IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 10, Issue 5 (Jan. 2014), PP 56-63
www.iosrjournals.org

Effect of blends of karanja oil on performance of a twin cylinder dual fuel diesel engine using producer gas

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Abstract : *In the present study, a twin cylinder 4-stroke dual fuel diesel engine is tested using diesel, K10 (10 % neat oil + 90% diesel) and K20 (20% neat oil + 80% diesel) with woody biomass producer gas. The test is performed using the above test fuels in dual fuel mode at different gas flow rates under a constant load of 10 kW. This work demonstrates the effect of gas flow rates and neat oil blends on performance, emission and pilot fuel savings of the test engine. It is observed that with increase in gas flow rates for all test fuels, performance parameters like brake specific energy consumption (BSEC) and exhaust gas temperature (EGT) increases, whereas brake thermal efficiency decreases. The emission parameters like carbon monoxide, hydrocarbon and carbon dioxide values are increases. However, the oxide of nitrogen (NOx) and smoke emission parameters are decreases with increase in gas flow rates. Similarly, in comparing between liquid fuels, with increase in blend percentage, BSEC and EGT increases compared to diesel. The BTE is the reverse case of BSEC. In case of blended fuels, all the above mentioned emission parameters shows lower values compared to diesel. The highest pilot fuel savings occurs in case of diesel, K10 and K20 are. 56%, 54% and 52% respectively at highest gas flow rates.*

Keywords: *Biomass; Dual Fuel; Producer gas; Twin cylinder*

I. INTRODUCTION

Due to higher brake thermal efficiency of diesel engine compared to gasoline engine, it is quite popular in agriculture and transport sector. Since, India being an agricultural country, huge amount of diesel fuel is consumed in agriculture sector. Due to rapid depletion of diesel fuel, its rising prices and hazards emissions from vehicles, an alternative fuel for diesel is critically important for our nation's economic growth and security. Keeping this in view, more interest is generated to do research work to find out the viable alternative fuel for diesel engine in India. Non-edible vegetable oil (Karanja) and its derivatives can be used as an alternative fuel for compression ignition engine. It is renewable, highly available and environmental friendly. Due to higher viscosity of vegetable oil it creates some engine problems like poor fuel atomization which leads to poor engine performance, ring sticking, injector pump failure and injector deposit etc. To reduce viscosity of vegetable oil and to improve the engine performance blending with diesel is necessary. The different blends are made by mixing vegetable oil with diesel in a proportion of volume/ volume ratio or weight/weight ratio. Wang et al. [1] conducted experiment using vegetable oil blends with diesel and reported that higher exhaust gas temperature, lower NOx and a small change in CO emission compared to diesel. Similarly, biomass derived producer gas can be used as an alternative fuel for diesel engine due to their eco-friendly nature [2, 3]. Producer gas when burnt produces insignificant SOx and little NOx, the main constituent of acid rain and smog than fossil fuel [4]. However, due to higher octane number of producer gas, it cannot operate in diesel engine with the help of small amount of injected pilot fuel. Hence, a diesel engine needs to be dual fueled. Power derating is the major problem with producer gas operation in a gas engine. A power drop of 40% to 70% can be expected as mentioned in literature [5, 6, 7]. Due to very high derating nature, retrofit application of existing SI engine is not so much attractive. From fuel flexibility and derating point of view, dual fuel engine can be highly used for decentralized power generation and agriculture purpose. Engine modification of existing diesel engine in to dual fuel mode operation of producer gas is very easy and power derating is limited to 20-30%. In the literature it is mentioned that diesel savings up to 70-90% occurs in dual fuel operation using renewable alternative fuels [8, 9, 10]. The fuel used for dual fueling includes hydrogen, LPG, CNG and alcohols [11, 12]. Due to lower running cost and use of different alternative fuel sources in dual fuel mode, it attracts many investigators to use this engine in different areas.The current dual fuel engine can be operated interchangeably, either on gaseous fuel with diesel pilot ignition or wholly on liquid fuel injection as a diesel engine. Due to this switching over mechanism from dual fuel to single mode operation in a dual fuel engine, it tends to retain most of the positive features of diesel operation [13]. The main objective of using dual fuel engine is to reduce NOx and particulate emission (PM). In case of diesel engine, it is difficult to reduce simultaneously both NOx and smoke due to the tradeoff curve between NOx and smoke. One suitable method is to solve this problem by using alternative oxygenated fuel which provides more oxygen for combustion. Gasification is the process of conversion of solid/liquid bio fuels in to gaseous fuel in a gasifier by pyrolysis process at high temperature. Producer gas is a low calorific value gas, which is generated by the conversion of high calorific value wood in a gasifier. It is a mixture of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen. The typical compositions of producer gas generated from Babul wood with desired moisture content are measured by the help of Microprocessor based gas Chromatograph (model No. 2010) supplied by Chromatography and instruments company Pvt. Ltd. Baroda and shown in Table 1. The properties of test fuels are given in Table 2. In the literature it is reported that wood producer gas single cylinder dual fuel diesel engine can run efficiently up to 50-60% of the full load, after that performance is inferior [14]. Many investigators in their research work mentioned that maximum diesel savings occurs up to 71% [15], 64% [16]and 72% [10] using wood producer gas at optimum load condition.

TABLE 1. Composition of producer gas

Carbon monoxide	19±3%
Carbon dioxide	10±3%
Nitrogen	50%
Hydrogen	18±2%
Methane	Up to 3%

TABLE 2. Properties of producer gas

Properties	Producer gas
Calorific Value	1000 Kcal/ NM3
Density (Kg/m3)	1.28
Cetane number	-
Octane number	100-105
Laminar burning velocity	0.5±0.05 m/s

The present work is an effort to evaluate the feasibility of producer gas generated from Babul wood and blends of neat Karanja oil and its effect on the performance of a twin cylinder 4-stroke diesel engine in dual fuel mode for maximum replacement of pilot fuels, better emissions and without any undue vibration of the engine. The photograph of sample of wood pieces is shown in figure 1.

Fig.1.Photograph of sample of wood pieces

II. PREPARATION METHODS OF VEGETABLE OIL BLENDS

1. Materials

1.1. Collection of crude Karanja oil

The crude karanja oil is collected from North Odisha which is a clear, viscous and dark brown in colour. After collection, then it is filter with a nylon mesh cloth filter.

1.2. Preparation of blends

The Karanja oil was then blended with fossil diesel (FD) in various concentrations to get vegetable oil blends. These blends were used in the engine test. In the present work, the blends used are K10, and K20. The blend K10 and K20 is prepared by mixing 10% and 20% Karanja oil with 90% and 80% diesel respectively by weight basis.

1.3. Determination of fuel properties

After production of oil blends some of the important properties of the fuels were testedin the laboratory before use in diesel engine. Fuel properties like density, kinematic viscosity, flash point, fire point, point and calorific value etc. were estimated using various ASTM methods and equipment's. The estimated fuel properties of different test fuels are given in Table 3.

III. CHARACTERISTICS OF BIOMASS USED

Woody biomass is used as a well-known suitable and traditional fuel in India, where generation of heat is necessary. This is because of higher heating value and low ash content of the wood. In the present study for gasifier feedstock, small pieces of babul wood with approximate size 25 mm length and 25 mm diameter is generated in our laboratory and suitably used. For getting better quality and higher calorific value of gas, the moisture content of wood used is kept less than 20%. The average gas calorific value was found to be 4186 kJ/m3.

IV. TEST PROCEDURE AND METHODOLOGY

The schematic diagram of the experimental setup is shown in Figure 2. The experimental setup consists of a twin 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, gas filter supplied by Anker Scientific Energy Technology Pvt. Ltd., Baroda. The photograph of experimental setup is shown in Figure 3. The detailed specifications of the engine and downdraft woody biomass gasifier are given in Table 3 & 4 respectively. The biomass is loaded from the top of the gasifier and ash is removed after a regular interval. The partial combustion of biomass in the gasifier reactor is converted in to high temperature producer gas, which enter in to the gas cooler. The moisture, tar and dust particle is removed by passing through a two set 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 surge tank. Manometers are used to measure the air and gas flow separately. The producer gas and air are mixed in the intake pipe and then the mixture enters into the engine cylinder. The engine was always operated at its rated speed of 1500 rpm, injection timing of 23° before top dead centre (BTDC) and injection pressure of 220 bars. Tests were carried out at constant load conditions of 10 kW using the test fuels such as fossil diesel (FD), K10, K20 and producer gas in dual fuel mode operation under variable gas flow rate. In dual fuel operation, the gas flow rate was measured by using an orifice meter and manometer attached to the gas surge tank. For a particular gas flow rate, by rotating a mechanical control valve, the head difference in the manometer tube is kept to be constant. So for different gas flow rates, the head difference is varied by rotating the control valve. However, the injected diesel flow rate was not maintained constant. The temperature of combustion gas before enter in to the cooling system was measured by the help of thermocouple and found to be 458 °C and after cooling and cleaning, it was found to be 37°C. The performance and emission studies were observed under different substitution of gas-air ratio at constant load conditions. The AVL make 5-gas analyzer (model No. AVL Degas 444) and smoke meter (model no. AVL 437 C) with accuracy ±1% is used to measure exhaust gas emission parameters and smoke opacity respectively. The parameters like CO, HC and CO2 are measured by NDIR (Non-dispersive infrared) method and NOX and O2 are measured by using electro chemical method.

TABLE 3. Properties of test fuels

Properties	Diesel	Karanja oil	K10	K20	ASTM Methods	Measurement apparatus
Density at 25^{o}C(Kg/m^{3})	825	925	832	837	D 1298	Hydrometer
Kinematic viscosity At 40^{o}C (cost.)	2.76	28.69	3.7	4.36	D 445	Red wood viscometer
Calorific value (MJ/kg)	42.5	34.7	41.7	40.9	D 240	Bomb calorimeter
Cetane number	47	32.33	-	-	D 613	Ignition quality tester
Flash point (^{o}C)	73	219	89	109	D 93	Pinks martins apparatus
Fire point (^{o}C)	103	235	119	135	D 93	Pinks martins apparatus

TABLE 4.Test engine specifications

Parameters	Description
Rated horse power	14 Hp
Make	Prakash Diesel Pvt. Ltd. Agra
No of cylinder	Two
No of stroke	4-stroke
Rpm	1500
Compression ratio	16.:1
Bore diameter	114 mm
Stroke length	110 mm
Injection pressure	220 bar
Injection timing	23˚ BTDC
Alternator	10.3 kW, directly coupled to engine

	15 KVA, 21 amp, 3-phase, 415 volt

TABLE 5. Specification of down draft gasifier

Parameters	Description
Supplier	Ankur Scientific Energy Technology Pvt. Ltd., Baroda
Model	WBG-10 in scrubbed, clean gas model
Gasifier type	Down draft
Rated gas flow	25 NM^3/hr.
Average gas calorific value	1000 Kcal/ Nm^3
Gasification temperature	1050 °C– 1100 °C
Fuel storage capacity	100 Kg
Permissible moisture	Less than 20% (wet basis)
Rated hourly consumption	8-9 Kg
Ash removal	Manually, dry ash discharge

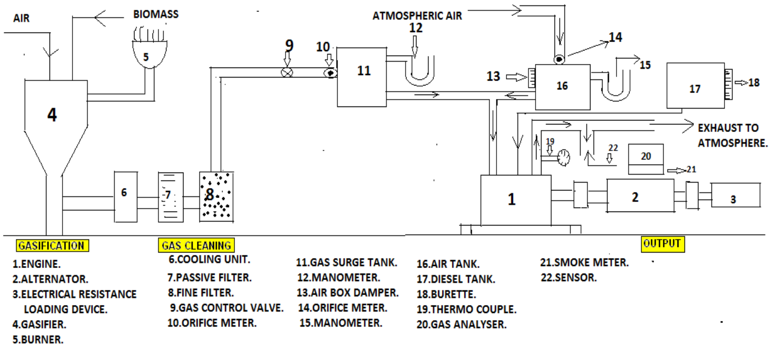

Fig. 2. Schematic diagram of the experimental setup

V. RESULT AND DISCUSSION

5.1 Brake Specific Fuel Consumption

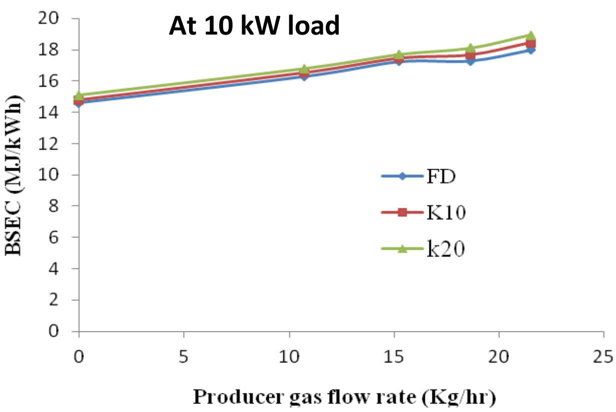

Fig. 3.Variation of BSEC with different gas flow rates

Figure 3 illustrates the variation of brake specific energy consumption with different substitution of gas flow rates at constant load of 10 kW for all test fuels in dual fuel mode. It is observed that with increase in blend percentage in diesel, BSEC increases as compared to diesel. The reason is being the calorific value of biodiesel is less compared to diesel. Again, with increase in gas flow rate, the BSEC increases due to lower energy content and adiabatic flame temperature of producer gas. The highest values of brake specific energy consumption for FD, K10 and K20 are found to be 18MJ/kWh, 18.45MJ/kWh and18.95MJ/kWh respectively at highest gas flow rate.

5.2 Brake Thermal Efficiency

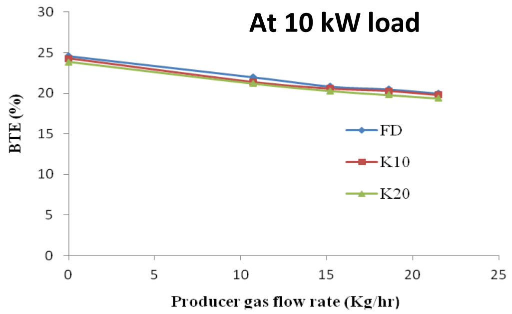

Fig. 4.Variation of BTE with different gas flow rates

From figure 4, it is seen that the brake thermal efficiency for all test fuels in dual fuel mode decreases with increase in gas flow rates due to increase in BSEC. Also with increase in blend percentage, BTE decrease due to decrease in BSEC. The highest values of BTE obtained for FD, K10 and K20 are 24.67%, 24.2%, and 23.78% respectively at zero substitution of producer gas, whereas, at highest substitution of gas flow rate i.e., 21.49 Kg/hr, the BTE for FD, K10 and K20 are found to be20%, 19.78% and 19,39% respectively.

5.3 Exhaust Gas Temperature

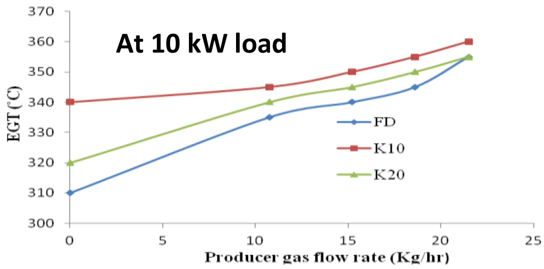

Fig. 5.Variation of EGT with different gas flow rates

The variation of exhaust gas temperature with different gas flow rates for all test fuels in dual fuel mode at a constant load of 10 kW is plotted in figure 5. The figure reveals that with increase in gas flow rate from zero substitution to maximum substitution, the EGT of all test fuels increases. This may be due to more energy input with increase in gas flow rate. However, the blend K10 produces highest EGT compared to K20 and FD. The variation of EGT for FD, K10 and K20 at maximum gas flow rates is very small.

5.4 Carbon Monoxide Emission

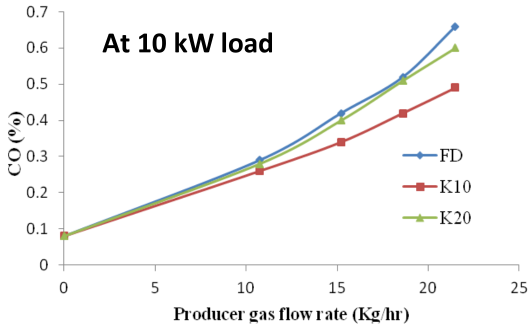

Fig. 6. Variation of CO emission with different gas flow rate

Figure 6 shows the variation of CO emission of all test fuels with producer gas flow rates at constant load of 10 kW. The figure indicates that with increase in gas flow rate, CO emission increases linearly. The reason may be due to the presence of CO in producer gas composition. Hence, more amount of gas flow rate enters in to the system means more amount of CO emission produces. Again, blended fuel shows lower CO emission compared to diesel. This is due to complete oxidation of vegetable oil as a result of presence of oxygen compared to diesel. But comparing in between K10 and K20, the CO emission value of K20 is higher than K10 at highest gas flow rate. This may be due to incomplete combustion as a result of higher viscosity of K20 fuel compared to K10 fuel.

5.5 Hydrocarbon Emission

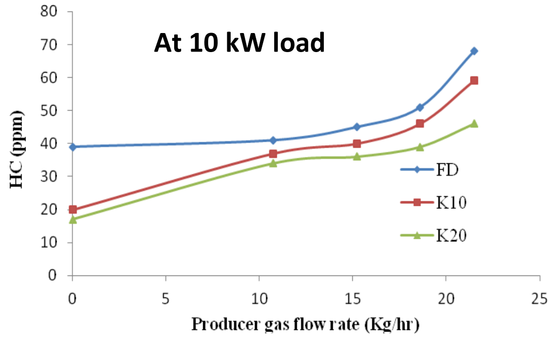

Fig. 7. Variation of HC emission with different gas flow rate

The variation of HC emissions for all test fuel with different gas flow rates at a constant load of 10 kW are plotted in figure 7. The figure indicates that with increase in gas flow rate, HC emission increase. This may be due to incomplete combustion as a result of slow burning nature of producer gas. However, with increase in blend percentage in diesel, HC emission decreases compared to diesel due to better oxidation of vegetable oil as a result of presence of oxygen. At highest gas flow rate, the HC emission of FD, K10 and K20 is found to be 68ppm, 59ppm and 46ppm respectively.

5.6 Carbon dioxide Emission

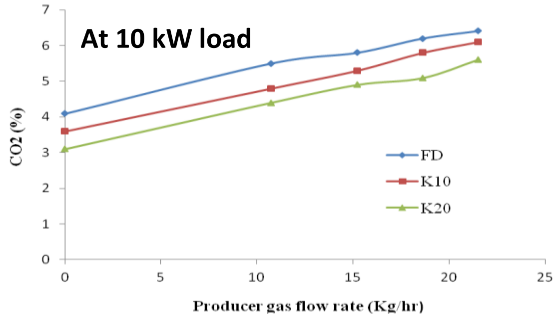

Fig.8.Variation of CO_2 emission with different gas flow rates

Figure 8 shows the variation of CO_2 emission for all test fuels with different gas flow rates at a constant load of 10 kW. From this figure, it is seen that with increase in gas flow rate, CO_2 emission for all test fuels increases. This is because of as producer gas is a mixture CO and CO_2; its combustion increases the CO_2emission [10]. Again, with increase in blend percentage in diesel, CO_2 emission decreases at all gas flow rate. The reason being vegetable oils an oxygenated fuel which burns clearly to produce less CO_2 emission. The highest value of CO_2 emission for FD, K10 and K20 at highest gas flow rate is found to 6.41%, 6.1% and 5.6% respectively.

5.7 Nitrogen Oxide Emission

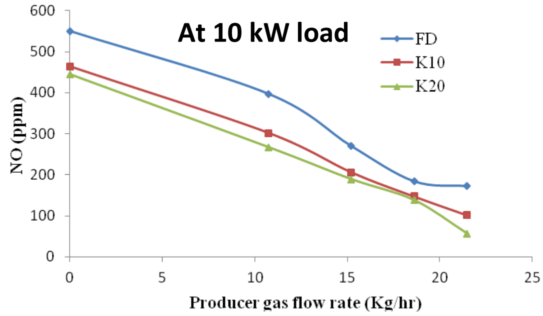

Fig.9.Variation of NOx emission with different gas flow rates

The variation of NOx emissions for all test fuels with different gas flow rates at a constant load of 10 kW are plotted in figure 9. From the figure it is observed that NOx emission decreases with increase in gas flow rate. This is due to lower adiabatic flame temperature and absence of organic nitrogen in producer gas [15]. Also with increase in blend percentage in diesel, NOx emission decreases. This could be attributed to the lower peak combustion temperature as a result of lower energy released during pre-mixed combustion phase due to larger droplet size of blended fuel compared to diesel. This result is agreed with the result reported by Agarwal and Rajamanoharan [17]. The highest value and lowest value of NOx emission obtained for all test fuels at zero substitution and highest substitution of gas flow rate respectively.

5.8 Smoke Opacity

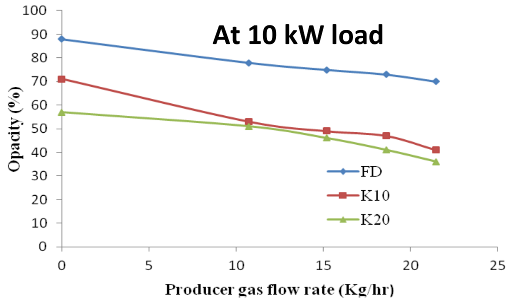

Fig. 10.Variation of smoke opacity with different gas flow rates

The variation of smoke opacity emissions for all test fuels with different gas flow rates at a constant load of 10 kW are plotted in figure 10. From the figure it is observed that smoke opacity decreases with increase in gas flow rate. This may be due to clean burning of producer gas in dual fuel mode. Again, with increase in blend percentage in diesel, smoke opacity decreases compared to diesel due to better combustion of blended fuel with producer gas. The smoke opacity values for fossil diesel, K10 and K20 are 70%, 41% and 36%.respectivelyat highest gas flow rate.

5.9 Pilot Fuel Savings

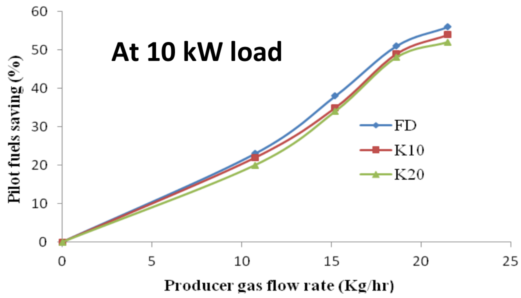

Fig. 11.Variation of pilot fuel savings with different gas flow rates

Figure 11 shows the variation of pilot fuel savings for all test fuels with different gas flow rate at a constant load of 10 kW. The figure indicates that with increase in gas flow rate the pilot fuel savings increases. This is because of more amount of energy supplied by the gaseous fuel as the gas flow rate increases. To keep total energy constant, pilot fuel consumption must be decreases. Hence, pilot fuel savings increases. Again, with increase in blend percentage, pilot fuel savings decreases due to decrease in calorific value of vegetable oil blended fuels. The highest fuel savings occurs in case of FD, K10 and K20 are 56%, 54% and 52% respectively at highest gas flow rates at optimum load conditions.

VI. Conclusion

The following conclusions were drawn from the above cases studies.

- With increase in gas flow rates for all test fuels, BSEC and EGT increases
- BSEC and EGT increases with increase in blend percentage compared to diesel
- The BTE is the reverse case of BSEC at the above mentioned conditions
- With increase in gas flow rates for all test fuels, the emission parameters like CO, HC and CO_2values are increases
- In case of blended fuel, all the above mentioned emission parameters shows lower values compared to diesel
- The NOx and Smoke emission parameters are decreases with increase in gas flow rates. Also these values are decreases with increase in blend percentage compared to diesel.

From the above case studies, it is confirmed that blends of Karanja vegetable oil and woody biomass producer gas can be used as a potential fuel with reduced emissions in a diesel engine without any engine modification.

ACKNOWLEDGEMENT

The authors are thankful to the Department of Mechanical Engineering, SOA University, India for providing experimental setup to complete this experimental work.

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