www.serd.ait.ac.th/reric

Emission Characteristics of a Naturally Aspirated C I Engine with Biofuels and Bio-FossilFuel Mixtures

R N Singh, S P Singh and B S Pathak
Thermochemical Conversion Division
Sardar Patel Renewable Energy Research Institute
Vallabh Vidyanagar – 388 120, Gujarat
INDIA

ABSTRACT

A naturally aspirated compression ignition (CI) engine was operated successfully with muti-fuel (fossil-diesel, Karanja oil & producer gas from a wood gasifier). Emission characteristics and performance of diesel engine in fossil-diesel and mixed fuels mode (with Karanja oil and Producer gas) at different engine load conditions are presented in this paper. The emission concentration of CO_2 *and of the pollutants carbon monoxide (CO), oxide of nitrogen (NOx) and hydrocarbon (HC) were monitored. It was observed that the relative concentration of emissions depends on the engine load, fuels conditions and engine conditions. However NOx concentration decreases in mixed fuels mode compared to fossil-diesel and Karanja oil and fossil-diesel mixture. In addition to the findings on environmental aspects, the study also proved that the diesel engine could be run in mixed fuel mode (70 to 83% Producer gas, rest karanja oil and fossil- diesel at the ratio of 1: 5 and heated at 80 °C).*

1. INTRODUCTION

The continuous hike in global price of crude oil has reflected an adverse impact on the local economy of many countries, especially oil importing countries like India posing a severe burden on their foreign exchange. Apparently alternative fuels have been gaining worldwide attraction as an energy source because they are environment-friendly and renewable in nature. Moreover, they may operates well in a conventional diesel engine with very few or no modifications.

Alcohols, biogas, producer gas, plant oils (11) and their esters are the important biomass based renewable fuels, which are being experimented as alternative fuels for IC engines. Many research workers have operated IC engines on plant oils or on mixture of plant oils and fossil-diesel. Plant oils tried in diesel engines were soybean, sunflower, safflower and rapeseed (3, 4, and 12). These oils are essentially edible oil in Indian context and use of these oil as a substitute to diesel fuel may lead to a concept of self –sufficiency in plant oil production, which India has not attained yet. With the abundance of forest and tree borne non-edible oils available in India (Table 1)(10), not much attempt has been made to use of these non-edible oil as a substitute to diesel.

Literature indicates that up to 75% of the fossil -diesel could be replaced by plant oils with satisfactory engine performance (3, 4, 5, 11 and 12). Producer gas based IC engine system in duel fuel mode (70% producer gas and 30 % fossil- diesel) is one of the promising methods to reduce fossil-diesel consumption (8). In India such systems are in commercial use up to a few hundred kWe capacities.

As mentioned above, fossil-diesel is still required (25 to 30% of the specific fuel consumption) to supplement producer gas or plant oil. Replacement of fossil - diesel in producer gas - fossil-diesel mode by plant oils is expected to make the package more attractive. Hence a study was undertaken at Sardar Patel Renewable Energy Research Institute Vallabh Vidyanagar to run a diesel engine with mixed fuels such as producer gas, Karanja oil and its blend with fossil-diesel.

Table 1. Production of Non-Edible Oil Seeds and Bio-Residues in India

Species	Oil fraction (%)	Seed current estimates (10^6 tonne/y)	Oil (tonne/ha.y)
Castor	45 – 50	0.25	0.5 – 1.0
Jatropha	50 – 60	0.20	2.0 – 3.0
Mahua	35 – 40	0.20	1.0 – 4.0
Sal	10 – 12	0.20	1.0 – 2.0
Linseed	35 – 45	0.15	0.5 – 1.0
Neem	20 – 30	0.10	2.0 - 3.0
Pongamia (Karanja)	30 – 40	0.06	2.0 - 4.0
Others	10 – 50	0.50	0.5 - 2.0

Source: (10)

2. METHODS AND MATERIALS

2.1 Characteristics of Plant Oils

Characterization of fossil-diesel and Karanja oil were done as per the ASTM standards (Table 2) (1 and 9). Various characteristics studied were Kinematic viscosity, density, gross heating value, flash point, cloud point, pour point and carbon residues.

Table 2. ASTM Standards for Fossil-Diesel Fuel

Property	ASTM Method	Limits
Flash Point	D93	100 min. (°C)
Water & Sediment	D2709	0.050 max (% vol.)
Kinematics Viscosity, 40°C	D445	1.9 – 6.0 (mm^2/sec.) at 40 ^{0}C
Sulfated Ash	D874	0.020 max. (% mass)
Sulfur	D5453	0.05 max. (% mass)
Copper Strip Corrosion	D130	No.3 max.
Cetane Number	D613	46 min.
Cloud Point	D2500	Report to Customer (°C)
Carbon Residue, 100 % sample	D4530	0.050 max (% mass)
Carbon Residue, Rams bottom	D524	0.090 max. (% mass)
Acid Number	D664	0.80 max (mg KOH/gm)
Free Glycerin	D6584	0.020 max. (% mass)
Total Glycerin	D6584	0.240 max. (% mass)

Source (1,9)

2.2 Experimental Setup and Measuring Devices Used

A 20 kW Kirlosker engine as per details speciation given in table 3 was used. An electrical heated loading resistance was used for loading the engine. The fuel flow rate was measured on volumetric basic. The mixture of Karanja oil and fossil-diesel was heated in a well thermally insulated electrically heated oil tank having control panel. A microprocessor based flue gas analyzer was used for the measurement of emissions level. A gas flow rate recorder (manufactured by Star Scientific Mumbai, India) was used to measure the flow rate of producer gas. Experiments were initially carried out on the engine at four loads (14%, 35%, 42%, and 63%) using fossil-diesel and fossil-diesel and producer gas respectively to provide base data line. In addition to emissions data, parameters related to thermal performance of engine such as fuel consumption, crank oil temperature, noise level, rpm of engine, Tar and SPM in producer gas, gas composition, flue gas temperature were also measured and recorded. The calorific value of producer gas was calculated from the composition of producer gas. A sampling port was provided in the exhaust pipe for measuring flue gas temperature and to collect flue gas samples.

Table 3. Engine Details

Name and Model of engine	:	Kirloskar, KCD 2K
General Details	:	Constant speed, three cylinder, naturally aspirated, four stroke, direct injection
Bore x Stroke	:	100 x 120 mm
Compression ratio	:	17: 1
Rated output	:	23.6 kW at 1500 rpm
Fuel injection opening pressure	:	175-180 kg/cm^2
Injection timing	:	26° BTDC
Engine conditions	:	Old engine and operated around 1000 hours at duel fuel mode (Producer gas + fossil-diesel).

The producer gas was derived from wood fuel in a down draft gasifier, Figure 1. The gasifier was a choke plate type with centrally top air nozzle manufactured by M/s Cosmo Products, Raipur, India. Tar and dust contents in raw producer gas obtained from this gasifier ranged from 210 to 250 mg/N cum. The gas was further cooled and cleaned using cooling tower, organic filter and fabric filter developed at SPRERI. Cleaned gas was used to drive the diesel engine in mixed fuel mode along with fossil-diesel. The tar and particulates matter load of clean producer gas was in the range of 40 to 42 mg/N m^3.The schematic of the experimental set up is shown in Figure 1.

For conducting the experiments the engine was always started and closed with fossil-diesel fuel. After stabilization of engine (after 30 minutes of engine start up) it was changed at dual fuel mode. Experiments in mixed fuel mode were started after an hour of engine start up. The gasifier was also started during the engine start up and producer gas was flared in a flare port. Small pieces of ganda bavel wood (Juliflora) (20-30 mm dia & length) were used as feedstock for gasification. The test was conducted as per BIS Code No.13018 (1990) (2)

3. RESULT AND DISCUSSION

3.1 Characterization of Fuel

Fossil-diesel and Karanja oil were characterized for Viscosity, Flash point, Cloud point Calorific value and Carbon residues. The results obtained are given in table 4. It was found that all properties of Karanja oil is close to fossil-diesel except their high viscosity & low volatility. Karanja oil had very high viscosity and low volatility. Because of its high viscosity and low volatility it have moderately higher density, lower heating value and required higher stoichiometric fuel/air ratio. The differences contributed to the poor atomization, choking tendencies, carbon deposition and wear, which adversely affects the durability of engine (5).

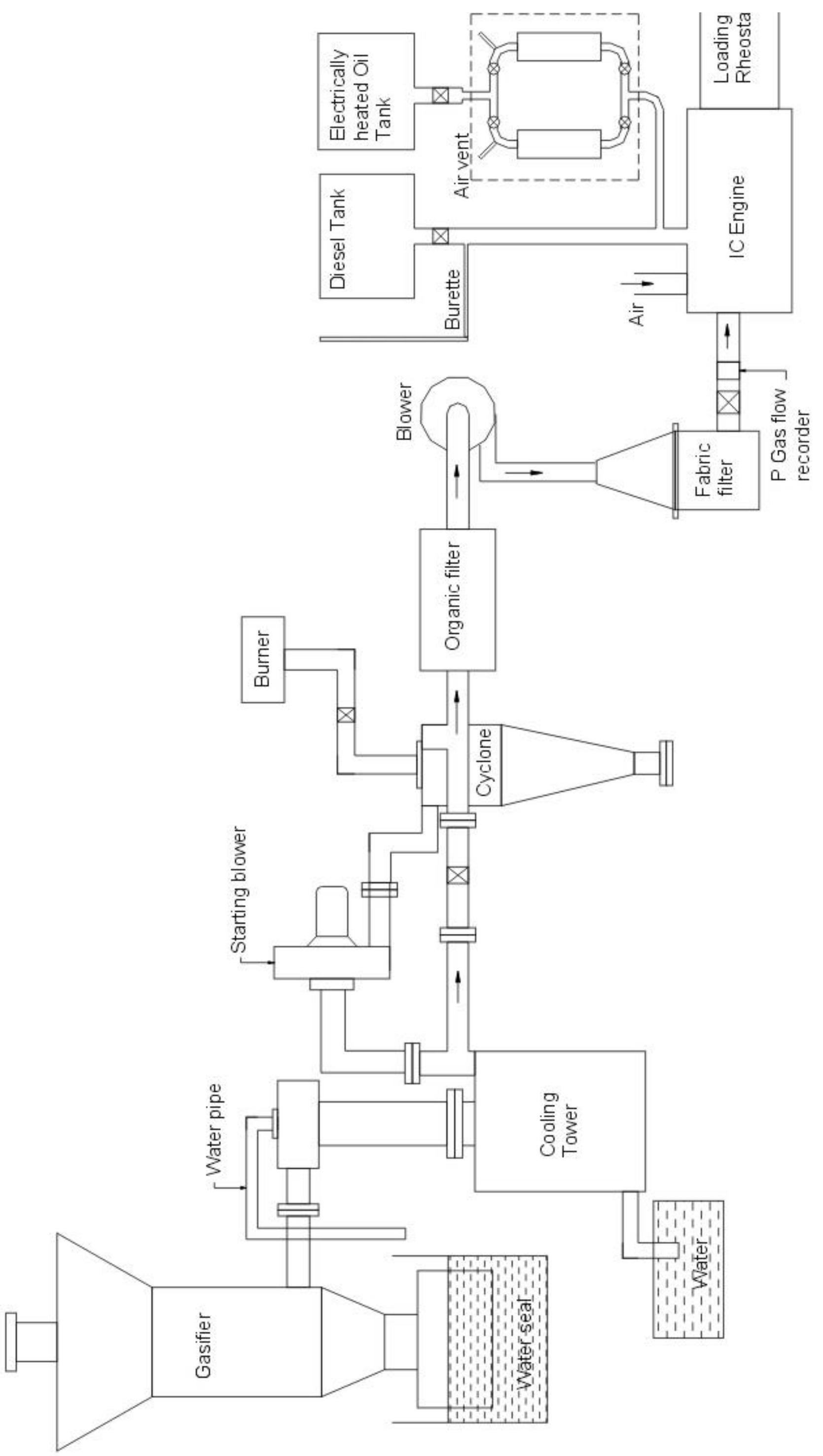

Fig. 1 Experimental Setup for I.C. Engine

Table 4. Characteristic of Fuels

Fuel Type	Viscosity at 38^0 C, cSt	Density at 38^0 C, g/cc	Flash point, ^oC	Cloud point, ^oC	Carbon residues, %	Fee fatty acid, %	Calorific value, MJ/kg	% Wax & Gum
Fossil-diesel	5.8	0.84	66	13	0.3	--	44.761	--
DDKO	47.16	0.8242	226	15	2.2	3.78	38.545	4.00

DDKO— De-waxed and de-gummed Karanja oil

3.2 Effect of Heating on Viscosity and Density of Fuel

It was observed that with increase of temperature and diesel in mixture, viscosity and density both decreased (Table 5 and 6). Other research workers also reported similar results (3, 4, 5, 12, and 13).

Table 5. Effect of Temperature on Viscosity of Dewaxwd and Degummed Blended Karanja Oil

Sr. No.	10% KO + 90 %FD		20%KO +80% FD		35%KO + 65% FD		50%KO + 50% FD		75%KO + 25% FD		90%KO + 10% FD		100%KO+ 0% FD	
	Temp. ^oC	Viscosity, cS	Temp. ^oC	Viscosity, cS	Temp. ^oC	Viscosity, cS	Temp. ^oC	Viscosity, cS	Temp. ^oC	Viscosity, cS	Temp. ^oC	Viscosity, cS	Temp. ^oC	Viscosity, cS
1	40				25	14.51	31	17.5	30	36	40	44	28	82
2	50				40	7.159	36	14	36	27.5	50	23	36	57
3	60	2.73	60	3.78	60	5.17	44	12	45	20.5	62	17	50	33.5
4	70		70		80	4.188	53	9.5	53	17.5	81	13	60	25
5	80	1.83	80	2.51			62	8.5	64	13.5	88	10.5	80	13.5
6	90						67	7.25	85	8.5	95	8.5	90	11
7	100						85	6.5	95	7.25			110	8.0

KO – Karanja Oil, FD – Fossil-diesel

Table 6. Effect of Temperature on Density of Blended Karanja Oil

Sr. No.	10% KO + 90 %FD		20%KO +80% FD		35%KO + 65% FD		50%KO + 50% FD		75%KO + 25% FD		90%KO + 10% FD		100%KO+ 0% FD	
	Temp. ^oC	Density, kg/m^3	Temp. ^oC	Density, kg/m^3	Temp. ^oC	Density, kg/m^3	Temp. ^oC	Density, kg/m^3	Temp. ^oC	Density, kg/m^3	Temp. ^oC	Density, kg/m^3	Temp. ^oC	Density, kg/m^3
1	40		40		25	846.02	31	823.99	30		40		28	911.48
2	50		50		40	834.68	36		36	855.4	50	826.55	36	
3	60	0.8077	60	818.4	60	823.46	44		45		62	789.49	50	835.1
4	70		70		80	821.56	53	795.49	53		81		60	805.4
5	80	0.8045	80	807.8			62	755.39	64	721.3	88		80	503.1
6	90		90				67		85		95	720.0	90	
7	100		100				85	712.3	95	712.0			110	695.71

KO – Karanja Oil, FD – Fossil-diesel

Note 1: Viscosity and density of diesel at 35 ^0C is 2.94 cS and 805.12 kg/m^3 respectively.

3.3 Testing of Unmodified C I Engine

A constant speed, three cylinders, naturally aspirated DG set of 20 kW capacities was used for studying the performance of mixed fuels. Engine details are given in Table 3.

The literature survey showed that edible oil could be mixed in fossil-diesel up to 50% to 75% and used in engine (3, 4, 5, 12, and 13). In view of this the trials were first started at mixture of (50% Karanj Oil and 50% fossil-diesel) at 80^0 C of mixture temperature, but unsatisfactory performance of diesel engine was observed. It may due to very poor quality of Karanja oil (Table 4) and /or in reported literature most of the research workers used edible oils, which have less viscosity compared to non-edible oils. Later karanj oil was dewaxed and degummed. It was found that total percentage of wax and gum in the karanj oil was 4% by weight. To see the effect on viscosity after dewaxing and degumming of karanj oil, it was heated up to 90^0C and its viscosity were compared with untreated karanj oil. It was observed that there was no significant difference in the viscosity of karanj oil after dewaxing and degumming.

Later trials were again initiated with 80 ^{0}C heated mixture of 10%, 20%, 25%, and 35% of dewaxed and degummed Karanja oil blended with 90%, 80%, 75%, and 65% of fossil-diesel respectively at 4 load (2.8 kW (14%), 7.0 kW (35%), 8.4 kW (42%) and 12.6 kW (63 %)). For 10% and 20 % dewaxed and degummed Karanja oil blends with 90% and 80 % fossil-diesel results were found encouraging.

At 35% dewaxed and degummed Karanja oil and 65% fossil-diesel mixture, the engine produced much smoke. Unburnt Karanja oil dripped from the exhaust manifold. Also fuel consumption (FCR) was not uniform, for the first two hours it was constant, there after it started increasing with time throughout the experiment. So it was decided to go for lower composition. A 25% dewaxed and degummed Karanja oil and 75% fossil-diesel mixture was tried. Again performance was not satisfactory. Engine produce much whitish smoke with unburnt oil particulates, except dripping of oil from exhaust manifold. It may be due to poor quality of Karanja oil and engine conditions (Table 3 and 4). Results are tabulated in table 7 and 8. Karanja oil blend of more than 20% could not be used satisfactorily for 20 kW diesel engine operation, even though the blended oil had a comparable viscosity to that of fossil-diesel after dewaxing, degumming and heating (up to 80 ^{o}C) (Table 5 and 6).

Finally 20% dewaxed and degummed Karanja oil and 80% fossil-diesel at 80^{0}C of mixture temperature was used with producer gas to run compression ignition (C I) engine.

Table 7. Performance of Diesel Engine at Duel Fuel Mode (35% Dewax and Dummed Karanj Oil and 65% Fossil-Diesel) at 80 ^{0} C Mixture Temperature

Table 7a. Effect of Emission on Performance of Diesel Engine at Duel Fuel Mode (35% Dewaxed and Degummed Karanj Oil and 65% Fossil-Diesel) at 80^{0} C Mixture Temperature

Mode of operation	% Load of rated capacity	LFCR, l/h	Temperature, ^{0}C		Exhaust Gas analysis						Remarks
			Ambient, ^{0}C	Engine exhaust, ^{0}C	$C0_2$ %	C0 %	O_2 %	NO ppm	NO_2 ppm	HC %	
*Fossil-diesel **	*2.8 KW, 14%*	*2.082*	*22*	*215*	2.55	0.218	17.46	189	36	0.51	
Duel fuel **	2.8 KW, 14%	2.40	20	227	3.03	0.367	16.8	133	39	0.55	Unsatisfactory engine performance

- 100% fossil-diesel, ** 65% fossil-diesel and 35% de-waxed and de-gummed Karanja oil, LFCR-Liquid fuel consumption rate

Note: All the data are average of 5 readings taken at interval of one hour and total working of diesel engine at duel fuel mode was 6 hours

Table 8. Performance of Diesel Engine at Duel Fuel Mode (25% Dewaxed and Degummed Karanj Oil and 75% Fossil-Diesel) at 80^{0}C Mixture Temperature

* 100% fossil-diesel, ** 75% fossil-diesel and 25% de-waxed and de-gummed Karanja oil

Table 8a. Effect of Emission on Performance of Diesel Engine at Duel Fuel Mode (25% Dewax and Degummed Karanj Oil and 75% Fossil-Diesel) at 80^0 C Mixture Temperature

Mode of operation	% Load of rated capacity	LFCR, l/h	Temperature, ^{0}C		Exhaust Gas analysis						
			Ambient	Engine exhaust	$C0_2$ %	C0 %	O_2 %	NO *ppm*	NO_2 *ppm*	HC %	Remarks
*Fossil-diesel**	*2.8 KW, 14%*	*2.082*	*22*	*215*	2.55	0.218	17.46	189	36	0.51	Unsatisfactory engine performance
Duel fuel **	2.8 KW, 14%	2.83	21	239	3.25	0.526	16.5	169	47	0.68	

* 100%fossil-diesel, ** 75 % fossil-diesel and 25% dewaxed and degummed Karanja oil, LFCR- Liquid fuel consumption rate

Note: All the data are average of 5 readings taken at interval of one hour and total working of diesel engine at duel fuel mode was 6 hours

3.4 Fuel and Specific Energy Consumption

Specific energy consumption in fossil- diesel, dual fuel and mixed fuels were calculated from the fuel consumption and the calorific value of fossil-diesel, blends of fossil-diesel and Karanja oil and producer gas. The Calorific value of fossil-diesel and Karanja oil were determined from bomb calorimeter, while the calorific value of different blends was calculated as per their composition. Producer gas composition was as follow: 8.06% CO, 16.78% H_2, 2.85% CH_4, 9.59% CO_2 and the remaining was N_2. Calorific value computed from the gas composition was 4.504 MJ/Nm^3. Specific fuel consumption for all the fuel is presented in table 9.

3.5 Liquid Fuel Replacement rate

Liquid fuel replacement rate under different load conditions have been calculated from the liquid fuel consumption in fossil-diesel and liquid fuel consumption in mixed fuel mode and the results are tabulated in table 9.

3.6 Emission of C I Engine

Published data shows that emission levels of diesel engine are in the order of NOx 500 to 1000 ppm or 20-gm/ kg of fuel and HC, 3000 ppm or 25-gm/kg fuels. It also emits significant amount of CO, sulfur and particulates. Sulfur contains in fossil-diesel fuel is in larger amounts (0.5%). The sulfur is oxidized and produces sulfur dioxide (SO_2). The permissible limit of emission concentrations for different capacity of DG sets is tabulated in table 10 (6).

3.7 Emission in Mixed Fuel Mode

When C I engine was operated on fossil-diesel fuel and a mixture of fossil-diesel, Karanja oil the percentage of unburned hydrocarbons and carbon monoxide remained at low levels over a broad range of the engine load. At low level of engine load when producer gas was used, emissions of HC and CO were much higher. These emission levels of HC with producer gas decreased and CO_2 level increased as the load on the engine increased, until, maximum load. It is believed that the larger cylinder pressure and temperatures associated with higher load were responsible for increased complete combustion of producer gas (Figure 2 and 3). Ogunlowo also reported the similar results for dual fuel (fossil-diesel and producer gas) engine (11).

Table 9. Performance of Diesel Engine at Mixed Fuel Mode (Mixture of 20% De-waxed and De-Gummed Karanja Oil and 80% Fossil-Diesel at 80 ^{0}C Mixture Temperature and Producer Gas)

% Load of rated capacity	Alternate output				RPM of engine	Lub oil pressure, kg/sq.cm	Engine output, kW	SEC, MJ/kWh	Db, meter, reading	Crank Oil temp., C	Frequency, HZ	% Liquid fuel replacement
KW (%)	Mode of operation	KVA= ?3 x V_{arg} x A_{arg}	PF	kW								
2.8 kW, 14 %	Fossil- diesel	2.587	1	2.587	1470	3.2	3.23	22.601	99.52	68.6	50	-
2.8 kW, 14 %	Duel fuel (KO + FD)	2.591	1	2.591	1467	3.05	3.239	23.778	99.4	78.67	50	--
2.8 kW, 14 %	Duel fuel (P gas + FD)	2.585	1	2.585	1457	2.5	3.22	96.834	97.6	82.2	50	78.58
2.8 kW, 14 %	Mixed fuels (KO+P gas + FD)	2.45	1	2.45	1455	2.4	3.063	92.973	98.5	80.3	50	70.50
7.0 kW, 35%	Fossil-diesel	6.7834	1	6.783	1465	3.0	8.479	11.719	100.24	82.6	50	--
7.0 kW, 35%	Duel fuel (KO + FD)	6.80	1	6.80	1468	2.48	8.5	12.378	99.86	85.67	50	--
7.0 kW, 35%	Duel fuel (FD + P gas)	6.582	1	6.582	1457	2	8.227	41.34	98.68	89.28	50	60.32
7.0 kW, 35%	Mixed fuels (KO+P gas + FD)	6.692	1	6.692	1453	2.17	8.365	40.923	99.5	85.6	50	68.33
8.4 kW, 42 %	Fossil-diesel	7.94	1	7.94	1468	3.0	9.925	11.439	100.3	79	50	--
8.4 kW, 42 %	Duel fuel (KO + FD)	8.065	1	8.065	1467	2.8	10.08	11.202	99.86	80	50	--
8.4 kW, 42 %	Duel fuel (FD + P gas)	7.866	1	7.866	1454	1.5	9.832	21.129	95.83	91.8	50	79.97
8.4 kW, 42 %	Mixed fuels (KO+P gas + FD)	7.878	1	7.878	1455	2.0	9.85	23.966	98.1	86.2	50	71.53
12.6 kW, 63 %	Pure diesel	12.57	1	12.57	1462	2.0	15.71	9.686	100.44	92.4	50	--
12.6 kW, 63%	Duel fuel (KO + FD)	12.699	1	12.699	1467	2.38	15.874	9.549	100.9	91	50	--
12.6 kW, 63%	Duel fuel (P gas + FD)	12.312	1	12.312	1461	1.32	12.312	17.912	97.2	96.42	50	82.22
12.6 kW, 63%	Mixed fuels (KO + P gas + FD)	12.287	1	12.287	1458	1.25	12.287	17.923	97.12	95.78	50	83.19

KO- De-waxed de-gummed Karanja Oil, FD—Fossil-diesel, P gas – Producer gas

1. Duel fuel (80% Fossil-diesel and 20% de-waxed and de-gummed Karanja oil) at 80^{0}C mixture temperature,
2. Duel Fuel (Fossil-diesel and Producer gas), Tar and SPM in cool and clean producer gas was 40 to 42 mg/N cum
3. Triple fuel (80% Fossil-diesel and 20% de-waxed and de-gummed Karanja oil and Producer gas), Tar and SPM in cool and clean producer gas was 40 to 42 mg/N cum
4. All the data are average of 5 readings taken at interval of one hour and total working hour of diesel engine at mixed fuel mode was 6 hours.

Table 10. Emission Limits for DG Sets (Up to 800 kW)

Capacity of DG Sets	Date of implementation	Emission limits (g/k Wh)				Smoke limit (at full load)	Test Cycle		Sound pressure level up to 1000 KVA
		NOx	HC	CO	PM		Torque/ Load	Weighing Factors	
Up to 19 kW	01/07/2003	9.2	1.3	5.0	0.6	0.7	100	0.05	75 db (A) at a 1 meter from the enclosure surface
	01/07/2004	9.2	1.3	3.5	0.3	0.7	75	0.25	
19–50 kW	01/07/2003	9.2	1.3	5.0	0.5	0.7	50	0.30	
	01/07/2004	9.2	1.3	3.5	0.3	0.7	25	0.3	
50 -260 kW	01/07/2003	9.2	1.3	3.5	0.3	0.7	10	0.10	
260- 800 kW	01/07/2004	9.2	1.3	3.5	0.3	0.7			

Source: 6

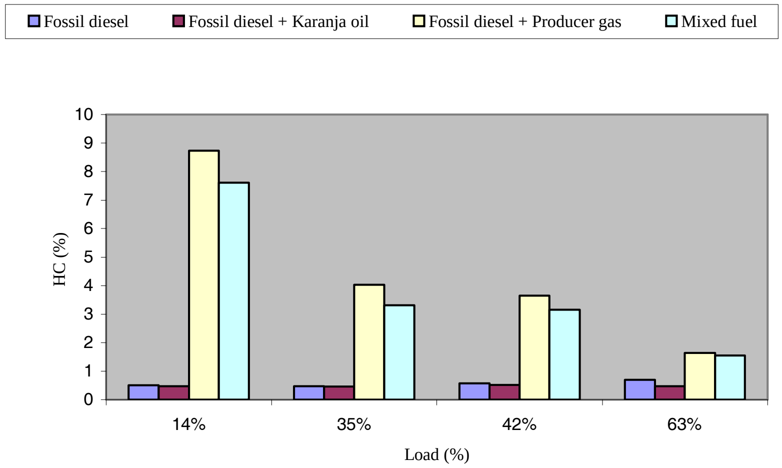

Fig. 2. Variation of HC with fuel at different engine loads

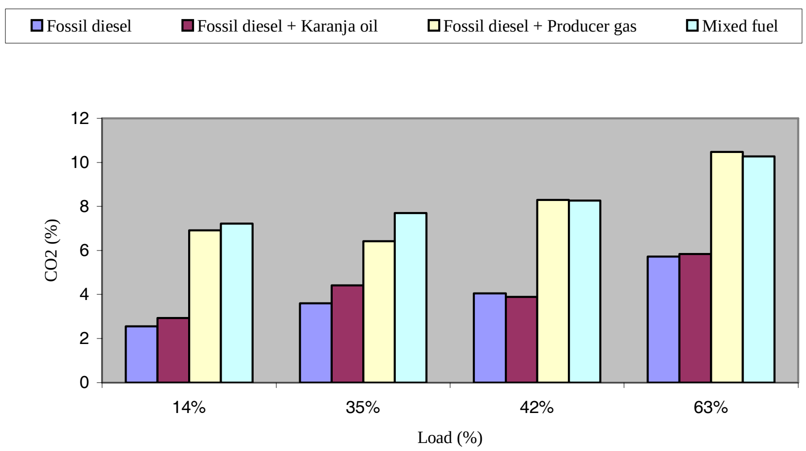

Fig. 3. Variation of CO2 with fuels at different engine loads

Carbon monoxide (CO) emission concentration in dual fuel mode (fossil-diesel and producer gas) and mixed fuels (fossil-diesel and Karanja oil and producer gas) were larger than the CO emission concentration in fossil-diesel and fossil-diesel and Karanja oil mode (Figure 4). High emission in mixed fuel mode operation could be due to combination of factors such as low heating value of producer gas and Karanja oil, low adiabatic flame temperature and low mean effective pressures. Additionally, the engine had already run about 1000 hours on a mixture of fossil-diesel and producer gas. Moreover the engine was not actually designed for producer gas and plant oil operation, but for fossil-diesel only (14).

NOx emission concentration in mixed fuels were much less than the emission concentrations from fossil-diesel and fossil-diesel and Karanja oil mode (Figures 5 and 6). It may be due to fact that organic nitrogen from the air caused NOx to be formed. Producer gas does not have organic nitrogen; it has only atmospheric nitrogen i.e. inorganic nitrogen. Plant oils also have less inorganic nitrogen compared to fossil-diesel.

Nitric oxide is formed through the high temperature burnt gasses in the flame through chemical reactions involving nitrogen and oxygen atoms and molecules, which do not attain chemical equilibrium. The higher the exhaust gas temperature, the higher the rate of formation of NO. As the burnt gases cool during the expansion stroke the reactions involving NO becomes slower and so leave NO concentrations in excess of levels corresponding to equilibrium at exhaust conditions. Moreover with decrease of engine load addition of oxygen increases the flame temperature and therefore increases the NOx emissions (7).

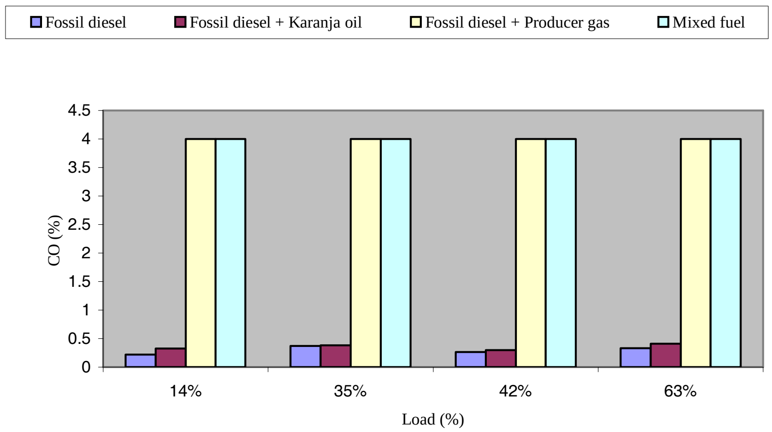

Fig. 4. Variation of CO with fuels at different engine loads

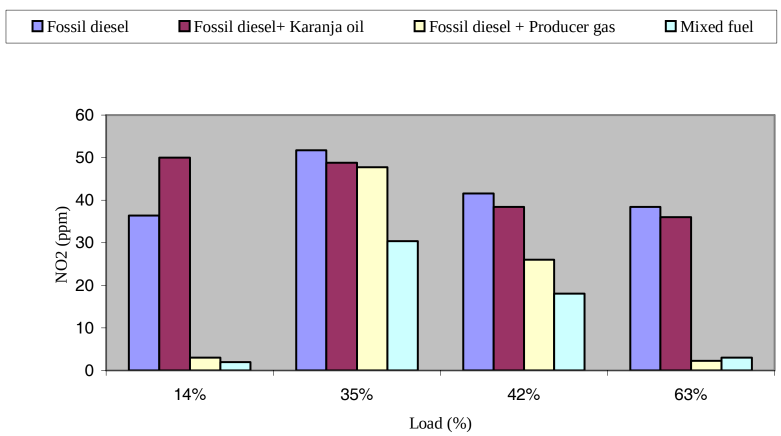

Fig. 5. Variation of NO2 with fuels at different engine loads

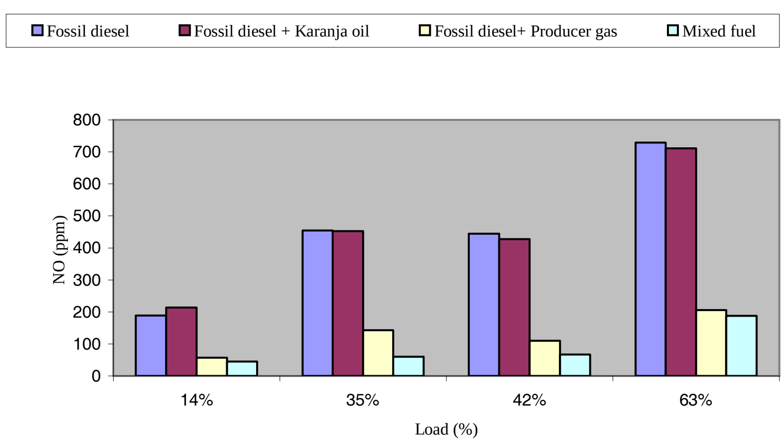

Fig. 6. Variation of NO with fuels at different engine loads

Variations of exhaust gas temperature for different loads on the engine are shown in Figure 7. The exhaust gas temperature increased with increasing engine loads. The maximum temperature of exhaust was 456 ^{0}C at 63% engine loads. It was due to the fact that Karanja oil and producer gas both are being late burning fuels compared to fossil-diesel. Because of lower combustion characteristics of Karanja oil and producer gas, combustion of these fuels were delayed and could not completely burn in the main combustion phase, and subsequently continue to burn in the late combustion phase, resulted higher exhaust temperature.

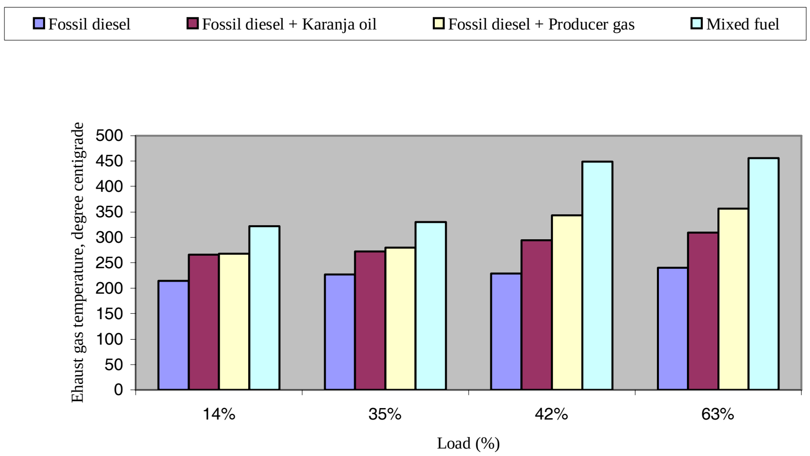

Fig. 7. Variation of exhaust gas temperature with fuels at different engine loads

4. CONCLUSION

A naturally aspirated C I engine was operated successfully with mixed fuels (fossil-diesel, Karanja oil and producer gas). This paper has yielded some basic information on the environmental aspects of a power generation system operated in mixed fuels. In addition to the findings on environmental aspects, the short trial study (6 hours continuously) also proved that the compression ignition engine could run in mixed fuel mode (70% to 83% Producer gas, rest karanja oil and fossil-diesel at the ratio of 1: 5 and heated at 80 °C. Key finding on the environmental aspects are as follows.

1) At 63% load of the rated capacity, the emission concentration were generally less than the emission norms except for carbon monoxide emission concentration from mixed fuel operation, which exceeds the standard.
2) Carbon monoxide emission concentration from mixed fuel operation was much larger than fossil-diesel at all operated load conditions.
3) Multi-fuel operation reduces NOx considerable at all the tested loads.

5. ACKNOWLEDGEMENT

The authors are grateful to Prof. (Dr.) B S Pathak, Director and Dr. N. S. L. Srivastava, Joint Director, Sardar Patel Renewable Energy Research Institute, for providing facilities, the valuable guidance and encouragement to carry out the study.

6. REFERENCES:

[1] American Society for Testing of Materials (ASTM). Annual Book of ASTM Standards. Philadelphia: ASTM 19103, 1983.

[2] BIS Code No.13018 (1990). Internal Combustion Engine – method of test for pressure charge engine.

[3] Bhattacharya, S and Reddy, C S (1994) "Vegetable oil as fuel for Internal combustion engine: A Review" J. Agric. Engg. Res. 57, pp: 157-166.

[4] Barisic, N J and Humke A L (1981) " performance and emission characteristics of a naturally aspirated diesel engine with vegetable oil fuels SAE Paper No 810262

[5] Bhatt, V.C.; Murthy, N.S. and Datta, R.K. (2001) "Karanja (Pongamia glabra) oil as a fuel for diesel engines" Agril. Engg. Today Vol. 25 (5-6) pp.45-57.

[6] "ENVIRO NEWS" Newsletter on Environment & Forest Policies, Programmes and activities Vol.6 July - September 2002.

[7] Hey Wood John, B (1988) " Internal Combustion Engine Fundamentals" International Edition, NewYark: McGraw-Hill.

[8] Jain , VK Patel, SR and Rao ,CS (1991) " Performance evaluation of a continuous 3.5 k W throat less rice husk gasifier system for power generation" SESI Journal 1(2) : 81-94.

[9] Nambiar (2004) "Energy resources of the future", Biofuels India, Sustainable Fuel for the Transport Sector, II issues, pp.4-5 & 8.

[10] Mukunda, H.S. (1999) "A Biomass option for enhancing Energy security" Published by National Institute of Advanced studies, IISc, Bangalore, pp.36.

[11] Ogunlowo, A S; Chancellor, W J and Goss, J R (1981) " Dual fueling a small diesel engine with Producer gas" Transaction of The ASAE, PP; 48-51

[12] Shyam, M; Verma, SR and Pathak, BS (1984) " Performance of 5 hp diesel engine with various blends of plant oil and diesel/kerosene oils" J. Agril. Engg. ISAE, Vol. 21(3) 113.

[13] Sigar, C.P.; Mathur, J.; Sigad, J.P. and Poonia, M.P. (2002) "Karanj oil finding a place in alternative technology: Another view". Proc. Of International Conference on Technological Aspects of decentralized approach in waste to energy held at MNIT, Jaipur, pp.1-3.

[14] Uma, R Kandpal, T C and Kishore, V V N (2004)" Emission characteristics of an electricity generation system in diesel alone and duel fuel modes" Biomass & Bioenergy 27 pp: 95-203.