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A Methodological Research on Sunflower Biodiesel and Diesel Blends

Namrata Mishra [1], Amar Kumar Das[2]
[1]*(Department of Mechanical Engineering, Gandhi Engineering College, India)*
[2]*(Department of Mechanical Engineering, Gandhi Institute For Technology, India)*

Abstract: *So as to meet the prerequisite of an inexhaustible fuel for pressure start diesel motors, biodiesel was transesterified from sunflower oil, which was gooey and denser than regular petrodiesel. With the benefits of improved burning productivity and decreased outflows, as the writing recommends, biodiesel can be utilized to run the motor yet to a detriment of expanded fuel utilization, poor atomization and splash qualities. Mixing diesel with biodiesel could help somewhat in conquering the disservices of perfect biodiesel, with properties lying between those of flawless diesel and slick biodiesel. In such manner, diesel-biodiesel mixes were set up in various volume extents and the primary fuel properties like kinematic thickness, thickness, streak point and fire purpose of the mixes were resolved. By expanding biodiesel content, streak point and fire point expanded, which is invaluable as far as wellbeing and fuel versatility. In any case, higher the biodiesel content, higher was the kinematic consistency and thickness which pulls down the atomization attributes as well as debilitates the vitality substance of the fuel. Mixes with biodiesel content over 60% end up being exceptionally thick and consequently can be precluded from being utilized. Connections were created to decide the properties of the mix, given the level of biodiesel mixed. These relationships were approved utilizing various mixes other than those used to create them.*
Key words: *Flash Point, Fire Point, Kinematic, Viscosity and Density, Biodiesel*

I. Introduction

The fact that conventional petrol and diesel fuels would get extinct in near future has driven the world of research to search for an alternative renewable fuel. The alternative fuel is supposed to be a solution for both the availability and the pollution caused by the conventional fuels. Vegetable oils were found to be promising alternatives which were not only renewable but were also easy to produce [1-6]. Several experiments [7, 8] on diesel engine with vegetable oils as fuel were conducted and it was concluded that the performance is poor because of high viscosity, high density, poor calorific value and polyunsaturated content of the vegetable oils. The high viscosity of the vegetable oil resulted in poor atomization characteristics and increased penetration leading to engine deposits [7, 9] which can be reduced by techniques like pyrolysis, transesterification, blending or micro-emulsification. Transesterification is the most viable process adopted so far for reducing the viscosity of vegetable oils [1, 10] in which alcohol is added to separate glycerin by converting triglycerides to monoglycerides, thus processing pure biodiesel [11-16]. Thus processed biodiesel is defined as the mono alkyl esters of long-chain fatty acids, for use in CI engines [13, 14, 17].

When compared to diesel, biodiesel results in better ignition quality and reduced emissions. It has higher flash point, negligible sulfur content and higher cetane number [18]. However, it is disadvantageous in terms of its higher viscosity and density [19].

Viscosity of a fuel is an indication of its ability to flow through injection nozzles and pipelines [5]. More viscous fuel leads to increased penetration and poor atomization while a less viscous fuel results in excessive wear [1]. Apparently, kinematic viscosity of sunflower methyl esters is found to be double the kinematic viscosity of diesel [2]. Thus, kinematic viscosity becomes an important parameter to be focused on.

Denser the fuel used in a diesel engine, more will be the amount of fuel consumed and thus density of a fuel plays a vital role in the fuel consumption along with its calorific value. The densities of biodiesels are generally higher than those of fossil diesel fuel. The values depend on their fatty acid composition as well as on their purity [1].

Flash point of a fuel indicates how quick it gets ignited [5]. A fuel with high flash point would be less volatile in nature. The fire point is the minimum temperature at which the fuel vapors will continue burning after being ignited even after the removal of the ignition source.

Thus, the biodiesel obtained by transesterification can be blended with conventional diesel, which could be a solution to disadvantages of both the biodiesel and the diesel. Along with the study of blending effect on the properties, this study aimed at estimating the mathematical relationships between the properties of the fuel that characterize it and the percentage of biodiesel blended with the conventional diesel to improve its combustion characteristics.

II. Methodology

Refined sunflower vegetable oil was purchased from a local market and was analyzed based on density at 25 `C (ASTM D4052), kinematic viscosity (ASTM D445), free fatty acid content (AOCS Ca-5a-40), and water content (AOCS Aa 3e38). Methanol (purity> 99.8%), n-hexane, sodium hydroxide (85%, pellets) were supplied by a local vendor. Methanol was added to sunflower oil, preheated to 60`C, in 6:1 ratio with 1% of sodium hydroxide as catalyst [2] and stirred at a speed of 500 rpm for 6 hours. The mixture was then allowed to settle in a separation flask for glycerin recovery. The processed sunflower biodiesel was blended with No.2 Diesel in different volume proportions. The samples prepared were named as SD0 (Neat Fossil Diesel), SD10, SD20…up to SD100 (Neat Sunflower Biodiesel). The kinematic viscosity of each sample prepared was determined by an Ostwald's U-tube glass viscometer at 313K, which was calibrated using distilled water. Density measurements were made using a pycnometer of 25mL capacity, at a temperature of 313K, calibrated using distilled water. Flash point and fire point of the prepared samples were determined by Cleveland's open cup apparatus as specified by ASTM. The uncertainty for all the measurements is between 0.5-1.5 percent for three separate determinations.

III. Results And Discussion

The measured kinematic viscosity (ν), density (ρ), flash point (FlP) and fire point (FiP) of eleven samples (including neat fossil diesel and neat sunflower biodiesel) prepared are given in Table 1.

Table 1 Viscosity, density, flash point and fire point measurements of eleven samples

NO	Blend sample	Kinematic viscosity (mm^2/s)	Density (gm/cm^3)	Flash point (`C)	Fire point (`C)
1	SD0	3.14	0.796	52	57
2	SD10	3.38	0.812	54	59
3	SD20	3.43	0.814	57	63
4	SD30	3.87	0.822	60	65
5	SD40	4.35	0.831	64	67
6	SD50	4.64	0.837	69	74
7	SD60	4.96	0.841	73	79
8	SD70	5.51	0.846	78	83
9	SD80	5.80	0.852	110	115
10	SD90	6.01	0.855	135	140
11	SD100	6.35	0.863	177	182

3.1. Effect of biodiesel percentage on Kinematic Viscosity

Viscosity of a fuel is an indication of its ability to flow through injection nozzles and pipelines. The kinematic viscosity of sunflower methyl esters (6.35 mm^2/s) is found to be double the kinematic viscosity of diesel (3.14 mm^2/s). The kinematic viscosity has to be optimum and should lie between 1.9-6.0 mm^2/s as per ASTM D445 [1]. The kinematic viscosity of pure sunflower biodiesel is found to be 6.35mm^2/s. However, its viscosity could be decreased and set within the limits by blending it with diesel as shown in Table 1. It is found that SD60, SD70, SD80, SD90 and SD100 get eliminated from being used as a fuel in diesel engine as per EN ISO-3104 standards, according to which the kinematic viscosity is limited between 3.5-5.0 mm^2/s. The viscosity of the conventional diesel increases with the increasing sunflower biodiesel content in it, as shown in Figure 1. The viscosity (ν) of the fuel is related to the percentage of biodiesel (X) content as

$\nu = 0.0342\ X + 2.9686$ (1)

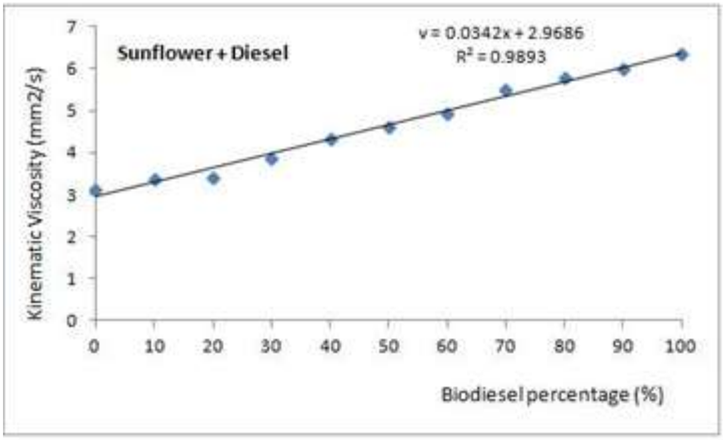

Figure 1 Correlation between biodiesel percentage in diesel and the viscosity of the blends.

The coefficient of regression is 0.9893. To validate the equation (1), a sample with 15% sunflower biodiesel and 85% diesel was prepared and the properties were determined. The kinematic viscosity of SD15 was found to be 3.41 mm^2/s, while the value predicted using equation (1) was 3.48 mm^2/s, which confirms the validity of the equation (1). Viscosities of the blends were calculated using Arrhenius, Bingham, Kendall & Monroe [20] equations and compared to those predicted using equation (1) in Table 2.

Arrhenius equation: $\log \nu_{blend} = x_{v1} * \log \nu_1 + x_{v2} * \log \nu_2$ (2)

Bingham equation: $1/\nu_{blend} = x_{v1} / \nu_1 + x_{v2} / \nu_2$ (3)

Kendall & Monroe: $\nu blend^{1/3} = xv1 * \nu 1^{1/3} + xv2 * \nu 2^{1/3}$ (4)

Where, xv1 and xv2 are the volume fractions of diesel and biodiesel respectively. ν1 and ν2 are kinematic viscosities of neat diesel (3.14 mm^2/s) and neat biodiesel (6.35 mm^2/s) respectively.

Table 2 Comparison of predicted kinematic viscosities of the blends

	SD 0	SD 10	SD 20	SD 30	SD 40	SD 50	SD 60	SD 70	SD 80	SD 90	SD 100
Arrhenius	3.14	3.37	3.61	3.88	4.16	4.47	4.79	5.14	5.52	5.92	6.35
Bingham	3.14	3.31	3.49	3.7	3.94	4.2	4.51	4.86	5.27	5.76	6.35
Kendall & Monroe	3.14	3.4	3.66	3.95	4.25	4.56	4.88	5.23	5.58	5.96	6.35
Equation (1)	2.97	3.31	3.65	3.99	4.34	4.68	5.02	5.36	5.7	6.05	6.39
Experimental value	3.14	3.38	3.43	3.87	4.35	4.64	4.96	5.51	5.8	6.01	6.35

The data pertaining to determined kinematic viscosity and density, flash point, fire point of the samples with the varying sunflower biodiesel content in the conventional diesel, was used to establish the relationships between viscosity and the density, flash point, fire point of the blend as shown in Figure 2 and the relations are found to be

$= 0.0166\ \nu + 0.7572$ (5)

$$FlP = 12.018\ \nu^3 - 152.51\ \nu^2 + 644.74\ \nu - 844.23 \quad (6)$$

$$FiP = 11.76\ \nu^3 - 148.68\ \nu^2 + 626.34\ \nu - 810.67 \quad (7)$$

A high regression of 0.9897 is found between density and viscosity of the blends. The regression coefficient for viscosity and flash point, fire point is 0.9873 and 0.9865 respectively. Experimentally determined density, flash point and fire point of SD15 are 0.814 gm/cm^3, 55`C and 60`C respectively. Experimental viscosity of SD15 was used in equations (5), (6) and (7) to predict density, flash and fire points and they are found to be 0.815 gm/cm^3, 57.9`C and 62.9`C respectively, validating the used equations.

Blending diesel with sunflower biodiesel made the sample more viscous which is not preferred. Though, blending has shown negative effects, it helped in concluding that sunflower biodiesel should not be blended more than 60% to avoid increased viscosity. Thus, it can be concluded that SD10 to SD50 samples would exhibit reduced emissions but at the cost of higher specific fuel consumption [5].

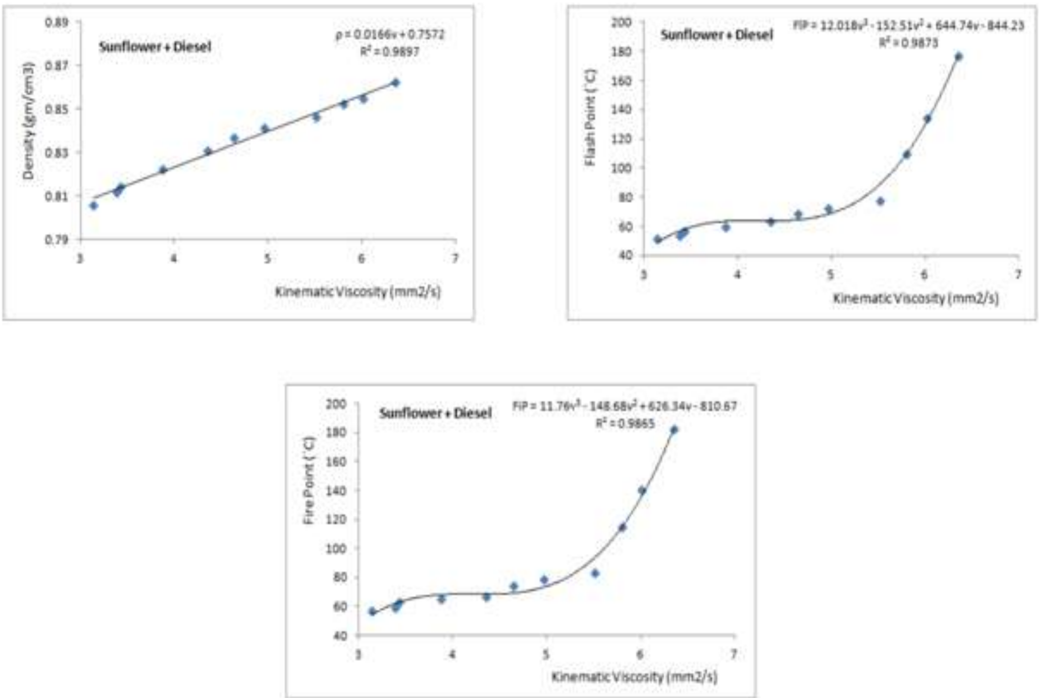

Figure 2 Comparison of kinematic viscosity and density, flash point, fire point of the blends

3.2. Effect of biodiesel percentage on Density

Density of a fuel is one of the most important fuel properties that affect engine performance. It is found to be slightly higher than that of Diesel fuel as shown in Table 1. However, it could be reduced by blending diesel with the biodiesel. It is found that, with the increasing sunflower biodiesel content in Diesel, the density increases, as shown in Figure 3. Density of the blend is related to biodiesel blend percentage ($R^2 = 0.9919$) as

$$\rho = 0.0006\ X + 0.8061 \quad (8)$$

Equation (8) is validated using SD15 whose experimental density is 0.814 gm/cm^3 and the value predicted using the given relation is 0.815 gm/cm^3. As the density of fuel was increased by increasing the biodiesel content, the viscosity also found to increase and they are related as (shown in Figure 4)

$$\nu = 59.773\ \rho - 45.209 \quad (9)$$

Validation of equation (9) is done using SD15 whose experimentally determined viscosity is 3.41 mm^2/s and the predicted one being 3.44 mm^2/s.

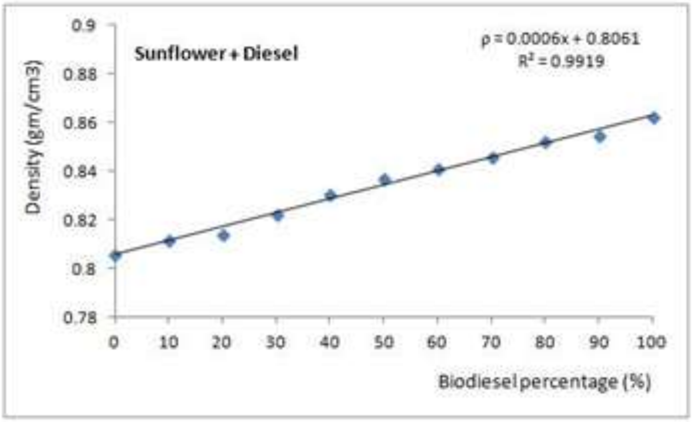

Figure 3 Variation of density with varying biodiesel percentage.

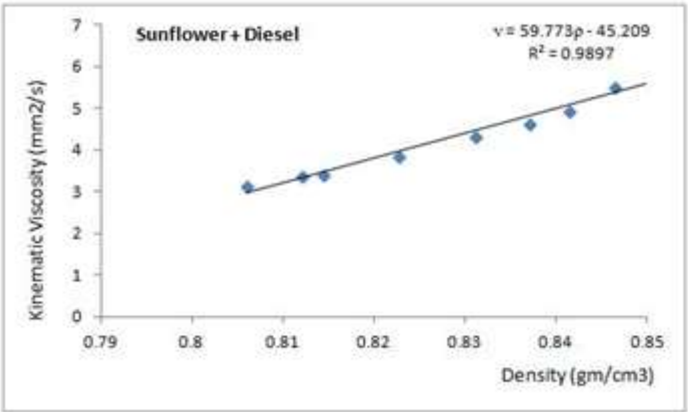

Figure 4 Comparison of kinematic viscosity and density of the blends

3.3. Effect of biodiesel percentage on Flash point

Flash point of the sample increased with the increasing biodiesel content, as shown in Figure 5. Neat sunflower biodiesel has a flash point of 177`C which is not acceptable according to ASTM D-93 where it is limited to 130`C. However, other samples with portion of diesel exhibited acceptable values as shown in Table 1. The relation between biodiesel percentage and the flash point of the sample is given as equation (10).

$$FlP = 0.0003\,X^3 - 0.0262\,X^2 + 0.8551\,X + 50.014 \qquad (10)$$

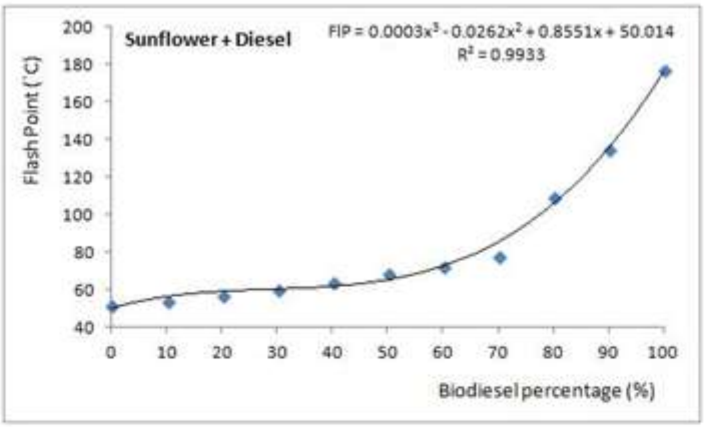

Figure 5 Variation of flash point with biodiesel percentage in diesel

Equation (10) is validated using SD15 whose experimental flash point is 55`C and that predicted using the above equation is 57.9`C. Determined the Flash point of a blend experimentally, kinematic viscosity, density and fire point of the sample can be predicted using the following equations (11), (12) and (13) respectively.

$$\nu = 7e\text{-}6\ FlP^3 - 0.0027\ FlP^2 + 0.3501\ FlP - 8.7308 \qquad (11)$$

$$\rho = e\text{-}7\ FlP^3 - 5e\text{-}5\ FlP^2 + 0.0067\ FlP + 0.5837 \qquad (12)$$

$$FiP = 1.0001FlP + 4.9894 \qquad (13)$$

The coefficients of regression for equations (11), (12) and (13) are 0.9861, 0.9908 and 0.9996 respectively. Figure 6 represents the variation of viscosity, density and fire point with varying flash point.

Flash point of SD15 is determined to be 55`C. The kinematic viscosity, density and fire point of the sample predicted using the determined flash point are 3.52 $mm^2/s$, 0.8715 $gm/cm^3$ and 59.99`C respectively. These values are close to experimentally determined kinematic viscosity, density and fire point which are 3.41 mm^2/s, 0.814 gm/cm^3 and 60`C respectively.

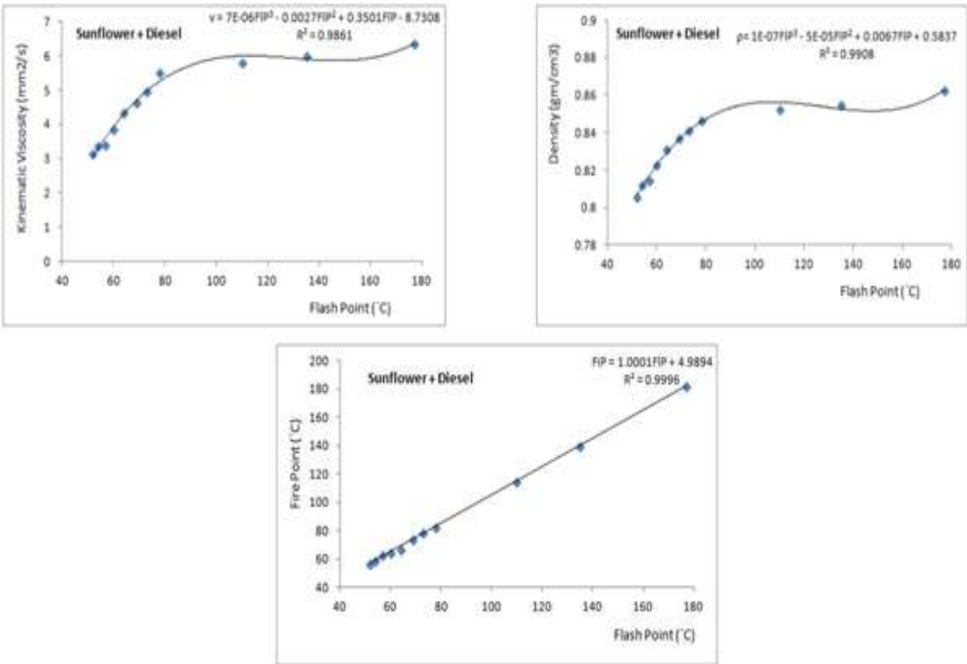

Figure 6 Comparison of flash point and kinematic viscosity, density, fire point of the blends

3.4. Effect of biodiesel percentage on Fire point

As the biodiesel percentage increased the fire point of the sample also increased, as shown in Figure 7. The relation between biodiesel percentage and the fire point of the sample is given as

$$FiP = 0.0003\ X^3 - 0.0255\ X^2 + 0.8235\ X + 55.294 \qquad (14)$$

Equation (14) is validated using SD15 whose experimental fire point is 60`C and that predicted using the above equation is 62.9`C.

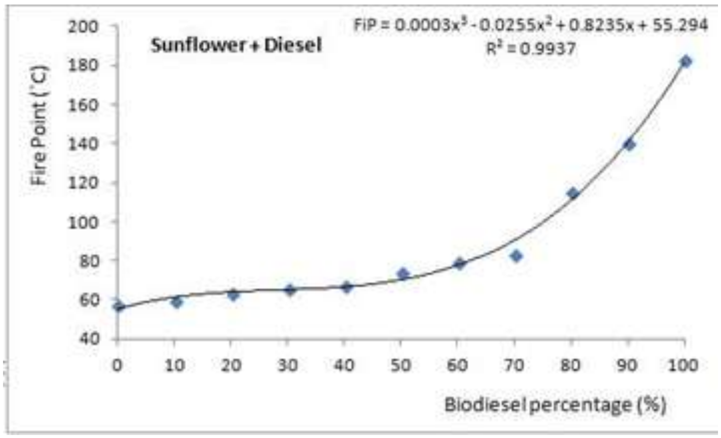

Figure 7 Variation of fire point with biodiesel percentage in diesel

Known the fire point of a blend, the kinematic viscosity, density and flash point of the sample can be predicted using equations (15), (16) and (17) respectively.

$$\nu = 7e\text{-}6\ FiP^3 - 0.0028\ FiP^2 + 0.3741\ FiP - 10.405 \quad (15)$$

$$\rho = e\text{-}7\ FiP^3 - 6e\text{-}5\ FiP^2 + 0.0072\ FiP + 0.5514 \quad (16)$$

$$FlP = 0.9995\ FiP - 4.9551 \quad (17)$$

The coefficients of regression for equations (15), (16) and (17) are 0.978, 0.9808 and 0.9996 respectively. The variation of viscosity, density and fire point of the blends, with varying flash point is shown in Figure 8.

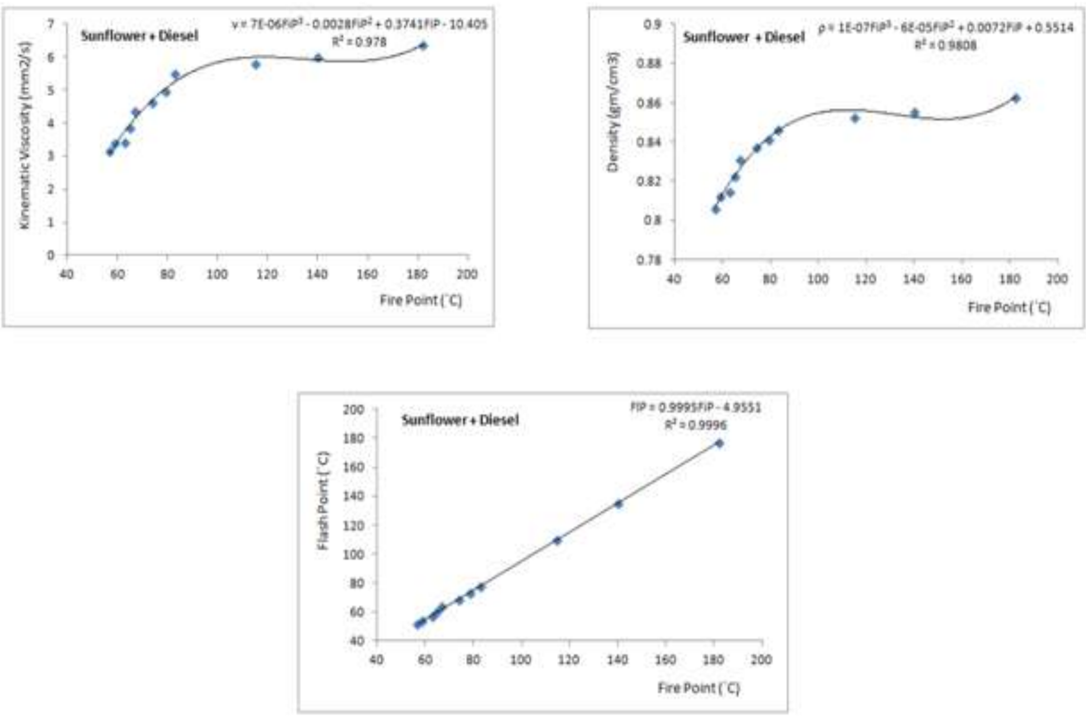

Figure 8 Comparison of fire point and kinematic viscosity, density, flash point of the blends

Fire point of SD15 is determined to be 60`C. The kinematic viscosity, density and flash point of the sample predicted using the determined fire point are 3.47 $mm^2/s$, 0.789 $gm/cm^3$ and 55`C respectively. These values are close to experimentally determined kinematic viscosity, density and flash point which are 3.41 mm^2/s, 0.814 gm/cm^3 and 55`C respectively.

IV. Conclusions

The following conclusions can be drawn from the study

1. A high regression between viscosity and density of the blends is observed. Increasing the density of the diesel (by blending it with sunflower biodiesel) from 0.806 to 0.860 gm/cm^3 increased its viscosity from 3.14 to 6.35 mm^2/s.
2. Blending sunflower biodiesel with diesel helped in getting down its kinematic viscosity within the acceptable limit of 1.9-6.0mm^2/s as per ASTM D6571.
3. It is found that SD60, SD70, SD80, SD90 and SD100 get eliminated from being used as a fuel in diesel engine as per EN ISO-3104 standards, according to which the kinematic viscosity is limited between 3.5-5.0 mm^2/s.
4. The values of kinematic viscosity predicted using the proposed equation (1) were comparable to already established Arrhenius, Bingham and Kendall & Monroe equations.
5. Blending could not bring in appreciable changes to the density of the sample.
6. Blending sunflower biodiesel with diesel helped in pulling down its flash point within the acceptable limit of 135`C as per ASTM D93.
7. Blending has increased the flash point of diesel which is advantageous in terms of fuel storage but disadvantageous in terms of volatility.
8. Equations have been developed to calculate the properties of sunflower biodiesel and diesel blend, given the biodiesel percentage blended with the diesel.
9. Well lying within the limits, all the samples showed an expected trend.
10. Equations which interrelate the properties are also established, which will facilitate the prediction of other properties with one determined property for a sample with any percentage of sunflower biodiesel in diesel.

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