International Journal of Advance Research in Science and Engineering
Volume No.06, Special Issue No.(02), December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

A Comparative Study on the Performance and Emission Analysis of a Dual Fuelled Diesel Engine with Karanja Biodiesel and Natural Gas

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ABSTRACT

In the present study, a single cylinder four stroke dual fuel diesel engine was tested to investigate the performance and emission characteristics of various test fuels. The engine was tested in dual fuel mode using diesel and Karanja biodiesel blends as pilot fuel along with Natural gas as primary fuel with a constant gas flow rate under different loading conditions. From the experimentation it was found that smoke opacity and oxides of nitrogen (NOx) are at low level for all the prepared test fuels in dual fuel mode but the emissions of carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbon (HC) were found higher. In comparison to diesel fuel, by increasing the blend percentage different emission parameters are found to be reduced. At different loading conditions all the test fuels show poor performance in dual fuel mode of operation when compared with single mode of operation with diesel and biodiesel. With increase in gas flow rates, except (NOx) and smoke emissions, the other emission parameters like CO, HC and CO_2 values increased for all test fuels. Again, all blended fuels showed lower performance compared to diesel. The maximum pilot fuel savings for diesel was found decreasing with the increase in karanja biodiesel. From the present work it may be concluded that Karanja biodiesel with Natural gas in dual mode can be can used as promising alternative for diesel with some required engine modifications and further research must be carried out to minimize the emissions of CO, HC and CO_2.

Keywords: Diesel, biodiesel, Natural gas, dual fuel, performance, emission

ABBREVIATIONS:

LPG	Liquefied Petroleum Gas	**CI**	Compression ignition
CNG	Compressed Natural Gas	**CO_2**	Carbon di oxide
CI	Compressed Ignition	**CO**	Carbon monoxide
KOME	Karanja Oil Methyl Ester	**PM**	Particulate matter

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NOx	Oxides of Nitrogen	**DI**	Direct Injection
BMEP	Brake mean effective pressure	**DCR**	Diesel consumption rate
BSFC	Brake specific fuel consumption	**%**	Percentage
BTE	Brake thermal efficiency	**PPM**	Parts per million
		g/kW h	Gram per kilowatt-hour

I INTRODUCTION

In recent era, considerable increases in demand of fossil fuels resulting from industrialization have resulted rises in prices because of the limitations of reserves and supply. Again, this is also a growing concern for the developing nations as they expend a significant part of their national income to import petroleum products. Addressing the above concerns, researchers around the world are searching for alternative fuels for engines. Attractive behaviours of Bio-fuels (oil and gas) in combustion and emission have been subject to intensive research work globally [1,2].

Present striking solution is the utilization of alternative fuels in diesel engines for both environmental and economical problems due to the increasing concern regarding diesel engines emissions, including NOx, smoke, and PM, and the rising cost of the liquid diesel fuel as well. In order to meet the stringent future emission legislations like particulate matter PM and NO_X, one of the approaches proposed to overcome the diesel engine emission issues is to use Dual fuel system in compression ignition (CI) engines [3]. The emission benefits of dual fuel CI engine operation are mainly based on a more homogeneous air–fuel mixture and low temperature combustion operation than in the case of conventional CI engine combustion [4,5].

Among several alternative fuels Natural gas is very promising and highly attractive. Beside its availability in several areas worldwide at encouraging prices, natural gas is eco-friendly fuel that has clean nature of combustion. It can substantially reduce the NOx emissions by approximately 50–80% while produces almost zero smoke and PM; which is extremely difficult to achieve in DI (Direct Injection) diesel engines. It can also contribute to the reduction of carbon dioxide (CO_2) emissions, due to the low carbon-to-hydrogen ratio. In addition, natural gas has a high octane number, and hence has high auto-ignition temperature. Therefore, it is suitable for engines with relatively high compression ratio without experiencing the knock phenomenon. Moreover, it mixes uniformly with air, resulting in efficient combustion to such an extent that it can yield a high thermal efficiency comparable to the diesel version at higher loads.

The most common natural gas–diesel operating mode is referred to as the pilot ignited natural gas diesel engine; where most of the engine power output is provided by the gaseous fuel, while a pilot amount of the liquid diesel fuel, represents around 20% of the total fuel supplied to the engine at full load operation, is injected near the end of the compression stroke to act as an ignition source of the gaseous fuel–air mixture. The injected spray ignites several points in the gaseous fuel–air mixture, forming multi flame-fronts that travel throughout the entire mixture. The engine power output is controlled by changing the amount of the primary gaseous fuel, while the pilot fuel quantity is kept constant [6-8].

It is common to use CNG (Compressed Natural Gas) for bi-fuel operations because the engine does not lose the output power. For better fuel economy and more efficient combustion natural gas is directly injected into cylinder before the end of the compression stroke. This also helps in maintaining the power output and the thermal efficiency of an equivalently-sized conventional diesel engine. However, direct injection of natural gas requires the development of special high-pressure gaseous injectors. Therefore, in most applications to date, natural gas is inducted or injected in the intake manifold to mix uniformly with air, and the homogenous natural gas–air mixture is then introduced to the cylinder as a result of the engine suction. The measurement of the gaseous fuel flow rate becomes a point of doubt and should be emphasized and carefully treated, in order to avoid the use of inappropriate measurement technique that does not take into account that the actual gaseous fuel consumption takes place in only one stroke per cycle; i.e. the suction stroke. As in typical four-stroke engine has only one suction stroke per cycle while there is no suction in the other three stokes. As the gaseous fuel should be inducted into the cylinder as a result of the engine suction only, its pressure should be kept as low as possible to prevent the flow while there is no suction. To provide better understanding of the combustion process in gas–diesel engines and some of their performance features and emission characteristics, numerous analytical models have also been developed [9-11].

Moreover, the effects of some important parameters, such as pilot diesel fuel quantity, pilot injection timing, natural gas percentage, natural gas composition, and intake air temperature have also been studied [12-16].

II EXPERIMENTAL SETUP

The aim of the study is to establish a combination of biodiesel in dual fuel mode and to study the various performance and characteristic of the engine with Natural gas as the gaseous fuel. The base engine for this work is kirloskar four stroke, single cylinder, direct injection stationary diesel engine. The modification is being done in intake manifold to run engine on dual fuel mode. The engine intake system is modified via the installation of a specially designed venturi-type gas mixer that allows the introduction of natural gas, and mix with the fresh air. The mixture is allowed to preheat then induced to the cylinder as a result of engine suction. The natural gas is supplied through high-pressure (200 bar) commercial CNG bottles; typical to those used in vehicular applications. A multi stage pressure regulator is used to reduce CNG pressure to sub atmospheric level for suction of engine. An electrical dynamometer coupled to the engine was used as a loading device. The load can be assorted on the dynamometer and there by engine by switching on or off the load resistances. The technical specifications of engine and dynamometer are listed below in Table 1.

Fuel consumption was measured with the help of a digital stopwatch and burette for JOME whereas mass flow rate of gaseous fuel is measured using a specially-designed Pitot-tube connected to a low pressure transducer having a maximum range of one inch of water. The pressure transducer converts the measured pressure to an analogue electrical signal, which is further manipulated via digital multi meter with computational functions, to be presented in the units of mass flow rate. The gaseous fuel, before entering the engine cylinder, passes through a small tank to damp the pressure fluctuation resulting from the engine suction.

AVL Di gas analyzer is used to record engine emission parameters like HC, NOx, CO etc. AVL smoke meter is used for measurement of engine smoke. All the instruments used in the test rig were of standard quality and the error within the permissible range. Detailed specification of test rig is mentioned in table 2. The engine trial was conducted as specified in IS: 10,000 and engine to operate at no load, 20, 40, 60 and 100% load condition.

Table 1 Technical specification of the engine and the alternator.

Engine Specification	
Make	Kirloskar oil Engine Ltd., India
Model	DAF 8
Rated Brake Power (bhp/kW)	8/5.9
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	95 X 110
Compression Ratio	17.5 : 1
Cooling System	Air Cooled (Radial Cooled)
Lubrication System	Forced Feed
Cubic Capacity	0.78 L
Starting	Hand Start with cranking handle
Dynamometer Specification	
Manufacturer	Kirloskar Electric Co. Ltd., India
Dynamometer Type	Single phase, 50 Hz, AC alternator
Rated Output	5 KVA @ 1500 rpm
Rated Voltage	230 V
Rated Current	32.6 A

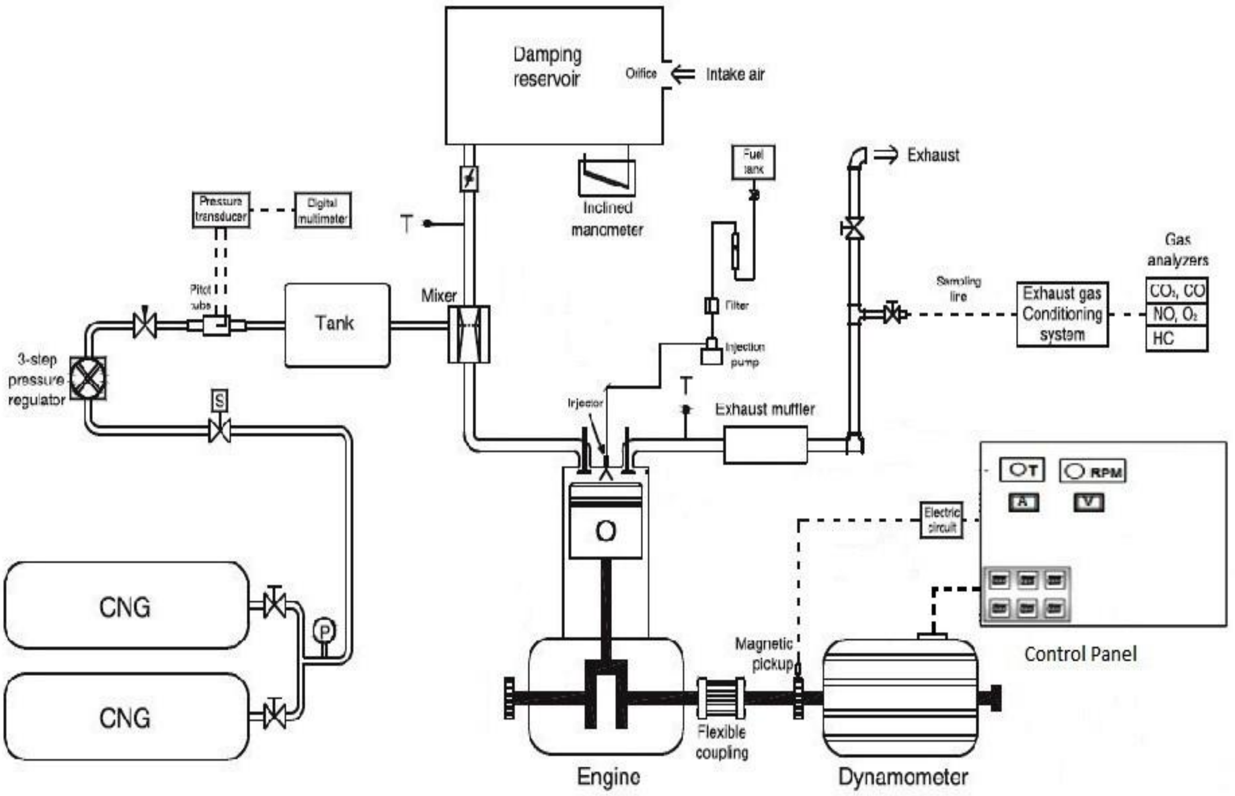

Figure 1 Schematic diagram of experimental test rig setup.

Table 2 Test rig specification

AVL Di Gas Analyser					
S.No.	Instrument Name	Measurement Range	Resolution	Measurement Technique	Percent Uncertainty
1	Carbon Monoxide	0 – 10 % volume	0.01 % Volume	Non dispersive infra-red sensor	0.2 %
2	Hydrocarbons	0 – 20,000 ppm Volume	1 ppm	Flame ionization detector - FID	0.2 %
3	Oxides of Nitrogen	0 – 5,000 ppm Volume	1 ppm	Chemi – luminescence principle, electro chemical sensor	0.2 %
4	AVL SMOKE METER	0 – 100 %	± 1 % Volume	Hatridge principle	0.1 %

Table 3 Physico-chemical properties of fuel.

S.No.	Fuel	Sp. Gravity	Kinematic viscosity(cSt) at 40ºC	Flash Point (ºC)	Calorific Value (MJ/kg)	Cetane Number
1.	Mineral Diesel	0.832	1.9	64	42.212	45-55
2.	KOME	0.885	4.5249	187	36.120	-
3.	Natural Gas	0.422	-	-184	55.530	-

III RESULTS AND DISCUSSION

The variations of performance and emission parameters with Natural gas flow rate are discussed in this section. As previous researchers indicated that biodiesel with lower blends show better performance as well as improved emission characteristics, while with higher blends the reduction in calorific value hampers the performance of the engine [17]. The physico-chemical properties of fuel are shown in table 3.

Performance Characteristics:

Fig. 2 shows the variation of brake thermal efficiency with respect to brake mean effective pressure. It is observed that the brake thermal efficiency of CNG with KOME at 80% load is 35.9% compared to diesel of 28.3%. The increase in brake thermal efficiency in the case of CNG-KOME operation is due to higher inlet charge cooling that reduced the temperature by about 12–15ºC due to the presence of KOME as a result of its higher latent heat of vaporization. As the inlet charge cools, the inlet charge (both CNG and air) density increases, which in turn results in better combustion, hence an improvement in brake thermal efficiency is noticed. The increase in brake thermal efficiency for dual fuel operation is due to uniformity in mixing CNG with air.

Fig. 3 shows the variation of specific energy consumption with load. The specific energy consumption of CNG-KOME dual fuel is reduced by 45% for dual fuel operation at 80% load compared to diesel. The lower specific energy consumption for CNG-KOME dual fuel is due to better mixing of CNG with air resulting in complete combustion of fuel.

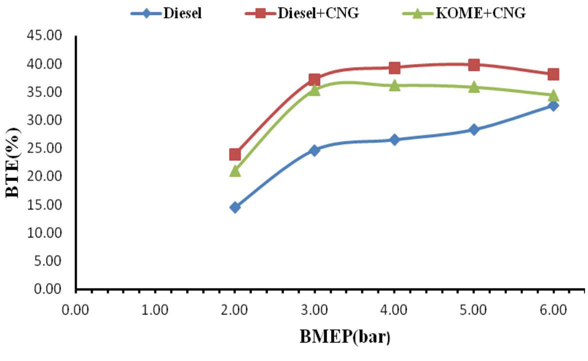

Figure 2 Variation of BTE Vs BMEP

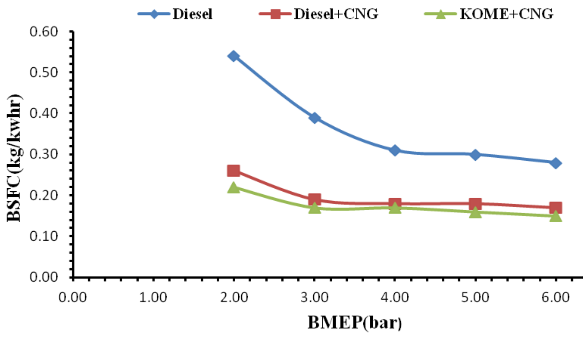

Figure 3 Variation of BSFC Vs BMEP

IJARSE
ISSN: 2319-8354

Emission Characteristic:

Fig 4. Show the variation of NOx emission. With CNG-KOME dual fuel operation NOx is reduced by 12% as compared with diesel at 80% load. At low load concentration of NOx is much less than diesel but it increases at higher load. The higher concentration of NOx is due to the peak combustion temperature [18].

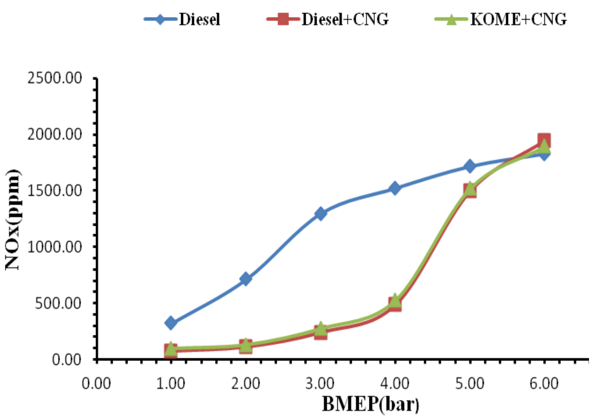

Figure 4 Variation of NOx with BMEP

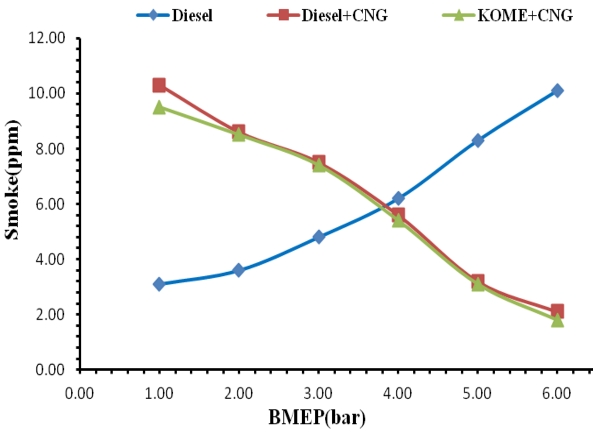

Figure 5 Variation of Smoke Vs BMEP

The variation of smoke with BMEP is shown in Fig. 5. The smoke of 0.7 PPM is observed in CNG-Diesel operation compared to base diesel fuel of 2.2 PPM and 0.8 PPM for CNG-KOME dual fuel at 75% load. The CNG on combustion produces mainly water vapour and does not form any particulate matter due to the absence of carbon atom, hence lower smoke level [19].

Fig. 6 shows the variation of hydrocarbon with BMEP. The hydrocarbon increases for CNG-Diesel operation compared to that of CNG-KOME dual fuel operation and base diesel fuel mode. At 25% load hydrocarbon emission are maximum, it is 2.01 g/kW h in JOME operation compared to both diesel and CNG-JOME dual fuel of 0.3 g/kW h. The increase in HC emission is due to the non-availability of oxygen during diffusion combustion period, since CNG and JOME undergoes instantaneous combustion as soon as the ignition starts [20].

The variation of carbon monoxide emissions with BMEP is shown in Fig. 7. At low load condition CO emission is similar for all fuel samples. Whereas while increasing load, in the CNG-KOME dual fuel mode it is reduced by 70% compared to diesel. The higher CO emission during dual fuel operation is due to the lower combustion temperature.

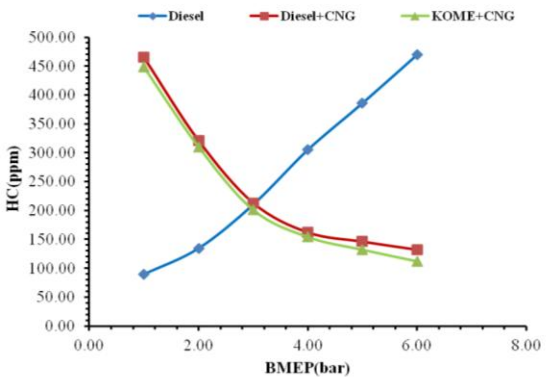

Figure 6 Variation of HC with BMEP

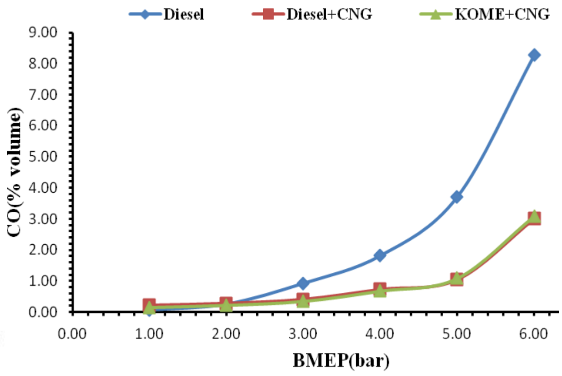

Figure 7 Variation of CO with BMEP

The variation of carbon dioxide emissions with load is shown in Fig. 8. At 20% load the CO_2 emissions are higher in diesel operation; CNG-KOME dual fuel mode gives 70% less CO_2 emission as compared to diesel. At 80% load the carbon dioxide emission is 55% more for KOME-CNG as compared with diesel. The CO_2 emissions are lower compared with the base diesel fuel, because of the low amount of carbon in CNG.

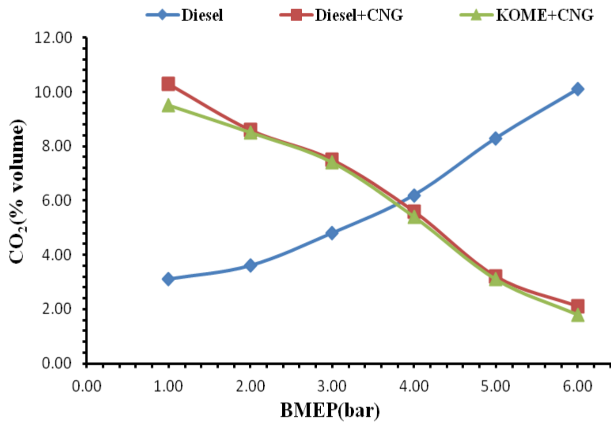

Figure 8 Variation of CO_2 with BMEP

IV CONCLUSION

Experiments were done on a diesel engine using CNG with KOME and CNG with diesel in the dual fuel mode and KOME is used ignition source. In general it is found that for dual fuel the part load performance with a significant reduction in emissions. The following conclusions are drawn from the present investigation:

1. CNG with KOME and CNG with diesel in dual fuel operation showed an increase in brake thermal efficiency by about 22% and 35%, respectively compared to diesel.
2. A significant reduction in NOx emissions was obtained with CNG-KOME blends dual fuel mode as well as baseline diesel.
3. CNG-KOME operation exhibited a significant reduction in smoke emissions compared to base diesel fuel.
4. A severe knocking was noticed during the operation of the engine with CNG-KOME blends operation beyond 75% load due to the instantaneous combustion at high loads.

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