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Effect of CNG Flow Rate and Combustion Chamber Shapes on the Performance of Dual Fuel Engine Operated with HnOME and CNG

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Abstract

Stringent environmental regulations to control NOx and Particulate matter simultaneously with acceptable efficiency from diesel engines is the need of hour. Use of fossil fuels which are depleting in nature and the harmful tail pipe emissions from diesel engines have envisaged concern in unique combustion technology that uses alternate and renewable fuel as the energy sources. Pilot -ignited (CNG) compressed

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natural gas engines that employ small bio-diesel preliminary injection to burn a premixed and mixture of air-compressed natural gas is receiving significant interest. This paper deliberates the influence of injection timing, gas flow rates of CNG, combustion chamber shapes on the performance of DF engine operated with biodiesel extracted from honne oil so called honne oil methyl ester (HnOME) and manifold induction of CNG. From this work, we have determined that a 27 BTDC enhanced injection timing, 0.5 kg/h moderate gas flow rate, Reentrant Toroidal combustion chamber shape and 6-hole injector resulted in decreased smoke, carbon monoxide and hydrocarbons emission and increased brake thermal efficiency. However, there is a significant rise in the emission of oxide of nitrogen (NOx). With the help of EGR method these NOx can be reduced efficiently. An injection timing of 27oBTDC, 0.5 kg/h, Reentrant Toroidal combustion chamber shape are found to be optimal for modied compression ignition engine that operates on CNGHnOME DF mode.

1 Introduction

The depletion of fossil fuels led to search for alternative fuels like biodiesel and CNG [1-2]. Natural gas is believed as a most prominent alternate fuel for the reason of its lower emissions and ready availability. The present available diesel engines can be modified readily to work basically on the natural gas, with pilot injection of biodiesel/diesel to attain ignition [3-6]. However, earlier efforts to employ this method were vulgar, lead to extreme diesel/biodiesel usages, over fuelling to attain satisfactory power levels, and unsatisfactorily higher emissions. The diesel/biodiesels introduced into the combustion chamber will go through ignition first then in-turn would assist in burning of CNG. The dual fuel engines shows substantial potential matching diesel engines for full and part load efficiencies and is equally meant to decrease the emissions from diesel engine through dual fuel alteration [7-11].

CNG would be best employed in the diesel engine under dual fuel mode with diesel/biodiesel preliminary injection as a source of ignition. Dual fuel combustion (DFC) of CNG in diesel engine presents promising prospects as it results in improved thermal efficiency and reduced the exhaust emissions. NOx and PM levels in are significantly lesser than that of traditional diesel engine [5, 7]. Lower smoke, lower peak cylinder pressure and even thermal efficiencies are reported equivalently in DFC for majority of operational conditions whereas some researchers claim greater efficiency than single fuel (diesel) mode. Poor part load efficiency due to lean homogenous charge was also reported for dual fuel engine operation [4-5, 7, 12-18].

Accumulation of premixed CNG with the intake air in the combustion chamber crevices during the compression stroke in DFC leads to increased HC emissions in the engine exhaust was reported [7, 9, 16, 18-21]. Several methods of improving the poor low load characteristics, including EGR, throttling, increased air inlet temperature, or shifting over to the diesel mode was reported [7]. Lower brake thermal efficiency (BTE) for diesel-CNG DFC than diesel specific fuel consumption (SFC) was reported with a modified diesel engine at part and low torque conditions. Use of micro-pilot injector to reduce exhaust emissions in DFC systems have been reported [4, 11, 22]. Studies on diesel-CNG DFC systems have been conducted by many researchers. Few studies on the use of biodiesel as pilot fuel for DFC systems have been reported [7, 23-28]. Higher boiling point of biodiesel makes it easy and safe to handle. Shorter ignition delay because of greater cetane number and higher specific gravity of biodiesel are encouraging the biodiesel as a prominent alternative fuel for CI engines. In addition, it is eco-friendly fuel with lower smoke emissions.

A detailed literature review, showed that CNG with HnOME in Duel Fuel mode has not been used to study the working of Compression Ignition (CI) engine by varying flow rates of CNG. Hence in this work, we made an effort to study the performance of the engine with CNG-HnOME fuel combinations. The main objective of this experimental work is to evaluate the effect of injection timing, gas flow rate and combustion chamber shape and nozzle geometry on the performance of dual-fuel engine operated with HnOME and CNG.

2 Experimental section

2.1 Fuels used

In this work, CNG is as an inducted fuel and HnOME, a biodiesel extracted from the locally existing honne oil is used as the preliminary fuel for injection. The main constituent of CNG is methane (CH4), but it also contains some traces of carbon dioxide, ethane, nitrogen, propane, hydrogen sulphide, helium, and water vapor. The properties details of fuels used for the present investigation are summarized in tables 1 and 2. These properties of HnOME are measured at fuels test in House ResearchLaborato

Table 1. Properties of CNG

Properties	Natural Gas
Boiling range(K @101325Pa)	147
Density (kg/m³) at 1 atm. & 15°C	0.77
Flash Point (K)	124
Octane Number	130
Flammability Limits Range-Rich Lean	0.5873, 1.9695
Flame Speed (cm/s)	33.80
Net Energy Content (MJ/kg)	49.5
Auto Ignition Temperature (K)	923 (650°C)
Combustion Energy (KJ/m³)	24.6
Vaporization energy (MJ/m³)	215-276
Stoichiometric A/F (kg of air/kg of fuel)	17

Table 2. Properties of HnOME

Properties	Diesel	Honne Oil	HnOME
Density (kg/m³)	840	930	890
Specific gravity	0.840	0.930	0.890
Calorific Value (kJ/kg	45000	35800	36010
Cetane Number	45-55	40	40-42
Viscosity @ 40°C (cst)	4.59	56	5.4
Flash point (°C)	75	250	163

2.2 Methodology and Experimental set-up

Fig. 1 illustrates an experimental set up of the DF engine that is utilized for the present investigation of work. The engine tests are performed on single cylinder four-stroke water cooled direct injection CI engine. The engine operates at a rated speed of 1500rpm and the injection system used is conventional fuel injection system. The static injection timings and the injector opening pressure (IOP) as specified by an engine manufactures are 23obefore top dead center (BTDC) and 205bar respectively. The injection-timings in between 19 and 27oBTDC, CR of 17.5 and flow-rate of CNG from 0.25 to 1 kg/h, are made use of with HnOME and CNG fuel combination. To regulate engine speed an engine governor is used. The influence of injection timings, flow-rate of CNG and types of combustion-chamber shapes on the Duel Fuel emissions and engine performance that works on a HnOME-CNG fuel combination are inspected. Water is made to flow around cylinder head and engine block through the jackets to accomplish the cooling of engine.

3 Results and discussion :

The experimental investigations are carried out on a four stroke single cylinder CI engine test rig that operates on DFC mode. In this current work, engine tests are performed with DF using CNG and HnOME for 80% load and 100% load condition. .

Fig. 1 Experimental set up

3.1 Influence of flow-rates of CNG on the performance of HnOME-CNG operation

In this present investigations engine working parameter like IT, IOP and CR are reserved as constant at 27o BTDC, 230 bar, and 17.5 respectively for HnOME operations to relate these fallouts with DF outcomes. The gas flow-rate of CNG was varied from 0.25kg/hr to 1 kg/hr.

3.1.1 Performance Characteristics

3.1.2 Break Thermal Efficiency

Fig. 2, illustrates the influences of gas flow-rate of CNG on the BTE at 80% and 100% loads. It is observed from Fig. 2 that, has load increases there is increases in BTE. When compared to lesser gas flow rates of CNG, an increased BTE was noticed with CNG-HnOME duel fuel mode of working to that of greater CNG flow rates. Even if the injection fuel is same, but the variation of the inducted CNG fuel flow rate has a greater influence on the engine performance because of its slow burning characteristics.

Consequently, it can be resolved that an improved combustion efficiency and lower heat losses in the cylinder because of greater flame temperature of CNG-HnOME combination related to greater CNG flow rate which is achieved by lesser CNG flow rates. Hence, the DF combination showed decreased BTE with increased CNG flow rate; primarily due to lower pilot fuel quantity being injected. On an average the BTE was increased by 2.1% when the flow rate was decreased from 1kg/hr to 0.5 kg/h for the HnOME-CNG operation. At 80 % load highest BTE achieved in the DF operation at a CNG flow-rate of 0.25kg/h is 25.2%.

3.1.3 Emission Characteristic

3.1.4 Smoke-Opacity

Fig. 3 illustrates the deviations of the smoke opacity for CNG-diesel, CNG-HnOME dual-fuel combination for 80% and 100% loads. CNG-Diesel dual fuel operations shows decreased smoke opacity compared to HnOME-CNG for both the loads. It is believed that the HnOME biodiesel preliminary fuel is mostly associated with higher emission of smoke for the reason that CNG combustion involves methane and particulate emissions are not produce [21]. The increased CNG quantity results in better combustion and reduced smoke opacity. At maximum gas flow rates, soot oxidation rate increases due to increased exhaust gas temperature, which further decreases soot concentration in exhaust gas [22].Smoke emission levels for diesel-CNG, and HnOME-CNG dual-fuel operation at 0.5kg/h flow rate of CNG are found to be 55 and 67 respectively at 80% load.

3.1.5 HC Emissions

The presence of CNG charge, that results in a lean, homogeneous and low-temperature combustion results an incomplete combustion. For this reason the duel fuel condition as higher level of HC-emissions [21]. Fig. 4 shows the deviation of HC-emissions for CNG-diesel, CNG-HnOME dual-fuel mixtures for 80% and 100% load. HC-emissions of HnOME-CNG operation are obtained to be greater than diesel-CNG dual fuel set-up. HC emission levels for CNG- diesel, CNG-HnOME dual-fuel operation at 0.5 kg/h flow rate of CNG are found to be 61 and 65 ppm respectively at 80% load.

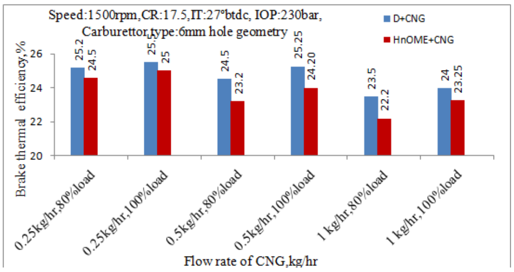

Fig. 2.Effect of Flow rate of CNG on BTE

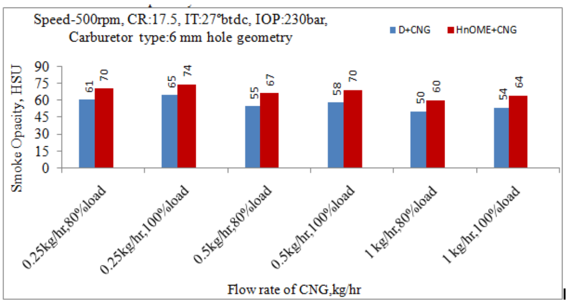

Fig. 3.Variations of Smoke with CNG flow rate

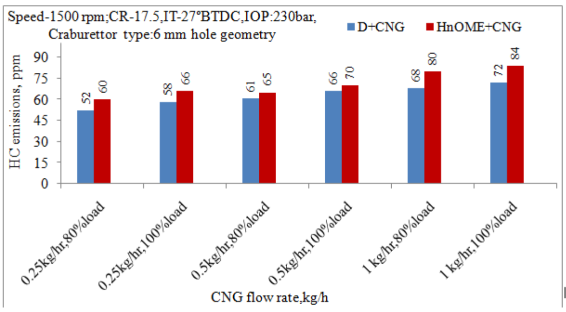

Fig. 4.Variation of HC with CNG flow rate

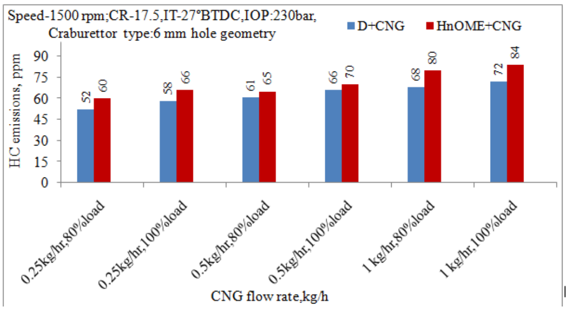

Fig.5. Variations of CO with CNG flow rate

3.1.6 CO Emissions

Fig. 5 shows the deviation of carbon monoxide generated with respect to load by varying CNG flow rates. he carbon monoxide present in the exhaust emissions were observed higher for CNG-HnOME compared to CNG-Diesel dualfuel setup respectively. This is because, in premixed burning phase an increased rate of heat released is observed then in diffusion burning phase in CNG-Diesel set-up [22]. Emissions of CO are greatly reliant on the air-fuel ratio relative to stoichiometric proportions. Rich combustion invariably produces CO and emissions increase linearly with the deviation from the stoichiometry. At extremely low CNG fuel admission CO emissions in exhaust are very small. CO emission levels for diesel-CNG, and HnOME-CNG dual-fuel operations at 0.5 kg/h flow rate of CNG are found to be 0.13 and 0.15% respectively at 80% load.

3.1.7 NOx emission

Fig. 6 illustrates the deviation of NOx-emission with different flow-rates of CNG for CNG-Diesel and CNG-HnOME duel fuel combinations. There is a significant increase in the NOx -emission as the gas flow rates of CNG increases, in the dualfuel combination at both80 % and 100 % loads respectively. The higher temperature prevailing inside engine cylinder and greater amount of heat output for increased gas flow rates. As the result, the combustion phase finished effectively that resulted in higher NOx-emission in exhaust. When compared with CNG-biodiesel a greater premixed combustion phase is seen with CNG-diesel. Mostly for this reason higher NOx-emission are observed in CNG-diesel dualfuel operation. Lower calorific value and heavier molecular structure of biodiesels of vegetables oil, may be the reason for lower emission of NOx in exhaust. NOx-emission levels for Diesel-CNG, and HnOME-CNG dual-fuel operation at 0.5 kg/h flow rate of CNG are found to be 910 and 800ppm respectively at 80% load.

3.2 Effect of Combustion chamber shape on the performance of HnOME-CNG operation

The influence of different Combustion-chamber shapes on the performance of HnOME CNG dual-fuel operation were studied and the operating parameters namely CNG flow rate, IOP, IT and CR are held constant at 0.5kg/h, 230 bar, and 17.5 respectively.

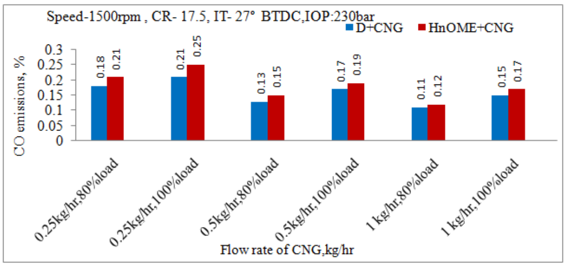

Fig.6. Variation of NOx with flow rate of CNG

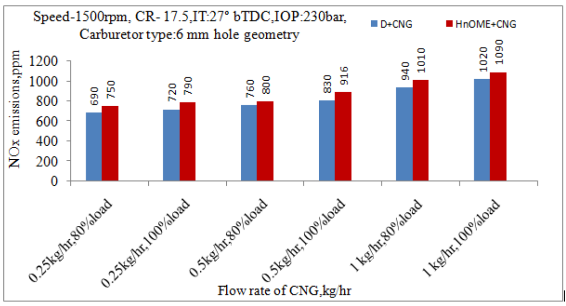

Fig.8. Variation of BTE with Combustion chamber type

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3.2.1 Performance characteristic

3.2.2 Brake thermal efficiency.

Fig. 8 illustrates the deviations of brake thermal efficiency (BTE) for different combustion chamber shapes. The consequences with different combustion chamber shapes illustrates that CNG-HnOME operation with TrCC leads to an enhanced performance compared to that of other combustion chamber shapes. It might be because of fact that, the flame spreading over to the squish region results a healthier mixture formation of HnOME along with air-CNG combinations is prevented by the TrCC,as a result enhanced air motion and exhaust soot are reduced by cumulative tumble and swirl. On the basis of results obtained, it is exhibited that TrCC has ability to direct the flow field into the sub volume for all engine loads and thereafter significant variation in mixing process might not be present. The BTE values for HnOME-CNG operation with HCC, CCC and TrCC were found to be 21.7, 22.5 and 23.2% compared with 24.8%for diesel CNG operation respectively with TrCC at 80%.

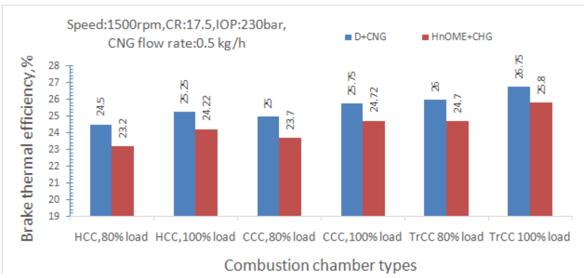

Fig.9. Variation of smoke with Combustion chamber type

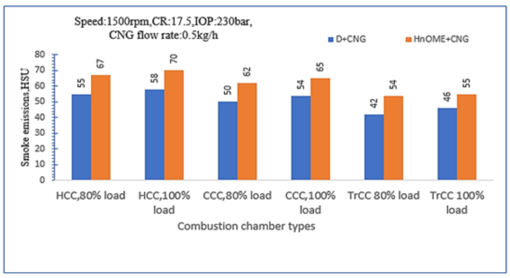

Fig. 10. Variation of CO with Combustion chamber type

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3.2.3 Emission Characteristics

3.2.4 Smoke-Opacity

Fig.9. illustrates the deviation of smoke-opacity with different combustion chamber shapes for CNG-Diesel and CNG-HnOME dual-fuel combinations. A higher levels of smoke-opacity is observed for CNG-HnOME dual-fuel when compared with CNG-Diesel operation for entire power outputs. This might be because of improper air-fuel mixing because of higher viscosity and presence of more free fatty acid in HnOME. On the other hand, the shapes of combustion chambers with CNG-HnOME ,compared to all other different types of combustion chambers ,TrCC gives the lesser smoke emission levels. It might be because of fact that, relatively high turbulence and prevalent air-fuel mixing inside the combustion chamber results an enhanced combustion and even soot particles are oxidized, which further affords reduction in smoke emission levels.The smoke emission levels for CNG-HnOME with TrCC,CCCand HCC are found to be 55,65 and 70HSU compared to that of 46HSU for CNG-Diesel respectively with TrCC.

3.2.5 Effect of Hydrocarbon (HC) and Carbon-monoxide (co)

The deviation of carbon monoxide (CO) and hydrocarbons (HC) emissions levels for CNG-Diesel and CNG-HnOME operations for various combustion chamber shapes used are shown in the Fig. 10 and 11 respectively. Both CO and HC emission positions are greater for CNG-HnOME operations compared to CNG-Diesel set up. It may be because of unfinished combustion of the HnOME-CNG combinations. The unfinished combustion found in case of DF mode of set up is because of inadequate oxygen obtained for combustion, decreased adiabatic flame temperature ,low calorific value of CNG and HnOME, high viscosity of HnOME and lower MEP (Mean Effective Pressures) results in increased level of CO and HC emission in exhaust gas. Regarding the shapes of combustion chambers. Regarding the shapes of combustion chambers with HnOME-CNG operations, compared to all the other different types of combustion chambers TrCC gives a lesser CO and HC emission levels. The reason being relatively greater temperature inside the combustion chamber and high turbulence obtained by TrCC that affords improved CO and HC oxidation which further decreases the level of emission in exhaust i.e. because of the better air swirl motion that leads to improved air and HnOME mixture formation along with CNG resulted in better HnOME combustion. Meanwhile the presence of more oxygen in HnOME along with TCC Results an improved combustion of mixture. The vortex formed due to the limitation in the inferior part of the bowl by TrCC, HCC and CCC these combination chambers fail to result proper fuel mixture combinations. HC levels in HnOME-CNG operation with TrCC, CCC and HCC are found to be 55, 64 and 65ppm, compared to 50ppm for CNG-Diesel operation respectively with TrCC. Likewise, CO levels for CNG-HnOME with TrCC, CCC and HCC are found to be 0.1, 0.14 and 0.15 % compared to 0.09% for CNG-Diesel respectively withTrCC.

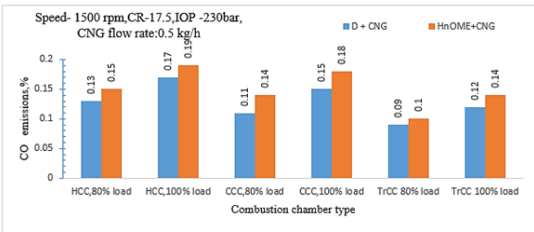

Fig. 11. Variation of HC with Combustion chamber type

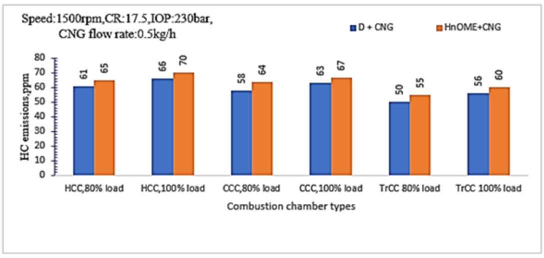

Fig.12. Variation of NOx with Combustion chamber type

3.2.6 Effect of Nitric oxide emissions

Higher levels of NOx emission are found for CNG-Diesel dual-fuel mode of operations as compared with CNG-HnOME operation for entire power outputs [Fig 12].The reason is that the rate of heat discharge is more in the process of premixed combustion phase in CNG-Diesel combination compared to CNG-HnOME combination. When combustion chamber are considered TrCC for CNG-HnOME results a marginally high NOx in emission compared with other combustion chamber shapes tested for all operation. This might be because of somewhat enhanced combustion occurs because of more homogeneous mixing and maximum amount of combustion take place just before TDC. The more oxygen presence in the HnOME is too responsible for this trend. As a result, greater peak cycle temperature is noticed. The NOx emission levels for CNG-HnOME operation with TrCC,CCC and HCC are found to be 830ppm,740ppm and 660ppm, when compared with 916ppm for CNG-Diesel operation respectively for full loads.

4 Conclusions

From this investigation, it is determined that an increased injection timing of 27oBTDC, 0.5kg/h a moderate flow rate of gas, ReentrantToroidal combustion chamber shape causes an improved brake thermal efciency and decreased carbon monoxide, hydrocarbons and smoke emissions. On the other hand, there is a substantial increase in the nitrogen oxides (NOx). An injection timing of 27BTDC, 0.5 kg/h, ReentrantToroidal (TrCC) combustion chamber shape were retrieved to be optimal for the altered compression ignition engine which is operated with CNGHnOME dual-fuel mode.

The Increase in flow rate of CNG from 0.25kg/h to 0.5kg/h decreased BTE, Smoke, HC and CO emissions. The NOX emissions marginally increased for all the pilot fuels. Further increasing the CNG flow rate from 0.5 to 1.0 kg/h, BTE, Smoke and CO emissions decreased, HC and NOX levels increased. The operation of the engine was very smooth with all the selected pilot fuels when the CNG flow rate at 0.5 kg/h. However for 1kg/h of CNG flow-rate engine knock was obtained that resulted in a bad engine performance.

References

[1] Jie Liu, Fuyuan Yang, Hewu Wang, MinggaoOuyang, ShougangHao, Effects of pilot fuel quantity on the emissions characteristics of a CNG/diesel dual fuel engine with optimized pilot injection timing. Applied Energy 2013;110: 201206.

[2] Banapurmath NR, Basavarajappa YH, Tewari PG. Effect of Mixing chamber venture, Injection timing, compression ratio and EGR on the performance of dual fuel engine operated with HOME and compressed natural gas (CNG). International Journal of Sustainable Engineering 2012; 5: 265-79.

[3] Carlucci AP, de Risi A, Laforgia D and Naccarato F. Experimental investigation and combustion analysis of a direct injection dual-fuel dieselnatural gas engine. Energy 2008;33(2): 256-263.

[4] Karim GA. The Dual fuel Engine, A chapter in Automotive Engine Alternatives, Edited by R.L. Evens bleham press 1987.

[5] Papagiannakis RG, Rakopoulos CD, Hountalas DT and Rakopoulos DC. Emission characteristics of high speed, dual fuel, compression ignition engine operating in a wide range of natural gas/diesel fuel proportions. Fuel 2010;89: 1397-1406..

[6] Nwafor OMI. Effect of advanced injection timing on emission characteristics of diesel engine running on natural gas. Renewable Energy 2007;32: 2361-2368.

[7] Banapurmath NR and Tewari PG. Performance combustion and emissions characteristics of a single cylinder compression ignition engine operated on ethanol-biodiesel blended fuels. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 2010; 224: 533-543.

[8] Sahoo BB, Sahoo N and Saha UK. 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.

[9] Mohamed Selim YE., Effect of engine parameters and gaseous fuel type on the cyclic Variability of dual fuel engines. Fuel 2005; 84: 961-971.

[10] Banapurmath NR, Marikatti MK, Hunashyal AM, and Tewari PG. Combustion characteristics of a four-stroke CI engine operated on Honge and Jatropha oil methyl ester-ethanol blends when directly injected and dual fuelled with CNG induction. International Journal of Sustainable Engineering 2011;4(2): 145-152.

[11] Banapurmath NR, Budzianowski WM, Basavarajappa YH,Hosmath RS,Yaliwal VS and Tewari PG, Effects of compression ratio, swirl augmentation techniques and ethanol addition on the combustion of CNGbiodiesel, in a dual-fuel engine, International Journal of Sustainable Engineering 2013, DOI:10.1080 /19397038. 2013. 798712.

[12] Ryu K. Effects of pilot injection timing on the combustion and emissions characteristics in a diesel engine using biodieselCNG dual fuel, Applied Energy 2013;111: 721730

[13] Karim GA, Jones W and Raine RR. An Examination of the Ignition Delay Period in Dual Fuel Engines. Society of Automotive Engineers; 1989, Paper No. 892140, USA.

[14] How HG, Mohamad TI, Abdullah S, Ali Y, Shamsudeen A and Adril E. Experimental investigation of performance and emission of a sequential port injection natural gas engine. European Journal of Scientific Research, 2009; vol. 30: pp. 204-214.

[15] Heywood, JB., Internal combustion engine fundamentals (New York: McGraw Hill), 1988.

[16] Budzianowski WM. A comparative framework for recirculating combustion of gases. Archivum Combustion is, 2010a ;30(1-2): 25-36.

[17] Karim G. A., and Burn K. S., (1980), The Combustion of Gaseous Fuels in a Dual Fuel Engine of the Compression Ignition Type with Particular Reference to Cold Intake Temperature Conditions, Society of Automotive Engineers, Paper No. 800263, USA.

[18] Karim GA and Amoozegar N. Determination of the performance of a dual Fuel Diesel Engine with addition of various liquid fuels to the Intake Charge. Society of Automotive Engineers1983; Paper No. 830265 USA.

[19] Karim GA. An Examination of Some Measures for Improving the Performance of Gas Fuelled Diesel Engines at Light Load. Society of Automotive Engineers1991; Paper No. 912366, USA.

[20] Seung Hyun Yoon , Chang Sik Lee, Experimental investigation on the combustion and exhaust emission characteristics of biogasbiodiesel dual-fuel combustion in a CI engine, Fuel Processing Technology 2011 ; 92 9921000.

[21] R.S. Hosmath, N.R. Banapurmath, S.V. Khandal, V.N. Gaitonde, Y.H. Basavarajappa, V.S. Yaliwal, Effect of compression ratio, CNG flow rate and injection timing on the performance of dual fuel engine operated on Honge oil methyl ester (HOME) and compressed natural gas (CNG), Volume 93, August 2016, Pages 579590, Journal of Renewable Energy, Elseveir publications,.