Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 04, pp.29321-29329, April, 2016

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

AFTERMARKET EXHAUST GAS EMISSIONS ANALYSIS OF A DIRECT INJECTION CNG-DIESEL DUAL FUEL ENGINE

[1]Hanna, R. N., [2]Mustafa, A. M., [2]Zefaan, H. and *[,2]Sameh M. Metwalley

[1]Senior Engineer, MCV- Manufacturing Commercial Vehicles Co. Egypt
[2]Department, Faculty of Engineering, Mataria, Helwan University, Egypt

ARTICLE INFO

Article History:
Received 23rd January, 2016
Received in revised form
26th February, 2016
Accepted 19th March, 2016
Published online 26th April, 2016

Key words:

Aftermarket conversion, Alternative fuel, Natural gas, Dual diesel engines, Exhaust emissions.

ABSTRACT

In the present paper an experimental research was carried out on a laboratory two cylinder, four-stroke, direct injection diesel engine, designed mainly to run on diesel fuel and converted with minor modifications to run on CNG-Diesel dual fuel mode. The aim is to analyze the emission characteristics of pure diesel first and then CNG-Diesel dual fuel mode. The measurements were recorded at CNG substitution rates of 10%, 20% and 30% and varying the load from 1.5 to rated load of 9kW in steps of 1.5. The results reveal that, there is drastic reduction in CO, CO2, HC, NO and smoke in the exhaust of dual fuel engine at all loads and for 10%, 20% and 30% CNG substitution rates. From the positive results obtained in this experimental research, it can be concluded that it is a promising technology for achieving controlling on emissions in conventional compression ignition engines with minor engine modifications, thus great saving the human and plant life from the hazardous effects of exhaust gas pollutants from the conventional diesel engines.

Citation: Hanna, R. N., Mustafa, A. M., Zefaan, H. and Sameh M. Metwalley, 2016. "Aftermarket exhaust gas emissions analysis of a direct injection CNG-Diesel dual fuel engine", *International Journal of Current Research*, 8, (04), 29321-29329.

INTRODUCTION

Gaseous fuels for ICE has become more attractive (Shawki *et al.*, 2005), not only from the standpoint of energy resources but also from environmental protection (Aslam *et al.*, 2006) by mixing with air to produce a mixture, which burns more completely than the liquid fuels. Physical delay is almost nil, generally build up minimum carbon deposition and quantity of contaminating residues is very small. Gaseous fuels produce less emission, at combustion, than gasoline (Cavalcante *et al.*, 2007). Also hydrogen is being widely explored as a fuel for passenger vehicles, it can be used in fuel cells to power electric motors or burned in ICE (Verhe *et al.*, 2006) and liquefied petroleum gas (LPG) is a clean- burning fossil fuel and less expensive than gasoline (Bayraktar and Durgun, 2001). Compressed Natural Gas and Diesel dual fuel operation is regarded as one of the best ways to control emissions from diesel engines and simultaneously saving petroleum based diesel fuel.

Corresponding author: Sameh M. Metwalley
Department, Faculty of Engineering, Mataria, Helwan University, Egypt.

Natural Gas as a Gaseous Fuel for IC Engines

CNG has been recognized as a promising gaseous fuel for ICEs, whereas there are many merits of it over conventional fuels, and abundant in many parts of the world (Shamekhi *et al.*, 2006). It consists of approximately 80 to 90% methane, lighter than air, inflammable, has higher octane number, lower fuel and maintenance costs than petrol, the hydrogen-carbon ratio of it is higher than any other hydrocarbon fuel. The combustion of it, produces fewer deposits and cleaner exhaust emissions, reduces lubrication oil contamination. Due to the low energy density, it is compressed to a pressure of 200 to 250 MPa to enhance the vehicle on-board energy storage. The lean-burn capability and flame burning velocity of it is improved by blending with fast burning velocity fuel such as hydrogen (Patil *et al.*, 2010). Two types of CNG engines are primarily studied.

Homogeneous SI engines

SI engines can be retrofitted to CNG operation quite easily, with the addition of a second fueling system. During part-load operation, the brake thermal efficiency can be substantially higher for these engines than gasoline (Dinh, 1994). During full-load operation, at all engine speeds, volumetric efficiency, BMEP, torque, power, BSFC are decreased, CO emissions decreased, HC emissions demonstrate reduction, and the NOX emissions are the only ones that show an increase in their amounts (Shamekhi and Khatibzadeh, 2008).

Dual fuel diesel engines

CNG combustion is characterized by a high self-ignition temperature so; it cannot be used directly as a fuel for diesel engine. Dual fuel diesel engine uses homogeneous CNG mixture and diesel fuel spray (Semin and Rosli, 2009). Existing diesel engines are under stringent emission regulation particularly of smoke and NO_X in their exhaust. Much interest has centered on CNG due to its potential for low particulate and NO_X emissions. CNG and diesel dual-fuel operation is regarded as one of the best ways to control emissions from diesel engines and simultaneously save petroleum based precious diesel fuel. Dual fuel engine is a conventional diesel engine which burn either gaseous fuel or diesel or both at the same time. The mode of operation is defined as straight diesel if only diesel fuel is used and dual fuel if two fuels are used at the same time. In dual fuel operation the gaseous fuel is mixed with air at lean gas-air ratios and the mixture is then compressed during the compression stroke. Near the end of compression stroke, diesel fuel is injected, after a short ignition delay the combustion of diesel occurs first, igniting the natural gas and the flame propagation begins. The introduction of CNG along with intake air changes the thermodynamic and chemical properties of the mixture in the cylinder and thus the dual fuel combustion has its own characteristics on performance and emission characteristics of a dual fuel engine. The diesel fuel which acts as a source of ignition is often referred to as pilot diesel. The quantity of pilot diesel and concentration of CNG in the intake air have important effects on the performance and emissions of a dual fuel engine. There have been several fundamental studies on dual fuel engines, (Karim, 1983) reviewed the prospects, problems and solutions of the dual fuel engine of the CI engine type. (Karim, 1991) examined some measures for improving the performance of gas fuelled diesel dual fuel engines at light load. (Karim and Burn, 1980; Xianhua and Philip,1986) have reported that at light load, dual fuel engines usually exhibit a drop in brake thermal efficiency and power output in comparison to pure diesel operation. The emissions of unburned hydrocarbons and carbon monoxide are found higher than net diesel operation at light loads. (Liu and Karim, 1997) developed simulation model of combustion process in gas-fuelled diesel engines. (Roydon, A. Fraser 1991) studied autoignition of pure methane and natural gas in a simulated diesel environment using a constant volume combustion vessel for the pressure and temperature ranges of 5 to 55 atm and 600 to 1700K. (Singh *et al*., 2004) studied the combustion and emissions of a diesel-natural gas dual fuel engine and shown that dual fuel engine combustion results in significant reduction in NOx and smoke emissions. (Youtong *et al*., 2003) formulated dual fuel engine simulation model and studied the combustion process of a diesel-natural gas dual fuel engine and good levels of agreement were obtained between measured and predicted results.

Objective of paper

The aim of study is to analyze the emission characteristics of pure local diesel first and then local CNG-Diesel dual fuel mode, where an experimental research was carried out on a laboratory of internal combustion engine at Automotive and Tractors Engineering Department, Faculty of Engineering, Mataria, Helwan University, Egypt of two cylinder, four-stroke and direct injection diesel engine, designed mainly to run on diesel, converted without minor modifications to CNG-Diesel dual fuel mode. Composition of NG used in this study is given in Table 1 and specifications of engine used in this study is given in Table 2.

Table 1. Composition of local CNG tested

Constituent %	By volume
Nitrogen (N_2)	1.17
Carbon Dioxide (CO_2)	0.37
Methane (CH_4)	94.4
Ethane (C_2H_6)	3.5
Propane (C_3H_8)	0.40
ISO-Butane	0.04
Normal Butane	0.06
ISO-pentane	0.03
Normal pentane	0.03
	100.00%
Heating Value K cal/m^3	10823
K cal/kg	12819

Table 2. Specifications of engine used in this study

Z602- E3B Kubota super mini series		
Model		Z602-E3B
Type		Vertical 4-stroke Liquid Cooled Diesel
Number of Cylinders		2
Bore	mm (in)	72 (2.83)
Stroke	mm (in)	73.6 (2.90)
Displacement	L (cu.in)	0.599 (36.55)
Maximum Speed	rpm	3600
Output: Gross Intermittent	kW	10.8
Length	mm (in)	384.6 (15.14)
Width	mm (in)	420.5 (16.6)
Height	mm (in)	544.1 (21.42)
Dry Weight	kg (lb)	60.0 (132.3)

Experimental test set up and measurements

A two cylinder, 4 stroke, water cooled diesel engine installed at laboratory was converted to operate on dual fuel mode by carrying out minor modifications. The CNG fuel was mixed with intake air at a point in the intake manifold just outside the cylinder. The test engine is directly coupled to a water dynamometer, for any set of operating conditions; the diesel was kept constant while the amount of CNG fuel was gradually increased. A set of reading was obtained first by running the engine with diesel fuel, varying the load from 1.5 to rated load.

The emissions were recorded by using Gas Analyzer (AGS 200) and the opacity was recorded by Smoke meter (OPA 100). Another set of reading was recorded for the operation of the engine in CNG-Diesel dual fuel mode. For this CNG conversion kit, the flow of the CNG substitution rate was set at 10, 20 and 30%. The various parameters recorded were engine load, exhaust gas emissions, CO in %, CO2 in%, unburned hydrocarbons (HC) in parts per million (ppm), oxides of nitrogen (NOX) in PPM and opacity of the smoke in the exhaust was measured in %.

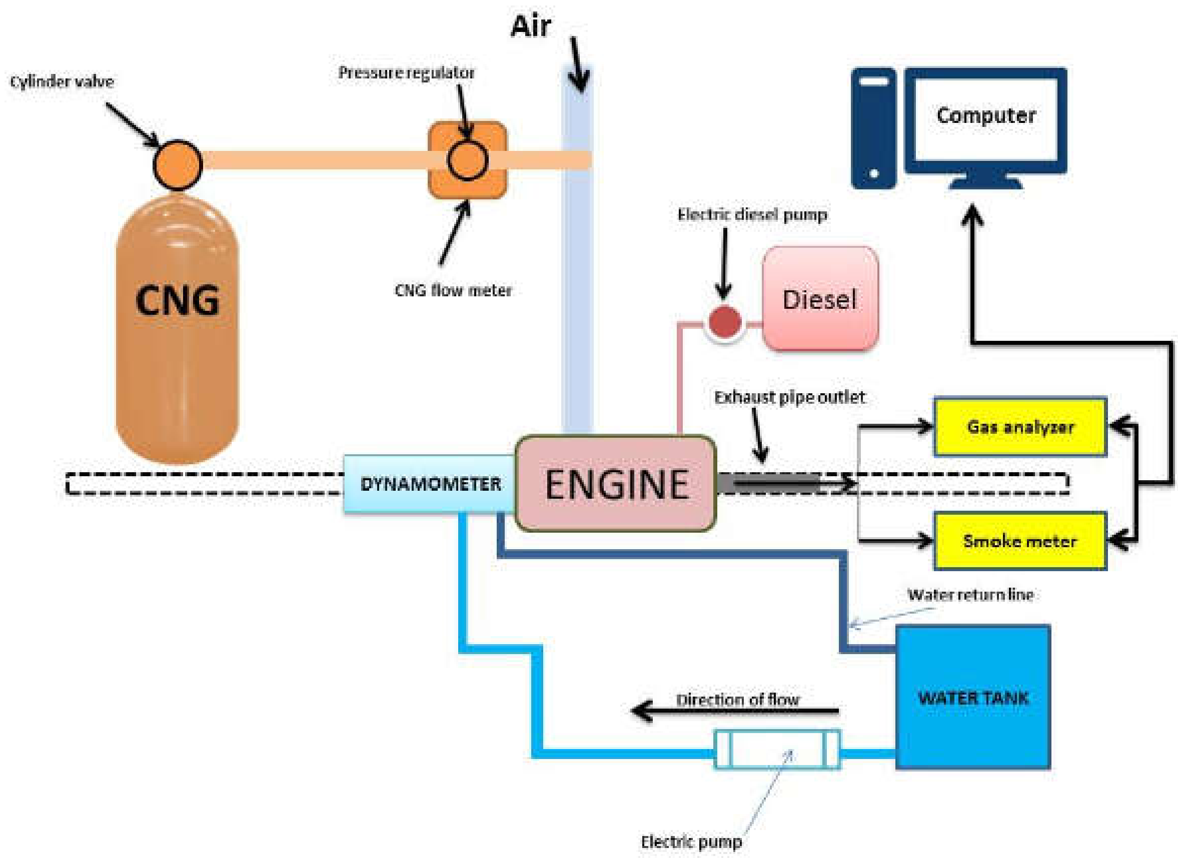

Fig.1. Schematic layout of CNG-diesel dual fuel engine test set up

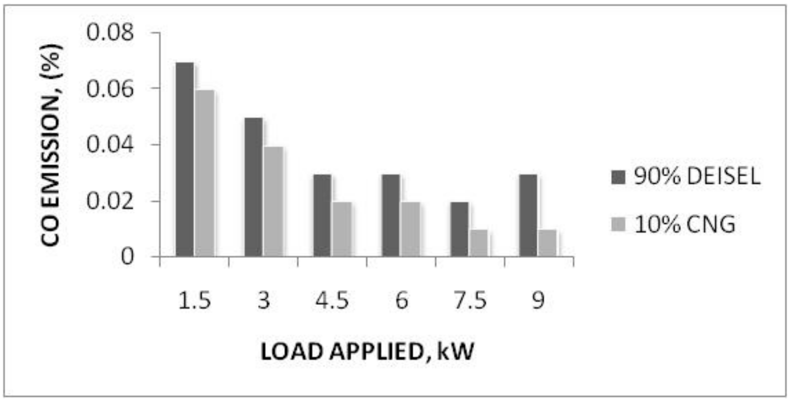

Fig. 2. CO emissions, (%) vs. load applied at 10% CNG

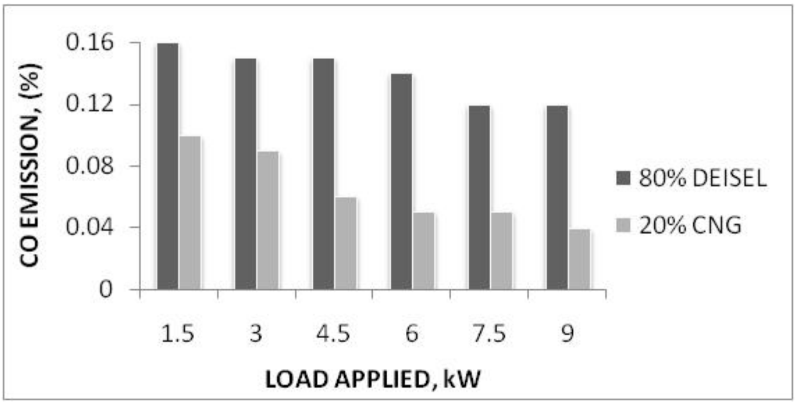

Fig. 3. CO emissions, (%) vs. load applied at 20% CNG

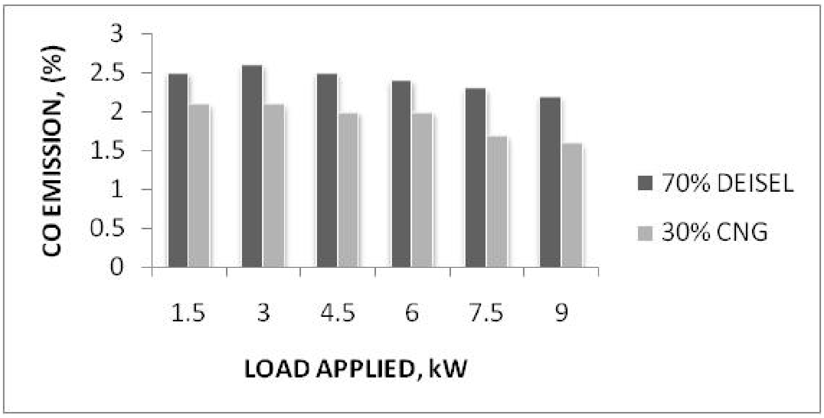

Fig. 4. CO emissions, (%) vs. load applied at 30% CNG

RESULTS AND DISCUSSION

In this section, the effect of load applied and CNG substitution rates on engine smoke and exhaust gases CO, HC, Co2 and NOx has been considered.

CO Emission analysis

Figs. 2, 3 and 4 show the effect of engine load and CNG substitution rates on CO emission concentration in diesel and dual fuel modes. It can be noticed that, CO emissions decrease as the load on the engine is increased for diesel and dual fuel modes, but CO dual fuel modes rates are lower than pure diesel mode at low load and more reduction at rated load, almost the same trend is observed for all CNG substitutions (10, 20 and 30%). This reduction in CO emissions for duel fuel operation is due to the less injected diesel fuel and its replacement with a clean burning CNG fuel, where λ gets closer to stoichiometric condition, consequently, CO emissions are decreased.

HC Emission analysis

Figs. 5, 6 and 7 depict the variation of unburned HC emissions for diesel and dual fuel modes. It is clear that HC concentration in the exhaust decrease with load applied for both diesel and dual fuel modes but its value further decrease than diesel at low load further decrease more at rated load in all CNG substitutions 10, 20 and 30% (almost same trend is observed for all). The same observation has been attained, as CO emission but with rate lower than CO. The reasons of these reductions are the higher average temperatures of combustion, increasing the duration of combustion and lower fuel trapping crevices while engine operates with CNG.

NOx Emission analysis

Figs. 8, 9 and 10 represent the effect of engine load and CNG substitution rates on NO_X emission formed inside engine cylinder for diesel and dual fuel modes. It can be noticed that level of NO_X emissions increase as the load on the engine increase for diesel and dual fuel modes, but its value for dual fuel mode further decrease than diesel at low load further decrease more at rated load in all CNG substitutions 10, 20 and 30% (almost same trend is observed for all). High peak temperatures and availability of oxygen are the two main factors for the formation of NO_X and it is directly related to adiabatic flame temperature. So as the CNG is introduced NO_X emissions decrease and as CNG supply is increased, NO_X further decrease. This decrease in NO_X in dual fuel engine is a positive merit in view of environmental concerns.

CO_2 Emission analysis

Figs. 11, 12 and 13 show the effect of engine load and CNG substitution rates on emission of carbon dioxide CO_2. It can be observed that level of emission of CO_2 increase with increasing load both for diesel and dual fuel modes but its value for dual fuel mode further decrease than diesel at low load further decrease more at rated load in all CNG substitutions 10, 20 and 30% (almost same trend is observed for all). This reduction in levels of CO_2 emissions on dual fueling a converted diesel engine is beneficial in the sense that CO_2 is a greenhouse gas and its concentration in the atmosphere should be minimum. The main factors for reduction of CO_2 in exhaust of a dual fuel engine include improper conversion of CO to CO_2 due to decrease in peak temperature because of lower adiabatic flame temperature of CNG than diesel and decreased diesel fuel quantity.

Smoke opacity analysis

Smoke opacity means the degree to which the smoke reduces the passage of light. It means more smoke in the exhaust will have high smoke opacity and vice-versa in the context of diesel emissions. It can be observed from Figs. 14, 15 and 16 that level of smoke increase with increasing load both for diesel and dual fuel modes but its value for dual fuel mode further decrease than diesel at low load and further decrease more at rated load in all CNG substitutions 10, 20 and 30% (almost same trend is observed for all). This decrease in smoke level with dual fueling is a positive merit in favor of dual fuel engines because diesel engines smoke reduction is the main cause of concern for researchers, manufacturers and users.

The main factors of decrease in smoke emissions due to dual fueling of a diesel engine include, reduced injected diesel fuel, complete and smooth combustion of clean CNG fuel.

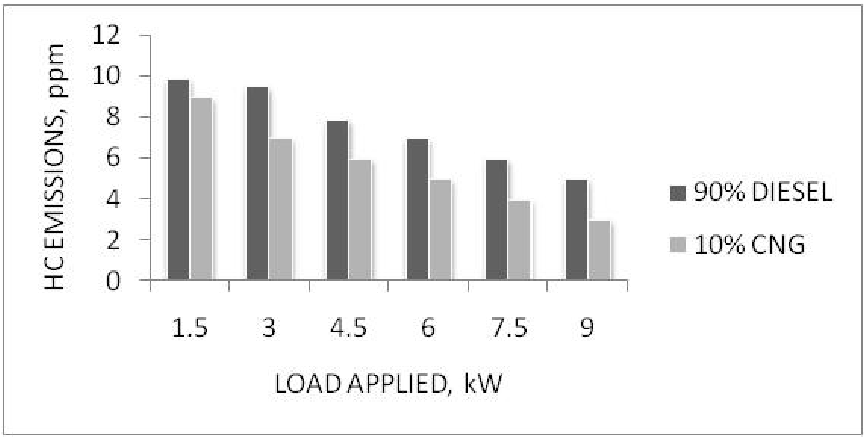

Fig. 5. HC emissions, (%) vs. load applied at 10% CNG

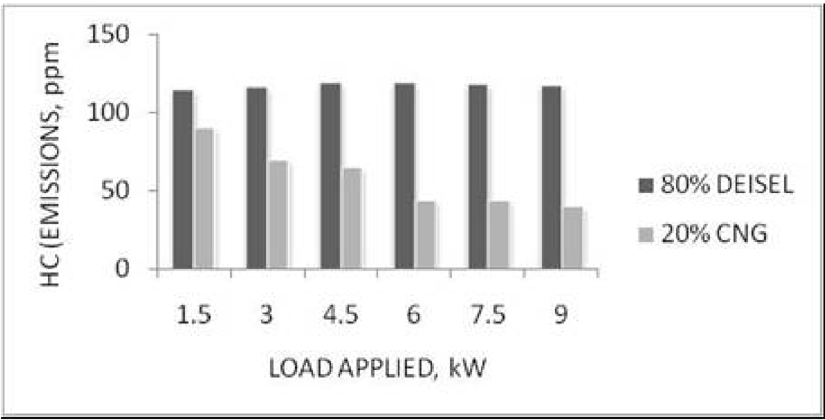

Fig. 6. HC emissions, (%) vs. load applied at 20% CNG

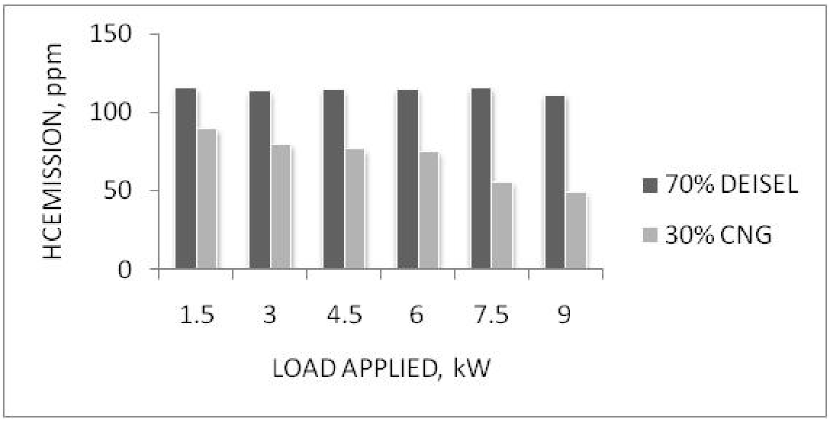

Fig.7. HC emissions, (%) vs. load applied at 30% CNG

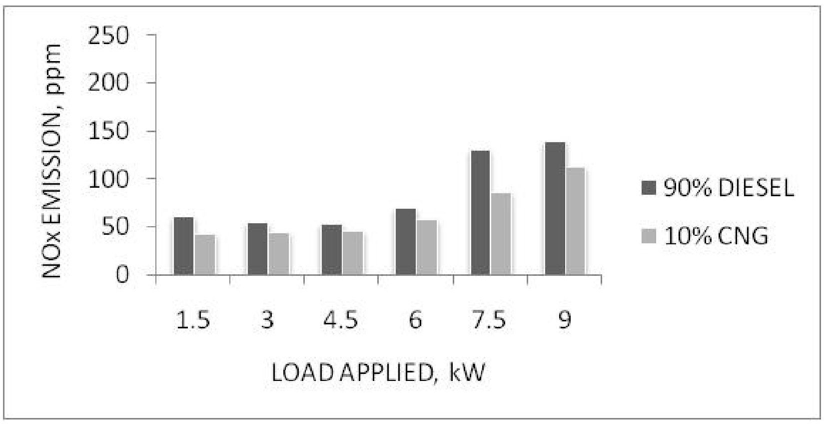

Fig. 8. NOx emission, (ppm) vs. load applied at 10% CNG

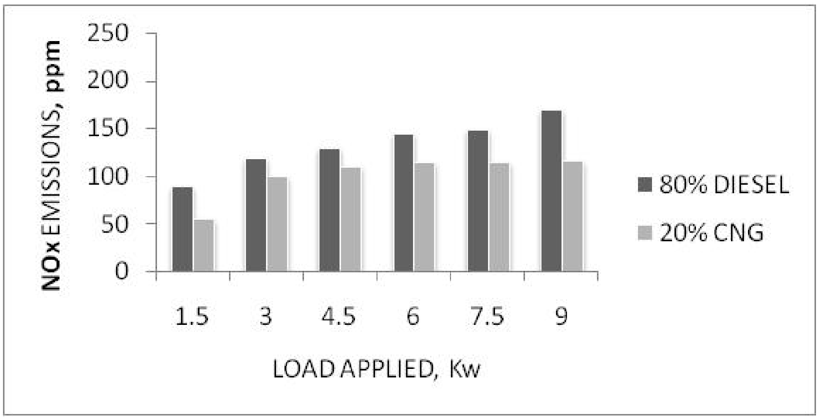

Fig. 9. NOx emission, (ppm) vs. load applied at 20% CNG

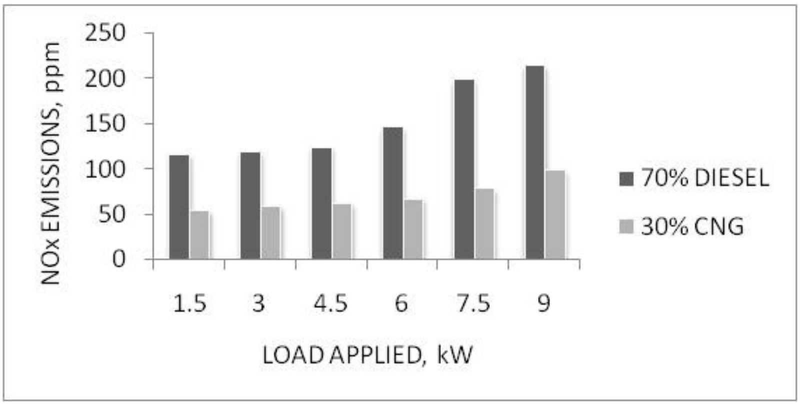

Fig. 10. NOx emission, (ppm) vs. load applied at 30% CNG

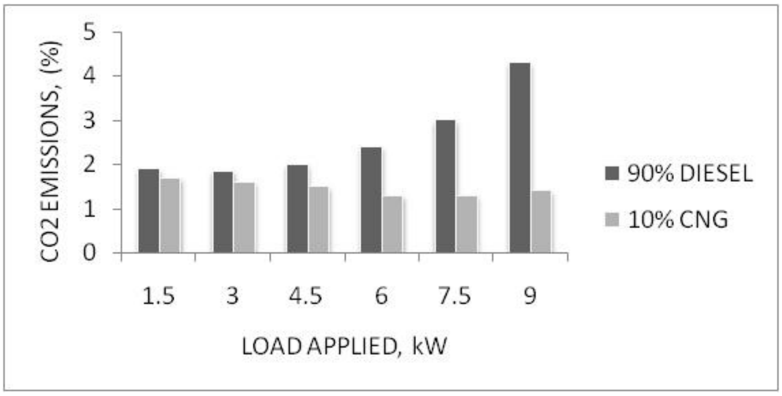

Fig. 11. CO_2 emission, (ppm) vs. load applied at 10% CNG

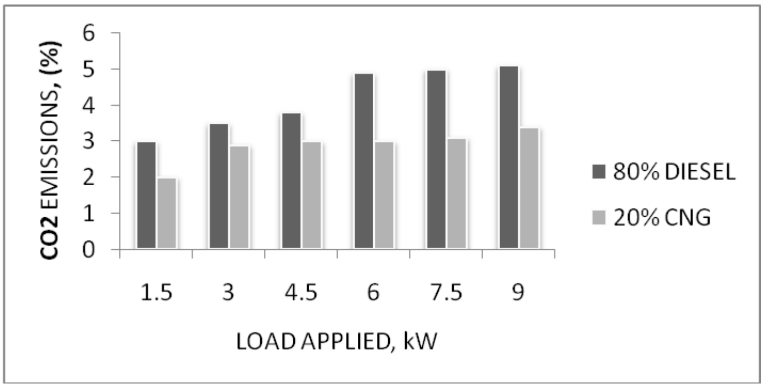

Fig. 12. CO_2 emission, (ppm) vs. load applied at 20% CNG

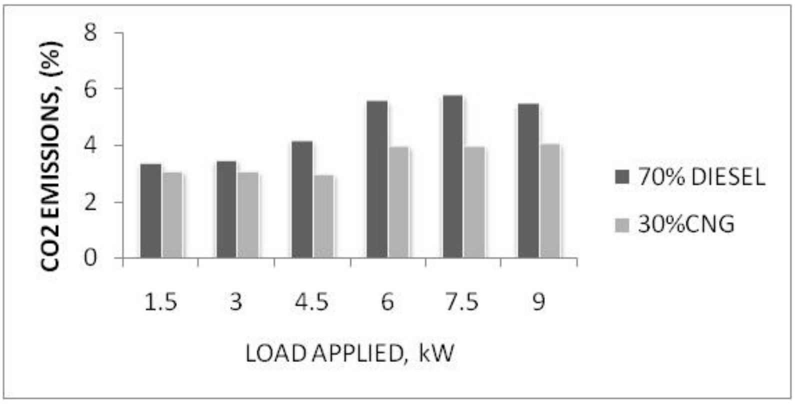

Fig. 13. CO_2 emission, (ppm) vs. load applied at 30% CNG

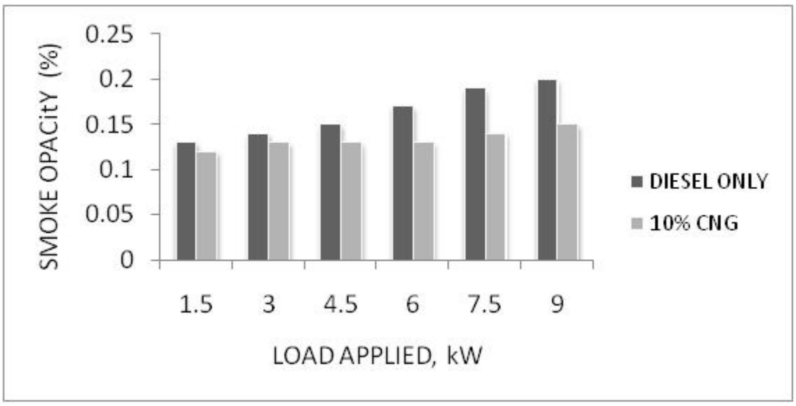

Fig. 14. Smoke (%) vs. load applied at 10% CNG

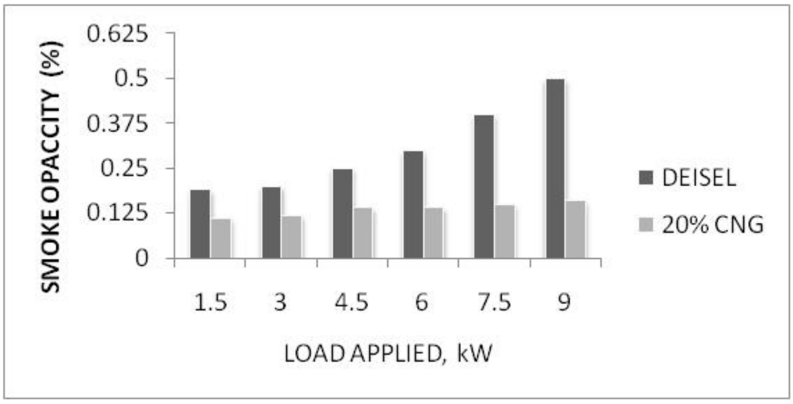

Fig. 15. Smoke (%) vs. load applied at 20% CNG

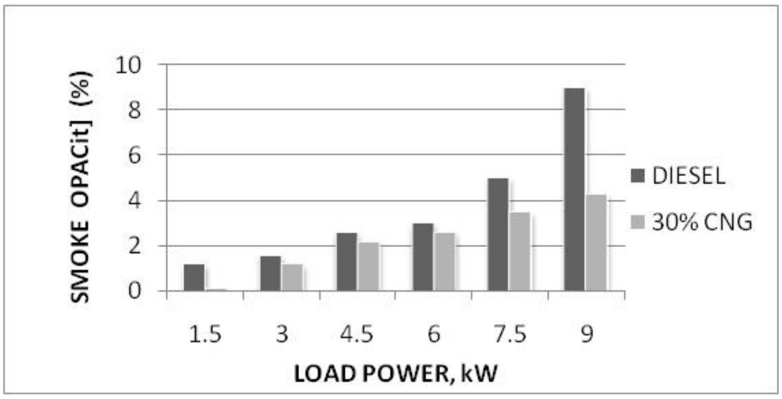

Fig.16. Smoke (%) vs. load applied at 30% CNG

In dual fuel engine, a flame front is formed by the ignition of small quantity of pilot fuel which sweeps the homogeneous mixture of CNG and air and exhaust contains less unburned fuel and hence less smoke. Moreover, soot particles form primarily from the carbon in the diesel fuel and in CNG, hydrogen/carbon ratio is high because of presence of smaller hydrocarbon as compared to diesel, soot formation is less and as a result Particulate Matter (PM) emission will also decrease with the use of CNG.

Conclusion

In the present paper an experimental research was carried out on a laboratory two cylinder, four-stroke, direct injection diesel engine, designed mainly to run on diesel fuel and converted with minor modifications to run on CNG-Diesel dual fuel mode. The main conclusions are summarized below, where the same trend is observed for all CNG substitutions, 10, 20 and 30 %; CO emissions decrease as the load on the engine is increased for diesel and dual fuel modes, but CO dual fuel modes rates are lower than pure diesel mode at low load and more reduction at rated load. The reasons of these reductions are the higher average temperatures of combustion, increasing the duration of combustion and lower fuel trapping crevices while engine operates with CNG. HC concentration in the exhaust decrease with load applied for both diesel and dual fuel modes but its value further decrease than diesel at low load further decrease more at rated load. The reasons of these reductions are the higher average temperatures of combustion, increasing the duration of combustion and lower fuel trapping crevices while engine operates with CNG.

1. CO_2 increase with increasing load both for diesel and dual fuel modes but its value for dual fuel mode further decrease than diesel at low load further decrease more at rated load. The main factors for reduction of CO_2 in exhaust of a dual fuel engine include improper conversion of CO to CO_2 due to decrease in peak temperature because of lower adiabatic flame temperature of CNG than diesel and decreased diesel fuel quantity.
2. NO_X emissions increase as the load on the engine increase for diesel and dual fuel modes, but its value for dual fuel mode further decrease than diesel at low load further decrease more at rated load. High peak temperatures and availability of oxygen are the two main factors for the formation of NO_X and it is directly related to adiabatic flame temperature. So as the CNG is introduced NO_X emissions decrease and as CNG supply is increased, NO_X further decrease. This decrease in NO_X in dual fuel engine is a positive merit in view of environmental concerns.
3. level of smoke increase with increasing load both for diesel and dual fuel modes but its value for dual fuel mode further decrease than diesel at low load and further decrease more at rated load. This decrease in smoke level with dual fueling is a positive merit in favor of dual fuel engines.

The positive results obtained in this experimental research in favor of CNG-Diesel dual fuel engine on performance and emissions, it can be concluded that it is a promising technology for achieving better thermal efficiency and controlling both NO and smoke emissions in existing conventional compression ignition engines with minor engine hardware modifications, thus great saving of precious diesel fuel and saving the human and plant life from the hazardous effects of exhaust gas pollutants from the conventional diesel engines.

Acknowledgment

This work was supported by Automotive and Tractors Engineering Department, Faculty of Engineering, Mataria, Helwan University, Egypt. So, the authors would like to convey sincere to all staff of the department.

LIST OF SYMBOLS

CNG	Compressed natural gas
CO	Carbon Monoxide
CR	Compression ratio
DF	Dual fuelling
DI	Direct injection
HC	Hydrocarbons.
ICE	Internal combustion engine
LPG	Liquid petroleum gas (propane)
MPa	Mega Pascal
NG	Natural gas
NGV	Natural gas vehicle
NOX	Oxides of Nitrogen
NOX	Oxides of Nitrogen
PPM	Particle Per Million
SI	Spark ignition
TUHC	Total unburned Hydrocarbons
λ	Excess air factor

REFERENCES

Aslam, M., Masjuki, H. H., Kalam, M. A., Abdesselam, H., Mablia, T. M. and Amalina, M. A. 2006. "An experimental investigation of CNG as an alternative fuel for a retrofitted gasoline vehicle Fuel", *Journal of Energy & Environment,* Vol. 85, pp. 717-724.

Bayraktar, H. and Durgun, O. 2001. "Investigating the Effects of LPG on Spark Ignition Engine Combustion and Performance, Energy Conversion and Management, Vol. 46, pp. 2317- 2333.

Cavalcante, C., Bastos, G., Machado, R. T., Pereira, C. R. and Pereira, P. P. 2007. "Thermodynamic Modeling of Compression, Combustion and Expansion Processes of Gasoline, Ethanol and Natural Gas with Experimental Validation on a Flexible Fuel Engine", Presented at SAE World Congress.

Dinh, H. T. 1994. Operating, "Performance and Emission Characteristics of Compressed Natural Gas Vehicle, Natural Gas and Alternative Fuels for engines", *ASME*, *JCE*, Vol. 21.

Karim, G A 1991. An examination of some measures for improving the performance of gas fuelled diesel engines at light load. SAE, Paper No. 912366.

Karim, G A and Burn, K S 1980. The combustion of gaseous fuels in a dual fuel engine of compression ignition type with particular reference to cold intake temperature conditions, SAE Paper No.800263.

Karim, G A. 1983. The dual fuel engine of the compression ignition type –prospects, problems and solutions –a review. SAE Paper No. 831073.

Liu, Z and Karim, G A. 1997. Simulation of combustion process in gas-fuelled diesel engines. *Proc. Instn. Mech. Engrs*., Volume, 211 Part A, 159-169.

Patil, K. R., Khanwalkar, P. M., Thipse, S., Kavathekar, K. P. and Rairikar, S. D. 2010. "Development of HCNG Blended Fuel Engine with Control of NOx Emissions", *IJCISIMA* ISSN: 2150-7988 Vol.2, pp.087- 095.

Roydon, A. Fraser 1991. Auto ignition of methane and natural gas in a simulated diesel engine environment. SAE Paper No. 910227.

Semin, A. R. and Rosli, A. B. 2009. "Combustion Temperature Effect of Diesel Engine Convert to Compressed Natural Gas Engine", *American J. of Engineering and Applied Sciences*, pp. 212-216.

Shamekhi, A. H. and Khatibzadeh, N. 2008. "Compressed Natural Gas as an Alternative Fuel in a Bi-Fuel Spark Ignition Engine", *Iran Chem. Eng*., Vol. 27, No.1.

Shamekhi, A., Khtibzade, N. and Shamekhi, A. H. 2006. "Performance and emissions characteristics of a bi fuel SI engine fueled by CNG and gasoline", *ASME*, Vol. 25.

Shawki, A., Zeffan, H. A., Aly, A. and Sameh, M. 2005. "Electronic Ignition Impact and on Reducing Exhaust Gas Emission of Bi-Fuel Engine", First Ain Shams University International Conference on Environmental Engineering, IPSI Conference SPAIN- Barcelona.

Shawki, A., Zeffan, H. A., Aly, A. and Sameh, M. 2005. "Evaluation of 2 Ways Catalytic Converter for Emission Reduction Potential on a Spark Ignition Bi-Fuel Engine", First Ain Shams University International Conference on Environmental Engineering, IPSI Conference SPAIN- Barcelona.

Singh, S *et al*. 2004. Modeling and experiments of dual fuel engine combustion and emissions, *SAE* Paper No. 2004-01-0092

Verhe, S., Sierens, R. and Verstraeten, S. 2006. "Development of a Simulation Code for Hydrogen Fuelled SI Engines", *ASME*, Vol. 25.

Xianhua, D and Philip, H 1986. Emissions and fuel economy of a pre-chamber diesel engine with natural gas dual fueling, SAE, Paper No. 860069.

Youtong, Z. *et al*. 2003. Modeling and simulation of a dual fuel (diesel/natural gas) engine with multidimensional CFD, SAE Paper No. 2003-01-0755, 336-346.

****