



## Assessment of density and kinematic viscosity of two methyl ester blends at elevated temperatures

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### ABSTRACT

Fuel properties are essential components in the performance and emission of internal combustion engines. To measure density, viscosity and other properties of methyl esters and two methyl esters blends in the temperature range of 25°C–95°C. Experimental investigations is carried out using standard equipments and methodology. Test fuels considered are Pongamia, Jatropha and Simarouba biodiesels and blends of two biodiesels in different volume fraction of 0% to 100%. Density of Pongamia-Jatropha and Pongamia-Simarouba biodiesel blends increases linearly with increase in volume fraction of Pongamia methyl esters at all the temperatures. Density of Jatropha-Simarouba biodiesel blends increases with increase in volume percentage of Jatropha in the blends. The kinematic viscosities of blends are found to reduce almost logarithmically with increase in temperature. Viscosity of the blends lies between the constituent fuels. The measured value of density and viscosity is correlated as function of blend percentage and temperature through an empirical relation. The correlations developed are unique and are model equations. The maximum % density variation between the experimental results and estimated results is 0.4%, where as percentage viscosity variation between experimental results and estimated results from correlation is 5%.

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### 1. Introduction

Petroleum fuels are depleting rapidly due to the growth in number of automobiles and amid increase in population throughout the world year by year. This demands an urgent need for exhaustive research for finding alternate fuels. Vegetable oils are the strong contender as an alternate fuel for diesel engines. Properties of vegetable oils are differing from diesel fuel hence it is required to bring the properties of vegetable oils close to diesel and to meet ASTM standard. Vegetable oils are processed by different methods to produce biodiesel. Transesterification is one of the processes used to convert vegetable oil to biodiesel. Methyl or ethyl alcohol is used for transesterification process to produce biodiesel in presence of catalyst [1]. Biodiesel fuel is receiving attention because these are sulfur free, non-toxic, biodegradable, oxygenated fuel [2,3], improves combustion efficiency [4], superior lubrication properties [2] and produces fewer harmful emissions and pollutants [2,3]. Properties of biodiesel and petroleum diesel are comparable [5].

Physical properties biodiesel can be improved by mixing with other biodiesel. The properties which could be improved are density, viscosity, low temperature properties such as pour point, cloud point and filter plugging point when it is mixed with other biodiesel [6]. However injection, vaporization of fuel may be affected because of higher viscosity of biodiesel, affecting the engine operation [7].

The advantage of biodiesel is that it may reduce global warming gas emissions, such as CO (carbon monoxide), HC (hydrocarbon), other air toxics and particulate matter [8]. Biodiesel has higher viscosity and improves lubrication and reduces wear of engine components and improve the engine life [3]. The environmental benefits of bio diesels are renewable, biodegradable, and have clean combustion behavior [3].

It is observed by number of researchers that 80%–90% of air pollution can be reduced using 100 percent biodiesel (B100), whereas toxics can only be reduced by 20–40% using B20 [9]. And it is further noticed that the risk of life threatening diseases and other illness such as cancer can be reduced using methyl-ester blends [10].

Researchers have carried out, experimental investigation to changes the properties of biodiesel after blending with diesel

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### Nomenclature

DRP-J	Density Ratio of Pongamia + Jatropha blend
J100	Neat Jatropha
J-S	Jatropha + Simarouba blend
P100	Neat Pongamia
P-J	Pongamia + Jatropha blend
S100	Neat Simarouba
T	Temperature [°C]
VRP-J	Viscosity Ratio of Pongamia + Jatropha blend
X	Biodiesel percentage in blend [%]

### Greek symbol

N	Kinematic Viscosity [mm <sup>2</sup> /s]
P	Density [Kg/m <sup>3</sup> ]

### Suffix

J-S	% of Jatropha in Jatropha + Simarouba blend
P-J	% of Pongamia in Pongamia + Jatropha blend

[11]. Empirical models and methods are developed for measuring and predicting density [12], dynamic and kinematic viscosity [13,14] of biodiesel and its blends by researchers and found that these are temperature dependent. An empirical correlation has been developed, which relate the density and viscosity of biodiesel is also reported [14]. However comprehensive studies are not carried out to find effect of temperatures on variation in the density and viscosity of blends of two or more biodiesel. Siraj Sayed et al. [15] investigated the dual biodiesel properties of Jatropha, Karanja, Mahua and Neem to check the performance and emissions developed in engine. Brake thermal efficiency was lower, also there was a significant decrease in carbon monoxide emissions. Harish et al. [16] conducted experiment by blending Pongamia biodiesel, animal fat oil biodiesel and waste cooking oil biodiesels in different proportions and reported that the physical properties match with ASTM standards of diesel. Pongamia pinnata is a plant which is a native of Asian subcontinent. It is a non-edible oil tree which produces 30–40% of oil from its seeds. Generally grows on the river banks, coasts as well as harsh weather conditions. Oil is thicker in nature as a result in winter seasons this may choke the fuel pipes and cause damage to the engine. Performance of Pongamia biodiesel on engine gave good results which matches nearly to that of diesel.

The present work investigates experimentally effect of temperature and variation of volume fraction of two different biodiesel on density, kinematic viscosity and dynamic viscosity. Three types of biodiesels are considered to carry out the investigations and for analysis of properties. Biodiesel preferred for the investigation are Pongamia, Jatropha, and Simarouba.

## 2. Experimental procedure

Experimental investigation is carried out using standard equipments with standard procedure. Fuels considered for the investigation are Pongamia, Jatropha and Simarouba methyl-esters. Two methyl esters are considered at a time and blended in different volume fraction. Two methyl-esters mixture is prepared in 500 ml flask. Two methyl-ester of different volume fractions are added and stirred continuously for the duration of mixture preparation to ensure uniformity of two methyl-esters. Various mixture prepared are P-J, J-S and P-S blends. Prepared mixtures are stored for 24 h in a closed container for inspection of their miscibility. It is observed that there is no separation of methyl-esters. Standard Red Wood Viscometer is used to determine the kinematic viscosity and dynamic viscosity of the methyl-esters and their blends using the standard method. Density of blends is measured using standard equipment using standard procedure. The methyl-esters and blends considered are heated from 25–95°C in the interval of 15 °C.

The variation of the properties such as density and viscosity with blend proportion and temperature are measured.

## 3. Results and discussions

The present work investigates the influence of temperature and blend proportion on the fuel properties like density, kinematic viscosity, dynamic viscosity of neat methyl-esters of Pongamia, Jatropha and Simarouba and their blends measured in the range of temperatures 25–95 °C experimentally. The results so obtained are discussed and analyzed.

### 3.1. Density measurements

Density of two different methyl-ester blends is measured. Kinematic viscosity of Pongamia, Jatropha and Simarouba methyl-esters and blends of two dissimilar methyl-esters like P-J, J-S and P-S are considered for experimental investigation. Methyl-esters considered are mixed in various volume fractions. Measurements are carried out varying temperatures and blend proportions. Once the stable temperature is reached the measurements are taken and recorded. The measurements are average of the triplicate determinations.

The variation of density of methyl-esters blends in various volume fractions with change in temperature range of 25–95 °C is shown in Figs. 1 and 2 and 5.

Fig. 1 shows the variation of density of neat Pongamia and Jatropha methyl-esters and their blends in various volume fractions of 10–90%. The results indicate that density of liquid methyl-esters of Pongamia, Jatropha and their blends decrease with rise in temperature. The decrease in density of methyl-esters and their blends are linear. The decrease in density is due to the increased volume of methyl-esters and their blends at higher temperatures.

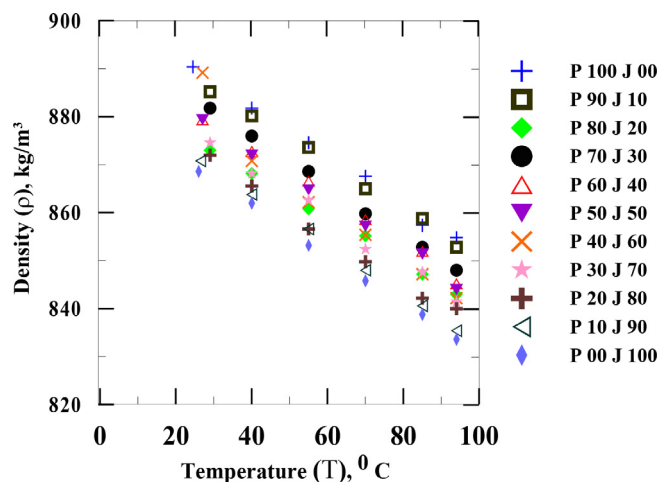


Fig. 1. Influence of temperature on density of P-J biodiesel blends.

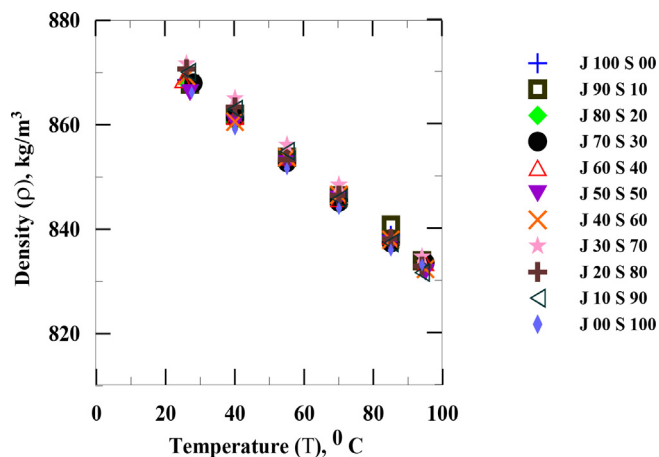


Fig. 2. Influence of temperature on density of J-S biodiesel blends.

Fig. 1 indicates that as the volume fraction of Pongamia methyl-esters increases, density of P-J blends increase. This is attributed to higher density of Pongamia methyl ester. The density variation of P-J methyl-esters blends at any temperature for any volume fraction may be determined by a correlation established. Correlation established as a function of percentage volume of Pongamia methyl-ester in the blend and temperature and Presented in the form of an Eq. (1).

$$\rho_{P-J} = [0.200(X_{P-J}\%) + 862][ -0.00058(T) + 1.02324] \text{ kg/m}^3 \quad (1)$$

where  $X_{P-J}$  = % of Pongamia in P-J blend (volume %) and  $T$  = temperature (°C).

Experimental values agree with values estimated from correlations and vary within 0.4%.

The correlations established for Pongamia-Jatropha methyl-esters and their blends referring to Figs. 3 and 4. The Fig. 3 shows variation of density ratio with temperature from 40 °C to 95 °C, the first term of the Eq. (1), in the correlation is taken from Fig. 4 and second term of equation from Fig. 3. Fig. 4 present density variations with the change in percentage of Pongamia biodiesel in P-J blend at the reference temperature of 40 °C. The straight line fit trend suit better for both the graphs. The effect of variables upon density is analyzed using regression analysis. In regression, R2

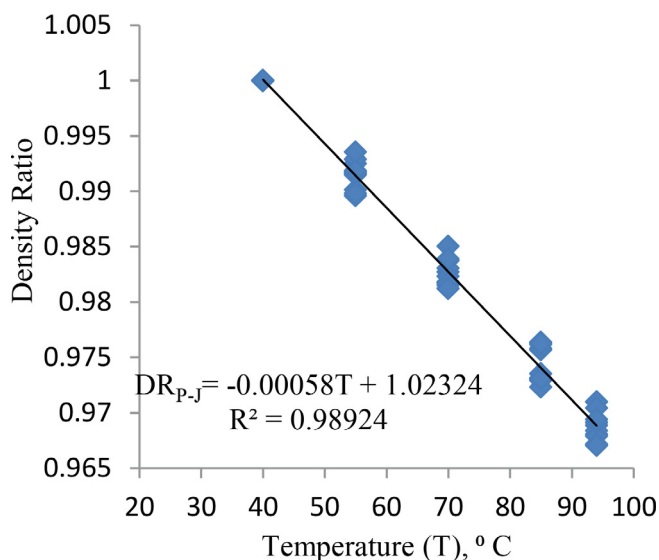


Fig. 3. Influence of temperature on density ratio of P-J biodiesel blend.

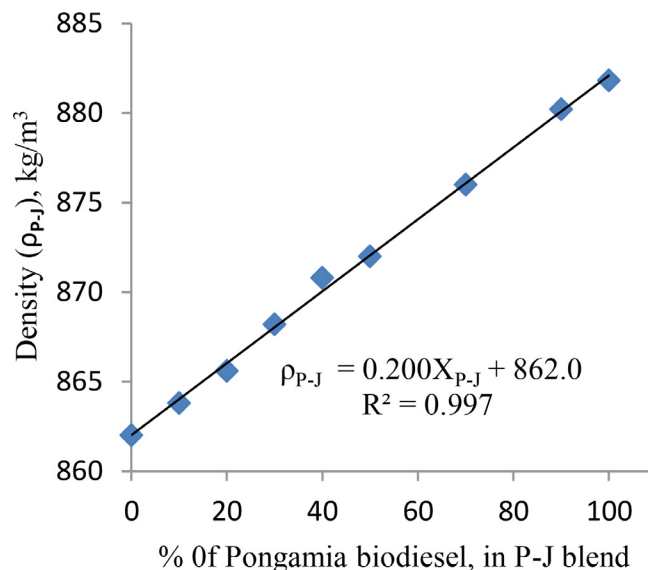


Fig. 4. Influence of % Pongamia biodiesel on density of P-J blend at reference temperature of 40 °C.

value is the measure of how best the regression line approximates tangible data. The value of R2 is 0.989 and 0.997 respectively.

The correlation for other two blends viz. J-S and P-S is also established using same method.

Fig. 2 shows the variation of density of Jatropha, Simarouba methyl-esters' blends with temperature range of 25-95 °C. Increase in volume percentage of Jatropha methyl-esters' in the blend, density of J-S methyl-esters increases. This is attributed to higher density of Jatropha methyl-esters. The density variation at any temperature at any fraction of methyl-esters' blends may be determined by a single correlation established as function of temperatures and volume fraction of Jatropha methyl-esters in the blends which is presented in the form of an Eq. (2).

$$\rho_{J-S} = [0.029(X_{J-S}\%) + 859.3][ -0.00061(T) + 1.02413] \text{ kg/m}^3 \quad (2)$$

$X_{J-S}$  is % of Jatropha methyl ester in J-S blend (volume %) and  $T$  = temperature (°C).

Experimental values are in good conformity with estimated values from correlations and vary within 0.23%.

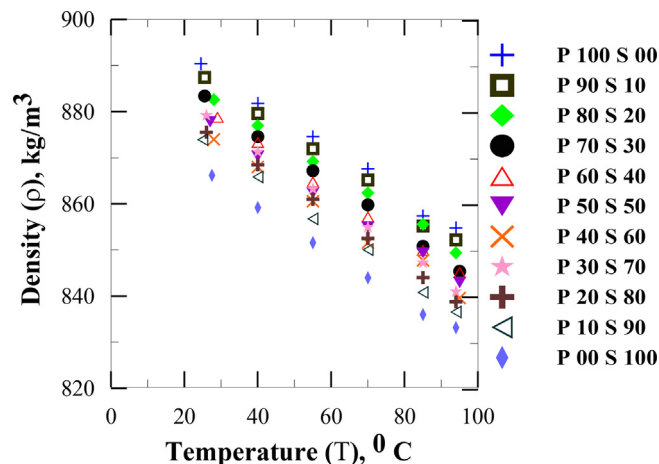


Fig. 5. Influence of temperature on density of P-S biodiesel blends.

Fig. 5 shows the variation of density of Pongamia, Simarouba methyl-esters and their blends at various temperature range of 25–95 °C. Density of blends increases as the volume fraction of Pongamia methyl-esters' increases in P-S methyl-esters blends. This is due to higher density of Pongamia methyl-ester compared to Simarouba methyl-esters. Density variation is function of temperature and volume fraction of Pongamia methyl-ester in the blend. Density can be determined by the correlation established at any temperatures for any volume fraction of Pongamia methyl-esters in the blend. The correlation is given in the form of an Eq. (3).

$$\rho_{P-S} = [0.225(X_{P-S}\%) + 859.1][−0.00060(T) + 1.0239] \text{kg/m}^3 \quad (3)$$

where  $X_{P-S}$  = % of Pongamia methyl ester in P-S blend (volume %) and  $T$  = temperature (°C).

Experimental values are in good agreement with estimated values through established correlations and vary within 0.17%.

Density of Pongamia, Jatropa and Simarouba methyl-esters at 40 °C are 881.8 kg/m<sup>3</sup>, 868.6 kg/m<sup>3</sup> and 859.2 kg/m<sup>3</sup> respectively where as the density of these methyl-esters at 95 °C are 854.8 kg/m<sup>3</sup>, 833.6 kg/m<sup>3</sup> and 833.2 kg/m<sup>3</sup> respectively.

### 3.2. Viscosity measurements

Change in kinematic viscosity of three methyl-esters and their blends are measured between temperatures range of 25–95 °C are shown in Figs. 6, 7 and 10.

Fig. 6 shows the variation of kinematic viscosity of Pongamia, Jatropa methyl-esters' blends with variation in temperatures. The results indicate that kinematic viscosity of Pongamia, Jatropa methyl-esters' blends decreases with increase in temperature. Decrease in kinematic viscosity with increase in temperature is due to reduced resistance to the flow of methyl-esters at higher temperatures. Kinematic viscosity of P-J blends increases with increase in volume percentage of Pongamia methyl-esters in the blends. This is due to higher kinematic viscosity of Pongamia methyl-esters in comparison with Jatropa methyl-ester. It is observed that decrease in viscosity is more at lower temperature compared to higher temperatures [15]. The correlation is established for finding kinematic viscosity of P-J methyl-esters' blends.

The correlation established as a function of percentage of Pongamia methyl-ester in P-J blend and temperatures. Established correlation is given as in Eq. (4).

$$\nu_{P-J} = [0.014(X_{P-J}\%) + 4.540][−0.78\ln(T) + 3.875] \text{mm}^2/\text{sec} \quad (4)$$

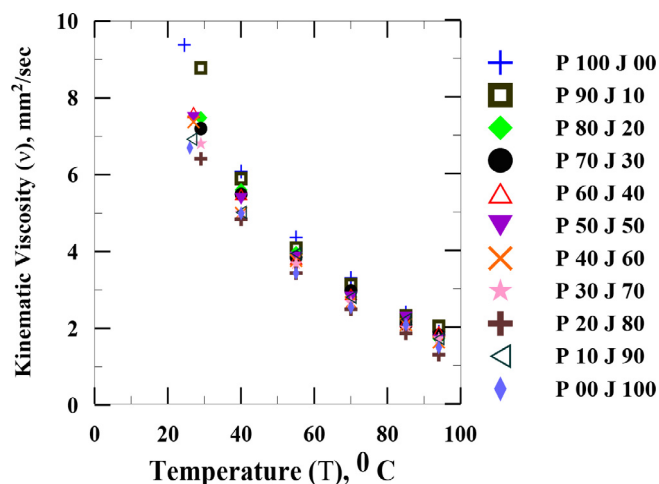


Fig. 6. Influence of temperature on kinematic viscosity of P-J blends.

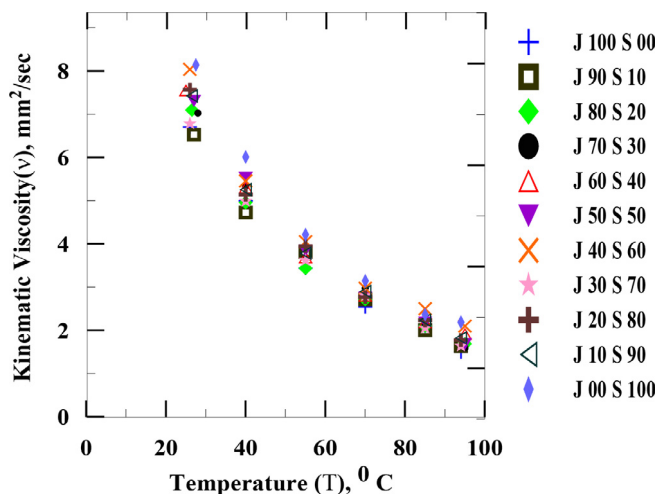


Fig. 7. Influence of temperature on kinematic viscosity of J-S blends.

where  $X_{P-J}$  = % of Pongamia in P-J blend (volume %), and  $T$  = temperature (°C).

Experimental values are in good agreement with values estimated using established correlations and differ within 5%.

The correlation for other two blends viz. J-S and P-S is also established using the same technique. Fig. 7 shows the variation of kinematic viscosity of Jatropa, Simarouba methyl-esters blends with change in temperatures. It is noticed that kinematic viscosity of Jatropa, Simarouba biodiesels' blends decreases as the temperature increases. Kinematic viscosity of the blend increases as the volume fraction of Simarouba methyl-ester increases in J-S blend. This may be due to higher viscosity of Simarouba methyl-esters. Correlation is established for estimation of Kinematic viscosity as function of temperature and percentage of Jatropa methyl esters in the blend. Through this correlation kinematic viscosity of the J-S blends and pure methyl esters can be estimated at any temperature and for any percentage of Jatropa methyl-ester in the blends. Correlation is presented as Eq. (5).

$$\nu_{J-S} = [−0.009(X_{J-S}\%) + 5.964][−0.76\ln(T) + 3.802] \text{mm}^2/\text{s} \quad (5)$$

where  $X_{J-S}$  = % of Jatropa in J-S blend (volume %) and  $T$  = temperature (°C).

Experimental values are in excellent agreement with values estimated from correlations and vary within 5%.

The correlation for the kinematic viscosity of P-J blends is ascertained using the Figs. 8 and 9 shown above. Fig. 8 shows the viscosity ratio variation with temperature from 40–95 °C, the first term of the Eq. (4), in the correlation is taken from Fig. 9 and second term from the Fig. 8. Fig. 9 presents the kinematic viscosity to percentage of Pongamia biodiesel in P-J blend at the reference temperature of 40 °C.

The logarithmic fit trend better suits for the variation of viscosity ratio to the change in temperature. Straight line fit trend suits for the viscosity to the change in volume percentage of Pongamia methyl-esters in P-J blends. The effect of variables upon the viscosity is analyzed using regression analysis. The value of regression, R<sup>2</sup> is measure of how best the regression line approximates the actual data. The value of R<sup>2</sup> is 0.99 and 0.974 respectively.

Fig. 10 shows the variation of kinematic viscosity of Pongamia, Simarouba methyl-esters and their blends with increase in temperature. It illustrate from the figure that kinematic viscosity decreases as the temperature of the methyl eaters blends increases [15]. The kinematic viscosity increases with increase in volume percentage of Pongamia methyl-esters in P-S blends. Increase in



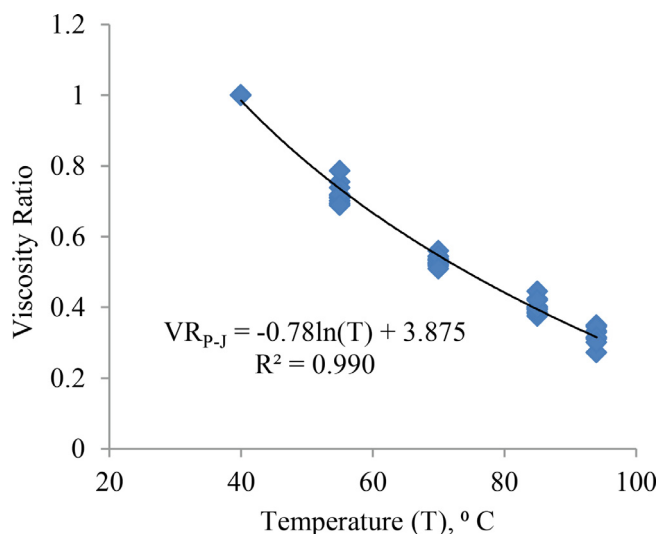


Fig. 8. Influence of temperature on viscosity ratio of P-J blends.

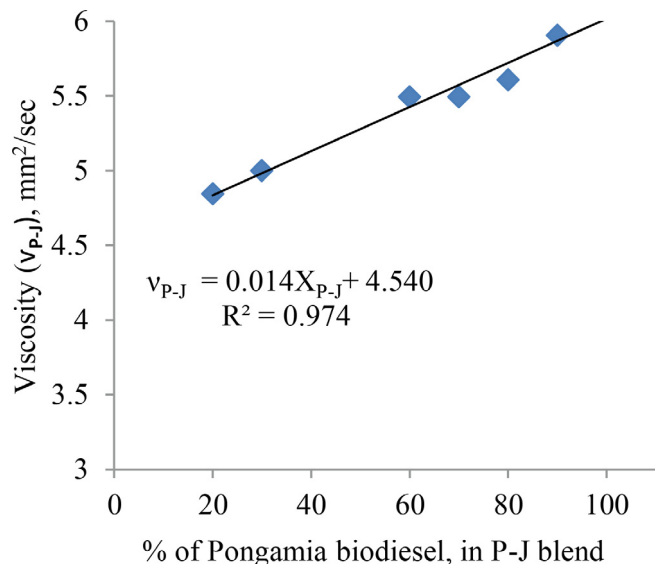


Fig. 9. Influence of volume % pongamia biodiesel on viscosity of P-J blends at reference temperature of 40 °C.

kinematic viscosity is attributed to higher viscosity of Pongamia methyl-ester. Correlation is set up for the estimation of kinematic viscosity as function of temperature and volume percentage of Pongamia methyl-ester of P-S blends.

Kinematic viscosity of P-S blends and pure methyl esters can be estimated at any temperature, for any percentage of Pongamia methyl-ester. Established correlation is presented as Eq. (6).

$$v_{P-S} = [0.012(X_{P-S}\%) + 4.977][-0.77\ln(T) + 3.862] \text{ mm}^2/\text{s} \quad (6)$$

where  $X_{P-S}$  = % of Pongamia in P-S blend (volume %) and T = temperature in °C.

Experimental values are in excellent agreement with values estimated from established correlations and differ within 5%.

Kinematic viscosity of Pongamia, Jatropha and Simarouba methyl-esters at 40 °C are 6.08 mm<sup>2</sup>/s, 5.00 mm<sup>2</sup>/s and 6.01 mm<sup>2</sup>/s respectively where as at 95 °C are 1.91 mm<sup>2</sup>/s, 1.5 mm<sup>2</sup>/s and 2.9 mm<sup>2</sup>/s respectively.

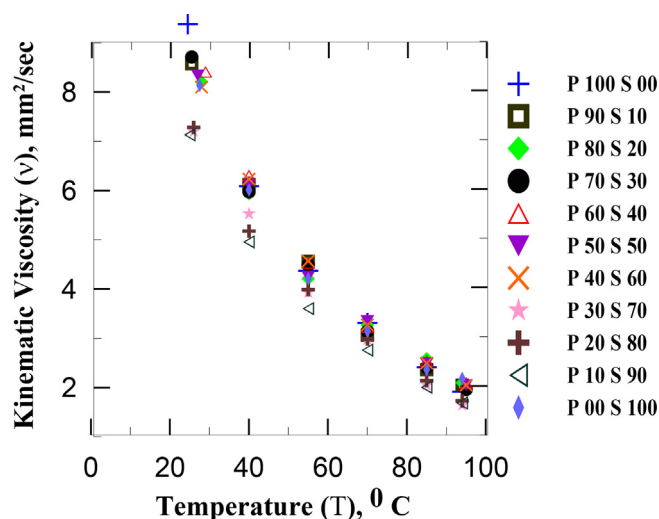


Fig. 10. Influence of temperature on kinematic viscosity of P-S blends.

#### 4. Conclusions

The influence of temperature and volume percentage of methyl esters of Pongamia, Jatropha and Simarouba methyl-esters on the properties such as density, kinematic viscosity and their mixtures in temperature the range of 25–95 °C are measured and following conclusions are drawn.

Increase in temperature decreases the density and Kinematic viscosity of blends. Density and kinematic viscosity increases as volume percentage of Pongamia methyl-ester increases in P-J and P-S methyl-ester blends. For J-S blends, density increases as the volume percentage of Jatropha methyl-ester increases where as kinematic viscosity decreases. Density of methyl ester blends decreases with increase in temperature and is linear. Kinematic viscosity decrease with increase in temperature and the decrease in kinematic viscosity are logarithmic. Decreases in kinematic viscosity are higher at lower temperatures compared to higher temperatures. Correlations are established for the density and kinematic viscosity of two methyl-ester blends. The established correlations are unique and they can be taken as model equations for finding the density and viscosity of two biodiesel blends. Estimated results using established correlations are in excellent confirmation with experimental values.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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