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AN EXPERIMENTAL ANALYSIS ON C.I ENGINE FUELED WITH BLENDS OF PONGAMIA BIODIESEL

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ABSTRACT

This paper investigates the performance and emission of a C.I. engine fueled with various blends of esters of Pongamia oil. In this experiment, transesterification process was done using different alcohols and catalyst. Transesterification process done using methanol as alcohol and KOH as catalyst produces a maximum yield of 96%. Hence, the alcohol produced by that method is used for this test purpose. The test samples used for the test purpose in this experiment were different blends of methyl esters of Pongamia oil, such as 0, 20, 40, 60, 80 and 100% (B0, B20, B40, B60, B80 and B100). Physical and thermal properties of different blends were measured and tabulated. Engine was tested using the blends, and the performance and emission characteristics were compared with diesel as a base fuel. From the result, it can be concluded that blend B20 produces a slightly higher efficiency than diesel and all the blends of biodiesel produce lesser CO than neat diesel. Except B20, all the blends of biodiesel produce lesser NO than diesel.

KEYWORDS: Transesterification, Pongamia, Performance, Emission.

Nomenclature
BTE- Brake Thermal Efficiency
BSFC-Brake Specific Fuel Consumption
NO-Nitrogen Oxide
HC-Hydro carbon
CO-Carbon Monoxide
TDC-Top Dead Center
BDC- Bottom Dead Centre
B0 -100% diesel
B20- [20% biodiesel - 80% diesel]
B40 -[40% biodiesel-60% diesel]
B60-[60% biodiesel -40% diesel]
B80-[80% biodiesel- 20% diesel]
B100-[100% biodiesel]

INTRODUCTION

Global warming is increasing every day. The main reason for global warming is the emission from automobiles which use fossil fuels. Usage of renewable fuel in C.I engine will have a great influence in the reduction of greenhouse gas. As the usage of renewable fuel results in nullified effect on global warming, renewable fuel would be the best future fuel. The very first designed C.I engine was fueled by vegetable oil. Due to the abundance of mineral oil, the usage of vegetable oil in C.I engine gets reduced, and so the C.I engines are modified accordingly to operate with mineral diesel as fuel. High viscosity of vegetable oil is the main constraint in the usage of it in C.I engine. High viscosity is due to the presence of free fatty acids. Molecular mass and chain length of free fatty acid in vegetable oil are higher, so this leads to higher viscosity of vegetable oil. To reduce the viscosity of vegetable oil, many methods are used. Some of the methods used were blending of vegetable oil with diesel, transesterification, preheating, pyrolysis and emulsification.

During the operation of the engine with 100% orange oil, NOx is higher than the other mode of operation. This was because of higher heat release rate during the preming combustion phase of orange oil. Engine operated with orange oil and 36mg/s of diethyl produces the least NOx, because of the higher latent heat of vaporization of diethyl ether, but the emission of HC increases. This was because the vapors of diethyl ether enter the crevices, which escape from the combustion process. The oxygen content in diethyl ether and in orange oil leads to produce lesser smoke emission [1].

An experiment was conducted using a C.I engine which operates on dual fuel condition. Pilot diesel fuel is injected into the cylinder through the injector, and combustible producer gas which was produced from a mixture of wood chips and mustard oil cakes is inducted into the cylinder through inlet manifold. A gasifier is used to produce the combustible gas. Engine operated in dual fuel condition produces lesser BTE than the engine operated on diesel alone. This was because of the lesser energy density of the producer gas. At duel fuel condition, the volumetric efficiency gets reduced, and obviously the oxygen content inside the producer gas gets reduced, which leads to incomplete combustion and increases CO and HC emission. NOx emission at dual fuel condition is lesser than at diesel operation, because of the scarcity of nitrogen in producer gas [2].

Agarwal and Rajamanoharan [3] studied the performance and emission characteristics of a single cylinder, constant speed, water cooled diesel engine with a rated power of 3.67 kW at 1500 rpm. The authors used karanja oil and its blends as fuel; its performance and emission characteristics were compared with diesel fuel. The blends used were 10%, 20%, 50%, 75% and 100% of karanja oil in diesel.

The BTEs of all the blends of karanja oil except 100% karanja oil have higher efficiency than diesel. The presence of oxygen in the karanja oil in the blends is mentioned as the reason for the better BTE of karanja oil blends. Upto 50% of karanja oil has lesser BSFC than diesel. With the increase in the concentration in of the karanja oil in the blend, the BSFC increases due to higher viscosity and density of karanja oil.

The BSEC for all the karanja oil blends used for the experiments is lesser than the diesel. The higher viscosity of karanja oil blends affects the atomization and vaporization property, so CO, HC and PM are found to be higher than diesel. Due to the higher viscosity of karanja oil blends, the droplet size injected inside the cylinder is higher than that of diesel; this reduces the peak combustion temperature; therefore, the NO produced is lesser for the karanja oil blends and the combustion takes place at later stage, and hence, the EGT for karanja oil blends was found to be higher than diesel.

As vegetable oil is available in wide range all over the word, it would be a reliable and alternate source of energy. Committee on development of bio fuel recommended Pongamia and jatropha as the best oil yielding plants for Indian soil and climate condition [4,5]. So, in this experiment, biodiesel of Pongamia oil is used as a test fuel .

From the previous study [6], after reviewing lot of technical papers related to vegetable oil as fuel, Pongamia oil could be concluded as a reliable source of fuel. So, Pongamia oil is chosen for this experiment.

In this paper, yield of Pongamia ester, while using different alcohols and catalysts such as ethanol, methanol and NaOH and KOH, is calculated. Physical and thermal characteristics of esters of Pongamia oil were measured. The performance and emission analysis was done for different blends of Pongamia oil methyl esters.

MATERIALS AND METHODS

2.1. Transesterification and Properties of Pongamia Oil

Biodiesel is an alternate fuel for using it as a fuel in C.I engine. It is a derived output of vegetable oil or animal fat, where mono alkyl ester is the main product and glycerol is the byproduct. Vegetable oil mostly contains triglycerides. Transesterification process is the process which involves the reaction between triglycerides and alcohol in the presence of catalyst and heat to obtain a product of biodiesel and glycerol. Figures 1 to 4 show the general chemical equation for transesterification process. The main reason to get involved in the transesterification of vegetable oil is to reduce the viscosity, where the biodiesel obtained after transesterification also has higher volatility and higher cetane number than the vegetable oil. Alkali or acid was used as a catalyst. The choice depends on the percentage of free fatty acid or acid value of the animal oil/vegetable oil used.

$$\begin{array}{llcll}
CH_2-OOC-R_1 & & & R_1-COO-R & CH_2-OH \\
| & & & & | \\
CH-OOC-R_2 & +3ROH & \xleftrightarrow{\text{Catalyst}} & R_2-COO-R\ + & CH-OH \\
| & & & & | \\
CH_2-OOC-R_3 & & & R_3-COO-R & CH_2-OH \\
\text{Triglyceride} & \text{Alcohol} & & \text{Esters} & \text{Glycerol}
\end{array}$$

Figure 1 General overall transesterification reaction; R1, R2 and R3 are fatty acid chains, which are made of long chain of carbon and hydrogen [7,8,9,10].

$$\begin{array}{lcl}
1.\ \text{Triglyceride (TG)} + R'OH & \xleftrightarrow{\text{Catalyst}} & \text{Diglyceride (DG)} + R'COOR_1 \\
2.\ \text{Diglyceride (DG)} + R'OH & \xleftrightarrow{\text{Catalyst}} & \text{Monoglyceride (MG)} + R'COOR_2 \\
3.\ \text{Monoglyceride (MG)} + R'OH & \xleftrightarrow{\text{Catalyst}} & \text{Glycerol (GL)} + R'COOR_3
\end{array}$$

Figure 2 General equation of Transesterification of triglycerides[11].

$$\begin{array}{llcll}
CH_2-COO-R & CH_3OH & & R-COO-CH_3 & CH_2-OH \\
| & | & & | & | \\
CH-COO-R & +\ CH_3OH & \xleftrightarrow{\text{Catalyst}} & R-COO-CH_3\ + & CH-OH \\
| & | & & | & | \\
CH_2-COO-R & CH_3OH & & R-COO-CH_3 & CH_2-OH \\
\text{Triglyceride} & +\ 3\ \text{Methanol} & \xleftrightarrow{\text{Catalyst}} & 3\ \text{Bio diesel} & +\ \text{Glycerol}
\end{array}$$

Figure 3 General equation of Transesterification of triglycerides using methanol[12,13,14,15].

$$\begin{array}{llcll}
CH_2-COO-R & C_2H_5OH & & R-COO-C_2H_5 & CH_2-OH \\
| & | & & | & | \\
CH-COO-R & +\ C_2H_5OH & \xleftrightarrow{\text{Catalyst}} & R-COO-C_2H_5\ + & CH-OH \\
| & | & & | & | \\
CH_2-COO-R & C_2H_5OH & & R-COO-C_2H_5 & CH_2-OH \\
\text{Triglyceride} & +\ 3\ \text{Ethanol} & \xleftrightarrow{\text{Catalyst}} & 3\ \text{Bio diesel} & +\ \text{Glycerol}
\end{array}$$

Figure 4 General equation of Transesterification of triglycerides using ethanol [11].

For this experimental purpose, vegetable oil is obtained from local market. Biodiesel production setup for this experiment consists of two litter beaker, magnetic stirrer with heater and a thermometer. Groundwork was done to find the suitable catalyst and alcohol. KOH and NaOH are used as catalysts and ethanol and methanol are used as alcohols. The respective temperature and reaction time used for the experiment is 50°C and 60 minute. The vegetable oil is heated in glass container above 100 °C to remove water content. Then, the vegetable oil temperature is water maintained at 50°C; the mixture of particular alcohol and particular catalyst is added to the vegetable oil and stirrer using magnetic stirrer. After the reaction time, biodiesel is allowed to settle in settling container; in 12 hours, the glycerin gets settled at the lower part of the chamber. Glycerin and biodiesel are separated. The biodiesel is washed using pure water for three to five times. Finally, the biodiesel is heated to 100°C, and the water content in the biodiesel is removed.

Table 1. Properties of raw materials used to produce biodiesel

Raw Material	Ethanol	Methanol	Pongamia oil	Test method
Calorific value MJ/kg	28.54	19.64	40.27	ASTM D-240
Density@15.56 C (kg/m^3)	780	781	924	ASTM D-1298
Flash point	14	12	230	ASTM D-93
Viscosity @ 40° C	1.2	0.62	37.12	ASTM D-445
Cetane number	7	6	40	ASTM D-613

Table 2. The physical, thermal and yield of Pongamia oil obtained during the transesterification process with different alcohol and catalyst.

Catalyst used	Weight of catalyst used for one liter of raw vegetable oil(g)	Alcohol	Molar ratio of alcohol to vegetable oil	Reaction time Minutes	Reaction Temperature	Calorific value (MJ/kg)	Kinetic viscosity (@40° C cSt)	Density (Kg/m^3)	Flash point	Yield %
KOH	10	Methanol	6	60	50	38.251	5.24	845	170	96
NaOH	10	Methanol	6	60	50	38.12	5.07	834	167	87
KOH	10	Ethanol	6	60	50	37.93	5.15	838	152	81
NaOH	10	Ethanol	6	60	50	38.22	5.35	856	160	85

Table 2 shows the physical , thermal property and percentage yield of biodiesel produced using different alcohol and different catalysts. Since the usage of methanol as alcohol and KOH as catalyst gave higher yield (96%) than all other combinations, Pongamia oil methyl esters are used for the test purpose.

Table 3. Properties of MEOP (Methyl ester of pungamia oil)

Fuels	Kinematic viscosity @ 40 ^{0}C (cSt)	Density @15.56 (kg/m^3)	Flash point (^{0}C)	Cetane number	Calorific Value (kJ/kg)	Cloud point (^{0}C)	Pour point (^{0}C)
Test method	ASTM D-445	ASTM D-1298	ASTM D-93	ASTM D-613	ASTM D-240	ASTM D2500	ASTM D2500
Diesel	3.42	838	58	43	43858	6.7	-3
B20	4.18	846	91	45	42741	7.9	2.7
B40	4.46	855	106	46	41622	8.4	3
B60	4.85	862	119	47	40492	10.7	3.3
B80	5.10	869	126	48	39372	10.9	3.7
B100	5.24	882	134	49	38251	13.4	4.5

2.2. Experimental Setup and Method

The engine used for the investigation is a single cylinder, four stroke, constant speed, vertical, water cooled, direct injection diesel engine. The technical specifications of the engine, dynamometer and flue gas analyzer used for the experiment are tabulated in the table 4, 5 and 7. Different blends such as B0, B20, B40, B60, B80 and B100 were used for the test purpose. The performance and emission characteristics were analyzed. The test was conducted at different BP such as 0, 0.740, 1.481, 2.221, 2.962, and 3.703 kW.

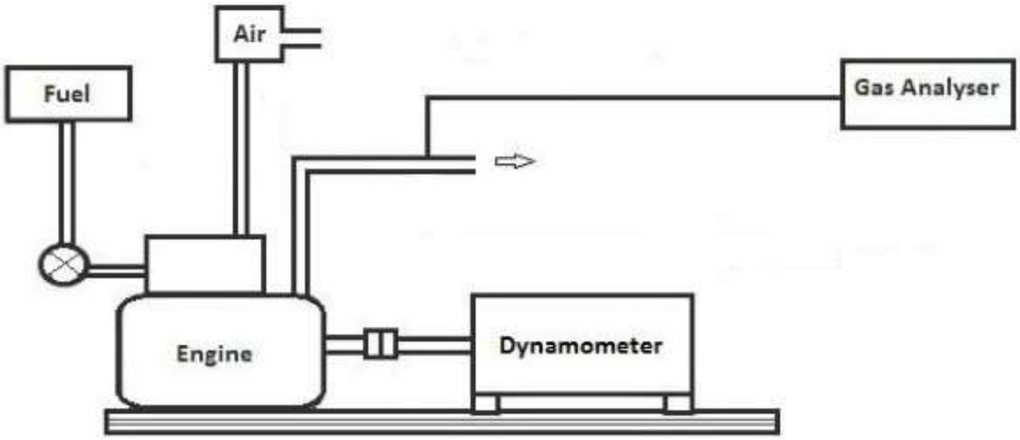

Figure 1. Schematic diagram of the experimental setup

Table 4. Technical specification of test engine

Make and model	Kirloskar, AV1
Number of stroke/configuration	4-Stroke/Vertical
Type	Compression Ignition
Number of cylinder	One
Bore	80 mm
Stroke	110 mm
Cubic capacity	553 cc
Compression ratio	17.5:1
Rated output	3.72 kW
Rated speed	1500 rpm
Combustion chamber	Hemispherical open
Type of cooling	Water cooled

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Table 5. Technical specification of dynamometer

Manufacturer	Reckers Automation India Private Limited
Type	Eddy current dynamometer
Model	E – 50
Maximum power	50 BHP – 60 BHP
W (PAN) Max	5
W (IND) = W (PAN) Max	5
Dynamometer Constant	7026
BHP	W (IND) x rpm/Dyn. Const.

Figure 2. Experimental set-up.

Table 6. Valve timing

Inlet valve opening	12 ^{0} Before TDC
Inlet valve closing	33 ^{0} After BDC
Exhaust valve opening	38 ^{0} Before BDC
Exhaust valve closing	13 ^{0} After TDC
Injection timing	28 ^{0} Before TDC

2.3. Emission Analyzer Specification
Flue gas analyzer Make: Landcom Series III

Table 7. Specification of flue gas analyzer

Sensor	Standard Range	Max. Range	Accuracy	Resolution
Oxygen, O2	0 to 25% Vol.	0 to 30% Vol.	±1%	±1% vol.
Carbon Monoxide, CO(low)	0 to 2000 ppm	0 to 100000 ppm	±2%	±1%
CO(H_2) Compensated	0 to 2000 ppm	0 to 4000 ppm	±2%	±1%
Carbon Monoxide, CO(high)	0 to 4%	0 to 10%	±2%	±1%
Sulphur Dioxide, SO_2	0 to 2000 ppm	0 to 50000 ppm	±2%	±1%
Nitrogen Dioxide, NO	0 to 100 ppm	0 to 1000 ppm	±2%	±1%
Hydrogen Sulphide, H_2S	0 to 200 ppm	0 to 1000 ppm	±2%	±1%
Carbon Dioxide, CO_2	0 to 25% volume	-	±5% Vol.	±0.1% Vol.
Flue gas temperature	0 to 1000^0C			
Ambient temperature	Measured			
Flow (velocity)	1 to 50m/s			

RESULTS AND DISCUSSION

3.1. Performance Analysis

In this paper, the performance chapter includes BTE, BSEC and TFC. All of the performances are totally interconnected, but, to understand the behavior of the fuel and the engine, each of them is calculated separately and plotted in this paper.

Brake thermal efficiency

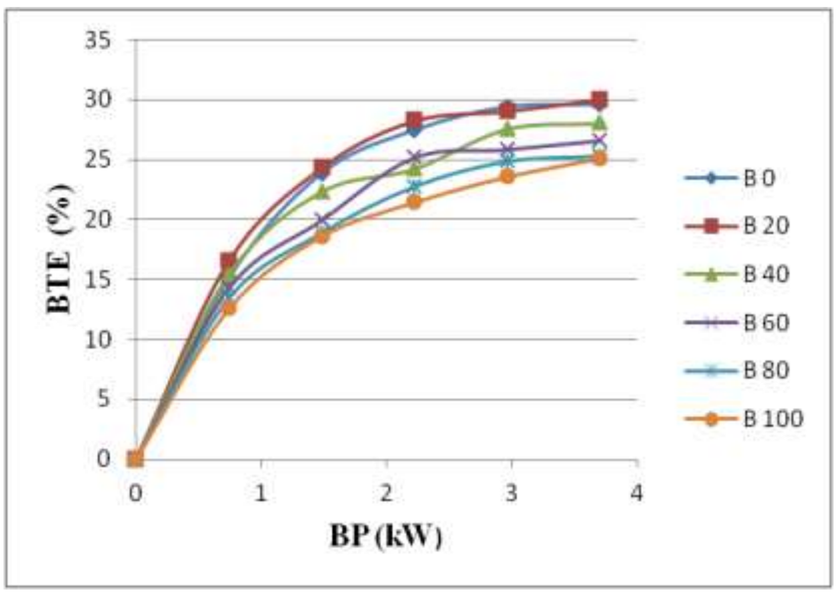

Figure 3. BP Vs BTE for different blends of Pongamia methyl esters.

Figure 3 shows variations of BTE at various BP for Pongamia biodiesel and its blends. For all the fuel used in this experiment, increase in load increases BTE. This is because of the increase in combustion quality with increase in load. Even though the viscosity (C.V) of B20 is higher (lower) than diesel, B20 produces higher BTE than diesel by 2% for most load conditions. A saturation limit is attained at a higher ratio above B20. As the ratio of biodiesel in the blend increases beyond 20%, BTE starts to decrease. An average drop in efficiency for B100, when compared with diesel, is about 10%. A slight interference of curve in the middle range loads is seen for B40 and B60. B20 produces higher BTE than diesel. The blend with higher ratios of biodiesel, i.e., B40, B60, B80 and B100, produces lower efficiency because of unsettled competition between the viscosity, calorific value and oxygen content. The lower calorific value would reduce the BTE, where the oxygen content in the biodiesel improves the combustion property and the viscosity reduces the atomization property, but at the same time, it improves the lubrication property [21,22].

Total fuel Consumption

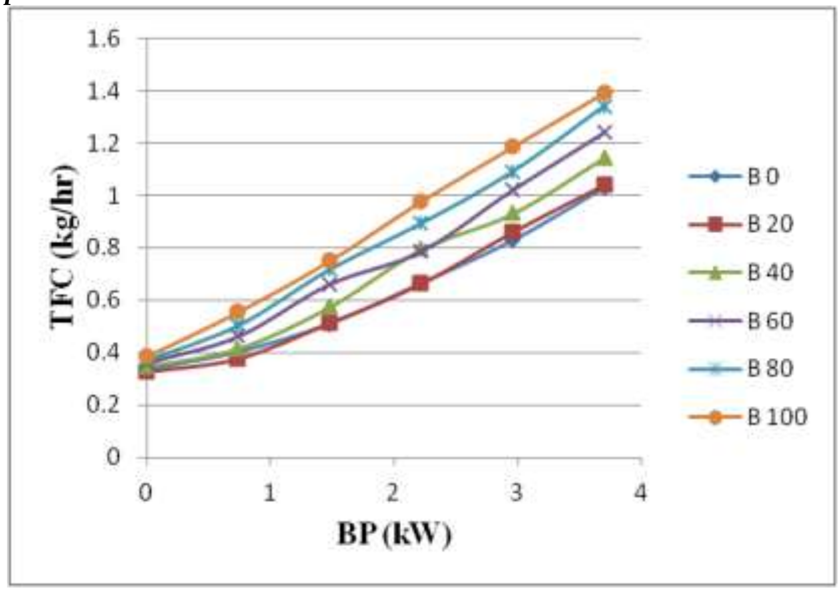

Figure 4. BP Vs TFC for different blends of Pongamia methyl esters

Figure 4 shows the variation of total fuel consumption at different BPs for different load conditions for diesel and blends of biodiesel with diesel. The total fuel consumption gives a value that gives the mass of fuel consumed to produce for particular time. Load and calorific value are not considered for calculating this. But, TFC gives a basic knowledge about the fuel consumption. For all the fuels used, TFC gets increased with the increase in load. Diesel produces the least TFC. Increasing the ratio of biodiesel in the blend increases TFC. This was because of the higher specific gravity and lower calorific value of biodiesel. TFC and BTE are inversely proportional to each other. [16-20].

Brake specific energy consumption

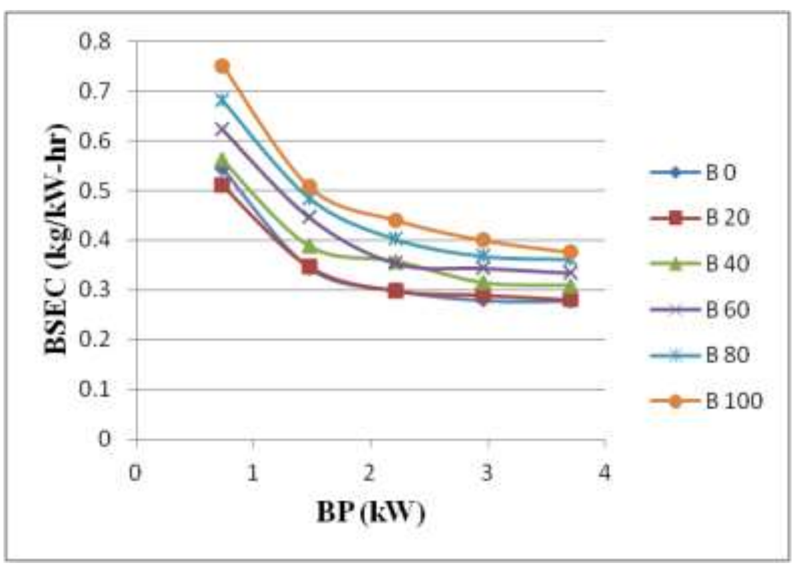

Figure 5. BSEC Vs BP for different blends of Pongamia methyl esters

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Figure 5 shows the variation of Brake specific energy consumption at different BP for different load conditions for diesel and blends of biodiesel with diesel. BSFC refers to the ratio of mass of fuel consumed by the engine to the power produced by the engine. Specific fuel consumption decreases sharply as the increase in load. This is because the amount of fuel needed to operate the engine at high load is lesser when compared with the increase in brake power, because of the lesser heat loss at higher load. As BSEC is calculated on mass basis, the denser fuel mostly produces higher BSEC. The density of biodiesel and its blends were higher than diesel. B20 produces almost equal BSEC of that of diesel. This may be due to the better combustion property due to the presence of oxygen content and higher cetane number and lubrication property of B20. With increasing the ratio of biodiesel in the blend, BSEC increases. B100 produces the highest BSEC (0.3756 kg/kW-hr), and diesel produces the least BSEC (0.2777 kg/kW-hr) [22].

3.2 Emission Analysis

3.2.1 Exhaust Gas Temperature

The engine used for the test purpose is constant speed engine. The air intake throughout the test condition for different load conditions was constant, where the volume and mass of fuel injected for different load conditions and different blends of fuels vary. As the load increases, the air fuel ratio gets decreased. The calorific value of biodiesel and its blends with diesel is lesser than pure diesel. As the ratio of biodiesel in the blend increases, the mass of fuel injected increases; this reduces the air fuel ratio. This air fuel ratio may have an effect on emission.

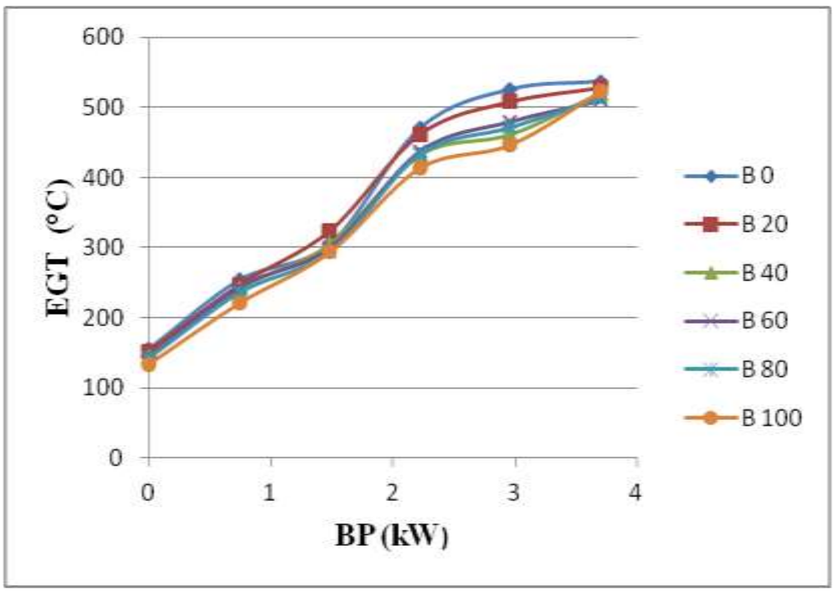

Figure 6. EGT Vs BP for different blends of Pongamia methyl esters

Figure 6 shows the variation of Exhaust Gas Temperature at different BP for different load conditions for diesel and blends of biodiesel with diesel. Irrespective of the fuel, increase in load increases the exhaust temperature. With the increase of biodiesel in the blend ratio, the EGT decreases for most conditions. The EGT of diesel, B20, B40, B60, B80 and B100 at 2.9626 kW load condition are found to be 526, 508, 461, 480, 472 and 447, respectively. This may be because of the presence of oxygen in biodiesel and higher cetane number in biodiesel than in the diesel. This may lead to reduced ignition delay, and the combustion process takes place in the early stage of combustion, so the EGT of biodiesel and blends were lesser than diesel [6,23].

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3.2.2 Carbon monoxide Emission

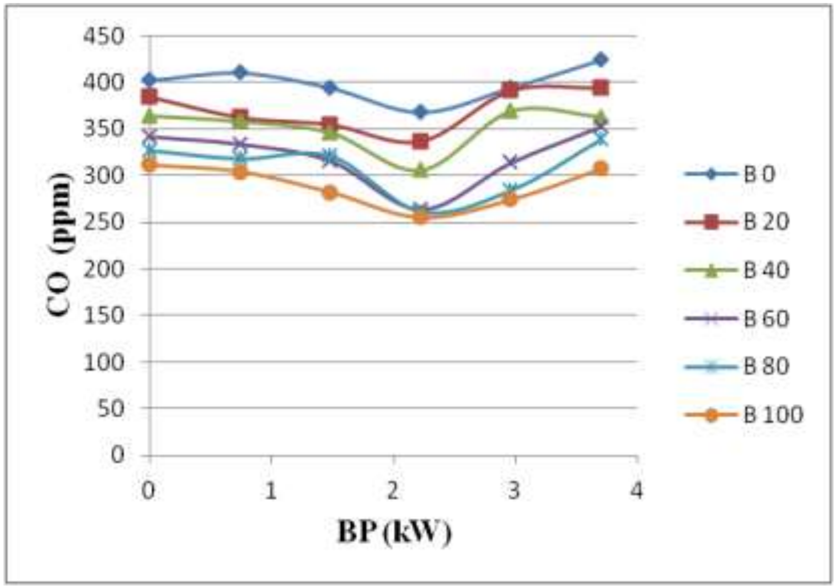

Figure 7. CO Vs BP for different blends of Pongamia methyl esters

The figure 7 shows the variation of Carbon monoxide at different BP for different load conditions for diesel and blends of biodiesel with diesel. CO is mainly produced as a result of incomplete combustion [24,26].Above 60 percentage load, CO emission increases slightly for all the test fuels. This was because of decrease in air fuel ratio at higher load [25]. With increase in the ratio of biodiesel in the blend, CO emission decreases. At lower loads to middle loads such as 0, 0.74, 1.48 kW, CO emission decreases for all fuels because of availability of higher air fuel ratio at lower load to middle load than at higher load.

The CO emission for B0, B20, B30, B40, B60, B80 and B100 at full load conditions are 424, 394, 363, 353, 339 and 307 ppm, respectively. the decrease in CO emission for increase in ratio of biodiesel in the blend is due to increase in the oxygen content in biodiesel[23,27].

3.2.3 Carbon dioxide

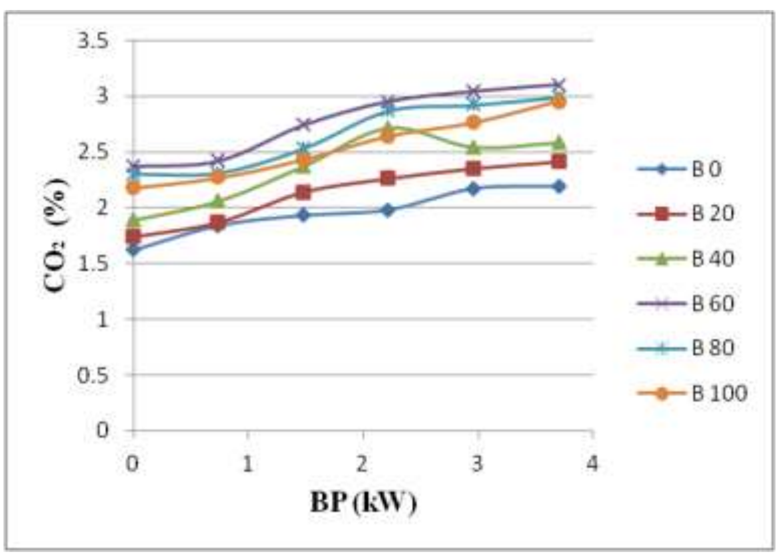

Figure 8. CO_2 Vs BP for different blends of Pongamia methyl esters

Figure 8 shows the variation of Carbon dioxide at different BP for different load conditions for diesel and blends of biodiesel with diesel. CO2 emission from C.I indicates the efficiency of combustion inside the combustion chamber. The percentage volume of CO2 emission for B0, B20, B40, B60, B80 and B100 at full load are 2.19, 2.41, 2.58, 3.1, 2.99 and 2.95 percentage, respectively. The lower blend such as B20, B40 and B60 increases accordingly to the increase in blend ratio. It was due to the increase in cetane number and the presence of oxygen in biodiesel. Increase in load increases the CO2 emission for all the fuels; this indicates that the fuel conversion efficiency was higher at higher load. In C.I. engine, always excess of fuel is admitted inside the cylinder; a local rich mixture may form at higher load due to the higher quantity of injection of fuel at higher load, but the C.I engine mostly operates on overall lean mixture. So, this leads to higher fuel conversion at higher loads. The blends above B60 start to produce lesser CO2 than the lesser ratio of biodiesel blends. This may be due to the reduction in combustion quality at higher ratio, because of the higher viscosity.

3.3.4 Nitric Oxide (NO)

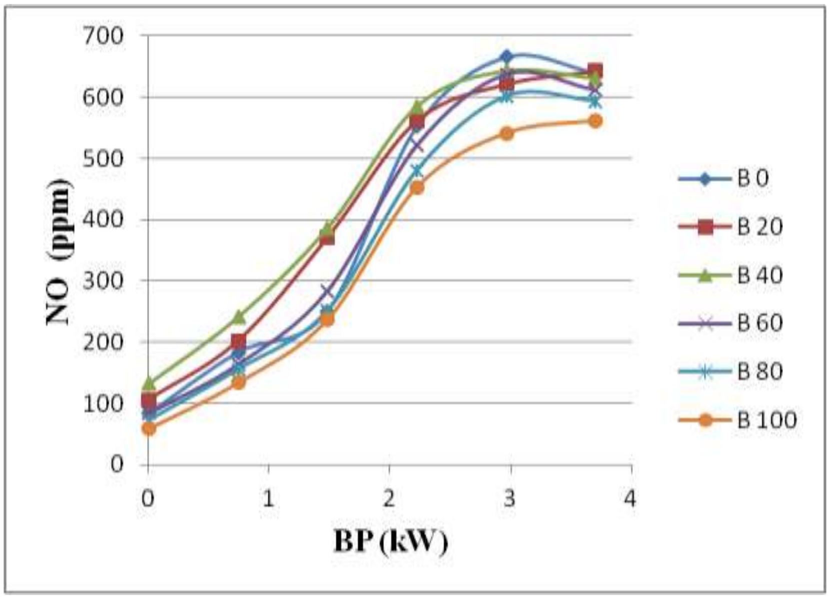

Figure 9. NO Vs BP for different blends of Pongamia methyl esters

Figure 9 shows the variation of NOx at different BP for different load conditions for diesel and blends of biodiesel with diesel.

NOx mainly depends upon the combustion temperature [28]. Irrespective of the fuel, increasing the load increases the quantity of fuel injected, and it increases the combustion chamber temperature. This also increases the NOx emission[29]. While increasing the blend ratio of biodiesel upto 40 percentage, the NOx emission gets increased and produces higher NOx than diesel, but the ratio higher than 40 percentage of biodiesel in the blend produces lesser NOx than diesel.

The lesser NO may be because of higher cetane number in higher ratios of biodiesel, which reduces the ignition delay and the period of combustion. The lesser delay period decreases the accumulation of fuel inside the combustion chamber and reduces peak temperature. The B60, B80 and B100 may have the higher dominating character of higher viscosity and higher cetane number than the influence of oxygen content in the biodiesel.

Since the higher ratio of biodiesel in the blend has lesser calorific value, more amount of biodiesel is injected inside the combustion chamber; this more amount of fuel may absorb more amount of heat from the combustion chamber and reduces the peak pressure. This may also be a reason for the lesser NOx for higher blend ratio[29].

CONCLUSIONS

In this study, performance and emission characteristics of various blends of Pongamia oil methyl esters are studied and compared with diesel as a base fuel. Based on the test result, the following conclusions were made.

1. The usage of Methanol as alcohol and KOH as catalyst produces the highest yield, leading to the selection of Pongamia oil for test purpose.
2. Albeit its high viscosity and low C.V, B20 produces 2% higher BTE than diesel almost for all loads. Increase in oxygen content improves the combustion. Higher viscosity leads to poor atomization but increased lubrication.
3. For almost all conditions, EGT gets reduced when the percentage of biodiesel increases in the blend.
4. TFC increases when the percentage of biodiesel increases in the blend (because of the higher specific gravity and lower calorific value of biodiesel).
5. The density of diesel is lesser than its blends with biodiesel. The BSEC produced by B20 is almost equal that produced by diesel, due to the better combustion property, which is a result of oxygen content, higher cetane number and lubrication property of B20. BSEC increases with respect to the ratio of biodiesel in the blend.
6. After a critical limit in the load, i.e., above 60%, the emission of CO increases slightly for all the test fuels, because of the decrease in air fuel ratio at higher loads [49].The emission of CO decreases when there is an increase in the biodiesel to diesel ratio in the blend.
7. The blends above B60 start to produce lesser CO2 than B40, because higher viscosity of biodiesel (at higher ratio) reduces the combustion quality.
8. Increase in the fraction of biodiesel in the blend upto a critical limit (say 40%) increases the emission of NO_x, while beyond that, NO_x decreases.

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