Temperature-Viscosity Correlation for Biodiesel Blends Derived from Corn, Olive and Palm Oil

Rashid Humaid Al Naumi and Sudhir Chitrapady Vishweshwara

***Abstract*— As the use of biodiesel becomes more wide spread, engine manufacturers have expressed concern about biodiesel's higher viscosity. In this paper demonstrates experimental investigation to study the effect of temperature on the viscosity of biodiesel and its blends at different temperatures. The feedstock which selected among five vegetable oils is Olive, Corn and Palm which have high variance in the viscosity. For biodiesel production, the catalyst used is NaOH pallets and methanol as alcohol. Biodiesel obtained through transesterification process, is tested to check the completion of transesterification reaction by methanol test, pH test and visual test. From the experimental investigation, it is understood that obtained viscosity of pure biodiesel haven't reached to the petroleum diesel viscosity even after heating up to 65°C. however, the higher viscosity of pure biodiesel is reduced by blending it with diesel fuel, three types of biodiesel blends have studied B10, B20 and B50 at different temperature in the range 25-65°C in step of 10°C. The lower blends which are B10 & B20 have reached to the diesel viscosity at temperatures much lesser than 65°C for the different types of biodiesel blends. The blends which is lower than 30% of biodiesel is matching the viscosity diesel fuels, while higher blends (higher than 30% of biodiesel) need to be heated further higher temperatures, heating for higher temperatures is waste of energy and considered as not economical. From the experiments conducted a simple liner correlation model were obtained for different oils. The correlation was developed to predict the viscosity of biodiesel at any different temperature and any blend ratio. Predicting viscosity of biodiesel at different temperature gives the advantage to further research work and also save time and raw materials.**

***Keywords*— Biodiesel, Viscosity, Blends and Temperature**

I. INTRODUCTION

Biodiesel is produced by the transesterification process. The raw materials which could be used to produces biodiesel are waste cooking oil, animal oils, and waste grease along with methanol results in producing biodiesel and the by-product called glycerin. Biodiesel is consisting of different fatty acid methyl esters (FAME) chains. Biodiesel has similar few of the properties of diesel such as specific gravity and heat combustion [1] there is also some properties do not match with diesel fuel such as the higher viscosity of blends which is the subject of making this research. The performance of engine is dependent on different variables, however, viscosity of fuel play an important role [2]. Biodiesel having higher viscosity thus could effect on the performance of the engines, there are different methods to reduce viscosity of biodiesel studied by other researchers. Blending with different amount of diesel fuel or by heating; since by heating fluids the viscosity decrease, these methods.

There are different reasons to make biodiesel blends, since pure biodiesel has higher values of viscosity which could effect on the performance of engine. The cold flow properties are very important because at lower temperature biodiesel becomes thick and can't be pumped into the engine [3]. Sarin, et al., [4] investiagted by blending biodiesel with petroleum diesel, and found it improves the flow properties at low temperature also. The cold flow properties increased with higher viscosity of oil, in additional the high viscosity fuels will take much time to mix with air inside the engine. Therefore it will reduce the quality of the vaporization and atomization of the fuel. To reduce the impact of viscosity the blending method have positive affect on diesel engine performance as it is improving lubricity [3]. Most of the literatures report that, Biodiesel blend ratio could be in any ratio but the most common are B50, B20,B10, B5 and B2, where : B100 means 100% pure biodiesel and B50 mean only 50% biodiesel and the rest are diesel by volume.

F. Aksoy, et al., [5] studied the effect of temperature on the viscosity of canola and corn oil at different temperature on the range of 0°C to 100 °C in step of 10 °C. They have obtained biodiesel from two refined vegetable oils by transesterification process. The viscosity of biodiesel and their blends were measured by the test devices included a DV-IIC Pro rotary viscometer. They have analyzed the viscosity of biodiesel fuels and diesel fuels under the same conditions. They have found viscosities of biodiesels are prominently decreased with increasing of their temperature thus its similar into the diesel fuels in the term of viscosity and conclude by use preheating to biodiesels, their viscosities can be close to diesel fuel.

Biodiesel properties depend on the feed stock, the common feedstock which used in worldwide is vegetable oils, there are different types of vegetable oils which could be used as a raw material to produce biodiesel such as Palm, Corn, Olive, Jatropha, Sesame, etc. K. Pramanik [6] have investigated properties of Jatropha curcas biodiesel and its blends efficiency in compression ignition engine. In their literature the author has discussed the most important properties of

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Jatropha biodiesel and compared with diesel fuel. Further, they found the heating value of vegetable oil is comparable to diesel and cetane number is slightly lower than diesel fuel. However, the kinematic viscosity and the flash point of Jatropha curcas oil are several times higher than the diesel oil. Further, different percentage blends with diesel was investigated and found that the biodiesel which is less than B30 have viscosity close to diesel fuel, biodiesels which is more than 40% percentage (more than B40) the viscosity of these higher blends higher than diesel fuels, further the viscosity of these higher blends reduced by heating. The viscosity of blends B70 and B60 reach viscosity of diesel at temperature 70–75 and 60–65 ^{0}C, respectively. The corresponding temperatures were found to be 55–60 and 45 ^{0}C for B50 and B40 blends. From their experiment it was found that the lower blends showed slightly higher exhaust gas temperatures when comparing to engine operating with diesel. Their studies conclude that, C.I engines can work normally with Jatropha blend percentage less than 50%.

The most widely the literature reports that biodiesel is unfavorable because of its higher viscosity and the specific gravity. These two physical properties determination is very important as their values determining if it suitable to use as diesel fuel. To achieve the similar viscosity of diesel fuels there is different solution developed through different studies.

The studies which have been done by Kimilu, et al., [7] was focused on the effect of temperature and blending on the viscosity of Jatropha methyl ester. Their literature shows that the different variations of viscosity were correlated using predictive models for the viscosity and specific gravity at different temperature and different blending percentage. The vegetable oil which used is Jatropha oil by make different blending ratio B20, B35, B50 and B75 and investigated at temperature in the range 15-60°C together with the pure diesel fuels. The specific gravity, calculated through specific gravity method and the viscosity was calculated using Ostwald viscometer. The calculated specific gravity of Jatropha pure biodiesel was found 4.83% higher than that diesel fuel. Blending with diesel fuel will reduce specific gravity and the viscosity and correlation model was developed for use to approximate specific gravity of any blend. By preheating fuels the specific gravity decreased. By using correlation model specific gravity of Jatropha blends can predicted at different temperature. Their results state that after making the needed calculation, the viscosity was found 42.09% higher than petroleum diesel. Blending Jatropha Methyl Eesters with diesel fuel reduces viscosity of biodiesel, which varied linearly with the amount of diesel fuel in the blend.

Pure Biodiesel is similar to diesel fuel in some of the physical and chemical properties and may be possible suit for diesel engines. A study done by Seung , et al., [8]to investigate diesel properties compared with biodiesel properties. The research was done to find out the different properties such as specific gravity, density, and viscosity of diesel and biodiesel fuel in the temperature range from 0 to 200°C. Biodiesel were made from soybean oil and the test have made for different blends ratios of 20%, 40%, 60%, and 80%. To investigate the different properties of biodiesel many experiments were carried out by the Seung , et al., [8] at different temperature for the different types of blends, the result of analysis were compared with petroleum diesel properties. By increasing blending ratio of biodiesel the specific gravity increased. The density value measurement was correlated as a function of fuel temperature and blending ratio by an empirical equation. From their analysis it was found that, the viscosity decreased linearly with increasing in their temperature and blending ratio

When making biodiesel there are different variables that could effect on the production of biodiesel. Mahajan, et al., [9] have studied the variables affecting the production of standard biodiesel. The raw materials which used to obtain biodiesel are palm oil vegetable oil alcohol and a catalyst. The catalysts used are different and each one gives different amount of biodiesel and quality. Their results show that if catalyst used in excess, might cause some problem in the final product. It is reported that too much quantity of sodium hydroxide catalyst can never be used as it causes soap formation, when soap formation its raises the acid number and make the product isolation difficult, also lowers the quantity of product biodiesel. The other variables which could has big impact on biodiesel production are molar ratio of alcohol to oil, solvent volume, and reaction time, as a result for their research they conclude the alcohol to molar ratio must be at least 14, and sodium hydroxide concentration should be at least 1.2 % by weight.

There are different methods used to produce biodiesel. Amit Sarin [4] reflects that the, biodiesel could be produced through dilution (blending), micro-emulsification, pyrolysis (thermal cracking), and transesterification. Amit Sarin [4] reports that Dilution (blending) as crude vegetable oils are blended directly with petroleum diesels. This type is not recommended since vegetable oils having high viscosity the blended solution will have higher viscosity and thus could effect on the performance of the diesel engine; also dilution is not suitable for long term use in a direct injection engine.

Secondly, Amit Sarin [4] reports Emulsification as a method used to reduce the high viscosity of vegetables oils. They define “Emulsion as dispersion of oil in water or water in oil and this dispersion are also known as micro-emulsion”

The third method which Amit Sarin [4] suggest is pyrolysis, which is a conversion of one material into another through heating, in or without presence of catalyst in absence of oxygen. The product produced from this process having properties same as diesel fuel.

Lastly Amit Sarin [4] reports that, Transesterification as the most world wide spread process which used to produce biodiesel, its catalytic chemical reaction where alcohol reacted with vegetable oil or animal fats to produce fatty acid alkyl esters (i.e., biodiesel) and glycerol.

The vegetable oil which was used to produce biodiesel was obtained from the local market (Corn, Olive, Coconut, Sunflower, and Palm). There are two types of alcohol which could be used to produce esters and glycerine. Methanol is the most common used in transesterification process. Daniel (2003) [10] reports that, the choice of the catalyst is very important decisions to be made to obtain biodiesel with lessen the reaction time and give higher percentage of biodiesel as product. In this investigation, NaOH pallets is used as catalyst as it most widely used by many researchers. The NaOH pallets which will dissolve completely in methanol, dissolving NaOH crystals is an exothermic reaction which was felt and observed during its hand mixing. Care was taken so that the pallets of NaOH should be never be kept outside the container for long time because its tend react with oxygen or air.

II. EXPERIMENTAL SET-UP

The oils which chosen to start transesterification process are Palm, Corn, and olive oils. First step is dissolve 1.75 g of NaOH pallets in 100 ml of methanol until it is clearly dissolved in the methanol and no pallets are seen. This is a very important check because if NaOH pallets did not dissolve completely it will effect on the reaction completion. Next step is to heat 500 ml of oil up to range from 55-60 ˚C, the thermometer as it have been early described measure the temperature of reaction in the RB flask the temperature on the RB flask should not exceed 60 ˚C, then pour the methoxide (NaOH + Methanol) slowly into the RB flask from the side openings of the RB flask. When pouring methoxide, the mixture is being stirred using magnetic stirrer. Then insert the thermometer and leave reaction for one hour. During this one hour water supply is connected to condenser to condense the evaporated methanol. This procedure will be applied to the three types of oils to obtain biodiesel and glycerol.

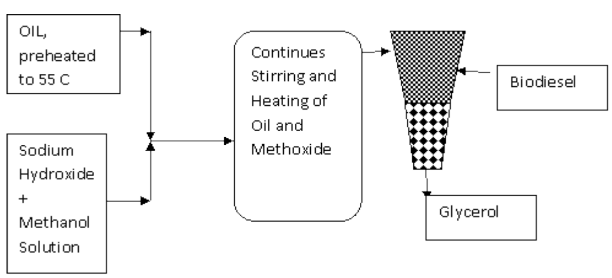

Fig. 1: Transesterification process flow diagram

After completion of reaction solution of Biodiesel and glycerol are obtained. To separate these to solution, a separator was used, biodiesel separates as the top layer and the lower layer is glycerol.

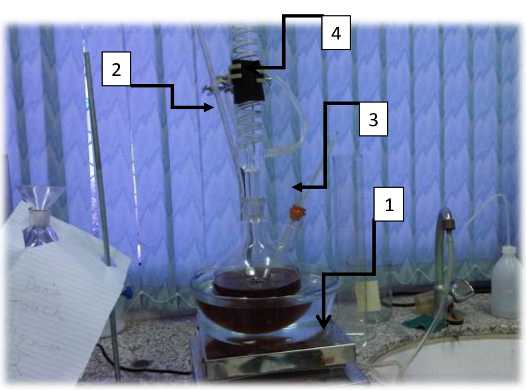

Fig. 2: Experimental Setup

1) Magnetic stirrer with heater
2) Condenser
3) Thermometer
4) RB Flask

Redwood viscometer is used to calculate the viscosity of the oils and biodiesels in function of time.

The equation used to calculate kinematic viscosity is

Kinematic viscosity (CST) = 0.260t - (0.0188/t), where (t) is the time in Redwood Seconds.

Fig. 3: Redwood viscometer

III. RESULTS AND DISCUSSION

Host of experiments were carried out in order to arrive at a conclusive understanding of viscosity variation with temperature relationship at different temperature. The scheme of experiments was so chosen so to meet the objectives framed under the study. In ordered to study the viscosity variations at different temperature, each sample were heated at the controlled environment using a table top water bath setup. The variation of pure biodiesel (B100) viscosity trend is shown in Fig. 4 for all their oils selected for study.

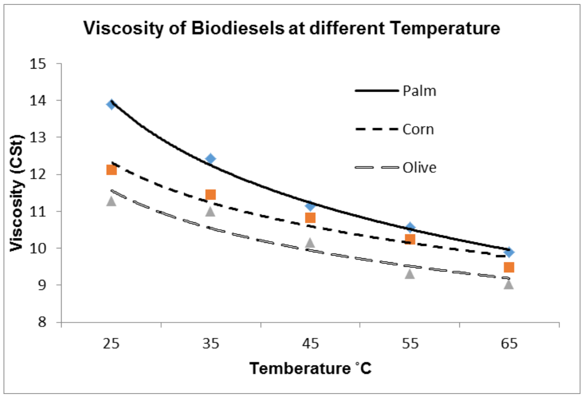

Fig. 4: Pure biodiesel (B100) viscosity trend

Seung et al., [8] reports that temperature at which the viscosity meet the universal accepted specification as 4.5 CSt at 40°C is more suitable for IC engine. When comparing biodiesel and diesel fuel found high variance between them even after heating up to 65 °C the viscosity reach to 9 CSt which is almost double diesel fuel viscosity. To reduce high viscosity of biodiesel, it was blended with different amount of diesel at different ratio.

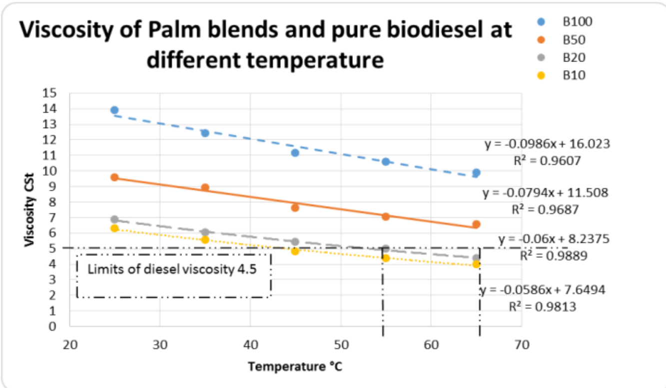

Fig. 5: Palm Biodiesel Blends & B100 viscosity

A) Correlation model to predict viscosity of Palm blends

As seen in the Fig. 5, the viscosity of palm biodiesel can be found at any given temperature and blend ratio using the equation, its observed as liner equation is good.

$$Y = Mp\,X + Cp \qquad (1)$$

Where,
Y is the Viscosity values
M_p is viscosity of correlation Constant for palm biodiesel
C_p is viscosity of correlation Constant palm biodiesel
X Temperature in °C

Fig. 5 illustrate the result of B10, B20, B50 & B100 at given temperature, its observed B10 reach to viscosity of biodiesel at 53 °C and B20 at 61 °C, B50 & B100 haven't reach to viscosity of diesel but by raising temperature to higher values it will decrease the viscosity of biodiesel to the limits specification of diesel but that will consume much energy and since it's not economical its undesirable.

To find (M_p& C_p) viscosity correlation constant, the trend line equations in Fig. 5 was useful. The Fig. 5 shows the variations of viscosity with different percentage of blends ratio depicts a linear relationship at different temperature. The correlation is shown in Table 1.

Table 1: Equations to Obtained C, M Correlation-constant

Pure Biodiesel and Blends	Equations	Correlation coefficient
B100	y = -0.0986x + 16.023	0.960
B50	y = -0.0794x + 11.508	0.968
B20	y = -0.06x + 8.2375	0.988
B10	y = -0.0586x + 7.6494	0.981

To obtain M_p constant, from the above table where the relation between blend percentage and x factor gives the equation for M_p constant.

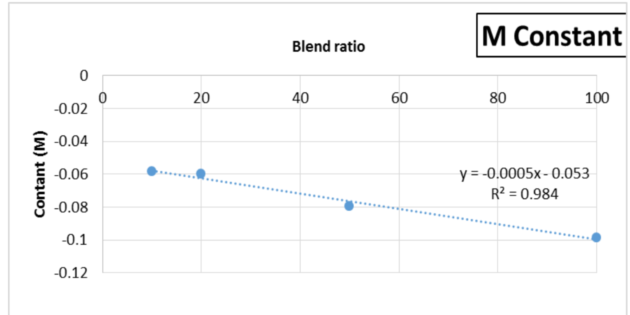

Fig. 6: Palm Biodiesel Correlation constant (M) equation

Viscosity correlation for Mp constant determined linearly from the Fig. 6 which is equal:

$$Mp = -0.0005x - 0.0533 \qquad (2)$$

Where,
x is blend ratio.
The same procedure is now applied to get Cp.

To obtain Cp constant, from Table 1 where the relation of biodiesel percentage % of with real numbers (B100,16.032), (B50,11.508), (B20,8.2375) and (B10, 7.6494) which represented in Fig. 7.

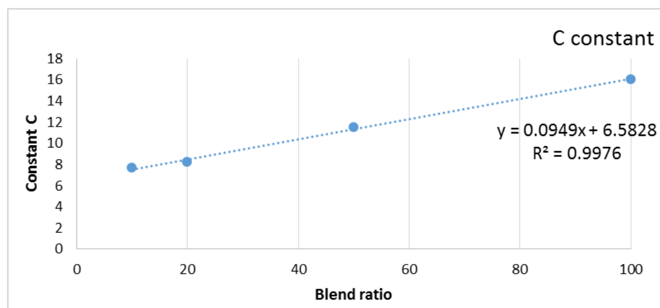

Fig. 7: Palm Biodiesel Correlation constant (C) equation

Viscosity correlation for C_p constant determined linearly from the above Fig. 7 which is equal to:

$$C_p = 0.0949x + 6.5828 \qquad (3)$$

Where x is blend ratio.

To obtain viscosity of any palm biodiesel blend ratio at different temperatures, as shown in formula 4, the viscosity correlation constants M_p and C_p, need to be obtained. For palm oil biodiesel, the correlation can thus obtained by linear equation as it shown in the Fig. 6 and Fig. 7.

$$M_p = -0.0005x - 0.0533 \qquad (4)$$

$$C_p = 0.0949x + 6.5828 \qquad (5)$$

Then substitute the above values in equation 1 at the required temperature (x), the viscosity of required blend ratio and temperature can be successfully evaluated using the above equation.

$$Y = Mp\,X + Cp$$

B) Viscosity of Corn blends and pure biodiesel at different temperature with correlation model to predict viscosity of blends

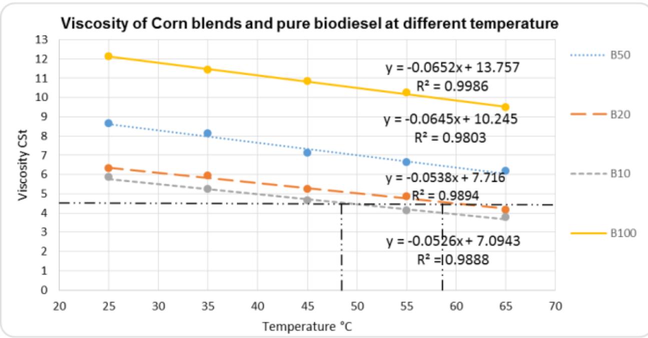

Fig. 8: Corn biodiesel and its blends viscosity

From Fig. 8, it is evident that, the B10 and B20 corn blends are reaching viscosity of biodiesel when raising temperature, B10 is reaching the limit of diesel viscosity when temperature is 49°C and B20 at 59°C, if we heat B50 to more high temperature it will reach to diesel viscosity but it will consider loss of energy and that is actually not economically. Temperature at which the viscosity of blends meet the upper limits of specification (i.e., 4.5 Cst). To obtain M_c constant, from Fig. 9 where the relation between blend percentage and x factor gives the equation for M_c constant.

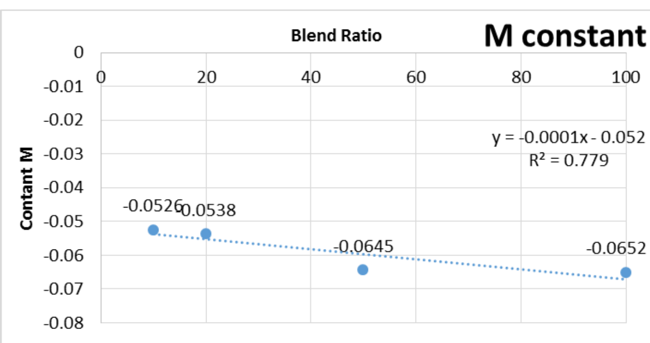

Fig. 9: Corn Biodiesel Correlation constant (M) equation

Viscosity correlation for C_c constant determined linearly from the Fig. 9 which is equal:

$$M_c = -0.0001x - 0.0524 \qquad (6)$$

Where; x is the blend ratio

To obtain C_c constant, from Fig. 10 where the relation of biodiesel percentage % of with real numbers as shown in the previous case with palm biodiesel:

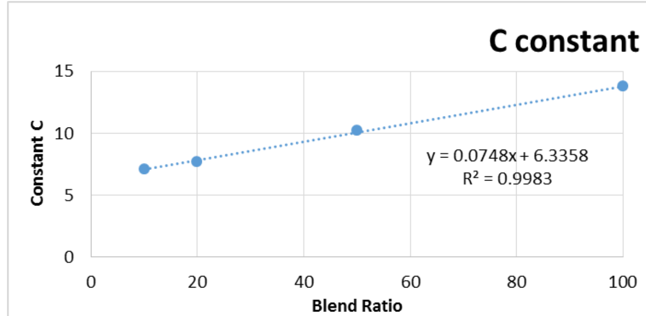

Fig. 10: Corn Biodiesel Correlation constant(C) equation

Viscosity correlation for C_c constant determined linearly from the Fig. 10 which is equal:

$$C_c = 0.0748x + 6.3358 \qquad (7)$$

Where x is blend ratio.

C) Viscosity of Olive pure biodiesel and its blends at different temperature with correlation model to predict viscosity of blends

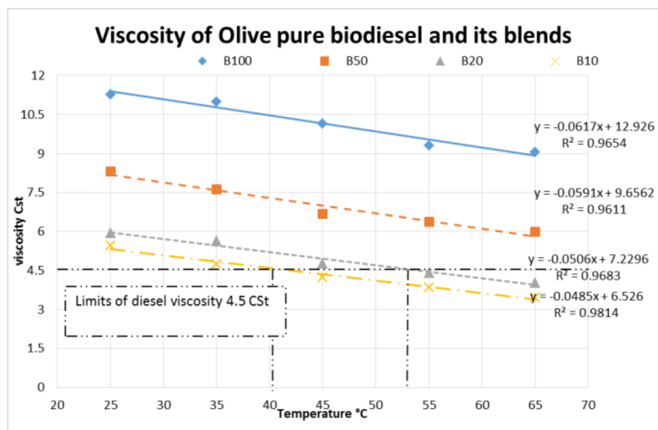

Fig. 11: Olive biodiesel and blend at different temperature

As seen in the Fig. 11, B10 is reaching to viscosity of biodiesel at 41°C while B20 at 53°C, B50 reach up to 6 Cst and if heated to higher temperature it will reach to viscosity of diesel.

To obtain viscosity of olive biodiesel at any blend ratio and different temperature using the same method used with palm and corn blends, using equation 4:

$$Y = Mo\,X + Co \qquad (8)$$

To obtain M_0 constant, from Fig. 12 where the relation between blend percentage and x factor gives the equation for M_o constant.

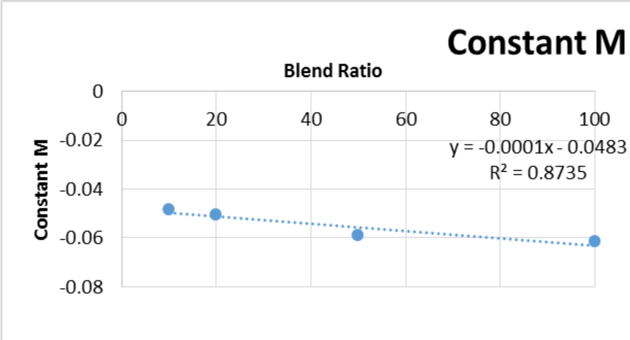

Fig. 12: Olive Biodiesel Correlation constant (M) Equation

Viscosity correlation for Mo constant determined linearly from the above Fig.12 which is equal:

$$Mo= -0.0001x - 0.0483 \qquad (9)$$

Where x is the blend ratio.

To obtain C constant, from Fig. 13 where the relation of biodiesel percentage % of with real numbers:

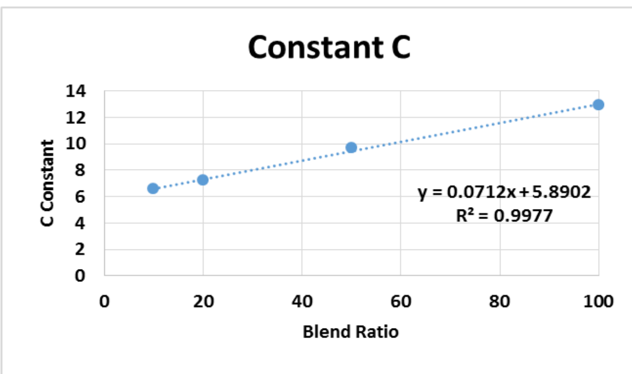

Fig. 13: Olive Biodiesel C Correlation constant (C) Equation

Table 2: Viscosity and temperature model

Sl. No	Biodiesel Feedstock Type	Equation to find the viscosity in CSt.	Where
1	Palm	$Y_p=M_p*X+C_p$	X = temperature (^oC) M_p= -0.0005x - 0.0533 C_p= 0.0949x + 6.5828 x =blend ratio (%)
2	Corn	$Y_c=M_c*X+C_c$	X = temperature (^oC) M_c= -0.0001x-0.0524 C_C= 0.0748 x+6.3358 x =blend ratio (%)
3	Olive	$Y_o=M_o*X+C_o$	X = temperature (^oC) M_c= -0.0001x - 0.0483 C_o=0.0712x + 5.8902 x =blend ratio (%)

Viscosity correlation for C_o constant determined linearly from the Fig. 13 which is equal:

$$C_o=0.0712x + 5.8902 \qquad (10)$$

Where x is blend ratio.

Predictive models for the three types of biodiesel blends:

From the above discussion it is now possible to summarize the outcome in terms of the empirical formula which was developed using the experimental data and also the correlation fitting to liner equation. These are the correlation models to obtain viscosity at any different temperature and blend ratio, for biodiesel obtained from olive, palm and Corn.

IV. CONCLUSION

From the experimental study on three types of biodiesel which were obtained from different origins using transesterification processes it can be concluded that all the pure biodiesel is having higher viscosity almost double comparing to the diesel fuel. From the literatures it was understood that the high viscosity of fuels effect on the performance of the diesel engines. Viscosity can be reduced by blending with fluids having lower viscosity or by pre-heating. The blends which obtained are B10, B20, and B50 of the three types of biodiesel from is Corn, Palm & Olive oils. The lowest viscosity of pure biodiesel was derived from Olive, and average was from Corn oil and Palm oil biodiesel was considered as in the higher range.

The viscosity of blends of each type of biodiesel was investigated at different temperature and compared to diesel. B10 & B20 blends of olive biodiesel was found reaching to the limits of diesel fuel viscosity (4.5 CSt) at 41°C & 53°C respectively, while B10 &B20 blends of corn biodiesel was found reaching the limits of biodiesel when temperature was in the range of 49°C & 59°C. For palm oil biodiesel blends B10 & B20 reached the diesel limits when temperature was around 53 °C & 61 °C. The viscosity of B50 for the three types of biodiesel haven't reach to the limits of diesel, thus the higher blends which is more than 30% not recommended to use because it will need much energy, heating for higher temperature will consume much energy and this considered not economical. Hence it can be now understood that if the biodiesel is to be used then it should be preheated to get some benefit. It is noted that in literatures that some people in western counties have installed second fuel tank for biodiesel. It is also noted that second fuel tank can be heated using the internal heat of the engine such as coolant circuit or by suing exhaust gas heat recovery methods.

Experimental data was further analyzed to develop the empirical correlation models to predict the viscosity of biodiesel at any different temperature and any blend ratio for a given oil origin biodiesel. A correlation equation for viscosity was developed for each of the biodiesel of three different origins. The correlation for viscosity has the temperature and blend ratio (%) as inputs to evaluate the viscosity in CSt. All the three correlation equation developed for each of the oil origins had the coefficient correlation above 95%. Predicting viscosity of biodiesel at different temperature gives the advantage to further researchers and students for finding the heating requirement for different blends so as to obtain the fuel viscosity in the range near to the limits of diesel engine fuel specifications.

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