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Effect of temperature on the physical properties of sunflower biodiesel and their mixtures with palm biodiesel and petro diesel fuel

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Abstract: Density, viscosity and ultrasonic speed have been measured in binary mixtures of sunflower biodiesel with petro diesel and palm biodiesel over the whole composition range at four different temperatures. Several thermodynamic parameters like bulk modulus of compressibility, surface tension, internal pressure and intermolecular free length are computed and reported. Linear correlation between viscosity, density and ultrasonic speed with concentration of biodiesel has been observed in the studied systems.
Key Words: Palm biodiesel, Sunflower biodiesel, Transesterification, Bulk Modulus, Surface Tension.

Introduction:

Diesel fuel has a pivotal role in the industrial economy of any country. As the petroleum reserves are rapidly depleting, every country is looking for alternative biodiesel from locally available edible and non edible sources. Countries like U.S.A and Brazil produces biodiesels largely from soybean; France and Italy from sunflower while Malaysia and Indonesia from palm seeds[1]. In India, on the other hand, due to the population constraints, non edible sources like Jatropha, neem, pongamia etc. have been tried, in recent times for the production of biodiesel[2]. Biodiesel is basically produced by the transesterification of vegetable oil with an alcohol (preferably methanol) using sodium/potassium hydroxide dissolved in the alcohol as a catalyst. The major advantages of the biodiesel are that, it is nontoxic, contains no aromatic hydrocarbons, is less pollutant to water/soil and does not contain sulphur. Furthermore, biodiesel can be blended at any level with petroleum diesel and used in compression ignition (diesel) engines with little or no modification[3]. It is reported in literature [4,5,6] that physical properties like viscosity, density, ultrasonic speed, bulk modulus of compressibility, surface tension etc. of the biodiesel blends vastly affects the engine parameters like performance, efficiency and emission. A detailed literature survey shows that only few reports are available on the physical properties of biodiesel and their blends [7-12] through the data on the effect of thermal energy on these parameters are scarce.

Thus in continuation of our studies on binary mixtures[13-19], in this paper, we report for the first time in literature, the experimental data on viscosity, density and ultrasonic speed of sunflower biodiesel and their mixture with palm biodiesel and petro diesel at four temperatures 30°C to 45°C respectively. From the above experimental data, several thermodynamic parameters like bulk modulus of compressibility, surface tension, internal pressure and inter molecular free length are calculated and their influence on the engine parameters are highlighted.

2. Experimental:

2.1 Materials:

Commercially available refined sunflower and palm oils have been used for biodiesel production. Petro diesel received from local Reliance outlet has been used. Analar grades of methanol and sodium hydroxide (E.merck, India) have been used in transesterification process.

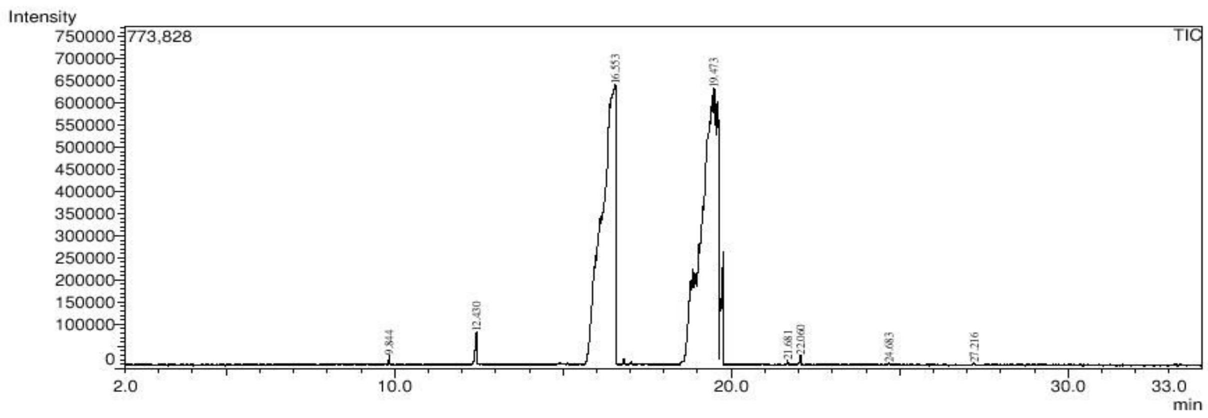
2.2 Methanolysis Reaction:

The transesterification process has been carried out on both sunflower oil and palm oil with a catalyst loading (1 % NaOH wt/wt) at 60 ± 0.1°C in 1 L reaction flask equipped with reflux condenser and magnetic stirrer and thermometer. The alcohol and oil have been taken in the molar ratio of 6:1 and the reaction time has been kept at 1 hr. After the pre established time, the reaction mixture is carefully transferred to a separating funnel and allowed to stand overnight. The lower layer (glycerol, unreacted methanol) was suitably drained out. The upper layer consisting of methyl esters, some methanol and traces of the catalyst is then cleaned roughly by washing with doubly distilled and de ionized warm water (70°C) in order to remove the impurities. The process of washing has been repeated until the lower layer has a pH similar to the pH of distilled water, indicating the methyl esters are free of catalyst. It is then heated to 110°C, have been dried with anhydrous Na_2SO_4 to get rid of any water. The gas chromatogram of both palm methyl ester and sunflower methyl ester are given in figure 1 and 2 respectively.

2.3 Measurement of Physical Properties:

The mixtures of biodiesel and petro diesels have been prepared by mass and have been kept in airtight bottles before use. Weighing is carried out using an electronic balance. (AND, HR series 300, Japan) with a precision of ± 0.1 mg. The uncertainty in the mole fraction has been estimated to be well within $\pm 1\times10^{-4}$.

The data on density,viscosity and ultrasonic speed of the pure samples and mixtures have been measured using a single stem pyncometer with a bulk capacity of 10 ml, an ubbelhode suspended level visocometer having a flow time of 174 sec. for triply distilled water at 25°C and a single crystal variable path multifrequency ultrasonic interferometer (Mittal agencies, New Delhi) operated at 5 MHz .The detail of the measurements have been reported in detail [13-19]. The reproducibility in the values of density, viscosity and ultrasonic speeds are within $\pm 2.8\times10^{-3}$ g cm^{-3}, $\pm 2\times10^{-3} mm^2s^{-1}$ and 0.03 % respectively. The temperatures of the test samples have been maintained with an uncertainty of ± 0.01 °C in an electronically controlled thermostatic water bath (Eurotherm, India).



Peak Report TIC

Peak#	R.Time	Area	Area%	Name
1	9.844	32191	0.08	Dodecanoic acid, methyl ester
2	12.430	214216	0.54	Tetradecanoic acid, methyl ester
3	16.553	17651798	44.31	Hexadecanoic acid, methyl ester
4	19.473	21837723	54.81	Methyl oleate
5	21.681	24086	0.06	Cyclopropaneoctanoic acid, 2-hexyl-, methyl ester
6	22.060	61410	0.15	Eicosanoic acid, methyl ester
7	24.683	13740	0.03	Docosanoic acid, methyl ester
8	27.216	6318	0.02	Tetracosanoic acid, methyl ester
		39841482	100.00	

Fig.1 Gas Chromatogram of Palm methyl ester

3 Theoretical background:

3.1 Thermo dynamic relation :

The thermo dynamical properties of the mixtures such as bulk modulus of compressibility, surface tension, internal pressure and intermolecular free length are calculated using the following relation [20]

i. Bulk Modulus of compressibility , β_t

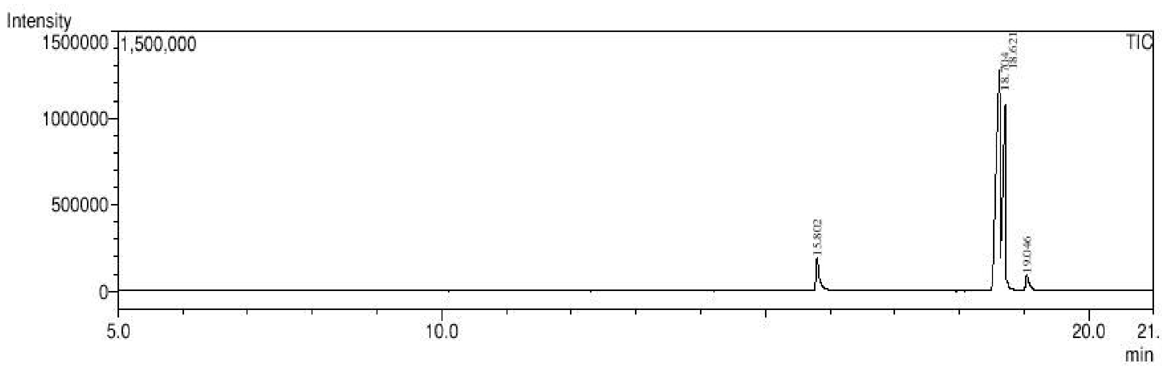
$$\beta_t = u^2\rho \quad (1)$$

ii. Surface Tension, σ

$$\sigma = 6.3\times10^{-3}\ \rho u^{3/2} \quad (2)$$

iii. Internal pressure, Π_i

$$\Pi_i = \alpha\ T/\beta \quad (3)$$



Peak Report TIC

Peak#	R.Time	Area	Area%	Height	Height%	Name
1	15.802	755260	7.92	193739	7.51	Methyl palmitate
2	18.621	5499763	57.69	1273774	49.36	Methyl linoleate
3	18.704	2941760	30.86	1020358	39.54	Methyl oleate
4	19.046	337072	3.54	92774	3.59	Methyl stearate
		9533855	100.00	2580645	100.00	

Fig.2 Gas Chromatogram of Sunflower methyl ester

Where α and β are the thermal expansion coefficient and Isothermal compressibility .They are evaluated using the following equations

$$\beta = 1.71\times 10^{-3}/T^{4/9}\ u^2\ \rho^{4/3};\ \alpha = (0.0191\times\beta)^{1/4}$$

iv. Intermolecular free length, L_f

$$L_f = K/u\ \rho^{1/2} \quad (4)$$

Where ρ and u are the density and ultrasonic speed of the mixtures respectively, K is Jacobson constant that depends on temperature and is given by [K= (93.875+0.375 T) × 10^{-8}].

4. Result and discussion:

Some of the experimentally measured physico chemical properties of pure biodiesel are given in Table 1 and compared with American (ASTM D 6751) and Indian Standard biodiesel standards[21] respectively. As these values of the FAME of both biodiesels are within the standards they may be used as fuels in diesel engines.

The experimentally measured density, viscosity and ultrasonic speed values of pure fuel samples are given in Table 2 at different temperatures. It is seen from Table 2 that the values of density, viscosity and ultrasonic speeds of pure biodiesels are greater than that of petro diesel. Further these values decrease with increase in temperature. Density is an important parameter of the biodiesel and related to the weight of a unit volume of the fuel. Fuel injection equipment operates on a volume metering system and hence when biodiesel is used as a fuel it results in the delivery of a slightly greater mass of the fuel because of its higher density values [23]. From the Table 2, it is also seen that the density of sunflower biodiesel is slightly higher than palm biodiesel due to reduction in chain length and increase in number of double bonds [24]. Viscosity, also a vital biodiesel parameter is a measure of internal friction of the fuel to its flow and closely related to the operation of fuel injection equipment. Whenever viscosity of the fuel increases it leads to poorer atomization of the fuel injectors, it also affects the fluidity of the fuel [23].The ultrasonic speed of the biodiesel is also an important physical parameter that is related to the starting of fuel injection timing of injector pump of the engine. When biodiesel is injected, the pressure rise produced by the pump is quicker as a consequence of higher bulk modulus and also propagates more quickly towards the injectors as a consequence of its higher sound velocity [4].

One of the methods to reduce the density, viscosity and ultrasonic speed of the biodiesel is to blend them with mineral diesel. Though universally it has been accepted that B20(Biodiesel 20% and mineral diesel 80%) may be the ideal choice for the operation of existing engines, several reports are available in literature on the performance of diesel engines with different blend proportions[4,5].

We report the values of density, viscosity and ultrasonic speed of three binary mixtures such as P.D+P.B.D, P.D+S.B.D and P.B.D +S.B.D over the entire composition range at different temperatures are given in the Tables 3-5.

From the Table 3 and 4 it is seen that the values of density, viscosity and ultrasonic speed increase with increase in composition of the biodiesel, in binary systems having petro diesel as one of the constituents at particular temperatures.. However the physical parameters values decrease with increase in temperature .An excellent linear correlations have been observed (See Figures 3- 5) between the above physical parameters namely density, viscosity and ultrasonic speed and the biodiesel concentration. For the mixtures, comprising of palm biodiesel and sunflower biodiesel as one of the components, linear correlation have also been observed between density and viscosity values with concentration of sunflower biodiesel (See Figures 6-8). Similar linear correlations may also be established at other studied temperatures. Recently Teixeira et al.[25] reported a linear correlation between viscosity and density with concentration of beef tallow biodiesel in the mixtures of beef biodiesel and mineral diesel/soybean biodiesel fuels. Similar linear correlation has been reported earlier by Demirrbas [23] between physical parameters of mixture of biodiesel fuels.

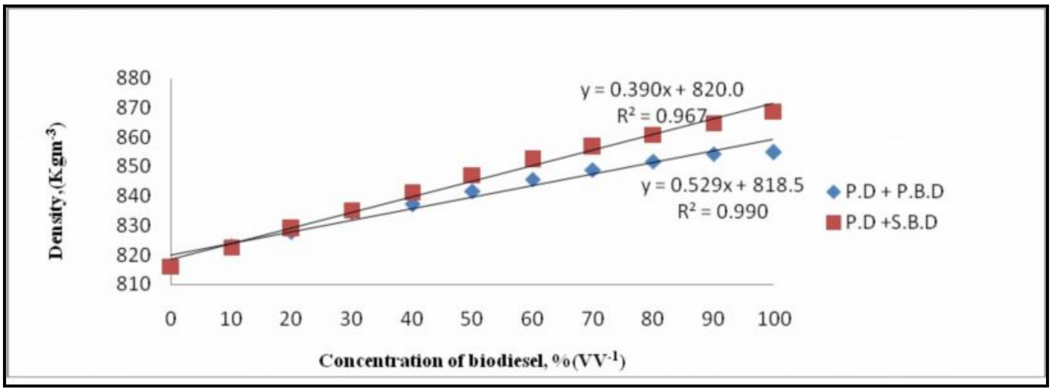


Figure 3 Density versus concentration of biodiesel

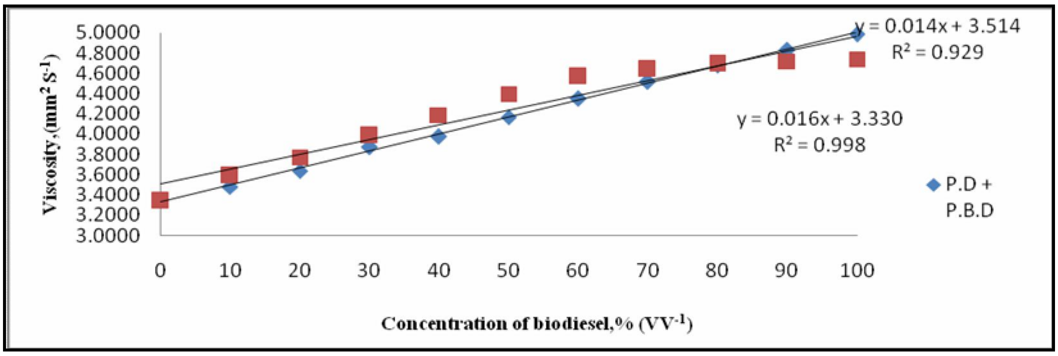


Figure 4 Viscosity versus concentration of biodiesel

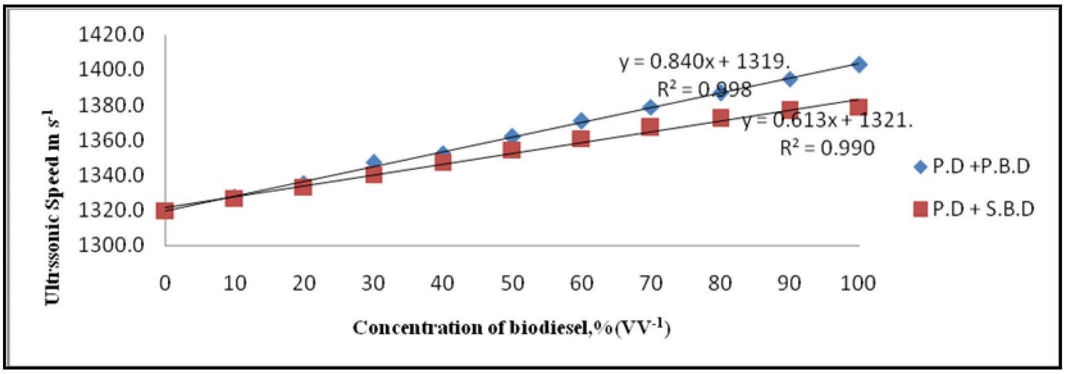


Figure 5 Ultrasonic speed versus concentration of biodiesel

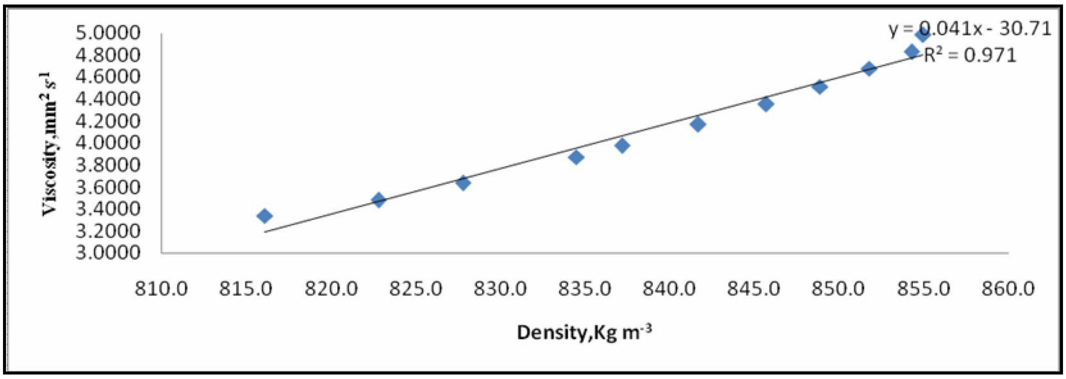


Figure 6 Correlation between density and viscosity for the mixtures of P.D+P.B.D.

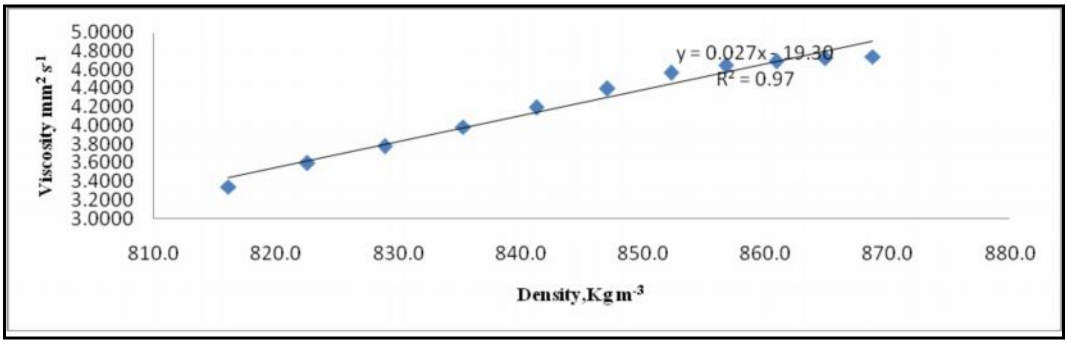


Figure 7 Correlation between density and viscosity for the mixtures of P.D+S.B.D .

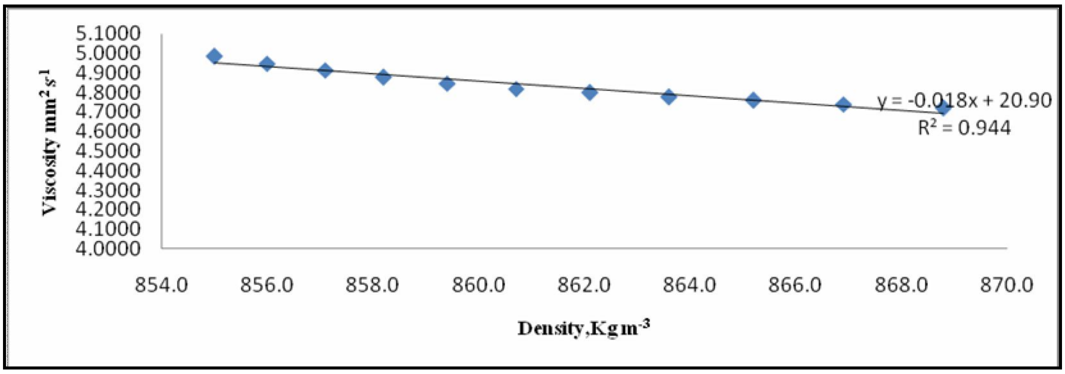


Figure 8 Correlation between density and viscosity for the mixtures of P.B.D+P.B.D .

Table 1 The comparison of physical properties of diesel ,palm biodiesel (P.B.D) and sunflower biodiesel(S.B.D) with various international standard.

Properties	**P.B.D**	**S.B.D**	**ASTM D6751-02**	IS 15607:2005
Density at 15°C, kgm^{-3}	871.0	876.0. 875.0[a]	870-895	860-900
Kinematic Viscosity at 40°C, mm^2s^{-1}	4.05	3.81 3.60 [a] at 38 °C	1.9-6.0	2.5-6.0
Acid number (mg KoH g^{-1})	0.1683	0.1122	0.50 Max	0.50 Max
Calorific value (KJ/kg)	39.92	38.20	-	-
Specific gravity	0.8719, 0.870[b]	0.8770	0.88	-
Flash point ,°C	174	173	130 Min	120 Min

a.ref 1; b.ref 22

Table 2 The values of density, viscosity and ultrasonic speed for the pure of diesel, palm biodiesel and sunflower biodiesel at different temperatures.

	30°C			**35°C**			**40°C**			**45°C**		
Sample	**ρ** **Kg m^{-3}**	**η** **mm^2s^{-1}**	**u** **ms^{-1}**	**ρ** **Kgm^{-3}**	**η** **mm^2s^{-1}**	**U** **ms^{-1}**	**ρ** **Kg m^{-3}**	**η** **mm^2s^{-1}**	**u** **ms^{-1}**	**ρ** **Kg m^{-3}**	**η** **mm^2s^{-1}**	**u** **ms^{-1}**
Diesel	816.1	3.3409	1320	816.3	2.8485	1315.0	810.3	2.7180	1308.0	808.5	2.5207	1283.0
P.B.D	855.0	4.9850	1403	853.2	4.6181	1363.5	850.5	4.0465	1353.0	844.0	3.8731	1335.0
S.B.D	868.8	4.7402	1379	867.2	4.0345	1378.0	864.5	3.8098	1363.5	862.8	3.3991	1336.0

Table 3 The values of density, viscosity and ultrasonic speed for the binary mixtures of Petro diesel (P.D) and palm biodiesel (P.B.D) for the whole range composition at different temperatures.

Composition of biodiesel (VV^{-1})		30°C			35°C			40°C			45°C		
P. D	P.B.D	ρ Kgm^{-3}	η mm^2s^{-1}	u ms^{-1}	ρ Kgm^{-3}	η mm^2s^{-1}	u ms^{-1}	ρ Kgm^{-3}	η mm^2s^{-1}	u ms^{-1}	P Kgm^{-3}	η mm^2s^{-1}	u ms^{-1}
100	0	816.1	3.3409	1320.0	813.6	2.8485	1315.0	810.3	2.7180	1308.0	808.5	2.5207	1283.0
90	10	822.8	3.4812	1327.2	819.2	2.9861	1319.0	815.7	2.8164	1311.4	812.8	2.6142	1286.5
80	20	827.8	3.6365	1335.0	824.3	3.1346	1324.0	820.4	2.9366	1315.5	817.1	2.7224	1291.0
70	30	834.5	3.8721	1347.0	830.9	3.3739	1332.0	826.9	3.1171	1322.5	822.8	2.8986	1298.0
60	40	837.2	3.9776	1352.5	833.8	3.4916	1335.8	829.7	3.2054	1326.0	825.2	2.9845	1301.5
50	50	841.7	4.1692	1362.0	838.5	3.6887	1342.0	834.2	3.3653	1332.0	829.2	3.1373	1307.5
40	60	845.7	4.3519	1371.0	842.8	3.8851	1348.0	838.6	3.5163	1337.5	833.0	3.2813	1313.5
30	70	848.9	4.5158	1379.0	846.1	4.0652	1352.5	842.1	3.6326	1341.5	836.1	3.4096	1318.2
20	80	851.8	4.6787	1387.0	849.2	4.2278	1356.0	845.1	3.7519	1344.5	838.9	3.5409	1323.0
10	90	854.3	4.8297	1395.0	851.6	4.3995	1359.0	847.9	3.8814	1348.0	841.5	3.6892	1328.0
0	100	855.0	4.9850	1403.0	853.2	4.6181	1363.5	850.5	4.0465	1353.0	844.0	3.8731	1335.0

Table 4 The values of density, viscosity and ultrasonic speed for the binary mixtures of Petro diesel (P.D) and Sunflower biodiesel (S.B.D) for the whole range composition at different temperatures.

Composition of biodiesel (VV^{-1})		30°C			35°C			40°C			45°C		
P.D	S.B.D	ρ Kgm^{-3}	η mm^2s^{-1}	u ms^{-1}	ρ Kgm^{-3}	η mm^2s^{-1}	u ms^{-1}	ρ $Kg\ m^{-3}$	η mm^2s^{-1}	u ms^{-1}	ρ $Kg\ m^{-3}$	η mm^2s^{-1}	u ms^{-1}
100	0	816.1	3.3409	1320.0	813.6	2.8485	1315.0	810.3	2.7180	1308.0	808.5	2.5207	1283.0
90	10	822.6	3.5921	1327.0	819.8	2.9801	1321.0	816.2	2.8230	1313.0	814.2	2.5858	1287.0
80	20	828.9	3.7724	1333.5	826.0	3.1570	1327.0	822.2	2.9422	1318.0	820.1	2.6827	1291.5
70	30	835.3	3.9829	1340.5	832.5	3.3208	1334.0	828.5	3.1106	1324.0	826.2	2.7828	1297.0
60	40	841.3	4.1897	1347.5	838.6	3.4917	1341.5	834.9	3.2526	1331.0	832.2	2.8967	1303.0
50	50	847.1	4.3965	1354.5	844.5	3.7106	1349.0	840.8	3.4754	1337.6	838.1	3.1192	1310.0
40	60	852.3	4.5662	1361.0	849.9	3.8891	1356.0	846.4	3.6455	1344.0	843.7	3.2543	1317.0
30	70	856.8	4.6435	1367.0	854.4	3.9642	1362.0	850.8	3.7152	1349.2	848.5	3.2957	1321.8
20	80	860.9	4.6910	1372.0	858.7	3.9927	1367.4	855.4	3.7249	1354.0	853.1	3.3287	1326.0
10	90	864.9	4.7206	1376.5	862.8	3.9949	1372.5	859.8	3.7519	1358.0	857.8	3.3607	1330.0
0	100	868.8	4.7402	1379.0	867.2	4.0345	1378.0	864.5	3.8098	1363.5	862.8	3.3991	1336.0

Table 5 The values of density, viscosity and ultrasonic speed for the binary mixtures of palm biodiesel (P.B.D) and sunflower biodiesel (S.B.D) for the whole range composition at different temperatures.

Composition of biodiesel (VV^{-1})		30°C			35°C			40°C			45°C		
P.B.D	**S.B.D**	**ρ Kgm^{-3}**	**η mm^2s^{-1}**	**u ms^{-1}**	**ρ $Kg\ m^{-3}$**	**η mm^2s^{-1}**	**U ms^{-1}**	**ρ Kgm^{-3}**	**η mm^2s^{-1}**	**u ms^{-1}**	**P Kgm^{-3}**	**η mm^2s^{-1}**	**u ms^{-1}**
100	0	855.0	4.9850	1403.0	853.2	4.6181	1363.5	850.5	4.0465	1353.0	844.0	3.8731	1335.0
90	10	856.0	4.9485	1382.3	854.4	4.5433	1353.0	851.8	3.9951	1345.0	845.8	3.7724	1328.0
80	20	857.1	4.9135	1350.0	855.6	4.4718	1334.0	853.0	3.9543	1330.0	847.6	3.6977	1317.0
70	30	858.2	4.8782	1333.3	856.7	4.3985	1317.0	854.2	3.9148	1312.0	849.4	3.6301	1303.0
60	40	859.4	4.8464	1326.4	857.9	4.3304	1310.0	855.4	3.8777	1305.0	851.1	3.5723	1297.0
50	50	860.7	4.8185	1329.5	859.2	4.2636	1315.0	856.7	3.8478	1310.0	852.8	3.5186	1299.0
40	60	862.1	4.7976	1335.0	860.7	4.2129	1325.0	858.1	3.8279	1318.0	854.6	3.4774	1305.0
30	70	863.6	4.7772	1343.5	862.2	4.1672	1337.0	859.6	3.8201	1330.0	856.6	3.4474	1313.0
20	80	865.2	4.7594	1354.0	863.8	4.1224	1350.0	861.2	3.8133	1342.0	858.7	3.4271	1323.0
10	90	866.9	4.7395	1366.3	865.6	4.0802	1364.0	862.9	3.8158	1354.0	860.8	3.4065	1330.0
0	100	868.8	4.7205	1379.0	867.2	4.0345	1378.0	864.5	3.8098	1363.5	862.8	3.3991	1336.0

Table 6 The values of Bulk Modulus β_t , surface tension σ, internal pressure Π_i and Intermolecular free length Lf for the binary mixtures of petro diesel(P.D) palm biodiesel(P.B.D) for various composition at different temperatures

Czomposition of biodiesel (VV^{-1})		30°C				35°C				40°C				45°C			
P.D	P.B.D	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m
100	0	0.1421	2.4657	3.5236	5.5041	0.1406	2.4442	3.5699	5.5835	0.1386	2.4148	3.6036	5.6752	0.1330	2.3407	3.5676	5.8436
90	10	0.1449	2.5063	3.5817	5.4519	0.1425	2.4722	3.6109	5.5475	0.1402	2.4404	3.6418	5.6417	0.1345	2.3628	3.6012	5.8122
80	20	0.1475	2.5438	3.6353	5.4037	0.1444	2.5018	3.6541	5.5094	0.1419	2.4660	3.6800	5.6080	0.1361	2.3878	3.6393	5.7767
70	30	0.1514	2.5990	3.7142	5.3340	0.1474	2.5447	3.7168	5.4546	0.1446	2.5054	3.7388	5.5563	0.1386	2.4240	3.6945	5.7256
60	40	0.1531	2.6234	3.7491	5.3037	0.1487	2.5645	3.7457	5.4296	0.1458	2.5239	3.7663	5.5323	0.1397	2.4409	3.7203	5.7019
50	50	0.1561	2.6654	3.8090	5.2526	0.1510	2.5970	3.7931	5.3893	0.1480	2.5548	3.8125	5.4925	0.1417	2.4698	3.7642	5.6621
40	60	0.1589	2.7046	3.8651	5.2058	0.1531	2.6278	3.8381	5.3516	0.1500	2.5842	3.8564	5.4555	0.1437	2.4982	3.8075	5.6233
30	70	0.1614	2.7386	3.9137	5.1658	0.1547	2.6513	3.8725	5.3234	0.1515	2.6066	3.8898	5.4280	0.1452	2.5209	3.8422	5.5929
20	80	0.1638	2.7719	3.9613	5.1273	0.1561	2.6714	3.9018	5.3000	0.1527	2.6247	3.9168	5.4062	0.1468	2.5432	3.8762	5.5633
10	90	0.1662	2.8042	4.0074	5.0904	0.1572	2.6878	3.9258	5.2808	0.1540	2.6437	3.9451	5.3833	0.1484	2.5656	3.9103	5.5338
0	100	0.1682	2.8306	4.0452	5.0593	0.1586	2.7062	3.9527	5.2584	0.1556	2.6666	3.9793	5.3552	0.1504	2.5936	3.9529	5.4966

Table 7 The values of Bulk Modulus β_t , surface tension σ, internal pressure Π_i , Intermolecular free length Lf for the binary mixtures of petro diesel (P.D) and sunflower biodiesel(S.B.D) for various composition at different temperature.

Composition of biodiesel (VV^{-1})		30°C				35°C				40°C				45°C			
P.D	S.B.D	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m
100	0	0.1421	2.4657	3.5236	5.5041	0.1406	2.4442	3.5699	5.5835	0.1386	2.4148	3.6036	5.6752	0.1330	2.3407	3.5675	5.8436
90	10	0.1448	2.5051	3.5800	5.4534	0.1430	2.4797	3.6217	5.5371	0.1407	2.4464	3.6506	5.6331	0.1348	2.3683	3.6095	5.8050
80	20	0.1473	2.5429	3.6339	5.4062	0.1454	2.5155	3.6740	5.4913	0.1428	2.4785	3.6985	5.5912	0.1367	2.3979	3.6547	5.7639
70	30	0.1500	2.5827	3.6908	5.3573	0.1481	2.5553	3.7323	5.4411	0.1452	2.5145	3.7523	5.5447	0.1389	2.4312	3.7055	5.7182
60	40	0.1527	2.6217	3.7465	5.3104	0.1509	2.5958	3.7914	5.3910	0.1479	2.5541	3.8113	5.4943	0.1412	2.4659	3.7583	5.6714
50	50	0.1554	2.6603	3.8018	5.2648	0.1536	2.6360	3.8501	5.3423	0.1504	2.5913	3.8669	5.4480	0.1438	2.5034	3.8155	5.6212
40	60	0.1578	2.6960	3.8527	5.2237	0.1562	2.6736	3.9049	5.2978	0.1528	2.6273	3.9206	5.4041	0.1463	2.5404	3.8718	5.5727
30	70	0.1601	2.7281	3.8987	5.1871	0.1584	2.7056	3.9517	5.2605	0.1548	2.6563	3.9639	5.3693	0.1482	2.5688	3.9152	5.5367
20	80	0.1620	2.7562	3.9388	5.1559	0.1605	2.7354	3.9952	5.2266	0.1568	2.6849	4.0066	5.3359	0.1499	2.5951	3.9552	5.5043
10	90	0.1638	2.7827	3.9766	5.1271	0.1625	2.7638	4.0368	5.1948	0.1585	2.7107	4.0450	5.3065	0.1517	2.6212	3.9950	5.4727
0	100	0.1652	2.8028	4.0054	5.1063	0.1646	2.7946	4.0818	5.1609	0.1607	2.7421	4.0919	5.2707	0.1540	2.6543	4.0455	5.4323

Table 8 The values of Bulk Modulus β_t , surface tension σ, internal pressure Π_i and Intermolecular free length Lf for the binary mixtures of palm biodiesel (P.B.D) and sunflower biodiesel (S.B.D) for various composition at different temperature.

Composition of biodiesel (VV^{-1})		30°C				35°C				40°C				45°C			
P.B.D	S.B.D	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} m	β_t 10^{10} Nm^{-2}	σ 10^5 Nm^{-1}	Π_i 10^{12} Pa	L_f 10^{-11} M
100	0	0.1682	2.8306	4.0452	5.0593	0.1586	2.7062	3.9527	5.2584	0.1556	2.6666	3.9792	5.3552	0.1504	2.5936	3.9529	5.4966
90	10	0.1635	2.7715	3.9606	5.1321	0.1564	2.6788	3.9126	5.2955	0.1540	2.6470	3.9500	5.3829	0.1491	2.5787	3.9302	5.5197
80	20	0.1562	2.6783	3.8275	5.2515	0.1522	2.6263	3.8358	5.3672	0.1508	2.6065	3.8896	5.4398	0.1470	2.5521	3.8897	5.5599
70	30	0.1525	2.6322	3.7615	5.3139	0.1485	2.5795	3.7676	5.4330	0.1470	2.5574	3.8162	5.5106	0.1442	2.5169	3.8360	5.6136
60	40	0.1511	2.6154	3.7376	5.3378	0.1472	2.5626	3.7428	5.4582	0.1456	2.5405	3.7911	5.5362	0.1431	2.5045	3.8172	5.6340
50	50	0.1521	2.6286	3.7564	5.3213	0.1485	2.5812	3.7700	5.4333	0.1470	2.5590	3.8187	5.5109	0.1439	2.5153	3.8336	5.6197
40	60	0.1536	2.6492	3.7858	5.2951	0.1511	2.6152	3.8197	5.3876	0.1490	2.5867	3.8600	5.4730	0.1455	2.5381	3.8684	5.5880
30	70	0.1558	2.6792	3.8287	5.2570	0.1544	2.6554	3.8785	5.3346	0.1520	2.6267	3.9197	5.4189	0.1476	2.5675	3.9131	5.5474
20	80	0.1587	2.7157	3.8809	5.2114	0.1574	2.6993	3.9425	5.2783	0.1550	2.6673	3.9802	5.3654	0.1503	2.6032	3.9676	5.4988
10	90	0.1618	2.7582	3.9416	5.1594	0.1610	2.7468	4.0118	5.2190	0.1581	2.7085	4.0417	5.3126	0.1522	2.6303	4.0089	5.4631
0	100	0.1652	2.8028	4.0054	5.1063	0.1646	2.7946	4.0818	5.1609	0.1607	2.7421	4.0919	5.2707	0.1540	2.6543	4.0455	5.4323

It is very well known that bulk modulus of the biodiesel, is generally higher than petro diesel, along with viscosity and sound velocity, play a prominent role in advancing the starting of injection process [26].It has been reported by Szybistetal[27] that bulk modulus of the fuel is related to the free space between the molecules of the medium (viz. intermolecular free length). Furthermore surface tension is a parameter that decides the fuel spray characteristics with viscosity such as droplet size distribution, droplet moment of inertia etc. In addition to this, surface tension of the fuel is also responsible on the delay time on the premixed/diffusion combustion ratio and NO formation. It is also available in literature [28] that surface tension of the liquid is inherently related to the internal pressure of the system. Thus we have evaluated these thermodynamic parameters using equations (1-4) for the binary system and reported the values in Table 6 to 8. It is seen that for the binary mixtures having petro diesel as one of the components (See Tables 6 and 7) the values of bulk modulus, internal pressure and surface tension increase with increase of concentration of biodiesel. However these values decrease with increase in temperature. The intermolecular free length inversely related to internal pressure, this trend is faithfully reflected in the present system. However in the binary mixture consisting of both biodiesel as one of the components (See Table 8) the values of bulk modulus, surface tension and internal pressure decrease up to 40% (V/V) of S.B.D and then increase with further increase in S.B.D concentration. A minimum value in ultrasonic speed has also been noticed at this composition(See table 5)at all studied temperature reflects that at this composition of the mixture, least interaction may be taking place between the molecules of the mixture. A reverse trend is noticed in intermolecular free length values complementing the existence of inverse relationship with internal pressure.

Conclusion :

Density, viscosity and ultrasonic speed of binary mixtures comprising of palm biodiesel, sunflower biodiesel and petro diesel have been measured for the whole composition at different temperatures. Several thermodynamic parameters are evaluated and reported that may be related to the engine performance, efficiency etc. Linear correlations between viscosity, density and ultrasonic speed with concentration of biodiesel have been observed in the studies systems.

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