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EFFECT OF PREHEATED JATROPHA OIL AND JATROPHA OIL METHYL ESTER WITH PRODUCER GAS ON DIESEL ENGINE PERFORMANCE

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ABSTRACT

The present experimental study demonstrates the performance and emission characteristics of a single cylinder dual fuel diesel engine with producer gas as the primary fuel and diesel, preheated Jatropha oil and Jatropha oil methyl ester as injected fuels. In order to reduce the viscosity of Jatropha oil, a shell and tube type heat exchanger was designed and fabricated for preheating Jatropha oil using engine exhaust gas. The performance parameters, such as brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature, have shown improved results with baseline diesel and producer gas, whereas the above parameters are very close to other test fuels under different loading conditions. All the emission parameters are found to be on the higher side for preheated oil- compared to diesel-producer gas dual fuel operation at all load conditions. With Jatropha oil methyl ester-producer gas dual fuel operation, however, emission parameters such as CO_2, smoke and NOx are higher compared to diesel-producer gas operation. The smoke emission for preheated Jatropha oil-producer gas dual fuel operation is approximately 60% higher than that of diesel-producer gas operation at full load. From the present experimental investigation it may be concluded that alternative fuel combinations such as preheated Jatropha oil-producer gas and Jatropha oil methyl ester-producer gas can successfully replace diesel as the major fuel in diesel engines with little modification. The present paper also recommends further investigation to improve fuel properties and in-cylinder combustion phenomena of preheated Jatropha oil and its methyl ester before use in a diesel engine.

Keywords: Dual fuel, diesel engine, producer gas, performance, emission.

INTRODUCTION

Due to the high brake thermal efficiency of diesel engines compared to gasoline engines they have become more popular in the transportation and agriculture sector. As a result of the rapid depletion, rising price, uncertainties over the supply of petroleum fuels and the need to clean up the environment, an intensive research for alternative fuels has been triggered (Azad, Ameer Uddin, & Alam, 2012; Edwin, Nagarajan, & Nagalingam, 2008; Ghobadian, Najafi, & Nayebi, 2013; Mat Yasin, Mamat, Sharma, & Yusop, 2012; Rahim, Mamat, Taib, & Abdullah, 2012; Senthil Kumar, Ramesh, & Nagalingam, 2003a; Soon, Rus, Anika, & Hasan, 2013). A lot of research is conducted into renewable fuels which are clean burning, and are being investigated as alternative fuels (Aziz Hairuddin, Wandel, & Yusaf, 2013; Sundar Raj & Sendilvelan, 2010; Yusaf, Hamawand, Baker, & Najafi, 2013). Alcohols, vegetable oil and its derivatives, gaseous fuel such as hydrogen, compressed natural gas (CNG), liquid petroleum gas (LPG) and producer gas are used as good alternative fuels for internal combustion (IC) engines in dual fuel mode (Azad et al., 2012; Lata & Misra, 2010; Senthil Kumar, Ramesh, & Nagalingam, 2003b). The physical-chemical properties of vegetable oil are comparable with diesel and can be used to run a diesel engine without any modification (Senthil Kumar et al., 2003a). Due to higher viscosity and lower volatility the nature of vegetable oil causes engine problems such as mixture formation, atomization and spray penetration, resulting in low brake thermal efficiency, increased smoke and gummy deposits on engine components (Kalam & Masjuki, 2004; Ramadhas, Jayaraj, & Muraleedharan, 2008). The fuel preheating technique offers the advantage of using heavy fuels in normal diesel engines without any modification. Past investigations have showed that preheated vegetable oils in diesel engines resulted in improved brake thermal efficiency, reduced smoke and particulate emissions (Bari, Lim, & Yu, 2002). Dual fuel operation in diesel engines over single mode operation results in lower smoke emissions with improved thermal efficiency. A conventional diesel engine can be easily be modified to dual fuel mode. In a dual fuel engine, a gaseous fuel is inducted as the primary fuel and ignited by diesel/neat vegetable oil/bio-diesel as the pilot fuel (Nwafor, 2000). Jatropha curcas is very popular among the rural population of India due to its many uses. This plant can grow in the western part of India and consumes less water. Depending upon its cultivation, seed collection, oil extraction, and bio-diesel production processes, this plant can generate large-scale employment (Pradeep & Sharma, 2007). Jatropha biodiesel is a sulfur free renewable fuel and still exhibits excellent lubricant properties (Sharma, 2003). It is safer than diesel oil due to its higher flash and fire point. Jatropha biodiesel possesses low calorific value and enhances nitrogen oxide (NOx) emissions due to the presence of oxygen, however, the presence of oxygen results in a lower carbon monoxide (CO) and hydrocarbon (HC) emission as result of the complete combustion of bio diesel. Higher bulk modulus is responsible for the dynamic advance of injection timing in bio diesel fuelled engines (Szybist, 2003). Bio-diesels are the mono alkyl esters of long chain fatty acids derived from renewable sources, for use in diesel engines. Bio-diesel from Jatropha oil (JO) is produced through transesterification processes in which straight vegetable oils are mixed with methanol in the presence of catalyst. Catalysts such as sodium or potassium hydroxide are generally used (Murugesan, Umarani, Subramanian, & Nedunchezhian, 2009). The objective of the transesterification process is to reduce the viscosity and density of neat vegetable oil and bring it closer to that of diesel. The bio-diesel thus obtained is engine friendly and its properties are very close to diesel fuel (Senthil Kumar, Ramesh, & Nagalingam, 2001; Sharma, 2003). Many researchers have reported that in spite of the many advantages of Jatropha oil bio-diesel (JOBD), it emits higher NOx emissions compared to diesel fuel (Chairman, 2003; Sharma, 2003) which is a serious environmental effect. The presence of oxygen in its structure, and higher bulk modulus and boiling point of JOBD are the factors responsible for aggravating the NOx emission (Sharma, 2003; Szybist, 2003).

Producer gas is a clear burning gas obtained from solid bio fuels by converting them into gaseous fuel inside a gasifier. A gasifier is a simple chemical reactor where both physical and chemical reactions take place. Producer gas can be generated from various sources such as bagasse, coir-pith, ground nut shell, saw dust, straw wood chips etc. From the literature it is revealed that according to direction of flow, gasifiers are of three types: up draft, down draft and cross draft (Ramadhas et al., 2008). The composition of producer gas obtained during gasification is measured using gas chromatography as shown in Table 1. Krishna and Ajit Kumar (1994) used coffee husk as a biomass for gasification and analyzed the performance of a diesel engine on dual fuel mode. They found that the maximum percentage diesel replacement was on 31%. Martin, Vikoria, and Gunnar (1999) analyzed the waste wood gasification process from a mill which was coupled with a combined cycle power production system. A photograph of the sample of Babul wood pieces used in the gasifier is shown in Figure 1. The laminar burning velocity of producer gas (at 0.1MPa, 300K) is about 0.5m/s as mentioned in the literature (Banapurmath & Tewari, 2009). It is a low-density energy fuel having low calorific value compared to diesel, natural gas and biogas. The knocking tendency of producer gas is low due to the presence of inert raw gas, carbon dioxide (CO_2) and nitrogen (N_2) (Banapurmath & Tewari, 2009)**.** The main objective of the present work is to test the technical feasibility of using pure Jatropha oil under preheated conditions, and its methyl ester, in combination with woody biomass producer gas in dual fuel mode in a diesel engine as a substitute for diesel fuel.

MATERIALS & METHODOLOGY

A schematic diagram of the experimental setup is shown in Figure 2. The experimental setup consists of a single cylinder 4-stroke dual fuel diesel engine coupled with generator and bulb loading devices supplied by Parkas Diesels Pvt. Ltd, Agra. A downdraft type biomass gasifier, gas cooler, and gas filter was supplied by Anker Scientific Energy Technology Pvt. Ltd. Baroda. A photograph of the experimental setup is shown in Figure 3. The detailed specifications of the engine and downdraft woody biomass gasifier are given in Tables 3 and 4 respectively. The biomass is loaded from the top of the gasifier and ash is removed at regular intervals. The partial combustion of biomass in the gasifier reactor is converted into high temperature producer gas, which enters the gas cooler. The moisture, tar and dust particles are removed through two sets of filters. At the outlet of the filter pipe a mechanical valve is provided to control the gas flow rate. For gas flow measurement, an orifice meter and a manometer is connected to a surge tank. Manometers are used to measure air and gas flow separately. The producer gas and air are mixed in the intake pipe and then the mixture enters the engine cylinder. The engine was always operated at its rated speed of 1500rpm, injection timing of 23° before top dead center (BTDC) and an injection pressure of 220 bars. Tests were carried out under different load conditions using test fuels such as baseline diesel, neat preheated Jatropha oil (PJO) and Jatropha oil methyl ester (Mohammadi, Rafiee, Emam-Djomeh, & Keyhani) with constant producer gas flow rate in dual fuel mode operation. The Jatropha oil was heated in a shell and tube heat exchanger using engine exhaust gas. In dual fuel operation, the gas flow rate was measured using an orifice meter and manometer attached to the gas surge tank. To obtain a particular gas flow rate, the head difference in the manometer tube was kept constant by rotating a mechanical control valve. For different gas flow rates, the head difference is thus varied by rotating the control valve. The injected diesel flow rate was not maintained as constant. The temperature of the combustion gas before entering the cooling system was measured with the help of a thermocouple and found to be 458 °C, and after cooling and cleaning, was found to be 37 °C.

The performance and emission were observed under different load conditions for all test fuels and compared with the baseline diesel. The AVL make a 5-gas analyzer (model

No. AVL Degas 444) and smoke meter (model no. AVL 437 C) with an accuracy of ±1%, which was used to measure exhaust gas emission parameters and smoke opacity respectively. Parameters such as CO, HC and CO_2 were measured by NDIR (non-dispersive infrared) methods and NO_X and Oxygen (O_2) were measured using electro-chemical methods.

Figure 1. Photograph of sample of wood pieces

Table 1. Composition of producer gas

Constituents	Percentage (%)	Levels	
		Low	High
Carbon monoxide	19±3	16	22
Carbon dioxide	10±3	7	13
Hydrogen	18±2	16	20
Nitrogen	50	-	50
Methane	Up to 3	-	3

Table 2. Properties of producer gas

Parameters	Values
Calorific value ratio	1000 Kcal/ NM^3
Stoichiometric air/fuel	1.16:1
Adiabatic flame temperature	1546±25K (Banapurmath et al., 2009)
Laminar burning velocity	0.5±0.05 m/s (Banapurmath et al., 2009)
Density	1.281 Kg/m^3 (Banapurmath et al., 2009)
Octane number	100-105

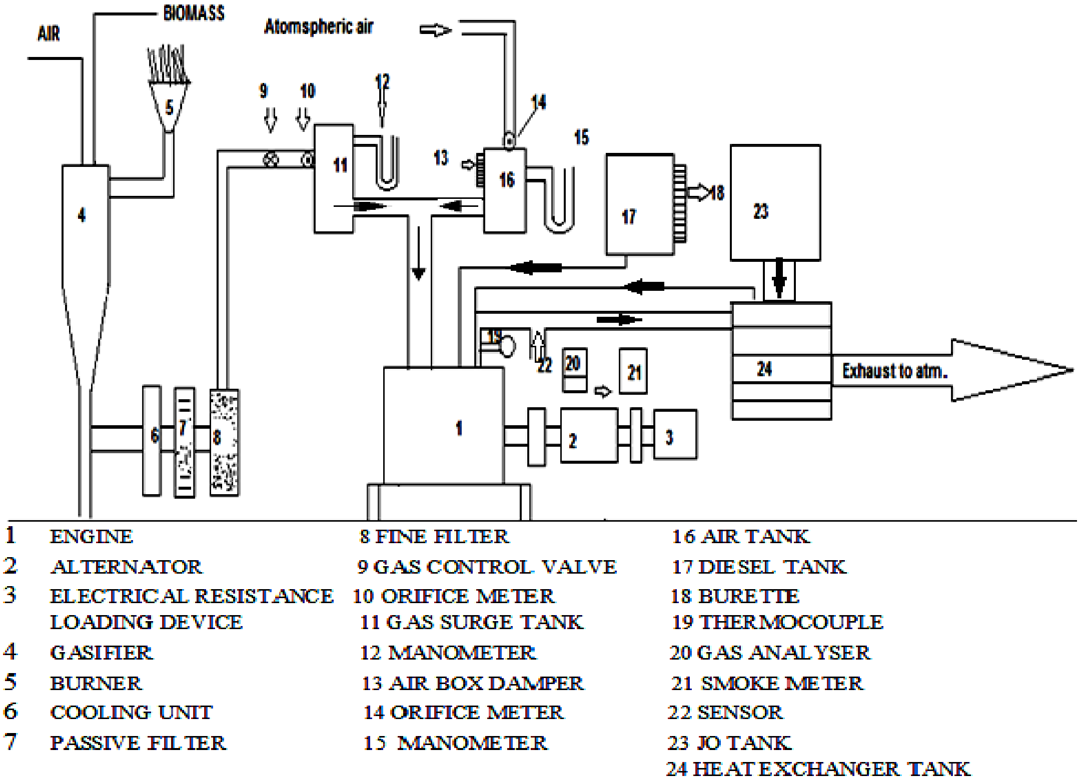

Figure 2. Schematic diagram of the test engine setup

Figure 3. Photograph of the test engine setup with gasifier

Table 3. Properties of JO, JOME and diesel.

Property	Diesel	Jatropha oil	JOME
Density (kg/m^3)	830	981	880
Kinematic viscosity at 40^o C (cSt)	2.5	37	5.65
Calorific value(KJ/Kg)	42,500	37,500	38,450
Cetane No.	48	45	50
Cloud point (^{o}C)	-12	9	-
Flash point (^{o}C)	70	239	171
Pour point (^{o}C)	-17	4	-

Table 4. Variation in viscosity of PJO with temperature.

Temperature (^{o}C)	Kinematic Viscosity of PJO (cSt)
40	37.0
60	25.1
80	17.5
100	10.25
120	8.2
140	6.85

Table 5. Test engine specification

Parameters	Specification
Machine supplier	Ankur Scientific Energy Technologies Pvt. Ltd. Vadodara – 390 024, India
Type	“Prakash” make,7.5 KVA Diesel generating set
No. of cylinders	One
No. of strokes	4-Stroke
Rated power	7.5 kW
Bore	80 (mm)
Stroke length	110 (mm)
Compression ratio	17.5:1
Rated speed	1500 (rpm)

Table 6. Specification of the gasifier used.

Parameter	Specification
Model	WBG – 10 in Scrubbed, Clean Gas Mode
Rated Gas Flow	25 (Nm^3/hr)
Gasifier type	Downdraft
Gasification temperature	1050 – 1100 (^{o}C)
Fuel Storage Capacity	100 (Kg).
Rated hourly consumption	8 – 9 (Kg).
Fuel type and size	Wood/woody waste with maximum dimension not exceeding 25 mm in diameter and length
Typical conversion efficiency	>75%
Permissible moisture content in biomass	Less than 20% (wet basis)

RESULTS AND DISCUSSION

Engine Performance Characteristics

Figure 4 shows the variation in brake thermal efficiency (BTE) with engine load for diesel–Producer gas, PJO–Producer gas and JOME–Producer gas dual fuel operation. Continuous improvement in BTE with increase in load was observed for all dual fuel combinations. This was because with an increase in load, the cylinder charge temperature increases, which promotes better combustion and leads to an increase in BTE. Again, the brake thermal efficiency of PJO-Producer gas operations were found to be lower than JOME–Producer gas and diesel–Producer gas operation. This is attributed to the lower calorific value, higher viscosity and energy consumption of PJO compared to JOME and diesel. A similar result was obtained by Chauhan, Naveen, and Cho (2012). It was also found that at higher engine loads, i.e. above 60%, the increase in BTE for all dual fuel combinations gradually reduces. This is because at 60% above load, due to fuel richness and incomplete combustion, BTE reduces gradually (Chauhan et al., 2012).

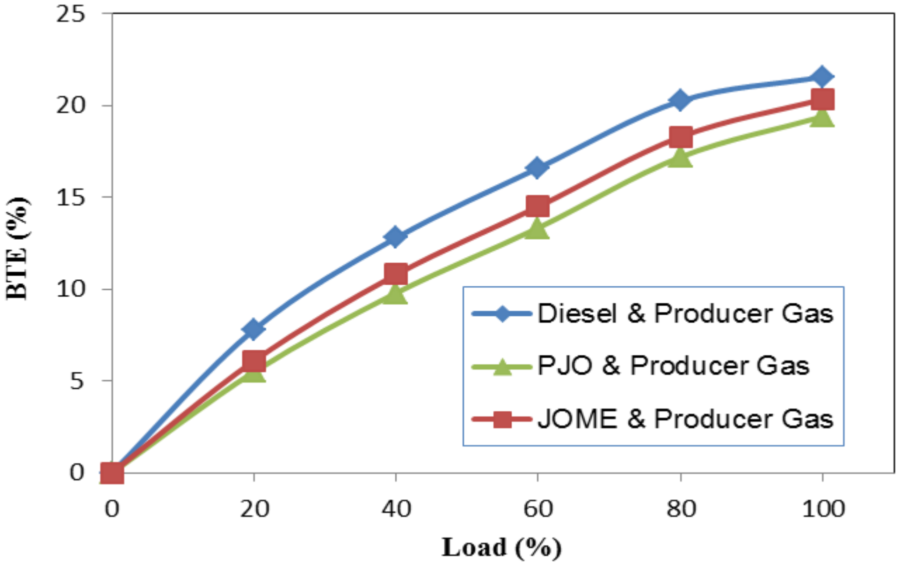

Figure 4.Variation in BTE with Load

The variation in brake specific energy consumption (BSEC) for various engine loads for all test fuels is shown in Figure 5. It can be seen that the BSEC for all test conditions gradually decreases with an increase in load because of improved combustion rates at higher load. The decrease in BSEC is also lower at higher loads for all dual fuel operations. A possible reason is that it is due to better combustion as a result of higher charge temperature at higher load (Chauhan, Naveen, Jun, & Lee, 2010). It is noted that the highest value of BSEC was obtained with PJO-Producer gas operation compared to JOME-Producer gas and diesel-Producer gas operation. This was due to the higher density, lower heating value and poor atomization of PJO compared to JOME and diesel oil (Chauhan et al., 2012; Chauhan et al., 2010).

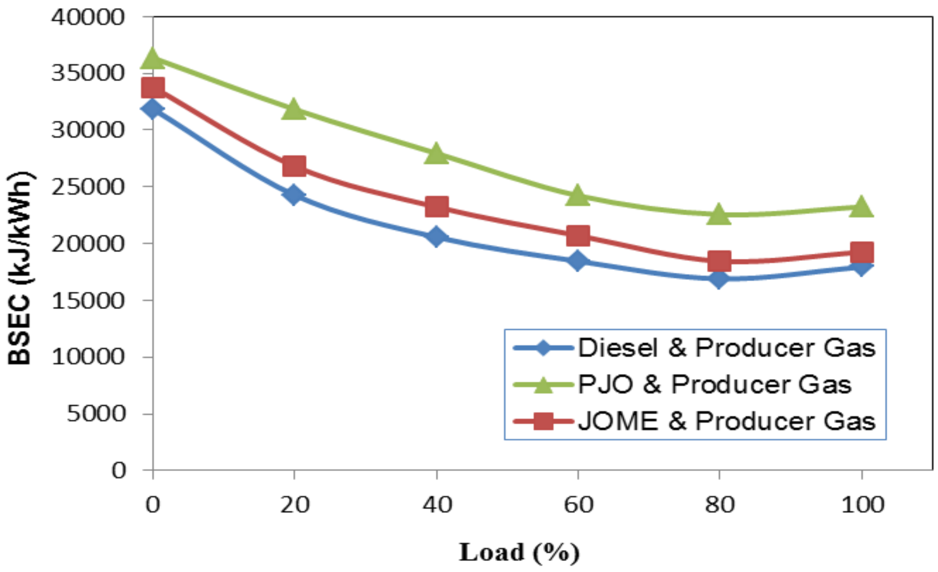

Figure 5. Variation in BSEC with Load

Figure 6 shows the variation in exhaust gas temperature (EGT) with different engine loads for the above three test fuels. It was found that the EGT linearly increases with an increase in engine load for all test conditions. This is due to the fact that at higher engine loads, higher energy is supplied to the engine and the combustion rate is higher, which results in higher EGT (Pattanaik, Nayak, & Nanda, 2013). The highest value of EGT is obtained with JOME-Producer gas dual fuel operation compared to PJO-Producer and diesel-Producer gas for the range of engine loads. This may be due to the greater availability of oxygen in JOME and PJO molecular structure compared to diesel, which enhances the combustion temperature resulting higher EGT, or may be due to the higher viscosity of JOME and PJO, meaning more energy is released after the combustion phase resulting in higher EGT (Chauhan et al., 2012).

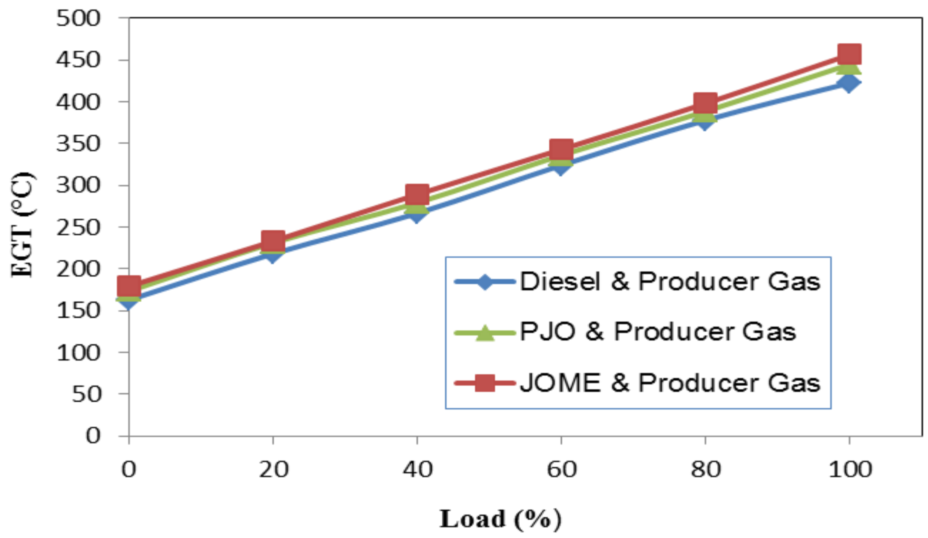

Figure 6. Variation in EGT with load

Engine Emission Characteristics

Figure 7 depicts the variation in HC emissions with engine load for the above mentioned dual fuel engine operations. The results obtained indicate that the HC emission increases with increase in engine load for all three test conditions. This is because at higher engine loads the availability of more fuel in the combustion chamber increases the possibility of incomplete combustion (Chauhan et al., 2012). The HC emissions were found to be highest in the case of PJO-Producer operation due to incomplete combustion as a result of higher viscosity and poor atomization of PJO compared to diesel and JOME. Again the minimum HC emission was found in JOME-Producer gas operation, which is due to the availability of oxygen in the JOME molecular structure which promotes better combustion and thus lowers HC emissions (Chauhan et al., 2012).

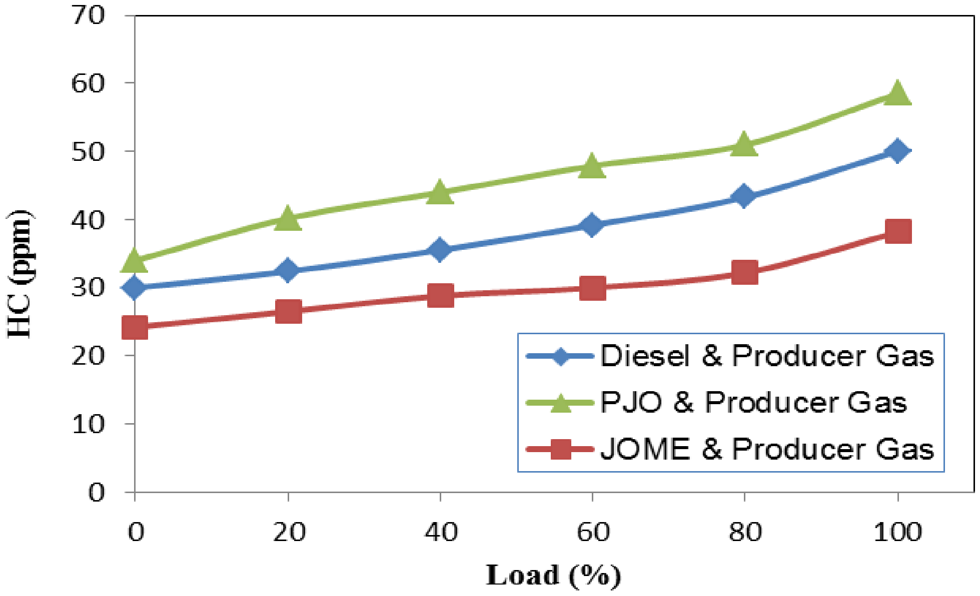

Figure 7. Variation in HC emission with load

Figure 8 shows the variation in CO emission with engine loads during dual fuel operation with three test fuels. The results obtained show that with an increase in engine load, the CO emission increases for all test conditions. This is due to the fact that with the increase in load in diesel engines, the fuel flow rate increases by decreasing the fresh air which results in incomplete combustion and thus more CO emissions (Agarwal & Rajamanoharan, 2009). The CO emission was found to be highest in PJO-Producer gas due to poor atomization and the higher viscosity of PJO compared to diesel and JOME. However, JOME-Producer gas shows lower values of CO emission compared to diesel-Producer gas and PJO-producer gas operation. This is attributed to the higher percentage of oxygen present in JOME molecular structure, which leads to better combustion and generates lower CO emissions (Chauhan et al., 2012). Figure 9 shows the variation in CO_2 emissions with engine loads for all three test conditions in dual fuel mode. It was found that the CO2 emission increases with an increase in load for all test fuels. With the increase in load, the producer gas flow rate increases, which is a mixture of CO and CO_2 resulting in more CO_2 emissions during combustion. However, the JOME-Producer gas operation produces the highest CO_2 emissions compared to the other two dual fuel combinations. This is due to the availability of more oxygen in the JOME molecular structure, the conversion from CO to CO_2 is enhanced during combustion.

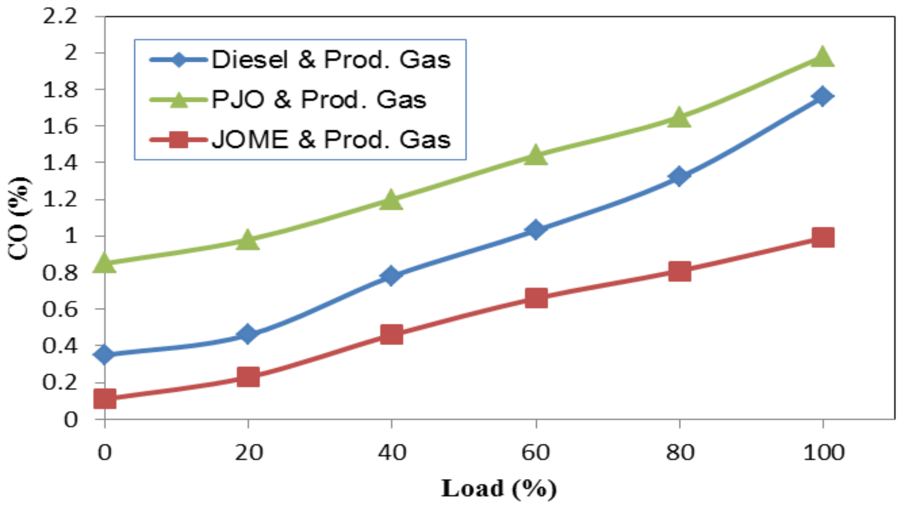

Figure 8. Variation in CO emission with load

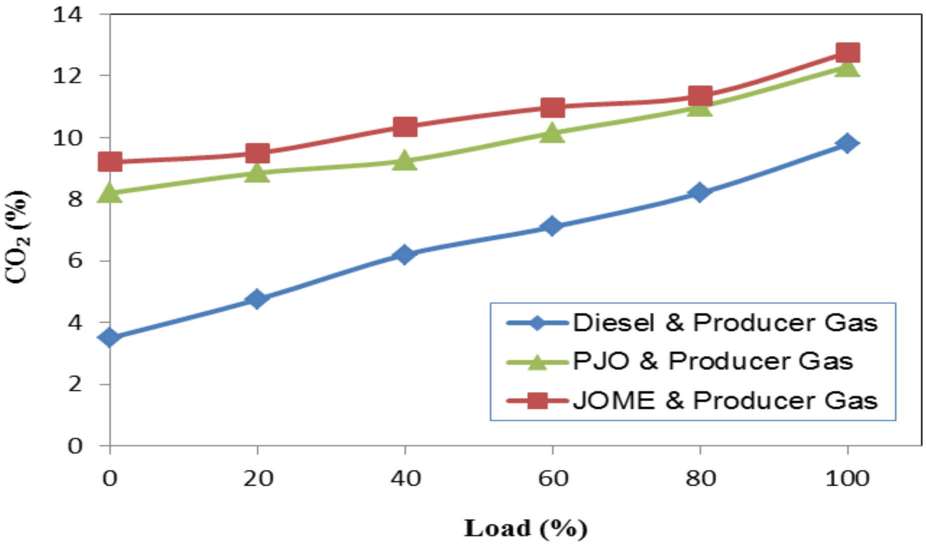

Figure 9. Variation in CO_2 emission with load

Figure 10 shows the variation in smoke emissions with engine load. It shows that with an increase in load the smoke emission increase for all test conditions. Again it is found that the combustion in PJO-Producer gas dual fuel mode produces the highest smoke emission due to the higher viscosity of PJO compared to JOME and diesel. Further, it was observed that the smoke opacity level of JOME-Producer gas is higher than that of diesel-Producer gas operation, due to the heavier molecular weight of JOME compared to diesel (Banapurmath, Yaliwal, Hosmath, & Tewari, 2012; Haiter Lenin, Ravi, Arumugham, & Thyagarajan, 2012). Figure 11 shows the variation in NOx emission with engine load while operating under all three given test fuels. The results obtained indicate an increase in NOx emissions with an increase in engine load for all test fuels. This is because with an increase in load, energy input increases and results in higher combustion temperature, and thus more NOx emissions. It was also found that the NOx emission is highest for vegetable oil (JOME and PJO)-Producer gas operation compared to conventional diesel. This is due to the fact that vegetable oil contains more oxygen. The formation of NOx emissions are basically due to two factors: higher combustion temperature and the availability of oxygen. In a comparison between JOME- Producer gas and PJO-Producer gas operation, JOME- Producer gas shows higher values of NOx emission, because a higher Cetane number and better atomization of JOME compared to PJO leads to higher combustion temperatures resulting in better combustion.

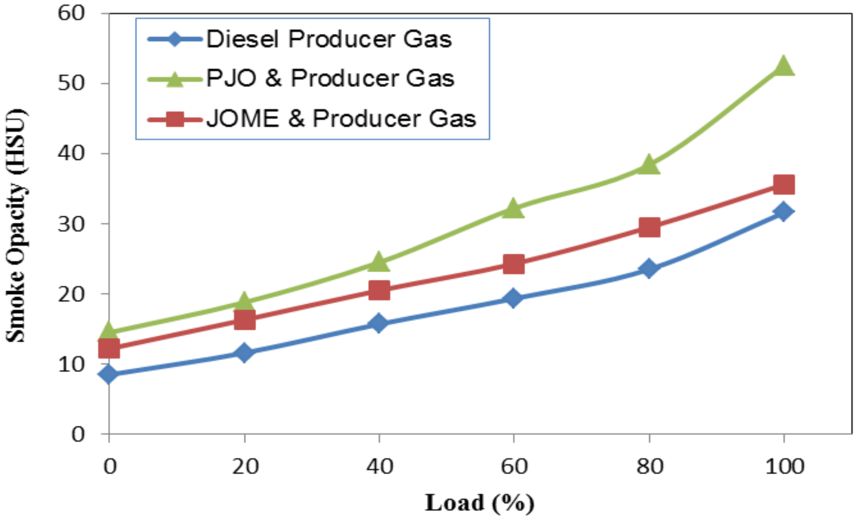

Figure 10. Variation in smoke emissions with load

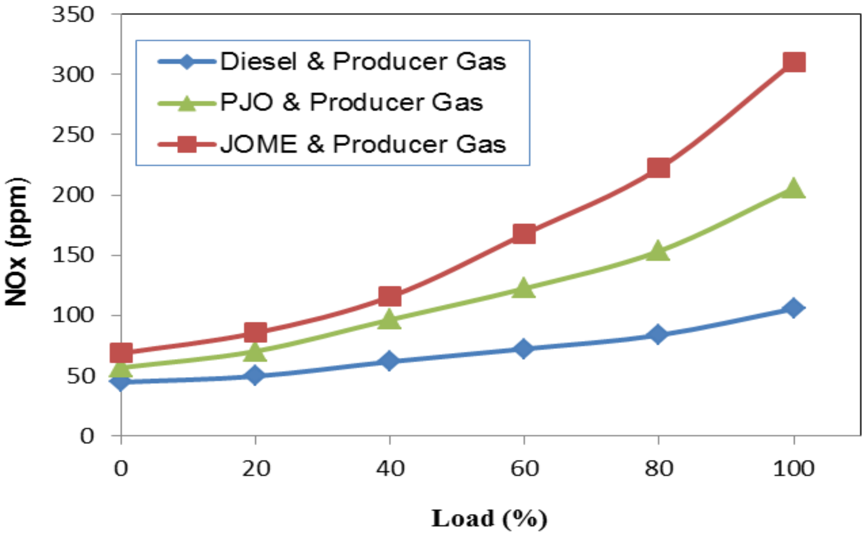

Figure 11. Variation in NOx emission with load

CONCLUSIONS

The primary objective of the present investigation was to test the effectiveness of PJO-producer gas and JOME-Producer gas in dual fuel mode operation in a single cylinder

CI engine. The secondary objective was to measure the various engine performances and emission parameters of the above combination of fuels. The following conclusions are drawn from this experimental investigation:

1. The BTE for diesel-producer gas was found to be higher than the other dual fuel operations of the engine, whereas BSEC was found to be lowest for diesel-producer gas and highest for PJO-producer gas dual fuel operation of the engine.
2. The HC, CO and smoke emissions were found to be highest for PJO-producer gas dual fuel operation and the lowest for diesel-producer gas dual fuel operation of the engine.
3. The CO_2 emission for JOME-producer gas dual fuel operation was found to be highest and lowest for diesel-producer gas operation.
4. The EGT and the NOx emissions were found to be highest for JOME-producer gas dual fuel operation. The same parameters were found to be lowest for diesel-producer gas dual fuel operation of the engine.

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NOMENCLATURE

Parameters	Description
CI	Compression Ignition
DI	Direct Injection
JOME	Jatropha oil Methyl Ester
JO	Jatropha Oil
PJO	Preheated Jatropha Oil
CNG	Compressed Natural Gas
LPG	Liquefied Petroleum Gas
JOBD	Jatropha oil Bio-diesel
ACA	Alternating Current
N_2	Nitrogen gas
HC	Hydrocarbon
CO	Carbon monoxide
CO_2	Carbon dioxide
NO_x	Nitrogen oxide
HSU	Heritage Smoke Unit
MJ/m^3	Mega Joules per Cubic meter
Kg/m^3	Kilo grams per cubic meter
KJ/kg	Kilo Joules per Kilogram
cSt	Centi Stokes
w/w	Weight by weight
rpm	Revolutions per minute
Nm^3/hr	Newton cubic meter per hour
KJ/KWhr	Kilo Joules per Kilo Watt hour
Ppm	Parts per million
NM^3	Normal cubic meters