Investigations on Performance and Emission Characteristics of Diesel Engine with Jatropha Biodiesel and Its Blends

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ABSTRACT

A 5.2 kW diesel engine with alternator was used to test jatropha biodiesel and its blends. A pilot plant was developed for biodiesel production from different vegetable oils and used for this study. In the case of jatropha biodiesel alone, the fuel consumption in the diesel engine was about 14 per cent higher than that of diesel. The percent increase in specific fuel consumption ranged from 3 to 14 for B_{20} to B_{100} fuels. The brake thermal efficiency for biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions and there was no difference between the biodiesel and its blended fuels efficiencies. For jatropha biodiesel and its blended fuels, the exhaust gas temperature increased with increase in load and amount of biodiesel. The highest exhaust gas temperature was observed as 463ºC for biodiesel among the three load conditions. The diesel mode exhaust gas temperature was observed as 375ºC. The CO_2 emission from the biodiesel-fuelled engine was slightly higher than diesel fuel as compared with diesel. The carbon monoxide reduction by biodiesel was 16, 14 and 14 per cent at 2, 2.5 and 3.5 kW load conditions. The NOx emissions from biodiesel was increased by 15, 18 and 19 per cent higher than that of the diesel at 2, 2.5 and 3.5 kW load conditions respectively.

Keywords : Jatropha oil, biodiesel, fuel properties, engine emissions, India

1. INTRODUCTION

India is home to over a billion people, about one-sixth of the world's population. The population continues to grow at 1.93% per annum, which is well above the global average (India, 2001). The population of India has nearly tripled in the last 50 years, from 361 million in 1951 to 1.027 billion in 2001. The country's economy has also been growing rapidly in the last decade, with real GDP growth rates remaining consistently over 5% (India, 2004). The petroleum products play on important role in our modern life. The costs of these products depend on international markets and petroleum reserves are limited to nearly 30 years. India is projected to become the third largest consumer of transportation fuel in 2020, after the USA and China, with consumption growing at an annual rate of 6.8% from 1999 to 2020. India's economy has often been unsettled by its need to import about 70% of its petroleum demand from the highly unstable and volatile world oil market (India, 2004). The acid rain, global warming and health hazards are the results of ill effects of increased polluted gases like Sox, CO and particulate matter in atmosphere. Rising petroleum prices, increasing threat to the environment from exhaust emissions and global warming have generated an intense international interest in developing alternative non-petroleum fuels for engines (Ajav and Akingbehin, 2002). In recent years, research has been directed to explore plant-based fuels and plant oils and fats as fuels (Martini and Shell, 1998). Biodiesel is described as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. It is oxygenated, essentially sulfur-free and biodegradable (Yuan *et al.,* 2004). The use of non-edible oils compared to edible oils is very significant because of the increase in demand for edible oils as food and they are too expensive as compared with diesel fuel. Among the various non-edible oil sources, *Jatropha curcas* oil has added advantages like pleasant smell, odorless and can easily mix with diesel fuel. Jatropha oil cannot be used for food or feed because of its strong purgative effect (Corner and Watanabe, 1979). The Jatropha plant having advantages namely; effectively yielding oilseeds from the 3^{rd} year onwards, rapid growth, easy propagation, life span of 40 years and suitable for tropical and subtropical countries like India (Patil *et al.,* 1991).

Henning and Kone (no date) reported activities involving the use of physic nut oil in engines in Segou, Mali during World War II. Research on this oil was first initiated during World War II to study the use of curcas oil as a liquid, renewable fuel source to substitute for diesel oil (Jones and Miller, 1992). The use of physic nut seed oil in diesel engines is reported in the literature (Mensier and Loury 1950**;** Cabral 1964; Takeda 1982; Ishil and Takeuchi 1987; Forson *et al.* 2004; Pramanik 2003; Senthil Kumar *et al.* 2003). Mori (1983) using refined *curcas* oil blends in precombustion chamber engine, and reported fair results for thermal efficiency and emission compared with diesel No.2 diesel. He also pointed out the problems of filter blockage, carbon deposits and oil incompatibility with fuel line materials. Pramanik (2003) found the jatropha oil blending up to 40 to 50 per cent with diesel fuel could be used in engine without modifications. In general, it has been reported by most researchers that if raw vegetable oils are used as diesel engine fuel, engine performance decreases, CO and HC emissions increase and Nox emissions also decrease accordingly (Sinha and Misra, 1997; Goering, *et al*., 1992; Altõn, 1998 and Shay 1993). However, Acrolein is high toxic substance released from the engine due to thermal decomposition of glycerol present in the oils (Schwab *et al.*, 1987). The problems encountered in raw oils are solved by forming biodiesel, which is non toxic, eco-friendly fuel, and have similar properties of diesel fuel (Krawczyk, 1996). Biodiesel consists of Fatty Acid Methyl Esters (FAMEs) of seed oils and fats and have already been found suitable for use as fuel in diesel engine (Harrington, 1986). CO_2 emission by use of biodiesel in diesel engines will be recycled by the crop plant resulting in no new addition in to atmosphere (Peterson and Hustrulid, 1998). It is estimated that petrodiesel demand in India by the end of 10^{th} Plan (in 2006-07) shall be 52.33 million MT. In order to achieve 5% replacement of petrodiesel by bio-diesel by the year 2006-07, there is need to bring minimum 2.29 million ha area under *Jatropha curcas* plantation (India, 2004). A study was taken for performance evaluation and and assesses the emissions from jatropha biodiesel fuelled engine.

2. MATERIALS AND METHODS

2.1. Pilot Biodiesel Plant

A pilot biodiesel plant was developed at Tamil Nadu Agricultural University, Coimbatore, for biodiesel production from the different oils (Figure 1). The process developed and used in the biodiesel plant was alkaline catalyst based biodiesel production. The biodiesel production capacity of the plant is 250 litres per day and the reaction time per batch is 2 hours. The pilot plant consists of biodiesel reactor with heating and agitating device, chemical mixing tank, glycerol settling tanks and washing tank.

2.2. Fuel Description

Jatropha oil was collected from a private firm Rural Community Action Centre, Erode and filtered for solid impurities. The curcas oil was transesterified using methanol in the presence of sodium hydroxide in the pilot biodiesel plant. Free Fatty Acid of jatropha oil used in the pilot biodiesel plant was less than 5 per cent. The molar ratio and sodium hydroxide amount used for biodiesel production were 1:6 and 0.8 (w/w), respectively. The fuel properties of jatropha biodiesel and its blends and diesel fuel are shown in Table 1. ASTM standard procedures were adopted in this analysis.

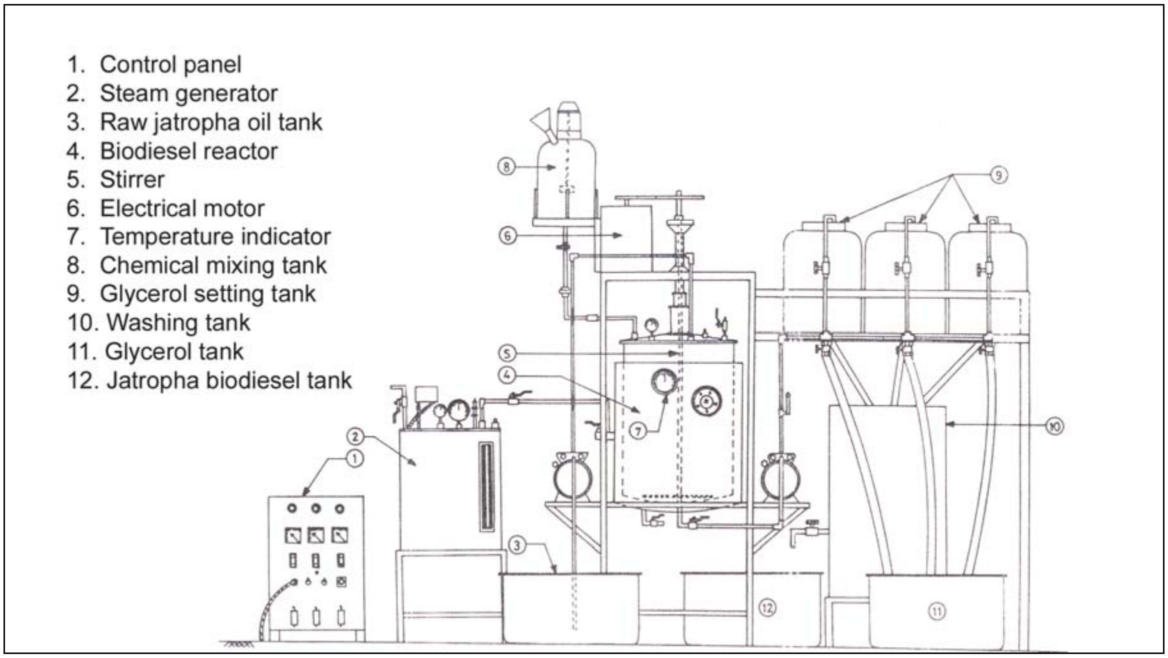

Figure. 1. Pilot biodiesel plant

2.3. Methodology Adopted for Engine Testing

2.3.1. Engine and Equipment Details

The engine testing setup consists of diesel engine coupled with AC alternator, fin type air heaters for electrical load. The diesel engine without any modifications was used for this study. The four levels of jatropha biodiesel blending at 20, 40, 60 and 80 per cent (B_{20}, B_{40}, B_{60} and B_{80}) with diesel, diesel and biodiesel were used for engine testing. The diesel generator set was tested at different loads by varying the electrical load. The engine speed was measured by a tachometer. A KM900 exhaust gas analyzer was used to determine the compositions of exhaust emission gases. The exhaust gas analyzer had sensors for NOx, SOx and CO to detect the exhaust gas compositions. The ambient and exhaust gas temperatures were also recorded by using KM900 exhaust gas analyzer attached with a k type thermocouple. The exhaust gas and ambient temperatures, CO, CO_2, NOx and O_2 were recorded by using this analyzer and all data were stored. The fin air heater consists of electrical heating heater capacity of 2000 W (1 no.), 1000 W (1no.) and 500 W (2 nos.). Technical specifications of the diesel engine ac alternator used for this study is given below.

The technical specification of diesel engine is given below.

Manufacturer	:	Kirloskar engines Ltd, Pune, India
No of cylinders	:	One
No. of strokes	:	Four
Capacity	:	5.2 kW
BHP of engine	:	7
Speed	:	1500 rpm
Mode of injection	:	DI
Type	:	AV1
Cooling system	:	Water

The technical specification of AC alternator is as follows.

Manufacturer	:	Kirlosker Electric Co Ltd., Bangalore, India
Volts	:	240
Amphere	:	14.6
Speed	:	1500 rpm
Phase	:	single
Cycle	:	50 Hz
KVA	:	3.5
Pf	:	1

2.3.2. Engine Testing

The engine was tested with three electrical load levels *viz*., 2, 2.5 and 3.5 kW. The engine was started with diesel and changed over to the desired biodiesel blend. Specific fuel consumption with the tested fuels was calculated as per I.S.I procedures (I.S.I., 1980).

3. RESULTS AND DISCUSSION

3.1. Biodiesel Production

A pilot biodiesel plant was used to produce biodiesel from jatropha oil for reducing viscosity of raw oil through transesterification process. The free fatty acid content of jatropha used for this study was 3 per cent. Fifty litres of jatropha oil was fed into the reactor by using a feed pump and a reaction temperature of $60^{o}C$ was maintained by supplying the steam around the reactor from the steam generator. The chemical tank was used to prepare the sodium methoxide by mixing of sodium hydroxide with methanol and supplied to the reactor. The speed of mechanical stirrer was fixed at 520 rpm for this transesterification process and stopped after 2 hours. The reactants mixtures (biodiesel and glycerol) were fed into glycerol settling tank by using outlet feed pump. The reactants mixtures were allowed to settle, so that glycerol will settle at the bottom of the tank by gravity. The jatropha oil methyl ester was sent to washing tank to get the pure biodiesel. The fuel properties of the jatropha biodiesel and its blends are furnished in the table 1.

Table 1. Fuel properties of jatropha biodiesel and its blends

S. No.	Properties	Diesel	Jatropha biodiesel				
			B_{20}	B_{40}	B_{60}	B_{80}	B_{100}
1	Specific gravity	0.8396	0.8437	0.8482	0.8530	0.8576	0.8621
2	Kinematic viscosity at 40ºC, cSt	4.86	4.96	5.03	5.14	5.26	5.37
3	Calorific value, MJ/kg	44.42	43.25	42.072	41.139	40.174	39.174
4	Flash point, ºC	51	55	76	98	109	174
5	Carbon residue, %	0.21	0.21	0.22	0.22	0.24	0.24

In jatropha biodiesel blended fuels increase in amount of diesel fuel showed no effect on specific gravity of fuels. The kinematic viscosity of jatropha biodiesel blended fuels increased with increase in amount of biodiesel level. The viscosity of B_{20} biodiesel blended fuel was 4.96 cSt which was almost closer to desirable viscosity of diesel fuel (4.86 cSt). The calorific value of blended fuels was improved by addition of diesel fuel in the biodiesel blends. The heating value was increased with decease in biodiesel amount and it ranged from obtained for B_{80} to B_{20} fuel. The blended fuels had effect in reducing the flash point of the jatropha oil blended fuels, which indicated the improvement in the volatile nature of the fuels. The flash point of blended fuels was increased with increase in amount of biodiesel in the fuels. Similar trend was observed for carbon residue of blended fuels. The fuel properties of jatropha biodiesel blended fuels met the diesel fuel and biodiesel standards.

3.2. Engine Performance

3.2.1. Fuel Consumption

The fuel consumption of engine was increased with increase in amount of biodiesel blends is shown in Figure. 2. In the case of jatropha biodiesel alone, the fuel consumption was about 14 per cent higher than that of diesel. This may be due to higher specific gravity and lower calorific value of the biodiesel fuel as compared with diesel fuel. The calorific value of the jatropha biodiesel was about 12 per cent lower than that of diesel fuel. The percent increase in fuel consumption of biodiesel blends (B_{20} to B_{80}) ranged from 2 to 13 per cent than diesel fuel due to increase in calorific value of these fuels.

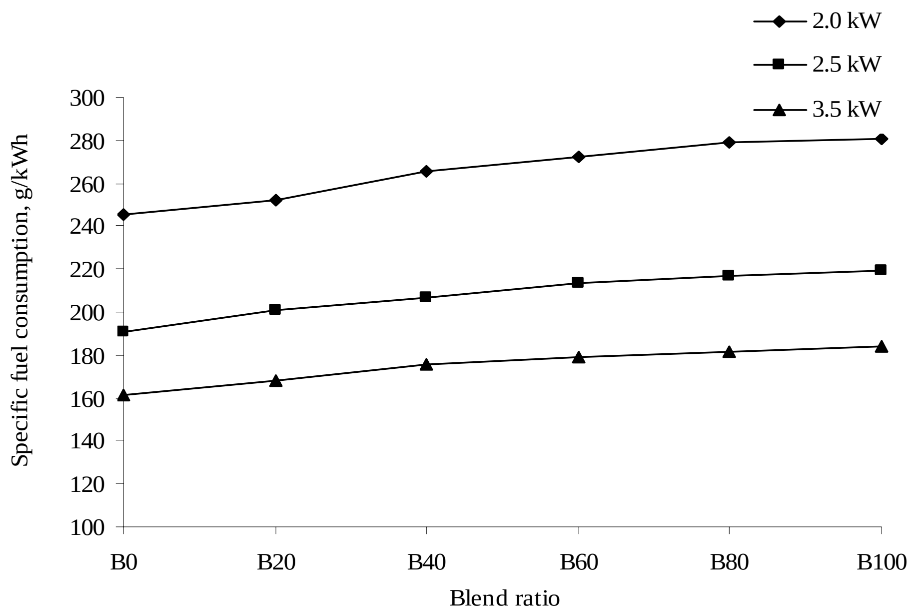

Figure. 2. Fuel consumption for biodiesel blended fuels

3.2.2. Power Output of the Engine

The power output of the engine was calculated from the electrical output of alternator. The power output of the engine on jatropha biodiesel blends at different loads is depicted in the table 2. At 2 kW load, power output of the engine in diesel mode was 2.03 kW, whereas it was 2.05 kW for biodiesel alone. The jatropha biodiesel performed similar to that of diesel fuel in diesel engine. The power output of the engine varied from 2.02 to 2.05 kW for jatropha diesel blended fuels. The power output of the engine operated with diesel fuel at 2.5 kW load condition was 2.53 kW, whereas it was 2.56 kW for biodiesel alone. The power output of the engine with jatropha biodiesel was similar to diesel fuel; but the consumption of the jatropha biodiesel was higher because of the calorific value of the jatropha biodiesel was 11 per cent lower that diesel. At this load condition power output of the engine for blended fuels ranged from 2.51 to 2.57 kW. In case of 3.5 kW load condition, the power output of the engine with biodiesel fuel mode was recorded as 3.58 kW, whereas it was 3.55 kW for diesel fuel mode. The power output of the engine varied from 3.55 to 3.57 kW for jatropha biodiesel blends. In general it can be concluded that there was no difference between jatropha biodiesel and it blends and diesel.

3.2.3. Specific Fuel Consumption

The specific fuel consumption was calculated by fuel consumption divided by the rated power output of the engine. The percent increase in specific fuel consumption ranged from 3 to 14 for B_{20} to B_{100} fuels. The range of increase in fuel consumption was found to be similar under all load conditions. The percent increase in specific fuel consumption was increased with decreased amount of diesel fuel in the blended fuels. This may due to lower heating value of the fuels and higher mass of fuel flow to meet the engine loads.

3.2.4. Brake Thermal Efficiency

According to Canakci and Van Gerpan, (2001) brake thermal efficiency is defined as actual brake work per cycle divided by the amount of fuel chemical energy as indicated by lower heating value of fuel. The brake thermal efficiency with biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions. It varied from 28.6 to 33.0 per cent for diesel fuel alone. There was no difference between the biodiesel and its blended fuels on efficiencies. The brake thermal efficiencies of engine, operating with biodiesel mode were 28.8, 30.6 and 33.1 per cent at 2, 2.5 and 3.5 kW load conditions respectively.

3.2.5. Exhaust Gas Temperature

The exhaust gas temperature gives an indication the amount of waste heat going with exhaust gases. The exhaust gas temperature of the different biodiesel blends is shown in Figure. 3. The exhaust gas temperature of blended fuels and biodiesel at 3.5 kW load condition was 19 per cent higher than that of 2 to 2.5 kW load conditions. The highest exhaust gas temperature was observed as 463ºC for biodiesel among three load conditions. The raise in exhaust gas temperature of 3.5 kW load followed similar trend for blended fuels. The diesel fuel mode exhaust gas temperature was observed as 375ºC.

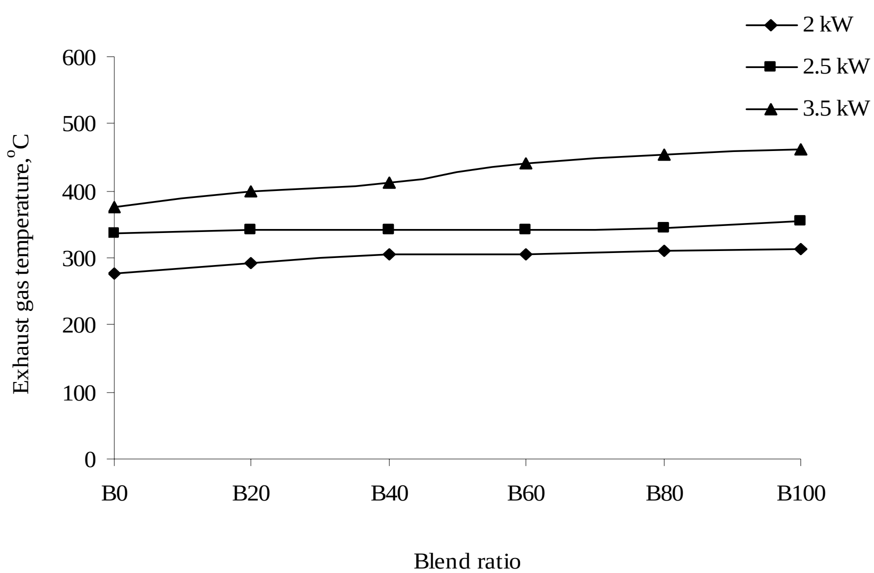

Figure. 3. Variation of exhaust gas temperature in diesel engine fuelled with different blended fuels

The exhaust gas temperature increased with increase in load and amount of blended biodiesel in the fuel. The exhaust gas temperature reflects on the status of combustion inside the combustion chamber (Nichaus *et al.,* 1986). The exhaust gas temperature increased with increase in load and amount of biodiesel blends. The reason for raise in the exhaust gas temperature may be due to ignition delay and increased quantity of fuel injected. The exhaust gas temperature can be reduced by adjusting the injection timing/injection pressure in to the diesel engine

3.3. Emission profile

3.3.1. Carbon Dioxide (CO_2) Emission

The carbon dioxide emission from the diesel engine with different blends is shown in Figure. 4. The CO_2 increased with increase in load conditions for diesel and for biodiesel blended fuels. The jatropha biodiesel followed the same trend of CO_2 emission, which was higher than in case of diesel. The CO_2 in the exhaust gas was same for jatropha biodiesel blended fuels and jatropha biodiesel.

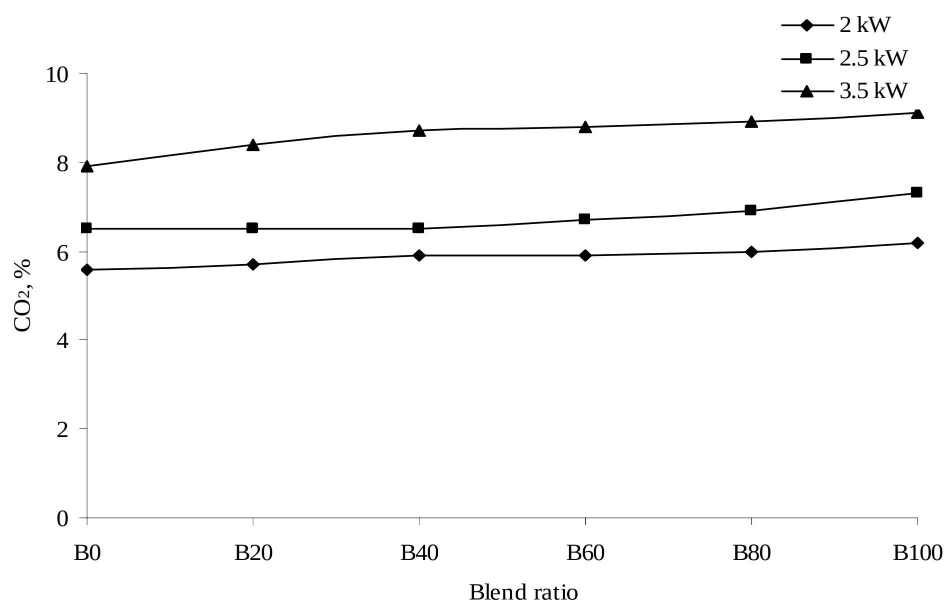

Figure. 4. CO_2 emission from diesel engine with different blended fuels

3.3.2. Carbon Monoxide (CO) Emission

The CO emission from the diesel fuel with biodiesel blended fuels and biodiesel is shown in Figure. 5. The CO reduction by biodiesel was 16, 14 and 14 per cent at 2, 2.5 and 3.5 kW load conditions. With diesel fuel mode the lowest CO was recorded as 520 ppm at 2 kW load and as load increased to 3.5 kW, CO also increased to 898 ppm. Similar results were obtained for biodiesel blended fuels and jatropha biodiesel with lower emission than diesel fuel. The amount of CO emission was lower in case of biodiesel blended fuels and biodiesel than diesel because of the fact that biodiesel contained 11 per cent oxygen molecules. This may lead to complete combustion and reduction of CO emission in biodiesel fuelled engine.

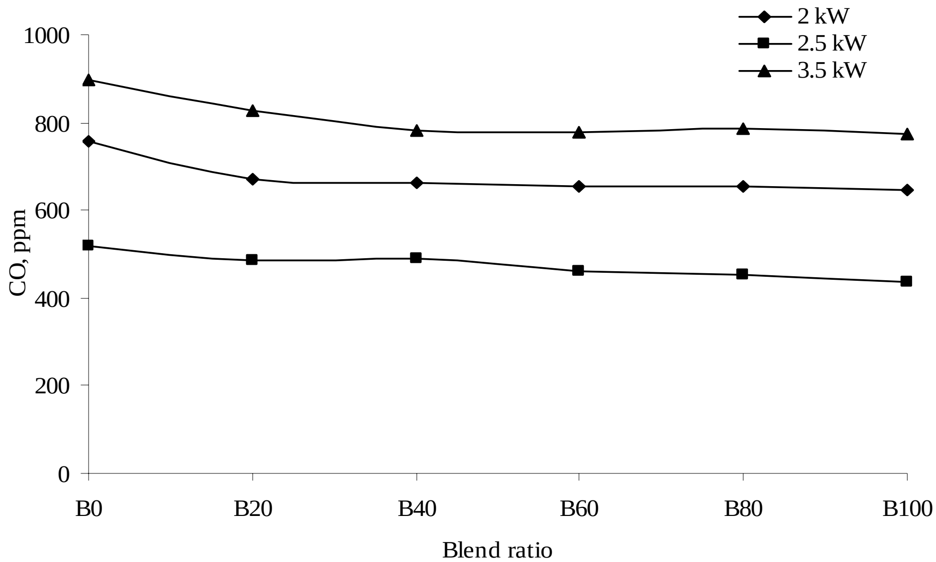

Figure. 5. CO emission from diesel engine with different blended fuels

3.3.3. NOx Emission

The NOx emission from engine with different jatropha biodiesel blended fuels and biodiesel is shown in Figure. 6. The NOx emission increased for biodiesel by 15, 18 and 19 per cent higher than diesel fuel at 2, 2.5 and 3.5 kW load conditions. The percentage of increase in NOx concentration for blended biodiesel fuels were observed as 6.6 to 19 per cent when compared with diesel fuel. The NOx emission increased with increase in biodiesel amount in the blended fuels and also found that NOx emission from the biodiesel fuel was higher than that of diesel. Probable reasons for increase in NOx concentration by about 2 to 10 per cent from biodiesel fuelled engine was due to higher oxygen level in the fuel and type of engine (Anon.,1993). Forgiel and Varde (1981) observed that the NOx concentration depended on the size of orifice. They reported that the NOx increased when the size orifice was reduced. Heywood (1988) reported that the NOx formation depended on combustion temperature and availability of oxygen. Fosseen and Goetz (1993) reported that the NOx concentration can be reduced by advancing the beginning of injection time by 0-3^{o}. However, the increase in NOx concentration is the main problem in biodiesel and it can be reduced by making suitable change in the engine parameters.

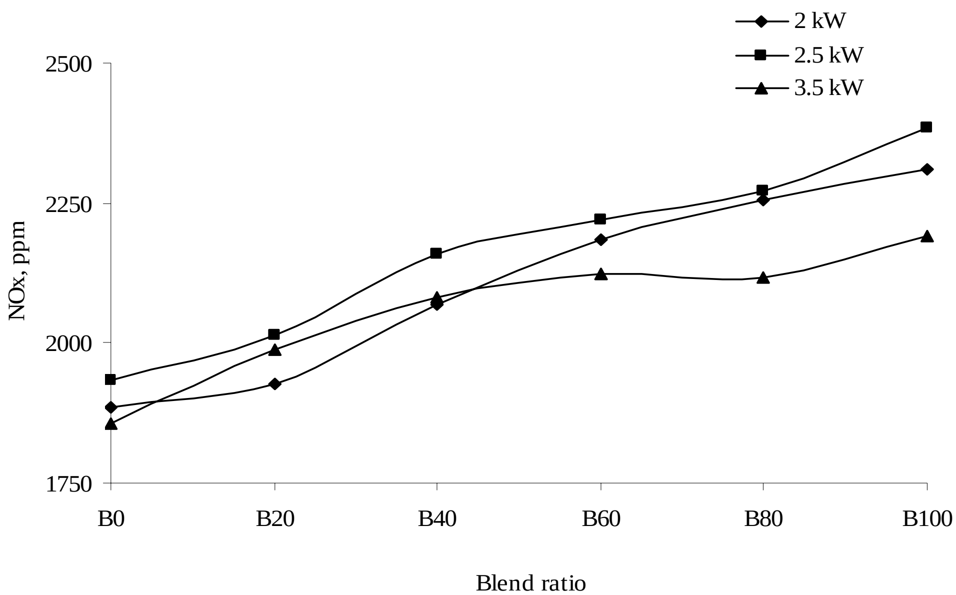

Figure. 6. NOx emission from diesel engine with different blended fuels

4. CONCLUSIONS

A 5.2 kW diesel engine with alternator was used to test *Jatropha curcas* biodiesel and its blends and compared with conventional commercial diesel fuel. A biodiesel pilot plant was developed and used for biodiesel production from jatropha oil. The fuel properties of jatropha biodiesel were found to be similar to the diesel fuel. In the case of jatropha biodiesel alone, the fuel consumption was about 14 per cent higher than that of diesel. The per cent increase in specific fuel consumption ranged from 3 to 14 for B_{20} to B_{100} fuels. The brake thermal efficiency for biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions and there was no difference between the biodiesel and its blended fuel efficiencies. For jatropha biodiesel and its blended fuels, the exhaust gas temperature increased with increase in load and amount of biodiesel. The carbon monoxide reduction by biodiesel was 16, 14 and 14 per cent respectively at 2, 2.5 and 3.5 kW load conditions. The NOx emission from biodiesel was increased by 15, 18 and 19 per cent higher than that of the diesel fuel at 2, 2.5 and 3.5 kW load conditions respectively.

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