

Performance Characteristics and Emissions Evaluation of Diesel and Dual Fuel (Diesel and CNG) Engine

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ABSTRACT: Exponential depletion of conventional energy sources, with increase in demand of energy is a crucial matter of concern for the mankind. There are reasonable factors as petroleum derivatives will neither be available in limited quantities and environmental pollutions, has received interest in exploring the field of alternative fuels for CI engines and should be drive from indigenous sources and preferable renewable energy sources.

In this work, experiments are conducted by governing pilot fuel and speed for defined loads by keeping output power constant. The engine performance and emission parameters are computed by taking CNG as main fuel and diesel as pilot fuel of dual fuel mode. From the various experiments conducted, it is concluded that engine performance of dual fuel mode is better than diesel fuel operation.

KEYWORDS: Dual Fuel, CNG, Alternating fuel, Emission, Eight mode cycle.

I. INTRODUCTION

Diesel engines are widely used due to their high combustion efficiency, reliability, adaptability and cost effectiveness [1, 2]. Taking into consideration the pollution caused by CI engines in form of construction equipment vehicle or automotive sector are one of the leading contributors [3, 4]. The harmful pollutants from diesel engine are NO_x and PM. Photochemical smog and acid rain are the reasons for earth degradation because of NO_x. Particulate matter from CI engines consists of various types of chemical components such as elemental carbon, organic carbon, inorganic ions, trace elements, etc. [5-8]. This emissions cause chronically health issues such as respiratory and cardiovascular. Therefore, emission regulations become increasingly stringent to reduce these harmful emissions [5]. On the other hand, spark ignition (SI) engines use low grade of carbon fuel, as a natural gas in turn result in reduction of carbon dioxide. However, complete substituting of diesel fuel to renewable, eco-friendly CNG (compressed natural gas) is not possible [10, 11]. After a lot of experiments a typical solution came out to be converting CI engine into partial SI engine, just by adding CNG kit to existing engine [9]. The approach of initiation of mixture of diesel and NG by a pilot diesel fuel injection is called Dual Fuel (DF) CI combustion.

Considering the various alternative fuels, natural gas is one of the most uprising and highly attractive in automobile sector. Compressed natural gas is available worldwide and at affordable prices. There are numerous ways of producing natural gas. Hence, the natural gas industry is producing gas from increasingly more challenging resources types: sore gas, tight gas, shale gas, coal-bed methane and methane gas hydrate [15]. Secondly, the content of natural gas is methane, is an eco-friendly fuel and also a greenhouse gas. Natural gas can substantially reduce the percentage of NO_x for certain range of speed and at the same time deteriorates to negligible amount of smoke and PM [16-18]; which is

International Journal of Innovative Research in Science, Engineering and Technology

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almost unachievable in conventional CI engines. Natural gas is more prone to leakages and so it must be taken care. There are less chances of knocking in dual fuel engine as methane is one of the major compositions in its content and also it can be used in engines with higher compression ratio and can obtain higher thermal efficiency [5].

In last few years, it has been observed that natural gas has been dedicated as supplementary fuel widely in diesel engine for its economical as well as environmental benefits. The core reason for study on natural gas as upcoming fuel is to provide a comprehensive review of literatures which co-relates its potential use particularly in CI (diesel) engines. Moreover, the paper throws light on combustion emission and performance characteristics of conventional used diesel and dual fuel (diesel and compressed natural gas).

II. LITERATURE SURVEY

Environmental hazards and the rising price of oil have stimulated fuel diversification & led to the creation of alternative fuel sources for conventional internal combustion engines. Adding gaseous fuel as partial supplement to liquid fuel in compression ignition engines is an example known as 'dual fuel'. The dual fuel mode concept includes utilization of gaseous fuel by mixing it with the intake air. The ignition of this premixed lean charge is achieved by injecting a small quantity of pilot diesel fuel, near top dead centre at the compression stroke. These pilot fuel droplets will auto-ignite to provide an ignition source for the surrounding fuel-air mixture. Dual fuel engines work at normal diesel compression ratio based on diesel cycle. The primary fuel is inducted with air using a gas-air mixer/venture or an injector in the inlet manifold.

Diesel engines were traditionally preferred due to their lower running cost and better torque characteristics; however during the past decade, due to the limit of oil resources and stringent emission norms have mandated use of several advanced combustion and after-combustion technologies, which in turn have made diesel engine power train expensive and complex. Dual fuel strategy offers great opportunity to reduce emissions like particulate matter and NO_x from compression ignition engine and use of clearer fuels like natural gas. Dual fuel engines have number of potential advantages like fuel flexibility, lower emissions, higher compression ratio, better efficiency and easy conversion of existing diesel engines without major hardware modifications. It is an ecological and efficient combustion technology.

Dr. S.S. Thipse, S.D. Rairikar (2017) et al represented their work by conducting trials on an in-line three litre, four-cylinder, four strokes, direct injection, water cooled, turbocharged diesel engine. A dual fuel kit comprising of CNG cylinders, pressure hoses, pressure regulator, gas-air mixer, CNG and diesel fuel actuators was mounted on engine and was tested under dual fuel operating mode. Conventional dual mode of fuelling the diesel engine was adopted and diesel quantity was varied from 100% to 20%. During starting and full load conditions, the engine runs under 100% diesel as a safety measure to avoid knocking, whereas under part load conditions it runs under the dual fuel mode. Fuel MAP was developed and optimized for converting normal diesel operation into dual fuel operation. FTP and PTP tests trials were conducted on engine dynamometer to obtain minimum diesel fuel quantity. Under dual fuel mode, CO and HC emissions were high at low loads but reduced with use of higher gas mass ratios at higher speeds, however, they were found to be exceeding their levels when compared to normal diesel operation. NO_x formation decreased under dual fuel mode as a result of less intense premixed combustion, lower oxygen concentration, and slow speed combustion.

Dr. S.S. Thipse et al (2016) summarized the recent research on dual fuel technology and future scope. They also represented present limitations and drawback of dual fuel technology and proposed methods to overcome these hurdles. Performance parameters and engine emission characteristics of six cylinder heavy duty diesel engine were studied to understand engine behaviour when operating on dual fuel mode. CFD (Computational Fluid Dynamics) simulation was carried out to study and evaluate dual fuel combustion phenomenon. A chemical kinetic mechanism was developed to simulate dual fuel combustion in dual fuel engine by merging diesel and gas fuel reaction mechanisms. Merged mechanism helped in studying diesel and natural gas combustion simultaneously. Engine was tested on ESC (European Steady-state Cycle) at each load and speed prepared in test matrix under normal diesel and dual fuel modes with gas supplement ratio of 20%, 40%, 60%, and 80% and maximum with stable operation. Test matrix was prepared with

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three loads and three speeds. The diesel fuel replacement strategy used was 100% diesel without CNG at idling speed of engine and 30% to 50% replacement at part loads with 75% maximum replacement. It was found that torque and brake power of dual fuel operation was similar to the baseline engine. HC and CO emissions increased under dual fuel mode under all operating conditions, whereas NO_x emissions reduced at low loads and increased at high loads with their levels below the NO_x levels of normal diesel operation. The specific fuel consumption increased under all operating conditions of dual fuel mode. However, increase was very significant at low loads and with increase in load, gas utilization further improved causing reduction in specific fuel consumption.

Kishor Kumar Kavathekar et al focused on, “**Development of Dual Fuel (Diesel-CNG) Engine for SUV Application in India**”, 2015. In this engine diesel and natural gas are burned simultaneously. Natural gas is fed into the cylinder along with intake air; the amount of diesel injection is reduced accordingly. It is an ecological friendly technology due to lower PM and smoke emissions and retains the efficiency of diesel combustion. Normally natural gas is a cheaper fuel compared to diesel. This work highlights the methodology and outcomes of the recent experimental research work carried out for development of dual fuel diesel CNG engine for SUV application. The work also throws light on present limitations and drawbacks of dual fuel engines and proposed methods to overcome these drawbacks. A parametric study of different engine operating variables affecting performance of diesel-CNG dual fuel engines diesel operation is also summarized for a four cylinder engine. The engine operation is more economical on the pure diesel mode at lower loads; however at higher loads dual-fuel operation is better. As far as pollutant emissions are concerned, the use of natural gas under dual fuel operation has a positive effect on NO_x emissions, and thus, NO_x concentration under dual fuel operation is lower compared to normal Diesel operation. On the other hand, CO and HC emissions levels are considerably higher compared to normal Diesel operation. Their value increases with the gaseous fuel mass ratio and only at high engine load and high natural gas mass ratios a decrease is observed. Thus, it seems that dual fuel combustion using natural gas is a promising technique for controlling both NO and soot emissions even on existing DI Diesel engines and requires only slight modification of the engine structure. This is extremely important if we consider the difficulties of controlling both pollutants, NO and soot, on DI Diesel engines.

III. NATURAL GAS AS AN UPRISING ALTERNATIVE FUEL

In CNG (compressed natural gas) composition, one of the main components is methane, which is the lowest or simplest hydrocarbon. From numerous findings, it is concluded that the combustion of natural gas is clean and emits less CO₂ as well as low smoke than almost all other petroleum fuels. Natural gas has been used to fuel vehicles since the 1930s [24].

Physicochemical properties of natural gas

Natural gas is an amalgam of variety of gases. It consists of various types of lightweight alkanes, such as methane, ethane, propane, n-butane and pentane. Methane is in maximum quantity. It also content trace of carbon dioxide, nitrogen and small amount of water vapour. As different type of production processes for natural gas are enlisted above are used so there is a slight variation in its composition and content [5]. Typical composition as well as content of natural gas is listed in table 1 [15]. Normally, methane accounts for 87% to 96% in its composition so the properties of natural gas are almost eccentric to physicochemical properties of methane. Table 2 [25-28] illustrates the comparison of properties of natural gas, gasoline and diesel fuels. There is an exponential growth in requirement of fuel (natural gas) in automobile sector because it contains less carbon content per unit of energy from any other fossil fuel and generates less CO₂ per mile vehicle travelled. However, it is difficult to use CNG as main fuel in CI engines due to its high auto-ignition temperature but due to its anti-knocking properties it suits SI engines.

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Components	Typical analysis (% vol.)	Range (% Vol.)
Methane	94.9	87.0-96.0
Ethane	2.5	1.8-5.1
Propane	0.2	0.1—1.5
Isobutane	0.03	0.01-0.3
n-Butane	0.03	0.01-0.3
Isopentane	0.01	Trace to 0.14
n-Pentane	0.01	Trace to 0.14
Hexane	0.01	Trace to 0.06
Nitrogen	1.6	1.3-5.6
CO₂	0.7	0.1-1.0
Oxygen	0.02	0.01-0.1
Hydrogen	Trace	Trace to 0.02

Table 1: Typical component of natural gas [15]

Typical use of natural gas in spark ignition engines is already accountable to a great extent, whereas its usage in compression ignition engine is still under development. Low cetane number and high auto-ignition temperature are the two main concerns of using natural gas as a variant in diesel engine as compared to other diesel fuels [29-31]. Therefore, as a pilot fuel to give spark or ignite the main fuel ignition source is always needed in the cylinder. According to the way the natural gas is injected into the cylinder with the ignition source, there are three major methods for using natural gas in diesel engine.

1. Dual fuel mode: In this mode, natural gas is introduced or is allowed to inject in the intake manifold to agitate equivalently with the air which is sucked and then is introduced to the cylinder, which is ignited by the aid of direct injected petroleum product with high cetane number [32–39]. Fig. 1 shows the schematic diagram of dual fuel system.

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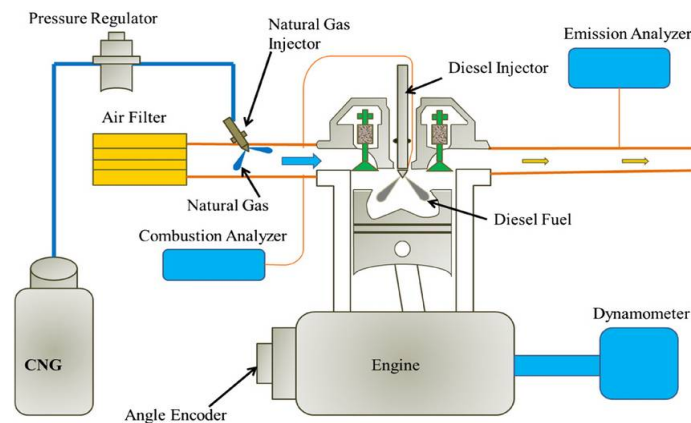


Figure 1: The schematic diagram of dual fuel system. (CNG: Compressed Natural Gas) [49].

2. High Pressure Direct Injection (HPDI): In this mode, a minute quantity of pilot diesel is initially injected late in the compression stroke and then natural gas (main fuel) is directly injected. At certain point during the time interval between the two injections or early in the natural gas injection, the diesel fuel auto-ignites, behaving as ignition source to initiate the natural gas in the combustion chamber [40–45]. Fig. 2 represents the schematic diagram of HPDI system.

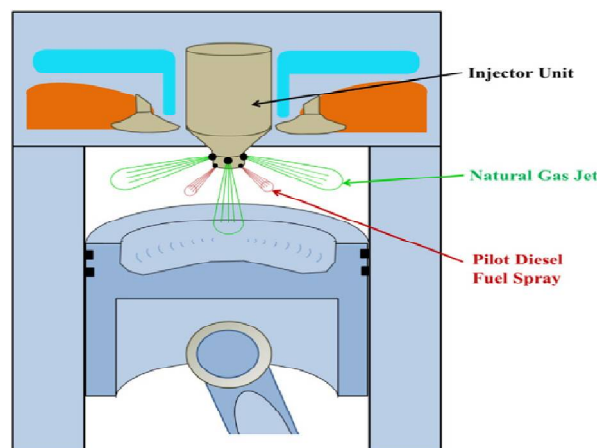


Figure 2: The schematic diagram of high pressure direct injection system [49].

3. Hot Surface Assisted Compression Ignition: In this mode, natural gas is injected directly into the cylinder close to a hot surface at the end of compression [46, 47]. The element acting as a hot surface is generally a glow plug within the temperature range of 1200–1400 K [48]. Fig. 3 shows the schematic diagram of this engine. The crucial positives of this concept are high specific power as well as thermal efficiency without the aspect of knocking characteristics. The critical element of the system is durability of the hot surface due to the high surface temperature required [47]. The directly introduced natural gas flames in a predominantly non-premixed combustion [50]. This combustion technique utilizes better fuel economy with more efficient combustion, and maintain the power output and the thermal efficiency of an equivalently-sized conventional diesel engine [51, 52], especially at low and medium loads. However, a special concentric-needle, dual fuel injector [51] is needed for HPDI mode. There is no major change in the conventional diesel engine to adopt this smart technology. The quantity of pilot diesel per cycle can usually be reduced to less than 10% of the total fuel amount to the engine [53]. In the studies of Krishnan et al. [54] and Srinivasan et al. [18] the pilot diesel

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only account for about a very little of the total injected energy and the natural gas replacement peaked at 95%. For the above reasons, dual fuel mode has been widely researched all over the world [55].

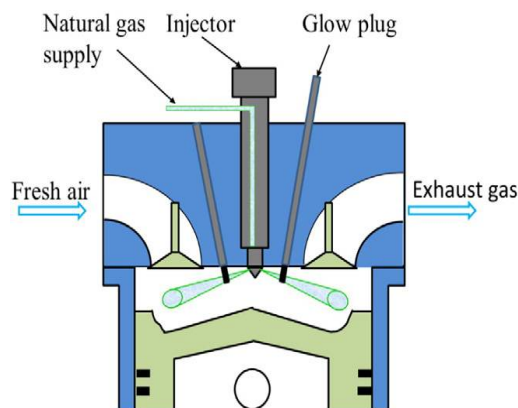


Figure 3: The schematic diagram of hot surface assisted compression ignition [49].

IV. FUEL PROPERTIES

Fuel properties	Natural gas	Diesel	Gasoline
Low heating value (MJ/kg)	48.6	42.5	43.5
Heating value of stoichiometric mixture (MJ/kg)	2.67	2.79	2.78
Cetane number	-	52.1	13-17
Octane number	130	-	85-95
Auto-ignition temperature (°C)	650	180-220	310
Stoichiometric air- fuel ratio (kg/kg)	17.2	14.3	14.56
Carbon content (%)	75	87	85.5

Table 2: Physicochemical properties of natural gas, diesel and gasoline [25-28]

V. ENGINE SPECIFICATION

The engine used during testing was Naturally Aspirated water cooled 4 stroke Diesel engines, with a firing order 1-3-4-2. This engine is used in off-road application.

Parameter	Specification
Engine Type	4 stroke water cooled diesel engine
Number of cylinders	4
Injection System	rotary mechanical pump
Maximum injection pressure	200 bar
Maximum power	45 KW (1800 rpm)
Maximum Torque	283 Nm (1200 rpm)

Table 3: Engine specifications

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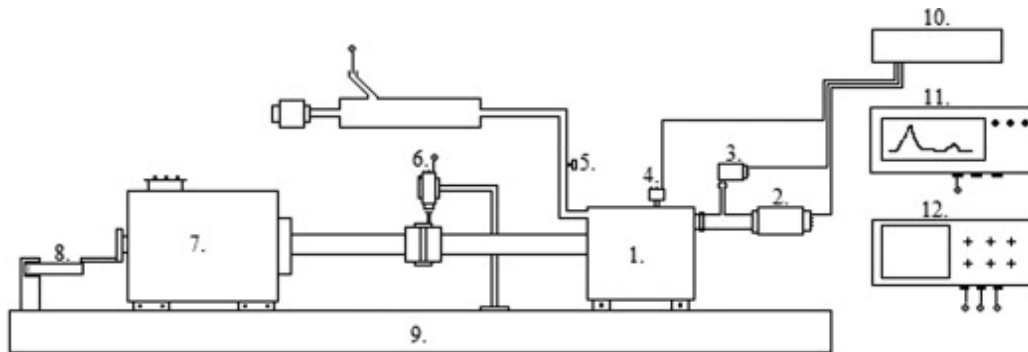
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VI. EXPERIMENTAL SET UP

Initially, the engine was mounted on the test bed. The dynamometer shaft was attached with the engine flywheel with the aid of drive plate. The drive plate in the flywheel and dynamometer was coupled with the shaft. Once the engine was mounted on the test bed, auxiliary components like fuel supply system, sensors, actuators, etc. were connected. The engine was taken into observation for the performance characteristics and emission of conventional diesel and dual fuel engine. The CNG kit retro-fitment was performed at ARAI, Pune. Full throttle position and part throttle position test were carried out to meet the objective made in experiment. The various sensors used in the system are temperature sensors for water, oil fuel and air, pressure sensors, rpm sensors, Throttle position sensors etc.



1. B & S Test Engine, 2. Mass Air Flow Sensor, 3. Manifold Pressure Sensor, 4. Cylinder Pressure Sensor, 5. Thermocouple(J), 6. Hall-effect Speed Sensor, 7. Eddy Current Dynamometer, 8. Load Cell, 9. Test Bed, 10. Data Acquisition Unit, 11. Oscilloscope, 12. Emission Analyzer.

Figure 4: Schematic layout of test bed system [14]

VII. METHODOLOGY

Mode number	1	2	3	4	5	6	7	8	9	10	11
Torque (%)	100	75	50	25	10	100	75	50	25	10	0
Speed	Rated speed					Intermediate speed					Low
Off road vehicles											
Type C1	0.15	0.15	0.15	-	0.10	0.10	0.10	0.10	-	-	0.15

Table 4: Eight mode cycle [8]

The 8178 is an International standard for exhaust emissions measurement from a number of non-Road engine applications. It is used for emission certification and type of approval testing in many countries including the United States, European Union and Japan. Depending on the legislation, the cycle can be identified by a reference to ISO 8178 standard or else by specifying a test cycle equivalent to ISO 8178 in National legislation.

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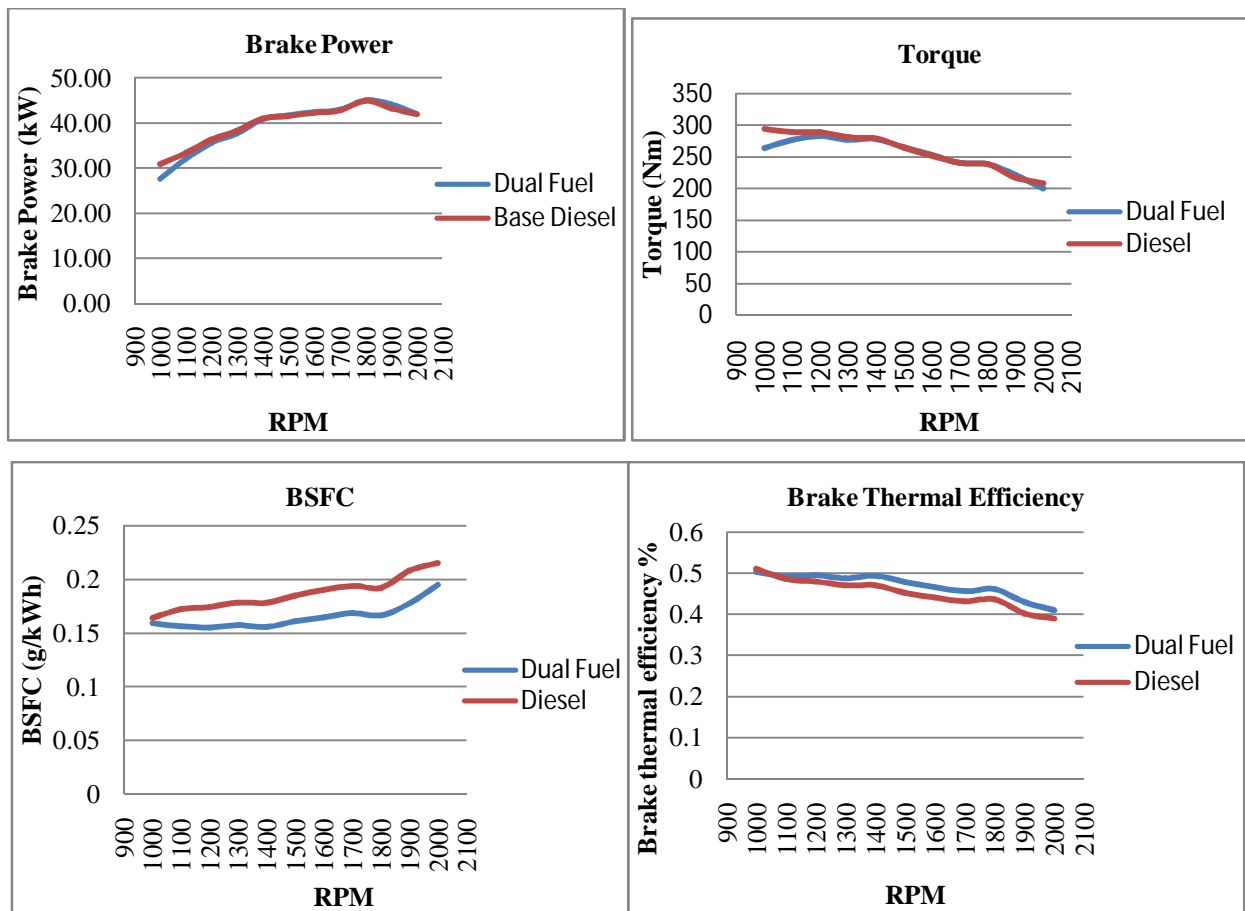
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Dual Fuel Mode Testing

1. The development of first MAP for dual fuel engine involved conducting a series of part throttle test in engine dynamometer lab. The test was carried over the entire engine operating speed range starting from 1000 to 2000 rpm. The test was conducted in N alpha mode.
2. In N alpha mode the engine speed was maintained and was set to 100% full throttle to update the full load condition at the corresponding engine speed. Later was reduced from 100% at a step of 5. In this process of determining the value till a certain point engine was giving the filter output beyond this point any for the decrease in diesel FLP percent the engine was no more producing the full load torque and at this stage CNG was introduced.
3. Later CNG was introduced by increasing the CNG FLP percent to maintain the full load condition, in this process we arrived at decreasing FLP percent and increasing CNG FLP percent for maintaining the full load condition at each engine speed.
4. At a particular diesel FLP percent the engine full load condition is difficult to maintain for any increase or value of CNG FLP percent. This marks the minimum diesel quantity needed for maintaining the engine full load condition at that particular engine speed. This process was repeated for all point of test matrix, which is shown in eight mode cycle.

VIII. RESULTS

Performance Characteristics of Diesel and Dual Fuel Engine



Above shown graphs clearly illustrate the performance characteristics of diesel and dual fuel engine and the objective of maintaining the output power and torque is obtained.

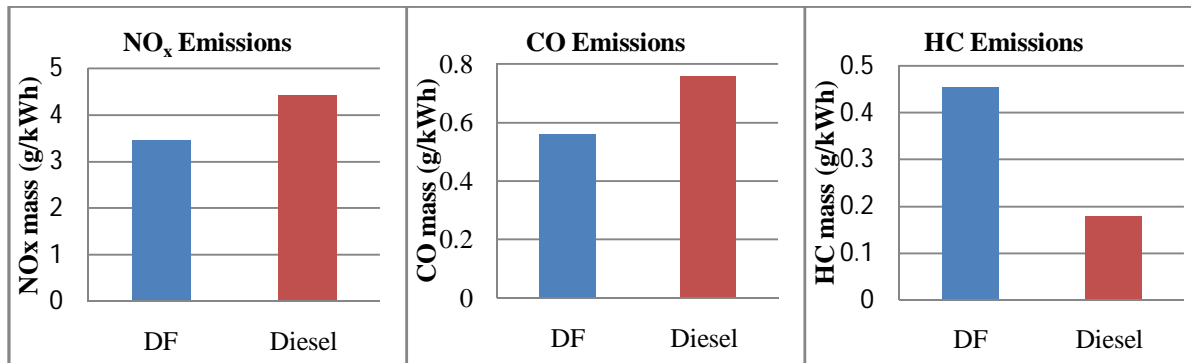
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Emissions of Diesel and Dual Fuel



The formation of nitric oxide is favored from the high oxygen concentration and the high charge temperatures. The increase of natural gas mass ratio results to a decrease of nitric oxide concentration compared to the one under normal diesel operation. At high engine load and low mass ratios of natural gas there is a sharper decrease of NO concentration, compared to part load conditions, with increasing gaseous fuel percentage.

The rate of CO formation is a function of available amount of unburned gaseous fuel and mixture temperature, both of which control the rate of fuel decomposition and oxidation. In general CO emission values under dual fuel operation are considerably lower compared to normal diesel operation.

Under dual fuel mode operation, the filling of the crevice volumes with un-burnt mixture of air and gaseous fuel during compression and combustion while the cylinder pressure continues to rise is an important source dominating the formation of HC emissions. This offers an explanation for the considerably increased HC emissions under dual fuel operation in all cases examined.

IX. CONCLUSIONS

Outcome of performance characteristics

1. Engine testing was carried out where the base MAP was obtained by obtaining the minimum amount of diesel quantity required for engine operation by varying the gas supplement ratio and further the MAP prepared for being optimized on vehicle trains for performance and emission targets.
2. CNG or diesel dual fuel system satisfied torque and Power equal with existing diesel engine by controlling the amount of CNG.
3. Brake specific fuel consumption decreased in dual fuel operation and a slight increase was attained in brake thermal efficiency.
4. The knocks or PM trade of diesel engine was broken down and it was observed that optimizing techniques used and retarding the injection timing reduce the PM as compared to Bharat stage III A norms.

Outcome of emission characteristics regarding NO_x, HC and CO

1. The reduction of NO concentration, observed in most cases is the less intense premixed combustion, the reduction of gas temperature due to increase of the specific heat capacity, the slower combustion and finally the reduction of oxygen concentration due to presence of the natural gas mass ratio, which replaces an equal amount of air in the cylinder charge.

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2. At part load increasing the amount of gaseous fuel, leads to a sharp increase of CO concentration. This is due to the slow combustion rate of gaseous fuel, which maintains the charge temperature at low levels result in poor reduction of oxidation process of carbon monoxide.
3. At high engine load, CO emissions increase with increasing natural gas mass ratio and beyond a certain value of gaseous fuels mass ratio they start to decrease as a result of the high gas temperature and faster combustion rate.
4. At low load HC increase as the percentage of gaseous fuel increases. The low charge temperature combined with a slower burning rate leads to an increase of gaseous fuel, which does not burn completely.
5. At high engine load there is an increase of HC emissions with increasing gaseous real mass ratio until a certain limit where they start to decrease, this is due to the increase of burnt gas temperature, which promotes the oxidation of unburned hydrocarbons.

X. FUTURE SCOPE

1. By introducing the throttle to control the amount of air to be delivered to the engine as stoichiometric combustion can be carried out which can reduce the HC emissions along with using three way catalytic converter as after the treatment device.
2. The future work should focus for optimizing the engine for more speed and load with final goal being a complete dual fuel controlled scheme with special attention to further reduction in pilot quantities.
3. Other method of emission reduction may be the part of research as some methods include exhaust gas recirculation which was name earlier as a means to reduce HC emission at high load, turbocharged air bypass.
4. Dual Fuel technology may optimize for use in conventional diesel bus and truck engines with minimum changes.
5. Further Development of after treatment solutions for dual fuel engines is required.

REFERENCES

- [1]. H. Bayraktar, An experimental study on the performance parameters of an experimental CI engine fueled with diesel-methanol-dodecanol blends, Fuel 87 (2) (2008) 158-164.
- [2]. L.J. Wei, C.D. Yao, Q.G. Wang, W.Pan, G.P. Han, combustin and emission characteristics of a turbocharged diesel engine using high premixed ratio of methanol and diesel fuel, Fuel 140 (0) (2015) 156-163.
- [3]. A.J. Torregrosa, A. Broatch, A. Garcia, L.F. Monico, sensitivity of combustion noise and NOx and soot emissions to pilot injection in PCCI diesel engines, Appl. Energy 104 (2013) 149-157.
- [4]. W. Tutak, K. Lukacs, S. Szwaja, A. Breczky, alcohol-diesel fuel combustion in compression ignition engine, Fuel 154 (0) (2015) 196-206.
- [5]. A. Shah, S.S. Thipse, A. Tyagi, "The ARAI, Literature review and simulation of dual fuel diesel CNG engine", SAE 2011-26-0001, 2011,doi:10.4271.2011—26-0001.
- [6]. Pablo García Valladolid et al, "Impact of diesel pilot distribution on the ignition process of a dual fuel medium speed automotive engine", 2017
- [7]. Dr. S.S. Thipse. "Alternative fuels, concepts, technology and developments", Jacco publication.
- [8]. Kishor Kumar Kavathekar et, "Development of Dual Fuel (Diesel-CNG) Engine for SUV Application in India", 2015.
- [9]. K.K. Kuo, "Principles of Combustion", John Wiley and Sons, New York, 2005.
- [10]. Wei L., Geng P. A review on natural gas/diesel dual fuel combustion, emissions and performance. Fuel process Technol 2016; 264-78. <http://dx.doi.org/10.1016/j.fuproc.2015.09.018>.
- [11]. J.B. Heywood, "Internal Combustion Engine Fundamental", McGraw-Hill Series in mechanical Engineering, 1998.
- [12]. V. Ganeshan, 2013. "Internal Combustion Engines", Tata McGraw-Hill, New Delhi.
- [13]. M.Y.E. Selim, Pressure-time characteristics in diesel engine fueled with natural gas, Renew. Energy 22 (4) (2001) 473-489.
- [14]. Nitesh Mittal et al.Study of performance and emission characteristics of a partially coated LHR SI engine blended with n-butanol and gasoline.
- [15]. A. Demirbas, Methane gas Hydrate: Springer Science and Business Media, 2010.
- [16]. V. Pirouzpanah, R.K. Sarai, Reduction of emissions in an automotve direct injection diesel engine dual-fulled with natural gas by using variable exhaust gas recirculation, Proc. Inst. Mech. Eng. D.J. Automobile engine 217(D8) (2003) 719-725.
- [17]. M.M. Abdelaal, A.H. Hegab, Combustion and emission characteristics of a natural gas-fulled diesel engine with EGR, Energy Convers. Manag. 64(0) (2012) 301-312.
- [18]. K.K.Srinivasan, S.R. Krishnan, Y. Qi, Cyclic combustion variations in dual fuel partially premixed pilot-ignited natural gas engines, J. Energy Resour. Technol. Trans. ASME (2014) 136(1).

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 5, May 2018

- [19]. W.W. Pulkrabek, Engineering Fundamentals of the Internal Combustion Engine, Prentice Hall, 2004
- [20]. D.I.G. Stiesch, Modeling Engine Spray and Combustion Processes: Springer Berlin Heidelberg, 2003.
- [21]. S. Fernando, C. Hall, S. Jha, NO_x reduction from biodiesel fuels, Energy Fuel.
- [22]. J. Liu, F. Yang, H.W. Wang, M.G. Ouyang, S.G. Hao, Effects of pilot fuel quantity on the emissions characteristics of a CNG/diesel dual fuel engine with optimized pilot injection timing, Appl. Energy 110 (0) (2013) 201–206.
- [23]. A. Gharehghani, S.M. Mirsalim, A. Jazayeri, Numerical and experimental investigation of combustion and knock in a dual fuel gas/diesel compression ignition engine, J. Combust. (2012)<http://dx.doi.org/10.1155/2012/504590>.
- [24]. S. Imran, D.R. Emberson, A. Diez, D.S. Wen, R.J. Crookes, T. Korakianitis, Natural gas fueled compression ignition engine performance and emissions maps with diesel and RME pilot fuels, Appl. Energy 124 (2014) 3284–365.
- [25]. Q.C. Zhang, G.S. Chen, Z.Q. Zheng, H.F. Liu, J. Xu, M.F. Yao, Combustions and emissions of 2,5-dimethylfuran addition on a diesel engine with low temperature combustion, Fuel 103 (2013) 730–735.
- [26]. B. Yang, X. Wei, C.X. Xi, Y.F. Liu, K. Zeng, M.C. Lai, Experimental study of the effects of natural gas injection timing on combustion performance and emissions of a turbocharged common rail dual-fuel engine, Energy Convers.Manag. 87 (2014) 297–304.
- [27]. B. Yang, C.X. Xi, X. Wei, K. Zeng, M.C. Lai, Parametric investigation of natural gas port injection and diesel pilot injection on the combustion and emissions of a turbocharged common rail dual-fuel engine at low load, Appl. Energy 143 (2015) 130–137.
- [28]. B.B. Yang, M.F. Yao, W.K. Cheng, Z.Q. Zheng, L. Yue, Regulated and unregulated emissions from a compression ignition engine under low temperature combustion fuelled with gasoline and n-butanol/gasoline blends, Fuel 120(0) (2014) 163–170.
- [29]. S.O. Akansu, Z. Dulger, N. Kahraman, T.N. Veziroglu, Internal combustion engines fueled by natural gas-hydrogen mixtures, Int. J. Hydrog. Energy 29 (14) (2004) 1527–1539.
- [30]. R. Chandra, V.K. Vijay, P.M.V. Subbarao, T.K.Khura, Performance evaluation of a constant speed IC engine on CNG, methane enriched biogas and biogas, Appl. Energy 88 (11) (2011) 3969–3977.
- [31]. T. Korakianitis, A.M. Namasivayam, R.J. Crookes, Natural-gas fueled spark ignition (SI) and compression ignition (CI) engine performance and emissions, Prog. Energy Combust. Sci. 37 (1) (2011) 89–112.
- [32]. O.M.I. Nwafor, Effect of choice of pilot fuel on the performance of natural gas in diesel engines, Renew. Energy 21 (3–4) (2000) 495–504.
- [33]. G.A. Karim, Combustion in gas fueled compression: ignition engines of the dual fuel type, J. Eng. Gas Turbines Power Trans. ASME 125 (3) (2003) 827–836.
- [34]. A.M. Namasivayam, T. Korakianitis, R.J. Crookes, K.D.H. Bob-Manuel, J. Olsen, Biodiesel, emulsified biodiesel and dimethyl ether as pilot fuels for natural gas fuelled engines, Appl. Energy 87 (3) (2010) 769–778.
- [35]. U. Azimov, E. Tomita, N. Kawahara, Y. Harada, Premixed mixture ignition in the end-gas region (PREMIER) combustion in a natural gas dual-fuel engine: operating range and exhaust emissions, Int. J. Eng. Res. 12 (5) (2011) 484–497.
- [36]. T. Korakianitis, A.M. Namasivayam, R.J. Crookes, Diesel and rapeseed methyl ester (RME) pilot fuels for hydrogen and natural gas dual-fuel combustion in compression– ignition engines, Fuel 90 (7) (2011) 2384–2395.
- [37]. K. Ryu, Effects of pilot injection pressure on the combustion and emissions characteristics in a diesel engine using biodiesel–CNG dual fuel, Energy Convers. Manag. 76 (0) (2013) 506–516.
- [38]. K. Ryu, Effects of pilot injection timing on the combustion and emissions characteristics in a diesel engine using biodiesel–CNG dual fuel, Appl. Energy 111 (0) (2013) 721–730.
- [39]. A. Paul, R.S. Panua, D. Debroy, P.K. Bose, Effect of compressed natural gas dual fuel operation with diesel and Pongamia pinnata methyl ester (PPME) as pilot fuels on performance and emission characteristics of a CI (compression ignition) engine, Energy 68 (2014) 495–509.
- [40]. Y. Daisho, Y. Toru, T. Koseki, T. Saito, R. Kihara, E.N. Quiros, Combustion and exhaust emissions in a direct-injection diesel engine dual-fueled with natural gas, SAE Technical Paper NO:950465, 1995.
- [41]. B. Douville, P. Ouellette, A. Touchette, B. Ursu, Performance and emissions of a twostroke engine fueled using high-pressure direct injection of natural gas, SAE Technical Paper NO:981160, 1998.
- [42]. G. McTaggart-Cowan, W. Bushe, P. Hill, S. Munshi, Nox. Reduction from a heavyduty diesel engine with direct injection of natural gas and cooled exhaust gas recirculation, Int. J. Eng. Res. 5 (2) (2004) 175–191.
- [43]. G. McTaggart-Cowan, S. Rogak, P. Hill, W. Bushe, S. Munshi, Effect of operating condition on particulate matter and nitrogen oxides emissions from a heavy-duty direct injection natural gas engine using cooled exhaust gas recirculation, Int. J. Eng. Res. 5 (6) (2004) 499–511.
- [44]. G.P. McTaggart-Cowan, H.L. Jones, S.N. Rogak, W.K. Bushe, P.G. Hill, The effects of high-pressure injection on a compression-ignition, direct injection of natural gas engine, J. Eng. Gas Turbines Power Trans. ASME 129 (2) (2007) 579–588.
- [45]. G. McTaggart-Cowan, S. Rogak, P. Hill, S. Munshi, W. Bushe, The effects of fuel dilution in a natural-gas direct-injection engine, Proc. Inst. Mech. Eng. D J. Automob. Eng. 222 (3) (2008) 441–453.
- [46]. M.L. Willi, B.G. Richards, Design and development of a direct injected, glow plug ignition-assisted, natural gas engine, J. Eng. Gas Turbines Power Trans. ASME 117 (4) (1995) 799–803.
- [47]. V. Aesoy, V. Harald, Hot Surface Assisted Compression Ignition of Natural Gas in a Direct Injection Diesel Engine, SAE Technical Paper NO: 960767, 1996.
- [48]. V. Aesoy, V. Harald, The Influence of Natural Gas Composition on Ignition in a Direct Injection Gas Engine Using Hot Surface Assisted Compression Ignition, SAE Technical Paper NO:961934, 1996.
- [49]. L. Sun, Y.F. Liu, K. Zeng, R. Yang, Z.H. Hang, Combustion performance and stability of a dual-fuel diesel natural-gas engine, Proc. Inst. Mech. Eng. D J. Automob. Eng. 229 (2) (2015) 235–246.
- [50]. G.P. McTaggart-Cowan, S.N. Rogak, S.R. Munshi, P.G. Hill, W.K. Bushe, The influence of fuel composition on a heavy-duty, natural-gas direct-injection engine, Fuel 89 (3) (2010) 752–759.
- [51]. J. Harrington, S. Munshi, C. Nedelcu, P. Ouellette, J. Thompson, S. Whitfield, Direct Injection Of Natural Gas In A Heavy-Duty Diesel Engine, SAE Technical paper 2002–01–1630, 2002.

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- [52]. G. McTaggart-Cowan, W. Bushe, P. Hill, S. Munshi, A supercharged heavy-duty diesel single-cylinder research engine for high-pressure direct injection of natural gas, *Int. J. Eng. Res.* 4 (4) (2003) 315–330.
- [53]. R.G. Papagiannakis, D.T. Hountalas, C.D. Rakopoulos, Theoretical study of the effects of pilot fuel quantity and its injection timing on the performance and emissions of a dual fuel diesel engine, *Energy Convers. Manag.* 48 (11) (2007) 2951–2961.
- [54]. S.R. Krishnan, K.K. Srinivasan, S. Singh, S.R. Bell, K.C. Midkiff, W. Gong, et al., Strategies for reduced NO_x emissions in pilot-ignited natural gas engines, *J. Eng. Gas Turbines Power Trans. ASME* 126 (3) (2004) 665–671.
- [55]. E. Tomita, N. Kawahara, Z. Piao, R. Yamaguchi, Effects of EGR and early injection of diesel fuel on combustion characteristics and exhaust emissions in a methane dual fuel engine, *SAE Technical Paper NO:2002-01-2723*, 2002.