

Conversion of Conventional DI Diesel Engine into Dual Fuel Engine (Diesel + CNG) and Performance Analysis

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ABSTRACT: The working fuel used in many of the prime movers, pumps and some other machinery is mostly 'diesel'. The use of diesel as a fuel in transport vehicles, that is engines gives exhaust emissions which contribute to the development of living health issues, pollution of air and water and global climate change. Addition to the mentioned side effects, the availability of diesel causes one to find some alternative for diesel as a working fuel. Compressed Natural Gas and Diesel dual fuel mode of operation in engine is one of the best methods to control the harmful emissions in the diesel engine and also saving non-renewable energy in the form of diesel. The experiments were carried on a diesel engine first and then modifications were done in the existing three-cylinder, four strokes, direct injection diesel engine such that it can be operated in Dual Fuel mode. It can work on both CNG as well as Diesel as a fuel. The experiments were done for performance analysis and emission analysis of dual fuel engine with respect to existing diesel engine.

KEYWORDS: Compressed Natural Gas; Exhaust Emissions, Direct Injection; Dual Fuel Engine; Performance Analysis

I. INTRODUCTION

The use of fossil fuel to large extent is contributing a lot to the degradation of environmental resources, increase in cost, toxic emissions and also causes human health hazards. Conventional diesel engines are under strict emission regulation particularly of smoke, unburnt carbon and NOX in exhaust. The exhaust gas control and reducing the use of petroleum-based diesel fuel has become very important need in the field of engine development. This need has led to find an alternate fuel to petroleum-based fuels. CNG is found out to be one the best alternatives for the diesel fuel. CNG and diesel can be used in dual fuel mode to acquire both energy and environmental benefits. The benefits of using CNG with diesel in dual fuel mode are low costs of working fuel, considerable reduction in particulate emissions and increased efficiency of engine. The problem associated with CNG alone is that its self-ignition temperature is very high which cannot be reached in the combustion chamber. Hence diesel is used as a pilot fuel for the ignition of the CNG. Pilot fuel is injected during compression stroke. CNG can be introduced with the airflow to the combustion chamber. In the Fumigation process, the gas is mixed proportionately with air and the mixture enters the Combustion chamber during the suction stroke. Engine can operate on pure diesel as well as in dual fuel mode (i.e. CNG + Diesel). In dual fuel operation the gaseous fuel is mixed with air at lean gas-air ratios and the mixture is then compressed in engine. Near the end of compression stroke, diesel fuel is injected. After ignition delay the combustion of diesel occurs first, igniting the natural gas and the flame propagation begins. The injection of CNG along with introduction of air fluctuates the thermodynamic and chemical properties of the combination in the cylinder and hence the dual fuel engine has its own characteristics performance. The diesel fuel which acts as a source of ignition is referred as pilot diesel. The quantity of pilot diesel and concentration of CNG in the air in engine have significant effects on the performance of a dual fuel engine.

II. MATERIALS AND EXPERIMENTAL SETUP / SYSTEM MODEL

- CNG as an Alternate Fuel:

CNG has come out as an alternative fuel due to its clean burning characteristics and very low amount of exhaust emissions. It can be considered as an ideal fuel. In petrol engines CNG can be used by installing a Bi-Fuel Conversion



kit and this engine has the option of operation either on CNG or petrol. Diesel engines can also be converted to run on CNG by installing a dual fuel conversion kit or converting the existing engine into dual fuel engine. Generally, CNG vehicles use petrol engines which is modified by after-market retrofit conversions and keep bi-fuel capability. Such bi-fuelled converted engines generally suffer from a power loss and encounters operational problems, due to the design and installation of the retrofit conversion kit. But single fuel engines enhanced for CNG more effective in terms of performance and emissions. In diesel engines CNG as a fuel can be used in dual fuel mode and offers the advantage of reduced emissions of NOX, particulate matter and CO2 while retaining the thermal efficiency of the conventional diesel engine, [1]. The safety aspects of converting engines to run on CNG are of great concern to users of CNG vehicles. However, CNG has four great safety features that make it safe fuel compare to petrol, diesel, or LPG. Its specific gravity is 0.587 which means that it is lighter than air and even if it leaks out it just rises up and disperse into atmosphere. Its self-ignition temperature is 5400C as compare to 227-5000C for petrol and 2570C for diesel fuel and higher flammability limits give it a high dispersion rate and make the fire accidents probability in the case of a gas leak much less than the case of petrol or diesel. CNG has to mix with air within small range of 4 to 14% by volume for combustion to occur which is far narrower range for petrol or diesel fuels. CNG cylinders are designed and built with special materials to the highest safety specifications, which makes its storage far safer than petrol or diesel fuel tanks. [1]. The life of engine increases by using CNG. Lubricating oil life is increased considerably because CNG doesn't pollute and dilute the crankcase oil. Great advantage of CNG is that it is almost pollution free. CNG has better mixture quality with air and when it is injected with air they mix completely and rapidly, which increases combustion efficiency of the engine. The higher Research Octane Number (130) for CNG as compared to that of petrol (87) allows a higher compression ratio (18:1) and consequently more effective fuel consumption. Due to higher compression ratio Diesel engines can also use CNG as main fuel. But it cannot replace diesel completely like petrol due to poor cetane rating of CNG, [3]. Hence CNG seems a better option for its use in diesel engines. The properties of CNG as a fuel for IC Engines are given in Table 1, [2].

Table1: Properties of CNG as a Fuel at 250°C and 1 atm.

CNG properties	Value
Density (kg/m3)	0.72
Flammability limits (volume% in air)	4.3-15
Flammability limits (Ø)	0.4-1.6
Auto ignition temperature in air (0 C)	723
Minimum ignition energy (MJ)	0.28
Flame velocity (m/sec)	0.38
Adiabatic flame temperature (K)	2214
Quenching distance (mm)	2.1
Stoichiometric fuel/air mass ratio	0.069
Stoichiometric volume fraction (%)	9.48
Lower heating value (MJ/Kg)	45.8
Heat of combustion (MJ/Kgair)	2.9

Comparison of properties between the two proposed fuels is given in Table 2 as given below.

Table 2: Comparison between properties of Diesel and CNG.

Properties	DIESEL	CNG
Auto-Ignition Temperature	210	723
Density(kg/m ³)	700	0.72
Fuel Cost	Low	High
Environment Friendly	Less Environment Friendly	More Environment Friendly
Emissions at the Exhaust	High Emissions of Unburnt Hydrogen, CO, NO _x emissions	Very Less Emissions

- Experimental Setup / System Model:

The set up consists of a three-cylinder, four strokes, and direct injection diesel engine. The engine specifications are listed below in Table 3.

Table 3: Diesel Engine specifications.

Engine Specification	Details
Number of cylinders	03
Bore x stroke	110mm x 116mm
Displacement	3300cc
Compression Ratio	18:1
Power	27.9kW at 1500 rpm

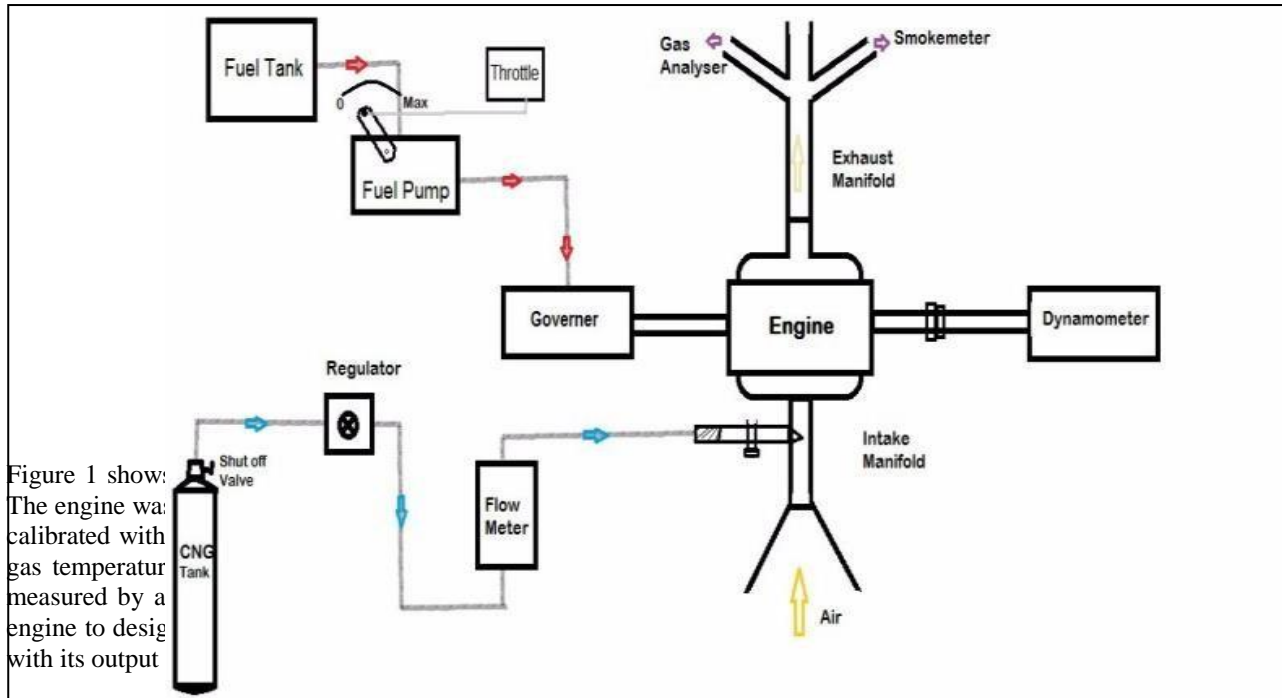
The diesel engine mentioned above was initially single fuelled (diesel) only. It was modified to work in dual fuel mode, that is both CNG and diesel (pilot fuel). There are several methods of making an engine work in dual fuel mode. But the method introduced in this paper is “fogging or fumigation type dual-fuel system”. Using this method, the engine was converted into a ‘dual fuel’ engine with some modifications. The mixture of CNG with the intake air charge is introduced into each 3 cylinders of the engine during the intake stroke and this is done by connecting CNG pipe just prior to air intake manifold. Rotameter is also introduced in CNG delivery pipe to monitor the flow rate. During compression stroke, the pressure and temperature of the mixture are increased in the conventional Diesel cycle manner. At of the compression stroke, a lesser than usual quantity of diesel fuel from the engine's diesel fuel injection system is injected into the cylinder. The diesel auto-ignites due to compression and in turn ignites the mixture of CNG and air, which in turn, propagates the flame front of the Diesel Fuel, enhancing the normal combustion process. The Engine modified with such fumigation systems may typically be operated in a dual-fuel mode or only diesel mode (when CNG is not available). In our experiment, we will be using this method of fumigation to run the three-cylinder, four stroke, direct injection diesel engine in dual fuel mode using Diesel and CNG.

The Following Procedure was adopted to convert diesel engine into duel fuel mode and for performance analysis

1. Exhaust was properly insulated.
2. For CNG entry valve with pump was provided.
3. Temperature Sensors were installed at coolant inlet and outlet and at exhaust pipe.
4. RPM sensor was installed to measure speed of engine.
5. Hydraulic Dynamometer was used for measuring output torque.

6. CNG flow measuring (rotameter) and flow controlling device was installed.
7. Weighing balance were used to measure the weights of CNG and Diesel used.
8. Stopwatch was used to measure time required for 50 g of CNG and 50g of Diesel to be consumed.

Figure 1. Experimental Setup / System Model (demonstrating modifications)



III. PROPOSED METHODOLOGY

As discussed earlier, we are using Diesel & the Diesel-CNG fuel mix to run our engine and CNG is been mixed by Fumigation technique.

At first, we start the engine and switch on every accessory such as water supply, temperature indicators and let the engine run for 20 minutes so that the engine can achieve its steady state. In the first set we run the engine on pure diesel fuel purchased from a Petrol Pump. We initially run the engine at Zero load and take readings of all the parameters required for our performance results. Following parameters are to be noted:

1. Fuel consumption (50g Diesel and Diesel+CNG)
2. Temperatures,
 - T1 = Temperature of the water entering into the engine jacket.
 - T2 = Temperature of the water coming out from the engine jacket.
 - T3 = Temperature of the Exhaust.
3. Load on the engine applied by the Hydraulic Dynamometer. (Kg.)
4. After noting down all the parameters, we gradually apply the load (in the steps of 10kgs.) on the engine and let it run for 15 minutes to achieve the steady state and then point down all the parameters again.
5. In the same manner, for increasing loads, all the parameters are noted down.
6. The results of the experiment are tabulated. (reference values)
7. In the next phase, we introduce CNG with the Diesel and take the readings following the same procedure from step 1 to step 5. In this stage, we have to take reading of one additional parameter i.e. CNG fuel consumption.

IV. OBSERVATIONS AND CALCULATIONS

As discussed above, all the readings for different set of loads on the engine were taken and are tabulated below (only reference values are shown).



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Table 4: Observations(readings) for Load of 40kg on the engine.

Sr.no.	Parameter to measure	Diesel	CNG +Diesel
1	Engine Speed	1500	1500
3	Max. CNG Accepted by engine	-----	30LPM
4	CNG Flow(LPM)	-----	30
5	Time for 50g Diesel	34 secs	52sec
7	Coolant Temp. In	61	65
8	Coolant Temp. Out	64	68
9	Exhaust Temp	285	295

Table 5: Observations(readings) for Load of 30kg on the engine.

Sr.no.	Parameter to measure	Diesel	CNG +Diesel
1	Engine Speed	1500	1500
3	Max. CNG Accepted by engine	-----	20LPM
4	CNG Flow(LPM)	-----	20
5	Time for 50g Diesel	46.17 secs	67sec
7	Coolant Temp. In	82	84
8	Coolant Temp. Out	83	85
9	Exhaust Temp	222	238

Table 6: Observations(readings) for Load of 20kg on the engine.

Sr.no.	Parameter to measure	Diesel	CNG +Diesel
1	Engine Speed	1500	1500
3	Max. CNG Accepted by engine	-----	20LPM
4	CNG Flow(LPM)	-----	20
5	Time for 50g Diesel	60 secs	104sec
7	Coolant Temp. In	75	80
8	Coolant Temp. Out	78	83
9	Exhaust Temp	182	191



Table 7: Observations(readings) for Load of 10kg on the engine.

Sr.no.	Parameter to measure	Diesel	CNG +Diesel
1	Engine Speed	1500	1500
3	Max. CNG Accepted by engine	-----	20LPM
4	CNG Flow(LPM)	-----	20
5	Time for 50g Diesel	91 secs	147sec
7	Coolant Temp. In	69	74
8	Coolant Temp. Out	72	77
9	Exhaust Temp	127	150

Below mentioned are the formulae for the entities to be calculated for analysis. And the outputs are directly plotted as graphs in results.

1. Input Power (only diesel) = $Mf_{diesel} * CV_{diesel}$
2. Input Power (cng + diesel) = $Mf_{diesel} * CV_{diesel} + Mf_{CNG} * CV_{CNG}$
3. Brake Power = $2\pi NT$
4. Brake Thermal Efficiency = Brake Output Power / Input Power.
5. Fuel Consumption can be directly calculated through above tables.

Here,

Mf= Mass Flow rate(kg/s)

CV = calorific value(of fuel)

N = Speed(rpm)

T = Torque (N.m)

V. RESULTS

The Brake Thermal Efficiency, Brake Power, Maximum amount of CNG required and Brake Specific Fuel Consumption at different values of the load applied on the engine were calculated from the data acquired through various trials on the set-up(tabulated in observations) and the following graphs were obtained as the results.

Fig.2. Graph - Thermal Efficiency vs. Load

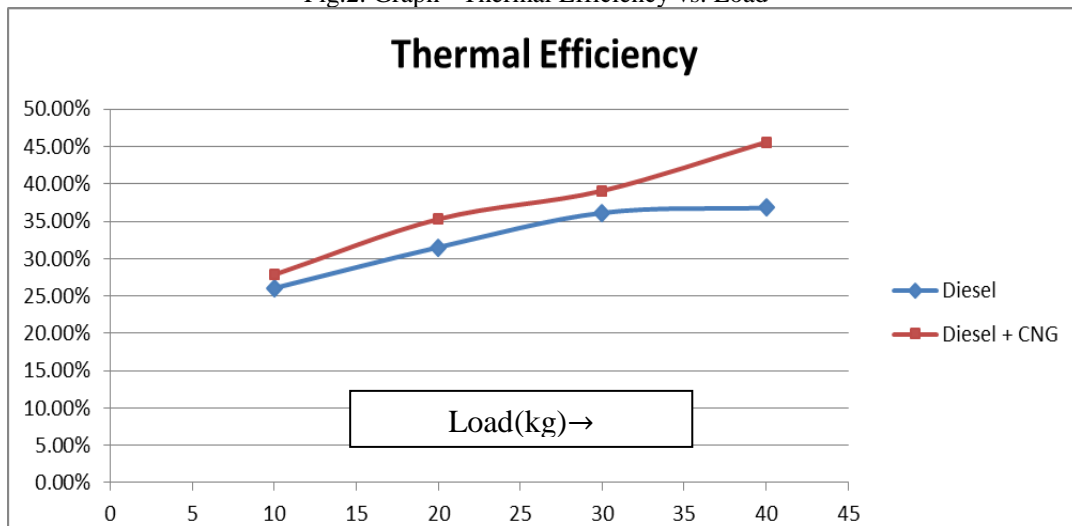




Fig.3. Graph – Brake Power vs. Load

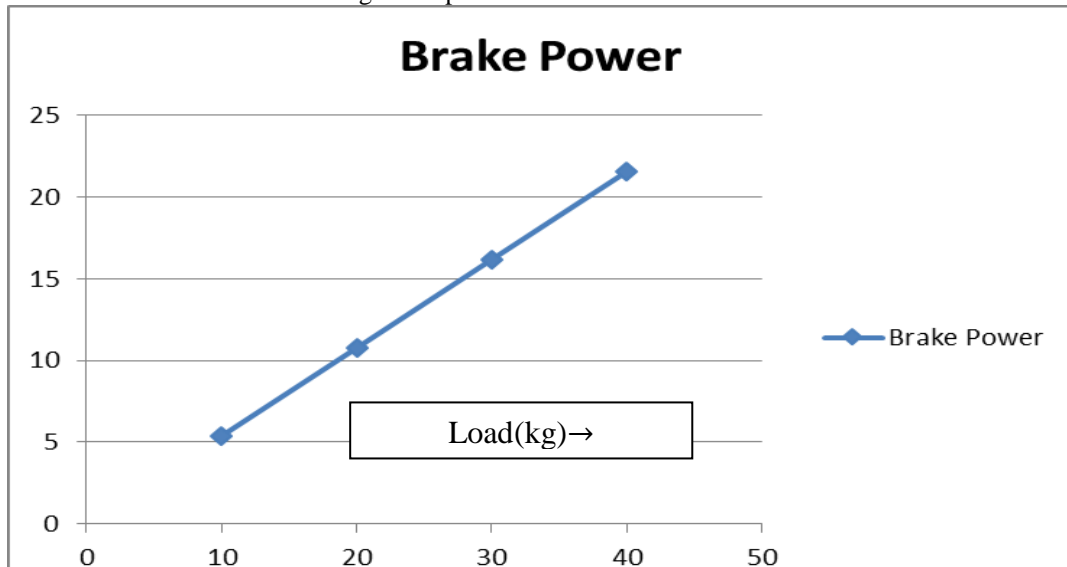


Fig.4. Graph – Maximum amount of CNG required vs. Load

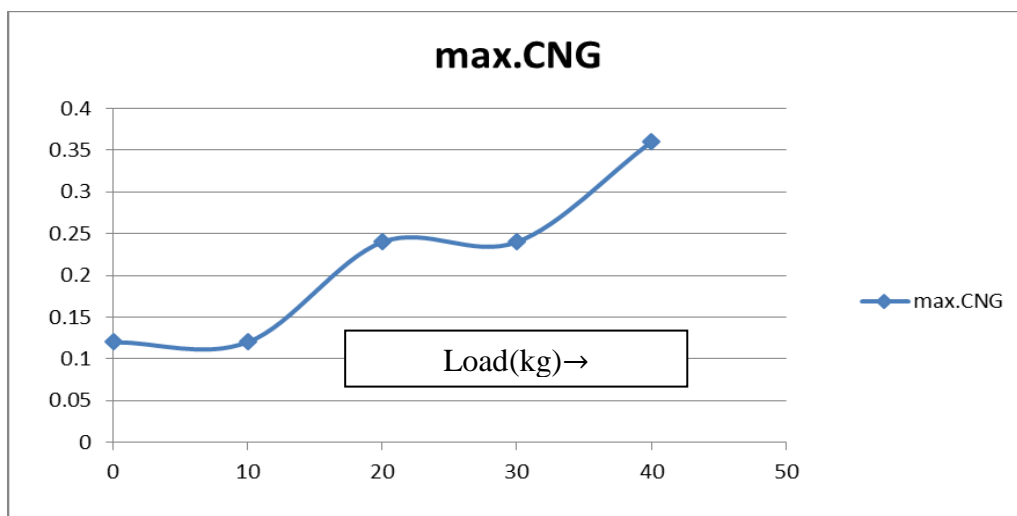


Fig.5. Graph – Brake Specific Fuel Consumption vs. Load

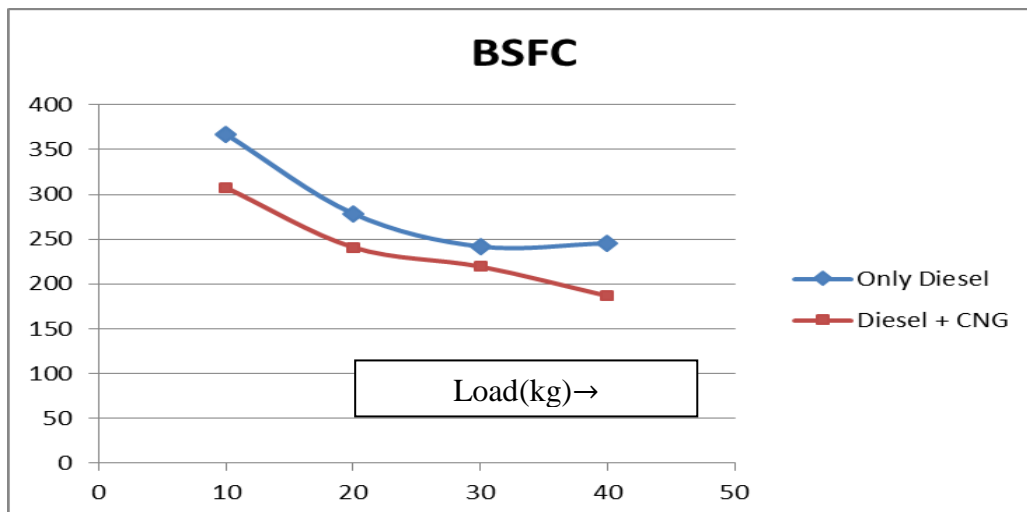




Table 8: Mass Flow Rate of diesel at different loads on the Engine

Load (kg)	Mass flow rate of Diesel for Pure Diesel Mode(g/sec)	Mass flow rate of Diesel for Dual Fuel Mode (g/sec)	% Reduction in the Mass flow rate of Diesel (%)
0	0.3278	0.2127	35.11287
10	0.5494	0.3401	38.0961
20	0.8333	0.4807	42.31369
30	1.0869	0.7462	31.34603
40	1.4705	0.7575	48.48691

Above results are used to compare and for the performance analysis of dual fuel mode with pure diesel mode.

VI. CONCLUSIONS

Various trials were done on the specified set-up, only the reference observations, calculations and results are discussed in this paper. All the ambient conditions were considered ideal while running the trials. After checking out the obtained results, following conclusions were made.

- From fig.(2), it is seen that the thermal efficiency of the engine increases as the applied load is increased for pure diesel mode. Same is the case observed in the dual fuel mode. But the Thermal efficiency – load curve was shifted upwards in dual fuel mode, which clearly indicates that Efficiency of engine was improved in dual fuel mode.
- From fig.(4), it is observed that the brake specific fuel consumption for dual fuel mode is decreased by a conspicuous amount as compared to pure diesel mode. The BSFC in dual fuel mode decreased, because the amount of diesel was replaced by CNG.
- From fig.(5), it is observed that the amount of diesel replaced by alternate Fuel CNG (maximum amount of CNG required) per stroke increased with increase in load applied. Also, more the amount of diesel replaced by CNG, more the engine is efficient (by performance and also economically).
- Table.8 shows that the reduction in mass flow rate of diesel used in pure diesel mode and dual fuel mode. There is considerable reduction in the amount of diesel in dual fuel mode (above 35% reduction and can go up to 50% or more)

The above conclusions indicate that when the engine is used in dual fuel mode, the consumption of primary fuel (Diesel) used to run the engine is reduced. And it is replaced by the secondary fuel (CNG), therefore the emissions performance and efficiency of the machine are increased. Also, as the secondary fuel is a natural gas and available in abundance, the cost of CNG is very less as compared Diesel. Hence, the operating cost of the engine also gets reduced considerably.

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