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Article

INTEGRATED RESEARCH ADVANCES

Experimental investigation on the effect of injection timing, carburetor type and exhaust gas recirculation on compression ignitionengine fuelled with diesel–compressed biogas and rice bran oil methyl ester–compressed biogas

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ABSTRACT

Energy is the basic stamina for economic growth of any country and also it carries same weightage to keep the environment free from pollution for the better health of all human beings. So to harness energy it is very much necessary to be depend on renewable energy instead of conventional fuels which conjointly helps to reduce emissions, increase human welfare in terms of self-entrepreneurship, avoiding foreign exchange by reduced consumption of petrol, diesel, CNG, LPG, nuclear fuel etc. among many available energy sources biogas also carries the high importance. Production, purification and storing of biogas at high pressure in cylinders can be made utilized in automobile sectors and also for the electrification in the rural areas. In the present study, an experimental work had been carried out to analyze the performance and emission characteristics of diesel engine by varying the injection timing, carburetor type, EGR when fuelled with Diesel–CBG and ROME–CBG at 80% and 100% load. From the test results it was observed that, maximum brake thermal efficiency, maximum peak pressure and lower emissions were found at 27° bTDC injection timing, carburetor type-2 (CRB2) and 10% EGR.

Keywords: Carburetor, Compressed biogas, Emission, Exhaust gas recirculation, Injection timing, Performance, Rice bran oil methyl ester.

INTRODUCTION

Compression ignition (CI) engines are widely used as power source for automobile due to their high thermal efficiency, excellent fuel economy and low regulated emissions of unburned hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide (CO_2) compared to those of spark ignition (SI) engines. From an environmental point of aspects, however, diesel engines generally exhaust a larger amount of particulate matter (PM) and nitrogen oxide (NOx) pollutant emissions than those of gasoline engines.[1,2] In recent years, the fossil-fuels have suffered from a sudden rise in prices because of the limitations of deposit, supply and considerable increases in demand for petroleum fuels resulting from the industrialization. Furthermore, the regulations for PM and NOx emissions from diesel engines have strengthened, and reductions in CO_2, which is a greenhouse gas, emissions also raised important issues on environmental problems.[3,4] For these reasons, bio-fuels (liquid and gaseous) have been subject to intensive research work all over the world because they are extraordinarily attractive alternative fuels. Biodiesel (liquid fuel) is nontoxic, renewable, and biodegradable, and is the most promising alternative energy for diesel engines. Biodiesel is produced by a trans-esterification process with renewable

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agricultural resources like vegetable oils, animal fats and waste oils. The principal advantages of biodiesel are that it reduces or suppresses the formation of sulfur dioxide (SO_2), CO, HC and PM emissions during the combustion process due to its low sulfur, low aromatic, and the presence of oxygen-containing compounds. In addition, biodiesel has good ignition ability in engine due to its relatively high cetane number compared to that of conventional diesel fuel.[5,6] Biogas (gaseous fuel) promisingly, is also to be abundantly available as fuel for CI engines and is regarded as an alternative clean energy resource in view of its friendly environmental nature because it has lower impact on pollution compared to fossil liquid fuels. In general, it is produced by the anaerobic fermentation of organic waste in landfills and the anaerobic digestion of sludge, crops, and agro-industrial byproducts and animal organic waste.[7] Methane (CH4) is the main component (about over 65% by vol.) of the biogas and exhibits greater resistance to the knock phenomenon due to its higher octane rating and auto-ignition temperature, making it appropriate for engines with high compression ratios. In addition, the carbon content of methane is also relatively low compared to that of conventional diesel fuel, resulting in a significant decrease in pollutant exhaust emissions.[8,9]Many researchers have studied the combustion and emission characteristics of the dual-fuel engines fueled with gaseous-liquid fuels. Mustafi and Raine[10] experimentally investigated the exhaust emission characteristics of a direct injection (DI) diesel engine operated with natural gas or biogas–diesel dual-fuels. Their study showed that stable engine operation is possible with natural gas (NG) and biogas fueling without any modifications to either the engine or its operation, and that the PM (about 70% by mass) and NOx emissions (maximum of 37% by mass) of duel-fueling are much smaller than those of diesel fueling operating under the same operation. Maji et al.[11] investigated the application of compressed natural gas (CNG) in reducing the noise level, specific fuel consumption, and NOx emissions, however, the UHC increased in the dual-fuel mode with a substitution of CNG for 75% of the diesel fuel. Shen et al.[12] investigated the influence of the CNG ratio, the advance of the pilot injection for diesel fuel and the intake temperature on the combustion process, emissions, and engine performance of a dual-fueled engine. The results showed that the CNG ratio, pilot injection timing and intake temperature play important roles in the formation of pollutant emissions and the performance of an engine fueled with dual-fuels.

Transesterification Reaction

It is most commonly used and important method to reduce the viscosity of vegetable oils. In this process triglyceride reacts with three molecules of alcohol in the presence of a catalyst producing a mixture of fatty acids, alkyl ester and glycerol. The process of removal of all the glycerol and the fatty acids from the vegetable oil in the presence of a catalyst is called esterification. The parameter such as temperature, molar ratio and catalyst concentration that affect the transesterification of Rice Bran oil were optimized initially. The transesterification set up houses 2 L capacity, round bottom flask provided with three necks that was placed in a water container for heating the oil. A heater with a temperature regulator was placed in the round bottom flask. A high speed motor with a magnetic stirrer was used for vigorous mixing of the oil. In the transesterification process triglycerides of Rice Bran oil reacts with methyl alcohol in the presence of catalyst (NaOH) to produce a fatty acid ester and glycerol. In this process 1000 g Rice Bran oil, 230 g methanol and 8 g sodium hydroxide pellets were placed in the round bottom flask. The contents were heated to 70°C and stirred vigorously for one hour to promote ester formation. The mixture was next transferred to a separating funnel and allowed to settle under gravity overnight. The upper layer in the separating funnel consists of ester whist the lower layer is glycerol which was removed. The separated ester with 250 g hot water and allowed to settle under gravity for 24 hours. Water washing separates residual fatty acids and catalyst and these were removed using a separating funnel. Finally the moisture from the ester was removed by adding silica gel crystals. Various biodiesel-diesel blends (B20, B40, B60, B80 and B100) were prepared for the experimental work.

Properties of fuels

Table 1. Properties of ROME and CBG compared with diesel

Properties	Diesel	ROME	CBG
Viscosity @ 40˚C (cSt)	4.59	5.16	_
Flash point (˚C)	56	176	_
Calorific Value (kJ/kg)	44146	39345	36540
Density (kg/m³)	827	860	0.68

Composition of CBG

Table 2. Composition of CBG

Composition	% Volume
CH_4	89
H_2S	1.5
CO_2	8
N_2	1.5

Experimental Setup

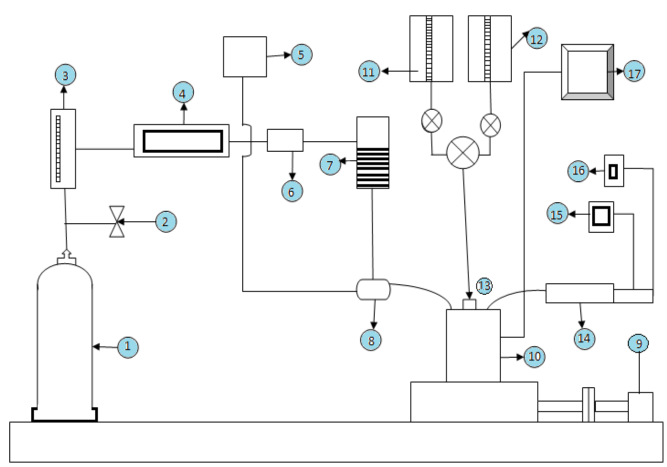

Figure 1. Schematic view of the experimental set up of dual fuel engine

1. CBG cylinder
2. Pressure regulator
3. CBG rotameter
4. Gas flow meter
5. Air box

6. Dry flame arrester
7. Wet type flame trap
8. Mixing chamber
9. Eddy current dynamometer
10. Diesel engine
11. Diesel tank
12. Biodiesel tank
13. Fuel injector
14. Exhaust gas line
15. Exhaust gas analyzer
16. Smoke meter
17. Computer connected to engine

ENGINE SPECIFICATIONS

Table 3. Engine specifications

Engine Parameters	Specifications
Type	TV1 (Kirloskar make)
No of cylinders	Single cylinder
No of strokes	Four stroke
Rated power	5.2 kW at 1500 RPM
Bore x Stroke	87.5 mm x 110 mm
Compression ratio	17.5 : 1
Injection timing	23° bTDC
Dynamometer	Eddy current

The experiment was carried out to investigate the performance and emission characteristics of CI engine fuelled with Diesel–CBG and ROME–CBGin a stationary single cylinder diesel engine for different injection timing, carburetor type and exhaust gas recirculation. Technical specifications of an engine were given above. The engine was coupled with eddy current dynamometer. The performance and emission parameters were analyzed from the graphs regarding brake thermal efficiency, HC, CO, NOx, smoke opacity.

Figure 2. Carburetor for air and biogas mixing

Figure 3. Ventury

RESULTS AND DISCUSSION

EFFECT OF INJECTION TIMING (OPTIMIZATION OF INJECTION TIMING)

Brake thermal efficiency (BTE)

As the injection timing is advanced from 19°BTDC to 27° BTDC, the BTE increased for 80% and 100% loads. The reason for this increased BTE is that, more time would be available for CBG fuel burning and results in better performance with improved brake thermal efficiency. BTE values for diesel–CBG and ROME–CBG dual fuel operation at 27° BTDC injection timing are found to be 23.48% and 21.29 % respectively at 80% load (Figure 4).

Brake specific fuel consumption (BSFC)

Increase in injection timing from 19°BTDC to 27°BTDC, it was found decrement in the BSFC value. The reason for this may be due to sufficient time availability for evaporation and mixing of fuel and air with increased premixed combustion and lower diffusion combustion (Figure 5).

HC emissions

As the injection timing increases the HC emission decreased considerably for both loads. The reason for decreased HC emissions with increased injection timing could be due to better combustion with increased BTE. This is due to a longer ignition delay of the mixture with the increased timing advance. The longer ignition delay allows a fuller spray penetration and development, creating a larger amount of the pilot fuel-air-gaseous fuel mixture (or flame propagation region) prior to ignition. The higher combustion rates of this larger premixed regions yields higher combustion temperatures and thus, lowers the UBHC emissions. HC emission levels for Diesel–CBG and ROME–CBG dual fuel operation at 19, 23 and 27° BTDC injection timing, at 80% load are found to be 76, 68 and 63 and 84, 74 and 71 ppm respectively (Figure 6).

CO emissions

The emission of CO results from incomplete combustion of HC fuel. As the injection timing was advanced from 19° BTDC to 27° BTDC the CO emission decreased considerably. With larger injection advance, overall better combustion and the activity of the partial oxidation reactions reduced the CO emissions. CO emission levels for Diesel–CBG and ROME–CBG dual fuel operation at 19, 23 and 27° BTDC injection timing, at 80% load is found to be 0.21, 0.14 and 0.12% and 0.24, 0.21 and 0.18% respectively. At 80% load and 27° BTDC the values of CO emissions for Diesel–CBG and ROME–CBG were 0.12 and 0.18% respectively (Figure 7).

NOx emissions

As the injection timing increases the emission of NOx increases considerably. The reason for increased NOx emissions with increased injection timing could be due to better combustion prevailing inside the engine cylinder and more heat released during combustion. NOx emission levels for Diesel–CBG and ROME–CBG dual fuel operation at 19, 23 and 27° BTDC injection timing are found to be 680, 890 and 910 and 660, 730 and 784 ppm respectively (Figure 8).

Smoke opacity

The smoke opacity decreases with increase in injection timing. This is because of better combustion prevailing inside the engine cylinder. It is also evident that as engine load increases, the smoke emissions increase slightly due to the decrease of air volumetric efficiency in dual fuel mode. Smoke levels for Diesel–CBG and ROME–CBG dual fuel operation at 19, 23 and 27° BTDC injection timing are found to be 66, 61 and 64 and 74, 68 and 71 HSU respectively at 80% load (Figure 9).

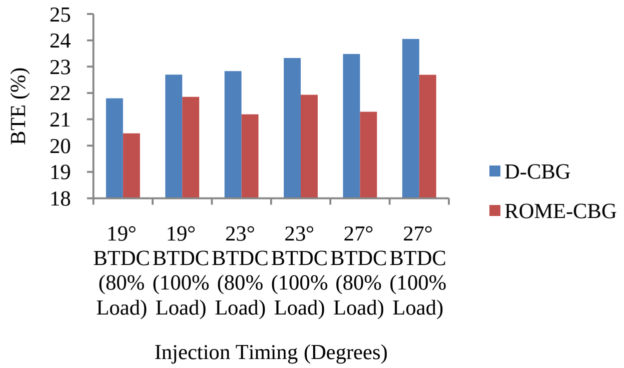

Figure 4. Variation of BTE with injection timing for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

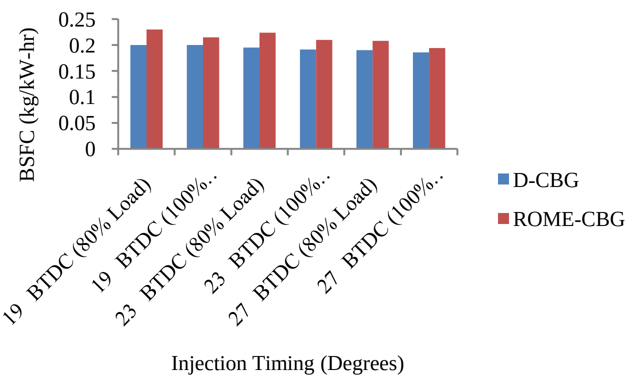

Figure 5. Variation of BSFC with injection timing for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

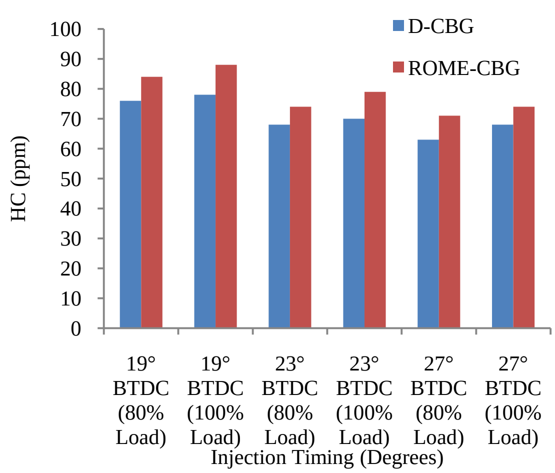

Figure 6. Variation of HC emissions with injection timing for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

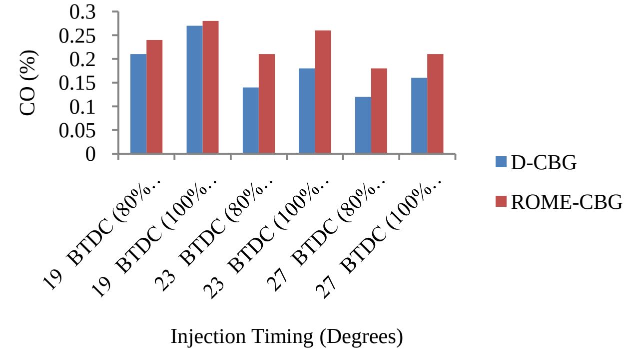

Figure 7. Variation of CO emissions with injection timing for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

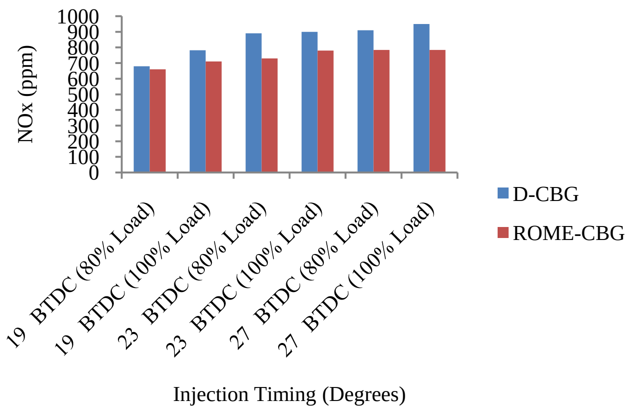

Figure 8. Variation of NOx emissions with injection timing for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

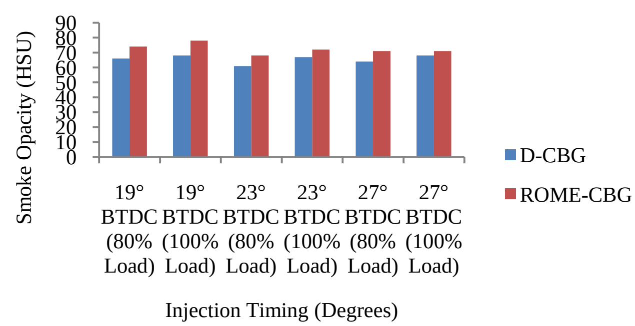

Figure 9. Variation of Smoke opacity with injection timing for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

Effect of carburetor type (optimization of carburetor)

Brake thermal efficiency (BTE)

With two carburetors one is of simple one (CRB1) and other is 3mm, 6 hole size or venture type carburetor (CRB2). Brake thermal efficiency was found to be higher for venture carburetor compared to simple carburetor. This is because venture carburetor provides better air-CBG mixing due to which almost complete combustion occurs hence thermal energy released will be high enough to produce high brake power output. BTE values for Diesel-CBG and ROME-CBG operation with 3mm hole geometry carburetor (CRB2) are found to be 26.16 and 22.88% respectively at 80% load (Figure 10).

Brake specific fuel consumption (BSFC)

BSFC value is less for the engine operation when CRB2 was used, because it mixes air and biogas in a proper mixture (stoichiometric) so combustion of mixture produces same power with less consumption of fuel when compared with values of BSFC when engine operated with CRB1 (Figure 11).

HC emissions

The HC emissions were least for 3mm carburetor. This is mainly because of better combustion associated with higher brake thermal efficiency observed with carburetor 2 which reduces HC emissions. HC levels for Diesel–CBG and ROME–CBG operation with 3mm hole geometry carburetor (CRB2) are found to be 63 and 64 ppm respectively at 80% load (Figure 12).

CO emissions

The CO emissions were least for 3mm carburetor in both the cases. The main reason for the cause of CO emission is insufficient availability of oxygen molecules for complete combustion which is caused by supply of excess (rich mixture) energy to fulfill the requirement. This is may be avoided with a carburetor of 3mm hole size. CO levels for Diesel–CBG and ROME–CBG operation with 3mm hole geometry carburetor (CRB2) are found to be 0.15 and 0.165% respectively at 80% load and 0.17 and 0.19% for 100% load (Figure 13).

NOx emissions

The NOx emissions were more for CRB2. This is mainly because with the use of CRB2, results in increased premixed combustion phase which resulted in higher heat release rate. These higher NOx emissions may be controlled by suitable exhaust gas recirculation method. NOx levels for Diesel–CBG and ROME–CBG operation with 3mm hole geometry carburetor (CRB2) are found to be 943 and 815 ppm respectively at 80% load (Figure 14).

Smoke opacity

The smoke opacity was lesser with mixing chamber venture (CRB2) having 3mm hole geometry. CRB2 ensures stoichiometric air gas mixture providing better combustion occurring inside the engine cylinder. Smoke values for Diesel–CBG and ROME–CBG operation with 3mm hole geometry carburetor (CRB2) are found to be 61 and 68 HSU respectively at 80% load (Figure 15).

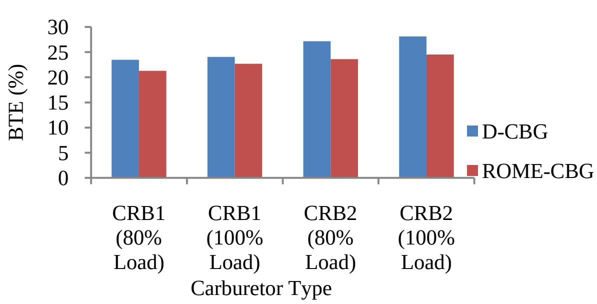

Figure 10. Variation of BTE with carburetor type for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

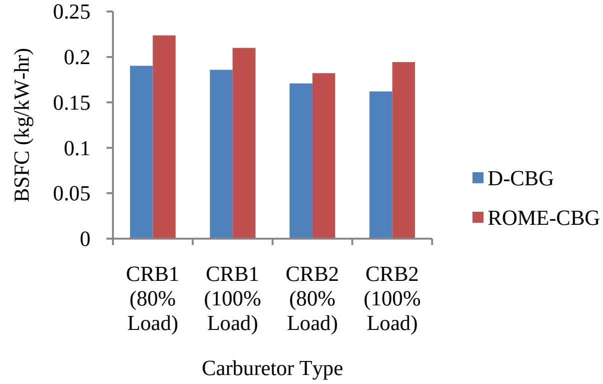

Figure 11. Variation of BSFC with carburetor type for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

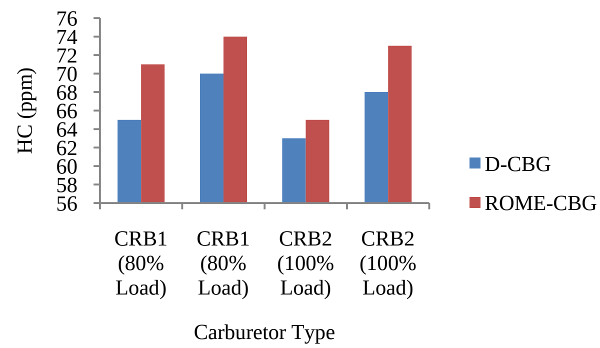

Figure 12. Variation of HC emissions with carburetor type for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

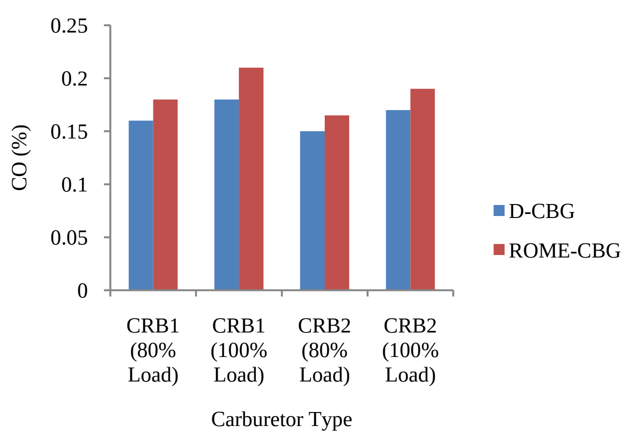

Figure 13. Variation of CO emissions with carburetor type for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

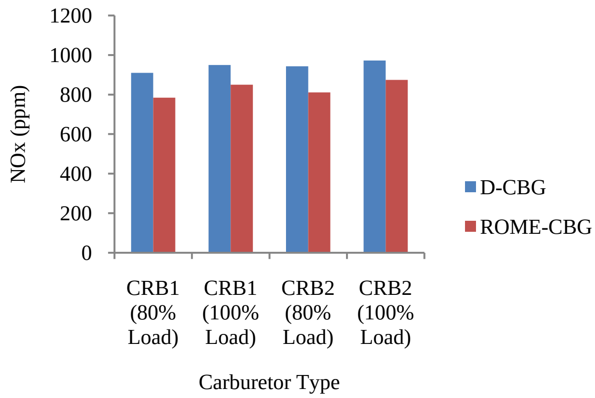

Figure 14. Variation of NOx emissions with carburetor type for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

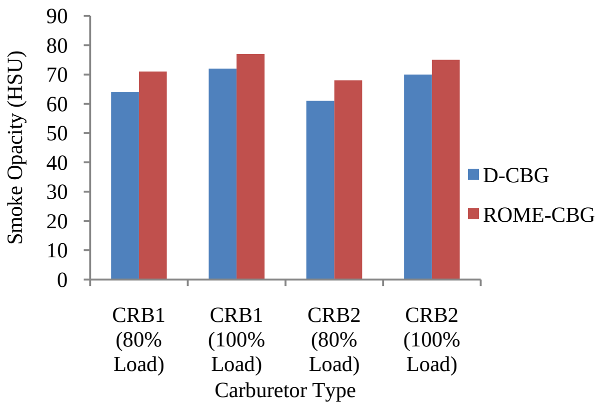

Figure 15. Variation of Smoke opacity with carburetor type for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

Effect of exhaust gas recirculation (optimization of egr)

Brake thermal efficiency (BTE)

As the EGR rate increases the values of BTE found to increase. Reason is the non-combusted hydrocarbons undergoes re combustion when exhaust gases were re circulated and also EGR increase leads to increase in intake charge temperature which increases the speed of combustion (Figure 16).

HC emissions

The value HC emission goes on increases with respect to increase in load and EGR. It may be due availability of oxygen may be reduced which results in rich mixture that leads to incomplete combustion and also emits high hydrocarbon (Figure 17).

CO emissions

The value of CO increases with increasing load and EGR. Reason may be unavailability of oxygen results in incomplete combustion which leads to CO emission at the initial stages but however biodiesel contains the higher oxygen which compensate the oxygen deficient under EGR (Figure 18).

NOx emissions

The value of NOx is decreased considerably with increase in EGR rate. Simple reason is when exhaust gases mixes with fresh air charge, the temperature of the combustion chamber reduces which results in lower NOx values (Figure 19).

Smoke opacity

The smoke increases slightly as the EGR rates increases. This is because of the recirculation of exhaust gases into the cylinder (Figure 20).

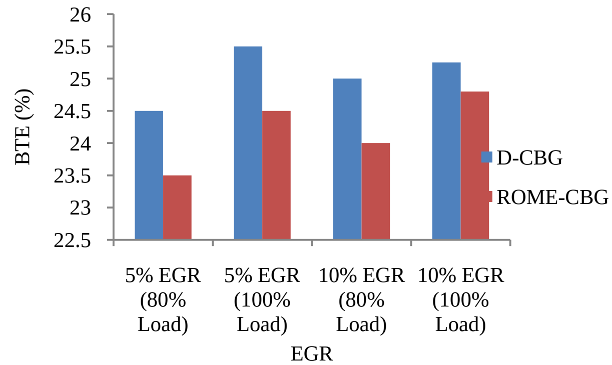

Figure 16. Variation of BTE with EGR for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

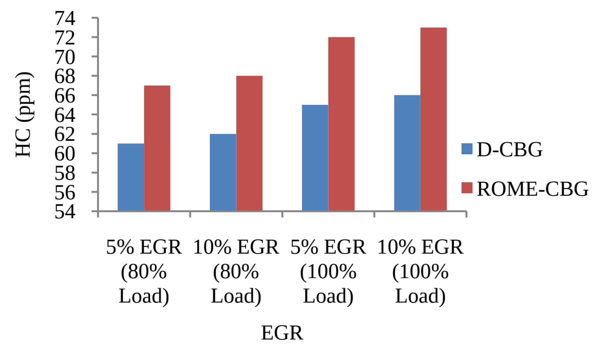

Figure 17. Variation of HC emissions with EGR for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

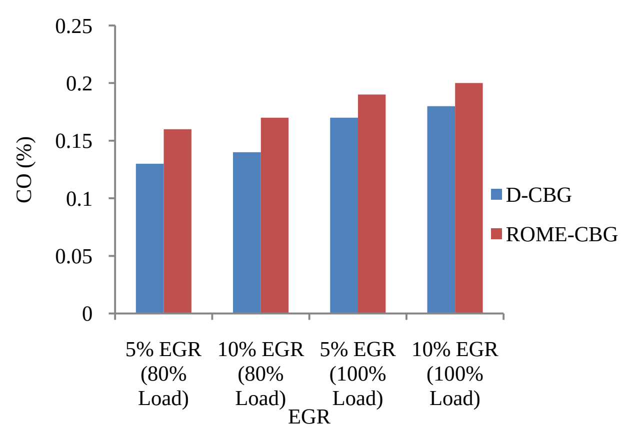

Figure 18. Variation of CO emissions with EGR for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

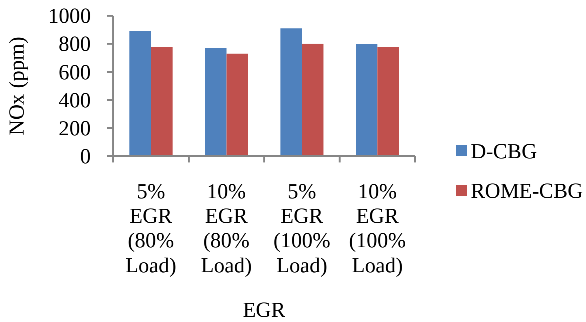

Figure 19. Variation of NOx emissions with EGR for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

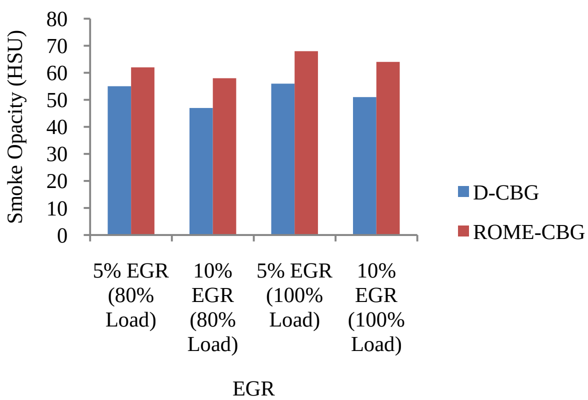

Figure 20. Variation of Smoke opacity with EGR for Diesel–CBG and ROME–CBG fuel combinations operated at 80% and 100% load.

Conclusions

With increase of injection timing from 19°BTDC to 27°BTDC leads to increase of BTE and NOx values but there is decrease of BSFC, CO, HC, Smoke emissions. At 100% load engine gives better performance as compared to 80% load. Among two different carburetors CRB1 and CRB2, the CRB2 gives better results of engine performance and emissions.The effect of EGR can be found predominant in reduction of NOx emissions. There is a slight increase in brake thermal efficiency of engine due to EGR. HC emissions are increases with increase in EGR rate. The CO increases with increase in EGR rate. Smoke increases slightly with increase in percentage of EGR. So taking all the results into consideration from the present experiment, EGR with 10% exhaust gas recirculation would result in optimum engine performance as well as reduction of NOx emissions and considerable values of other emissions.

Abbreviations

CBG – Compressed biogas

ROME – Rice bran oil methyl ester

CNG – Compressed natural gas

LPG – Liquefied petroleum gas

EGR – Exhaust gas recirculation

CRB – Carburetor

References

1 R.L. McCormic, C.J. Tennant, R.R. Hayes, S. Black. Regulated Emissions from Biodiesel Tested in Heavy Duty Engines Meeting 2004 Emission Standards. *SAE* **2005,** 2005-01-2200.

2 S.H. Yoon, S.H. Park, C.S. Lee.Experimental investigation on the fuel properties of biodiesel and its blends at various temperatures. *Energy and Fuels,***2008,** 22, 652–656.

3 M.Y. Kim, S.H. Yoon, C.S. Lee. Impact of split injection strategy on the exhaust emissions and soot particulates from a compression ignition engine fueled with neat biodiesel. *Energy and Fuels*, **2008,** 22, 1260–1265.

4 M.Y. Kim, S.H. Yoon, J.W. Hwang, C.S. Lee. Characteristics of particulate emissions of compression ignition engine fueled with biodiesel derived from soybean. *Journal of Engineering for Gas Turbine and Power*, **2008,** 130(5), 052805-1–052805-7.

5 S.H. Yoon, H.K. Suh, C.S. Lee. Effect of spray and EGR rate on the combustion and emission characteristics of biodiesel fuel in a compression ignition engine. *Energy and Fuels*, **2009,** 23, 1486–1493.

6 S.H. Park, S.H. Yoon, C.S. Lee. Effect of the temperature variation on properties of biodiesel and biodiesel–ethanol blends fuels. *Oil & Gas Science and Technology*, **2008,** 63(6), 737–745.

7 C. Rahmouni, M. Tazerout, O. Le Corre. A method to determine biogas composition for combustion control. *SAE* **2002,** 2002-01-1708.

8 C. Tricase, M. Lombardi. State of the art and prospects of Italian biogas production from animal sewage: technical-economic considerations. *Renewable Energy*, **2009,** 34, 477–485.

9 B.B. Sahoo, N. Sahoo, U.K. Saha. Effect of engine parameters and type of gaseous fuel on the performance of dual-fuel gas diesel engines – A critical review. *Renewable and Sustainable Energy Reviews*, **2009,** 13, 1151–1184.

10 N.N. Mustafi, R.R. Raine. A study of the emissions of a dual fuel engine operating with alternative gaseous fuels.*SAE***2008,** 2008-01-1394.

11 S. Maji, Amit Pal, B.B. Arora. Use of CNG and diesel in CI engines in dual fuel mode.*SAE* **2008,** 2008-28-0072.

12 S. Jie, Q. Jun, Y. Mingfa. Turbocharged diesel/CNG dual-fuel engines with intercooler: combustion, emissions and performance. *SAE* **2003,** 2003-01-3082.

13 M.D. Phan, W. Kanit. Study on biogas premixed charge diesel dual fuelled engine. *Energy Conversion and Management*, **2007,** 48, 2286–2308.

14 N. Bahman, P. Vahab, N. Gholamhassan, Y. Talal, G. Barat. Experimental investigation of performance and emission parameters of a small diesel engine using CNG and biodiesel.*SAE* **2007,** 2007-32-0075.

15 James P. Szybist, Stephen R. Kirby, Andre L. Boehman. NOx emissions of alternative diesel fuels: a comparative analysis of biodiesel and FT diesel. *Energy and Fuels*, **2005,** 19, 1484–1492.

16 G.A. Karim. The dual fuel engine of the compression ignition type—prospects, problems and solutions—a review. *SAE* **1983,** 831073.

17 G. Prakash, A. Ramesh, A.B. Shaik. An approach for estimation of ignition delay in a dual fuel engine.*SAE* **1999,** 1999-01-0232.

18 Y. Zhang, A.L. Boehman. Impact of biodiesel on NOx emissions in s common rail direct injection diesel engine. *Energy and Fuels*, **2007,** 21, 2003–2012.
19 I. Saanum, M. Bysveen, J.E. Hustad. Study of particulate matter, NOx and hydrocarbon emissions from a diesel engine fueled with diesel oil and biodiesel with fumigation of hydrogen, methane and propane. *SAE* **2008,** 2008-01-1809.
20 A. Upatnieks, C.J. Muller. Clean, controlled DI diesel combustion using dilute, cool charge gas and a short-ignition-delay, oxyenated fuel, *SAE* **2005,** 2005-01-0363.
21 G.A. Karim, A review of combustion processes in the dual fuel engine-the gas diesel engine. *Progress in Energy and Combustion Science*, **1980,** 6, 277–285.
22 C.S. Weaver, S.H. Turner. Dual fuel natural gas/diesel engines: technology, performance, and emissions. *SAE* **1994,** 940548.
23 P. Verma, V.M. Singh. Assessment of diesel engine performance using cotton seed biodiesel. *Integrated Research Advances*, **2014**, 1(1), 1-4.
24 Praveen A. Harari. Experimental Investigation on the Performance and emission characteristics of compression ignition engine fuelled with various blends of water melon biodiesel. *Integrated Research Advances*, **2017**, 4(1), 18-23.
25 D.N. Basavarajappa, N. R. Banapurmath, S.V. Khandal, G. Manavendra. Performance Evaluation of Common Rail Direct Injection (CRDI) Engine Fuelled with Uppage Oil Methyl Ester (UOME). *Int. J. Renewable Energy Development*, **2015**, 4(1), 1-10.
26 N.R. Banapurmath, P.G. Tewari, RS. Hosmath. Performance and emission characteristics of a DI compression ignition engine operated on Honge, Jatropha and sesame oil methyl esters. *Renewable Energy*, **2008**, 33, 1982-1988.
27 V.S. Yaliwal, N.R. Banapurmath, N.M. Gireesh, R.S. Hosmath, Teresa Donateo, P.G. Tewari. Effect of nozzle and combustion chamber geometry on the performance of a diesel engine operated on dual fuel mode using renewable fuels. *Renewable Energy*, **2016**, 93, 483-501.
28 Ranganatha Swamy L., T.K. Chandrashekar, N.R. Banapurmath, P. Nashipudi. Effect of Injection Timing, Combustion Chamber Shapes and Nozzle Geometry on the Diesel Engine Performance. *Universal Journal of Petroleum Sciences*, **2014**, 2, 74-95.
29 D.N. Basavarajappa, N. R. Banapurmath, S.V. Khandal, G. Manavendra. Effect of Combustion Chamber Shapes & Injection Strategies on the Performance of Uppage Biodiesel Operated Diesel Engines. *Universal J. Renewable Energy*, **2014**, 2, 67-98.
30 P. Verma, M. P. Sharma. Comparative analysis of effect of methanol and ethanol on karanja biodiesel production and its optimization. *Fuel*, **2016**, 180, 164-174.
31 N.R. Banapurmath, P.G. Tewari, V.S. Yaliwal, Satish Kambalimath, Y.H Basavarajappa. Combustion characteristics of a 4-stroke CI engine operated on Honge oil, Neem and Rice Bran oils when directly injected and dual fuelled with producer gas induction. *Renewable Energy*, **2009**, 34, 1877-1884.
32 P. Kumar, M.P. Sharma, G. Dwivedi. Impact of biodiesel on combustion, performance and exhaust emissions of diesel engines. *J. Int. Sci. Tech.*, **2014**, 2(2), 57-63.
33 G. Dwivedi, M.P. Sharma. Investigation of Oxidation stability of Pongamia Biodiesel and its blends with diesel. *Egyptian Journal of Petroleum*, **2016**, 25, 15-20.