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Evaluation and enhancement of cold flow properties of palm oil and its biodiesel



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ABSTRACT

Cold flow properties are the main issue to regular usage of Palm biodiesel as alternative fuel to diesel. The inferior cold flow property of biodiesel causes gum formation and crystallization of fuel particles which can be enhanced by winterization, blending and addition of cold flow improvers. The objective of this study is to improve cold flow properties of biodiesel obtained from palm oil. Blending and using of cold flow improver were adopted among various methods to enhance the cold flow properties. Results of the study show that with B20 blend of biodiesel using petroleum diesel and kerosene has significant improvement of the cold flow properties. Diesel improves CP and PP by 57.61% and 78.57% whereas kerosene improves CP and PP by 62.94% and 85.78% respectively for B20 blend. Ethanol had remarkable impact as 20% addition improves CP and PP by 60.48% and 63.96% respectively. The investigation concludes that PE80 is recommended as a fuel for engine operation under low temperature regions. For improving the cold flow properties, addition of cold flow improver is best method to attain the desired values of cold flow properties for biodiesel.

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1. Introduction

With continuous rise in population, energy requirements have also increased which has resulted in the extensive use of the fossil fuel resources. Due to high rate of fossil fuels consumption, these are going to be exhausted. So need of hour is to look beyond conventional sources of fuel and develop alternate sources of fuel (Dwivedi and Sharma, 2013). One of the viable options to counter the excessive usage of petroleum diesel can be biodiesel, because it possesses comparable fuel properties as of diesel. Moreover, biodiesel is mainly derived from renewable feedstocks like edible, non-edible oils or animal fats (Verma and Sharma, 2015; Dwivedi and Sharma, 2014b). Biodiesel can be defined as the fatty acid alkyl

Abbreviations: BXX, XX percentage of biodiesel in blend; CP, Cloud point; PP, Pour point; CFPP, Cold filter plugging point; LTFT, Low temperature filterability test; PMA, Polymethyl acrylate; MO, Methyl oleate; POME, Palm-oil methyl ester; EVAC, Ethylene vinyl acetate copolymer; JCB, Jatropha curcas biodiesel; WCB, Waste cooking biodiesel; RBE, Rapeseed butyl ester; RME, Rapeseed methyl ester; OECF, Olefin-ester copolymers; PO, Palm oil; PB, Palm Biodiesel; POXX, XX percentage of palm oil in blend; PKXX, XX percentage of palm oil in blend of palm oil and kerosene; PBDXX, XX percentage of biodiesel in blend of palm biodiesel and diesel; PBKXX, XX percentage of biodiesel in blend of palm biodiesel and kerosene; POEXX, XX shows the percentage of oil in palm oil–ethanol blend; PBEXX, XX shows the percentage of oil in palm biodiesel–ethanol blend.

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esters of edible oils, non-edible oils, animal fats or waste oils. The most followed technique for producing biodiesel is the transesterification reaction, in which triglycerides are reacted with alcohol in presence of catalyst (acid or base) to obtain methyl esters and glycerol as a by-product (Giraldo et al., 2013; Verma et al., 2015b; Wang et al., 2014; Altaie et al., 2015). Cold flow properties of diesel fuel are generally determined by the following parameters viz. CP (cloud point), PP (pour point), CFPP (cold filter plugging point) and LTFT (low temperature filterability test). When biodiesel is subjected to lower temperatures, the solid wax crystal nuclei was easily formed. Further decrease in temperature causes the crystal nuclei to grow and become visible, and this temperature is termed as CP. When the temperature is further decreased, the crystal nuclei aggrandize and thus prevent free pouring of fluid, this temperature is termed as PP. Therefore CP and PP are the essential parameters, which defines the cold flow property. Continuous efforts are being done to enhance the cold flow properties of biodiesel. To overcome the disadvantages arising at the low temperature, certain techniques are used to lower the CP and PP (Verma et al., 2015a; Jurac and Zlatar, 2013; Cao et al., 2014b,a; Verma and Singh, 2014).

2. Literature review

The main problem associated with biodiesel is its poor cold flow property, which results in degradation in quality of fuel and it may not be suitable for engine application. Various authors have

investigated the phenomena of cold flow properties of various biodiesels. Giraldo et al. (2013) studied the effect of various additives in range of 1%–10% on cold flow properties of palm biodiesel and observed that 5% addition of 2-butyl esters gave best results among other additives. Cold Filter Plugging Point decreased from 16 °C to 10 °C whereas PP reduced to 8 °C from 14 °C.

Upon addition of 0.04% of polymethyl acrylate (PMA), PP & CFPP of biodiesel were reduced by 8 and 6 °C respectively. CP, PP and CFPP on adding 0.04% PMA by weight to waste cooking biodiesel were observed to be −9, −19 and −15 °C respectively, which were lowest among other samples with different concentrations of additives in biodiesel. PMA changed the crystallization behaviour of the crystals by altering the shape of crystals and stopping the formation of larger crystals, which caused in the improvement of the biodiesel cold flow properties (Wang et al., 2014). Altaie et al. (2015) examined the cold flow properties of methyl oleate (MO) and palm-oil methyl ester blends (POME). It was observed that upon 50% addition of MO cloud point and cold filter plugging point, which were reduced to 70.38% and 91.69%, respectively. Cloud Point for POME was 18 °C which declined to 5.33 °C when MO was introduced by 50% proportion. Jurac and Zlatar (2013) developed linear correlations cold flow properties of product formed from mixtures of raw materials, and cold flow properties of the product formed from pure raw materials. CFPP for rapeseed and sunflower biodiesel was found to be −15 °C and −10 °C respectively. Cao et al. (2014b) varied the proportion of ethyl acetoacetate from 0% to 20% by volume in biodiesel produced from waste cooking oil. Both PP and CFPP decreased by 4 °C at 20 vol% ethyl acetoacetate. Reduction in CP was observed with rise in ethyl acetoacetate proportion in biodiesel. Freezing point of ethyl acetoacetate is substantially low (−45 °C) which can be primary reason in lowering down of CP of biodiesel. Ethyl acetoacetate tends to be in bulk liquid phase due to its low melting point. Cao et al. (2014a) identified that cloud point, cold filter plugging point and pour point of B20 decreased by 8 °C, 11 °C and 10 °C, respectively, after 0.04 wt% ethylene vinyl acetate copolymer (EVAC) treatment. Serrano et al. (2014) observed cold flow properties for biodiesel from various vegetable oils and found that CFPP was −4 °C, −14 °C, −6 °C and 13 °C, for soybean, rapeseed, high oleic soybean and palm biodiesel. Rasimoglu and Temur (2014) identified better cold flow properties when alcohol-to-oil ratio was kept between 3.15:1 and 4.15:1. Optimum CP, PP and CFPP of the biodiesel from corn oil were found to be −4, −10 and −12 °C. Nainwal et al. (2015) experimented with jatropha and waste cooking biodiesel for improvement in cold flow properties and observed that CP and PP (pour point) for Jatropha Curcas Biodiesel (JCB) for B20 blends with petro diesel were reported as 14.9 °C and 14 °C respectively, however, for Waste Cooking Biodiesel (WCB) it was 12 °C and 11.5 °C respectively. Kerosene K20 samples were showing best results as the reported CP and PP were −1 °C and −2.2 °C respectively for JCB. However in case of WCB blends with kerosene, the reported CP and PP for K20 blends are −10.5 °C and −12 °C respectively. Zuleta et al. (2012) found −7 °C CFPP for B100 castor biodiesel. Blend having 75% jatropha and 25% castor had CFPP of −12 °C. Lv et al. (2013) observed CP, CFPP and PP for Palm biodiesel to be 18, 16 and 13 °C. On using additive DEP:PGE:PA w in ratio of 3:1:1 or 2:2:1, the CFPP of palm biodiesel was decreased by 7 °C. Phung et al. (2014) experimented with autoxidation of triglycerides and concluded that CP for autoxidised biodiesel from soybean and canola was −13 °C for both cases. Makareviciene et al. (2015) examined the effect of butanol blending with methyl and butyl esters of rapeseed oil. The addition of butanol results in a gradual decrease in the cloud point. For blends containing 60%–100% rapeseed oil butyl esters, the CP ranges between −6 °C and −8 °C. Esters blends with butanol of concentration no less than 50% have a CFPP −17 °C that complies with the requirements established for E-Class diesel

fuel. As the amount of butanol in a blend is increased further, the CFPP steadily decreases until it reaches 30–31 °C below zero. CFPP of RBE blends are lower than those of RME blends of the same concentration because the CFPP of pure RBE is lower than that of pure RME. Wang et al. (2015) produced biodiesel via enzymatic process with help of fusel alcohol. The cold filter plugging point (CFPP) of the fusel alcohol esters was −11 °C, 16 °C lower than the methyl esters of the Waste cooking oil. Ali et al. (2016) suggested that B30 blend of palm biodiesel with petroleum diesel is optimum as per fuel property requirements. Reduction of the pour point from 14 °C for unblended biodiesel to less than 0 °C at a 30% biodiesel blending ratio. Boshui et al. (2010) made use of different cold flow improvers to check effect on soybean biodiesel. On use of olefin-ester copolymers (OECF) pour point and cold filter plugging point of biodiesel reduced significantly. 0.03% addition of OECF, PP was found to be −9 °C whereas CFPP was −6 °C. Joshi et al. (2011) used Ethyl Levulinate to improve cold flow properties of cottonseed oil. CP was lowered down by 4–5 °C, whereas PP and CFPP had 3–4 °C and 3 °C reduction respectively at 20 vol% ethyl levulinate. Numerous reports have been available regarding the poor cold flow property of biodiesel is the main cause for the plugging of fuel lines and filters, it also creates the fuel starvation in engine, which ultimately leads to ignition problem. Methanol ethanol, kerosene, Mg additives, etc. are reported to be useful by different researchers to enhance the cold flow behaviour of biodiesels (Misra and Murthy, 2011; Dwivedi and Sharma, 2014a, 2015a). The poor cold flow property for Palm biodiesel can be improved by several methods like winterization, addition of cold flow improver and blending. This paper investigates the cold flow properties of palm oil and its biodiesel and effect of diesel, kerosene and ethanol as cold flow improver on cloud point and pour point.

3. Methodology for biodiesel production

Palm oil (PO) was purchased from local market. All chemicals like KOH, methanol, were of AR grade and 99% pure. Palm oil was filtered to remove all insoluble impurities from the oil followed by heating at 100 °C for 10 min to remove all the moisture. The fuel properties of Palm oil and its biodiesel after refining were determined as per standard methods and reported in Table 1.

Table 1 shows that a FFA content of the oils is as 0.7%. Owing to low FFA content (<1%), here we have adopted base catalyzed transesterification processes. Palm biodiesel (PB) yield of 97.9% was achieved with methanol/oil molar ratio (10.5:1) using KOH as catalyst (1.25% w/w) in duration of 90 min at the temperature of 60 °C.

3.1. Palm biodiesel

The biodiesel samples were tested for physicochemical properties as per ASTM D-6751 and Indian IS 15607 specification and the properties are given in Table 1 which shows that although the PB meets most of the specifications but according to Indian Climate it cannot be used in winter season. The PB samples were analysed for ME formation at a pre-determined interval of time by Gas Chromatograph (Netal make) equipped with a flame ionization detector and a capillary column for injecting the sample (Anon, 2003). The GC oven was kept at 230 °C (5 °C/min). Nitrogen was used as carrier gas. Quantitative analysis of % ME was done using European standard EN 14,103:2003 (DIN EN, 1410). The % ME yield was calculated using Eq. (1).

$$\% \text{ of ME} = \frac{\sum A - A_{EI}}{A_{EI}} \times \frac{C_{EI} - V_{EI}}{m} \times 100 \quad (1)$$

Table 1
Physiochemical properties of palm oil and palm biodiesel.

S. No.	Property (unit)	ASTM 6751	ASTM standard limit	IS 15607	IS 15607 limit	Palm oil	Palm biodiesel	Diesel	Kerosene	Ethanol
1.	Flash point (°C)	Pensky-Martens closed cup test apparatus (D-93)	Min. 130	IS 1448	–	252	175	55	38	13
2.	Viscosity at 40 °C (cSt)	Test method for kinematic viscosity of transparent and opaque liquids (D-445)	1.9–6.0	IS 1448	–	39.4	4.43	2.46	1.16	1.22
3.	Density (kg/m ³) at 40 °C	Standard test method for density, relative density, or API gravity of crude petroleum and liquid petroleum products by hydrometer method (D 1298)	–	–	–	919	880	836	797	789
4.	Water and sediment (vol%)	Test method for water and sediment in middle distillate fuels by centrifuge (D-2709)	Max. 0.05	D-2709	Max. 0.05	0.05	0.05	–	–	–
5.	CP (°C)	Test method for cloud point of petroleum products (D2500-11)	–	IS 1448	–	25.2	21	6	–11	–
6.	PP (°C)	Standard test method for pour point of petroleum products (D97-12)	–	IS 1448	–	23.6	19.7	5	–13	–
7.	Cetane number	Standard test method for cetane number of diesel fuel oil (D613-15ae1)	–	–	–	40	49	52	36	41.4
8.	% FFA	Standard test method for determination of free fatty acids contained in animal, marine, and vegetable fats and oils used in fat liquors and stuffing compounds (D5555-95)	0.25	–	–	0.7	0.1	–	–	–
9.	Acid value	Standard test method for acid value of fatty acids and polymerized fatty acids (D 1980-87)	0.50 mg KOH/g	–	–	1.4	0.2	–	–	–

Table 2
Fatty acid composition of palm biodiesel.

S. No.	Fatty acid	Structure	% composition (PB)
1	Lauric acid	C(12:0)	0.64
2	Myristic acid	C(14:0)	1.02
3	Palmitic acid	C(16:0)	40.2
4	Stearic acid	C(18:0)	4.6
5	Arachidic acid	C(20:0)	0.08
6	Palmitoleic acid	C(16:1)	0.36
7	Oleic acid	C(18:1)	42.4
8	Linoleic acid	C(18:2)	9.9
9	Linolenic acid	C(18:3)	0.47
10	Gadolic acid	C(20:1)	0.33
	Saturated fatty acid		46.54
	Unsaturated fatty acid		53.46

$\sum A$ = Total peak area from the methyl ester in C12 to that in C24:1;

A_{El} = Peak area corresponding to methyl heptadecanoate;

C_{El} = Concentration of the methyl heptadecanoate solution (mg/ml);

V_{El} = Volume of the methyl heptadecanoate solution (ml);

m = Mass of the sample (mg).

For the purpose of error analysis, 2 tests were conducted for single sample and then the average of the 2 readings was taken for further investigation purpose. After each experiment, pour point (D 97-11) and cloud point (D 2500-11) were analysed according to related EN standards. Table 2 shows the fatty acid composition of Palm Biodiesel.

Table 2 shows the fatty acid composition of Palm biodiesel. The high content of Oleic acid results in poor cold flow properties of Palm biodiesel. Lv et al. (2013) stated that Palm biodiesel had lesser unsaturated fatty acids (49.54%) in comparison to other soybean (84.36%) and rapeseed (88.01%) which caused inferior CFPs among different biodiesel. Kim et al. (2012) also observed 49.16% of unsaturated fatty acids, which result in inferior cold flow properties among different biodiesel of their study. Experiments

show 53.46% of unsaturated fatty acids for Palm biodiesel. This difference may be due to origin of oil and quality also. It is here to be noted that having more unsaturated fatty acids than saturated ones like in this study does not necessarily mean that biodiesel will have good CFPs. For superior CFPs, unsaturation should be lot higher like in case stated above by Lv et al. (2013).

3.2. Experimental analysis of cold flow properties

Cloud Point and Pour Point were measured as per the standards i.e. ASTM D-6751, ASTM D2500, D97 respectively. The sample was cooled in a glass tube under given conditions and observed at intervals of 1 °C until a cloudy structure became visible. This temperature was noted down as CP. In determination of PP, sample was cooled in a glass tube under prescribed conditions and inspected at intervals of 3 °C till no movement was observed even when place of surface was held vertical for 65 s; the PP was then taken as 3 °C above the temperature of stopping of flow. Data for all analytical measurements are means of triplicate. Subsequent analysis showed no statically significant difference among the measurements.

4. Results and discussion

4.1. Cold flow mechanism

Primary complication related with engine operation with use of Palm Biodiesel is its stability and cold flow properties. Both these properties are dependent on fatty acid composition of oil that is saturated and unsaturated fatty acids present in oil (Echim et al., 2012; Hoekman and Broch, 2012; Verissimo and Teresa, 2011).

Fig. 1 shows the effect of fatty acid on cold flow property of biodiesel. Saturated fatty acids form crystals in colder weather that results in clogging of fuel filters and fuel lines which in turn causes improper engine operation. As the temperature drops down biodiesel tends to get solidified on achieving pour point, the lowest temperature at which biodiesel is unable to flow. Due to higher

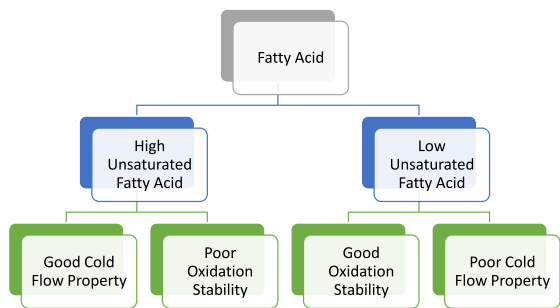


Fig. 1. Effect of Fatty acid composition on cold flow property and oxidation stability.

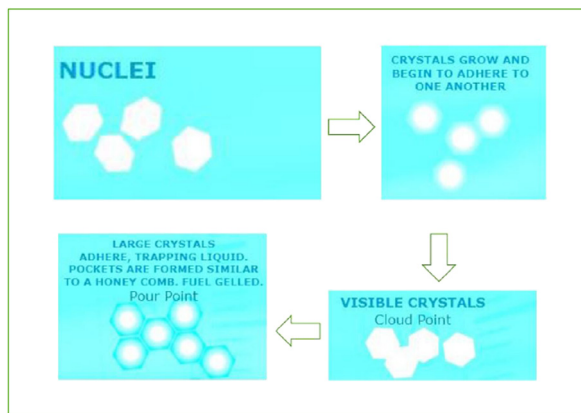


Fig. 2. Cold flow mechanism of biodiesel.

amount of saturated fatty acids in biodiesel, higher will be its CP and PP which lowers down its cold flow properties. In colder regions, components having high melting point will nucleate and start solidifying to form crystals. The temperature where the crystals become visible and form a hazy or cloudy suspension is defined as the cloud point (CP). Pour point (PP) of the fuel is defined as the lowest temperature where the fuel flows or can be pumped.

Fig. 2 shows Cold Flow Mechanism of Biodiesel. The CP of biodiesel is normally more than petroleum diesel. Continuous usage of fuel in low temperature regions at or below CP results crystals to grow and form interlocking networks. Both CP and PP should be closely monitored by the user to ensure trouble-free operation in cold climates. Feed stocks with highly saturated fatty acids structures have biodiesel with inferior cold flow properties in contrast to which feed stocks with highly unsaturated fatty acid structures result in fuels having superior performance. Degree of unsaturation has significant impact on cold flow properties, as more unsaturation results in better cold flow performance (Usta and Aydogan, 2011; Nita et al., 2011; Torres and Mayoral, 2011; Chastek, 2011; Dunn et al., 1996).

4.2. Cold flow properties of palm oil and its blends

Palm Oil was blended with diesel, kerosene and ethanol to investigate its cold flow properties. Binary blending was done as POXX, PKXX where XX means weight percentage of biodiesel in blends of diesel, kerosene in palm oil respectively. Blends were prepared by mixing diesel and kerosene separately into Palm oil and Palm Biodiesel respectively. PO100 shows pure oil whereas PBD100 shows pure palm biodiesel. Similarly, PK and PBK show blends of kerosene in palm oil and palm biodiesel for example, PK20 shows 20% of oil by weight in kerosene and PBK20 shows 20% of biodiesel in kerosene. Moreover, PE80 and PBE80 show, 80% of

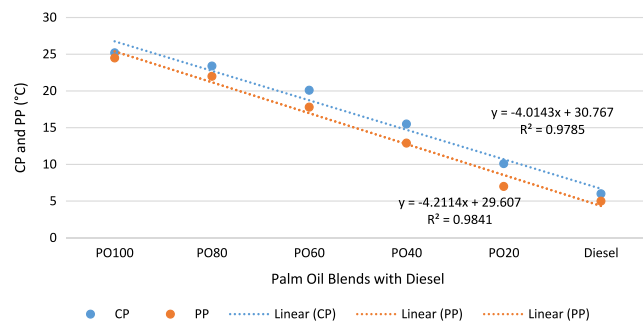


Fig. 3. Variation of CP and PP between palm oil blends with diesel.

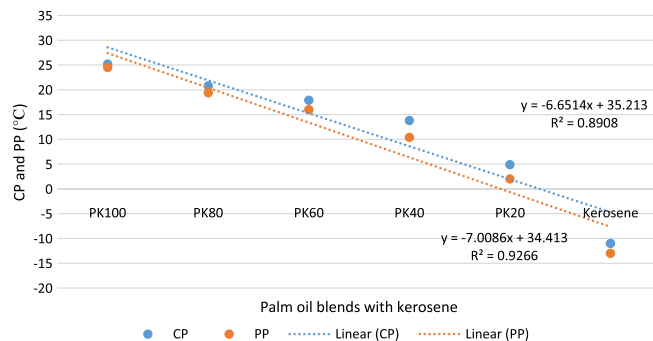


Fig. 4. Variation of CP and PP between palm oil blends with kerosene.

oil and biodiesel respectively when ethanol was used as cold flow improver.

Fig. 3 shows that high CP and PP of Palm oil was reduced after blending with the Diesel having low CP and PP. For pure palm oil (PO100), CP and PP were found to be 25.2 and 23.6 °C respectively where lowered down to 10.1 and 7 °C on for PO20 blend that 20% addition of biodiesel on volume basis to diesel. CP and PP for PO00 i.e. pure diesel 6 and 5 °C.

Fig. 4 shows that high CP of Palm oil was lowered after blending with Kerosene having low CP. The Blend of Palm oil and Kerosene has low CP and PP as compared to the blend of Palm oil with diesel. The CP and PP value of PK20 is lower that is 4.2 and 2 °C as compared to PO20 due to low CP and PP for kerosene. As reported by Nainwal et al. (2015) with use of Kerosene cold flow properties improve and authors recommended the use of Kerosene up to 20% by volume in biodiesel. Similar results were reported by Dwivedi and Sharma (2015b) for which they used kerosene blending to improve low temperature properties of Pongamia Biodiesel. Thus, results incorporated in this study are well according to literature.

4.3. Cold flow properties of palm biodiesel and its blends

Biodiesel prepared from palm oil was analysed for its cold flow properties after its blending with petroleum diesel and kerosene.

Fig. 5 shows that high CP and PP of Palm biodiesel was reduced after blending with the Diesel having low CP and PP. For pure biodiesel (PBD100), CP and PP were found to be 21 and 19.7 °C respectively which is comparatively lower than that of palm oil. CP and PP was lowered down to 8.9 and 6.2 °C for PBD20 blend.

Fig. 6 shows that CP and PP of Palm biodiesel were reduced significantly on blending with Kerosene due to its lower CP and PP. The Blend of Palm oil and Kerosene has low CP and PP as compared to the blend of Palm oil with diesel. The CP and PP value of PBK20 is 2.8 and -1.9 °C which is lower as compared to that of PBD20 (8.9 and 6.2 °C respectively) due to low CP and PP for kerosene. Bhale et al. (2009) also recommended use of 20% Kerosene which improved CP of Mahua biodiesel from 18 °C to 5 °C and PP was

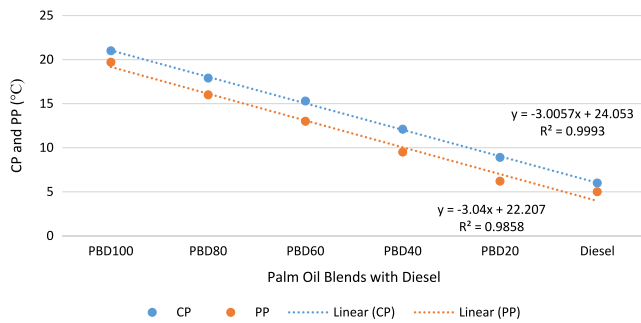


Fig. 5. Variation of CP and PP between different blends of palm biodiesel and diesel.

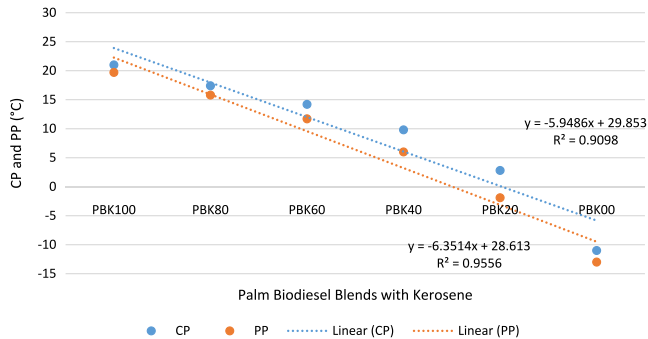


Fig. 6. Variation of CP and PP between different blends of palm biodiesel and kerosene.

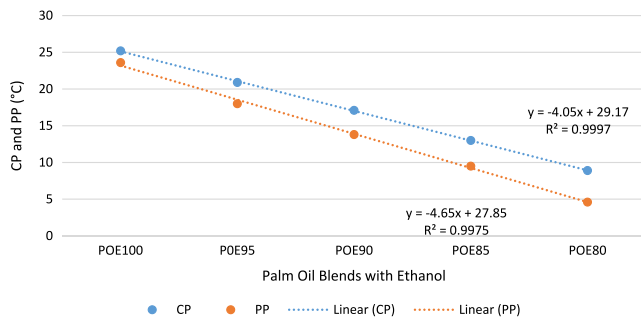


Fig. 7. Variation of CP and PP between palm oil blends with ethanol.

reduced from 7 °C to −8 °C. Therefore results of present studies are according to literature as far as suggestion of kerosene is concerned for blending.

5. Ethanol as cold flow improver

Ethanol was added to palm biodiesel in weight percent 100:00, 98:02, 95:05, 90:10, 85:15, and 80:20 (Ethanol). The figure shows that high CP and PP of Palm oil and its biodiesel were substantially reduced after addition of ethanol having low CP and PP. It is due to low CP and PP value of ethanol.

The result of experiment are shown in Figs. 7 and 8 which reveals the improvement in cloud point and pour point of Palm biodiesel by addition of ethanol. It also shows that as the biodiesel concentration percentage decreases the value of CP and PP is improved. It is observed that with addition of ethanol to palm biodiesel (PBE80) it shows improvement in CP and PP value from 21 °C and 19.7 °C to 7.3 °C and 4.1 °C respectively. We can also observe that fuel PBE80 can be recommended for cold climatic condition. Dwivedi and Sharma (2015b) recommended use of ethanol as an improver for fuel for colder region operation as CP and PP for their case dropped from 20 to 8.5 °C and 19 to 6.5 °C respectively. Similar results are reported in this study. Bhale et al.

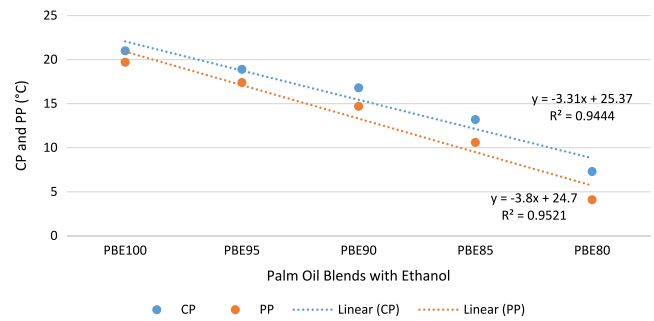


Fig. 8. Variation of CP and PP between different blends of palm biodiesel and ethanol.

(2009) also recommend use of 20% ethanol for mahua biodiesel as CP and PP dropped from 18 and 7 °C to 8 and −7 °C. Therefore use of ethanol as cold flow improver is recommended even in literature. Edith et al. (2012) also recommended blending with petroleum diesel or use of different short chain alcohols as a cold flow improver.

6. Main finding

The result of experimental investigation shows that:

1. Palm oil and its biodiesel have inferior cold flow property in comparison to diesel.
2. B20 blend of palm oil with diesel and kerosene enhances the CP by 59.92% and 80.55% and PP by 71.42% and 91.83% respectively.
3. B20 of palm biodiesel with diesel and kerosene improves CP by 57.62% and 86.87% and PP by 68.52% and 109% respectively.
4. Ethanol happens to be a good cold flow improver for Palm Biodiesel as 20% addition improves CP and PP by 65.23% and 79.18% respectively.
5. Blending requires large quantity of blending agent which is not economically feasible for the development of alternative fuel.

7. Conclusion

The experiment result shows that the Cloud Point and Pour Point of Palm oil, Palm biodiesel, Diesel, and Kerosene are 25.2 °C, 21 °C, 6.0 °C, and −11.0 °C and respective pour points are 23.6 °C, 19.7 °C, 5.0 °C, and −13.0 °C respectively. The blending of Palm biodiesel with Diesel and Kerosene remarkably improved the CP and PP of Palm biodiesel. Blending of biodiesel is simple but effective method to improve the low temperature flow properties, of biodiesel. The result of experimental analysis reveals that CP and PP of Palm biodiesel improved from 21 °C to 8.9 °C and 19.7 °C to 6.2 °C respectively by blending with diesel (PBD20) while blending with kerosene it showed even better results as CP and PP value improved from 21 °C to 2.8 °C and 19.7 °C to −1.9 °C respectively. Blending requires larger proportion of blending agent which is not economically feasible for the development of alternative fuel. Ethanol remarkably improved the CP and PP of Palm biodiesel. The CP and PP of Palm oil improved from 25.2 °C to 8.9 °C and 23.6 °C to 4.6 °C whereas same for Palm biodiesel improved from 21 °C to 7.30 °C and 19.7 °C to 4.1 °C respectively by blending with ethanol. Blending of biodiesel is simple but effective method to improve the low temperature flow properties, of biodiesel. The result shows that PE80 fuel can be recommended for cold climatic conditions.

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