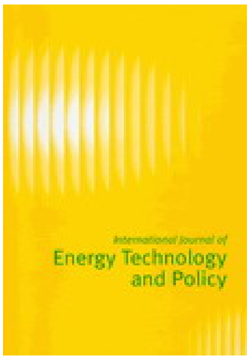

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Experimental investigations of dual fuelled two-cylinder diesel engine with biodiesel and natural gas using a novel air-gas mixer

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Experimental investigations of dual fuelled two-cylinder diesel engine with biodiesel and natural gas using a novel air-gas mixer

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Abstract: In this study, natural gas (NG) and biodiesel were used to investigate the emission, combustion and performance behaviour of a CI engine in twin fuel mode. A mixture of natural gas and air using a newly designed coaxial multi holes air gas mixer has been naturally inducted during intake stroke of the engine as the main fuel whereas diesel/MOME biodiesel is used as pilot fuel to initiate the combustion. The experimental results show that brake thermal efficiency is 1.26% lower, BSEC is 1.17% higher than diesel. Nitrogen oxides are reduced by 4.12% when using DCNG and by 63.07% when using DLF. The level of smoke opacity emission in BCNG is 76% lower than in DLF, but 6.67% higher to DCNG modes at full load. In comparison to other modes of operation, BCNG has a higher value of exhaust gas temperature, and emission.

Keywords: natural gas; NG; combustion; emission; renewable fuel; mustard oil methyl ester; air fuel mixture.

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1 Introduction

Implementation of progressively strict worldwide exhaust gas emissions regulations from the internal combustion engine and rapidly depleting fossil fuel reserves are the reason behind extensive investigation in the field of alternative clean fuel (Bai et al., 2020). Diesel engines produce the largest contributor to the deteriorating environmental conditions is the exhaust gases in the form of NO_x (Akadiri et al., 2019). In the emissions, NO_x has unfavourable effects on the human physical condition (Hosseinzadeh-Bandbafha et al., 2022). To reduce the emissions, especially NO_x emitting from direct injection diesel engines, investigators have suggested various improved alternatives, example as partial diesel replacement with gaseous fuel. The engine that uses both gaseous and liquid fuel is known as DF IC engines (Ray et al., 2020; Sharma and Sharma, 2021b). Among various solutions available, the adoption of CNG as an alternative fuel is the utmost promising (Meng et al., 2020). The environmental and financial profits of using NG in internal combustion engine was predicted to be substantial. The major constituent of CNG is the simplest hydrocarbon known as methane. NG is a clean-burning fuel as a result of this, less polluting than the combustion of mineral fossil fuels. It emits less CO_2 and is used in automobile engines since the 1930s (Imran et al., 2014). Besides this, the factor of fuel diversification is also one of the reasons for turning to the application of CNG. There is the widespread usage of CNG as a transportation fuel and it is further predictable that the use of CNG in the transport sector is bound to increase. In this context, the potentially encouraging solution can be the use of dual-fuel strategies for reducing emissions and improving the overall efficiency of IC engines and hence this conception is based on the use of a minimal amount of pilot fuel to start the ignition and CNG being the main fuel (Bui et al., 2021; Lee et al., 2020).

Another promising alternative fuel that can replace the use of mineral diesel and solve the problem of excessive emission is biodiesel. Biodiesel is recyclable, sustainable and it is less poisonous and has approximately equal properties to minerals diesel fuel when burnt. Biodiesel is produced through a chemical process known as transesterification. Both vegetable-based and animal fatty acids can be used for this purpose (Sharma, 2021b; Sharma and Sahoo, 2022). Because oils cannot be utilised directly in IC engines due to their high viscosity, the goal of this method is to reduce their viscosity. Besides this oil in raw form have a lower heating value and there are also chances of thermal cracking during spray in hot combustion chamber conditions. After the transesterification process, the biodiesel can be used in IC engines like fossil-based diesel with little or no hardware modifications (Sharma, 2020). The oil used to prepare biodiesel can be suitable for eating (like mustard, rapeseed, soybean, palm, etc.) or non-edible (like algal, neem, jatropha, karanja, rubber seed, mahua, etc.) (Sharma and Sharma, 2020; Singh et al., 2020). Furthermore, in considerations of engine wear, availability and cost, biodiesel has proven to be superior to mineral diesel. On the other hand combustion of biodiesel in the IC engine produces less detrimental pollutants and also provides improved better lubricity in comparison with fossil-based diesel fuel (Bora and Saha, 2016; Mahmudul et al., 2017; Sharma, 2021a; Sharma and Sharma, 2021a).

The lab-based experimental studies done on dual-fuel engines to observe the ignition and discharge characteristics of diesel engine operated on CNG (Edara et al., 2019). The study reported improvement in thermal efficiency by retarding fuel injection but split injection causes reduced ignition delay, lower combustion duration, and reduced EGT (Mohsin et al., 2014), used a multi-cylinder CI engine. Different combinations of diesel, biodiesel, CNG-diesel, and CNG-biodiesel were used. The experimental results illustrated brake power in biodiesel fueled engine improved up to 20% in comparison to fossil-based fuel. Biodiesel (20%)–CNG combination caused the highest engine shaft torque than other blends. On the emission side biodiesel significantly reported higher carbon monoxide (CO) (15–32%) and NO_x (6.67–7.03%) however it reduced the unburned hydrocarbons (5.76–6.25%) and CO (0.47–0.58%). The study concluded that biofuels may be utilised as a clean fuel without requiring any engine changes, especially in the heavy engines. A single-cylinder DI fossil fuel based CI engine operated on CNG and diesel was investigated by Ryu (2013). The pilot fuel injection was maintained at 120 MPa injection pressure while the pilot fuel injection was varied to different time settings starting at 11 and up to 23 degrees bTDC. It was reported that retardation of injection timing at higher loads and advancing the pilot injection timing in case of lower loads improved engine performance and thermal efficiency. At higher engine shaft loads reduction in the ignition delays are observed. A reduction in smoke and NO_x emissions are reported over most of the operating range. CNG and biodiesel combination result higher levels of carbon monoxide together with higher HC emissions during the lower engine loads operation. It was recognised to the reduced CNG combustion in the engine cylinder. Basavaraja et al. (2018) in a lab-based study is to learn more about the performance and emissions of a diesel engine that runs on CNG-diesel/biodiesel. The study concluded that this mode of operation of the engine using CNG-biodiesel proved better than the CNG-diesel combination both improved performance and reduced exhaust emission.

The gas mixer plays a very important role for the optimum performance of the engine under all working conditions, as it provides a desired combustible mixture in the required quantity and quality. The various factors incorporated are rated power, speed, volumetric efficiency, specific fuel combustion and manifold connection diameter for the design of a gas carburetor for a particular engine. From the literature it has been concluded the various researchers investigated the diesel engine on DF mode using venturi metre type air gas mixer which supplies the heterogeneous mixture to the engine for combustion. In most of the cases, a T-junction gas carburetor is used in DF operation of the modified diesel engine. A T-junction gas mixer has one inlet for CNG and other for air and a mixture outlet. The gas inlet and air inlets are fixed at an angle of 90° with each other and the exit of the mixer is attached with engine ingestion manifold. When two streams clash at high velocities, this design results in a considerable energy loss.

Figure 1 Schematic diagram of test engine set up (see online version for colours)

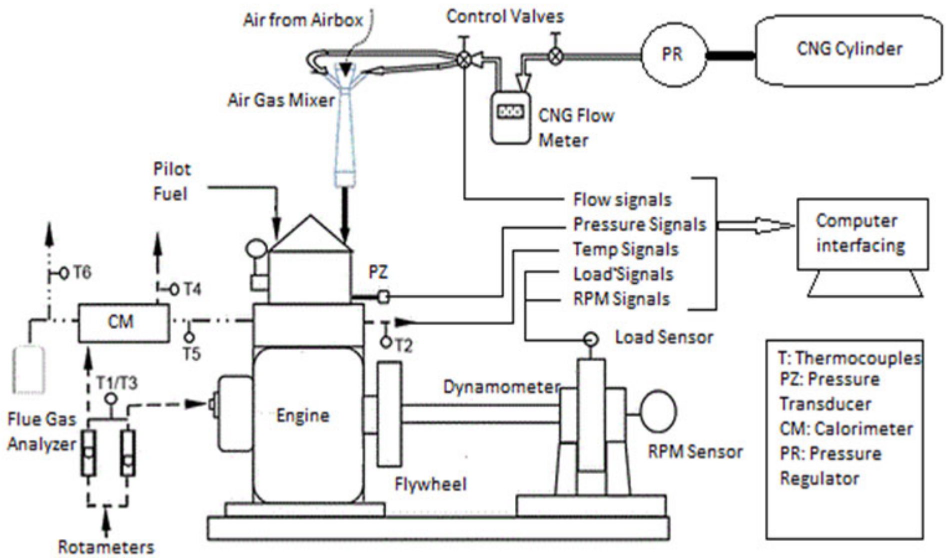


Figure 2 Actual photograph of engine test bench (see online version for colours)

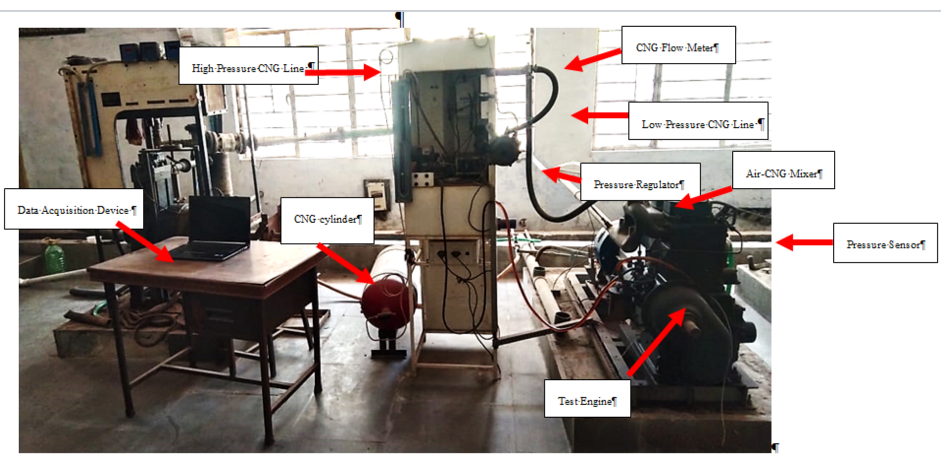
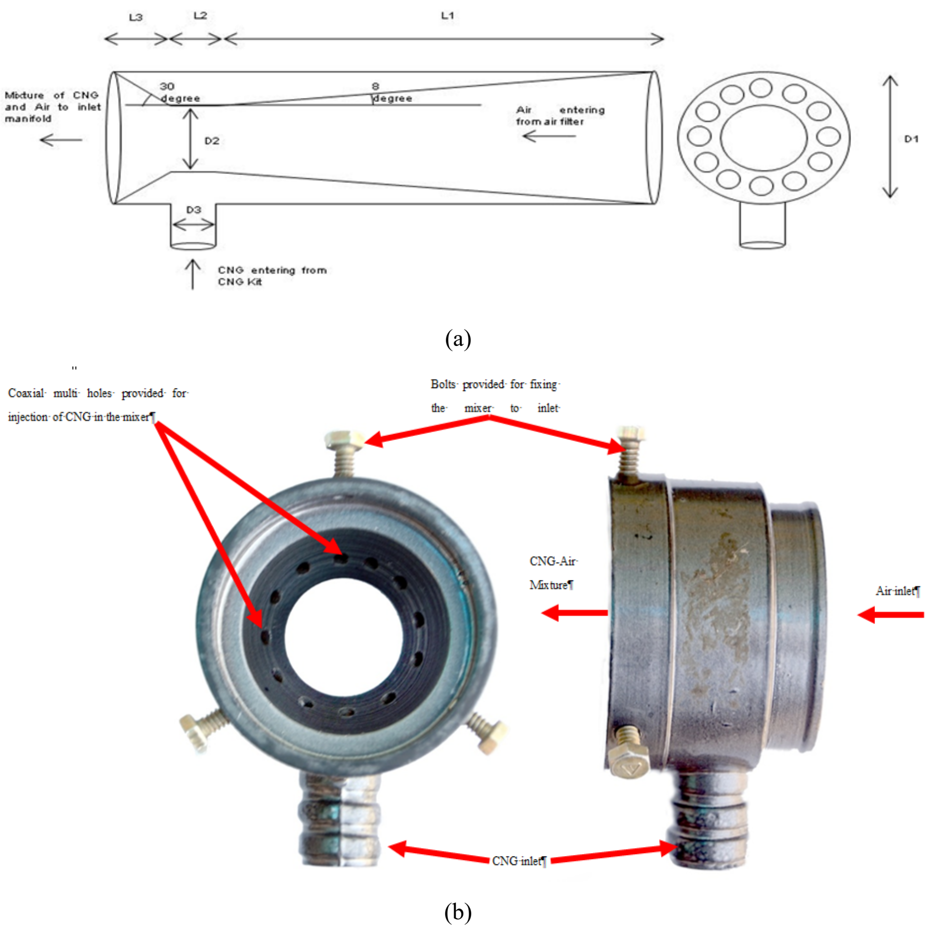


Figure 3 (a) schematic of air-gas mixer (b) actual photograph of air-gas mixer (see online version for colours)



To reduce this loss and increase the quality of the mixture's mixing, a new air gas mixer is designed and developed is used in the present experimental work. This design is also based on the concept of venturi metre provided with 12 coaxial small inlet holes for gas, one inlet for air and one outlet for mixture shown in Figure 3(a) and (3b). It is provided with a smooth contraction and an expansion section has an ability to reduce the pressure loss. The converging section increases the velocity of the air and decreases its pressure at throat which causes more turbulence in this zone. As a result, pressure and velocity are lowest and highest in the neck area, respectively. The throat diameter, intake manifold diameter, and CNG inlet diameter are all 25 mm, 54 mm, and 2.5 mm in diameter, respectively. All of the air fuel mixer's design specifications are based on a dual CI engine with a power rating of 7.5 kW that has been upgraded with a CNG kit. This type of engine is used in the industrial as well as the agricultural sector for different purposes such as electricity generation, irrigation, flour mill, etc. The engine's volumetric effectiveness and speed are set to 90% and 1,500 rpm, respectively. CNG may be used to substitute up to 85% of diesel in this engine. In addition, 15 percentage pilot fuel is utilised to start the combustion. The goal of this research is to look into and evaluate the combustion, emission, and performance requirements of a twin-cylinder diesel engine that can run on diesel alone, CNG-diesel, and CNG biofuel DF mode, and has a multi-hole air-gas mixer.

2 Material and methods

2.1 Fuel selection

Fuel selected for the present study was CNG and mustard oil methyl ester (MOME). MOME as a liquid pilot fuel to be injected through the nozzle while CNG is combined with air and injected into the system through an induction manifold. On a computerised engine test bench, a prefilled portable CNG cylinder was obtained and mounted. Mineral diesel was obtained from Sonipat, Haryana-based state-owned diesel provider. MOME was made in-house and evaluated in lab for its properties and qualities. Table 1 lists the parameters of the petro diesel, mustard oil methyl ester and NG utilised in the study.

Table 1 Comparison of fuel properties

Property	*Diesel*	*MOME*	*CNG*
Specific gravity	0.83	0.673	0.424
Density kg/m^3	830	880	0.7
Cetane number	45–50	53	6
Flash point °C	61	155	–222.5°C
Calorific value in kJ/kg	45,000	38,000	50,000
Gross heat of combustion, MJ/kg	42–46	39.5	50
Viscosity @ 40°C (cst)	4.4	4.1	--

2.2 Preparation of mustard biodiesel

The availability of mustard oil in rural India is the key reason for using it to generate biodiesel. Cold-pressed mustard seeds (Brassica Nigra) are used to make mustard oil. An electric oil expeller was used for the extraction of crude mustard oil. This crude mustard oil is laden with impurities and needs to filter before use. This crude oil was filtered using a paper filter. After filtration, the crude oil was heated up to 120°C to remove evaporative components. Then the titration technique was used to find the fatty acid value. The catalyst was prepared by mixing sodium hydroxide with methanol (Dager et al., 2022). This sodium hydroxide was mixed with filtered mustard and then the mixture was heated to 65°C. It was then stirred for 90 minutes on an ultrasonic stirrer. After that, it was left to settle at room temperature for 12 to 14 hours. The reacting mixture now settles into distinct layers and can be separated using a separating funnel. The dense layer of glycerin settles at the bottom and can be easily removed. Furthermore, biodiesel was filtered, cleaned and water washed in the presence of an anhydrous sodium sulfate (Mahla et al., 2021; Sharma and Sharma, 2021c).

2.3 Experimental setup

A 4-stroke CI engine of 7.35kW was modified and transformed to run on DF mode. Engine specifications and instrumentation used are listed below in Table 2. The schematic illustration and actual photograph showing the engine bench are shown as Figures 1 and 2 respectively. This study involves the use of an eddy current dynamometer for changing the load on the engine with the help of a knob provided on the engine test bench's panel. The shaft end of dynamometer is fitted with a crank angle sensor to compute rpm and crank angle. The engine cylinder is fitted with a piezo-electric based pressure sensor for measuring combustion pressure. HRR and other combustion parameters are calculated using this information. The engine test bench is fitted with rotameters to measure water flow for cooling. A vertical burette is installed in the diesel tank to keep track of the mass flow. Inflow is detected using an orifice metre connected to the air box, while gas flow is monitored and quantified with a flow measurement instrument.

Table 2 Specifications of test engine and instrumentation

Parameter	*Description*
Make	Kirloskar AV2
Number of cylinders and stroke	2 and 4
Stroke	110 mm
Bore of cylinder	80 mm
Engine rated power	7.35 kW@1,500 rpm
Cooling system	Water-cooled
Compression ratio	16.5: 1
Fuel injection pressure	200 bars
Dynamometer	Eddy current type
Exhaust gas analyser	AVL Di Gas 444G
Cooling water flow measurement	Rotameter
Fuel flow measurement	Vertical burette

At a pressure of approximately bar, CNG is held in the fixed cylinder. The pressure is reduced from 200 to 1 bar via the pressure regulator. In a newly constructed air-gas mixer, it is combined with air. During the suction stroke, the air-fuel gas combination is then fed through the induction manifold. A check valve in the system prevents gasoline from flowing backwards. The AVL series 5 gas tester is used to measure the constituents of engine emissions with the help of a flexible hose provided to take the samples of exhaust gases.

2.4 Air-gas mixer

Engine performance, in-cylinder combustion and emission reduction are extensively depending upon the mixture homogeneity. The homogeneity of the mixture directly affects the emission level, performance of the engine and combustion inside the cylinder. Incomplete combustion inside the engine emits more HC reported in several studies. Furthermore, incomplete combustion of heterogeneous air fuel mixture of HCs of fuel and lubrication oil causes the production of more PMs. NO_x and CO emission can be condensed by complete combustion of the air fuel mixture inside of internal combustion engine. Hence in order to get better performance, combustion and emission distinctiveness of the engine, it is essential to maintain the homogeneity of the mixture (air-fuel) during operation of the engine.

Furthermore, most of the air gas mixers are incapable to prepare homogeneous mixture at a precise air fuel ratio. Due to the incapability of fuel air mixers causes more exhaust emissions and high brake specific energy consumption. Many investigations show that due to lower density and fuel penetration of gaseous fuel, it is difficult to prepare a uniform mixture of air and gaseous fuel than liquid fuels. However, because of the property of high diffusivity of gaseous fuels, they can be easily mixed with air at slow engine speeds. But at high engine speeds the time for mixing is insufficient, thus resulting in preparation of a heterogeneous mixture.

In the present study, air-gas mixer is intended and developed which is suitable to mix air with CNG for different operating situations of CI engine in DF mode. The schematic and actual photograph of the air- gas mixer is shown in Figure 3(a) and 3(b) respectively. This mixer will produce homogeneous mixtures of CNG and air as per the different operating conditions. The new air-fuel mixer is fitted with coaxial multi holes to inject CNG in the air. The direction of injection of CNG is coaxial to the direction of air inside the suction manifold. Hence the coaxial multi holes technique can produce the homogeneous air-fuel ratios inside the mixer as per the various engine speeds and loads. The size of new mixer is designed as per the size of intake manifold of the engine consists of air inlet, fuel inlet, mixing outlet, provided with 12 fuel injection holes to inject the CNG and bolts for fixing the mixer on inlet manifold of engine. It provides the air fuel mixture according to the power, toque and speed requirements.

2.5 Experimental procedure

The experiments on the retrofitted CNG-diesel dual-fuel engine are carried out in phases. The initial phase consists of engine operation with mineral diesel to prepare the baseline data so that its performance can be compared with other test fuel compositions. In the second phase, the test engine is fuelled with diesel and CNG as the pilot and main fuel respectively. In the final stage, a combination of CNG and MOME biodiesel is used to run the engine. The first fuel sample is marked as DLF (diesel liquid fuel), while the second is marked as DCNG (diesel + CNG) and the third one is marked as BCNG (MOME diesel + CNG). This will help in the easy identifications of different fuel samples while representing the output data through graphs. In all three cases, the engine is operated on 1,500 + 50 rpm besides constant fuel injection timing of 23°bTDC. Constant rpm in this engine is maintained by a mechanical governor by varying the fuel supply as per the load. To improve the consistency of output results, the engine is initially run with neat diesel and EGT is observed until the EGT is stabilised. This indicates the steady function of the engine. Initially, the engine is started at a low engine load (20%), and then the load is augmented up to the full load (100%) through an eddy current dynamometer. As the test bench is computerised, it is easy to load the engine and note down the load readings. All the tests were carried out at least three times and then their mean value was taken to rule out any reliability error.

2.6 Analysis of uncertainty

Uncertainty is being used to compute any deviation from a conclusion. Because of some uncertainties, the validity of the experiment conducted may be jeopardised. Uncertainty analysis is required to ensure that the acquired reports are correct. Calibration of all experimentation apparatus is also required to obtain the exact value. The majority of well-known investigators recommend performing this analysis. To accomplish a valid value, all experiments were carried out in such a way that observations were taken more than twice, and then the average of the entire range of outcomes was calculated. Table 3 shows the calculated uncertainty for various measurement values such as brake power, thermal efficiency, BSFC, and emission indices measurement. There are kinds of errors that can be calculated for measurable data. The first one is a bias error, and the other one is an accuracy error. Bias errors are regarded as irreversible errors in this study. Correction steps, which were previously followed in the study's final phase, have been used to calculate such errors. The following expression is used to calculate output data that are highly depended on two or more distinct factors in the synthesis of uncertainty.

Table 3 Analysis of uncertainty

Parameter	*Inaccuracy*	*Uncertainty (%)*
Air flow rate (kg/hr.)	0.018	± 1.47
Speed of engine (rpm)	15–20	+ 1.29
Air flow rate (kg/hr.)	1–2	+ 2.38
BTE (%)	-	± 1.48
BSFC (kg/kW.hr)	-	+ 1.21
NO_x (ppm)	1	+ 3.1
NO_x (ppm)	1	+ 3.1
Smoke (%vol.)	0.1	+ 1.5
UHC (ppm)	1.1	+ 48
CO (%vol.)	0.001	+ 31

3 Results and discussion

There are three parts to the result and discussion sections. The first paragraph focuses on engine performance metrics, while the second focuses on engine combustion parameters, and the third focuses on exhaust emission analyses. A comparative examination of three test fuel samples (DLF, DCNG, and BCNG) is offered in each subsection.

3.1 Engine performance

3.1.1 Brake thermal efficiency

BTE in diesel fuel only (DLF), DF mode (DCNG), and (BCNG) is calculated and presented in Figure 4. It is observed that the highest BTE at 33.13% is achieved for a single fuel mode using fossil diesel. In the case of DCNG, BTE is lower in comparison of DLF is observed. However, the BTE for DCNG is higher than the BCNG combination.

This is attributed significantly to the higher calorific value of liquid mineral diesel than that of MOME biodiesel. In all three cases maximum BTE is achieved near to 80% engine load condition due to better volumetric efficiency than to full load. In all the three types of fuels BTE increases with load, this is due to the fact that unaccounted and frictional losses are reduced at higher loads, according to the BP developed. The BTE for BCNG and DCNG is lower than that of DLF mode. This is due to the lower heating value of CNG and MOME compared to diesel (Radhakrishnan et al., 2018).

Figure 4 BTE vs. brake power (see online version for colours)

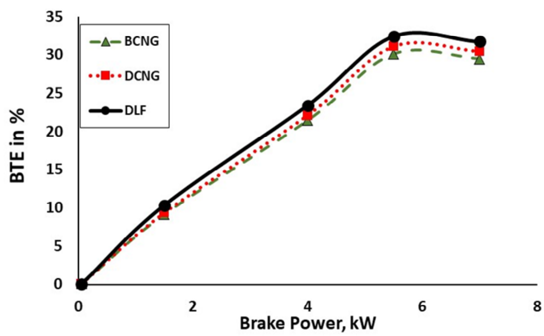
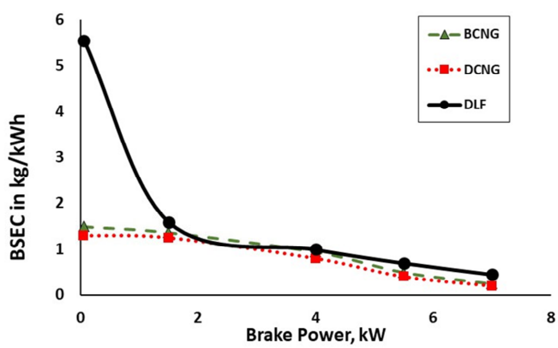


Figure 5 BSEC vs. brake power (see online version for colours)



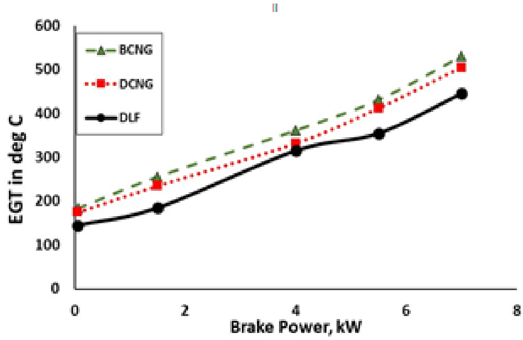
3.1.2 Brake specific energy consumption

BSEC is important when we use two different types (state-wise, i.e., liquid and solid) of fuel as their measurement method is different. The results of BSEC vs. brake power are presented in Figure 5. BSEC in DCNG/BCNG is better than the diesel-only fuel operation. BSEC is higher at the lower range of loads due to poor gas utilisation and improves with the load. These results in lower operational cost in DCNG/BCNG, nevertheless the BSEC is better in the case of BCNG among all the three fuel samples being tested. The higher lubricity and homogenous combustion in case biodiesel is the reason for improved BSEC in the case of BCNG. The availability of a greater number of oxygen molecules in vegetable-based biodiesel makes the combustion homogenous in comparison with mineral-based diesel. The results show that as the engine load increased, the brake specific fuel consumption (BSFC) decreased. This is due to the fact that the engine's brake horse power (constant speed type) increases with an increase in brake load, but after a certain percentage of maximum loads, only a minor increase in brake horse power was observed. As a result, the brake specific fuel consumption increased. In a DF system, the complete combustion rate of higher calorific value CNG consumes less fuel, potentially lowering the BSFC (Senthilraja et al., 2016).

3.1.3 Exhaust gas temperature

EGT is deliberate with a thermocouple inserted in the drain pipe. Exhaust temperature is a prominent parameter that indicates combustion healthiness. Continuously changing EGT indicates unstable ignition in the engine cylinder. In Figure 6, the EGT of all three samples is displayed under a variety of engine load settings. It is pragmatic from the graph that dual-fuel operation (DCNG and BCNG) results in higher EGT than to single fuel (DLF) attributed to the inferior heating value and gaseous nature of CNG. It is also seen that there is a marginal difference over the whole range of operation in the EGT values for both DCNG and BCNG.

Figure 6 EGT vs. BP (see online version for colours)



3.2 Combustion performance

In this subsection, various combustion parameters like in-cylinder pressure and ignition lag will be discussed. These parameters define the health of the combustion inside the engine cylinder.

3.2.1 In-cylinder pressure

In this subsection, the inside cylinder pressure during fire of different fuel samples is presented. It is used for investing the effect of CNG addition to the diesel and MOME biodiesel. Pressure and corresponding crank angle are plotted at three engine load settings of 60%, 80% and100% as presented in Figure 7. In the situation of diesel, the highest pressure is recorded for all three fuel samples at all load values. In the case of the DCNG/BCNG operation, the peak pressure is comparatively higher than BCNG. It is attributed to better combustion at a higher load. The phenomenon of better combustion of biodiesel over diesel is due to the presence of a greater number of oxygen molecules. The highest-pressure level of all the fuel samples at various loads is illustrated in Figure 8.

Highest cylinder pressure value increases with load owing to better fuel utilisation at higher loads.

Figure 7 Combustion pressure vs. crank angle diagram (a) at 60% load (b) at 80% load (c) at 100% load (see online version for colours)

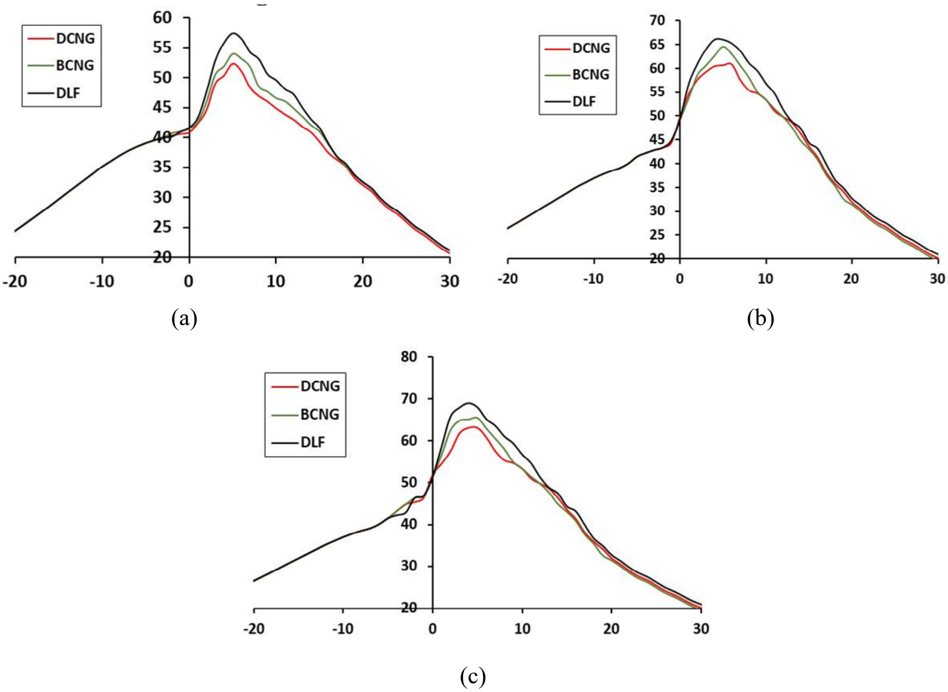
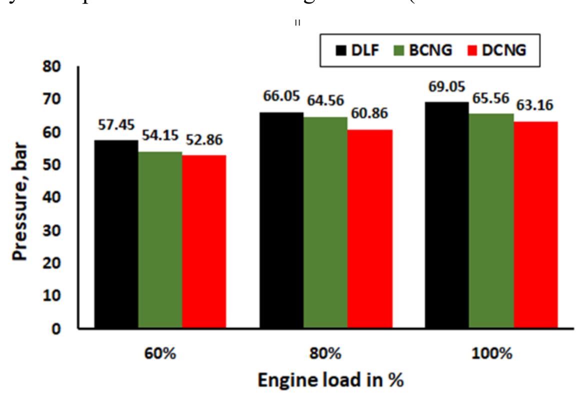


Figure 8 Peak in-cylinder pressure at different engine loads (see online version for colours)

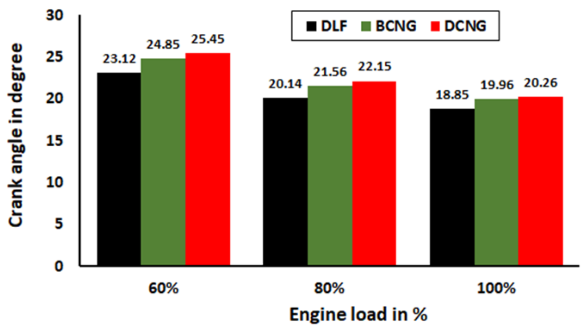


3.2.2 *Ignition delay*

Ignition delay is the stage in terms of crank position in degrees between the start of fuel insertion to the point of ignition start. During this period of ignition delay, a series of chemical and physical processes occur. It can be calculated from the p-θ diagram and

HRR diagram. The delay was calculated for three engine load settings 60%, 80%, and 100%, and plotted as a bar graph Figure 9. It is pragmatic from the graphs Figure 8 that extended ignition delay happens in the case of dual-fuel ignition over the entire range of engine operation. NG inclines to reduce auto-ignition due to the incidence of free radical and hence it increases the ignition delay. It is purely a chemical factor that results in a longer ignition delay (Lee et al., 2020).

Figure 9 Ignition delay in CAD peak in-cylinder pressure at different engine loads (see online version for colours)



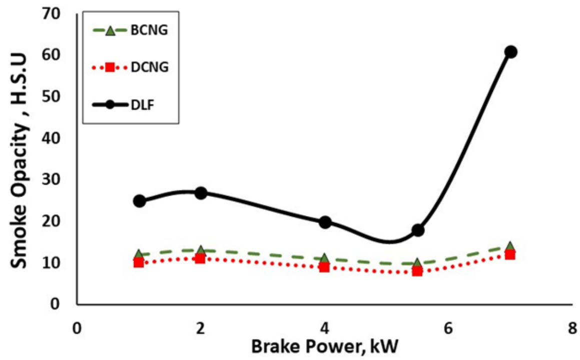
3.3 *Exhaust emission characteristics*

NG and biodiesel are considered improved substitute of fuels in IC engines than mineral diesel due to their lower polluting exhausts emission. In the present study, a relative investigation for the three fuel combinations (DLF, DCNG and BCNG) has been carried out at different engine loading.

3.3.1 *Smoke opacity*

The smoke dullness for DLF as well as DCNG/BCNG fuel operation for all the fuel combinations is illustrated in Figure 9. As shown, DCNG fuel mode has lower smoke levels in comparison to BCNG. The highest value of smoke is reported in single fuel mode, i.e., DLF. The higher combustion temperature of DCNG and BCNG due to the presence of the higher amount of CNG increases the heat output is the reason for reduced smoke levels. At lower load conditions the DCNG and BCNG operation was almost smokeless. At higher engine loads smoke opacity is drastically reduced in the BCNG and DCNG cases than to compare to DLF mode as depicted in Figure 10. The greater use of fuel at peak load accounts for the rising trend in combustion products with increasing load. When too much fuel is introduced into the cylinder at high engine speeds, partial combustion occurs, resulting in increased smoke emissions. At full load, fossil diesel created the most smoke, but BCNG and DCNG caused the least plume of smoke. Because biodiesel emits less smoke than pure diesel and has a larger amount of oxygen, it assists in the full burning of the fuel. More oxygen atoms in the fuel helps to deliver a suitable number of oxygen atoms to the products of combustion, resulting in full fuel combustion. (Goga et al., 2019).

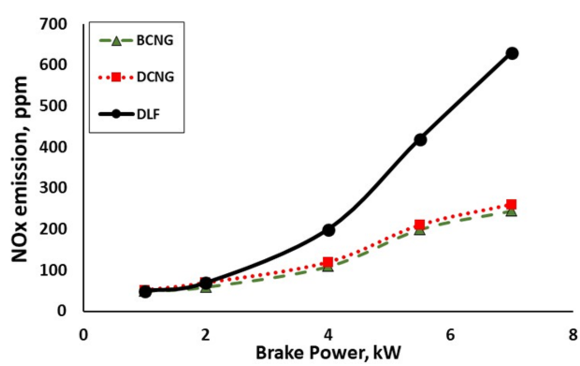
Figure 10 Smoke opacity at different engine loads (see online version for colours)



3.3.2 Nitrogen oxides

NO_X is the most detrimental pollutant specifically emitted by diesel engines. It is a combination of nitrogen dioxide (NO_2) and nitrogen monoxide (NO). The main component out of these two is NO (almost 90%). Fig .11, illustrates the NOX emission for DLF, DCNG, and BCNG for different engine loads. DF operation has almost one-third of NO_X emission in comparison to single fuel operation. The NO_X emission results are in close vicinity for DCNG and BCNG as a large proportion of the CNG fuel is common in them while diesel and biodiesel are just used for pilot injection. NO_x are the products of the reaction of oxygen and nitrogen particles inside the engine cylinder, particularly at high temperatures. Increased temperature accelerates the reaction of oxygen and nitrogen atoms during combustion. The lowest and extreme NO_x emissions for BCNG, DCNG, and DLF fuel blends were measured at 20% and 100% load, respectively.

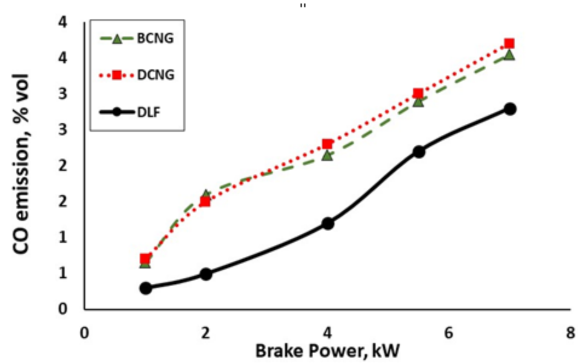
Figure 11 No_x levels at different engine loads (see online version for colours)



3.3.3 Carbon monoxide emission

Carbon monoxide (CO) production in the engine cylinder is a function of incomplete combustion and temperature inside the cylinder. These two factors are responsible for the rate of oxidation of fuel. A higher amount of CO is the result of an over-rich fuel zone constituted during atomisation of fuel and hence causes lack of oxygen in that zone but it is also formed in the lean fuel region if the cylinder temp is less than 1,450 K (Kitamura et al., 2002). The results of the present study for the CO emission in respect of all the three-test fuel are presented in Figure 12. It can be observed that there is a raise in the CO emission in the case of DCNG/BCNG fuel operation owing to the phenomenon of bulk quenching. In the present study this may be due to the lack of adequate air, as CNG was mixed with air and inducted in the cylinder during intake stroke. As the volume of air that to be inducted in DLF mode was occupied by the CNG in DCNG and BCNG mode, resulting in the higher formation of CO emissions. CO emissions decrease with engine load until a particular point, after which they increase with load. The lean air–fuel combination produces partial flame propagation and greater CO emissions at increasing engine loads. This is attributed to the lower speed of flame propagation resulting in incomplete combustion (Raihan et al., 2015).

Figure 12 Co emission at different engine loads (see online version for colours)

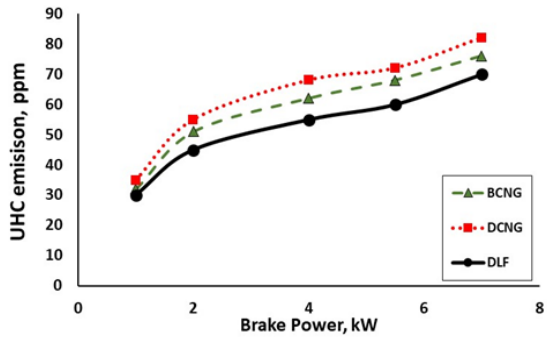


3.3.4 Unburned hydrocarbon

UHC emissions are caused by incomplete fuel combustion. In DCNG/BCNG combination at lower engine load, the unburned hydrocarbon emission is slightly higher side in comparison to single fuel operation (DLF). Some of the partial ignited fuel particles to outflow to exhaust and leads to unburned exhaust emission. However, at the higher loads, there is a considerable drop in unburned hydrocarbon in dual-fuel operation. Higher temperature during combustion helps in quick oxidation of hydrocarbon fuel and a reduction in the unburned emission can be observed at higher loads. The unburned hydrocarbon emission is measured and a graph is plotted for the three test fuels in Figure 13. UHC emission in DCNG/BCNG is higher than the DLF. It is also reported that UHC emission significantly high but the rate of growth tapers down with increasing load due to improved combustion.

The primary cause of hydrocarbon emissions is a lean mixture, which results in low flame speeds and hence causes incomplete combustion. Carbon deposits inside the combustion compartment are porous. In the compression stroke some mixture particles are trapped in these pores and do not ignite during the power stroke and continuously being emitted during the exhaust stroke. The smallest value of UBHC was recorded at 10% engine load, and the extreme value of UBHC emissions was recorded at 100% load in all the combination of fuels. Pure diesel exhibits the highest emission value of UBHC was found 64.41 ppm at 100% load and the lowest value was found to be 27ppm at 10% load condition for pure diesel.

Figure 13 Unburned hydrocarbon at different engine loads (see online version for colours)



4 Conclusions

Based on exhaustive experimental studies using CNG and diesel/biodiesel in diesel engine, the following conclusions are made:

- The methyl ester of mustard oil was created, and the diesel engine was fully turned to a dual-fuel engine that could run on DCNG and BCNG modes of operation.
- It is established from the present study that the employment of mustard oil methyl ester up to 20% is safe and advantageous to use in single as well as in DF mode of operation of the engine.
- BTE and BSEC are considerably lower in dual-fuel mode than in diesel-only mode.
- A significant reduction in smoke clarity and NO_x emissions in DF mode compared to DLF fuel operation over the full operating range. At the same time, CO and UBHC emissions are trending in the other direction.

Overall, it can be concluded that DF operation of a CI engine is an appealing alternative mode of operation for better values of hazardous emission constituents.

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