International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-06, Sep 2018

Property Prediction of Jatropha Oil based Biodiesel – Petrodiesel blends using Refractive Indices

S. R. Shah, Ph. D. Scholar, Gujarat Technological University, Ahmedabad-382424, India.

srshah@ldce.ac.in

A. P. Vyas, Ph. D. Supervisor, Gujarat Technological University, Ahmedabad-382424, India.

amish71in@yahoo.com

Abstract: Biodiesel is a sustainable source of energy derived from living beings including; plants, animals, micro-organism and their wastes. It has been more than a century since the discovery of Biodiesel and till date number of research work is going on in proving it the best alternate source of energy. Many literature sights the various ways for property prediction, but each of them has some or the other limitations either in terms of applicability or accuracy. This paper is an attempt to resolve the issue of prediction of properties like Density and Viscosity of Jatropha Oil based Biodiesel – Petrodiesel blends using Refractive Indices. The paper discloses the experimental data of refractive indices for various degrees of blends and correlations to predict density and viscosity without actual experiments. This will ease the work of researchers who are working on establishing the applications of Jatropha Oil based Biodiesel – Petrodiesel blends.

Keywords* — *Jatropha Biodiesel, Refractive Index, Density, Viscosity, Correlations

I. INTRODUCTION

Jatropha based biodiesel is one of the key biodiesels around which the biofuel development in India focuses. Jatropha plant seeds are rich in oil with almost 40% volume and do not need any specific refining for using in diesel generators and engines. [1] Jatropha has the potential to provide economic benefits at the local level since under suitable management it has the potential to grow in dry marginal non-agricultural lands, thereby allowing villagers and farmers to leverage non-farm land for income generation.[2,3] There are two technical benefits of Jatropha; (a) it is non-food crop, it thus, do not hinder the food crop cycle; [4,5] (b) it is carbon-neutral.[6] In India, the total plantation area of Jatropha is $7.48*10^3$ km^2, and an oil potential of $15*10^3$ t/y.[7]

In this paper, discussion is made on correlations for determination of density and viscosity using refractive index, also data has been tabulated for various temperatures between ranges of 298.15 K to 323.15 K for Jatropha based biodiesel – petrodiesel blend fractions between 0 and 1.

Refractive Index is measured using Refractometer, ASTM D-3321 12/13 [8], so far in no literature this property for various blends at different temperatures has been sighted. [9,10] Thus, in the current work the density and refractive index of Jatropha based biodiesel and petro diesel blend was analyzed and data were obtained at different absolute temperature ranging 298.15K - 323.15 K. The resulting correlation used to calculate the refractive index of the blend. Later on these calculated values are compared with the currently available mixing rules like Kay, Newton, Eykman, Dale-Gladestone and Lorentz-Lorenz correlations.[11,12] Also from the calculated values of refractive index, the correlation for density is also derived. [13]

II. EXPERIMENTAL SETUP[14]

The experiments were performed on the refractometer Reichert AR200 which can give accuracy upto 4 decimal places. The readings are taken for all the blend concentration with the temperature variation of the 298.15 K, 303.15 K, 313.15 K 318.15 K and 323.15. All the data are measured with ±0.0001 accuracy.

2.1 Biodiesel Blends and mixing[13]

The sample considered for present study are B00, B05, B10, B15, B20, B25, B30, B35, B40, B45, B50, B55, B60, B65, B70, B75, B80, B85, B90, B95 and B100.

B100 is 100% biodiesel. It has a solvent effect and it can clean a vehicle's fuel system and release deposit accumulated from previous petroleum diesel use. The release of this deposit may initially clog filters and require replacement. It may require special handling and equipment modification. To avoid engine operational problems, B100 must meet the requirement of standard specification for biodiesel fuel.[2,15,16] B100 use could also increase nitrogen oxide emissions, although it greatly reduces other toxic emissions. B100 is less common than B5 or B20 due to a lack of regulatory incentives.[17] B20 (20% biodiesel, 80% petroleum diesel) is the most common biodiesel blend. B20 is popular because it represents a good balance of cost, emission, cold-weather performance, materials compatibility, and ability to act as a solvent. Using B20 provides substantial benefits and avoids many of the cold-weather performance and material compatibility concerns associated with B100. Biodiesel blend B20 must meet prescribed quality standards. [18] Biodiesel contains about

 DOI : 10.18231/2454-9150.2018.0753

8% less energy per gallon than petroleum diesel. [19] For B20, this could mean a 1% to 2% difference, but most B20 users report no noticeable difference in performance or fuel economy. Greenhouse gas and air-quality benefits of biodiesel are roughly commensurate with the blend. B20 use provides about 20% of the benefit of B100 use. A B5 blend is 5% biodiesel and 95% petroleum based diesel. It is one of the most common blends associated with biodiesel because of the use of B5 blend in state or municipal mandates.[20] Most major engine manufactures have approved the use of a B5 blend in their engines. The American standard for testing materials (ASTM) which sets the international standards for diesel fuel has revised its statement so that a B5 blend is treated the same as conventional diesel, specification for diesel fuel oils, revised to allow for up to 5 percent biodiesel content. This allows B5 blends to be treated the same as conventional diesel for testing purpose. The properties of Jatropha oil are usually dependent on fatty acids. Approximately 98% of crude Jatropha oil is made up of fatty acids. [21]

Table 1:FFA Composition of Jatropha oil [21]

Sr. No.	Fatty acid	Fuel	% in Jatropha Oil
01	Saturated	Palmitic	13
		Stearic	2.53
02	Unsaturated	Oleic	48.8
		Linoleic	34.6

Blending biodiesel with petroleum diesel may be accomplished by:

1. Mixing in tanks at manufacturing point prior to delivery to tanker truck
2. Splash mixing in the tanker truck (adding specific percentages of biodiesel and petroleum diesel)
3. In-line mixing, two components arrive at tanker truck simultaneously.
4. Metered pump mixing petroleum diesel and biodiesel meters are set to X total volume, transfer pump pulls from two points and mix is complete on leaving pump.

2.2 Measurement of Refractive Index

The refractive index was measured using refractometer, started by cleaning of the prism by help of warm water and soap and drying well with a soft wipe which left no residue. Samples of 1ml of each blend were taken and the prism was well covered with a black paper to get accurate readings.[22] The higher temperature variation was achieved by changing the oil sample temperature and allowed reaching its thermal stability at each temperature. All the experiments were repeated three times and the average reading was considered. Before starting of the experiments, the equipment was calibrated using the standard available buffer solution and the deviation was observed to be 0.02%.

2.3 Measurement of Density

For the density measurement specific gravity bottle was used with temperature controlled water bath. For the measurement of density the specific gravity bottle of 25 ml capacity was filled with the blend sample. Then the bottle was placed inside the water bath and allowed to attain equilibrium at the given specific temperature. For the current study purpose, the temperatures that were taken into consideration were 298.15 K, 303.15 K, 313.15 K, 318.15K and 323.15K. All the values were determined as the average of two readings.

2.4 Measurement of Viscosity

The viscosity of the blend was determined using the Rheometer. The sample of 60 ml was filled in the sampling crucible. Then the rotating float was inserted in the crucible. The heating was done with the external oil heating system. The sample was allowed to attain equilibrium at the given temperature. For current biodiesel petro diesel blend viscosity was experimented at constant shear rate. Numbers of set points were taken as the constant points. For each sample reading were taken at 298.15 K, 303.15 K, 313.15 K, 318.15K and 323.15K

2.5 Apparatus

Figure 1: Specific gravity bottle with constant temperature water bath

Figure 2: Rheometer

III. RESULT AND DISCUSSION

3.1 Refractive Index

The refractive index values were measured for all the blend of the Jatropha oil base biodiesel and petro diesel. The experimental values are tabulated in the table 2. Two parameters correlation (Temperature and biodiesel percentage) was developed using the experimental values obtained for Refractive Index. Table 2 shows the comparison of the results obtained experimentally and using available models for blend samples ranging from B00 to B100. There are other parameters available for the prediction of properties for the binary mixtures. [23]

 DOI : 10.18231/2454-9150.2018.0753

ISSN : 2454-9150 Vol-04, Issue-06, Sep 2018

Table 2: Refractive Index Values obtained for various blend percentages at different temperatures via Experiment as well as Correlations

Blend Fraction		B0	B05	B10	B15	B20	B25	B30	B35	B40	B45	B50	B55	B60	B65	B70	B75	B80	B85	B90	B95	B100	RMSPD%
Temp. (K)	Model																						
298.15	Experimental	1.4579	1.4577	1.4574	1.4567	1.4564	1.4560	1.4555	1.4550	1.4544	1.4541	1.4538	1.4533	1.4531	1.4530	1.4528	1.4526	1.4523	1.4520	1.4518	1.4515	1.4512	
	Kay	1.4579	1.4576	1.4572	1.4569	1.4566	1.4562	1.4559	1.4556	1.4552	1.4549	1.4546	1.4542	1.4539	1.4535	1.4532	1.4529	1.4525	1.4522	1.4519	1.4515	1.4512	0.0321
	Newton	1.4579	1.4576	1.4572	1.4569	1.4566	1.4562	1.4559	1.4556	1.4552	1.4549	1.4546	1.4542	1.4539	1.4535	1.4532	1.4529	1.4525	1.4522	1.4519	1.4515	1.4512	0.0322
	Eykman	1.4579	1.4576	1.4572	1.4569	1.4566	1.4562	1.4559	1.4555	1.4552	1.4549	1.4545	1.4542	1.4539	1.4535	1.4532	1.4529	1.4525	1.4522	1.4519	1.4515	1.4512	0.0317
	Dale-Gladstone	1.4579	1.4576	1.4572	1.4569	1.4566	1.4562	1.4559	1.4556	1.4552	1.4549	1.4546	1.4542	1.4539	1.4535	1.4532	1.4529	1.4525	1.4522	1.4519	1.4515	1.4512	0.0321
	Lorentz-Lorenz	1.4579	1.4576	1.4572	1.4569	1.4566	1.4562	1.4559	1.4556	1.4552	1.4549	1.4545	1.4542	1.4539	1.4535	1.4532	1.4529	1.4525	1.4522	1.4519	1.4515	1.4512	0.0319
303.15	Experimental	1.4552	1.4549	1.4548	1.4544	1.4541	1.4536	1.4534	1.4531	1.4528	1.4525	1.4522	1.4519	1.4516	1.4513	1.4510	1.4506	1.4503	1.4500	1.4497	1.4494	1.4491	
	Kay	1.4552	1.4549	1.4546	1.4543	1.4540	1.4537	1.4534	1.4531	1.4528	1.4525	1.4522	1.4518	1.4515	1.4512	1.4509	1.4506	1.4503	1.4500	1.4497	1.4494	1.4491	0.0045
	Newton	1.4552	1.4549	1.4546	1.4543	1.4540	1.4537	1.4534	1.4531	1.4528	1.4525	1.4522	1.4518	1.4515	1.4512	1.4509	1.4506	1.4503	1.4500	1.4497	1.4494	1.4491	0.0044
	Eykman	1.4552	1.4549	1.4546	1.4543	1.4540	1.4537	1.4534	1.4531	1.4528	1.4524	1.4521	1.4518	1.4515	1.4512	1.4509	1.4506	1.4503	1.4500	1.4497	1.4494	1.4491	0.0047
	Dale-Gladstone	1.4552	1.4549	1.4546	1.4543	1.4540	1.4537	1.4534	1.4531	1.4528	1.4525	1.4522	1.4518	1.4515	1.4512	1.4509	1.4506	1.4503	1.4500	1.4497	1.4494	1.4491	0.0045
	Lorentz-Lorenz	1.4552	1.4549	1.4546	1.4543	1.4540	1.4537	1.4534	1.4531	1.4528	1.4525	1.4521	1.4518	1.4515	1.4512	1.4509	1.4506	1.4503	1.4500	1.4497	1.4494	1.4491	0.0046
313.15	Experimental	1.4523	1.4521	1.4519	1.4515	1.4511	1.4509	1.4506	1.4503	1.4500	1.4497	1.4494	1.4491	1.4488	1.4485	1.4482	1.4479	1.4476	1.4473	1.4470	1.4467	1.4464	
	Kay	1.4523	1.4520	1.4517	1.4514	1.4511	1.4508	1.4505	1.4502	1.4499	1.4496	1.4493	1.4490	1.4487	1.4485	1.4482	1.4479	1.4476	1.4473	1.4470	1.4467	1.4464	0.0041
	Newton	1.4523	1.4520	1.4517	1.4514	1.4511	1.4508	1.4505	1.4502	1.4499	1.4496	1.4493	1.4490	1.4488	1.4485	1.4482	1.4479	1.4476	1.4473	1.4470	1.4467	1.4464	0.0040
	Eykman	1.4523	1.4520	1.4517	1.4514	1.4511	1.4508	1.4505	1.4502	1.4499	1.4496	1.4493	1.4490	1.4487	1.4484	1.4482	1.4479	1.4476	1.4473	1.4470	1.4467	1.4464	0.0043
	Dale-Gladstone	1.4523	1.4520	1.4517	1.4514	1.4511	1.4508	1.4505	1.4502	1.4499	1.4496	1.4493	1.4490	1.4487	1.4485	1.4482	1.4479	1.4476	1.4473	1.4470	1.4467	1.4464	0.0041
	Lorentz-Lorenz	1.4523	1.4520	1.4517	1.4514	1.4511	1.4508	1.4505	1.4502	1.4499	1.4496	1.4493	1.4490	1.4487	1.4484	1.4482	1.4479	1.4476	1.4473	1.4470	1.4467	1.4464	0.0042
318.15	Experimental	1.4498	1.4497	1.4495	1.4489	1.4485	1.4483	1.4479	1.4476	1.4472	1.4469	1.4466	1.4462	1.4459	1.4455	1.4452	1.4449	1.4445	1.4442	1.4438	1.4435	1.4432	
	Kay	1.4498	1.4495	1.4491	1.4488	1.4485	1.4481	1.4478	1.4475	1.4471	1.4468	1.4465	1.4461	1.4458	1.4455	1.4452	1.4448	1.4445	1.4442	1.4438	1.4435	1.4432	0.0079
	Newton	1.4498	1.4495	1.4491	1.4488	1.4485	1.4481	1.4478	1.4475	1.4471	1.4468	1.4465	1.4462	1.4458	1.4455	1.4452	1.4448	1.4445	1.4442	1.4438	1.4435	1.4432	0.0078
	Eykman	1.4498	1.4495	1.4491	1.4488	1.4485	1.4481	1.4478	1.4475	1.4471	1.4468	1.4465	1.4461	1.4458	1.4455	1.4451	1.4448	1.4445	1.4442	1.4438	1.4435	1.4432	0.0082
	Dale-Gladstone	1.4498	1.4495	1.4491	1.4488	1.4485	1.4481	1.4478	1.4475	1.4471	1.4468	1.4465	1.4461	1.4458	1.4455	1.4452	1.4448	1.4445	1.4442	1.4438	1.4435	1.4432	0.0079
	Lorentz-Lorenz	1.4498	1.4495	1.4491	1.4488	1.4485	1.4481	1.4478	1.4475	1.4471	1.4468	1.4465	1.4461	1.4458	1.4455	1.4451	1.4448	1.4445	1.4442	1.4438	1.4435	1.4432	0.0080
323.15	Experimental	1.4471	1.4470	1.4468	1.4464	1.4461	1.4459	1.4456	1.4454	1.4451	1.4449	1.4446	1.4443	1.4441	1.4438	1.4436	1.4433	1.4430	1.4428	1.4425	1.4423	1.4420	
	Kay	1.4471	1.4468	1.4466	1.4463	1.4461	1.4458	1.4456	1.4453	1.4451	1.4448	1.4446	1.4443	1.4440	1.4438	1.4435	1.4433	1.4430	1.4428	1.4425	1.4423	1.4420	0.0049
	Newton	1.4471	1.4468	1.4466	1.4463	1.4461	1.4458	1.4456	1.4453	1.4451	1.4448	1.4446	1.4443	1.4440	1.4438	1.4435	1.4433	1.4430	1.4428	1.4425	1.4423	1.4420	0.0048
	Eykman	1.4471	1.4468	1.4466	1.4463	1.4461	1.4458	1.4456	1.4453	1.4451	1.4448	1.4445	1.4443	1.4440	1.4438	1.4435	1.4433	1.4430	1.4428	1.4425	1.4423	1.4420	0.0050
	Dale-Gladstone	1.4471	1.4468	1.4466	1.4463	1.4461	1.4458	1.4456	1.4453	1.4451	1.4448	1.4446	1.4443	1.4440	1.4438	1.4435	1.4433	1.4430	1.4428	1.4425	1.4423	1.4420	0.0049
	Lorentz-Lorenz	1.4471	1.4468	1.4466	1.4463	1.4461	1.4458	1.4456	1.4453	1.4451	1.4448	1.4445	1.4443	1.4440	1.4438	1.4435	1.4433	1.4430	1.4428	1.4425	1.4423	1.4420	0.0049

The various models used to predict the properties, Refractive Index, Density and Viscosity are tabulated in table 3. [9] In the models, n_m is refractive index of blend, n_i is refractive index of component i, v_i is volume fraction of component i.

Table 3: Various Models Used to predict the Properties

Models	Governing Equations	
Kay	$n_m = v_1 n_1 + v_2 n_2$	(1)
Newton	$n_m^2 - 1 = \sum_{i=1}^{n} \{vi(n_i^2 - 1)\}$	(2)
Eykman	$\frac{n_m^2 - 1}{n_m^2 + 0.4} = \sum_{i=1}^{n} \left\{vi\left(\frac{n_i^2 - 1}{n_i^2 + 0.4}\right)\right\}$	(3)
Dale-Gladston	$n_m - 1 = \sum_{i=1}^{n} \{vi(n_i - 1)\}$	(4)
Lorentz-Lorenz	$\frac{n_m^2 - 1}{n_m^2 + 2} = \sum_{i=1}^{n} \left\{vi\left(\frac{n_i^2 - 1}{n_i^2 + 2}\right)\right\}$	(5)

The accuracy of predictive models was estimated with Root Mean Square Prediction Difference (RMSPD).

$$RMSPD = 100 \times \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} \left[\frac{Y_{Cal,i} - Y_{exp,i}}{Y_{exp,i}}\right]^2} - - - - (6)$$

Where, Y_{Cal} and Y_{exp} were the calculated and experimental values respectively and *n* is no. of experimental data.

The obtained correlation for refractive index using blend percentage for the specified temperature range is given by equation 7, where *n* is refractive index of blend at given temperature and n_0 is refractive index of pure diesel at that temperature.

$$n = n_0 - 13 \times 10^{-5} \times (Blend\ Percentage) - - - (7)$$

The experimental data shows that the value of refractive index (R. I.) of a sample blend decreases with the increase in biodiesel content in sample blend and temperature. A linear dependence on logarithmic scale of the refractive index of the blend with composition can be observed.

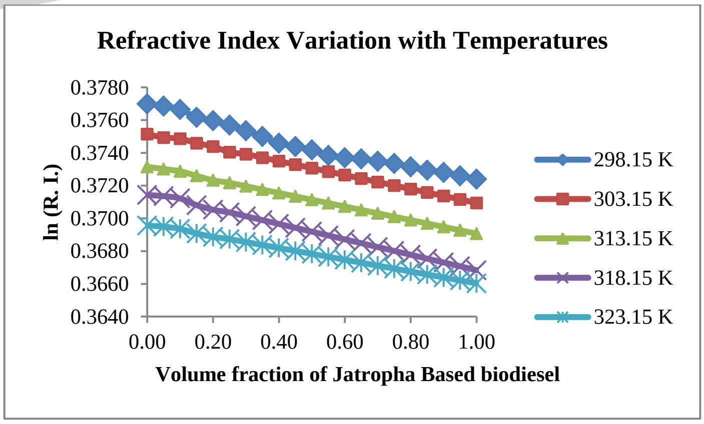


Figure 3: Experimental refractive index data is presented versus composition at different temperatures

 DOI : 10.18231/2454-9150.2018.0753

ISSN : 2454-9150 Vol-04, Issue-06, Sep 2018

The accuracy of experimental work is determined by RMSPD values given in Table 2, the values show the high accuracy of the data. The correlation for the development of the prediction of the refractive index using two parameter models are explained below: [12]

$$\ln n_m = a' + b'v_1 \text{ ------------- } (8)$$

Where, n_m = refractive index of the biodiesel blend,

v_1= volume fraction of biodiesel in the mixture of biodiesel blend,

a' and b' are the empirical correlation constant.

The constants are defined as,[12]

$$a' = a + \frac{c}{T} \text{ -------------- } (9)$$

$$b' = b + \frac{d}{T} \text{ ------------- } (10)$$

Where, T = Temperature of the biodiesel blend

Based on this method, the empirical correlation developed from the experimental data for the prediction of the biodiesel blend refractive index is,

$$\ln n_m = 0.289 + 0.006v_1 + \frac{27.044}{T} - \frac{3.443 \times v_1}{T} \quad (10)$$

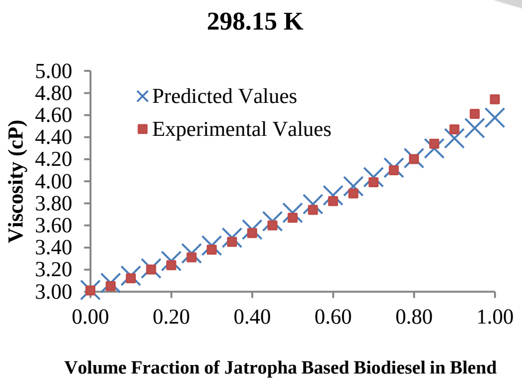
Table 4: Accuracy for developed correlation as per equation (10)

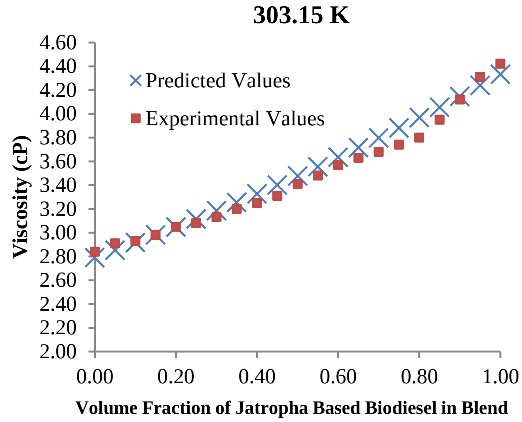
Temperature (K)	298.15	303.15	313.15	318.15	323.15
RMSPD (%)	0.2560	0.2552	0.3125	0.3746	0.3847

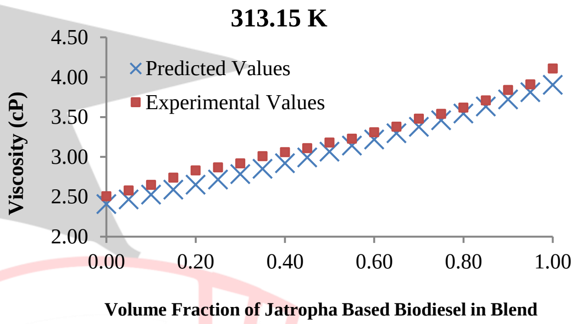
The accuracy of data as computed using RMSPD formula is tabulated in table 4 and the lower values of RMSPD % shows high accuracy of data.

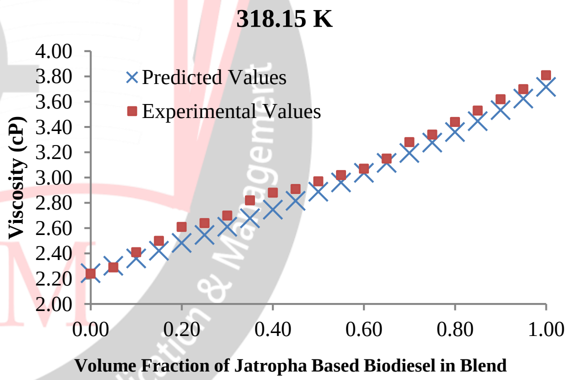
3.2 Viscosity

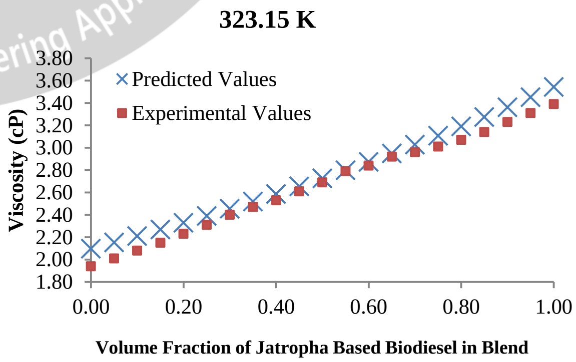
The values of viscosity for various blend fractions and temperature range was determined by the earlier mentioned experimental methodology. Using these two parameters and the experimental data co-relation was obtained by the two parameter method. The resultant prediction correlation depends on two variables, i.e. refractive index and the temperature as shown in Eq. 11











$$\ln \mu_m = -3.592 + 1.808 \times n_m + \frac{1400}{T} - 414.7 \times \frac{n_m}{T} \quad (11)$$

Table 5: RMSPD value for eq. (11)

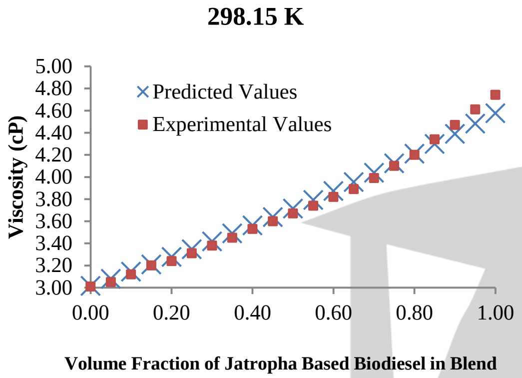
Temperature (K)	298.15	303.15	313.15	318.15	323.15
RMSPD (%)	1.43	2.21	3.99	2.84	4.04

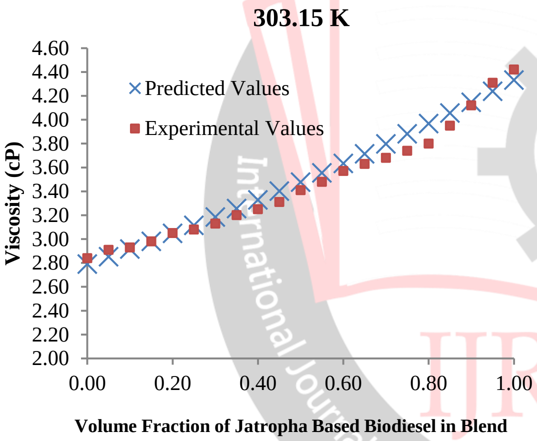
 DOI : 10.18231/2454-9150.2018.0753

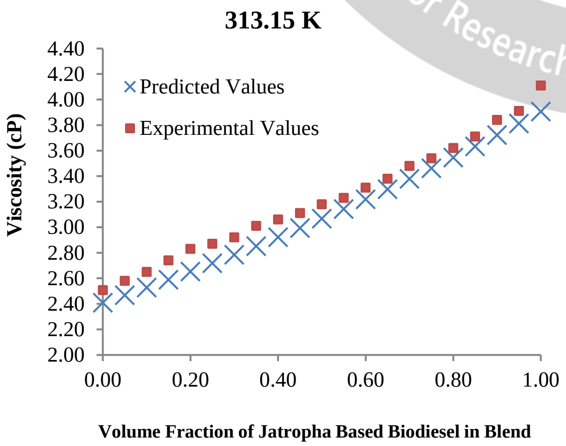
3.3 Density

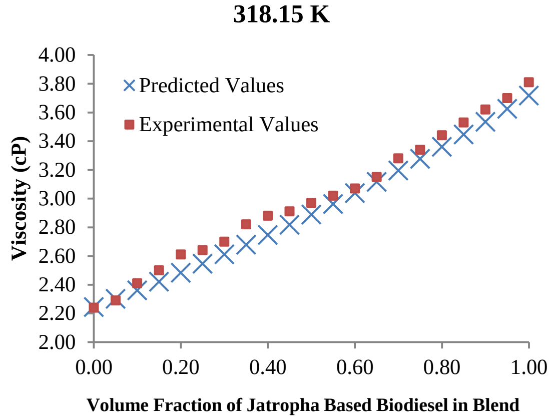
The values of density for various blend fractions and temperature range was determined by the earlier mentioned experimental methodology. Using these two parameters and the experimental data co-relation was obtained by the two parameter method. The resultant prediction correlation depends on two variables, i.e. refractive index and the temperature as shown in Eq. 12

$$\ln \rho_m = 6.509 + 0.08 \times n_m + \frac{58.4}{T} - 5.585 \times \frac{n_m}{T} \quad (12)$$









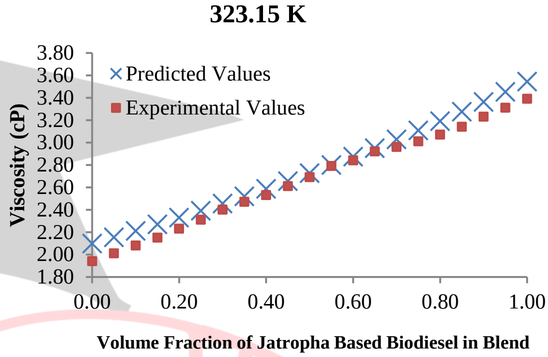


Table 6: RMSPD value for eq. (12)

Temperature (K)	298.15	303.15	313.15	318.15	323.15
RMSPD (%)	0.138	0.073	0.244	0.178	0.166

IV. CONCLUSION

In the present study the generalized correlation for the prediction of the refractive index with the absolute temperature and volume fraction of Jatropha Oil Based Biodiesel were developed. With the help of correlation of the refractive index and temperature, other correlations for the prediction of the viscosity and density for biodiesel and petro-diesel blends were derived with the accuracy to get the property prediction over the entire concentration profile of the biodiesel percentage.

REFERENCES

[1] NOVOD. Non- edible oil potential in India. Minist Agric Govt India 2016:1–20. http://shodhganga.inflibnet.ac.in/bitstream/10603/48954/6/06_chapter1.pdf (accessed January 30, 2018).

[2] Patel AR, Bhatt SM, Jani DB, Vala SB. Biodiesel as future fuel of I. C. Engine. Futur. Trends Mech. Eng., Limda, Gujarat: Parul Institute of Engineering & Technology; 2009, p. 76–81.

[3] Patel AR, Gupta M, Jani DB, Vala SB, Prajapati NJ. Palm Oil Based Biodiesel as Alternative Bio-fuel. Dev. Green Fuel Energy Secur. Environ. Prot., 2009, p. 97–100.

 DOI : 10.18231/2454-9150.2018.0753

[4] Lama AD, Klemola T, Saloniemi I, Niemelä P, Vuorisalo T. Factors affecting genetic and seed yield variability of Jatropha curcas (L.) across the globe: A review. Energy Sustain Dev 2018;42:170–82. doi:10.1016/J.ESD.2017.09.002.

[5] Contran N, Chessa L, Lubino M, Bellavite D, Lobina R, Sahanoon O, et al. Potentialities and limits of Jatropha curcas L. as alternative energy source to traditional energy sources in Northern Ghana. Energy Sustain Dev 2016;31:163–9. doi:10.1016/J.ESD.2016.02.004.

[6] Xue J, Grift TE, Hansen AC. Effect of biodiesel on engine performances and emissions. Renew Sustain Energy Rev 2011;15:1098–116. doi:10.1016/J.RSER.2010.11.016.

[7] Kumar S, Ram T, Mukesh S, Ali M, Arya S. Sustainability of biodiesel production as vehicular fuel in Indian perspective. Renew Sustain Energy Rev 2013;25:251–9. doi:10.1016/j.rser.2013.04.024.

[8] ASTM. ASTM D3321 - 13 Standard Test Method for Use of the Refractometer for Field Test Determination of the Freezing Point of Aqueous Engine Coolants. ASTM Int 2013. https://www.astm.org/Standards/D3321.htm (accessed January 5, 2018).

[9] Geacai S, Niţă I, Iulian O, Geacai E. Refractive Indices for Biodiesel Mixtures. UPB Sci Bull, Ser B 2012;74.

[10] Igbokwe JO, Nwufo OC, Nwaiwu CF. Effects of blend on the properties, performance and emission of palm kernel oil biodiesel. Biofuels 2015;6:1–8. doi:10.1080/17597269.2015.1030719.

[11] Nita I, Geacai S, Iulian O. Measurements and correlations of physico-chemical properties to composition of pseudo-binary mixtures with biodiesel. Renew Energy 2011;36:3417–23. doi:10.1016/J.RENENE.2011.05.020.

[12] Krisnangkura K, Sansa-ard C, Aryusuk K, Lilitchan S, Kittiratanapiboon K. An empirical approach for predicting kinematic viscosities of biodiesel blends. Fuel 2010;89:2775–80. doi:10.1016/J.FUEL.2010.04.033.

[13] Shah SR, Vyas AP. Property Prediction of Palm Oil based Biodiesel – Petrodiesel blends using Refractive Indices. Int J Eng Res Adv Dev 2018;4:16–28.

[14] ASTM. AR200 Refractometer User's Guide. Reichert Technol Anal Instruments 2013:1–16. http://www.reichertai.com/clientuploads/directory/download_pdfs/AR200 User Guide.PDF (accessed January 5, 2018).

[15] Arbab MI, Masjuki HH, Varman M, Kalam MA, Imtenan S, Sajjad H. Fuel properties, engine performance and emission characteristic of common biodiesels as a renewable and sustainable source of fuel. Renew Sustain Energy Rev 2013;22:133–47. doi:10.1016/J.RSER.2013.01.046.

[16] Maina P. Investigation of fuel properties and engine analysis of Jatropha biodiesel of Kenyan origin. J Energy South Africa 2014;25:107–16.

[17] Wirawan SS, Tambunan AH, Djamin M, Nabetani H. The Effect of Palm Biodiesel Fuel on the Performance and Emission of the Automotive Diesel Engine. Agric Eng Int CIGR J 2008;X.

[18] Chitra P, Venkatachalam P, Sampathrajan A. Optimisation of experimental conditions for biodiesel production from alkali-catalysed transesterification of Jatropha curcus oil. Energy Sustain Dev 2005;9:13–8. doi:10.1016/S0973-0826(08)60518-9.

[19] Prueksakorn K, Gheewala SH, Malakul P, Bonnet S. Energy analysis of Jatropha plantation systems for biodiesel production in Thailand. Energy Sustain Dev 2010;14:1–5. doi:10.1016/J.ESD.2009.12.002.

[20] Knothe G. The Biodiesel Handbook. Hist. Veg. oil-based diesel fuels. 2nd ed., Elsevier Ltd; 2010, p. 5–19.

[21] Kumar A, Sharma S. An evaluation of multipurpose oil seed crop for industrial uses (Jatropha curcas L.): A review. Ind Crops Prod 2008;28:1–10. doi:10.1016/J.INDCROP.2008.01.001.

[22] Nair J, Kalyani S, Deepthi J. Study Of Biodiesel Blends And Emission Characteristics Of Biodiesel. Int J Innov Res Sci Eng Technol 2013;2.

[23] Vasconelos B, Andrade RS, Iglesias M, Simoes ALA, Sanchez A. Analysis of Empirical models of Refractive index for biodiesel & ultra low sulfur diesel blends. IJCERT 2017;6.

 DOI : 10.18231/2454-9150.2018.0753