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Effect of Pilot Fuel Quantity on the Performance and Emission Characteristics of a Pre-Mixed CNG - Diesel Dual Fuel Mode Engine

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***Abstract**: The serious environmental pollution and the energy crisis all over the world has caused for development of the lower pollution and lower energy consumption automobile to become major research goal. With huge back ground, Compressed Natural Gas (CNG) is projected as the best alternative fuel for the country like India. The properties of CNG make it an ideal fuel for direct use in spark ignition engines. Conversion of any existing spark ignition engine to operate on natural gas is relatively simple with available equipment. Many spark ignition engine vehicles are successfully operating in major cities of India with CNG fuel. However CNG cannot be used as a fuel in diesel engines with ease. Since the maximum engines at present run on diesel, it will be very much useful if a solution could be found to alter the existing diesel engine with minimum modifications to run on CNG. Several researchers could attempt to run diesel engines with CNG. In the process three methods were reported to be successful to use CNG as a fuel in diesel engines, they are (i) Spark ignited gas mode (ii) Direct injection of CNG in dual fuel mode and (iii) Premixed CNG dual fuel mode. In the present work a premixed dual fuel engine was developed which can perform well for the entire range of load and experiments are carried out by varying the pilot fuel amount and studied the effect of pilot fuel amount on engine performance and emissions characteristics and determined optimum fuel injection quantity for better performance and lower emissions.*

I. Introduction:

During the last 60 years, research activity in the field of internal combustion engines has been directed towards fuel efficiency and reduction of exhaust emission levels. The approach has been to modify the engine design and or make use of efficient low polluting alternative fuels. Renewable energy sources, such as natural gas, bio-derived gas and liquid fuels appear more environmentally friendly. Among the renewable energy sources the use of natural gas as fuel as a great interest for two reasons. It is available as natural or waste products in considerable quantities throughout many parts of the world. It has high resistance to knock when used as a fuel in CI engines owing to its high octane value (RON 131). It is therefore suitable for engines of high compression ratios. The fuel properties of natural gas do not permit its direct use as fuel in diesel engines [1, 2, 3, 7]. Two methods are adopted to use natural gas as a fuel in diesel engines is (i) Dual fuel mode (ii) Spark ignited gas (100%) mode.

In the premixed CNG dual fuel mode, CNG is admitted through a gas carburetor at the suction stroke. In this case the basic diesel engine configuration is retained and only the components of conversion system are additionally added to the diesel engine setup. As the basic engine system is unaltered, the engine can be easily switched back to operate as a standard diesel engine [3-7]. Karim [10] has reported that in dual fuel engines at low loads when the gaseous fuel concentration is low, ignition delay period of the pilot fuel increases and some of the homogeneously dispersed gaseous fuel remains unburned and results in poor performance. A concentrated ignition source is needed for the combustion of the induced fuel at low loads. Further the injection timing of the pilot fuel, injector opening pressure, pilot fuel quantity and intake temperature are some of the important variables controlling the performance of dual fuel engines at high loads.

In the present experimental work, engine performance and emission characteristics of a 5 HP single cylinder diesel engine under CNG-diesel dual fuel operation at different engine loads for different pilot fuel amounts have been studied. Further the pilot amount is optimized for better performance and low emissions. In addition, experiments were also conducted under neat diesel operation to make comparative study between zero percent CNG substitution (neat diesel operation) and dual fuel engine operation.

SPECIFICATIONS OF THE FUELS:

Natural gas:

Methane (CH4)	88 – 98% v/v
Ethane (C_2H_6)	2 – 8% v/v
Other higher hydrocarbons:	< 2% v/v
Appearance:	Colourless
Odour:	Odourless, Ethyl Mercaptan (C_2H_5SH)
Specific gravity:	0.55 – 0.67
Calorific value:	43.56 MJ/ Kg
Solubility in water at 30^0 C:	Soluble
PH:	NH pertinent
Boiling point:	161.5 C
Melting point:	- 182.6^0 C
Reference:	Mahanagar Gas limited

Diesel:

Density:	0.83 gm / cc
Cetane number:	51
Calorific value:	42.95 MJ/ Kg

ENGINE DATA:

5 HP Single cylinder Kirloskar make four stroke, vertical, water cooled, direct injection diesel engine

Bore	: 80 mm
Stroke	: 110 mm
Compression Ratio	: 20: 1
Injection Pressure	: 205 bar
Fuel injection timing	: 23^0 bTDC

Experimentation:

Different load tests are conducted at various operating conditions during the experimentation. In the experimentation, load and pilot fuel quantity are the parameters selected for variation. Initially the load is varied by keeping the pilot fuel quantity as constant. Next, pilot fuel quantity is varied by keeping the load as constant. At each operating condition dynamometer load, air flow rate, fuel flow rate, exhaust gas temperature, manifold pressure, cooling water flow rate, pressure time signal, HC, CO, and smoke readings are noted and recorded after allowing sufficient time for the engine to stablise.

The exhaust gas analyzer and smoke meter are switched on quite early so that its entire systems can stabilized before the commencement of the experiment. The data length, frequency range to trigger the data acquition for computer is carefully selected, based on the approximate cycle time of the engine operation. Ambient condition of the pressure and temperature are noted. The pressure and TDC mark signals are recorded on the disk, arranged for 100 consecutive cycles.

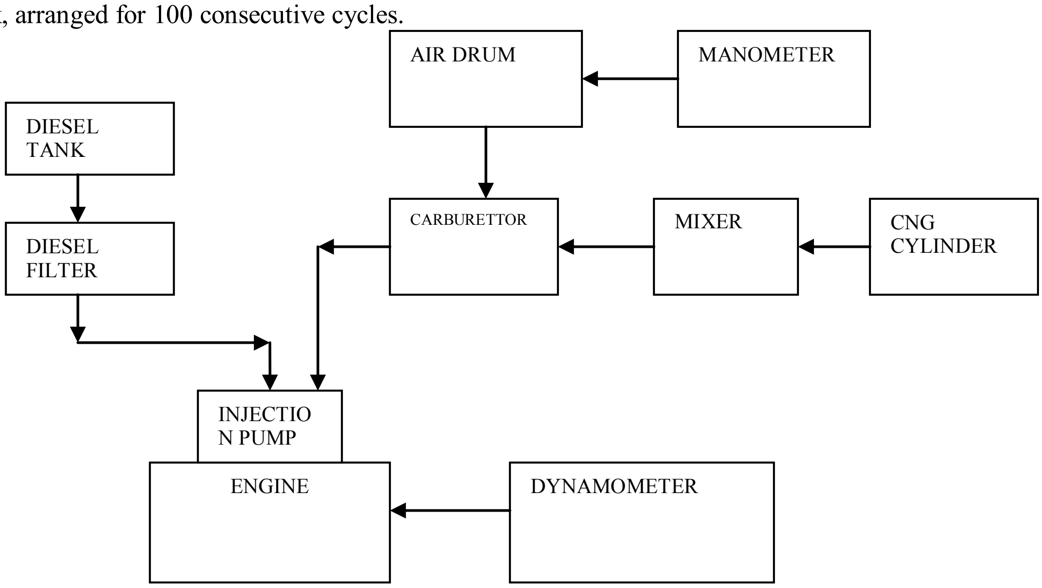

FIG. 1 EXPERIMENTAL SETUP

II. Test Results And Discussion:

In the present work the data presented for 100% diesel and dual fuel mode for the following operating parameters.

1. The load varying from 0.25 to 3.75 KW
2. The pilot diesel quantity injected, varying from 3 to 12 mm^3 / stroke

The following data are measured / calculated by varying the one of the above parameters and keeping the other as constant.

a. Specific energy consumption
b. Peak pressure
c. Ignition delay
d. Combustion duration
e. HC emission
f. CO emission
g. Smoke

SPECIFIC ENERGY CONSUMPTION:

The fig. 1 shows the variation of specific energy consumption with engine output at standard injection timing of 27^0 bTDC and rated speed of 1500 RPM. When the pilot diesel quantity is increased from 3 to 11 mm^3 / st. there is 6% decrease in specific energy consumption at rated output (3.75 KW).At 50% rated output (1.75 KW) there is 13% decrease in specific energy consumption.

At 3 mm^3 / st pilot diesel injection, there is no possibility of sufficient number of flame nuclei to burn the air-gas mixture. However, when the pilot diesel quantity is increased to 11 mm^3 / st the spray can penetrate all parts of the combustion chamber and the air-gas mixture can burn almost completely as it gets entrained into the burning diesel spray. Pilot diesel quantity of 9 mm^3 / st at standard injection timing is considered 'optimum' since it gives the lowest specific energy consumption.

100% Diesel Vs 'Optimum' Dual Fuel Mode:

The fig. 2 shows the comparison of specific energy consumption between optimum dual fuel mode and 100% diesel at standard injection timing of 27^0 bTDC. The specific energy consumption at rated output in the 'optimum' dual fuel mode is 2% lower than the 100% diesel mode, while at 50% rated output it is 7% higher.

At the rated output, the pilot spray is sufficient to completely burn the air-gas mixture which is relatively rich (air-gas ratio of 35),. So the energy efficiency in dual fuel mode is better than that of 100% diesel mode. However at 50% output, even though the pilot diesel quantity is nearly the same, air-gas mixture is relatively very lean (air-gas ratio of 63) and this burns slowly resulting in higher specific energy consumption.

PEAK PRESSURE:

Peak pressure is one of the important combustion characteristic, its time of occurrence and magnitude has effect on engine performance. So the variation of Peak pressure against engine output is plotted in the fig.3 by varying the pilot diesel quantity at constant speed of 1500 RPM and standard injection timing of 27^0 bTDC. When the pilot diesel quantity is increased from 3 to 11 mm^3 / st,, at rated output the peak pressure increases from 44 bar to 65 bar, while at 50% rated output, it increases from 41 to 48 bar.

When the pilot diesel quantity is increased, the number of flame nuclei is more and so the total ignition energy is higher. This increases the total combustion energy release and hence the peak pressures are higher.

100% diesel Vs 'Optimum' Dual Fuel Mode:

Fig.4 show the variation of Peak pressure in case of optimum dual fuel mode and 100% diesel at a given injection timing of 27 bTDC.

The peak pressure in dual fuel mode depends on the combustion rate of air-gas mixture, the combustion and oxidation reactions are slow and incomplete at part loads. Hence the peak pressures in dual fuel mode are generally lower than in 100% diesel mode.

IGNITION DELAY:

Ignition delay is an important combustion characteristic and directly related to combustion duration, which affects the engine performance. Hence ignition delay against engine output is plotted in figs. 5 and 6 by varying the pilot quantity at constant speed of 1500 RPM. When the pilot quantity is increased from 3 to 11 mm^3 / st, ignition delay decreases from 4^0 at rated output (3.75 KW), while at 50% rated output (1.75 KW) a similar trend is observed.

In the dual fuel mode of combustion, the pilot diesel spray is surrounded by air-gas mixture and the net heat available for auto-ignition of many nuclei could be affected. The air-gas mixture around the active pre-flame nuclei can go into pre-ignition process of their own because of the heat available from cool flame regions involving the flame. In the race of the active radicals in the pre-flame chemical activity, the mere presence of these gases could alter the course of the chemical kinetics.

The ignition and combustion phenomenon in the dual fuel mode is the aggregate of the complex pre-ignition reaction of the gaseous fuel. The net heat generated from the pre-ignition reaction of the gaseous fuel may be insufficient to overcome the unknown inhibition act played by the small gaseous concentration. However, if the amount of such heat generated becomes substantial, as with higher air-gas ratio, there is a tendency to shorten the ignition delay.

100% diesel Vs 'Optimum' Dual Fuel Mode

The fig.6 shows the comparison of ignition delay of optimum dual fuel mode with 100% diesel at standard injection timing. At rated output the ignition delay in 'optimum' dual fuel mode is 3^0 higher than in 100% diesel mode; while at 50% rated output a similar trend is observed.

It seems likely that the lengthening of the delay period in dual fuel mode is caused by the reduced oxygen concentration due to the air displacement by methane, and a chemically inhibiting effect of the presence of methane on the diesel liquid fuel reaction rate within the combustion chamber. The longer delay period is equivalent in some way to lowering of the cetane rating of the diesel.

III. Combustion Duration

The fig.7 shows the variation of combustion duration with the engine output in dual fuel mode at standard injection timing of 27^0 bTDC and rated speed of 1500 RPM. When the pilot diesel quantity is increased from 3 to 11 mm^3 / st, Combustion duration decreases by 3^0 at rated output (3.75 KW). While at 50% rated output (1.75 KW) similar trend is observed. When the pilot diesel quantity increases, the ignition energy increases, leading to faster combustion and reduced combustion duration.

Standard Diesel Vs 'Optimum' dual Fuel Mode

The fig.8 shows the comparison of combustion duration of optimum dual fuel mode with 100% diesel at standard injection timing. At rated output the combustion duration in 'optimum' dual fuel mode is 3^0 higher than in 100% diesel mode; while at 50% rated output a similar trend is observed. The slower flame speed of natural gas contributes to the longer combustion duration as compared to standard diesel mode.

EMISSIONS – CARBONMONOOXIDE (CO)

The Fig. 9 shows the variation of CO emission with engine output at 1500 RPM and standard injection timing of 27^0 bTDC. When the pilot diesel quantity is increased from 3 to 11 mm^3 / st, CO emission decreases by 0.33 to 0.23% volume at rated output (3.75 KW). While at 50% rated output (1.75 KW) similar trend is observed.

100% diesel Vs 'Optimum' Dual Fuel Mode

The fig.10 shows the comparison of CO emission between optimum dual fuel mode and 100% diesel at standard injection timing of 27^0 bTDC. At rated output the CO emission in 'optimum' dual fuel mode is marginally higher than in 100% diesel mode. While at 50% rated output it is higher by 0.09% vol. The higher CO concentration in dual fuel mode is direct result of quenching near the walls of the slow burning air gas mixture.

EMISSION – HYDROCARBON (HC)

The fig.11 shows the variation of HC emission with engine output at 1500 RPM, and standard injection timing of 27^0 bTDC when the pilot diesel quantity is increased from 3 to 11 mm^3 / st, HC emission decreases from 440 to 365 ppm at rated output (3.75 KW). While at 50% rated output (1.75 KW) it decreases from 910 to 540 ppm. When the pilot diesel flow is increased, the partial reaction and the flame propagation increase, resulting in change in oxidation reaction from unsuccessful to successful flame propagation, which result in reduction of HC emission.

100% diesel Vs 'Optimum' Dual Fuel Mode

The fig.10 shows the comparison of HC emission between optimum dual fuel mode and 100% diesel at standard injection timing of 27^0 bTDC. At rated output the HC emission in 'optimum' dual fuel mode is 170 ppm higher than in 100% diesel mode. While at 50% rated output it is higher by 460 ppm.

EMISSION – SMOKE

The fig.12 shows the variation of smoke emission for 100% diesel operation at engine speed of 1500 RPM. When the injection timing is advanced from 27^0 to 33^0 bTDC, at rated output smoke emission decreases by 12%. While at 50% rated output also similar trend is observed. At rated output the exhaust smoke in the 100% diesel mode decreases as the injection timing is advanced.

IV. Conclusions

Based on the present study conducted at the rated engine speed of 1500 RPM and standard Injection timing of 27^0 bTDC, the following important conclusions have been derived.

- The specific energy consumption is found to be lowest for particular diesel quantity. The most optimum pilot diesel quantity is found as 9 cu.mm / st.
- The specific energy consumption in optimum dual fuel mode is lower than the standard diesel mode at part loads but is slightly higher at rated power (3.7 KW).
- When the pilot diesel quantity is increased at standard injection timing and rated engine speed causes an increase in peak pressure at rated power, but at 50% of the rated power the variation in peak pressure is less.
- At the rated output, the peak pressure (66 bar) for the most optimum dual fuel mode is almost equal to that in 100% diesel mode (65 bar). At 50% rated output, it is 6 bar less than 100% diesel mode.
- At the rated output, the increase in pilot diesel quantity causes a decrease in ignition delay.
- At the rated output, the combustion duration in most optimum dual fuel mode is 4^0 higher than the 100% diesel mode and 3^0 higher at 50% rated output.
- At the rated output, when the pilot diesel quantity is increased in dual fuel mode causes a marginal decrease in CO emission.
- At the rated output, the CO emission in the most optimum dual fuel mode is nearly same with the 100% diesel mode, while at 50% rated output it is 0.12% volume higher than 100% diesel.
- At the rated output, the HC emission in the most optimum dual fuel mode is 140 ppm higher than the 100% diesel mode, while at 50% of rated output it is 330 ppm higher.
- At the rated output, there is 82% smoke reduction in optimum dual fuel mode than the 100% diesel operation.

GRAPHS:

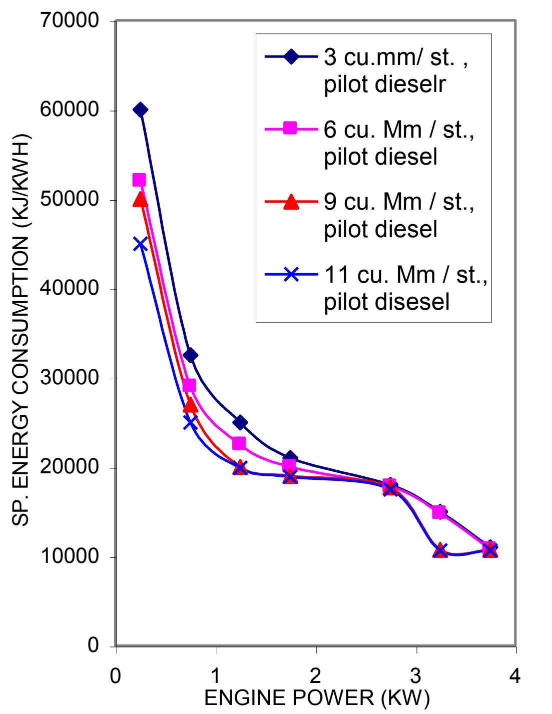

Fig. 1 COMPARISON OF SPECIFIC FUEL CONSUMPTION – DUAL FUEL MODE FOR DIFFERENT PILOT QUANTITY

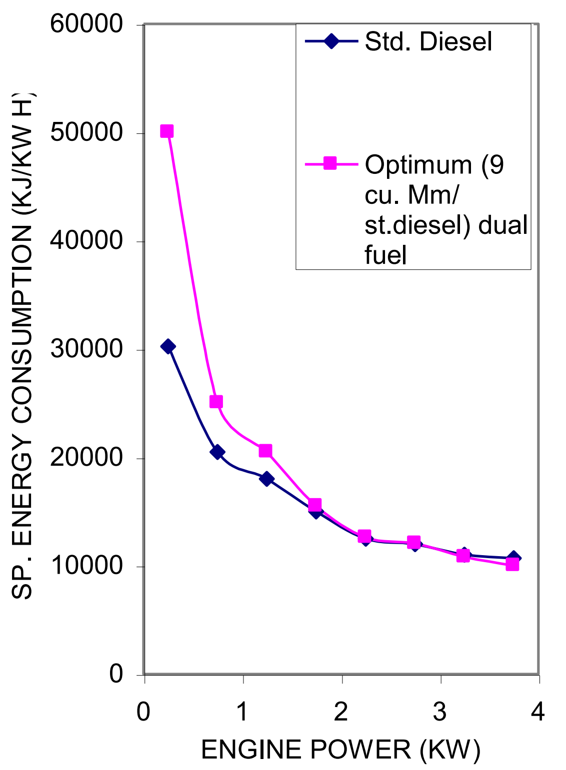

Fig. 2 COMPARISON OF SPECIFIC FUEL CONSUMPTION – STANDARD DIESEL VS OPTIMUM DUAL FUEL MODE

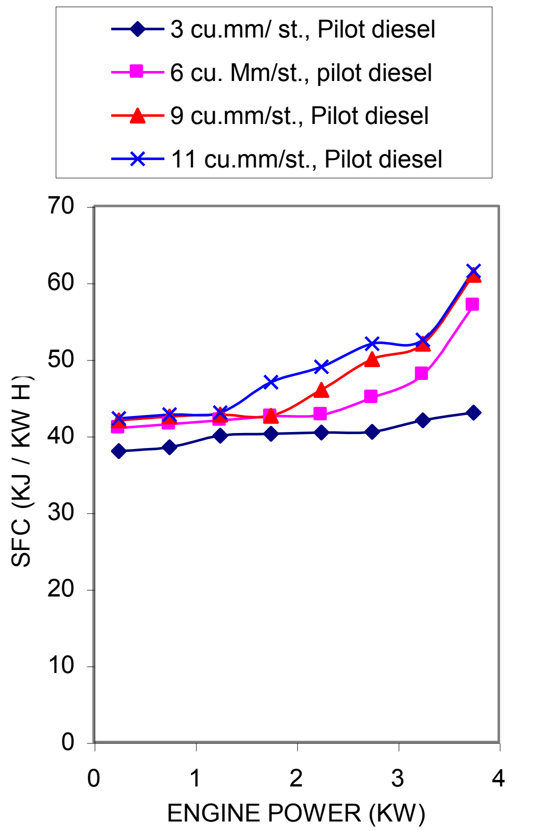

Fig.3 COMPARISON OF PEAK PRESSURE – DUAL FUEL MODE FOR DIFFERENT PILOT QUANTITY

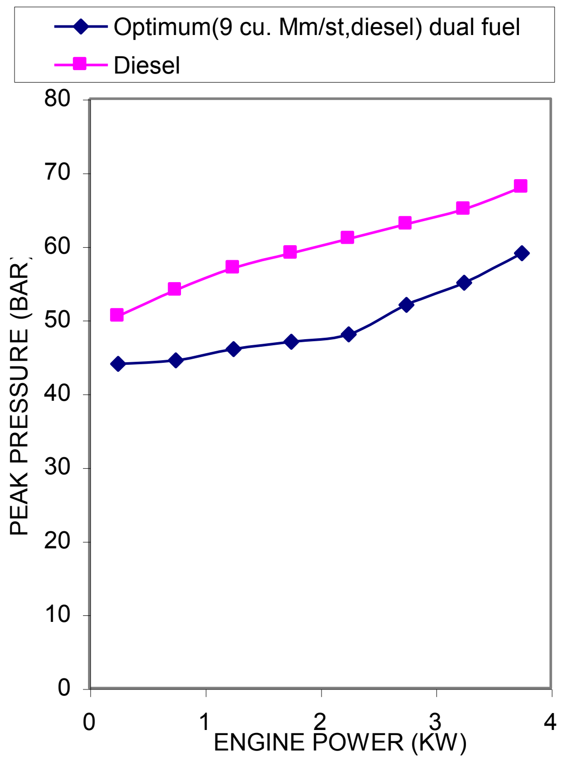

Fig. 4 COMPARISON OF PEAK PRESSURE – STANDARD DIESEL VS OPTIMUM DUAL FUEL MODE

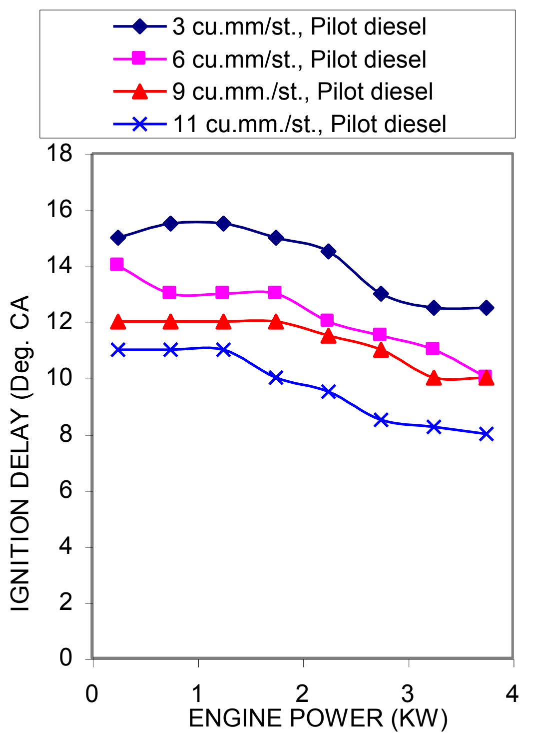

Fig. 5 COMPARISON OF IGNITION DELAY – DUAL FUEL MODE FOR DIFFERENT PILOT QUANTITY

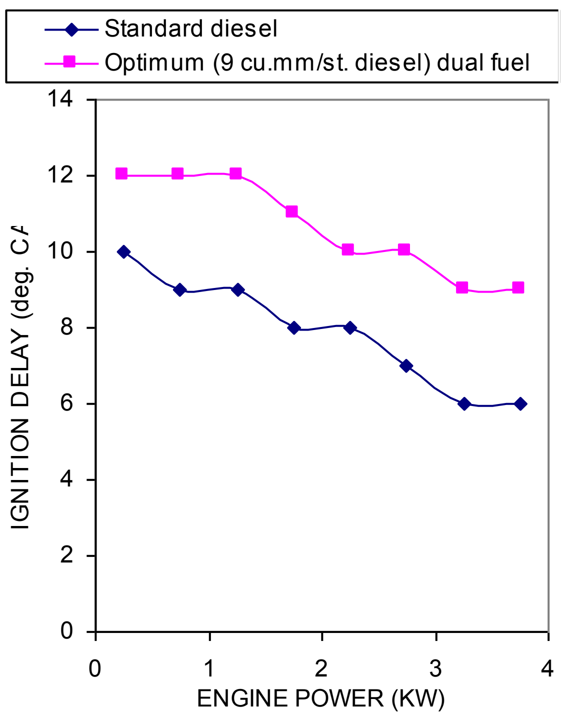

Fig. 6 COMPARISON OF IGNITION DELAY – STANDARD DIESEL VS OPTIMUM DUAL FUEL MODE

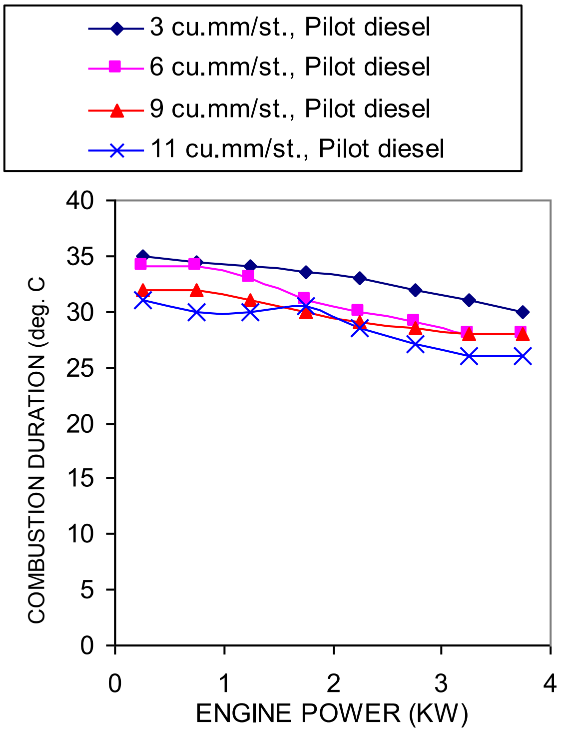

Fig .7 COMPARISON OF COMBUSTION DURATION – DUAL FUEL MODE FOR DIFFERENT PILOT QUANTITY

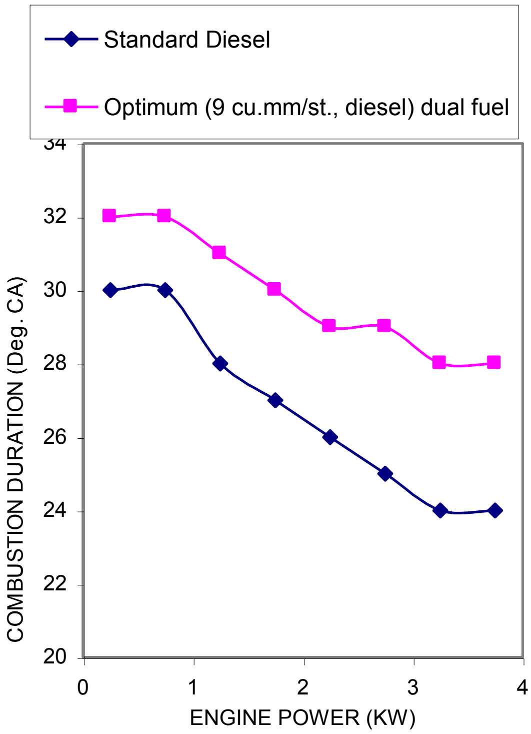

Fig. 8 COMPARISON OF COMBUSTION DURATION – STANDARD DIESEL VS OPTIMUM DUAL FUEL MODE

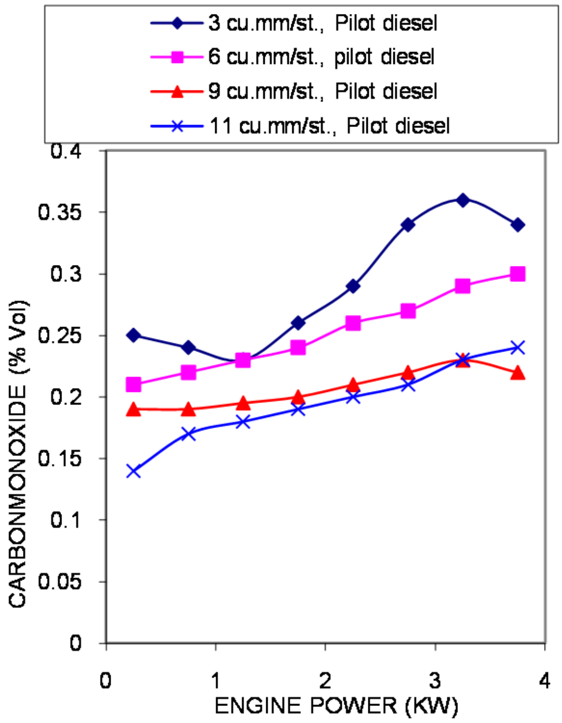

Fig. 9 COMPARISON OF CARBONMONOXIDE EMISSION – DUAL FUEL MODE FOR DIFFERENT PILOT QUANTITY

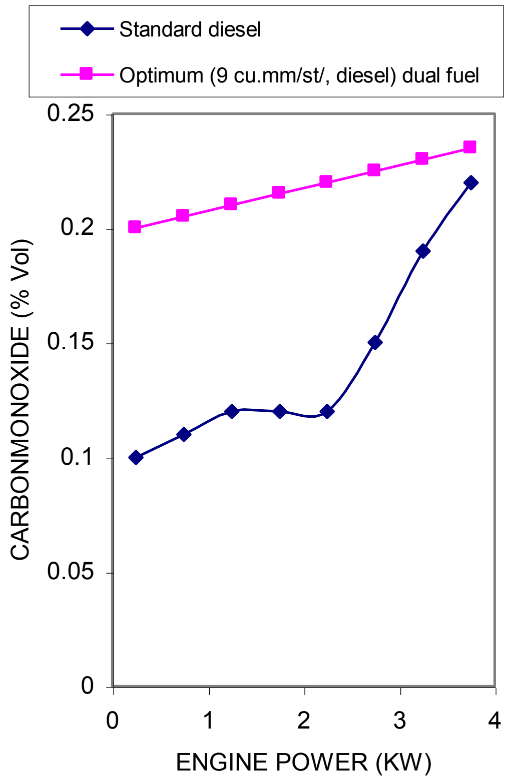

Fig. 10 COMPARISON OF CARBONMONOXIDE EMISSION – STANDARD DIESEL VS OPTIMUM DUAL FUEL MODE

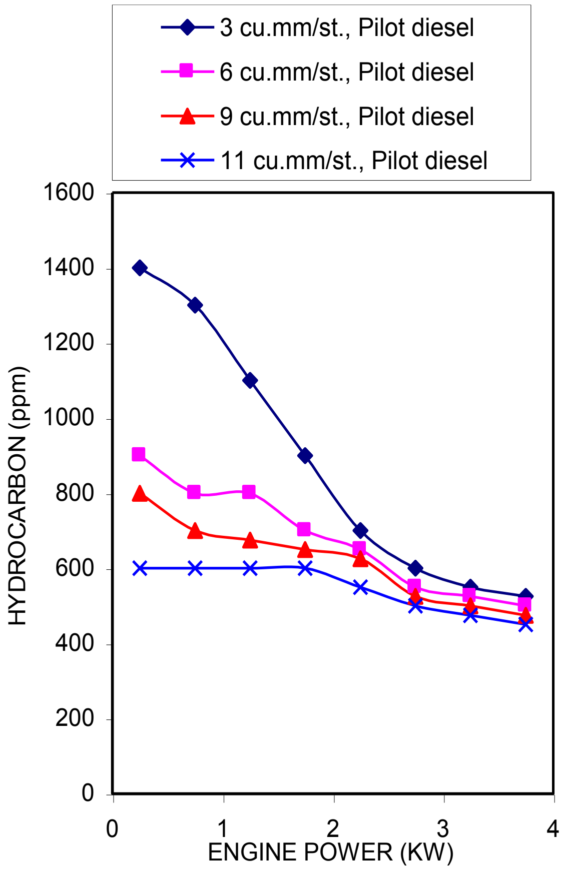

Fig. 11 COMPARISON OF HYDRO CARBON EMISSION – DUAL FUEL MODE FOR DIFFERENT PILOT QUANTITY

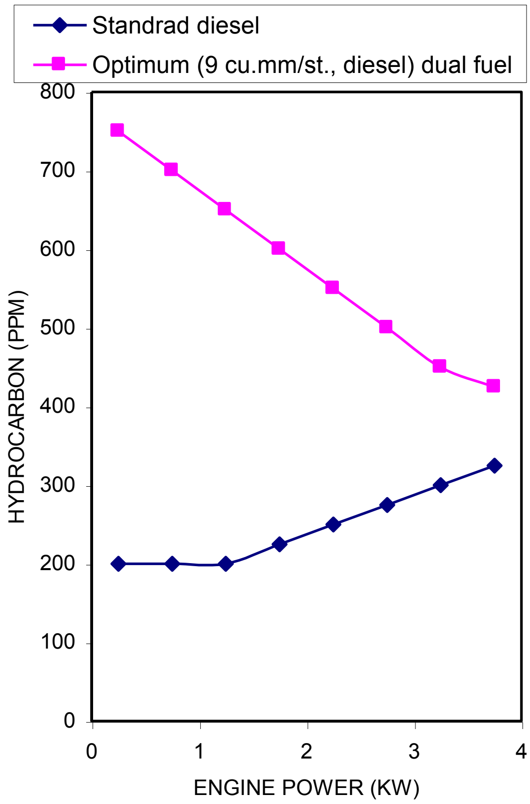

Fig. 12 COMPARISON OF HYDROCARBON EMISSION – STANDARD DIESEL VS OPTIMUM DUAL FUEL MODE

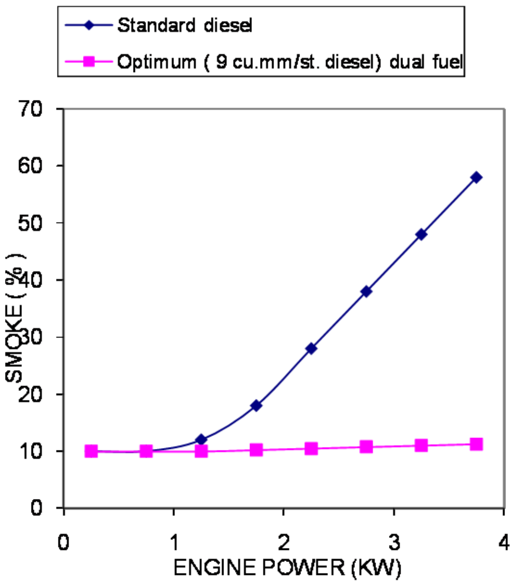

Fig. 13 COMPARISON OF SMOKE EMISSION – STANDARD DIESEL VS OPTIMUM DUAL FUEL MODE

References:

[1]. Heywood, J.B., "Internal Combustion Engine Fundamentals", McGraw-Hill international Edition, Singapore, ISBN 0-07-100499-8.
[2]. Maji, S., Pal, A., and Arora, B., "Use of CNG and Diesel in CI Engines in Dual Fuel Mode," SAE Technical Paper 2008-28-0072, 2008, doi: 10.4271/2008-28-0072
[3]. Bhandari, K et al. (2005): Performance and emissions of natural gas fueled internal Combustion engine, A review, JSIR Volume 64 333-338.
[4]. Papagianakkis, R., and Hountalas, D., "Combustion and exhaust emission characteristics Of a dual fuel compression ignition engine operated with pilot diesel fuel and natural gas," Energy conversion and management, 45, 2971-2987, 2004, doi:10.1016/j.enconman.2004.01.013
[5]. Papagianakkis, R., and Hountalas, D., "Experimental investigation concerning the effect of natural gas percentage on performance and emissions of a di dual fuel diesel engine," Applied Thermal Engineering, 23, 353-365, 2003, doi: 10.1016/S1359-4311(02)00187-4
[6]. Balasubramanian, V. Dr. K. Sridhara and Dr. V. Ganesan (1995) "Performance evaluation of a small agricultural operated on dual fuel (diesel + natural gas) system", SAE 951777.
[7]. Andera, U., R.M. Bata and D.W. Lyons (1993) "Natural gas A promising fuel for I.C. engines", SAE 930929.
[8]. Fraser, R.A., D.L. Sieebers and C.F. Edwards (1991) "Auto ignition of methane and natural gas in a simulated diesel environment", SAE 910227
[9]. Raine, R.R., J. Stephenson,and S.t. Elder (1987) "Optimisation of diesel engines converted to high compression spark ignited natural gas operation", Proceedings of Fourth International Pacific conference on automotive engineering (IPC4), Melboune, Australia, November 28-30.
[10]. Karim, G. A. (1981) "Methane and diesel problems and solutions Proceedings of International conference on Methane fuel for the future". British Columbia, Vanconver B. C., September 28 – 29