DETERMINATION OF CETANE NUMBER OF BIODIESEL AND IT'S INFLUENCE ON PHYSICAL PROPERTIES

K. Sivaramakrishnan[1] and P. Ravikumar[2]
[1]Anjalai Ammal Engineering College, Kovilvenni, Tamil Nadu, India
[2]Principal St. Joseph College of Engineering and Technology, India
E-Mail: sivaporkodi2000@yahoomail.co.in

ABSTRACT

Biodiesel, an alternative fuel can be used in diesel engine as neat or blended with diesel. The physio-chemical properties of fuel are important in design of fuel system for compression ignition engine run on diesel, biodiesel or biodiesel blends. Cetane number is an important parameter in evaluating the quality of biodiesel fuel. Its determination is usually arduous and expensive. The present study is aimed at developing the mathematical relationship between viscosity, density, calorific value, flash point and cetane number (CN). An equation was developed relating the cetane number and thermal properties. The predicted cetane number values are compared with the measured cetane number values. This work establishes the general dependence of cetane number on the thermal properties of biodiesel.

Keywords: biodiesel, cetane number, oil, fuel properties.

1. INTRODUCTION

Renewable energy sources are receiving increasing attention due to decreasing oil reserves and increasing environmental consciousness. Vegetable oils are one of the important sources of renewable energy, and can be transesterified to biodiesel, which is an alternative fuel for diesel engines.

Biodiesel is a non-toxic, biodegradable, and renewable diesel fuel and can be used neat or blends with petroleum diesel fuels. Biodiesel has many advantages compared to diesel fuels. It has higher cetane number than diesel fuel, and contains no aromatics, almost no sulfur and 10-12% oxygen by weight. Biodiesel-fueled engines produce less CO, HC and particulate emissions than petroleum diesel-fueled engines [1, 2]. Biodiesel improves the lubricity, which results in longer engine component life [3-5]. Attempts have been made by various researchers to determine the best composition of biodiesel that would enhance the combustion process. It was observed that the fuel properties of biodiesel play a significant role in the combustion process. One of such properties is cetane number, (CN) influence the combustion process and engine performance. The CN is a commonly used indicator for the determination of diesel fuel ignition the quality. It measures the readiness of the fuel to auto-ignite when injected into the engine [6]. Many performance characteristics such as density, heating value are related to cetane number [7]. Cetane number is the parameter used to determine the quality of biodiesel; it is proportionate to the fuel ignition delay time in CI engines. A fuel's CN rating can be applied to determine ignition characteristics of biodiesel fuels [8].

The test procedure of CN has been subject to criteria based on the difference between the cetane numbers test configuration and operating condition. The CN test procedure is complex and inherently involves considerable uncertainty due to experimental error. It is not always easy conducting engine test to determine CN due to the cost of the reference fuels and the effort required. Cetane number is measured using blends of two reference fuels, namely n-Cetane (100CN) and hepta methyl Cetane (15CN). Cetane number of the test fuel is the percentage by volume of n-Cetane in a blend of n-Cetane (100CN) and hepta methyl Cetane (15CN) having the same ignition quality when tested in the same engine under the same test conditions. One of the ways of solving the problem of CN determination is to develop models to predict the CN when some parameters are known [7]. The predicated CN of biodiesel is comparable to that of the actual CN of the biodiesel, and it has been concluded that the CN of biodiesel can be predicted based on thermal properties. The focus of this work is to develop an empirical equation for predicting the CN of biodiesel.

Equations were developed for the calculation of the Higher Heating Value of vegetable oils and biodiesel from their viscosity (ν), density (ρ) and flash point (FP) [9]

The equations between viscosity and higher heating values are for vegetable oils.

$$HHV= 0.0317\ \nu +38.053 \quad (1)$$

For biodiesels

$$HHV = 0.4625\ \nu +39.450 \quad (2)$$

The equation between density and higher heating value for biodiesel is:

$$HHV= -0.0259\ \rho + 63.776 \quad (3)$$

The equation between flash point and higher heating value for biodiesel is:

$$HHV = 0.021FP+32.12 \quad (4)$$

The measured Cetane number and physical properties of the biofuels were analyzed to obtain regression equation and to rank the physical properties based on R^2 values. The following physical properties are ranked in descending order based on precision (R^2) of predicting Cetane numbers: boiling point> viscosity>

heating value> carbon number> melting point> density [10].

2. MATERIALS AND METHODS

2.1 Measurement of different fuel properties

The important physical and chemical properties of oil and biodiesel were determined by standard methods. In order to measure the properties of the diesel fuels, the biodiesels and the blends, the test methods were used as follows:

2.1.1 Relative density

Density is an important property of biofuel. Density is the mass per unit volume of any liquid at a given temperature. Density measurements were carried out using a pycnometer at a temperature of 312K.

2.1.2 Flash and fire point

The flash point temperature of biodiesel fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source. Flash point varies inversely with the fuel's volatility. Minimum flash point temperatures are required for proper safety and handling of diesel fuel. Fire point is the lowest temperature at which a specimen will sustain burning for 5 seconds. These two parameters have great importance while determining the fire hazard (temperature at which fuel will give off inflammable vapour). Flash point of the samples were measured in the temperature range of 60 to 190°C by an automated Pensky-Martens closed cup apparatus

2.1.3 Calorific value

Calorific value of a fuel is the thermal energy released per unit quantity of fuel when the fuel is burned completely and the products of combustion are cooled back to the initial temperature of the combustible mixture. It measures the energy content in a fuel. This is an important property of the bio-diesel that determines the suitability of the material as alternative to diesel fuels. The calorific value of vegetable oils and their methyl esters were measured in a bomb calorimeter according to ASTMD240 standard method. An oxygen-bomb was pressurized to 3MPa with an oxygen container. The bomb was fired automatically after the jacket and bucket temperature equilibrated to within accuracy of each other

2.1.4 Viscosity measurements

Viscosity is a measure of the internal fluid friction or resistance of oil to flow, which tends to oppose any dynamic change in the fluid motion. As the temperature of oil is increased its viscosity decreases and it is therefore able to flow more readily. The lower the viscosity of the oil, the easier it is to pump and atomize and achieve finer droplets. Viscosity is measured using Redwood viscometer. The Redwood viscosity value is the number of seconds required for 50 ml of oil to flow out of a standard viscosimeter at a definite temperature.

2.1.5 Cetane number

The physical and chemical properties of fuel play very important role in delay period. The Cetane Number (CN) of the fuel is one such important parameter which is responsible for the delay period. Cetane number of a fuel is defined as the percentage by volume of normal cetane in a mixture of normal cetane and α-methyl naphthalene which has the same ignition characteristics (ignition delay) as the test fuel, when combustion is carried out in a standard engine under specified operating condition. A fuel of higher cetane number gives lower delay period and provides smoother engine operation. Biodiesel has a higher CN than petrodiesel because of its higher oxygen content.

Table-1. Measuring devices and test methods for measuring fuel properties.

Properties	Measurement apparatus	Standard test method
Density	Hydrometer	ASTM D941
Flash and fire point	Penksy martins apparatus	ASTM D93
Calorific value	Bomb calorimeter	ASTM D240
Viscosity	Red wood viscometer	ASTM D445
Cetane number	Ignition quality tester	ASTM D613

3. RESULTS AND DISCUSSIONS

The viscosity, Higher heating value (HV), flash point, density and Cetane number measurements of eight oil are given in Table-2. The viscosity, Higher heating value (HV), flash point, density and Cetane number measurements of six Vegetable oil methyl esters are given in Table-3. The viscosity, Higher heating value (HV), flash point, density and Cetane number measurements of six Biodiesel blends are given in Tables 4 and 5.

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Table-2. Properties of oil characteristics.

Oil	Kinematic viscosity (mm^2/sec) **ν**	Heating value (MJ/kg) **HV**	Flash point (°C) **FP**	Density (kg/l) **ρ**	Cetane number
Karanja	27.84	34.0	205	0.912	52.0
Babassu	30.30	37.5	150	0.946	38.0
Soyabean	32.60	39.6	254	0.914	37.9
Sunflower	33.90	39.6	274	0.916	37.1
Rapeseed	37.00	39.7	246	0.912	37.6
Peanut	39.60	39.8	271	0.903	41.8
Palm	39.60	39.5	267	0.918	42.0
Jatropha	52.76	38.2	210	0.933	38.0

Table-3. Properties of vegetable oil methyl ester.

Biodiesel	Kinematic viscosity (mm^2/sec) **ν**	Heating value (MJ/kg) **HV**	Flash point (°C) **FP**	Density (kg/l) **ρ**	Cetane number
Babassu	3.6	41.15	127	0.875	63
Rapeseed	4.2	41.55	80	0.882	54
Soyabean	4.5	41.28	178	0.885	45
Sunflower	4.6	41.33	96	0.860	49
Peanut	4.9	41.71	176	0.883	54
Palm	5.7	41.24	183	0.880	62

Table-4. Properties of biodiesel-blends-Karanja.

Biodiesel	Kinematic viscosity (mm^2/sec) **ν**	Heating value (MJ/kg) **HV**	Flash point (°C) **FP**	Density (kg/l) **ρ**	Cetane number
B0	2.71	42.5	55	0.836	51.00
B20	4.01	41.5	65	0.849	51.70
B40	5.23	39.9	77	0.858	52.82
B60	6.72	38.7	88	0.862	53.15
B80	8.19	37.0	101	0.878	53.86
B100	9.60	35.9	114	0.900	54.53

Table-5. Properties of biodiesel-blends-Jatropha.

Biodiesel	Kinematic viscosity (mm^2/sec) **ν**	Heating value (MJ/kg) **HV**	Flash point (°C) **FP**	Density (kg/l) **ρ**	Cetane n number
B0	2.71	42.50	55	0.836	51.0
B20	3.20	41.52	78	0.840	51.2
B40	3.85	41.16	102	0.845	51.4
B60	4.02	40.10	124	0.851	51.9
B80	4.82	39.30	148	0.856	52.2
B100	5.70	39.17	174	0.862	53.0

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It can be observed that vegetable oils posses a lower gross calorific value, high viscosity, high flash point and higher density than biodiesel and its blends.

The Heat of combustion refers to the measure of energy content in the fuel. Heating value of fuels is an important measure of its releasing energy for producing work. So the lower heating value of biodiesel is attributed to the decrease in engine power. The blend 20% jatropha was observed to record the highest calorific value of 41.52 MJ/kg apart from diesel, whilst the lowest calorific value of 34 MJ/kg was measured with respect to karanja. The energy content of oils depends on the place where they are grown, the season, composition and other factors. The calorific value of vegetable oils was observed to be lower than those of biodiesels. For methyl esters, the heat content increases as the length of the fatty acids chain increases. The presence of a significant amount of oxygen contributes to the lower energy content of biodiesel fuels Viscosity is a measure of the internal friction or resistance of oil to flow. As the temperature of oil is increased, its viscosity decreases and it is therefore able to flow more readily. Viscosity is the most important of biodiesel since it affects the operation of fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors.

The viscosity values of vegetable oils are between 27.84 and 52.76 mm^2/sec at 40°C whereas those of vegetable oils methyl esters are between 3.6 and 5.7 mm^2/sec Non edible oils were observed to have high viscosity values about six times more than ASTM limits. Jatropha was the most viscous with a viscosity of 52.76 mm^2/sec at 40°C. The methyl esters and the blends were observed to have viscosity within the ASTM limits.

Density is another important property of biodiesel. It can be observed from the readings that babassu oil sample has the highest value of 0.946 kg/l as compared to all other samples. The sun flower oils methyl ester has a minimum density value of 0.86 kg/l. The diesel fuel sample was observed to have a density value of 0.836 kg/l which is lower than edible, non edible oils, methyl esters and its blends.

The flash point of vegetable oil methyl esters is much lower than those of vegetable oils. The flash point of sun flower oil was observed to be highest 274°C among methyl esters rape seed was observed to be lowest with 80°C.

3.1 Cetane number

The ignition quality of a fuel can be deduced through its cetane number. A fuel with good ignition quality has a high cetane number, where the ignition delay period between the start of fuel injection and the onset of auto ignition is short. Cetane number of biodiesel varies with the feed stock used, but it is generally in the higher end of the typical diesel fuel range. The value of cetane number is found to generally increase with increasing carbon chain length. It was observed from the tables that vegetable oils have a low cetane number; this is due to the presence of bulkier molecules in the triglycerides which have a high viscosity. Babassu records the highest CN of 63. Sun flower oils have a lowest of 37.1. Methyl esters (biodiesel) are observed to possess a higher CN when compared to their corresponding oils. The babassu oil methyl ester has the highest CN, whereas soyabean methyl ester records the lowest among the oils tested. Methyl esters have a lower viscosity than their corresponding vegetable oils. Biodiesel records high CN values; these values are higher than that of diesel fuel with CN of 52. The high CN of biodiesel may be influenced by their characteristics of the feed stock. Factors that affect the CN in the biodiesel are, e.g. the number of carbon atoms of the original fatty acids, the number of double bonds and the ester yield [11]. It can also be observed from the readings that non edible oils blends have CN values close to those of the diesel fuel samples; this is due to the presence of diesel in blends. It is clear that, the higher the density the lower the Cetane number.

3.2 Mathematical equation

Based on the above reference there exists a relation between cetane number and properties of biodiesel so a correlation was developed which is given as equation 5.

$$CN = K_5 + K_4\,\nu + K_3\,HV + K_2\,FP + K_1\,\rho \quad (5)$$

Where K_1, K_2, K_3, K_4, K_5 are constants and ν is kinematic viscosity (mm^2/sec), HV is heating value (MJ/kg), FP is flash point (°C), ρ is density (kg/l).

Equation 5 shows the relationship between the Cetane number and the thermal properties. Using this relation the Cetane number for Oils, biofuel, biodiesel blends were calculated and given in Table-6 and graph has been drawn between measured value and calculated value which is shown in Figures 1, 2, 3 and 4.

The average measured values of CN obtained compare well with the predicated values using the generated equation. However there are slight variations in rapeseed, sunflower and palm. This is due to high viscosity and high calorific value of the vegetable oils. The predicted values, however, fall within the range of measured values. The equation developed was used to predict the CN values of different biodiesels consisting of different thermal properties. A plot of predicted values of CN against the measured values is shown in Figure. The coefficient of determination was 0.9, which indicates that the CN can be predicted with 90% accuracy based on thermal properties of biofuel.

Table-6. The calculated and measured values of cetane number.

Oils				
Specifications	**Measured**	**Calculated**	**Absolute error**	**Error %**
Peanut	41.8	40.30	1.50	3.58
Soyabean	37.9	38.80	0.90	2.31
Babassu	38.0	37.19	0.81	2.97
Palm	42.0	38.97	3.03	7.21
Sunflower	37.1	39.05	1.95	4.99
Rapeseed	37.6	38.74	1.14	2.94
Karanja	52.0	52.06	0.03	0.05
Jatropha	38.0	39.06	1.06	2.71
Biodiesel methyl ester				
Peanut	54	50.84	3.16	6.21
Soyabean	45	47.21	2.21	4.68
Babassu	63	62.76	0.24	0.38
Palm	62	62.87	0.87	1.38
Sunflower	49	49.14	0.14	0.28
Rapeseed	54	54.09	0.09	0.16
Biodiesel Jatropha blends				
B0	51.0	51.08	0.08	0.17
B20	51.2	51.15	0.05	0.09
B40	51.4	51.59	0.19	0.38
B60	51.9	51.99	0.09	0.17
B80	52.2	52.43	0.23	0.45
B100	53.0	53.10	0.10	0.20
Biodiesel Karanja blends				
B0	51.0	51.20	0.20	0.40
B20	51.7	51.58	0.12	0.23
B40	52.8	52.60	0.19	0.40
B60	53.2	53.19	0.01	0.02
B80	53.9	53.84	0.06	0.11
B100	54.5	54.60	0.10	0.18

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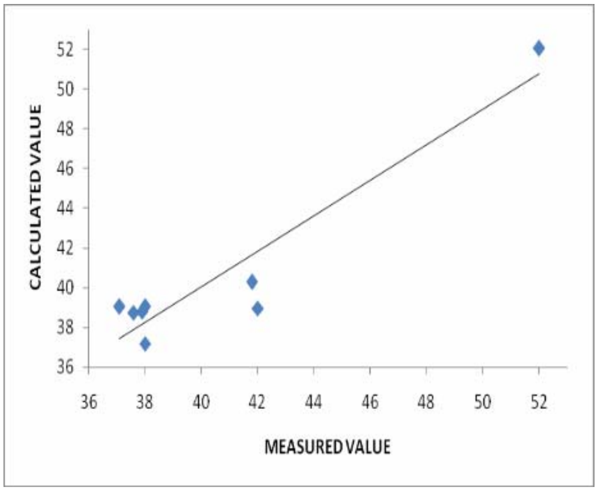

Figure-1. Relation ship between measured and predicted value of cetane number of oils.

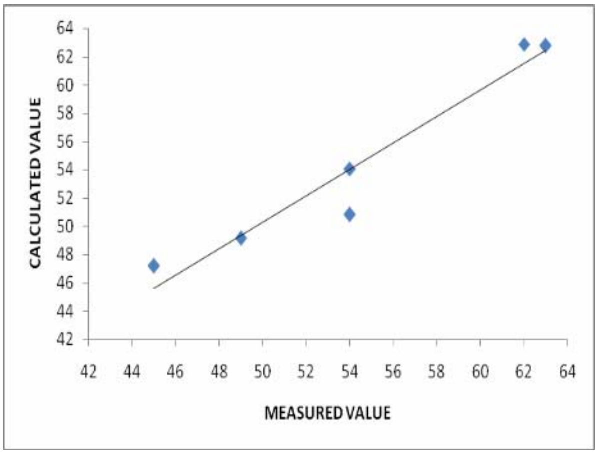

Figure-2. Relation ship between measured and predicted value of cetane number of bio fuels.

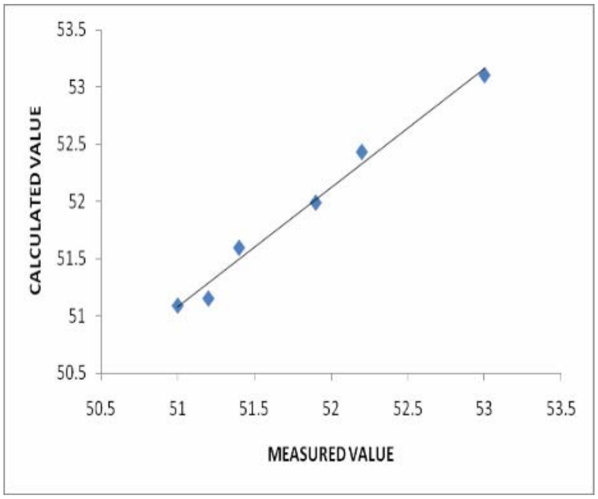

Figure-3. Relation ship between measured and predicted value of *Jatropha* bio diesel.

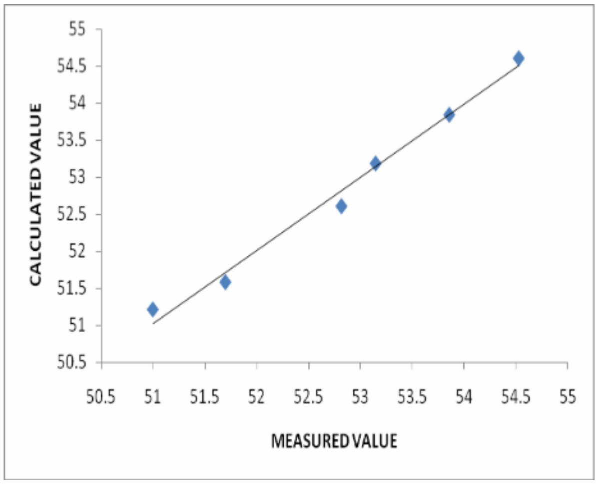

Figure-4. Relation ship between measured and predicted value of karanja bio diesel.

4. CONCLUSIONS

Equations 5 have been developed to calculate cetane number of various vegetable oils and their biodiesel from their viscosity, density, flash point and higher calorific value.

The vegetable oils are extremely viscous with viscosities ranging from 9 to 16 times greater than petroleum diesel. Biodiesel an alternate diesel fuel is made from renewable biological sources such as vegetable oils and animal fats by transesterification reaction using methanol. The purpose of the transesterification process is to lower the viscosity of the oil.

From the results obtained it is found that CN is affected by the physical properties.

An equation was developed to predict the CN based on physical properties and it was able to predict with …90%….accuracy.

The developed equation can effectively predict the CN of the biodiesel based on its physical properties.

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