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Research Paper

PERFORMANCE AND EMISSION CHARACTERISTICS OF SINGLE CYLINDER 4-STROKE DIESEL ENGINE USING PONGAMIA PINNATA METHYL ESTER (PPME) AS FUEL

K Sureshkumar[1]* and K Muralidharan[1]

*Corresponding Author: K Sureshkumar, ✉ kskumar792@gmail.com

Vegetables oils are simplest route of biofuel utilization in Direct Injection Compression Ignition (DICI) engines however several operational and durability problems are encountered while using straight vegetable oils in CI engines due to their high viscosity and low volatility. In this study, performance and exhaust emission characteristics of Pongamia Pinnata oil blends (BD5, BD10, BD20 and BD30) with mineral diesel were investigated in unheated conditions in a single cylinder 4-Stroke direct injection CI engine at different engine operating torque and constant engine speed 1500 rpm. Analysis of performance parameters such as Brake Specific Fuel Consumption (BSFC), Brake thermal efficiency, Mechanical efficiency and Indicated thermal efficiency and various gaseous exhaust emissions like CO and Nitrogen oxide (NOx) were carried out. Investigation revealed that the performance parameters like Mechanical efficiency increases with increase in biodiesel mixtures and maximum of 68.42% is observed for BD20, Brake specific fuel consumption increases with biodiesel mixtures, thermal efficiency decreases with biodiesel mixtures and it is compared with baseline test with neat mineral diesel. Also emission CO decreases with biodiesel mixtures whereas NOx increased significantly for biodiesel mixtures even with smaller concentration of pongamia oil in the fuel blend.

Keywords: Biodiesel, Pongamia pinnata, Performance, Emission, Diesel engine

INTRODUCTION

Newer options of alternative fuels should be technically feasible, economically competitive, environment friendly and provide energy security without compromising the engine performance and emitting lesser quantity of harmful pollutant species (Barnwal and Sharma, 2004; and Demirbas, 2007). Even Rudolf Diesel, the inventor of CI engine expressed the possibility of using vegetable oil as CI engine fuel during 1900 world exhibition in the Paris and demonstrated using peanut oil as fuel in his newly invented diesel engine (Tsolakis and Megaritis, 2004).

The energy needs of the world are increasing rapidly. The decrease in fossil fuels, emission

[1] Department of Mechanical Engineering, PSNA College of Engineering & Technology, Dindigul 624622, Tamil Nadu, India.

pollution caused by them and increasing fuel prices make biomass energy sources more attractive. The increase in energy demand and decrease in oil reserves (Lin and Lin, 2006) have focused attention on biofuels (Lapuerta *et al.*, 2007). Biodiesel is a fuel that is manufactured from vegetable oils with the help of catalysts, and may be directly used in diesel vehicles with little or no modification. When biodiesel is used, HC, CO, and PM ratios in exhaust emissions are lower, while sometimes very small NOx increases occur (Tsolakis and Megaritis, 2004). In many studies, it has been reported that biodiesel causes significantly lower PM and CO emissions compared with fossil fuels (Lin and Lin, 2006; Lapuerta *et al.*, 2007; Sahoo *et al.*, 2007; and Bouaid *et al.*, 2007).

Using high-viscosity vegetable oils in diesel engines without any modification negatively affects both performance and engine parts. The most important problem in directly using vegetable oils is that contamination forms and adheres to the piston rings (Altin, 1998). Several methods exist for making vegetable oils usable in engines. The most significant is the transesterification method. In transesterification, vegetable oil is added to a mono hydroxyl alcohol (ethanol, methanol) in the presence of a catalyst, and the vegetable oil is broken into diesel fuel and glycerin; then it is reacted with triglyceride to form alcohol ester and glycerol (Yamane *et al.*, 2001; Raheman and Phadatare, 2003; Mehar *et al.*, 2004; Puhan *et al.*, 2005; and Generic-Biodiesel-Reaction1.gif, 2012). The resources of petroleum as fuel are dwindling day by day and increasing demand of fuels, as well as increasingly stringent regulations, pose a challenge to science and technology. With the commercialization of bioenergy, it has provided an effective way to fight against the problem of petroleum scarce and the influence on environment. Biodiesel, as an alternative fuel of diesel, is described as fatty acid methyl or ethyl esters from vegetable oils or animal fats. It is renewable, biodegradable and oxygenated. Although many researches pointed out that it might help to reduce greenhouse gas emissions, promote sustainable rural development, and improve income distribution, there still exist some resistances for using it. The primary cause is a lack of new knowledge about the influence of biodiesel on diesel engines (Bryant, 1976; Kyriakidis and Katsiloulis, 2000; Srivastava and Prasad, 2000; Agarwal, 2007; and Generic-Biodiesel-Reaction1.gif, 2012).

As the fossil fuels are depleting day by day, there is a need to find out an alternative fuel to fulfill the energy demand of the world. Biodiesel is one of the best available sources to fulfill the energy demand of the world. The petroleum fuels play a very important role in the development of industrial growth, transportation, agricultural sector and to meet many other basic human needs. However, these fuels are limited and depleting day by day as the consumption is increasing very rapidly. Moreover, their use is alarming the environmental problems to society. Hence, the scientists are looking for alternative fuels. India is importing more than 80% of its fuel demand and spending a huge amount of foreign currency on fuel. Biodiesel is gaining more and more importance as an attractive fuel due to the depleting nature of fossil fuel resources. The purpose of transesterification process is to lower the viscosity of the oil. The main drawback of vegetable oil is their high viscosity and low volatility, which causes poor combustion in diesel engines. The transesterification is the process of removing the glycerides and combining oil esters of vegetable oil with alcohol. This process reduces the viscosity to a value comparable to that of diesel and hence improves combustion. Biodiesel emits fewer pollutants over the whole range of air-fuel ratio when compared to diesel (Bryant, 1976; Srivastava and Prasad, 2000; Altin *et al.*, 2001; and Wander *et al.*, 2011).

Biodiesel can produce by using different techniques such as ultrasonic cavitation, hydrodynamic cavitation, microwave irradiation, response surface technology, two-step reaction process, etc. Experiments had been conducted for different types of combustion chambers. It was found that spherical combustion chamber gives better results than other type of combustion chambers. The scientists tested a number of different raw and processed vegetable oils like rapeseed oil, sunflower oil, palm oil, soybean oil (Haldar *et al.*, 2009; Leevijit and Prateepchaikul, 2011; and Misra and Murthy, 2011).

In this paper, the nonedible source of methyl ester of Pongamia Pinnata is derived by chemical process of Transesterification, its properties are measured and detailed experimental investigation is carried out for different biodiesel (BD) mixtures like BD5, BD10, BD20 and BD30.

MATERIAL AND METHOD

Seed Material

The seed are collected near town and village around Sathiyamangalam, Coimbatore District, Tamilnadu. Pongamia Pinnata tree grows well in waste land, provides one of the highest oil yield among tree-borne oil seeds. India has nearly 33 million hectares of wastelands which could be used for cultivation of such oil-bearing plants. The seeds are selected according to their conditions where damaged seeds were discarded before seeds in good conditions were cleaned, deshelled and dried at high temperature at 100-105 °C. For 30 minutes. Seeds where then taken for oil extraction.

Extraction of Oil

The oil can be extracted by mechanical expeller and by soxhlet extraction method. We are chosen soxhelt extraction method for best result. Mechanical press extraction method-(Single chamber and double chamber oil Expeller). It is an ordinary method used for the extraction of all types of oil. This process requires extra time and recovers oil in fewer amounts as compared to other methods.

Soxhelt Extraction Method-(Solvent Extraction Method)

The seeds were grinded into fine particles and 50 gms of grinded was taken and a thimble was made. The soxhelt apparatus was set up and 300 ml hexane was added to thimble from above.

Working of Apparatus

A soxhelt extractor is a piece of laboratory apparatus invented in 1879 by Franz Von Soxhlet. Typically, a soxhlet extraction is only required where the desired compound has a limited solubility in a solvent and the impurity is insoluble in that solvent. Normally a solid material containing some of the desired compound is placed inside a thimble made from thick filter paper, which is loaded into the main chamber of the Soxhlet extractor. The Soxhlet extractor is placed onto a flask containing the extraction solvent. The Soxhlet is then equipped with a condenser. The Soxhlet is then heated to reflux. The solvent vapor travels up a distillation arm and floods into the chamber housing the thimble of solid. The condenser ensures that any solvent vapors cools and drips back down into the chamber housing the solid material. The chamber containing the solid material is slowly filled with warm solvent. Some of the desired compounds then get dissolved in the warm solvent. When Soxhlet chamber is almost full, the chamber is automatically emptied by a siphon side arm, with the running back down to the distillation flask. This cycle is allowed to repeat several times within 8hrs of extraction. During each cycle, a portion of the non-volatile compound dissolves in the solvent. After many cycles the desired compound is concentrated in the distillation flask. After extraction, the solvent is removed, typically by means of a rotary evaporator at 40-50 °C, yielding extracted oil. The non-soluble portion of the extracted solid remains in the thimble, which is removed separately.

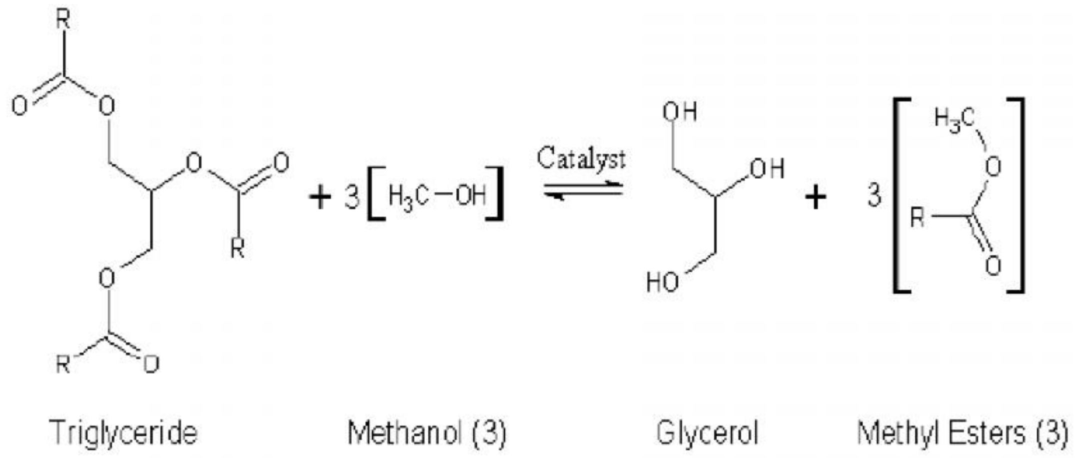
Tamilnadu's first and the world's 141st biodiesel manufacturing plant setup by the Bannari Amman Group, has started functioning at Sathyamangalam,near 60 km from Coimbatore. The plant which produced 3000 liters of biodiesel from jatropa and Pongamia seeds,was inaugurated by minister of state of rural developement, Chandra Sekar Sahu on April 7, 2007. The overnment has allowed blending of 5% of biodiesel with conventional diesel. India's National Policy on biofuels aims to permit a maximum blend of up to 20%, which will not require any modification to automobile engines. The company has trained farmers to grow both jatropa and pongamia plant and have educated the reluctant farmers about the usefulness of growing biodiesel bearing plants. Over 1700 Acres of jatropa and pongamia plantation has been done by the company in the adjoining areas of sathyamangalam, nestling in the foothills of the Nilgiri mountains. The only other biodiesel plant in south india is in Andtra Pradesh.

PRODUCTION OF BIODIESEL

The transesterification process is the reaction of triglyceride (fat/oil) with an alcohol in the presence of acidic, alkaline or lipase as a catalyst to form mono alkyl ester that is biodiesel and glycerol. However the presence of strong acid or base accelerates the conversion. It is reported that alkaline catalyzed transesterification is fastest and require simple set up therefore, in current study the oil of Pongamia Pinnata were transesterified with methyl alcohol in presence of strong alkaline catalyst like sodium hydroxide or potassium hydroxide in a batch type transesterification reactor. The transesterification reaction is given Figure 1 process has been widely used to reduce the high viscosity of triglycerides.

To prepare biodiesel from pongamia crude oil first sodium hydroxide was added in to the methyl alcohol to form sodiummethoxide, simultaneously oil was heated in a separate vessel of tranesterifaction reactor and subjected to heating and stirring. When temperature of oil reached at 60 °C then sodium methoxide was mixed in to the oil and reaction mixture was stirred for one and half hour. After reaction completion, the reaction mixture was transferred in separating funnel. The mixture of glycerol and methyl ester was

Figure 1: Transesterification Process



allowed to settle for 8 hours. After settling for 8 hours glycerol and methyl esters was separated manually. The methyl ester was the washed with hot water to remove traces of sodium hydroxide impurity. The washed biodiesel then distilled to remove moisture and final good quality biodiesel was subjected for chemical analysis. The property table is given in Table 1.

EXPERIMENTAL SETUP AND PROCEDURE

The engine used in this experiment was a single cylinder water-cooled, 4-stroke, DI diesel engine. The engine was a commercial diesel engine and it was coupled with electric dynamometer. The specifications of the engine are shown in Table 2. All experiments were conducting at standard temperature and pressure. The engine speed was measured directly from the tachometer attached with the dynamometer. An electrical brake dynamometer was used for engine torque measurement. The outlet temperatures of cooling water and exhaust gas were measured directly from the thermocouples (Ni-Cr) attached to the corresponding passages. The dynamic fuel injection timing was set at 24°

Table 1: Properties of Biodiesel

Property	Raw Oil	Pongamia Pinnata Methyl Ester (PPME)	BD5	BD10	BD20	BD30	Diesel
Density in kg/m^3	938.2	857.9	838.6	841.4	845.8	848.2	833.7
Kinematic Viscosity at 40 °C in Cst	35.98	21.45	14.32	16.21	17.31	17.45	2.72
Flash Point (°C)	237	172	92	102	112	118	48
Fire Point (°C)	320	210	145	156	158	162	220
Calorific Value (MJ/KG)	37.87	41.66	40.34	40.84	41.45	41.78	43.06
Cetane Index	46	48	51	51	53	54	50

Table 2: Test Engine Specification

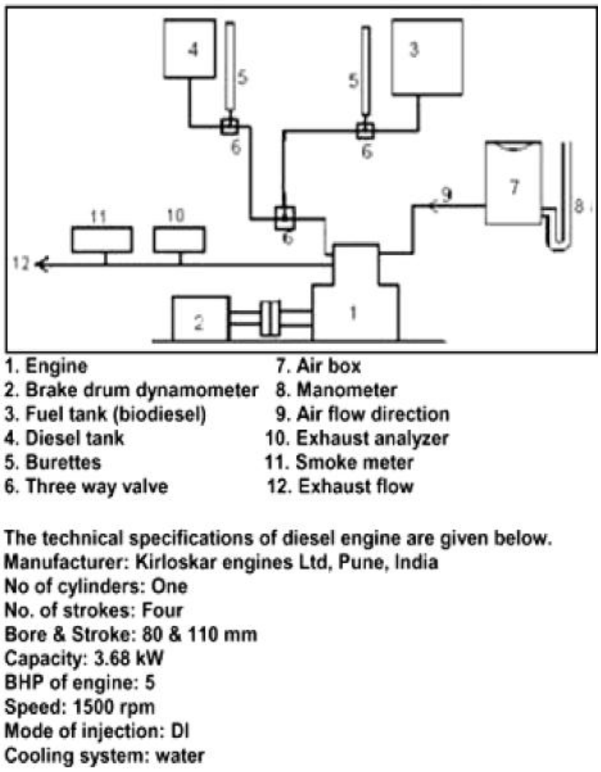
Engine Make	Kirloskar Engine
Engine Types	Single Cylinder Four Stroke Diesel Engine
Rated HP/KW	5/3.7
Engine Rated Speed	1500 rpm
Bore Diameter	80 mm
Stroke	110 mm
Brake Specific Fuel Consumption	245 gm/KW-hour
Compression Ratio	16.5:1
Types of fuel pump	High Pressure Mechanical Type

Table 3: AVL Five Gas Analyzer Specification

Type	Digas 444
Power Supply	11 to 22 VDC/100-300 VAC @ 50Hz
Power Consumption	25W maximum
Operating Temperature	5 to 45 °C
Storage temperature	0-50 °C
Relative Humidity	≤95% Non-Condensing
Inclination	0 to 90°
Normal Gas flow	1801/h
Maximum Over Pressures	450 hpa
Oxygen Sensor Type	Electro chemical
Oxygen sensor Model	O_2 SENS1

BTDC (before top dead center). The engine exhaust emissions like Unburned hydrocarbon (HC), Nitrogen Oxide (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO_2) and Opacity or Smoke particles were measured with AVL Five gas analyzer. AVL Five gas analyzer specification shown in Table 3. Fuel consumption was measured by a burette attached to the engine and a stop watch was used to measure fuel consumption time for every 10 cm^3 fuel. A mechanical fuel pump was used in the injection system. Nozzle with a hole diameter of 0.35 mm was used in the injection system. Each experimental data reading was taken three times and the mean of the three was taken.The experimental set up shown in Figure 2. The experiments conducted at different blending of biodiesel BD5, BD10, BD20, BD30 and pure Diesel. The time taken for 10 cm^3 fuel consumption, speed, Torque is noted and corresponding performance parameters like mechanical efficiency (η_{mech}), Brake Specific Fuel Consumption (SFC), Brake thermal efficiency (η_{bth}), Indicated thermal efficiency (η_{Ith}), Indicated Mean Effective Pressure (IMEP) are calculated. The Exhaust emissions like Nitrogen Oxide (NOx) and Carbon Monoxide (CO) were measured and it is noted. The experiments conducted three times and average values are taken for results and discussion.

Figure 2: Experimental Setup



RESULTS AND DISCUSSION

Performance Characteristics

Mechanical Efficiency vs Engine Torque

Figure 3 shows the range of percentage change in performance parameters such as mechanical efficiency for biodiesel blends with respect to mineral diesel for the entire operating torque range of the engine. It is observed that, biodiesel mixture having increased mechanical efficiency compared with mineral diesel and increased by 12% for BD 20% biodiesel mixture at higher operating engine Torque. This is due to the reason of cetane index higher for higher blending ratio.

Brake Specific Fuel Consumption vs Engine Torque

Figure 4 shows the variation of brake specific energy consumption with load. The energy consumed by the engine to produce 1 kW of power in 1 h time is called brake specific energy consumption. The brake

Figure 3: Mechanical Efficiency vs Engine Torque

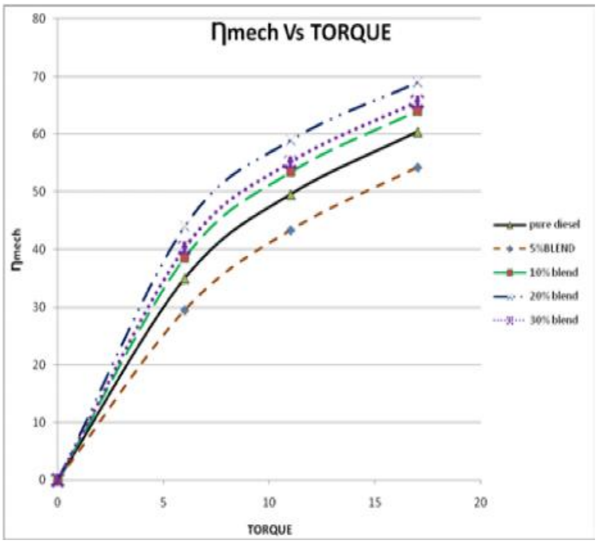
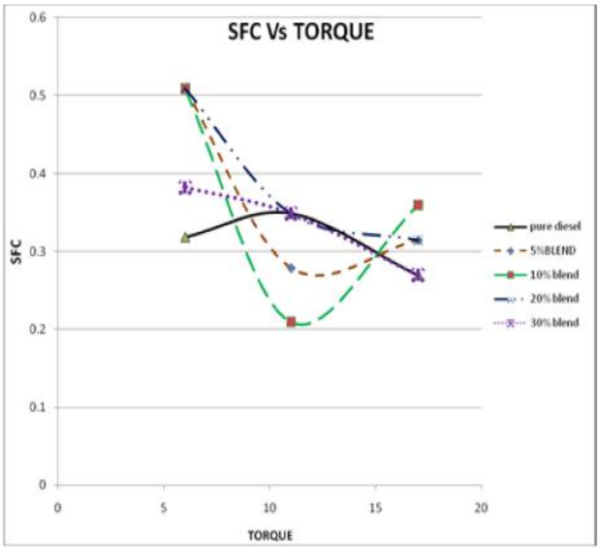


Figure 4: Specific Fuel Consumption vs Engine Torque



specific energy consumption is higher for biodiesel mixtures due to its poor combustion. As seen in the Figure 4, the presence of pongamia oil in the blend reduces the energy consumption due to easy mixing and better burning. BSFC was observed to have increased with increasing proportion of biodiesel in the fuel.

Brake Thermal Efficiency vs Engine Torque

The variation of brake thermal efficiency is shown in Figure 5. The brake thermal efficiency is the ratio of brake power output to heat input rate. At rated higher output torque, the brake thermal efficiency of the diesel engine with neat biodiesel mixture (BD30) operation is 32.43.1% whereas it is 29.94% for diesel. This is due to the fact that high viscosity of neat PPME results in poor atomization leading to improper mixing and poor combustion. By blending Pongamia oil with neat mineral diesel the viscosity is lowered. This leads to improved atomization,

Figure 5: Brake Thermal Efficiency vs Engine Torque

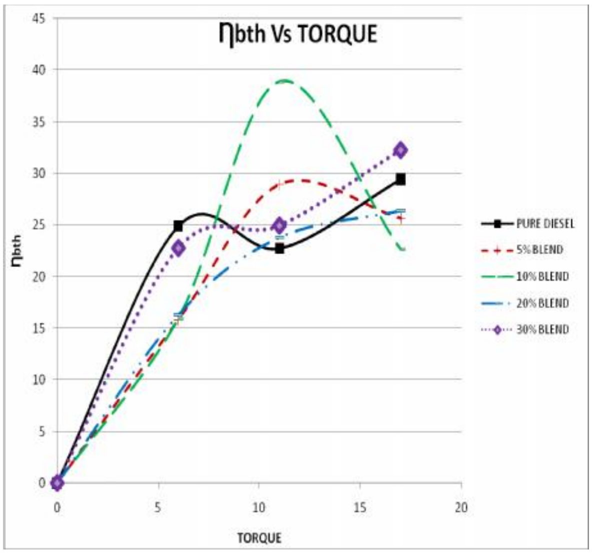
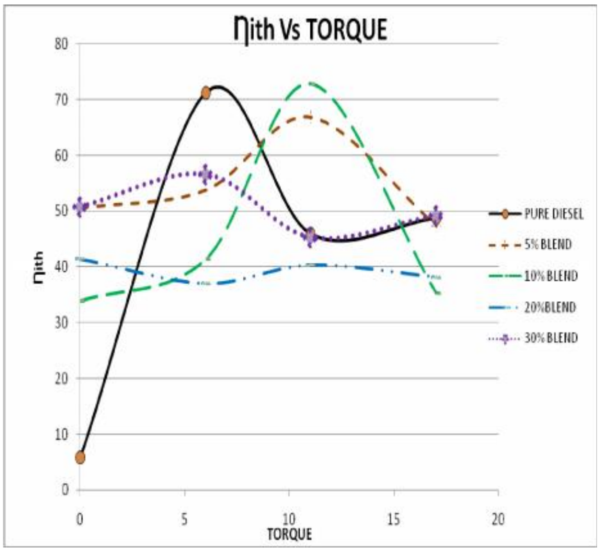


Figure 6: Indicated Thermal Efficiency vs Engine Torque



vaporisation, ignition and combustion characteristics. Presence of oxygen in the biodiesel molecules improve the combustion efficiency of biodiesel hence its brake thermal efficiency increases with respect to mineral diesel at higher operating torque. All blends showed lower thermal efficiency than mineral diesel when operating torque becomes linear. Combustion of higher biodiesel blends starts relatively earlier and their combustion ends earlier also compared to lower biodiesel blends therefore one can observe relatively higher exhaust gas temperature compared to lower biodiesel blends. Lower exhaust gas temperatures resulting due to shorter combustion duration for biodiesel blends reduced CO and HC emissions are causing better thermal efficiency for biodiesel blends at higher operating torque.

Indicated Thermal Efficiency vs Engine Torque

Figure 6 Shows the range of percentage change Indicated thermal efficiency for all biodiesel blends with respect to mineral diesel for the entire torque range of the engine. Indicated Thermal efficiency of Pongamia oil blends was lower than mineral diesel. Indicated Thermal efficiency of only BD10 at lower engine torque was observed to be close to that of mineral diesel. This is due to cycle to cycle variation during higher torque operating condition. Also, relatively higher viscosity and poor volatility of Pongamia oil leads to poor fuel atomization and mixing of air and fuel spray, which leads to incomplete combustion in fuel rich regions inside the combustion chamber. Therefore, Indicated thermal efficiency is found to be lower for higher blends compared to mineral diesel. The exhaust gas temperature for all blends of pongamia oil was higher compared to mineral diesel at all engine operating conditions ,which also confirms lower Indicated thermal efficiency of Pongamia oil blends with increasing concentration of Pongamia oil in the fuel blend.

EXHAUST EMISSION ANALYSIS

Carbonmonoxide vs Engine Torque

Figure 7 shows the CO emissions of the neat diesel fuel and the biodiesel mixtures. CO is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete, CO is converted to CO_2. If the combustion is incomplete due to shortage of air or due to low gas temperature, CO will be formed. Usually high diesel CO emissions formed with fuel-rich mixtures, but as diesel combustion is occurred with lean mixture and has an abundant amount of air, CO from diesel combustion is low. The comparative analysis of CO is shown in Figure 7. For biodiesel mixtures CO emission was lower than that of diesel fuel, because biodiesel mixtures contain some extra oxygen in their molecule that resulted in complete combustion of the fuel and supplied the necessary oxygen to convert CO to CO_2. Compared to neat diesel fuel, biodiesel mixtures reduced CO emissions by 24%.

Nitrogen Oxide vs Engine Torque

Figure 8 shows the effect of engine torque on NOx emission. Naturally NOx emission increases with the increase in engine torque. It is well known that nitrogen is an inert gas, but it remains inert upto a certain temperature (1100 °C) and above this level it does not remain inert and participate in chemical reaction. At the end of combustion, gas temperature inside cylinder arises around 1500 °C. At this temperature oxidation of nitrogen takes places in presence of oxygen inside the cylinder. On the other hand, since the formation of nitrogen oxides do not attain chemical equilibrium reaction; then after the end of expansion stroke when the burned gases cool and the formation of NOx freeze, the concentration of the formed NOx in the exhaust gas remain unchanged. Figure 8 also shows that NOx level was higher for biodiesel mixtures than conventional diesel fuel at the

Figure 7: Carbon Monoxide (CO) Emission vs Engine Torque

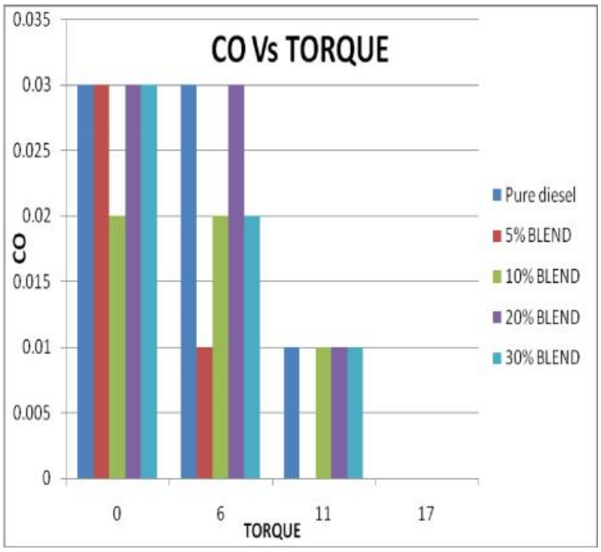
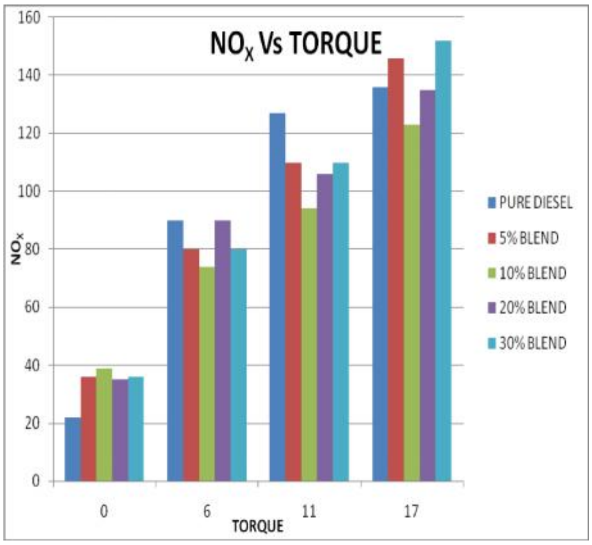


Figure 8: Nitrogen Oxide (NOx) Emission vs Engine Torque



same engine torque. This can be explained due to the presence of extra oxygen in the molecules of biodiesel mixtures. This additional oxygen was responsible for extra NOx emission. Approximately 10% increase in NOx emission was realized with 30% biodiesel mixtures. Reduction of NOx with biodiesel. may be possible with the proper adjustment of injection timing and introducing to Exhaust Gas Recirculation (EGR).

CONCLUSION

This work investigated the production of biodiesel from nonedible Pongamia Pinnata Methyl Ester (PPME) and performance and exhaust emission study of diesel engine with diesel fuel and various biodiesel mixtures (BD5, BD10, BD20 and BD30). The results of this report are summarized as follows:

- BD was prepared from Pongamia kernel seed by transesterification process.
- A maximum of 750 ml BD production was found at 20% methanol and 0.5% NaOH at 60 °C reaction temperature.
- Brake thermal Thermal efficiency with biodiesel mixtures was slightly lower than that of neat diesel fuel due to lower heating value of the mixtures. However, volatility, higher viscosity, higher density may be additional reasons for efficiency reduction with biodiesel mixtures. At rated higher output torque, the brake thermal efficiency of the diesel engine with neat biodiesel mixture (BD30) operation is 32.43.1% whereas it is 29.94% for neat mineral diesel.
- Biodiesel mixtures showed less CO than those of neat diesel fuel. NOx emission with biodiesel mixtures showed higher values when compared with neat diesel fuel.

Compared to the neat diesel fuel, 5% biodiesel mixtures reduced, smoke emissions, unburned hydrocarbon emission by 8% and 14%, respectively. Biodiesel mixtures (30%) reduced CO emissions by 24%, while 10% increase in the NOx emission was experienced with the same blend. The reason for reducing CO and increasing NOx emission with biodiesel mixtures was mainly due to the presence of oxygen in their molecular structure. Also low aromatics in the biodiesel mixtures may be an additional reason for reducing these emissions.

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