ISSN : 2347 - 8446 (Online)
ISSN : 2347 - 9817 (Print)

Bio Diesel - Non Conventional Source of Energy

[I]Shailendra N. More, [II]Krantiveer M. Pawar
[I]Principal, Nutan Maharashtra Vidya Polytechnic, Talegaon Dabhade Pune, India
[II]Training & Placement Officer, Institute of Technology, Malegaon (Bk), India

Abstract

Diesel fuels have an essential function in the industrial economy of a country. Compared to the rest of the world, India's demand for diesel fuels is roughly six times that of gasoline. The consumption of diesel fuels in India in 1994-95 was 28.30 million tons, which was 43.2% of the total consumption of petroleum products. This requirement was met by importing crude petroleum as well as petroleum products. The import bill on these items was Rs. 17,838 Crores. With the expected growth rate of diesel consumption of more than 14% per annum, shrinking crude oil reserves and limited refining capacity, India will be heavily dependent on imports of crude petroleum and petroleum products. It is logical that research and development on different possible sources of petroleum products should be carried on with the special emphasis on yield and quality of diesel fuels. Today every major country has its own energy program. Preliminary studies have proved that vegetable oils can have a good replacement of petroleum oil.

In the present work, Preparation of biodiesel i.e. Methyl esters by transesterification from Karanja oil, its physical and chemical properties are explained. Bio diesel prepared from Karanja is referred here as KB and the blends with diesel are termed as KB25, KB50. Biodiesel with these forms is used in Single cylinder- 4s diesel engine and its performance is evaluated. Also, combustion analysis, Injector performance, carbon deposition on injector tip and exhaust emission are studied.

I. Introduction

There was considerable interest in the use of vegetable oils as fuels for diesel engine, before wide spread use of petroleum fuels. Dr. Rudolf Diesel, the inventor of the CI engine used peanut oil to fuel one of his engines for demonstration at the Paris exposition in 1900 [1]. In recent times, the world has been confronted with an energy crisis due to depletion of resources and increased environmental problems. The situation has led to the search for an alternative fuel, which must be sustainable as well as environment friendly [2]. The strongest impulse was given by the crisis in supply of mineral oil as the major source for energy in the 1970s and again by the Gulf war in 1991. Being highly dependent on huge imports of fossil oil as a finite energy source the European Union has to face today again an increasing risk in security of energy supply for the transport sector caused by the following issues as emphasized by the International Energy Agency (IEA): a) the production-demand gap of fossil oil is declining world-wide, b) North Sea oil will be finished by the year 2010 latest, and c) the energy demand of the non-OECD world is growing dramatically e.g. in China [3]. As petroleum refiners face new sulfur and aromatic compound specifications, an alternative fuel is entering the competition: bio diesel [4].

II. Biodiesel

Bio diesel is the name of a clean burning alternative fuel, produced from domestic, renewable resources. It contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel. It can be used in compression ignition (diesel) engines with little or no modifications. It is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics. It is a completely natural, renewable and is 100% vegetable oil based. Technically, bio diesel is Vegetable Oil Methyl Ester. It is formed by removing the triglyceride molecule from vegetable oil in the form of glycerin (soap). Once the glycerin is removed from the oil, the remaining is a bio diesel [2], [4].

The bio diesel molecules are very simple hydrocarbon chains; containing no sulfur, no ring molecules or no aromatics associated with fossil fuels. It is made up of almost 10% oxygen, making it a naturally "oxygenated" fuel [5], [6].

A. Review of Sources of Vegetable Oil

Vegetable oils have become more attractive recently because of their environmental benefits and the fact that it is made from renewable resources. Vegetable oils have the potential to substitute for a fraction of the petroleum distillates and petroleum based petrochemicals in the near future. Vegetable oil fuels are not now petroleum competitive fuels because they are more expensive than petroleum fuels. However, with the recent increases in petroleum prices and the uncertainties concerning petroleum availability, there is renewed interest in using vegetable oils in diesel engines [6]. The diesel boiling range material is of particular interest because it has been shown to reduce particulate emissions significantly relative to petroleum diesel , [7].

Edible oils that can be used as alternative fuels are-Safflower oil, Sunflower oil, Soybean oil, Groundnut oil, Cottonseed oil, Coconut oil, Rice bran oil, Mahuwa oil, Linseed oil etc.

Non-edible oils that can be used as alternative fuels, are – Karanja oil, Neem oil, Undal oil and Ratanjyot (Jatropha curcas) etc. [7]. But considering the pressure on edible oils in India, the vegetable oils of non-edible origin can be tested for its suitability with diesel fuel. The oils can be extracted using conventional equipment. The byproduct left over is rich in protein and can be used as an animal feed, fertilizer or solid fuel [7]. Oil content in percent of some non-edible oil seeds is given in Table 2.1

Table 2.1 : Oil contents of tree origin oilseeds[7]

Sr.No.	Name of oilseed	Oil content in percent
1	Karanja	27-39
2	Mahua	50
3	Ratanjyot	60
4	Neem	40-50

In the present work, Karanja (Pongamia glabra) is selected for preparation of biodiesel because it is most commonly available throughout India in abundant quantity and atmospheric conditions are favorable for cultivation also. In India, we have a well-established collection and marketing network for non-edible oils, going back to the Vedic days, for use as fuel for lighting lamps. Presently there is an extended use of these in soaps, lubricants etc. and the Mumbai market controls the prices. There are more than

300 different species of trees, which produce oil-bearing seeds. Karanja (Pongamia glabra) is most commonly available tree in India. 100 trees per hectare, many of these trees yield 10 to 15 tons of seeds per hectare after 5 years of plantation [8], [6].

III. Engine Performance Using Karanja Biodiesel

Performance tests were conducted on stationary Single cylinder, diesel engine by using Karanja bio diesel and its various blends with diesel for no load to full load condition. The tests were also conducted with conventional diesel fuel for comparison. Bio diesel is blended with diesel in proportion like 25% and 50%. These blends are termed as KB25 (25% Bio diesel + 75% Diesel) and KB50 (50% Bio diesel + 50% Diesel). Engine performance, Heat balance, Carbon deposition on injector tip and Fuel spray pattern of injector using these blends and pure bio diesel have been evaluated and presented in following articles.

IV. Experimental Setup

The performance tests are conducted on a computerized single cylinder, four stroke, naturally aspirated, direct injection, water-cooled diesel engine test rig. The schematic diagram of the experimental set up is shown in figure 4.1. The engine is directly connected to eddy current dynamometer for variable loading. The signals of combustion pressure and crank angle are interfaced to computer through engine indicator for P-θ and P-v diagrams along with airflow, fuel flow, temperatures and load measurements. An engine indicator is fitted in the control panel which senses pressures and crank angle data and interfaces with computer. Digital display of speed in RPM is indicated on engine indicator. The engine indicator is connected to COM port of computer. The engine and dynamometer were interfaced to a control panel, which is connected to a computer. Performance analysis software Engine Soft Version 2.4, supplied by the test rig supplier "Apex Innovations Pvt. Ltd." was used for recording the test parameters such as fuel flow rate, air flow rate, temperatures, load etc. and for evaluating the performance characteristics such as brake thermal efficiency, specific fuel consumption, mechanical efficiency, volumetric efficiency etc. The calorific value and density of the particular fuel was fed to the software for calculating the above said parameters.

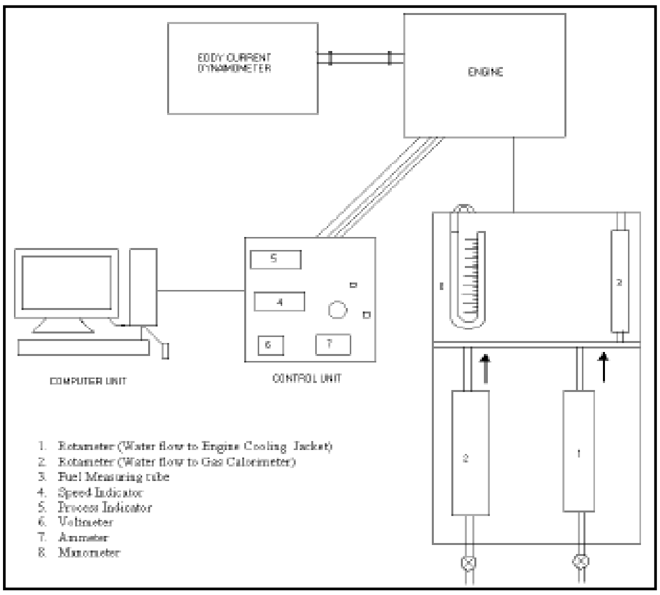

Fig. 4.1 : Schematic Diagram of Experimental Setup (Computerized I.C. Engine Test Rig)

A. Experimental Procedure

First of all, make all the electric supply switches 'ON' and check water supply connections to engine and dynamometer through rotameter. Make fuel supply 'ON', if separate arrangement is done for storage and supply of biodiesel. After conditioning the equipment, the engine is started and warm-up for 10 minutes. Start the computer and select the mode 'Configure' to enter the data like fuel density and calorific value etc. Then select the 'Run' option, which continuously displays the process screen. Each test is conducted and data is stored at five different loads, conditions namely no load, 25%, 50%, 75%, and full load. Engine is run continuously and load is increased after interval of every 25 minutes approximately and data available is stored by Log key at the end of time interval. Simultaneously, with the help of Bosch smoke meter Bosch smoke number is obtained by inserting the probe of smoke meter in engine exhaust pipe. Thus test using each blend is conducted for about 2 hours. After conducting test for one fuel, fuel injector is removed and fuel spray pattern is examined on mechanical Injector Spray Tester. The spray pattern is recorded by using analog Video Camera. Carbon deposition on injector tip is also recorded and then scrapped of and weighed. The injector is again fitted to engine and next tests are conducted. The tests are conducted in sequence like pure diesel, KB25 and KB50.

V. Engine Performance Analysis

The performance of an internal combustion engine is mainly studied with the help of combustion and operating characteristics.

A. Operating Characteristics

The practical engine performance parameters of interest are power, torque and specific fuel consumption etc. Power and torque depends on engine-displaced volume. All the measurements and results supplied by Engine software and graphs prepared for comparison purpose are given in following articles

B. Measurements and Results

Measurements and results got by conducting trials using diesel and blends of Karanja biodiesel with the help of engine software are represented in the following tables 5.1 to 5.5. These results are used to study various operating characteristics of engine such as specific fuel consumption, brake thermal efficiency, mechanical efficiency, volumetric efficiency, indicated and brake mean effective pressure, torque and power etc. It also provides the necessary data for calculating heat balance [9].

Speed	Load	T1	T2	T3	T4	T5	T6	Fuel	Air	F1	F2	F3	F4
1601	0	33.1	38.7	33.1	35.1	151.5	138.2	7.63	107.2	0.4	33.5	270	59
1557	4.57	33.5	41.2	33.5	37.1	250.3	222.6	12.5	101.4	0.6	32.6	265	58
1523	9.42	34.3	43.6	34.3	40.4	353.5	312.5	20.0	96.72	1.0	31.8	265	55
1482	13.9	34.7	46.8	34.7	43.4	483.5	426.5	29.1	91.13	1.5	30.9	260	56
1419	18.3	35.2	51.2	35.2	46.2	573.8	510.1	28.8	83.83	1.5	29.6	255	55

Vol. 6, Issue 2 (April - June 2018)
ISSN : 2347 - 8446 (Online)
ISSN : 2347 - 9817 (Print)

Torque	BP	FP	IP	BM EP	IM EP	BTh Eff	ITh Eff	Mech Eff	SFC	Vol Eff	AF Ratio
0	0	2.12	2.01	0	2.23	0	38.95	0	0	90.44	77.16
0.83	1.32	1.07	2.39	1.54	2.79	16.53	29.9	55.28	0.519	91.42	47.76
1.56	2.43	1.29	3.72	2.9	4.44	23.28	35.66	65.29	0.368	91.2	35.76
2.4	3.66	1.1	4.77	4.48	5.82	25.67	33.39	76.86	0.334	90.86	25.44
3.2	4.66	1.35	6.01	5.97	7.71	19.7	25.43	77.49	0.435	90.86	14.63

Table 5.2 Measurements and results of trial using KB25

Torque	BP	FP	IP	BM EP	IM EP	BThE	IThE	MechE	SFC	VolE	AF Ratio
0	0	1.48	1.3	0	1.57	0	28.1	0	0	92	78.77
0.77	1.2	1.35	2.5	1.43	3.02	15.17	31.9	47.44	0.57	91.5	46.14
1.67	2.6	1.48	4.1	3.12	4.89	24.04	37.6	63.79	0.36	91.0	33.41
2.38	3.6	1.78	5.4	4.44	6.63	23.47	35	67.05	0.37	90.3	22.87
3.19	4.6	1.6	6.2	5.94	7.98	28.92	38.8	74.46	0.30	90.6	21.01

1. Operating Characteristics Graphs

Load Vs Specific fuel consumption

The variation of the sfc with load of Karanja biodiesel and its blends and diesel fuel are shown in figure 3.12. The fuel consumption characteristics of an engine are generally expressed in terms of sfc in kilograms of fuel per kilowatt-hr. It is important parameter that reflects how good the engine performance is. It is inversely proportional to thermal efficiency of the fuel [9]. The figure shows that the sfc for all biodiesel blends is higher than diesel fuel for all partial loads. It was observed due to low heating value, higher density and viscosity of biodiesel and its blends than diesel [10]. It is also observed that the sfc for KB25, KB50 and KB100 is considerably lower than the diesel at full load condition. The maximum (at 25% load) and minimum (at 75% load) values are indicated by the fuel KB100. However, KB25 shows average values of sfc at all load conditions.

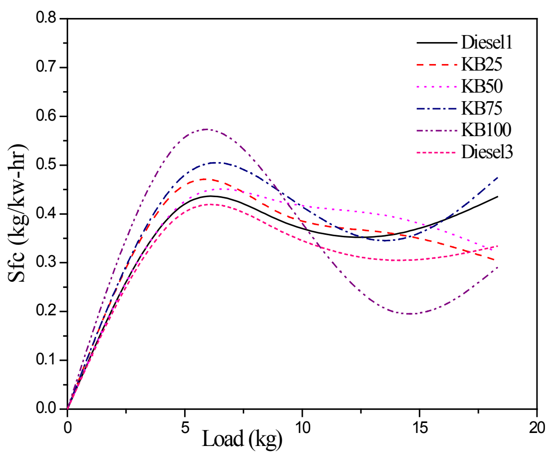

Figure 3.12 Load(kg) Vs Sfc(kg/kw-hr) for various blends of Karanja biodiesel

Load Vs Brake Power

The variation of brake power of Karanja biodiesel and its blends and diesel fuel with load is shown in figure 3.13. It is observed that the brake power is increasing with load and is approximately equal to diesel at all loads. For KB100, it is higher at full load condition. It is observed that, even if, blending of biodiesel with diesel fuel decreases its heating value, higher power was obtained in the experiments. This is because; the biodiesel contains approximately 10% (in weight) oxygen that can be used in combustion, thereby increasing the torque and power. Also, density of biodiesel and its blends is higher than the diesel fuel. Therefore, larger mass flow rate of same fuel volume is pumped to the engine cylinder, resulting in the increase in the torque and power. Meanwhile, the more viscous blend means less internal leakage in the fuel pump. Again, this results in an increase in the torque and power. Lower heating value and higher viscosity of fuel results in slightly poorer atomization and poorer combustion ([10], [11], [12]).

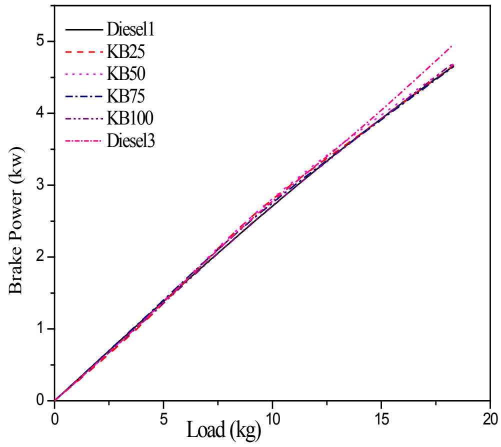

Figure 3.13 Load(kg) Vs Brake power(kw) for various blends of Karanja biodiesel

Load Vs Indicated Power

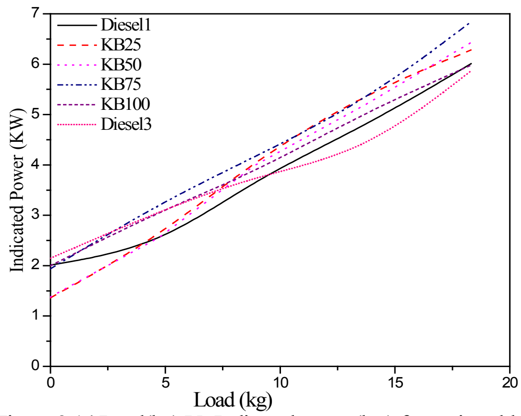

Figure 3.14 Load(kg) Vs Indicated power(kw) for various blends of Karanja biodiesel

The indicated power is the average rate of work transfer from the gases in the engine cylinder to the piston during the compression and expansion strokes of the engine cycle. The shape of the indicated power curve follows from the Imep curve [13]. The variation of indicated power of Karanja biodiesel and its blends and diesel fuel with load is shown in figure 3.14. It is observed that indicated power for biodiesel and blends except KB 25 is higher than the diesel fuel at all loads. Indicated power of KB25 at no load to 25% load is lower than the diesel fuel.

Load Vs Friction Power

The variation of friction power of Karanja biodiesel and blends and diesel fuel with load is shown in figure 3.15. The friction power curve trend seems similar to that of diesel fuel. Friction power of biodiesel decreases from no load to 50% load and again increases at full load condition. It is observed that friction power of biodiesel and its blends at all loads are significantly higher than the diesel fuel.

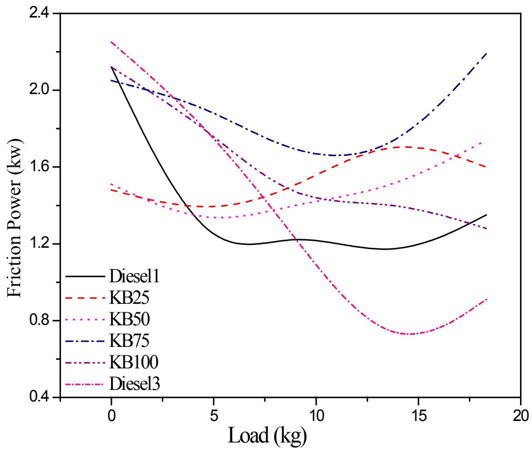

Figure 3.15 Load(kg) Vs friction power(kw) for various blends of Karanja biodiesel

Load Vs Torque

The effects of Karanja biodiesel and its blends and diesel fuel on engine torque are shown in figure 3.16. The engine torque increases with increasing loads for biodiesel and diesel. It is observed that the torque values of biodiesel and blends are slightly higher than diesel at all load conditions. But there is no significant variation.

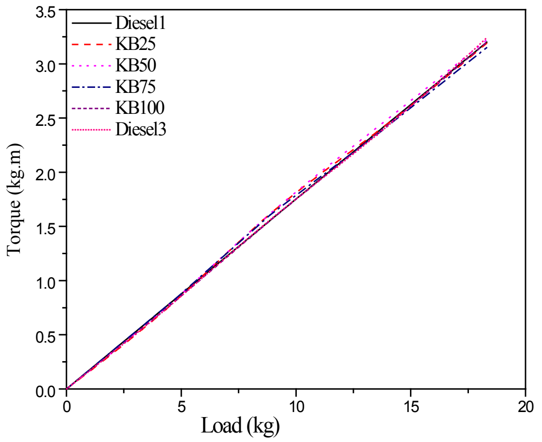

Figure 3.16 Load(kg) Vs Torque(kg-m) for various blends of Karanja biodiesel

Load Vs Indicated Mean Effective Pressure (Imep)

The variation of Imep of Karanja biodiesel, its blends and diesel with various loads is shown in figure 3.17. It is observed that Imep for biodiesel and its blends is lower than diesel at partial loads (up to 50% load) and higher at 75% and full load conditions. Imep of KB100 is much higher than diesel at full load condition. However, there is no significant variation in Imep values between all blends.

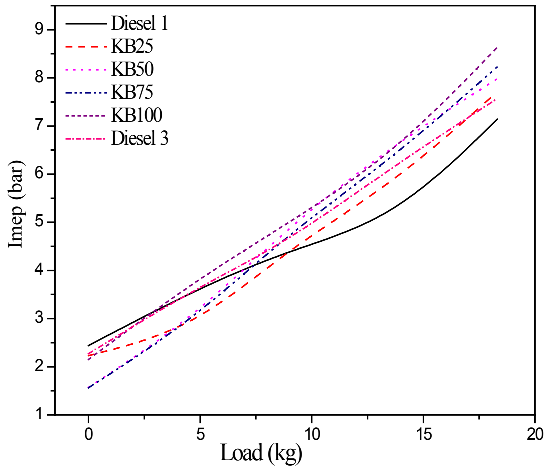

Figure 3.17 Load(kg) Vs Imep(bar) for various blends of Karanja biodiesel

Load Vs Brake Mean Effective Pressure (Bmep)

The maximum or normal rated brake power and quantities such as Bmep derived from it define engines full potential. The variation of brake mean effective pressure of Karanja biodiesel, its blends and diesel with loads is shown in the figure 3.18. There is no significant variation in values of Bmep of biodiesel, its blends and diesel at all load conditions. All the curves are seems to be coincided.

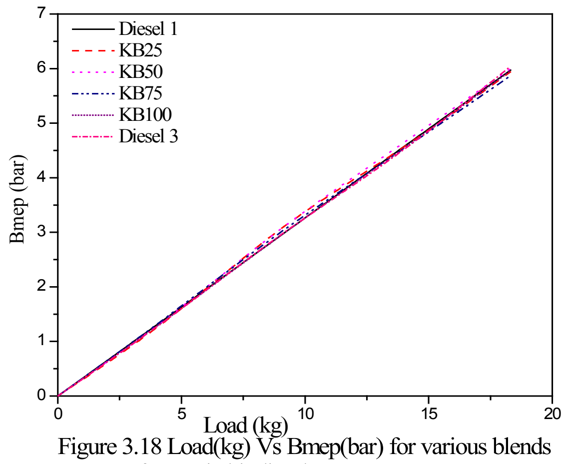

Figure 3.18 Load(kg) Vs Bmep(bar) for various blends of Karanja biodiesel

Load Vs Brake Thermal Efficiency

The variation of Brake thermal efficiency with various load conditions for biodiesel, its blends and diesel is shown in figure 3.19. The BThE of a diesel engine is inversely proportional to its bsfc and the heating value of fuel. It is observed that for all fuels BThE is increasing with load, but in case of KB100, higher value is obtained at 75% load and decreasing significantly at full load condition. KB25, KB50, KB75 shows slightly lower values of BThE than diesel at partial loads and higher values at full load condition. In fact, there is no significant variation between diesel and biodiesel blends.

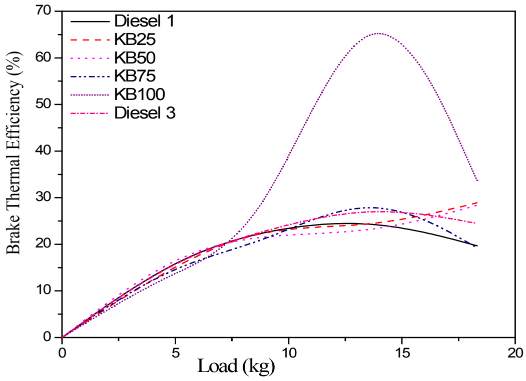

Figure 3.19 Load(kg) Vs Brake Thermal Efficiency (%) for various blends of Karanja biodiesel

Load Vs Indicated Thermal Efficiency (IThE)

The indicated and brake thermal efficiencies are based on the IP and BP of an engine respectively. These efficiencies give an idea of the output power generated by the engine with respect to the heat supplied by the fuel in the form fuel. The variation of IThE of Karanja biodiesel, its blends and diesel with load is shown in figure 3.20. It is observed that the values of IThE for biodiesel and blends are lower than the diesel at no load and 25% load and higher at increased load conditions. However, there is no much difference except KB100. The fuel KB25 indicates maximum IThE at no load and maximum IThE at full load condition among all blends and diesel.

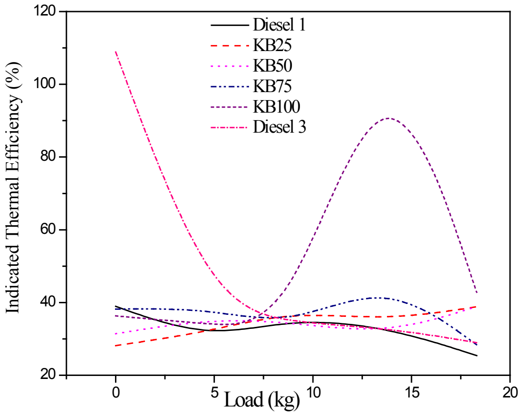

Figure 3.20 Load(kg) Vs Indicated Thermal Efficiency(%) for various blends of Karanja biodiesel

Load Vs Mechanical Efficiency

The variation of Mechanical efficiency using biodiesel, its blends and diesel with various load conditions are shown in figure 3.21. It is seen from the figure that the Mechanical efficiency for all the blends is lower than that of the diesel fuel at all load conditions. Diesel 3 indicates higher mechanical efficiency than diesel and bidiesel at 50% to full load conditions.

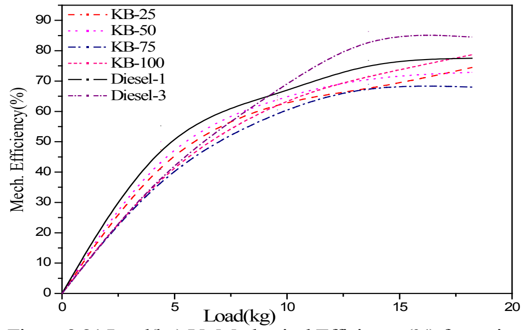

Figure 3.21 Load(kg) Vs Mechanical Efficiency (%) for various blends of Karanja biodiesel

Load Vs Volumetric efficiency

The volumetric efficiency is the measure of the success with which the air supply, and thus the charge, is inducted into the engine. It is very important parameter, since it indicates the breathing capacity of the engine. The variation of the volumetric efficiency of Karanja biodiesel, its blends and diesel with various load conditions are shown in figure 3.22. It is observed that the volumetric efficiency of biodiesel and blends is initially higher than the diesel 1 (up to 6 kg load) and lower at partial and full load conditions. The fuel KB75 indicates lower volumetric efficiency than all other fuels at all load. The maximum value (92 %) of volumetric efficiency is observed with KB25 at no load condition.

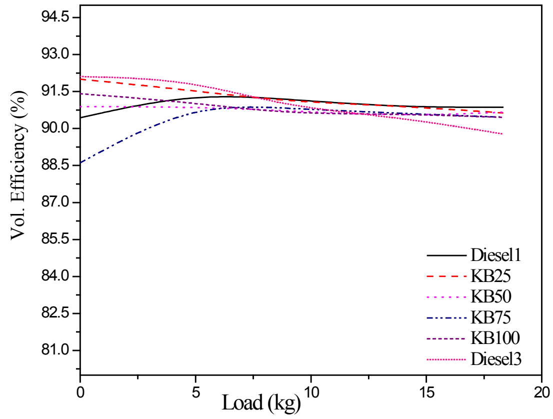

Figure 3.22 Load(kg) Vs Volumetric Efficiency(%) for various blends of Karanja biodiesel

VI. Heat Balance Sheet

The performance of an engine is generally given by heat balance sheet. Energy supplied to an engine is the heat value of the fuel consumed. It is known that only a part of this energy is transformed into useful work. The rest of it is either wasted or utilized in special application like turbo compounding. The utilization of the fuel's heat energy is higher in C.I. engines because of its higher compression ratio [14], [9].

The values in percentage of above-mentioned terms obtained relative to energy supplied by the fuel as 100% for each test are enumerated in table 3.6

From the table 3.6, it is observed that, for more useful work is indicated by KB100 at full condition. The fuel

KB75 at full load condition indicates the maximum value and the fuel

KB100 at 75% load condition indicate the minimum value of heat supplied. It is also found that the heat supplied by the biodiesel and its blends is comparatively more than the diesel fuel at various load conditions. This may be because of property of biodiesel that it contains 10% more oxygen originally, which enables a complete combustion, and more heat is generated. Also, from operating characteristics it is found that the fuel consumption of biodiesel at various load conditions is more than the diesel fuel. The above heat balance analysis shows that the heat loss behaviour of an engine using Karanja biodiesel and its blends is similar to that of diesel fuel.

Table 3.6 : Heat Balance Sheet for diesel 1 and biodiesel blends

Fuel Type	Load %	Heat Supplied in kJ/min as 100%	HBP (Heat equivalent to Brake Power) %	HJW (Heat rejected to cooling medium) %	HGas (Heat Carried away with the exhaust gases) %	Un-accounted losses %
Diesel 1	25	475	16.53	31.02	28.84	23.61
	50	623	23.28	27.99	30.06	18.67
	75	854	25.67	24.49	30.9	18.95
	100	1421	19.7	19.21	24.28	36.81
KB25	25	484.84	15.17	27.65	28.24	28.93
	50	655.52	24.04	25.89	30.39	19.68
	75	928.65	23.47	22.17	28.24	26.12
	100	969.62	28.92	27.37	36.95	6.76
KB50	25	433.68	17.75	33.01	31.14	18.11
	50	689.94	22.42	24.7	28.27	24.6
	75	1005.34	22.23	22	28.27	27.49
	100	992.20	28.36	28.71	35.6	7.32
KB75	25	490.62	15.68	24.23	26.12	33.97
	50	726.37	20.12	22.57	25.23	32.08
	75	662.65	31.91	31.69	36.89	0
	100	1401.77	19.26	19.53	25.07	36.14
KB100	25	540.47	14.06	24.68	24.94	36.33
	50	700.15	20.97	24.67	27.08	27.27
	75	257.95	83.86	85.37	97.76	0
	100	835.27	33.67	35.03	43.28	0

VII. Conclusion

From the above results, it is found that the performance of compression ignition engine is better when fueled with KB 25 and KB 50 than the petroleum diesel. The maximum cylinder pressure is indicated more for Karanja biodiesel and its blends than diesel at all load conditions. Therefore the indicated power at all load conditions is more than the diesel. The brake power curve shows that the brake power for biodiesel and its blends is more at all partial loads and similar to diesel at no load and full load conditions.

The specific fuel consumption using biodiesel and blends is more at partial loads and less than the diesel at full loads. Inversely, the brake thermal efficiency is higher at full loads and no significant difference is observed at partial loads. It is also observed that the heat loss behaviour of biodiesel and blends is somewhat similar to diesel fuel.

Using the Karanja biodiesel and blends no significant variation in smoke level is observed. Moreover, the smoke tests shows that the smoke quality is better at 25, 50 and 75% blends. Carbon deposition is found more than the diesel for 75 and 100% biodiesel. Also, it is found that the fuel spray characteristics for biodiesel and blends are similar to diesel fuel.

With the above conclusions, it is recommended that the Karanja biodiesel in the form of 25 and 50% blends with diesel fuel can be effectively used in the diesel engines without any

References

[1]. Goering C.E., Schwab. A.W., Daughtery. H.J., Pryde E.H. and Heakin A.J., "Fuel properties of eleven vegetable oils", *Trans of ASME* (1982); 25 (6), 1472-1477.

[2]. B.K. Barnwal, M.P. Sharma. "Prospect of Bio Diesel production from vegetable oils in India", Renewable and sustainable energy reviews (2004) www.elsevier.com/ locate/ rser.

[3]. W.Korbitz, "Bio diesel production in Europe and North America: A encouraging prospect", *Renewable energy*, (1999) 1078- 108

[4]. Yusuf Ali and M.A. Hanna. "Alternative Diesel fuels from Vegetable oils", www. elsevier.com, 0960-8524(94) 00072-7

[5]. Anjana Srivastava, Ram Prasad, "Triglycerides – Based Diesel fuels", *Renewable and sustainable energy reviews*, 4 (2002) 111 – 133

[6]. www. biodiesel.org

[7]. Y.C.Bhatt, N.S.Murthy, R.K.Datta "Fuel properties evaluation of five non edible vegetable oils as diesel fuel". Proceeding of 10th national conference on IC Engines and Combustion", Rajkot, India.

[8]. A.M.Nagaraja, G.P.Prabhukumar, "Effect of injection pressure on the engine performance with ricebran oil as bio diesel", AICTE-ISTE Sponsered STTP on Modern trends in automobiles, 23 June-4July 2003, RIT, Sakharale.

[9]. Pawl W. Gill et al., " Fundamentals of Internal Combustion Engines", Oxford and IBH Publication, 4th revised edition –1989.

[10]. N.Usta, E.Ozturk, O.Can, E.S.Conkur, S.Nas, A.H.Con, A.C.Can, M.Topcu, "Combustion of bio diesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a Diesel engine".

[11]. Kyle W. Scoll, Spencer C.Sorenson, "Combustion of soybean oil methyl ester in a Diesel engine" 930934 SAE

[12]. Yu Zhang and Jon H. Van Gerpen, "Combustion analysis of esters of Soybean oil in a diesel engine", 960765 SAE.

[13]. S. Jabez Dhingar, B.N. Nagalingam and K.V. Gopalkrishnan, " A Comparable Study of the Exhaust Emisssion Characteristics of Diesel and Vegetable oil operation in a Single Cylinder Low Heat Rejection Research Engine", Proceedings of the XIII National Conference on Internal Combustion Engines and Combustion, Banglore, 18-20 January 1994.

[14]. John B. Heywood, "Internal Combustion Engine fundamentals", McGraw Hill International edition.

[15]. Basavraja T, Rana Prathap Reddy, "Performance and emissions of diesel engine using methyl esters of Hong oil and its blends", National Conference On Energy And Fuel Issues of Future, 2004; 132: 52-56

[16]. K.C. Sinhai, A. Rehman, "Plant-Oil as Diesel- engine fuel", Proceedings of the XIII National Conference on Internal Combustion Engines and Combustion, Banglore, 18-20 January 1994