DUAL-FUELLING OF A DIRECT-INJECTION AUTOMOTIVE DIESEL ENGINE BY DIESEL AND COMPRESSED NATURALGAS

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Abstract Application of Compressed Natural Gas (CNG) in diesel engines has always been important, especially in the field of automotive engineering. This is due to easy accessibility, better mixing quality and good combustion characteristics of the CNG fuel. In this study the application of CNG fuel along with diesel oil in a heavy duty direct-injection automotive diesel engine is experimentally investigated. In order to convert a diesel engine into a diesel-gas one, the so called " mixed diesel-gas" approach has been used and for this purpose a carburetted CNG fuel system has been designed and manufactured. For controlling quantity of CNG, the gas valve is linked to the diesel fuel injection system by means of a set of rods. Then, the dual-fuel system is adjusted so that, at full load conditions, the quantity of diesel fuel is reduced to 20% and 80% of its equivalent energy is substituted by CNG fuel. Also injection pressure of pilot jet is increased by 11.4%. Performance and emission tests are conducted under variation of load and speed on both diesel and diesel-gas engines. Results show that, with equal power and torque, the diesel-gas engine has the potential to improve overall engine performance and emission. For example, at rated power and speed, fuel economy increases by 5.48%, the amount of smoke decreases by 78%, amount of CO decreases by 64.3% and mean exhaust gas temperature decreases by 6.4%.

Key Words Dual-Fuel Engine, CNG, Automotive Diesel

1. INTRODUCTION

Nowadays, stringent emission legislation have focused attention on the using of clean gaseous fuels, especially in the heavy duty automotive diesel engines (i. e. bus engines). An effective approach to use gaseous fuels in the above engines is the application of a gaseous fuel (i.e. CNG) parallel to diesel fuel. These types of engines are called dual-fuel engines or diesel-gas engines. In this method, engine internal design is not altered and the engine working cycle remains as efficient as diesel like working cycle. In the diesel-gas engines, during the intake stroke, a lean mixture of CNG and air is drawn, through a CNG fuel system, into the engine. At the end of compression stroke, at nominal injection timing a smaller part of liquid diesel fuel (pilot jet) is injected into the homogeneously premixed hot gas-air mixture by means of conventional fuel injection system. Then it is ignited by the droplets of the pilot jet.

For many years, the dual-fuel engines have been used in the slow and medium-speed stationary engines. However high-speed automotive diesel engines do not lend themselves well to diesel-gas operation. Their lower excess air coefficient (near stoichiometric) and rapid variation of load and speed during the engine operation, can be a problem for dual-fuel combustion. In spite of performance enhancement and remarkable reduction in black smoke emission level, the main drawback in these types of engines is that the amount of other exhaust pollutants, such as carbon monoxide (CO) and unburnt hydrocarbons (UHC) increase relative to baseline diesel engine [1-7].

To investigate this environmental weakness of these engines, in this research a programme is proposed and conducted experimentally. In order to convert diesel engine into a diesel-gas one, a carburetted CNG fuel system has been designed and manufactured.
Then it has been fitted on the engine inlet manifold. Therefore, in this conversion, no internal engine change was required. Also the diesel-gas engine is not throttled, runs with a very lean mixture under all conditions, and has a very powerful ignition source with the diesel pilot injection.

For reducing the above-mentioned pollutants, alterations are made in the Fuel Injection System (F1S) of the diesel-gas engine. It may be reasoned that the higher UHC originates from CNG fuel (due to lower cetane number of natural gas) while increasing CO is related to incomplete combustion of diesel fuel (pilot jet). So it is proposed that the number of ignition centers must be increased and distributed evenly throughout the cylinder charge. This can be obtained by increasing the number of fuel droplets, each of which acts as a pilot flame to ignite the lean mixture of CNG and air in the diesel-gas engines. For this purpose, in this work injection pressure has been increased. Consequently, the droplet numbers will increase (droplet sizes decreased) which will enhance the processes of mixing and combustion in the diesel-gas engine [8].

2. ENGINE DATA AND DESIGN OF DUAL-FUEL SYSTEM

Table 1 shows the technical data of the diesel-gas engine used in this investigation. The F1S was adjusted so that, at full load conditions, the amount of diesel fuel per cycle was reduced to 20% and this reduction was compensated by the aspiration of CNG into the inlet manifold. Also injection pressure is varied and adjusted in the injector nozzle by altering the thickness of the inserted washers.

Figure 1 shows schematically the layout of the diesel-gas engine and test set up used in this work. In this system, CNG fuel is delivered from high-pressure CNG pipe (1.5 bar) through a CNG filter to a pressure regulator unit. Here, the pressure of the CNG fuel is reduced to near atmospheric pressure (20-25mbar). Then CNG enters through a gas flow meter into the venturi of the CNG carburettor, where it mixes with air

TABLE 1. Engine Specification.

Parameters	Description
Engine type	4-stroke, naturally aspirated, D.I, diesel engine
Cylinder number	6
Bore	0.128m
Stroke	0.150m
Displacement volume	11.58 lit
Compression ratio	16:1
Rated power	170kw at 2200 rpm
Injection pressure	175 bar
Injection timing	-20^{o} CA BTDC

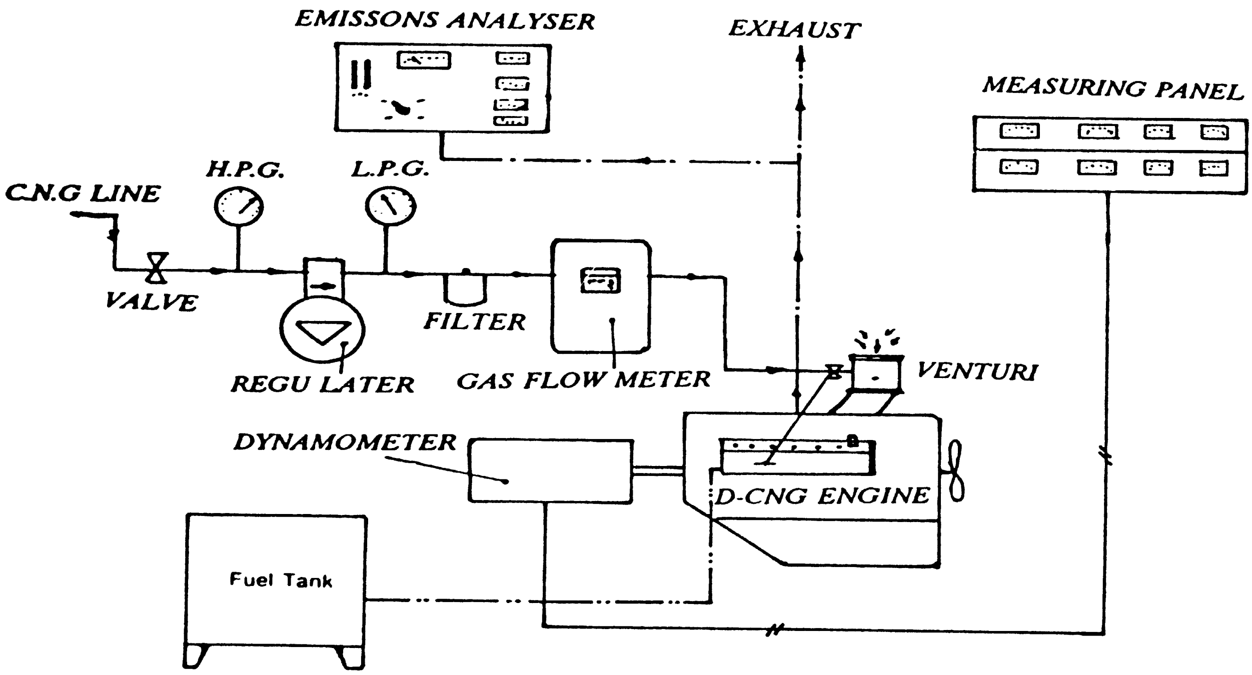

Figure 1. Schematic layout of diesel gas engine and test set up.

and the mixture passes through the inlet manifold to the cylinders. The dimensions and profile of the venturi are calculated by means of a computer code which is written and developed locally [9]. Then the carburettor body and venturi are manufactured according to the drawings obtained from the computer code. Under various speeds and loads, the amount of CNG fuel is controlled by air flow passing through the venturi and by the CNG regulating valve operated by the governor of the injection pump through a system of rods.

3. TEST PROGRAMME

Due to simultaneous variation of load and speed in an automotive diesel-gas engine,

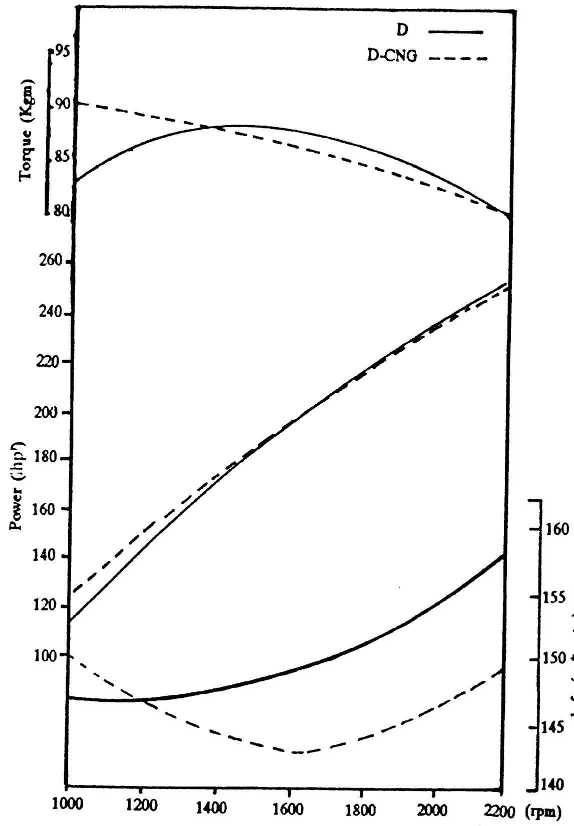

Figure 2. Engine Performance.

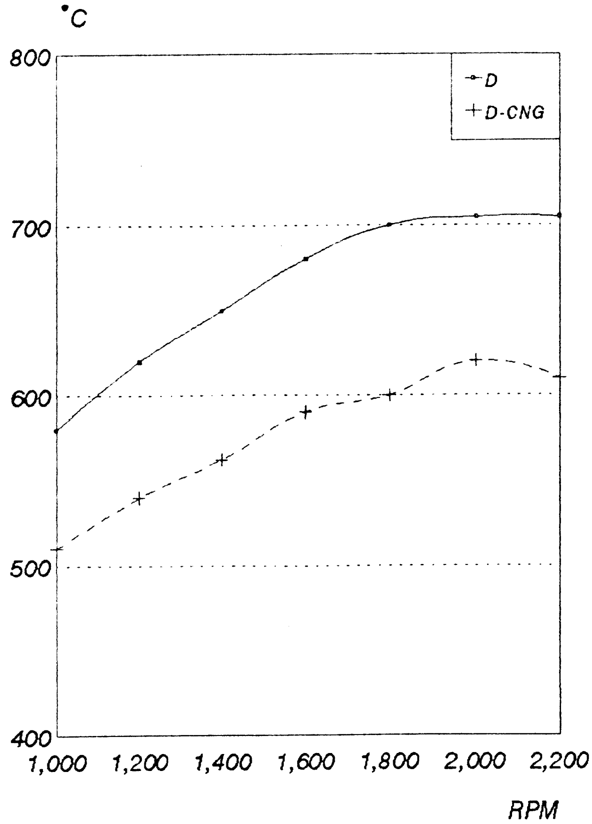

Figure 3. Exhaust gas temperature.

performance and emission tests are conducted under variation of speed and loads operating conditions. It is worth noting that, the results obtained from performance and emission tests remained virtually the same throughout the test programme. The observed results such as engine torque, power and smoke were corrected to standard atmospheric conditions (pressure 760 mmHg, temperature 20°C) and with other observed results plotted versus the engine speed.

4. TEST RESULTS AND DISCUSSIONS

The performance and pollutants emission results of the diesel-gas engine and baseline engine are shown in Figures 2-6. Comparing these results, it may be noted that the quantities brake power, brake torque and brake specific fuel consumption are more or less the same in both engines (Figure 2).

Figure 3 shows the curves of exhaust gas temperature versus engine speed. It can be seen that diesel-gas engine at the end of expansion stroke works cooler than diesel-engine. This is due to the increasing air-to-fuel ratio of the diesel-gas engine, which leads to a lowering of the flame temperature and subsequently the exhaust gas temperature. Furthermore, this trend may also be due to a lower proportion of the diffusion part of the combustion of the dual-fuel. The lower exhaust temperature decreases thermal stresses in the cylinder head and exhaust valve seat, which may result in an improvement in the usual service life of the engine.

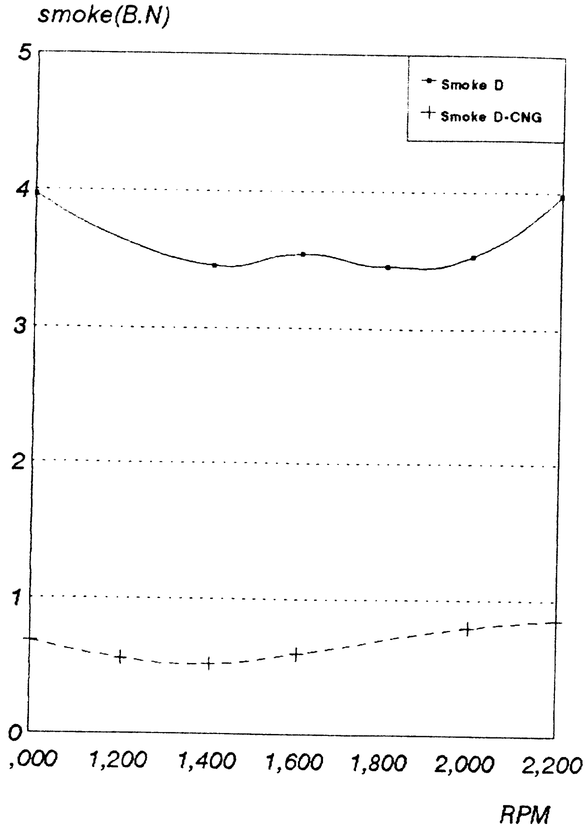

Figure 4. Black smoke emission.

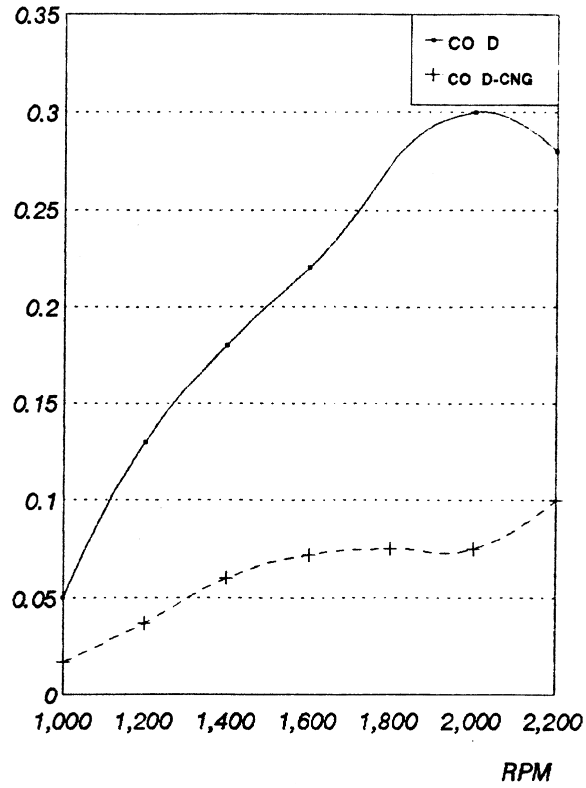

Figure 5. Carbon monoxide emission.

Figure 4 illustrates the curves of black smoke versus speed for both engines. As the curves show, the amount of black smoke of the diesel-gas engine is considerably lower than that of the diesel engine (nearly 4.5 times) at all speeds. In a diesel engine, there is not enough time for complete mixing of liquid diesel fuel and air. On the other hand, in the diesel-gas engine, about 80% of the total fuel is vapor mixed with inlet air. Eighty percent of the mixture is premixed which leads to cleaner combustion in the diesel-gas engine. Smoke characteristics of the diesel-gas engine are more desirable. Any reduction of smoke will have positive effects on the engine oil life, therefore engine service intervals may possibly be extended. Considering Figure 4, the newly developed diesel-gas engine may be called "Smokeless" engine.

Figure 5 shows the volume percentages of carbon monoxide (CO) gas in the exhaust gas of both engines versus speed. Here it is important to highlight that, by increasing injection pressure (11.42%) the amount of CO in the diesel-gas engine has been reduced considerably, even to a lower level than that of the baseline engine.

Figure 6 depicts the curves of total UHC in the exhaust gas versus engine speed for both engines. It can be seen that, in the diesel-gas, the amount of UHC is higher than that in the diesel engine and increases with an increase in the engine speed. This is mainly due to an increase in ignition delay of dual-fuel (a reduction of cetane number). By increasing the ignition delay period, gaseous fuel will not burn completely, and part of it will appear as UHC (unreactive hydrocarbons) in the exhaust gases

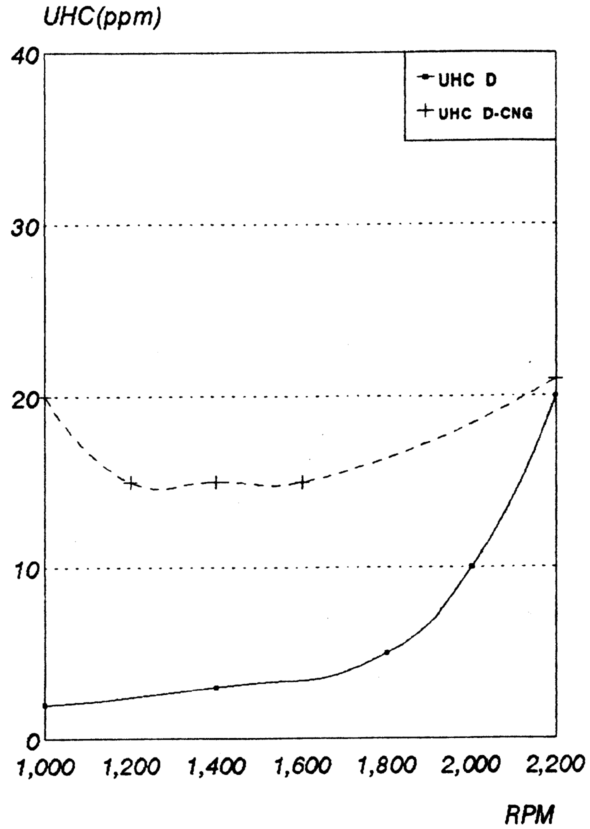

Figure 6. Unburnt hydrocarbon emission.

of the diesel-gas engine [1]. Fortunately, at both engines, the amount of UHC is very low comparing with other typical automotive petrol and diesel engines. Table 2 compares some important performance and pollutants emission parameters of both engines at rated speed. From the above table, it is clearly seen that a higher injection pressure enables diesel-gas engine to operate efficiently with low polluting emissions (specially CO and smoke).

5. CONCLUSIONS

The followings are the results obtained by comparing the performance and emission parameters of a modified diesel- gas engine with a conventional diesel engines:

1. Diesel-gas method is a suitable and feasible means of using CNG fuel in diesel engines, because converting a diesel-gas engine for diesel-only operation is possible at any time.
2. By increasing the injection pressure in a diesel-gas engine (11.43%) black smoke decreases by 78% (4.5 times), CO decreases by 64.3% and UHC increases by 12.5%
3. In addition to improving the performance and emission of diesel-gas engine, its operation is smooth and has no increased noise and vibration.
4. By converting emission quantities into brake specific mass units, it is found that pollutants emission level of modified diesel-gas engine is comparable with levels of current

TABLE 2. Comparison of Performance and Emission Parameters.

Parameters	Diesel-Gas engine	Pure Diesel engine	Deviation%
Brake power (kw)	182.7	182.6	+ 0.055
Brake torque (kgm)	81.0	81.0	+0.00
BSFC (gr/kw.hr)	148.6	157.22	- 5.48
Smoke (Bosch)	0.88	3.98	-78.0
UHC (PPM)	22.5	20	+12.5
CO (%)	0.1	0.28	-64.3
Exhaust Temp. (°C)	660	707	-6.4

European standards (i.e. EURO 2)

5. From measuring thermal parameters (exhaust temperature, cooling water outlet temperature,...) it can be concluded that, in comparison to baseline engine, diesel-gas engine operation is very cool and red-hot exhaust manifold is not observed at any operating condition.

6. ACKNOWLEDGEMENT

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