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Determination of fuel characteristic of tyre pyrolysis oil and compare with waste lubricating oil and high speed diesel

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Abstract
The increasing demand and high prises of petro fuels in India and other part of the globe has drawn attention of researchers to explore possibilities of different type of alternative fuel in internal combustion engines. In India alone the production of vehicles have increase 23.4 milion motor vehicles in 2014-15. Presently 697 000 commercial and 3.22 million passenger vehicles are on road. Besides these tractors sales in India raised by about 20 per to an all time high 6, 33,656 units in fiscal in 2013-14. Also, about 131.80 lakh diesel engine operated pump sets are in use in agriculture. It is observed that annually large number of waste tyres available every year which become major problem to decompose it, also it has been estimated that above 3.74 MMT of waste lubricating oil is produced in India which is used application fuel as burners, heaters (furnaces) and boilers. In agriculture sector some of the farmer use waste lubricating oil for fuel purpose mixing some quantity with diesel for use in small constant speed diesel engine. Since, lubricating oil has certain properties close to the high speed diesel. It is therefore necessary to compare the Raw Tyre Oil, used lubricating oil with high speed diesel based on their fuel properties to ascertain its use as fuel in small constant speed CI engines.

Keywords: Fuel characteristic, pyrolysis, high speed diesel

Introduction

The production of waste tyre oil is increasing as the number of vehicle and number of waste tyre increasing with high rate. Also, on other side, the production of waste automotive engine oil (WO) is estimated at 24 million tons each year throughout the world, posing a significant treatment and disposal problem for modern society. WO, containing a mixture of low and high molecular weight aliphatic and aromatic hydrocarbons, also represents a potential source of high-value fuel and chemical feedstock. (Nasim *et al.,* 2014)

Today the used oil is discarded into the ground or landfills which neither protects the environment nor conserves it resource value. The used oil poured into the land penetrates the ground rapidly and causes serious ground water contamination. The burning of used oil in kilns and incinerators produces lots of ash and carcinogens causing environmental pollution. Refining of used oil can produce more valuable products and can prevent pollution. (Kannan *et al.,* 2014)

In recent years, recycling of the waste lubricant oils and utilizing of the products as fuels have become important topics for researchers. Most of the lubricant oils are generally obtained from petroleum resources. The used or waste oils can be refined and treated to produce fuels or lubricating oil base stock. On the other hand, the waste oils pose an environmental hazard due to both their metal content and other contaminants (Nerin *et al.* 2000) [27]. The high-volume waste oils can be turned into valuable fuel products by refining and treating processes. Converting of the waste oils into diesel-like fuels to be used in engines without disposing is very important. Utilization of the diesel-like fuels produced from the waste lubricant oils and blending of the produced fuels decrease consumption of petroleum based fuels, protecting environment from toxic and hazardous chemicals (Bhaskar *et al.* 2004) [9]. It also saves of foreign exchange, reduces greenhouse gas emissions and enhances regional development especially in developing countries. Characteristics of any fuel are very important from the point of deciding whether the fuel can be used for desired application or not. Therefore, it is necessary to examine the important characteristics fuel properties like density, viscosity, flash point, Fire Point etc. of unfiltered and filtered lubricating oil in comparison with Diesel and

Version Lubricating Oil. Hence, this paper work is aimed to study the comparative analysis of waste lubricating oil before and after filtration with respect to diesel and 20W40 version lubricating oil.

Material and Method

Selection of tyre pyrolysis oil

Tyre pyrolysis oil sample was collected from sitarganj (Uttarakhand) tyre pyrolysis oil plant

Selection of waste lubricating oil

Waste lubricating oil available from 35-60 Hp farm tractors in which normally 20W40 oil is used obtained. The lubricating oil in these tractors is periodically changed at a frequency of 250-300 h of tractor use. Since theses oil has impurities like carbon, metallic salts, dust…etc a filtration setup as shown in fig. 1 was developed to reduce the contamination like soot, sludge, gums…etc.

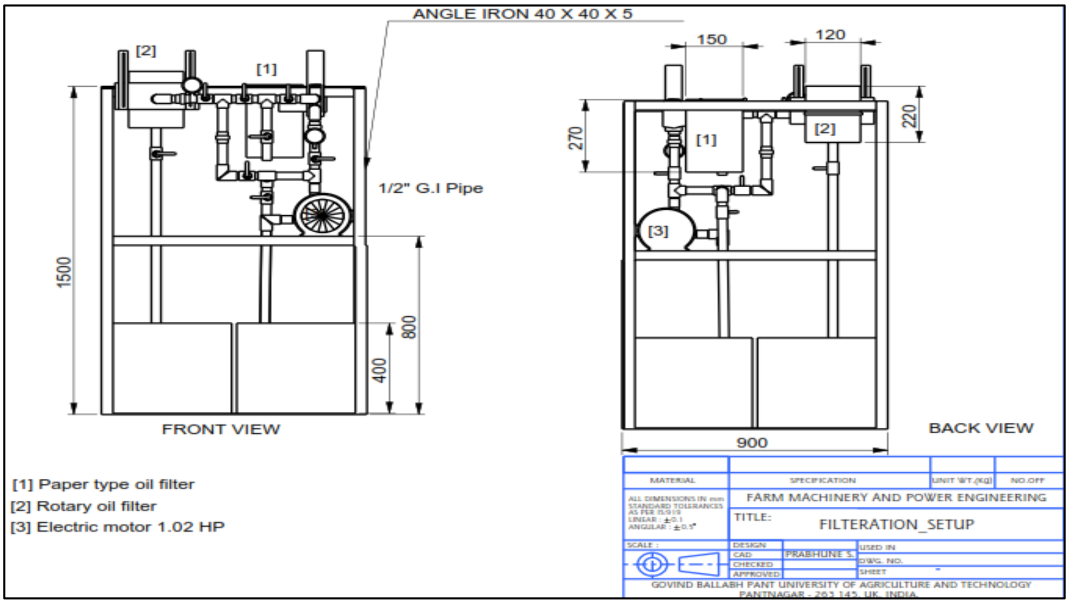

Fig 1: Waste Lubricating Oil Filtration Setup

Waste Lubricating Oil Filtration Setup: The filtration setup is a semi continues batch type primarily consist of two different oil filter i.e. rotary oil filter and paper type oil filter with 1.02 hp motor. The frame of the setup made up of cast iron angle of size 40x40x5 mm. The capacity of oil filtration is 92.2 l/h at 3.50 kg/cm^2 and 151.2 l/h at 3.50 kg/cm^2 for rotary and paper cloth oil filter respectively. While, the oil filtration through both oil filter at 3.50 kg/cm^2 is 82.8 l/h. The filtration of waste oil can be done at different selected pressures as 1.00, 1.50, 2.00, 2.50, 3.00 and at 3.50 kg/cm². Provisions are available to filter the lubricating oil at different flow rates with different pressures of 1.00, 1.50, 2.00, 2.50, and 3.00 and at 3.50 kg/cm² through each of filter individually and combined.

Fuel Samples Selected

HSD (High Speed diesel)
WLO (Waste Lubricating Oil)
FO (Filtered Waste Lubricating Oil)
HSD80: FO20 (Blend 20)
HSD70: FO30 (Blend 30)
HSD60: FO40 (Blend 40)

Fuel Properties

The fuel properties such as Kinematic Viscosity, Carbon Residue, Relative Density, Flash Point…etc. were studied for these fuel samples selected as described above.

Relative density

Fuel density affects engine performance because fuel injection pumps meter fuel by volume, not by mass. Thus, mass of fuel is injected depending upon its density and, also, the air–fuel ratio and energy content within the combustion chamber are evidently influenced by fuel density. The relative density of the selected fuels at 15^{0}C was determined as per IS: 1448 [P: 32]: 1992 [20] using the following relationship.

$$\text{Relative Density} = \frac{\text{Density of fuel at } 15°C\,(\rho_f)}{\text{Density of distilled water at } 15°C\,(\rho_w)} \qquad \text{...... (1)}$$

Where,
ρ_w = Density of water (0.9904 g/cc)
ρ_f = Density of fuel, g/cc

Kinematic viscosity

Viscosity can be defined as the resistance to flow of liquid due the internal friction between the liquid and surface. It plays an important role in the performance of an engine fuel system operating through a wide range of temperature. Low viscosity can result in an excessive wear in injection pumps whereas high viscosity may result in excessive pump resistance, filter blockage, high pressure

The kinematic viscosity of the selected fuels at 40°C was determined using a Redwood Viscometer No. 1 as per [IS: 1448 (P: 25): 1976] [19] was calculated using the empirical relation (Nakra and Chaudhary, 1985) [26] given below.

$$\upsilon = At - \frac{B}{t} \qquad \text{..... (2)}$$

Where,
υ = kinematic viscosity, CST
t = time of efflux, s (or degrees for Engler viscometer)

A and B are constants applicable to the type of the viscometer

Dynamic Viscosity
The dynamic viscosity was determined as per the IS: 1448[P: 10]: 1976 [19] by using the equation given below

$$ŋ = \rho \text{ x } υ \quad ..... (3)$$

Where,
ŋ = dynamic viscosity in centipoises
ρ = density, g/cm^3
υ = kinematic viscosity, cSt

Flash and fire point
Flash point measures the tendency of the sample to form a flammability mixture with air under controlled laboratory conditions. This is the property that must be considered in assessing the overall flammability and hazard of material. The flash and fire point of the fuel samples was determined as per IS: 1448 [P: 21]: 1992 [18] by a Pensky Martin Flash Point (closed) apparatus.

Cloud and pour point
The cloud and pour point is the measure which indicates that the fuel is sufficiently fluid to be pumped or transferred. It holds significance to engines operating in cold climate. The cloud and pour point of fuel samples were determined as per IS: 1448 [P: 10]: 1970 using the Cloud and Pour point apparatus.

Aniline Point
Aniline point (AP) is a important characteristic of petroleum fractions that indicates the degree of aromaticity of hydrocarbon mixtures. Aniline point is defined as the lowest temperature at which equal volumes of aniline and the sample become completely soluble. As amount of aromatics in a petroleum fraction increase the aniline point decreases. Therefore, the aniline point is a parameter that is highly related to the hydrocarbon types in petroleum fractions. The aniline point of fuel samples was determined using Aniline point apparatus. IS: 1448 [P: 3]: 2007 [15].

Carbon residue
Carbon residue is a measure of the tendency of a fuel to form carbon deposits during combustion and indicates the relative coke forming tendencies of heavy oil. Carbon rich fuels are more difficult to burn and have combustion characteristics which lead to the formation of soot and carbon deposits. Since carbon deposits are a major source of abrasive wear, the carbon residue value is an important parameter for a diesel engine. A high carbon residue level denotes a high residue level after combustion and may lead to ignition delay as well as after burning of carbon deposits leading to engine fouling and abrasive wear. Fuels with high carbon residue values have an increasing tendency to form carbon deposits on injection nozzles, pistons and in the ports of 2-stroke engines. This causes reduction in the efficiency and performance of those components and increased wear.
Carbon residue of different fuels was determined as per the IS 1448 [P: 122]: 2013 by using equation given below:

$$\text{Carbon Residue (\%)} = \frac{m3-m1}{m2-m1} \times 100 \quad .... (4)$$

Where,
m_1 = Mass of the empty crucible (g)
m_2 = mass of crucible + test portion (g)
m_3 = mass of crucible + residue (g)

Ash content
Ash in a fuel oil can result from oil, water soluble material compounds or extraneous solids, such as dirt and rust. The ash content of selected test oil samples was measured by electric muffle furnace as per the standards IS: 1448 [P: 4] – 1984 by using the following relationship.

$$\text{Ash percent by mass} = \frac{m}{M} \times 100 \quad ….. (5)$$

Where,
As = Ash content, (%)
m = mass of ash, (g)
M = mass of sample, (g)

Copper strip corrosion test
The use of alternate fuels may pose a problem to the engine material especially when the fuel sample contains water or any oxygenate. Copper strip corrosion test is intended to measure the corrosiveness of copper caused by fuel sample. The corrosiveness to copper was determined as per IS 1448 [P: 15]: 2004 [17] by using Copper corrosion testing apparatus which is based on the principle that a polished copper strip is immersed in a given quantity of sample fuel and at a temperature and for a time characteristic of the material being tested. At the end of this period the copper strip is removed, washed and compared with the copper strip corrosion standards.

Results and Discussion
Studies on fuel properties of different selected fuels like RTPO, HSD, WLO, FO, HSD and FO Blends were conducted. The WLO was filtered to evaluate their suitability as a CI engine fuel by compare the relevant properties such as kinematic viscosity, flash and fire point, calorific value, carbon residue, ash content, relative density… etc. A study carried out to examine the properties of filtered waste oil so that it could solve some of the energy problem by using in blend with diesel fuel. The Table 1 shows the observed fuel properties of selected fuels.

Table 1: Fuel properties of different related fuels.

Sr. No.	Properties	Samples						
		RTPO	HSD	WLO	FO	HSD80:FO20	HSD70:FO30	HSD60:FO40
1.	Kinematic viscosity at 40 ^{0}C (cSt)	6.28	3.2	71.33	62.66	6.2	8.1	8.3
2.	Dynamic viscosity at 40 ^{0}C (cP)	5.79	2.62	59.91	52.63	5.18	7.12	7.48
3.	Flash point (^{0}C)	56.4	52	187	177	61.00	67.00	71.00
4.	Fire point (^{0}C)	59.6	55	191	181	64.00	69.00	73.00
5.	Anilline point (^{0}C)	-	79	23	19	72.00	68.00	61.00
6.	Carbon residue, (%)	1.394	0.06	9.07	7.28	0.21	0.32	1.12
7.	Ash content, (%)	0.143	0.03	1.48	1.34	0.39	0.58	0.78
8.	Relative Density (15 ^{0}c)	0.9230	0.8412	0.8691	0.8619	0.8432	0.8457	0.8510

9.	Cloud Point (^{0}c)	-	0.8	-	-	-	-	-
10.	Pour Point (^{0}c)	-	-9	-32	-28	-12	-15	-17
11.	Copper Strip Corrosion	1b	1b	2c	2c	1b	1b	1b
12.	Sediment Content (%)	10	0.10	31.10	24.17	1.05	2.13	3.24

The comparative evaluation different of different selected fuels based on specific fuel properties as discussed below:

Kinematic viscosity

The kinematic viscosity of TPO, HSD, WLO, FO, Blend 20, Blend 30 and Blend 40 were observed as 6.28, 3.20, 71.33, 62.66, 6.20, 8.10 and 8.30 respectively. The kinematic viscosity of HSD was as 3.2 cSt which is within the range specified by BIS. The value of kinematic viscosity reported by Altun (2011) [5] was found to be 2.95mm^2/s or cSt, which is nearer to measured value of diesel. Also diesel viscosity value reported by Beg (2010) [8], is found to be 1.98 cSt. The value of UFO, reported by Abdulkareem (2014) [1], found to be 62 cSt. The kinematic viscosity of WLO was found to be 71.33 cSt which indicate that the WLO has sludges, contaminants and impurities present in the oil. After the filtration the viscosity decreased and observed to be 62.66 cSt in FO. It is also clear from the data that in case of all the blends the viscosity get drastically reduced and come nearly close to the HSD. The decreasing trend was observed from blend 20 to blend 40 as the percentage of HSD get increased. It is due to the lower kinematic viscosity of HSD. So it is clear from the data that viscosity get reduced by filtration and blending FO with HSD in mentioned proportion and observed nearly equal to HSD.

Dynamic viscosity

The dynamic viscosity for RTPO, HSD, WLO and FO was observed as 5.79, 2.62, 59.91 and 52.63 respectively. In case of blends HSD80:FO20, HSD70:FO30 and HSD60:FO30 it was found as 5.18, 7.12 and 7.48 respectively. As the WLO get filtered its viscosity get reduced from 59.91 to 52.53cP. A gradual increased was observed in the viscosity as the HSD percentage is increased due to the low viscosity of HSD. By filtration and blending viscosity of WLO is decreased and come close to acceptable range as fuel.

Flash and fire point

The flash point of the RTPO, HSD, WLO, FO, Blend20, Blend30 and Blend40 was found to be 56.4, 52, 187,177, 61, 67 and 71 while the fire point was observed as 59.6, 55, 191, 181, 64, 69 and 73 respectively. The Flash and fire point observed for HSD was found to be in the range specified by BIS. Chandra (2003) [28] reported flash point and fire points of diesel as 60 ^{0}C and 67.4 ^{0}C respectively and Maurya (2004) [22] reported the same for diesel as 64 ^{0}C and 68 ^{0}C. The flash and fire point for WLO was found to be higher because of its impurities and contaminants present. Flash and fire point were found in inversely proportional to filtration quality as filtration quality increases, there was decrease in flash and fire point and vice-versa. In case of blend it was observed that as the diesel quantity is increased the flash and fire point get decreased it is because of the low flash point, fire point and viscosity of diesel.

Aniline point

The aniline point of HSD was found as 79 ^{0}C. The aniline point reported by Agarwal and Das (2001) [3], Sudhir *et al.* (2007) [29], Nabi and Hoque (2008) [24] for diesel is 69, 77.5 and 75 ^{0}C respectively. In case of WLO and FO it was found as 23 and 19 respectively which may be due to the high aromaticity of hydrocarbon mixture. As the FO blends with HSD drastic increase was observed as the percentage of HSD increased in the blend. The aniline point for blend20, blend30 and blend40 was observed as 72, 68 and 61 respectively. The increase in the aniline point with increased amount of HSD was due to the high aniline point of the HSD.

Carbon residue

Carbon residue gives an approximate measure of the carbon depositing tendencies of a fuel oil. The carbon residue content of diesel and RTPO was found as 0.06 and 1.394 percent respectively. The maximum recommended carbon residue level in diesel as per IS: 1460-1974 is 0.2 percent. The carbon residue of diesel reported by Ajiwe *et al*. (2003) [4] is 0.17% and by Negi *et al.* (2008) [25] is 0.14%.

The carbon residue percent in WLO was observed to be as 9.07% which is due to the high contaminant and impurities present in the oil. After the filtration it was decreased and observed as 7.28% in case of FO. It was due to the removal of most of the contaminants by the paper and rotary filter. As the FO is blend with HSD it was found that carbon residue percent get reduced as the quantity of HSD increased and found as 0.21,0.32 and 1.12% for blend20, blend30 and blend 40 respectively. It is because of the very low carbon residue present in the HSD. It was found that carbon residue percent comes nearly close to HSD after blending and can be accepted as fuel for CI engine.

Ash content

The percentage of ash in diesel was 0.03. As per IS 1460:2005 ash content was found to be 0.01 percent. The ash of RTPO, UFO, FO and VO was found to be 0.143, 1.48, 1.34 and 0.96 percent respectively, however ash content of UFO, reported by Shakirullah *et al*. (2006), found to be 1.20±0.10%. Also this value reported by Abro *et al*. (2013) [2], found 2.02%. The decreasing trend was for ash content values as the FO is blended with the HSD in increasing proportion. The ash content values for blend20, blend30 and blend 40 was observed as 0.39, 0.58 and 0.78 respectively. It is due to the lower ash content values of HSD (0.03%).

Relative density

The relative of HSD was observed as 0.841 gm/cm^3 at 15^{0}C. The relative density for HSD is reported as 0.829 to 0.848 gm/cm^3. [Goering *et al.* (1983) [14], Chatterjee (2000) [12], Chandra (2003) [28] and Maurya (2004)] [22]

In case of RTPO, WLO and FO it was observed as 0.923, 0.869 and 0.861 respectively. Relative density of waste lubricating oil by Abdulkareem (2014) [1] is reported as 0.900 gm/cm^3. High value of relative density for WLO was observed because it has more density and contains more percentage of contaminants and impurities. As the FO oil is blend with the HSD it was observed that as the percentage of HSD increasing the relative density get reduced it because of the lower relative density value of the of HSD. For the blend 20, blend 30 and blend 40 it was observed as 0.843, 0.845 and 0.851 gm/cm^3 respectively.

Cloud point and pour point

The cloud and pour point HSD, FO and different blends is shown in above table1. The cloud and pour point of diesel was found as 0.8 and -9 ^{0}C respectively. The cloud and pour point as reported by Ram Chandra (2003) [28] for diesel is 1.5 and -7.5 ^{0}C respectively. Bajpai *et al.* (2009) [7] reported the same for diesel as 6.5 and 3.1 ^{0}C respectively. The cloud and pour point for diesel reported by Jimenez *et al*. (2011) [21] is -3 and -9 ^{0}C respectively. The pour point for WLO and FO was observed as -32 and -28. The decrease in the pour point in case of FO may be due to the filtration process by which the oil get cleaner, pure and contamination free. Pour point for blend20, blend30 and blend 40 was noted as -12, -15 and -17 respectively. As the percentage of HSD reduced in the blends pour points get reduced of the blends. It may be due to the lower pour of the FO.

Copper strip corrosion test

This test serves as a measure of possible difficulties with copper, brass, or bronze parts of the fuel system. High copper strip corrosion indicates a severely degraded or acid-contaminated fuel. The Copper strip corrosion test results of HSD, WLO, FO and Blends of HSD with FO are shown in above table 1. The level of corrosion created by diesel and RTPO was found to be 1a and 1b respectively. Same findings for diesel have been reported by Caro (2001) [10], Jimenez *et al*. (2011) [21] and Mehta *et al.* (2012) [23]. Level of corrosion for WLO and FO was observed as 2c which shows the slightly more corrosive than the HSD but as the FO blend with the HSD in the different ratio again 1a level of corrosion was observed in all the blends. It is so because of the less corrosive nature of HSD.

Conclusion

From all of the above observation it is clear that raw tyre pyrolysis oil (RTPO) has different properties than high speed diesel (HSD). Also, filtered oil has improved properties due to the filtration process as compared to waste lubricating oil but still there is some difference when compared with diesel fuel. So, to make it diesel like fuel and further improvements in properties we can blend it with diesel in different proportion for reused.

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