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Effect of Temperature on the Viscosity and Density of Tyre Pyrolytic Oil – Diesel Blends: An Alternate Fuel

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Abstract: Tyre Pyrolytic Oil (TPO) is a renewable fuel, produced from scrap tyres by means of pyrolysis, thereby solving the problem of waste tyre disposal. The straight use of TPO or TPO-diesel blends as a fuel in diesel engines initiates adjusting certain physical properties such as density and viscosity for certain samples. Hence by adequately heating these samples in particular, before introducing to the engine, its physical parameters can reach value very close to that of diesel fuel, thereby facilitating a comparison with diesel fuel properties. In this study the viscosity of several sample of TPO and TPO-diesel blends were studied within a wide variety of temperatures. For testing the viscosity of samples, a Redwood viscometer no 2 was employed and the densities using a weighing machine and measuring jar apparatus. The test results were analyzed to adjust the density and viscosity values of the TPO and its blends with that of other fuels currently being used in diesel engines.

Keywords: Tyre Pyrolytic Oil, Viscosity, Density, Temperature

I. INTRODUCTION

The global initiative to find an alternate fuel for automobile engines due to the diminishing reserves and price instability of the world's petroleum fuels lead to the inception of bio-fuel researches. The first generation bio fuel consists of vegetable oils and their methyl esters. The second generation includes non-edible feed stock oils and recycled waste oils. Tyre Pyrolytic Oil is a second generation bio-fuel obtained through pyrolysis followed with distillation of waste tyres. Pyrolysis is a simple method to convert waste automobile tyres in to value added products. In pyrolysis, long chain polymers are thermally broken down at high temperatures (300-900 °C) into small molecules in the absence of oxygen. The recovered TPO obtained through distillation is a mixture of paraffins, olefins and aromatic compounds. It is dark-brown liquid and has considerable heating value. Its properties are similar to those of diesel [1]. Complete elimination of diesel by the use of bio-fuels is still a matter of doubt. It is due to the dissimilarities in physical and chemical properties of bio-fuels to that of gasoline and diesel. Properties like viscosity and density are crucial in determining the potential use of bio-fuels in CI engines. Viscosity affects injector lubrication and fuel atomization. Fuels with low viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps or injector plungers resulting in leakage or increased wear. Fuels which do not meet viscosity requirements can lead to performance complaints. Fuel atomization is also affected by fuel viscosity. Diesel fuels with high viscosity tend to form larger droplets on injection which can cause poor combustion and increased exhaust smoke and emissions.

The kinematic viscosity of bio-fuels is significantly influenced by compound structure. Influencing factors are chain length, position, number, and nature of double bonds, as well as nature of oxygenated moieties. Kinematic viscosity increases with chain length of either the fatty acid or alcohol moiety in a fatty ester or in an aliphatic hydrocarbon [2].

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Federico Millo et al [3] have conducted the study on effects of different bio-fuels blends on performance and emissions of an automotive diesel engine. He observed that for short injection events the transient behavior of the injector can be significantly affected by the fuel density, viscosity, and bulk modulus. Various authors studied temperature dependence of density and viscosity of biodiesel derived from vegetable oils. Mohankumar Chinnamma et al [4] have conducted viscosity analysis of Coconut Methyl Ester (CME) oil. Viscosity of CME was found close to that of diesel when compared with other methyl esters of plant origin. The similarity observed in the viscosity of CME with diesel strongly indicates the smooth operational power of the fuel. Bernat Esteban et al [5] have conducted a study of temperature dependencies of density and viscosity of vegetable oil. Results show that the analyzed vegetable oil requires preheating to 120^{0}C minimally to match the physical properties of automotive diesel fuels. R Vellinayagam et al [6] has analyzed feasibility of using less viscous fuels in diesel engine. He shows that alcohol, Eucalyptes and pine oil has low viscosity because they don't cause any fatty acids and their carbon chain lengths are relatively shorter. A Corsini et al [7] analyzed the viscosity of Rapeseed Oil and discovered that it has to be heated upto 90^{0}C to obtain properties similar to that of diesel fuel. Magin Lapuerta et al [8] experimented the blending scenarios for soybean oil derived bio fuels. He observed that the high viscosity has been correlated with poor fuel atomization and deposit formation in the combustion chamber, the narrower variation range of 20% biodiesel blends can be considered as an advantage. Thus most of the bio-fuels need to be preheated or blended with diesel to reduce their viscosity before using in CI engines. TPO has a different composition compared to the normal range of bio-fuels derived from edible feedstock. It consists of C, H, O, N and S containing organic compounds and water. The organic compounds range from C_5 to C_{20}. Pyrolysis oil thus contains fractions of volatility consistent with gasoline, kerosene and diesel. However their viscosity may vary with different distillate streams. As a result, the TPO was tried as an alternative fuel in both Spark Ignition (SI) engines and Compression Ignition (CI) engines. Bhatt et al [9] have studied the suitability of TPO as a fuel to be used in IC engines. According to their research about 190 million tonnes of tyres are produced each year in India alone. They analyzed the properties of TPO and concluded that it can be used as a fuel for industrial furnaces and boilers in power plants due to their high calorific value, low ash and Sulphur content. But TPO has higher density, kinematic viscosity and lower cetane value compared to that of diesel. This limits its use as a fuel in IC engines. They proposed to use TPO blended with diesel fuel in various proportions by volume keeping the blend quality under permissible limits. Kinematic viscosity of the tyre oil is 6.3 cSt at 40^{0}C which is slightly higher than the limits specified for Euro IV diesel fuel. Bhatt Prathmesh M et al [10] has conducted a study on suitability of TPO in IC engines. His results shows that, higher density and kinematic viscosity of tyre oil suggests behavior of TPO in IC engines and by blending TPO with diesel in various proportions keeping the blend quality within the permissible limit of Euro IV diesel requirement. Rajesh Abburi et al [11] tested the viscosity of TPO and compared with diesel and found that TPO has higher viscosity than diesel, a performance test is conducted on a single cylinder four stroke naturally aspirated water cooled engine and found that 20% TPO blended with diesel have high BTE[2] and 30% TPO blended with diesel have higher mechanical efficiency. Only a limited number of studies have been previously performed to investigate the temperature dependence on kinematic viscosity of TPO and its blends.

The aim of this paper is to obtain insightful knowledge about the temperature dependencies of the critical physical parameters, such as density and viscosity of commercial TPO and its blend with diesel. The results presented in this study will allow adjusting the density and viscosity values of the TPO and its blends with that of other fuels currently being used in diesel engines.

FUEL SAMPLES

Tyre pyrolysis process is the anaerobic thermal digestion of rubber tyre which leads to break down of hydrocarbon bonds in rubber leading formation of vapours with new hydrocarbon structures. This group of vapours has condensable and non-condensable components. They are lead to a condenser where the condensable components form liquids and non-condensable part remains as gases. Condensed liquids are combustible and are stored separately. The TPO thus obtained after this process is subjected to fractional distillation and various samples are taken based on distillation temperature. For the present investigation we have collected TPO sample of different distillate streams P1, P2 and P3 as follows:

P1 - 180^{0}C - 225^{0}C, P2 - 225^{0}C - 275^{0}C, P3 - 275^{0}C – 300^{0}C

For the present investigation three samples of Tyre Pyrolytic Oil (TPO) at different distillation temperatures was collected from a commercial Pyrolytic plant. The properties of the samples are listed in table1.

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Table 1: Properties of TPO samples.

Sl NO:	PARAMETERS	P1	P2	P3
1	Distillation temperature(^{0}C)	180 - 225	225-275	275-300
2	Density (g/cc)	0.82	0.86	0.92
3	Gross Calorific Value (kcal/kg)	10577	10392	10684
4	Flash Point (^{0} C)	38	54	131
5	Sulphur as S (%)	0.08	0.10	0.11
6	Ash Content (%)	0.01	0.02	0.0
7	Acidity	0.45	0.38	0.42
8	Water Content (%)	0.04	0.10	0.08

Selected samples were blended with diesel in different proportions (30%, 40%, 50%, 60% and 70%). 30% of sample P1 blended with 70% diesel is designated as P1B30. Other samples are also designated in similar way. The viscosity and density variations of these samples for different temperatures were analyzed.

II. EXPERIMENTAL SETUP

In this study samples of TPO and its blends with diesel were analyzed. Automotive diesel fuel was also included in the analysis. Originally Redwood viscometer no 2 was developed for measurement of viscosity of petroleum products. Redwood viscometer determines the viscosity in terms of seconds, a time taken by oil to pass through a standard orifice and collection of the same oil in 50 cc flask. The complete outfit comprises of stainless steel bath having drain plug with electrical heating arrangement with tap, silver plated oil cup, precision stainless steel jet, ball valve, cover thermometer clip, stirrer and suitable stand with leveling screws.
Inorder to find out the viscosity of the sample we have to obtain the flow time for a fixed volume of liquid in viscometer that can be measured with the aid of stopwatch and measuring jar. The viscometer has been calibrated by the manufacturer and the calibration constant C and B are supplied with the instrument. The viscosity is obtained from the following equation:

$$\upsilon = Ct - \frac{B}{t}$$

υ - Kinematic viscosity in centistokes (cSt), t – Flow time in seconds of fixed volume of liquid in viscometer at the test temperature., C = 0.26 cSt/sec, constant of viscometer , B = 172, an experiment constant in centistokes second. Additionally, a weighing balance and a measuring flask were used to measure the density of the various samples. A fixed volume of sample at different test temperatures was collected and weighed in the weighing balance. The temperature of the oil bath was adjusted from 300^{0}C to 800^{0}C. Both viscosity and density were measured within the temperature interval.

III. RESULTS AND DISCUSSIONS

One of most important properties of biodiesel is kinematic viscosity. The experimental values thus obtained for different fuel samples and its blends are discussed below. Results show that there is change in viscosity values over different blend proportions. According to Krisnangkura et al. [12] viscosity may be considered the integral of the interaction forces of molecules. When heat is applied to fluids, molecules can then slide over each other more easily making the liquid to become less viscous. From the table of each sample P1, P2 and P3, it is seen that the viscosity value decreases with the rise in temperature. Whereas a slight variation was observed in density for a wide ranges of temperatures. At room temperature, the molecules are tightly bound together by attractive intermolecular forces and this force is responsible for the viscosity. The increase in temperature causes the kinetic energy to increase and the molecules become more mobile. Hence the attractive binding energy is reduced and therefore the viscosity is also reduced. We cannot heat the TPO samples to a higher temperature because the kinetic energy will exceed the binding energy and it can become vapour. The experimental results that have been obtained is discussed below. By standards the viscosity of diesel varies in the range of 2-4 cSt. For the present study diesel fuel having a viscosity of 2.24 cSt has been used for comparison of TPO samples.

4.1 Sample P1

Table2 shows the variation of kinematic viscosity and density with temperature for the TPO sample P1 and its blends that are in the ratios B30, B40, B50, B60 and B70. The test has been conducted for a temperature range of 30^{0}C – 80^{0}C.

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Table 2: Viscosity and Density values of sample P1

Property	Temperature (^{0}C)	Sample P1					
		B30	B40	B50	B60	B70	B100
Kinematic viscosity (cSt)	30	2.468	2.77	2.81	3.03	3.2	4.1
	80	0.847	0.99	1.422	0.699	1.516	2.246
Density (g/cc)	30	0.82	0.82	0.82	0.82	0.84	0.84
	80	0.78	0.80	0.78	0.78	0.8	0.78

By analyzing the values of sample P1, it is observed that at room temperature the viscosity value of sample P1 is 83% higher than that of diesel and for the lower blending ratio sample that is P1B30 , it is 10.17% higher than that of diesel fuel.

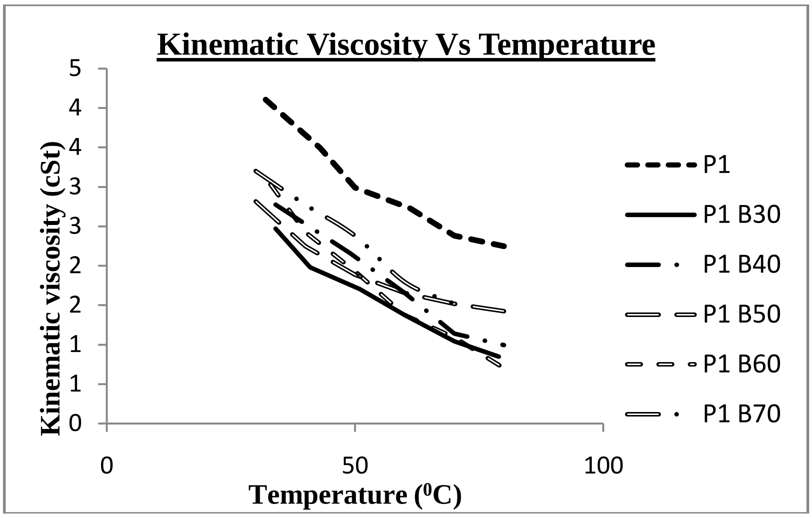

Figure 1: Kinematic viscosity variation of sample P1 with temperature.

Figure1 shows the graphical representation of variation of kinematic viscosity with temperature. On comparing the kinematic viscosity values of these blends with that of diesel (2.24 cSt at room temperature), we can observe that TPO sample P1B30 and P1B50 shows comparable value with that of diesel at room temperature itself. But samples P1B60 and P1B40 must be preheated to temperature range of 40^{0}C-50^{0}C to obtain values similar to that of diesel. Whereas the sample P1B70 need to be heated to 60^{0}C- 70^{0}C and if the raw sample P1 is used, preheating temperature reaches above 70^{0}C for obtaining values similar to diesel.

4.2 sample P2

Table3 shows the variation of kinematic viscosity and density with temperature for the TPO sample P2 and its blends that are in the ratios B30, B40, B50, B60 and B70. The test has been conducted for a temperature range of 30^{0}C – 80^{0}C

Table 3: Viscosity and Density values of sample P2

Property	Temperature (^{0}C)	Sample P2					
		B30	B40	B50	B60	B70	B100
Kinematic viscosity (cSt)	30	2.29	2.47	2.73	3.24	3.57	4.27
	80	1.3	1.52	1.655	1.52	1.75	2.11
Density (g/cc)	30	0.82	0.82	0.82	0.84	0.84	0.86
	80	0.78	0.78	0.8	0.78	0.78	0.8

By analyzing the values of sample P2, it is observed that at room temperature the viscosity value of sample P2 is 90.6% higher than that of diesel and for the lower blending ratio sample that is P2B30 , it is 2% higher than that of diesel fuel.

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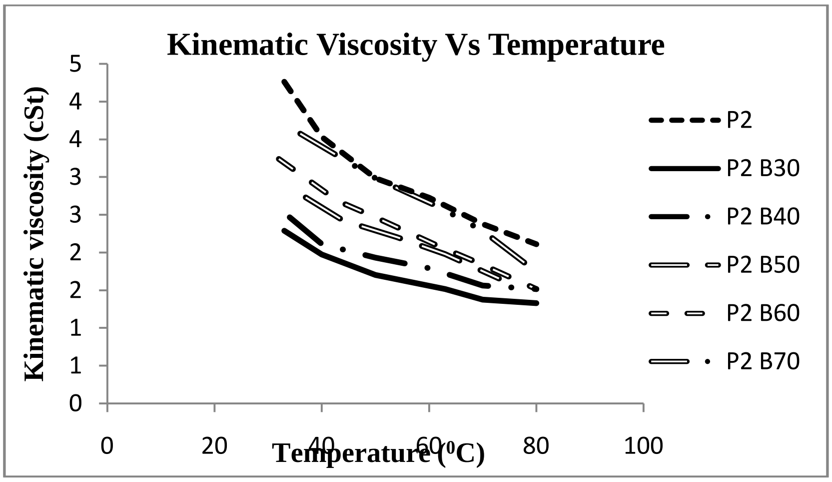

Figure 2: Kinematic viscosity variation of sample P2 with temperature.

Figure 2 shows the graphical representation of variation of kinematic viscosity with temperature. On comparing the kinematic viscosity values of these blends with that of diesel (2.24 cSt at room temperature), we can observe that TPO sample P2B30 and P2B40 shows comparable value with that of diesel at room temperature itself. But samples P2B50 and P2B60 must be preheated to temperature range of 50^{0}C-60^{0}C to obtain values similar to that of diesel. Whereas the sample P2B70 need to be heated to 70^{0}C- 80^{0}C and if the raw sample P2 is used, preheating temperature reaches above 80^{0}C for obtaining values similar to diesel.

4.3 Sample P3

Table4 shows the variation of kinematic viscosity and density with temperature for the TPO sample P3 and its blends that are in the ratios B30, B40, B50, B60 and B70. The test has been conducted for a temperature range of 30^{0}C – 80^{0}C.

Table 4: Viscosity and Density values of sample P3

Property	Temperature (^{0}C)	Sample P3					
		B30	B40	B50	B60	B70	B100
Kinematic viscosity (cSt)	30	3.28	4.74	6.79	9.13	11.99	18.33
	80	1.79	1.84	2.29	2.68	3.073	4.63
Density (g/cc)	30	0.82	0.82	0.84	0.86	0.86	0.92
	80	0.76	0.76	0.78	0.8	0.8	0.88

By analyzing the values of sample P3, it is observed that at room temperature the viscosity value of sample P3 is 7 times that of diesel and for the lower blending ratio sample that is P3B30 , it is 46% higher than that of diesel fuel.

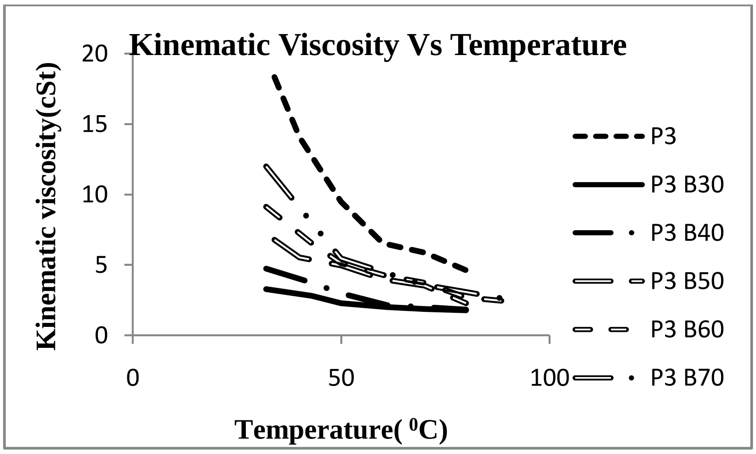

Figure 3: Kinematic viscosity variation of sample P3 with temperature.

Figure 3 shows the graphical representation of variation of kinematic viscosity with temperature. On comparing the kinematic viscosity values of these blends with that of diesel (2.24 cSt at room temperature), we can observe that TPO sample P3B30 and P3B40 shows comparable value with that of diesel for a temperature range of 40^0C-50^0C. For the sample P3B50, P3B60 and P3B70 must be heated to temperature range of 80^0C-90^0C to obtain values similar to that of diesel. Whereas for the raw sample P3, heating temperature reaches above 100^0C for obtaining values similar to diesel.
Both density and even more viscosity have a profound impact on the combustion efficiency of diesel engines, thus having a notable influence on their expected life [5]. Higher viscosity can cause excessive fuel injection pressures for the engine warm-up, increasing the energy demand of pumps and tending to form larger droplets up, leading to a poorer spray. Those phenomena can cause an incomplete combustion, wear of the fuel pump elements, choking of the fuel injectors, and ring carbonization. [13]. Apart from that, the viscosity is important in the design of the equipment to be used in industry as pipes.

IV. CONCLUSION

With increased interest in biodiesel production, the issue of product quality will be an ongoing concern. As mentioned, it is well known that both density and even more viscosity have a profound impact on the combustion efficiency of diesel engines, thus having a notable influence on their expected life. In this study the temperature dependencies of density and viscosity of TPO and their blends were measured and furthermore, the density, viscosity dependence was analyzed. Results of this research shows that samples P1, P2and P3 require preheating to 70^0C, 80^0C and 90^0C respectively to matchup with the viscosity values of standard diesel fuel used in engines. Viscosity values of various blends are found to be reduced with increase in blending proportions of diesel. Among these B30 and B40 blends shows viscosity values similar to diesel in room temperature. All other higher blends of samples requires preheating to adjust the viscosity values. Heating temperature of these blends are found to be increased with increase in blending ratios.

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