Effects of blending on the properties of diesel and palm biodiesel

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Abstract. Palm biodiesel is blended to diesel in different volume percentages to improve certain properties. This would help in having a good understanding of the dependence of the diesel properties on the biodiesel proportion. The properties of interest in the present work are density, kinematic viscosity, flash point and fire point of the blends which are determined and compared to petrodiesel. It is observed that the kinematic viscosity and density of the diesel increase with the palm biodiesel proportion and it is not preferable. Blends with higher palm content possess higher flash point and fire point. Apparently, blending worsens the conditions and hence might be of no use when compared to diesel, but when compared to neat palm biodiesel, blending helped in pulling down the density, viscosity, fire point and flash point of the latter. Using regression analysis and the properties data of respective blends, correlations are developed to predict the properties of diesel and biodiesel blends known the percentage of biodiesel added to diesel, which are validated using biodiesel and diesel blends which are not used as an input to develop them.

1. Introduction:
Biodiesel derived from vegetable oils was found to be a promising replacement for the conventional engine fuels in terms of both the availability and pollution owing to the conventional fossil, non-renewable fuels. It is the monoalkyl esters of long-chain fatty acids derived from renewable feedstock, such as vegetable oil or animal fats, for use in compression ignition engines [1-6]. It is typically obtained by transesterification of vegetable oils and comprises of mono alkyl esters of fatty acids [3-7]. Transesterification is a process in which the viscosity of the feedstock is reduced to 10 times by converting triglycerides to monoglycerides and glycerol [1, 2, 8-12]. Other methods developed to reduce the viscosity of the feedstock are pyrolysis, micro-emulsification and blending (dilution) [5]. However, transesterification is believed to be the most viable process among all the techniques used to lessen the viscosity, thus producing Biodiesel [1, 14]. In transesterification, triglycerides react with alcohol in the presence of a catalyst, with biodiesel as the main product and glycerol as the by product. The catalysts used in transesterification reaction can be alkalis [15-18], acids [19] or enzymes [20-23]. Apart from being cheap, the physical and chemical advantages of methanol justify its wide usage as a solvent rather than ethanol [11]. The biodiesel produced this way is totally miscible with petrodiesel in any proportion [24]. Biodiesel is better to conventional diesel in terms of its availability, ignition quality, energy content, negligible sulfur content, higher flash point, reduced emissions and high cetane number [25, 26]. However, the viscosity and density of many biodiesels are found to be slightly more than that of mineral
diesel, which is in general not preferred. The cold flow properties of biodiesel are also poor when compared to diesel [14, 29].

Viscosity is the property of fluid because of which there is resistance offered by one layer of fluid over its adjacent layer against relative motion between them [11, 24, 27]. A fuel which is more viscous has poor atomization characteristics and narrow spray angle [14]. One with poor viscosity, leads to excessive wear and poor lubrication [14]. Thus, it is desired for a fuel to possess optimum value of kinematic viscosity. It is therefore an important parameter to compare the atomization and spray characteristics of biodiesel and diesel. The minimum temperature at which a fuel produces vapors sufficient to ignite in the presence of an ignition source is known as the flash point. Therefore, it is important to understand flash point and fire point of a fuel as they characterize its fire hazards and also its volatile nature [24]. A highly viscous and less volatile fuel could result in misfire, ignition delay and thus poor cold starting [24]. Because a fuel is metered in volume basis in a fuel injection system, a fuel with higher density results in a higher mass of it being injected [28]. Thus, fuel density affects its consumption. Biodiesel and diesel being advantageous and disadvantageous in their respective terms, blending them would yield a fuel with intermediate properties which may improve the combustion and emission characteristics of neat palm biodiesel and thus its usage as a fuel in a diesel engine. This study aims to establish the relationships between the percentage of palm biodiesel blended with diesel and the properties like density, kinematic viscosity, fire point and flash point.

2. Methodology:

The vegetable oil considered for the experiment was palm, which was obtained from commercial sources. Methanol was added to 0.1% FFA procured oil in 1:4 ratio along with sodium hydroxide pellets and heated to 60°C for 6 hours. This converts it to 90-97% of palm biodiesel with remaining 3-10% of glycerol. It was then allowed to settle for 16 hours and glycerol was separated from the processed biodiesel. To ensure zero moisture, the obtained biodiesel was reheated for 3 hours at 60°C. Thus the feedstock was converted to methyl esters by transesterification. Blend of the produced palm biodiesel and diesel in different volume percentages were prepared and designated as PD0 (Neat Diesel), PD10, PD20…up to PD100 (Neat Palm Biodiesel). Ostwald’s U-tube glass viscometer was used to determine the kinematic viscosity (at 38°C) of each sample prepared. Density of the blends at a temperature of 38°C was measured using a pycnometer of 25mL capacity [30]. Cleveland’s open cup apparatus was used to determine the flash and fire points of the prepared samples. For three separate determinations the uncertainty for all the measurements was 1%.

3. Results and discussion:

The kinematic viscosity (ν), density (ρ), flash point (FIP) and fire point (FiP) of the prepared blends are determined and tabulated as Table 1.
Table 1 Properties of the samples

| Blend | Kinematic viscosity (mm²/s) | Density (gm/cm³) | Flash point (°C) | Fire point (°C) |
|-------|-----------------------------|------------------|------------------|----------------|
| PD0   | 3.14                        | 0.796            | 52               | 57             |
| PD10  | 3.47                        | 0.806            | 61               | 66             |
| PD20  | 3.62                        | 0.812            | 68               | 74             |
| PD30  | 4.07                        | 0.818            | 70               | 75             |
| PD40  | 4.30                        | 0.823            | 72               | 77             |
| PD50  | 4.35                        | 0.826            | 74               | 80             |
| PD60  | 4.60                        | 0.829            | 78               | 82             |
| PD70  | 4.98                        | 0.830            | 85               | 91             |
| PD80  | 5.34                        | 0.833            | 104              | 109            |
| PD90  | 5.58                        | 0.840            | 120              | 126            |
| PD100 | 6.01                        | 0.846            | 172              | 177            |

3.1 Effect of blending on Kinematic Viscosity (ν): Viscosity is the property of fluid because of which there is resistance offered by one layer of fluid over its adjacent layer against relative motion between them [27]. A fuel which is more viscous has poor atomization characteristics and narrow spray angle [14]. One with poor viscosity, leads to excessive wear and poor lubrication [14]. Thus, it is desired for a fuel to possess optimum value of kinematic viscosity. Kinematic viscosity is included in biodiesel standards and the range is 1.9-6.0 mm²/s according to ASTM D6571 [31]. It can be noted that the viscosity of neat palm biodiesel, PD100, is almost double the viscosity of mineral diesel, PD0. However, the kinematic viscosity of the neat palm can be lessened to desired value by diluting it with diesel in different proportions, as shown in Table 1. PD10, blend with 10% of Palm in 90% of diesel has lowest viscosity followed by PD20, PD30 and so on. Addition of a higher viscosity component would obviously increase the viscosity of the sample and the experimental values were found to obey this fact. With the increasing palm biodiesel percentage, the viscosity of the sample was found to increase as shown in Fig. 1, but well lying within the lower limit (viscosity of neat diesel PD0) and the upper limit (viscosity of neat palm biodiesel PD100). The relation between kinematic viscosity of the blend and the biodiesel percentage (X) blended is

\[ ν = 0.0274 \times X + 3.1286 \]  (1)
Figure 1. Variation of kinematic viscosity of the blends with the biodiesel percentage blended.

The coefficient of regression is 0.9871. Equation (1) can be used to predict kinematic viscosity of a palm biodiesel-diesel blend, known the percentage of palm biodiesel added. It was validated using PD15 whose predicted viscosity and experimental viscosity are compared in Table 2.

Table 2 Comparison of viscosities predicted using equation (1) and the experimental values

|        | Predicted v (mm²/s) | Experimental v (mm²/s) |
|--------|---------------------|------------------------|
| PD10   | 3.41                | 3.47                   |
| PD15   | 3.54                | 3.50                   |
| PD20   | 3.67                | 3.62                   |

The viscosity of PD15 predicted using equation (1) is found to lie between the viscosities of PD10 and PD20, which validates it (Table 2). Viscosity of the blends is related to other properties as (Fig. 2)

\[
\rho = 0.0159 \nu + 0.752 \tag{2}
\]

\[
\text{FIP} = 12.822 \nu^3 - 159.01 \nu^2 + 664.82 \nu - 865.12 \tag{3}
\]

\[
\text{FiP} = 12.753 \nu^3 - 158.1 \nu^2 + 660.91 \nu - 854.53 \tag{4}
\]

The coefficients of regression for the equations (2), (3) and (4) are 0.9505, 0.9986 and 0.9985 respectively. A comparison of properties predicted using the above equations and the experimentally determined values is shown in Table 3. Kinematic viscosity of PD15 was determined as 3.50 mm²/s. Using this value in equations (2), (3) and (4), density, flash point and fire point of PD15 were predicted and are compared with the experimental values in Table 4.
Figure 2. Variation of density, flash point, fire point of the blends with the kinematic viscosity.

Table 3  Comparison of properties predicted using equations (2), (3), (4) and experimental values

|         | PD0 | PD1 | PD2 | PD3 | PD4 | PD5 | PD6 | PD7 | PD8 | PD9 | PD10 |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Predicted ρ | 0.80 | 0.81 | 0.82 | 0.83 | 0.82 | 0.83 | 0.83 | 0.83 | 0.83 | 0.84 | 0.847 |
| Experimental ρ | 0.79 | 0.81 | 0.82 | 0.82 | 0.82 | 0.83 | 0.83 | 0.83 | 0.83 | 0.84 | 0.846 |
| Predicted FlP | 51.5 | 66.0 | 71.1 | 72.9 | 73.3 | 76.4 | 85.7 | 103.2 | 121.2 | 171.6 | 171.6 |
| Predicted FlP | 9 | 6 | 4 | 5 | 6 | 4 | 6 | 2 | 2 | 6 |
Table 4 Validation of equations (2), (3) and (4)

|          | Predicted $\rho$ (gm/cm$^3$) | Experimental $\rho$ (gm/cm$^3$) | Predicted FIP (°C) | Experimental FIP (°C) | Predicted FIP (°C) | Experimental FIP (°C) |
|----------|-------------------------------|---------------------------------|--------------------|----------------------|--------------------|----------------------|
| PD10     | 0.807                         | 0.806                           | 62.93              | 61                   | 68.03              | 66                   |
| PD15     | **0.808**                     | **0.811**                       | **63.62**          | **62**               | **68.71**          | **67**               |
| PD20     | 0.809                         | 0.812                           | 66.04              | 68                   | 71.13              | 74                   |

It has to be noted that as per EN ISO-3104 the viscosity should lie between 3.5-5.0 mm$^2$/s, according to which PD70, PD80, PD90 and PD100 can be eliminated from the usage. However, it can be concluded that PD10 is better than PD60 in terms of atomization (less viscous) at an expense of higher emissions, as suggested by literature too [14].

3.2 Effect of blending on density: Density of a fuel influences its consumption. It is preferred to have a less denser fuel whose consumption would be less. Palm biodiesel is slightly denser than conventional diesel as shown in Table 1. Blending Palm biodiesel with diesel would reduce its density to some extent. Higher the palm biodiesel content, higher is the density of the blend as shown in Fig. 3. However, there is no much appreciable change found in the density of the sample. It is related to the content of Palm biodiesel in the blend ($R^2=0.963$)

$$\rho = 0.0004X + 0.8016$$  \hspace{1cm} (5)

![Figure 3. Variation of density of the blends with the biodiesel percentage blended.](image)
Density of a blend of 15% Palm biodiesel in 85% of diesel was determined using equation (5). Its density was experimentally found as 0.811 gm/cm³ and is compared to the predicted value in Table 5.

Table 5 Comparison of densities predicted using equation (5) and the experimental values

|       | Predicted ρ (gm/cm³) | Experimental ρ (gm/cm³) |
|-------|----------------------|-------------------------|
| PD10  | 0.806                | 0.806                   |
| PD15  | 0.807                | 0.811                   |
| PD20  | 0.809                | 0.812                   |

The density predicted using equation (5) not only lies between the densities of PD10 and PD20 but also is close to the density determined experimentally, validating equation (5). Density and viscosity are related to each other (shown in Fig. 4) as

\[ \nu = 59.601 \rho - 44.597 \]  

A comparison of properties predicted using the above equation (6) and the experimentally determined values is shown in Table 6. Density of PD15 was determined as 0.811gm/cm³. Using this value in equation (6) kinematic viscosity of PD15 was predicted as 3.73mm²/s. The kinematic viscosity of PD15 was also determined experimentally and is compared to the predicted value in Table 7.
Table 6 Comparison of viscosities predicted using equation (6) and experimental values

|        | PD0 0 | PD1 0 | PD2 0 | PD3 0 | PD4 0 | PD5 0 | PD6 0 | PD7 0 | PD8 0 | PD9 0 | PD10 0 |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Predicted v | 2.84  | 3.42  | 3.77  | 4.18  | 4.45  | 4.63  | 4.85  | 4.91  | 5.08  | 5.50  | 5.82   |
| Experimental v | 3.14  | 3.47  | 3.62  | 4.07  | 4.37  | 4.6    | 4.98  | 5.34  | 5.58  | 6.01  |        |

Table 7 Validation of equation (6)

|        | Predicted v (mm²/s) | Experimental v (mm²/s) |
|--------|--------------------|-----------------------|
| PD10   | 3.41               | 3.47                  |
| PD15   | 3.73               | 3.50                  |
| PD20   | 3.77               | 3.62                  |

3.3 Effect of blending on Flash point: Neat palm biodiesel PD100 is found to have flash point of 172°C, which does not satisfy the ASTM D93 standards according to which the maximum limit is 130°C [14]. Adding diesel to it in 10%, pulled down it value within the limits specified by ASTM D93. The flash point increases on increasing the percentage of palm biodiesel in diesel, as shown in Table 1. The changes in flash point with the changes in biodiesel percentage are shown in Fig. 5. The relation between flash point of the blend and the percentage of biodiesel (X) added is

\[
\text{FIP} = 0.0004 X^3 - 0.0444 X^2 + 1.6794 X + 50.126
\]  

(7)

Flash point of PD15 predicted using equation (7) and that determined experimentally are shown in Table 8. Its value not only lies between that of PD10 and PD20 but also is comparable to the experimentally determined value, as in Table 8. Once the flash point of a blend is determined experimentally other properties of the sample can be (variation is shown in Fig. 6) predicted using the equations (8), (9) and (10)

\[
v = 7e-6 \text{FIP}^3 - 0.0027 \text{FIP}^2 + 0.3501 \text{FIP} - 8.7308
\]  

(8)

\[
\rho = e-7 \text{FIP}^3 - 5e-5 \text{FIP}^2 + 0.0067 \text{FIP} + 0.5837
\]  

(9)

\[
\text{FiP} = 1.0001 \text{FIP} + 4.9894
\]  

(10)
Figure 5. Variation of flash point of the blends with the biodiesel percentage blended.

The coefficient of regression for equation (8), (9) and (10) are 0.9699, 0.9619 and 0.9996 respectively. A comparison of properties predicted using the above equations (8), (9), (10) and the experimentally determined values is shown in Table 9. The flash point of PD15 was determined experimentally as 62°C. This value was used in equations (8), (9) and (10) to predict other properties of PD15, tabulated in Table 10.

Table 8 Comparison of flash point predicted using equation (7) and the experimental values

|          | Predicted FIP (°C) | Experimental FIP (°C) |
|----------|--------------------|-----------------------|
| PD10     | 62.88              | 61                    |
| **PD15** | **66.67**          | **62**                |
| PD20     | 69.15              | 68                    |

Table 9 Comparison of properties predicted using equations (8), (9), (10) and experimental values

|          | PD0 0 | PD1 0 | PD2 0 | PD3 0 | PD4 0 | PD5 0 | PD6 0 | PD7 0 | PD8 0 | PD9 0 | PD10 0 |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Predicted ν | 2.84  | 3.40  | 3.78  | 3.87  | 3.96  | 4.04  | 4.20  | 4.44  | 4.84  | 4.97  | 4.66   |
| Experimental ν | 3.14  | 3.47  | 3.62  | 4.07  | 4.35  | 4.6  | 4.98  | 5.34  | 5.58  | 6.01  |        |
| Predicted ρ | 0.78  | 0.80  | 0.80  | 0.81  | 0.81  | 0.81  | 0.83  | 0.83  | 0.83  | 0.84  | 0.795  |
| Experimental ρ | 0.79  | 0.80  | 0.81  | 0.82  | 0.82  | 0.83  | 0.83  | 0.83  | 0.84  | 0.846 | 0.845  |
| Predicted FiP | 57.2  | 66.2  | 73.2  | 75.2  | 77.2  | 79.2  | 83.2  | 90.2  | 109.  | 125.  | 177.3  |
| Experimental FiP | 57    | 66    | 74    | 75    | 77    | 80    | 82    | 91    | 109   | 126   | 177    |
Figure 6. Variation of kinematic viscosity, density, fire point of the blends with flash point of the blends

Table 10 Validation of equations (8), (9) and (10)

|      | Predicted v (mm²/s) | Experimental v (mm²/s) | Predicted ρ (gm/cm³) | Experimental ρ (gm/cm³) | Predicted FiP (°C) | Experimental FiP (°C) |
|------|--------------------|------------------------|----------------------|-------------------------|--------------------|-----------------------|
| PD10 | 3.40               | 3.47                   | 0.800                | 0.805                   | 66.25              | 66                    |
3.4 Effect of blending on Fire point: It is observed that the fire point of the sample increases with the biodiesel percentage, as shown in Fig. 7. The relation between the fire point of the blend and the biodiesel percentage is given as

$$\text{FiP} = 0.0004 X^3 - 0.0446 X^2 + 1.6913 X + 55.224$$

(11)

Fire point of PD15 predicted using equation (11) and that determined experimentally are shown in Table 11. Its value not only lies between that of PD10 and PD20 but also is comparable to the experimentally determined value, as in Table 11. Found the fire point of a blend experimentally, other properties of the sample can be (variation is shown in Fig. 8) predicted using the equations (12), (13) and (14)

$$\nu = 2e-6 \text{FiP}^3 - 0.0027 \text{FiP}^2 + 0.3501 \text{FiP} - 8.7308$$

(12)

$$\rho = 9e-8 \text{FiP}^3 - 4e-5 \text{FiP}^2 + 0.0052 \text{FiP} + 0.6072$$

(13)

$$\text{FiP} = 0.9989 \text{FiP} - 5.1742$$

(14)

The coefficient of regression for equation (12), (13) and (14) are 0.965, 0.9559 and 0.9996 respectively. A comparison of properties predicted using the above equations (12), (13), (14) and the experimentally determined values is shown in Table 12. The fire point of PD15 was determined experimentally as 67°C. This value was used in equations (12), (13) and (14) to predict other properties of PD15, tabulated in Table 13.

| PD15 | 3.46 | 3.50 | 0.801 | 0.811 | 67.25 | 67 |
|------|------|------|-------|-------|-------|----|
| PD20 | 3.77 | 3.62 | 0.807 | 0.811 | 73.25 | 74 |

Figure 7. Variation of fire point of the blends with the biodiesel percentage blended.

Table 11 Comparison of fire point predicted using equation (11) and the experimental values
Table 12 Comparison of properties predicted using equations (12), (13), (14) and experimental values

|       | Predicted ν  | Experimental ν | Predicted ρ  | Experimental ρ  | Predicted FlP  | Experimental FlP |
|-------|--------------|----------------|--------------|-----------------|----------------|------------------|
| PD0   | 3.08         | 3.14           | 0.790        | 0.796           | 51.76          | 52               |
| PD1   | 3.73         | 3.47           | 0.802        | 0.802           | 60.75          | 61               |
| PD2   | 4.23         | 4.07           | 0.810        | 0.810           | 68.74          | 68               |
| PD3   | 4.29         | 4.3            | 0.811        | 0.813           | 71.74          | 70               |
| PD4   | 4.41         | 4.35           | 0.823        | 0.826           | 74.73          | 72               |
| PD5   | 4.57         | 4.6            | 0.829        | 0.832           | 76.73          | 74               |
| PD6   | 4.68         | 4.98           | 0.830        | 0.833           | 85.72          | 85               |
| PD7   | 5.12         | 5.34           | 0.833        | 0.838           | 103.7          | 104              |
| PD8   | 5.83         | 5.58           | 0.833        | 0.840           | 120.6          | 120              |
| PD9   | 6.36         | 5.58           | 0.834        | 0.846           | 171.6          | 172              |
| PD10  | 7.68         | 6.01           | 0.846        |                 |                |                  |

Table 13 Validation of equations (12), (13) and (14)

|       | Predicted ν  | Experimental ν | Predicted ρ  | Experimental ρ  | Predicted FlP  | Experimental FlP |
|-------|--------------|----------------|--------------|-----------------|----------------|------------------|
| PD10  | 3.73         | 3.47           | 0.802        | 0.802           | 60.75          | 61               |
| PD15  | 3.79         | 3.50           | 0.803        | 0.811           | 61.75          | 62               |
| PD20  | 4.23         | 3.62           | 0.809        | 0.812           | 68.74          | 68               |
4. Conclusions

The present study arrives at the following conclusions

1. Adding palm biodiesel to diesel worsened the diesel properties but it helped in lowering the kinematic viscosity of neat palm biodiesel within the allowable limit of 1.9-6.0 mm²/s as per ASTM D6571. According to EN ISO-3104, the kinematic viscosity is limited between 3.5-5.0 mm²/s and thus PD70, PD80, PD90 and PD100 can be eliminated from the usage. However, it can be concluded that PD10 is better than PD60 in terms of atomization (less viscous) at an expense of higher emissions, as suggested by literature [6].
2. Blending palm biodiesel with diesel lowered the flash point of the earlier such that it falls within the allowable limit of 130°C according to ASTM D93.
3. Equations to calculate the properties of the blend, with the biodiesel percentage added to diesel as input have been developed.
4. An inter-dependent relation between the density and viscosity of the blends is observed. Making the diesel denser (0.796 to 0.846gm/cm³) by adding palm biodiesel to it makes it more viscous (3.14 to 6.01mm²/s).
5. The inter-relationship between all the properties is established as equations.

Blending diesel with palm biodiesel may be of no use relative to diesel, but when compared to neat palm biodiesel, it helped in pulling down the viscosity, density, flash point and fire point and thus made it (palm biodiesel) better in terms of atomization and spray characteristics, specific fuel consumption and volatility.

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