INTERNATIONAL JOURNAL OF RESEARCH IN MECHANICAL, MECHATRONICS AND AUTOMOBILE ENGINEERING(IJRMMAE)
ISSN: 2454-1435 (Print) | 2454-1443 (online)
Volume 5 Issue 2 – www.ijrmmae.in – Pages 164-174

PERFORMANCE, COMBUSTION AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE OPERATED ON DUAL FUEL MODE USING METHYL ESTERS-COMPRESSED NATURAL GAS (CNG) AND HCNG

L.T.Deshi[1], V.H.Bhusaraddi[2], S.M.Mayammanavar[3]

[1,2,3] Department of Automobile Engineering,R. T. E. Society's Rural Engineering College Hulkoti-582205

Corresponding Author mail: ltdrec@gmail.com

ABSTRACT

Abstract— *This paper presents the performance,combustion and emission characteristics of a single cylinder four stroke water cooled 5.2 kW running at 1500 RPM diesel engine operated on CNG, Hydrogen blended compressed natural gas, (HCNG)- methyl esters of Honge oil (H) and methyl esters of Jatropha oil (J) combinations. The performanceof the biodiesel-HCNG fueled engine was optimized in terms of compression ratio, injection timing and exhaust gas recirculation (EGR) and was compared with base line diesel-HCNG operation. The engine performance was found to be better withincreased compression ratio, advanced injection timing and appropriatepercentage of EGR(**5**%) for the tested fuel combinations. Compared to diesel-HCNG baseline fuel combination, the methyl esters of Honge and Jatropha oil-HCNG operation resulted in overall poorer performance. Performance of the dual fuel engine was further enhanced foroptimized engine conditions of 17.5 compression ratio, 27^{0}bTDC injection timing and 5% EGR. The CNG enriched fuel and biodiesel combinations showednearer to diesel-HCNG combination performance in terms of brake thermal efficiency, combustion parameters and emission levels*

Key words: *Methyl esters of Honge oil (H),methyl esters of Jatropha oil (J), Hydrogen enriched Compressed natural gas (HCNG), Emissions, combustion, Exhaust gas recirculation..*

1. INTRODUCTION

Diesel engines are becoming more and more popular because of their higher brake thermal efficiency, power, reliability, and durability. Hence diesel engines plays a important role in various sectors like energy, agriculture and transportation. World wide bio fuels like Jatropa, Hongey and vegetable oils and other sources like alchol,CNG,biogas and producer gas have been used as alternatives instead of fossil fuels. Biofuels and gaseous fuels are the most promising alternatives to diesel. The natural gas is gaining more popularity as a fuel because it has higher octane and lower cetane number, lower production cost, lower operating cost, and lower emissions factors. CNG does not contain any harmful components such as lead. The energy utilization of CNG is maximized when it is mixed with hydrogen, because its flame speed increases and leads to better and faster combustion [Klaus von Mitzlaff 1998, Chandra et al 2011]. CNG and hydrogen are very stable at optimized compression ratio against abnormal combustion and can therefore be used in engines of higher compression ratio and thus, provides higher brake thermal efficiency and power output [Klaus von Mitzlaff 1998]. HCNG inducted penetrates into the air, and mixes with it and gets ignited by the liquid fuel injected and combustion may proceed much faster with hydrogen addition to CNG due to faster combustion properties of the hydrogen.CNG is a greenhouse gas and has relatively high lean flammability limit of HC fuel makes it difficult to achieve stable combustion near the burning regime. CNG always operate under lean burn condition hence it leads to increased performance. Therefore, excess air could increase the ratio of specific heats of the burned gas and improve combustion efficiency. Furthermore, the knocking tendency is reduced because of lower cylinder temperature. The lean burn operation not only improves the performance but also lowers the HC and CO emission levels. As the main component of natural gas is methane it has higher self ignition temperature and lower flame propagation speed. Therefore to enhance combustion of lean burn operation at faster rate, addition of small amount of hydrogen to CNG is recommended [Kasianantham et al (2011)].CNG and hydrogen are very stable at optimized compression ratioagainst knocking and can therefore be used in engines of higher compression ratio and thus, provides higher brake thermal efficiency and power output [Klaus von Mitzlaff 1998]. HCNG inducted penetrates into the air, and mixes with it and gets ignited by the liquid fuel injected and combustion may proceed much faster withhydrogen addition to CNG due to faster combustion properties of the hydrogen.CNG is a greenhouse gas and has relatively high lean flammability limit of HC fuel makes it difficult to achieve stable combustion near the burning regime. CNG always operate under lean burn condition hence it leads to increased performance. Therefore, excess air could increase the ratio of specific heats of the burned gas and improve combustion efficiency. Furthermore, the knocking tendency is reduced because of lower cylinder temperature. The lean burn operation not only improves the performance but also lowers the HC and CO emission levels. As the main component of natural gas is methane it has higher self ignition temperature and lower flame propagation speed. Therefore to enhance combustion of lean burn operation at faster rate, addition of small amount of hydrogen to CNG is recommended [Kasianantham et al (2011)].

The lot of works done on HCNG as alternative fuel on diesel engine combustion as per literature survey [Kasianantham et al (2011), Saravanan and Nagarajan (2008), Saravanan and Nagarajan (2009), Das (2002), Gopal et al (1982), Qian et al (2011), Lee et al (2002), Banapurmath et al. (2014),Yi et al (1996)]. Several researchers observed poor utilization of the gaseous fuel during dual fuel operation at low and intermediate load. This leads to poor engine performance and in higher concentrations of carbon monoxide emissions compared to the respective values observed under normal diesel operation. At higher load operation improved gaseous fuel utilization, engine performance and carbon monoxide emissions were observed, but they found inferior values of CO compared to the respective values observed under normal diesel operation [Papagiannakis et al (2004)].Increased CO and HC as well as decreased particulate have been reported in the literature [Papagiannakis et al (2007), Banapurmath et al (2014)]. Several researchers have reported that addition of hydrogen to CNG improves the combustion of CNG resulting in higher brake thermal efficiencies with smoother combustion than a diesel engine and lower emission levels[Raman et al (1994),Orhan Akansu et al (2011),Gosal et al (2013)]. 20 to 30% higher efficiency has been reported with hydrogen addition[Gosal et al (2013)].Hydrogen has higher flame speed than natural gas; therefore, the equivalence ratio is much higher than the stoichiometric condicondition, the combustion of methane is not as stable as with a blend of H2-CNG [Gosal et al (2013)]. Yi et al. [1996)] stated that brake thermal efficiency of intake port injection is clearly higher than in- cylinder injection at all equivalence ratios. Improved efficiency has been reported with intake port injection compared to in-cylinder injection at different equivalence ratios [Yi et al. (1996)].Decreased combustion duration with increased hydrogen blending fraction in CNG- hydrogen blended gasoline engine has been reported by Andrea *et al.* [1998].Apostolescu and Chiriac [1996] showed that hydrogen addition during combustion reduced cyclic variation. Some investigators have reported that introduction of hydrogen into the diesel engine causes the energy release rate to increase at the early stages of combustion, which increases the indicated thermal efficiency. This is also the reason for the lowered exhaust temperature. According to them, for fixed H2 supply at 50%, 75% and 100% load, H_2 replaces 13.4%, 10.1% and 8.4% energy respectively with high diffusive speed and high energy release rate [Jie et al (2013)].

Dual fuel engine using Hydrogen along with diesel injection to study performance of dual injection hydrogen fueled engine by using solenoid in-cylinder injection and external fuel injection technique has been reported [Lee et al. (2001)].Literatures on hydrogen fueled engine showed that, H_2 -diesel dual fuel mode with 90% enriched H_2 gives higher efficiency, but cannot complete the load range beyond that due to knocking problems. Lee et al. [2001] suggested that in dual injection, the stability and maximum power could be obtained by direct injection of hydrogen. Karim (1996, 1996)investigated H_2 and CH_4 blended fuel operation spark ignited engine using 100/0, 90/10, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70 and

20/80 CH_4-H_2 proportions by varying equivalence ratios. They investigated initiation speed (m/s), power output difference, indicated output efficiency, ignition lag, combustion duration (◦CA), maximum cylinder pressure, knocking regions in different proportions of H_2 and CH_4 percentage, at different equivalence ratios and different injection timings (10◦; 20◦; 30◦bTDC). Increased power output has been reported with increasing concentration of hydrogen in the engine at 20°bTDC and with the increasing concentration of hydrogen in the engine, at 30◦bTDC, power output decreased. If some amount of hydrogen was added to the methane as a fuel for the SI engine, performance characteristics of the engine increased drastically.

There have been several studies addressing the performance and emission characteristics of diesel engines operating on diesel-CNG combinations. When diesel engine is converted to run on dual fuel (DF) mode, where gas is the main fuel and diesel is the pilot fuel, the levels of emissions for this type of engine is much higher than that generated from regular diesel engines. Therefore, it is hardly to find less work that deals with effect of engine variable sinDF engines. In view of this, an effort has been made to enhance the overall performance of DF engine with reduced emission levels. Therefore, experimental investigations were conducted on a single- cylinder four-stroke wa water-cooled DI diesel engine operated in DF mode with methyl estersHonge and Jatropha oils and blend of CNG/H_2 induction. In the present work, the performance of the methyl estersHonge and Jatropha oils-HCNG fueled DF engine was optimized with respect to compression ratio, injection timing and exhaust gas recirculation (EGR) and compared with base line diesel-HCNG operation. Finally, results of methyl estersof Honge and Jatropha oils-HCNG DF operation was compared with base line data of diesel-HCNG operation.

2 FUEL PROPERTIES

The properties of Honge oil and HOME were determined and are summarized in Table 1. Table 2 presents the properties of the gaseous fuels, namely CNG and HCNG, respectively.

Table 1: Properties of Fuels Used

Sl. No.	**Properties**	**Diesel**	**Methyl esters of Hongeoil**	**Methyl esters of Jatropha oil**
1	Chemical Formula	$C_{13}H_{24}$	----	----
2	Density (kg/m^3)	840	870	880
3	Calorific value (kJ/kg)	43,000	39800	38,010
4	Viscosity at 40^{o}C (cSt*)	2-5	44.85	45.6
5	Flashpoint (^{o}C)	75	210	167
6	Cetane Number	45-55	40	45
7	Carbon Residue (%)	0.1	0.66	----

8	Cloud point	-2	----	7
9	Pour point	-5	----	4
10	Carbon residue	0.13	0.55	0.01
11	Molecular weight	181		227
12	Auto ignition temperature (^0C)	260		470
13	Ash content % by mass	0.57		0.01
14	Oxidation stability	High	Low	Low
15	Sulphur Content	High	No	No

Table 2: Properties of CNG, and HCNG

Sl. No	Properties	CNG	HCNG
1	Density of Liquid at 15^{0}C, kg/ m^3	0.77	---
3	Boiling Point, K	147 K	---
4	Lower calorific value, kJ/kg	48000	47170
5	Limits of Flammability in air, vol. %	5-15	5 - 35
6	Auto Ignition Temp, K	813	825
7	Theoretical Max flame Temp, K	2148	2210
8	Flash point ^{0}C	124	---
9	Octane number	130	---
10	Burning velocity, cm/sec	45	110
11	Stoichiometric A/F, kg of air/kg of fuel	17:1	----
12	Flame temperature, ^{0}C	---	1927
13	Equivalence ratio	0.7-4 0	0.5 - 5.4

3 EXPERIMENTAL SET-UP

The experimental set-up used for CNG and HCNG- operated dual-fuel engines is shown in Figure 1(a). Engine tests were conducted on a four-stroke single cylinder water-cooled DI compression ignition engine with a displacement volume of 662 cc, compression ratio of

INTERNATIONAL JOURNAL OF RESEARCH IN MECHANICAL, MECHATRONICS AND AUTOMOBILE ENGINEERING(IJRMMAE)
ISSN: 2454-1435 (Print) | 2454-1443 (online)
Volume 5 Issue 2 – www.ijrmmae.in – Pages 164-174

17.5:1 and developing power of 5.2kW at 1500 rev/min. Figure 1 (b) shows exhaust gas recirculation (EGR) usedin the dual fuel engine. The engine was always operated ata rated speed of 1500 rev/min. The engine had a conventional fuel injection system. The injector opening pressure (IOP) and the static injection timing (IT) was

205 bar and 23°Before Top Dead Centre (bTDC) respectively as specified by the manufacturer. To study the effect of different injection timings, static injection timings of 19°bTDC and 27° bTDC were adopted by varying the lift length of the rod in the mechanical fuel pump apart from the manufacturer recommended injection timing. To study the effect of CR the optimum injection timing was kept fixed and the CR was varied from 15 to 17.5. In addition, to study the effect of EGR, the optimum IT and CR were kept constant and the EGR was varied from 5 to 20% in steps of 5. The engine is provided with a governor and it maintains a constant engine speed at all the loads on the engine. The governor of the engine was used to control the engine speed. The engine wasprovided with a hemispherical combustion chamber with overhead valves operated through push rods. Cooling of the engine was accomplished by circulating water through the jackets on the engine block and cylinder head. A piezoelectric pressure transducer was mounted on the cylinder head surface to measure the cylinder pressure. Table 3shows the specification of the engine used for the study. Exhaust gas analyzer and Hartridge smoke meter were used to measure HC, CO, NO_X and smoke emissions. In the next work, arrangement was made to induct CNG and HCNG into the inlet manifold was established.

4. RESULTS AND DISCUSSIONS

This section presents the results of experimental investigations carried out on a diesel engine suitably modified to operate in dual fuel mode.

Figure 1 Dual fuel engine with CNG/Hydrogen induction arrangement

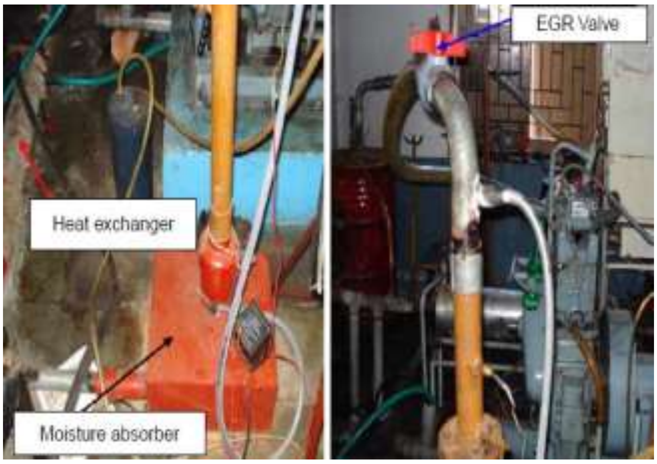

Figure 2 Exhaust gas recirculation System

During the experimentation, the gas flow rate of HCNG was maintained constant (0.25 kg/hr) and engine speed was maintained at 1500 rpm. In this study effect of injection timing, compression ratio and exhaust gas temperature (EGT) on the overall performance was presented. A suitable carburetor was developed with 12 holes having 6 mm orifices to ensure stoichiometric air- gas mixture to be supplied to the engine. The liquid fuel of methyl esters of Honge oil (H) and Jatropha oil (J) were used as injected fuels.

Table 3 Specification of the CI engine

Sl No	Parameters	Specification
2	Type	TV1 (Kirlosker make)
3	Software used	Engine soft
4	Nozzle opening pressure	200 to 225 bar
5	Governor type	Mechanical centrifugal type
6	No of cylinders	Single cylinder
7	No of strokes	Four stroke
8	Fuel	H. S. Diesel
9	Rated power	5.2 kW (7 HP at 1500 RPM)
10	Cylinder diameter (Bore)	0.0875 m
11	Stroke length	0.11 m
12	Compression ratio	17.5 : 1

Air Measurement Manometer:		
13	Made	MX 201

14	Type	U- Type
15	Range	100 – 0 – 100 mm
Eddy current dynamometer:		
16	Model	AG – 10
17	Type	Eddy current
18	Maximum	7.5 (kW at 1500 to 3000 RPM)
19	Flow	Water must flow through Dynamometer during the use
20	Dynamometer arm length	0.180 m
21	Fuel measuring unit – Range	0 to 50 ml

5. CONCLUSIONS

From the exhaustive study on the dual fuel engine using methyl esters of Honge, Jatropha oils and HCNG gaseous fuel the following conclusions were made

1. Dual fuel engines significantly reduce smoke, particulate and NOx emissions when compared to their counterpart biodiesel operated diesel engines.
2. Biodiesels of methyl esters of Honge and Jatropha oil can provide partial substitution to diesel when used in dual fuel mode along with CNG, HCNG gaseous fuels.
3. HCNG operated dual fuel engines besides using renewable fuels of methyl esters of Honge and Jatropha oilcan provide partial substitution to renewable fuels and leads to lower emissions of HC and CO emissions when compared to CNG operation
4. Adding hydrogen to CNG significantly improves brake thermal efficiency and reduces emissions of smoke, HC, CO emissions except NOx. At an IT 27^{o} BTDC and CR of 17.5, the BTE for the H-HCNG DF operation with EGR of 5, 10, 15% and 20% were 24.1, 23.5, 22.5 and 20.1 % respectively, compared to 25.8 % for the D- HCNG operation. HCNG enables engine operation with leaner fuel air mixture, resulting into lower emissions of HC and CO and higher NOx emissions.
5. Increased EGR rates increases smoke, HC and CO emissions and the brake thermal efficiency reduces while NOx reduces significantly.
6. Higher flame speed of hydrogen in HCNG results in reduced ignition delay,

combustion duration while the peak pressure and heat release rates both increased.

On the closure, it can be concluded that higher percentage of hydrogen in CNG can affect the engine performance favorably but limit the engine operation with severe knock especially at higher loads of engine operation. The problem of knocking can be effectively addressed by injecting HCNG into the intake manifold when the inlet valve opens to avoid pre-ignition. Advancing the IT of pilot biodiesel fuel and increased CR can improve the performance of such DF engines.

Current research work in diesel engines using gaseous fuels (LPG, CNG and HCNG) in single mode or with liquid fuels in DF mode make use of port or manifold gas injection systems and facilitate to overcome the drawbacks of the backfire and pre-ignition which is prone to occur in carbureted engines. This can be eliminated with proper gas injection timing using low pressure gas injector operated by a suitable Electronic Control Unit (ECU). The continued work by the authors will address the drawbacks of gas induction system using venture replaced by an ECU for CNG/HCNG injection in dual fuel modes of engine operation.

REFERENCES

1. Korakianitis T., Namasivayam A.M., Crookes R.J., Natural-gas fueled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions, Progress in Energy and Combustion Science 37 (2011), 89-112
2. Klaus von Mitzlaff. Engines for biogas. Published by Friedr. Vieweg & Sohn Verlagsgesellschaft GmbH; 1988.
3. *Kasianantham NANTHAGOPAL* a*, *Rayapati SUBBARAO* b, *Thangavelu ELANGO* a, *Ponnusamy BASKAR* a, *and Kandasamy ANNAMALA* . Hydrogen Enriched Compressed Natural Gas … THERMAL SCIENCE, Year 2011, Vol. 15, No. 4, pp. 1145-1154.
4. *Saravanan N., Nagarajan G.,* 'Experimental investigation on a DI dual fuel engine with hydrogen injection', *International Journal of Energy Research,* ***33, 3*** *(2008) 295–308.*
5. *Saravanan N., Nagarajan G.,* 'An experimental investigation on manifold-injected hydrogen as a dual fuel for diesel engine system with different injection duration', *International Journal of Energy Research* ***33, 15*** *(2009) 1352–1366.*
6. *Das L. M.,* 'Near-term introduction of hydrogen engines for automotive and agriculture application', *International Journal of Hydrogen Energy*, ***27, 5*** *(2002)479–487.*
7. *Gopal G., Rao P. S., Gopalakrishnan K. V., S.Murthy B.,* 'Use of hydrogen in dual-fuel engines', International Journal of Hydrogen Energy, ***7,3*** *(1982)*

267-272.

8. *Qian Y. J., Zuo C. J., Xu J. T. H. M.*, 'Effect of intake hydrogen addition on performance and emission characteristics of a diesel engine with exhaust gas recirculation', *proceedings of the institution of mechanical engineers, Journal of MechanicalEngineering Science,**225** (2011) 1919- 1925.*
9. *Lee J. T., Kim Y. Y., Caton J. A.*, 'The development of a dual injection hydrogen fueled engine with high power and high efficiency', *Proceedings of the 2002 Fall Technical Conference of the ASME Internal Combustion Engine Division, No. ICEF2002-514, NewOrleans, Louisiana, USA, (2002), 323–333.*
10. N. R. Banapurmath, N. M. Gireesh, Basavarajappa Y.H., R. S. Hosmath, V.S. Yaliwal, AbhayPai, Kishan Gopal Navale, Priyanka Jog, P.G. Tewari, Effect of hydrogen addition to cng in a biodiesel operated dual fuel engine
11. *Yi H. S., Lee S. J., Kim E. S.*, 'Performance evaluation and emission characteristics of in-cylinder injection type hydrogen fueled engine', *International Journal of Hydrogen Energy **21**, **7** (1996) 617–624.*
12. *Papagiannakis R.G., Hountalas D.T.,* 'Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot Diesel fuel and natural gas', *Energ Convers Manage, **45**(2004), 2971-87.*
13. *Papagiannakis R.G., Hountalas D.T., Rakopoulos C.D.*, '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 Conversion Management*, ***48*** *(2007), 2951-61.*
14. *Raman V., Hansel J., Fulton J., Brudery D.*, 'Hythane—an ultraclean transport fuel. Proceedings', *10th World hydrogen Energy Conference, Cocoa Beach, USA, June 20–24, 1994. p. 1797–806.*
15. OrhanAkansuSelahaddin, Mehmet Bayrak, "Experimental study on a spark ignition engine fueled by CH4/H2 (70/30) and LPG," Hydrogen energy, vol. 36, pp. 9260-9266, 2011.
16. Gosal M. M., Das L. M.,GajendraBabu M. K., Improved efficiency of CNG using hydrogen in spark ignition engine, Journal of Petroleum Technology and Alternative Fuels, DOI: 10.5897/JPTAF10.002, Vol. 4(6), June 2013, 99-112.
17. *Apostolescu, N., Chiriac, R.*, 'A study of combustion of hydrogen-enriched gasoline in a spark ignition engine', *SAE Paper No. 960603, (1996).1-10.*
18. *Jie Liu, Fuyuan Yang, Hewu Wang, Minggao Ouyang, ShougangHao*, 'Effects of pilot fuel quantity on the emissions characteristics of a CNG/diesel dual fuel engine with optimized pilot injection timing', *Applied Energy*, ***110*** *(2013), pp. 201–206.*
19. *Karim G.A.*, 'Hydrogen as an additive to methane for engine applications. 11th World Hydrogen Energy Conference', *Stuttgart, Germany, June 23–28, (1996)*

1921–526.

20. *Karim G.A., Wierzba I., Al-Lousi Y.*, 'Methane–hydrogen mixtures as fuels', *Int J Hydrogen Energy* ***20,*** *(1996) 625–31.*
21. López J.M., Alvaro Gomez A., Francisco aparicio, Fco.Javier Sanchez, Comparison of GHG emissions from diesel, biodiesel and natural gas refuse trucks of the city of Madrid, J.Applied Energy, Vol. 86, Issue 5, 2009, pp. 610-615.
22. Simio Luigi De, Michele Gambino, SabatoIannaccone, 2013. "Experimental and numerical study of hydrogen addition in a natural gas heavy duty engine for a bus vehicle". *International Journal of Hydrogen Energy* http://dx.doi.org/10.1016.
23. Jie Liu., Fuyuan Yang., Hewu Wang., Minggao Ouyang., Shougang Hao., Effects of pilot fuel quantity on the emissions characteristics of a CNG/diesel dual fuel engine with optimized pilot injection timing, Applied Energy, Vol. 110, 2013, pp. 201–206.
24. Mahla S. K., Das L. M., Babu M. K. G., Effect of EGR on Performance and Emission Characteristics of Natural Gas Fueled Diesel Engine. International (Jordan) Journal ofMechanical and Industrial Engineering, Vol.4, Issue 4, 2010, pp. 523-530.