

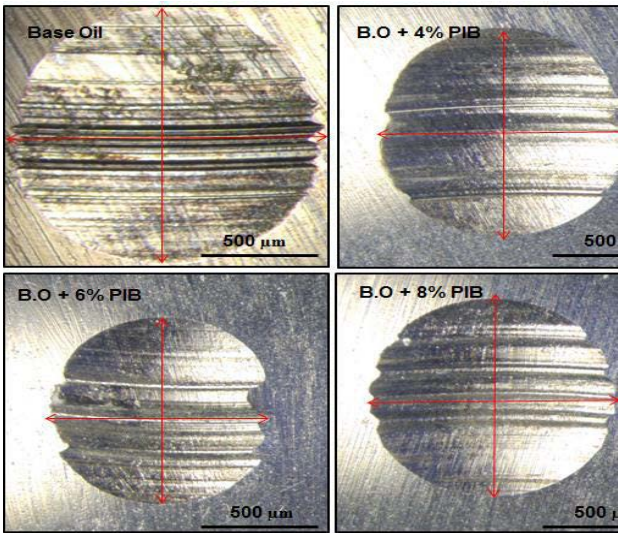

Figure 5.16 Wear Scar Diameter for the samples at ASTM D: 4172B conditions

VI. CONCLUSIONS AND FUTURE WORK

The study result describes a modeling system that link blends of mineral oil (N150) and PIB to their molecular structures and a method to calculate the rheological properties of them from their molecular structures. Using a combination of several established model, the volume, viscosity, and temperature viscosity relationship can be determined from molecular features such as branch types, contents, and degrees of polymerization. The four ball tribotester gives the Tribological properties of the mineral oil and its blends. The present study is focused only on the Mineral oil N150 and PIB blends for specific volume, viscosity and several other tribological characteristics. In further studies the focus will be on variation of chain length and degree of polymerization of PIB, and several other olefins such as Poly(methyl methacrylate) PMMA, before concluding the research.

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