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Performance evaluation of a diesel engine fueled with methyl ester of pongamia oil

A. Haiter Lenin[1], K. Thyagarajan[2]

[1] PET Engineering College, Department of Mechanical Engineering, Vallioor - 627 117, India.
[2] Noorul Islam College of Engineering, Department of Mechanical Engineering, Thuckalay, India.

Abstract
In this study pongamia methyl ester was prepared by transesterification using potassium hydroxide (KOH) as catalyst and was used as fuel in a four stroke, water cooled, single cylinder, direct injection diesel engine. Pongamia methyl ester fuel blends (75% and 100%) were used for conducting the engine performance tests at varying loads (20%, 40%, 60%, 80%, and 100%). Tests were carried out over entire range of engine operation at varying conditions of load. The performance, combustion and emission characteristics were determined. Based on these, the parameters such as brake thermal efficiency, specific fuel consumption, exhaust gas temperature, emissions in exhaust such as CO, CO_2, O_2, HC and NOx were recorded. The results show that the blend of pongamia oil with diesel fuel can be used as an alternative fuel successfully in a diesel engine without any modification.

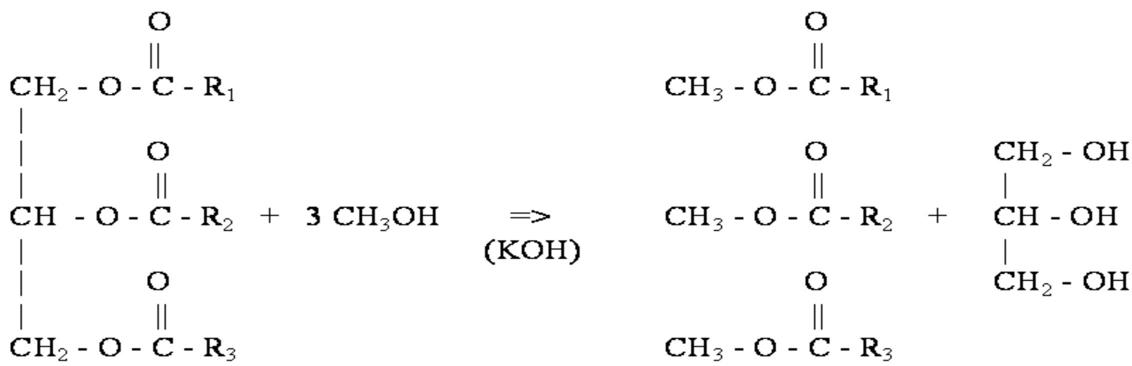
Keywords: Biodiesel; Transesterification; Pongamia oil; Performance; Emission; Combustion.

1. Introduction
Even though the transport sector plays a pivotal role in the economic development of any country, it brings an unavoidable specter of environmental deterioration along with it. Alternate fuels play a major role in emission mitigation. More and more vehicles are switching over to such alternate fuels worldwide, a sure sign that their age has arrived. Vegetable oils have some advantages. They are renewable, easily available in the rural areas, have high cetane number, heat release rate is similar to diesel, it's emission rate is relatively low to be used in Compression Ignition engines with simple modifications and can be easily blended with diesel in the neat and esterified (bio diesel) forms. Jatropha oil, sesame oil, coconut oil, sunflower oil, neem oil, mahua oil, peanut oil, palm oil, rubber seed oil, cotton seed oil and rape seed oil are some of the vegetable oils that have been tried as fuels in Internal combustion engines.
Rudolf Diesel developed the first diesel engine which was run with vegetable oil in 1900. The first engine was run using groundnut oil as fuel [1]. Investigations were focused on non-edible vegetable oils as an alternative for diesel. However, it was noted that the availability of non-edible vegetable oils studied [2-4] is very much limited.
A number of researchers have investigated experimentally the performance and emissions characteristics of either the vegetable oils [5-7] or bio-diesels [8-10] when fuelling Diesel engines and mainly focused on the use of rapeseed oil or soya bean oil.

Agarwal [11] observed significant improvement in engine performance and emission characteristics for the biodiesel fuelled engine compared to diesel fuelled engine. The Thermal efficiency of the engine improved, brake specific fuel consumption reduced and a considerable reduction in the exhaust smoke opacity was observed. Vegetable oils are alternate fuels and many attempts are being carried out on the development of these fuels [12, 13]. Nowadays, vegetable oils are good alternatives to those derived from petroleum oils and can be used instead of the ordinary diesel in diesel engines as fuels [10, 14].
In the present investigation, a bio diesel, prepared from pongamia oil is considered as fuel. The performance, emission and combustion characteristic of bio diesel blends were evaluated on a single cylinder, four stroke, water cooled diesel engine.

2. Transesterification reaction

The vegetable oil reacts with methanol and forms esterifies vegetable oil in the presence of sodium/potassium hydroxide as catalyst. The transesterification is represented as below [15].



Triglyceride methanol mixture of fatty esters glycerin

In transesterification, KOH and methanol are mixed to create potassium methoxide ($K^+ CH_3O^-$). When mixed with the oil, this strong polar-bonded chemical breaks the transfatty acid into glycerin and ester chains (biodiesel), along with some soap if you are not careful. The esters become methyl esters.

3. Experimental setup

The properties of the fuel are given in Table 1. The tests were conducted on a four stroke, water cooled, single cylinder, direct injection diesel engine connected to an eddy current dynamometer as loading device. The specifications of the engine are given in Table 2.
The experimental setup is shown in Figure 1. The fuel tank is filled with base oil (diesel) in which the experiment is to be carried out. Then the engine is started at no load condition. The following sets of readings are noted after a steady state is reached. Speed, fuel consumption, manometer head, load applied using dynamometer. Then the blends of biodiesel and diesel were made in different proportions such as B75 (75% biodiesel) and B100 (100% biodiesel). The same procedure is repeated for blended biodiesel. The emission values are also recorded.

Table 1. Properties of pongamia oil, pongamia methyl esters and its blends

Fuel	Density kg/m^3 at 40^{o}C	Calorific value MJ/kg	Viscosity mm^2/s at 40^{o}C	Flash point ^{o}C
B100	870	39.88	4.4	170
B75	860	40.61	4.25	120
Diesel	830	42.8	3.8	58
Pongamia oil	965	34.5	29.7	202

Table 2. Engine specifications

Make and model - Engine	Kirloskar, TV- I
Type	Single cylinder, vertical, direct injection constant speed, water cooled, four stroke diesel engine
Bore	87.5 mm
Stroke	110 mm
Cylinder diameter	0.0875 m
Stroke length	0.11 m
Compression ratio	17.5:1
Power	5.2 kW
Rated speed	1500 rpm
Injection pressure	220 kgf/cm^2
Injection starts at	23^o before TDC
Loading device	Eddy current dynamometer

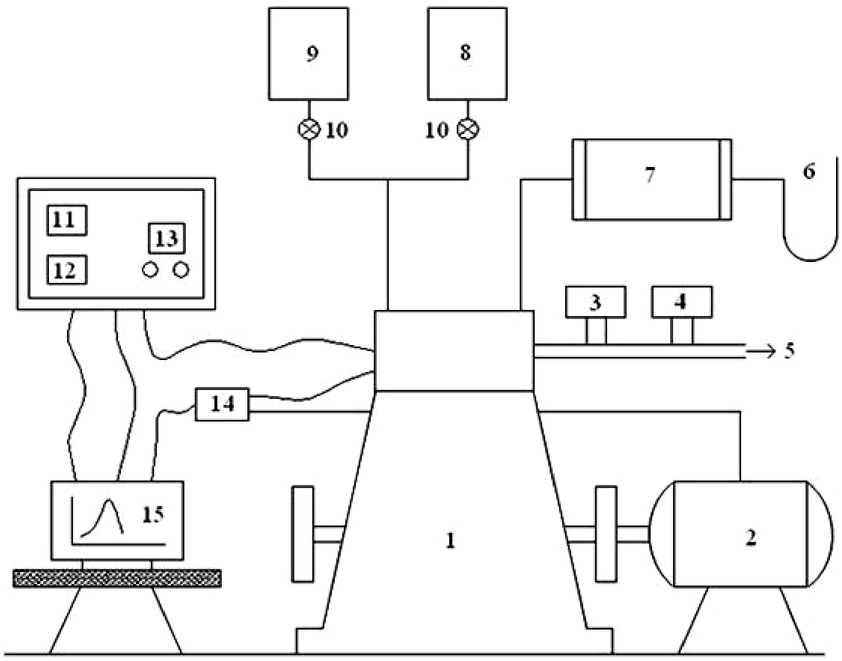


Figure 1. Experimental setup
1. Engine, 2. Eddy Current Dynamo Meter, 3. AVL Smoke Meter, 4. AVL Dia-Gas Analyses, 5. Exhaust Gas, 6. U Tube Mano Meter, 7. Air box, 8. Diesel Tank, 9. Bio Diesel Tank, 10. Control Valve, 11.Load Indicator, 12. Temperature Indicator, 13. Speed Indicator, 14. Amplifier, 15. Monitor

4. Results and discussions

The variation of brake thermal efficiency with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 2. When the brake power increases the brake thermal efficiency also increases. At low load condition the bio diesel blends have the higher brake thermal efficiency than the diesel fuel. At mean full load conditions the fuel blends (B75 and B100) have lower thermal efficiency than the diesel fuel. The brake thermal efficiency depends upon the viscosity and intermolecular friction of the fuel. When the viscosity and friction increase the brake thermal efficiency decreases. With high viscosity of the fuel blends the brake thermal efficiency reduces compared to diesel fuel.

The variation of specific fuel consumption with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 3. With increase in the brake power, the specific fuel consumption reduces at all load conditions. The specific fuel consumption depends upon the engine friction and the heat release rate. The B75 and B100 have higher specific fuel consumption than the diesel due to high heat release and the friction at all loads condition.

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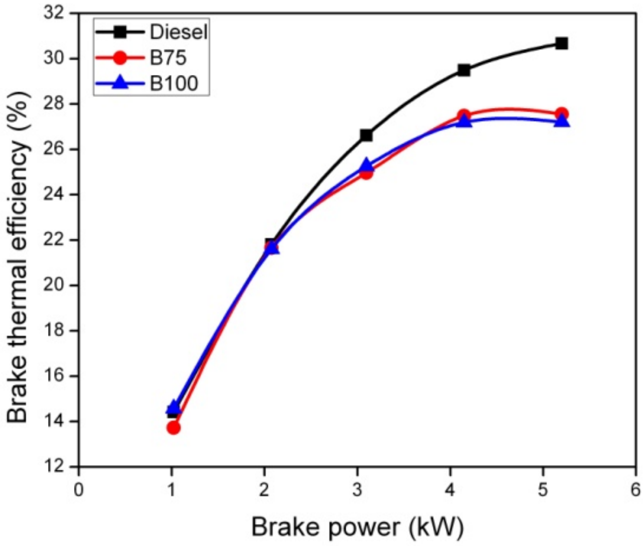

Figure 2. Variation of brake thermal efficiency with brake power

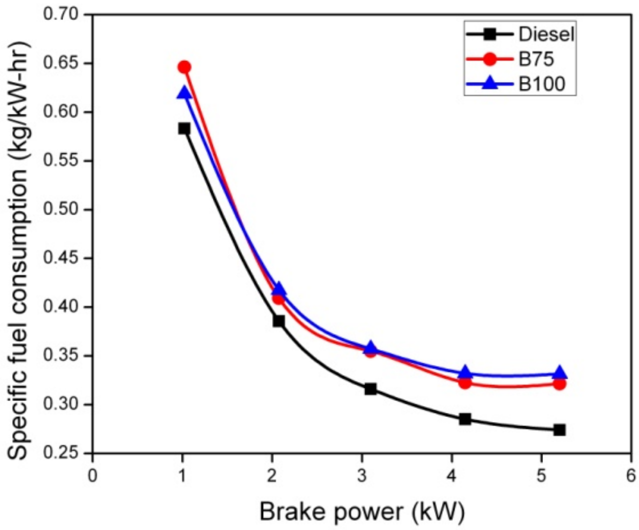

Figure 3. Variation of specific fuel consumption with brake power

The variation of exhaust gas temperature with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 4. When the brake power increases the exhaust gas temperature also increases. The exhaust gas temperature depends upon the flash point and viscosity of the fuels. As the flash point and viscosity increase the exhaust gas temperature also increase. The B75 and B100 have the high flash point and viscosity than diesel fuel. So the exhaust gas temperatures of the fuel blends are higher than the diesel fuel. But at the low load condition the B75 and B100 give the same value of the diesel fuel.

The variations of cylinder pressure with crank angle for diesel, pongamia methyl ester and their blends are shown in Figure 5. The developing pressure depends upon the various load conditions. As the load increases the cylinder pressure also increases. The fuel blends B75 have higher cylinder pressure than the other fuels. The maximum pressure is attained at the angle of 2 to 7 crank angle degrees after top dead center for both fuels at all load condition.

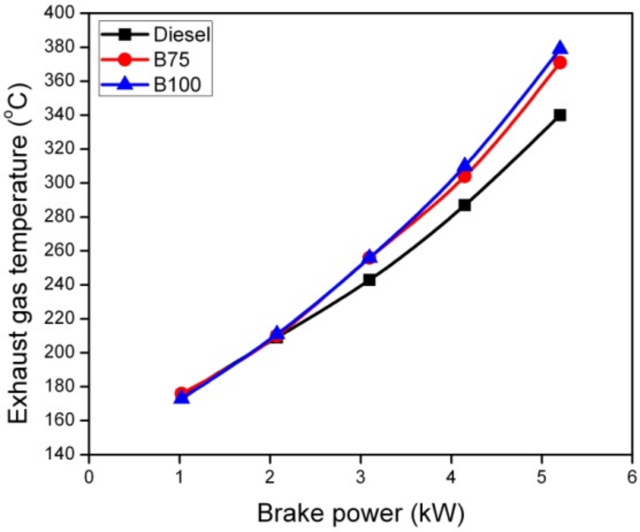

Figure 4. Variation of exhaust gas temperature with brake power

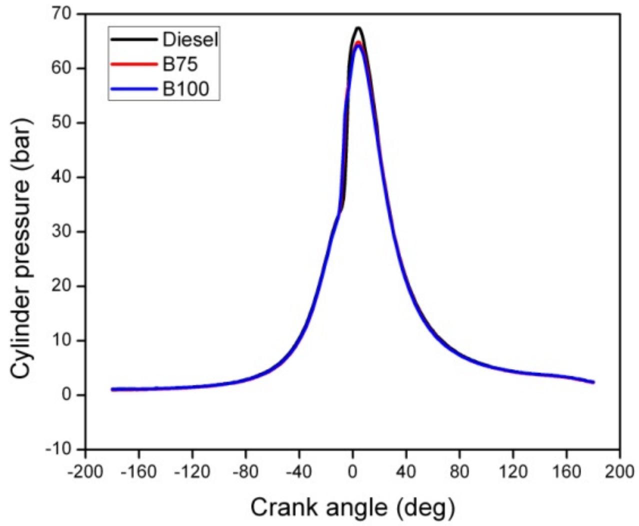

Figure 5. Variation of cylinder pressure with crank angle

The variations of heat release rate with crank angle for diesel, pongamia methyl ester and their blends are shown in Figure 6. After the ignition delay period the premixed air fuel mixture burns rapidly releasing heat at a very rapid rate, after which diffusion combustion takes place. The burning rate is controlled by the air fuel mixture. For fuel blend B75 the combustion starts earlier under all operating conditions. So the B75 has a higher heat release rate than the other fuels.

The variations of maximum cylinder pressure with number of cycles for diesel, pongamia methyl ester and their blends are shown in Figure 7. From the figure we can observe that the diesel fuel is having high cylinder pressure, followed by B75 and B100.

The variations of smoke density with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 8. When the brake power increases the smoke density also increases. The smoke density depends upon the specific gravity and the density of the fuel. The fuel blends B75 and B100 have higher smoke density than the diesel fuel due to the high specific gravity and density. The smoke density also depends upon the better spray formation than the fuel blends due to the viscosity of the fuel. The diesel fuel has lower viscosity. So the smoke density is lower than the fuel blends.

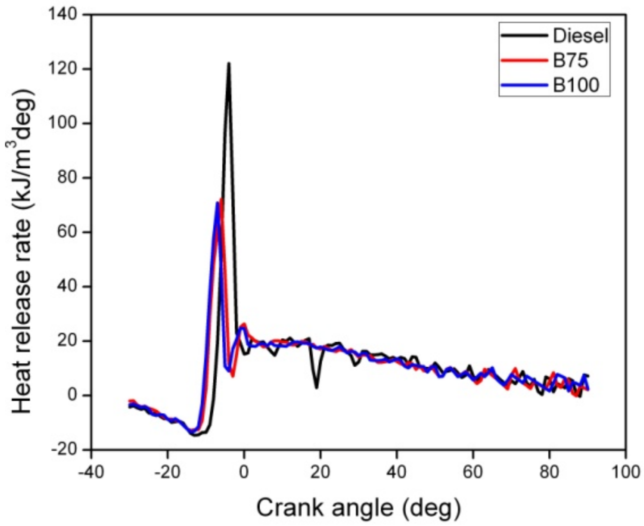

Figure 6. Variation of heat release rate with crank angle

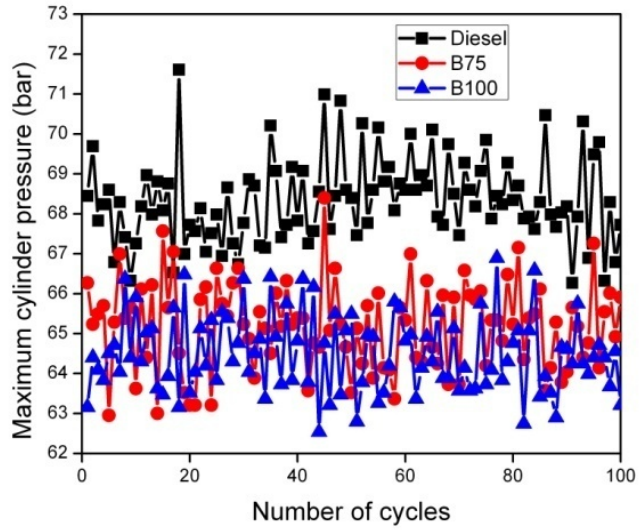

Figure 7. Variation of maximum cylinder pressure with number of cycles

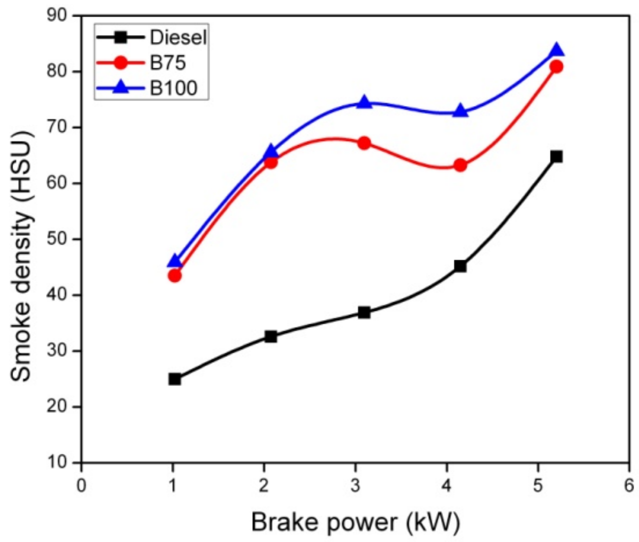

Figure 8. Variation of smoke density with brake power

The variations of carbon monoxide with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 9. The carbon monoxide emission depends upon the incomplete combustion. At low and medium load condition the fuel blends B75 and B100 give almost the same value of the diesel fuel. At maximum load condition the carbon monoxide of the fuel blends suddenly increases.

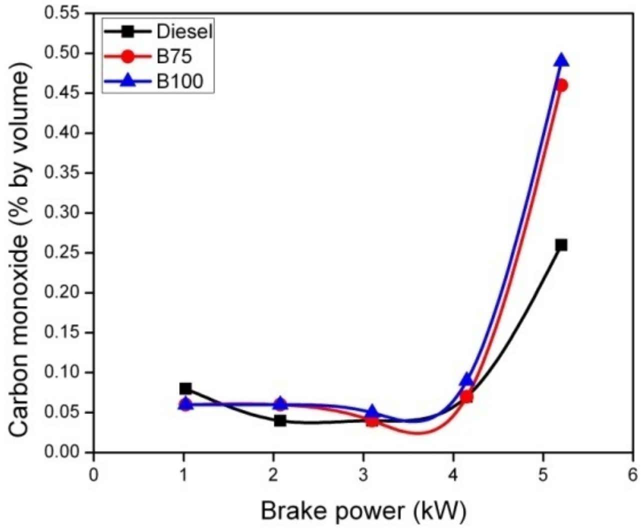

Figure 9. Variation of carbon monoxide with brake power

The variations of carbon dioxide with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 10. The carbon dioxide emission depends upon the complete combustion of the fuel. The bio diesel blends show complete combustion. Because the fuel blends have more oxygen content. With the complete combustion process the carbon dioxide level increases. At low load condition, the fuel blends (B75 and B100) have lower CO_2 emission than the diesel fuel. But at the normal and maximum load conditions the CO_2 emission of the B75 and B100 is higher than the diesel fuel due to complete combustion process.

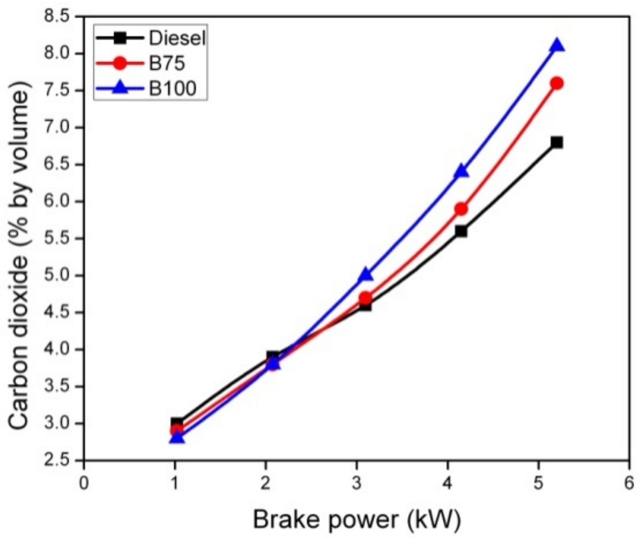

Figure 10. Variation of carbon dioxide with brake power

The variations of oxygen with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 11. The fuel blends B75 and B100 have lower oxygen levels than the diesel fuel. The exhaust gas oxygen content depends upon the combustion process. If the fuel is involved in complete combustion process the oxygen level reduces. The fuel blends have lower oxygen level due to complete combustion at high temperatures. But at low load conditions the B75 and B100 oxygen level is nearer to that of diesel fuel.

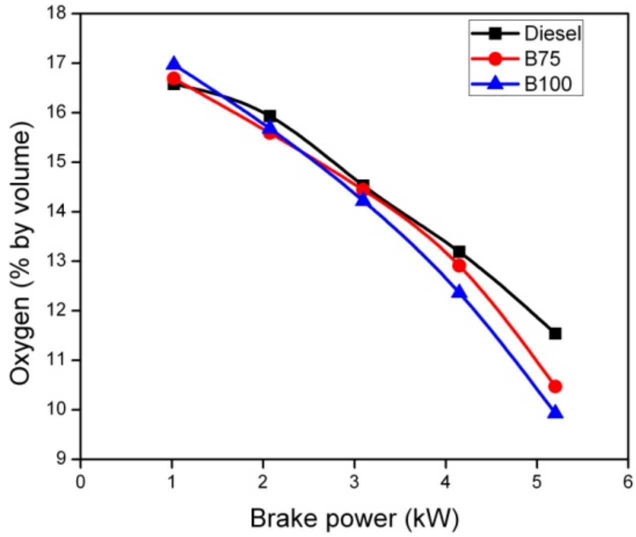

Figure 11. Variation of oxygen with brake power

The variations of hydrocarbon with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 12. The hydrocarbon emission depends upon the carbon residue and the hydrogen content. The B75 and B100 have lower carbon residue and the hydrogen content than diesel fuel, resulting in low hydrocarbon emission. The graph shows the B75 and B100 have low hydrocarbon emission than the diesel fuel. The hydrocarbon emission also depends upon the exhaust gas temperature. When the exhaust gas temperature increases the hydrocarbon emission reduces. The fuel blends have high exhaust gas temperatures. So the hydrocarbon emission is lower than diesel fuel.

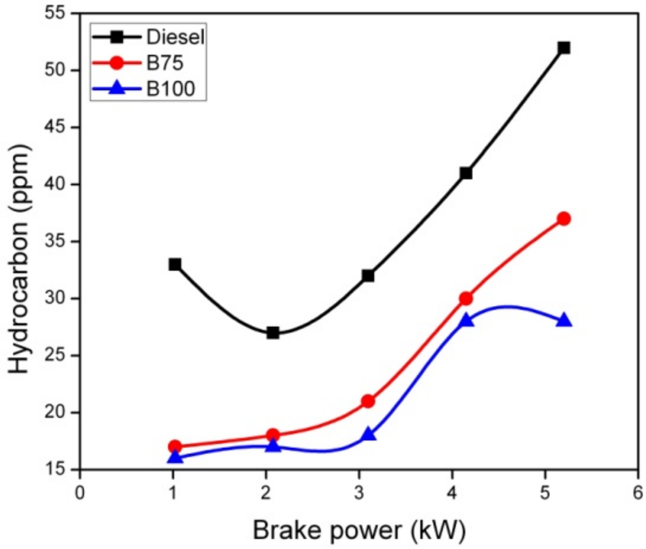

Figure 12. Variation of hydrocarbon with brake power

The variations of oxides of nitrogen with brake power for diesel, pongamia methyl ester and their blends are shown in Figure 13. When the brake power increases the quantity of oxides of nitrogen also increases. The oxides of nitrogen emission depend upon the peak combustion temperature and high residence time of the high temperature gases in the cylinder. The B75 and B100 have higher gas temperatures. So the oxides of nitrogen emission are higher than the diesel fuel at all load condition.

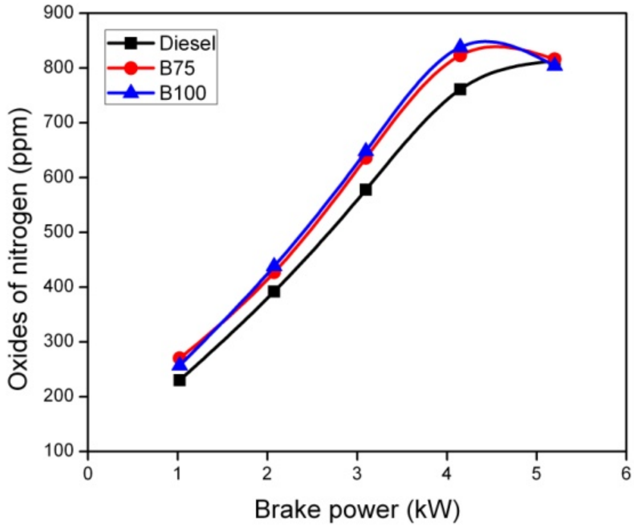

Figure 13. Variation of oxides of nitrogen with brake power

6. Conclusion

With the experimental results the engine performance run of pongamia oil blends is compared with that of standard diesel.

When the load increases brake specific fuel consumption decreases to the minimum of at 90% load and then increases for all the fuel samples tested.

The carbon monoxide emissions from methyl ester blends of pongamia oil B75 and B100 is more than the standard diesel. But the low load condition the methyl ester blends B75 and B100 is lower than the standard diesel.

At low load condition the brake thermal efficiency of pongamia oil blends is closer to the standard diesel but at full load condition, it gives the lower value than the standard diesel.

The NOx emission of the pongamia oil blends B75 is 10% higher than the standard diesel. But pongamia oil blends B100 is the nearest value to the standard diesel.

The smoke densities of the pongamia oil blends B75 and B100 were higher than the standard diesel at all load condition.

The hydrocarbon emission of the pongamia oil blends of B75 and B100 are 28.85% and 46.43%, lower than the standard diesel at all load condition.

Methyl ester blends of pongamia oil showed performance characteristics close to diesel fuel. Therefore pongamia methyl ester blends can be used in CI engines without any engine modification, in rural areas for meeting energy demands in various agricultural operations such as irrigation, threshing etc.

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Haiter Lenin is a Mechanical Engineer and doing PhD at Anna University Chennai, India. His research activities are mainly focused on bioenergy and biofuels, in which he is involved and working. In particular, the key issues of the work are related to the production of biofuels from vegetable oils and their use in standard and innovative systems, such as Diesel engines.
E-mail address: haiterlenina@gmail.com, Mob: +91 9443173450

K. Thyagarajan obtained his PhD in Combustion Kinetics at Indian Institute of Technology Madras (IITM). He have more than 34 years experience in teaching he teaches Thermal Engineering, renewable energy technologies at the Faculty of Mechanical Engineering and Former Principal Noorul Islam College of Engineering. His main scientific interest is on the production and the use of biofuels, Combustion and Heat Transfer in engines. He is a member of several associations, as MISTE, ISCA and MCIIS. He carried out MNES Sponsored projects. Patent awarded on Artificial Vision Implant Device for 20 years from 2005.
E-mail address: drktrnice@yahoo.co.in