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CONVERSION OF DIESEL ENGINE TO CNG ENGINE OF COMMERCIAL VEHICLES AND EMISSION CONTROL

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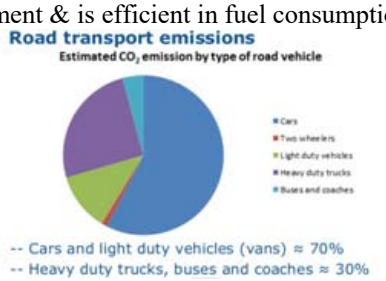
Abstract - Depletion of petroleum products is providing reasons for research of its alternate means, such as CNG or Natural Gas ,which looks promising in future. It will help to bring down the percentage of harmful emissions, regardless of any vehicle type or category. We have been using CNG as a fuel in stationary engines for a long time, but the trend of using CNG as a transport engine fuel have been developing due to use of new types of light weight high pressure storage cylinders. We can use compressed natural gas in IC engines in various methods and with little modifications. It is revealed that there is decrease in performance characteristics while the emissions characteristics for CNG are better as compared with diesel or petrol. This paper shows the conversion of diesel engine to a CNG engine with little modifications.
This paper gives a comprehensive review about the researches and the development of CNG engine to keep the output power, torque and emissions of compressed natural gas engines comparable to their gasoline or diesel counterparts. This paper introduces the use of gas injectors, three-way catalytic converter. To perform all the modifications, I have taken Cummins ISC 8.3 for commercial vehicle diesel engine as my baseline engine.

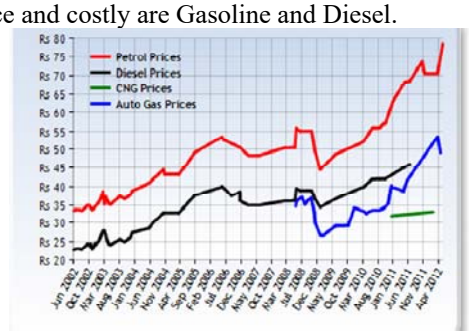
Keywords - Conversion, Diesel engine, CNG engine, Three-Way Catalytic convertor, Compression Ratio, Fuel Injector, Air Gas Mixture, Camshaft Position Sensor, Throttle Valve, MAP Sensor, Fuel Rail for CNG

INTRODUCTION:

1) Problems in the world regarding Internal Combustion engines primarily focuses on environmental protection and economically fuel consumption. Internal combustion engines are classified into gasoline and diesel engines which are used to generate power in industries and automobiles. This problem needs the approach of new designs, research& technology so that the diesel engines can run with natural gas which results in protecting the environment & is efficient in fuel consumption.

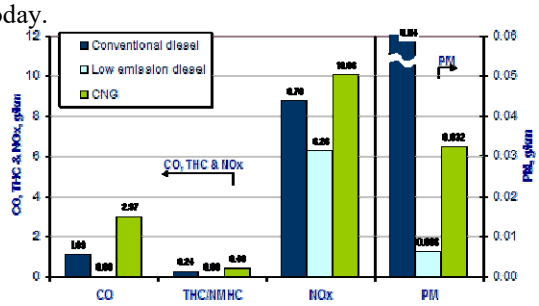


2) We are all aware about the diminishing of fossil fuel reserves all over the world and shortage of crude oil is to be expected during the early decades of the century. Crude oil and petroleum products are believed to become very scarce and costly to find and produce. Two must commonly products to become scarce and costly are Gasoline and Diesel.



3) In the coming decades, use of alternative fuel technology & its availability will become more common for internal combustion engines. Nowadays, the use of alternative fuel has been growing due to concerns that the fossil fuel reserves all over the world are finite and will run out completely towards the early decades of this century. Due to the current world energy crisis, fossil fuel prices has been increasing at a steady rate. On the other hand, fossil fuels contribute largely to environmental pollution. Many types of alternative fuels are available in the world from which Compressed Natural Gas (CNG) is increasingly becoming important.

4) Improving fuel efficiency and reduction of harmful emissions has become the most important job for the present engine researchers. Diesel engine has greater thermal efficiency, but the emission of NOx & particulate matters(PM) remains a major concern, till date. In these recent years, direct injection gasoline engine has became apparent to fulfil the need of improved fuel economy but still lacks to solve the problem of harmful PM emissions. With rising number of automobiles and decreasing number of oil resources, it seems that the use of alternative fuels is unavoidable in the future. To meet the required demands, the use of alternative fuels in gasoline and diesel engines are becoming the subjects of interest today.



5) While evaluating Compressed Natural Gas (CNG), I considered many aspects like Adequacy of fuel supply, Process efficiency, Ease of transport and safety of storage, Modifications needed in the fuel distribution network of the vehicle, Fuel compatibility with the engine. However, CNG has some advantages compared to gasoline and diesel from an environmental perspective. It is a cleaner fuel when compared with either gasoline or diesel as far as emissions are concerned. Compressed natural gas (CNG) is an Environmentally clean alternative to those fuels.

Properties of CNG as compared to Diesel: -

Table 1: Comparison between Diesel and CNG

Properties	*Diesel*	*CNG*
Chemical Formula (-)	$C_{15}H_{28}$	CH_4
Molecular Weight (-)	208	16
Carbon Content(%m)	86.1	75
Hydrogen Content(%m)	13.9	25
Oxygen Content(%m)	0	0
Density liquid at 20^0 (Kg/l)	0.840	-
Lower Heating Value(MJ/Kg)	42.7	47.7
Heat of Evaporation(KJ/MJ)	~6.0	-
Cetane Number (-)	45-55	-
Octane Number (-)	-	~130
CO_2 Emission(g/MJ)	74.2	57.7

Typical composition (percentage volume) of compressed natural gas:-

Table 2: Typical Composition (Vol %) of Compressed Natural Gas:

Component	Symbol	Volumetric %
Methane	CH_4	94.42
Ethane	C_2H_6	2.29
Propane	C_3H_8	0.03
Butane	C_4H_{10}	0.25
Nitrogen	N_2	0.44
Carbon dioxide	CO2	0.57
Others	-	2

Modifications: -

There are certain modifications which are done to convert the commercial diesel engine into CNG engine. The required modifications are explained below.

1) Reduction of Compression Ratio

Different methods that can reduce the compression ratio, are listed below:-

1. Modification of the piston groove or bowl
2. Modification in the length of the connecting rod
3. Insertion of the Thicker gasket(plate) onto the piston

The first method is implemented by milling the piston head to create a recessed bowl shape. The size of the bowl may vary depending upon the size of the piston. This method reduces the compression ratio.

The second method is to modify/reduce the length of the connecting rod. This method is very costly and the construction is complicated. Improper design will cause various types of vibration and cause thermal stress to build up in the piston.

The last method is chosen to design the piston in the combustion chamber, so as to reduce the compression ratio. A gasket with a thickness of about 2mm is added between the piston head and the cylinder block ,so that it could act as a seal between the engine block and the piston head. The shape of the plate will be made according to the shape of the top of the piston head. It is chosen due to its lower construction cost and its easiness to be built compared to the other methods explained earlier. Besides that, this design requires less complexity and simple calculation.

2) Rugged fuel rail for CNG systems: -

In the CNG fuel rail, Pressure regulators transfers the CNG to the injectors. Usually, CNG is stored temporarily at up to 10 bars and distributed to the CNG injectors connected to the fuel rail. A sensor is used to monitor the pressure.NGI2 injectors are used to inject the pressurized CNG into the intake manifold with the utmost precision. It results in forming the desired gas-air mixture. This mixture is ignited by the spark plug available in the cylinder. The completely bolted and tested CNG fuel rail is designed specifically for CNG applications. Medium-pressure and temperature sensors can optionally be equipped with the compact and rugged stainless steel assembly.

3) Fuel Injector: -

The injector is supplied by the CNG fuel rail for CNG systems. The electronic control unit (ECU) via a signal, is calculated by the engine management system(EMS), triggers the injection. The gas quantity required by the engine is dosed exactly as required. To meet the requirements of CNG operation NGI2 was specifically developed: as an electromagnetic valve for a higher gas volume, high flow speed and

wear resistance, even when operated with oil-free gas. Its quality and service life can be compared with those of fuel injectors.

4) Modification of inlet port: -

CI engines need swirl motion in order to mix with compressed air inside the Combustion chamber, where as in case of SI engines the tumble motion is to be provided. So, the replacement of helical inlet port with tangential inlet by machining is required to convert the swirl motion into tumble motion. The swirl and tumble motion is created in the cylinder as depicted in the Figure

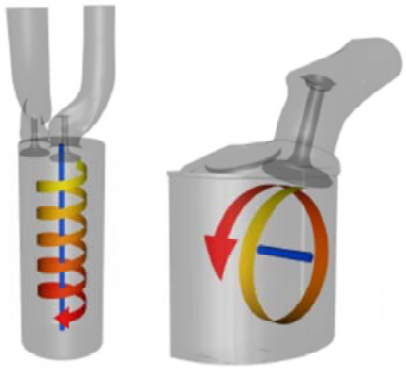


Figure 1: (Left) Stable, circulating flow pattern in a diesel engine designated as swirl motion, with the cylinder axis as the axis of rotation. The flow enters tangentially through the intake ports.(Right) Transient tumble motion in a gas engine. The axis of motion moves as the cylinder expands and stays in the middle between the cylinder wall at the top and the piston head at the bottom.

5) Air Gas Mixer: -

Gas mixer is a device which determines or measures the amount of compressed natural gas and air before entering the engine. It injects the gas into the intake air stream of an internal combustion chamber using a combination of radial holes and radial tubes located around the perimeter of an airflow passage. The size of intake air passage, the number and size of the radial holes and

tubes varies to achieve adequate gas or air mixing for the particular engine. Measurement of airflow necessary for engine operation is the selection criteria of mixers. The power obtained from engine is dependent on the size of the mixer. The experimental result shows that a smaller mixer causes higher pressure at the throat in comparison to the analytical result. High pressure causes low velocity at the throat. Both smaller and larger mixer was able to promote the methane into the outlet from the inlet tube. Smaller size throat mixer at the throat restricted caused undesirable results.

6) Cam Shaft Position Sensor: -

Optimum engine control is based on current, exact information from the power train. Various sensors provide this information. The camshaft position sensor uses the engine control unit uses to record the exact position of the camshaft to increases power and emissions reduction at the same time. Due to the electronic engine management ,precise control of all functions relevant for engine operation is enabled. This control is based on ongoing, exact information from the drive train. This information is provided by sensors. The camshaft speed sensor is used by the engine control unit to record the position of the camshaft. High precision of the sensor enables exact injection/ ignition timing and a precise variable camshaft phasing, which in turn increases power and supports emission reduction at the same time of the CNG engine of commercial vehicles.

7) Throttle Valve: -

The injected fuel mass must be perfectly matched to the air supply in the engine cylinder for efficient fuel combustion of commercial CNG engine. The electronic throttle valve in a CNG IC engine regulates the air supply in the combustion chamber by reducing or enlarging the intake manifold cross-section. The electronic actuators driven by the air management system is used to regulate the air mass supply with absolute precision. The throttle device consists of an electrically driven throttle valve and an angular-position sensor for position feedback. The throttle valve is electronically triggered by the electronic engine management unit. Variables from the trigger include the accelerator- pedal position and any system requirements that can influence the engine torque.

8) Introducing Three-Way Catalytic Converter (TWC)

The (TWC) is generally a multicomponent material. It can simultaneously perform the oxidation of carbon monoxide (CO), hydrocarbons (HC) and the reduction of nitrogen oxides (NOx). Usually noble metals are used, as the active phase in TWCs. Palladium(Pd) catalysts are especially attractive because it is by far the cheapest noble metal in the market and has better activity and is bias for hydrocarbons. Rhodium is one of the most efficient catalyst in promoting the reduction of NO to N2. The performance of the TWC in the emission control can be affected by operating the catalyst at elevated temperature (> 600 degree Celsius). Reactions occurring on the automotive exhaust catalyst are very complex as listed below.

The major reactions are the oxidation of CO and HC and the reduction of Nox. Also, water gets a shift and steam-reforming reaction occurs. Intermediary products like N2o and NO2 are also found. The NOx storage concept is based on the incorporation of a storage component into the three-way catalyst to store NOx during lean conditions for a time of minutes.

Reactions of Catalytic Converter:

Oxidation

2CO + O2 -> 2CO2

HC + O2 -> CO2 + H2O

Reduction

2CO + 2NO -> 2CO2 + N2

HC + NO -> CO2 + H2O + N2

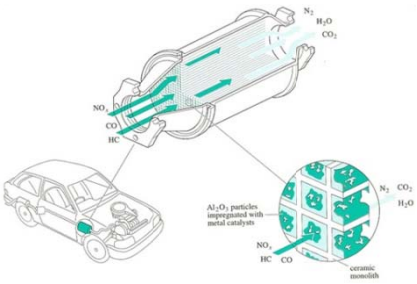
2H2 + 2NO -> 2H2O + N2

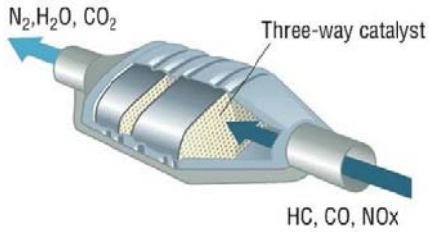
Water Gas shift

CO + H2O -> CO2 + H2

Steam reforming

HC + H2O -> CO2 + H2

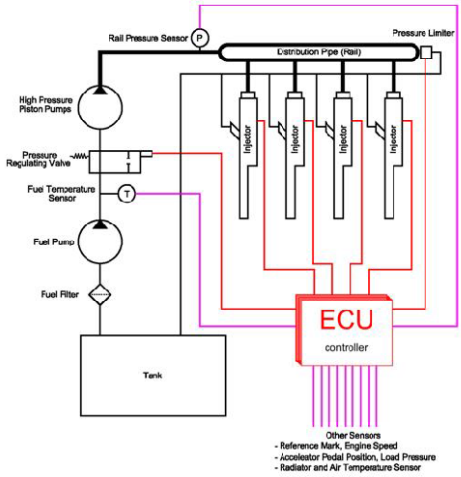




Replacement:

1) Replacement of CRDI: -

CRDI features a high-pressure fuel rail feeding individual solenoid valves. These are used to inject diesel into the combustion chambers of diesel engines with the required injection pressure, but the same pressure is not suited to inject CNG into the combustion chamber. So by replacing the CRDI with gas injectors, the suitable injection pressure can be maintained. The fuel is sprayed by the fuel injectors into intake port at system pressure. They inject the precise metering of the quantity of fuel required by engine. The high-pressure natural gas from the gas cylinder is first pass through the gas pressure regulator to reduce the pressure in the range of 5 to 6 bar.



2) Replacement of Glow Plug: -

In a diesel engine glow plug is used near the injection port in the combustion chamber to provide the sufficient temperature required for the ignition. Whereas spark plugs are used in CNG engines to ignite the fuel air mixture. The Cetane number of CNG is far less that the cetane number of diesel, the higher the cetane number the, easier and faster the auto ignition will occur. So, replacing the glow plug with spark plug and making necessary modifications in the cylinder head is essential.

3) Fuel injection pump

An Injection Pump is a device that pumps diesel (as the fuel) into the cylinders of a diesel engine.

Traditionally, the injection pump is driven indirectly from the crankshaft by gears, chains or a toothed belt (often the timing belt) that also drives the camshaft. It rotates at half crankshaft speed in a conventional four stroke diesel engine. Its timing is such that the fuel is injected only very slightly before the top dead centre of that cylinder's compression stroke. It is also common for the pump belt on gasoline engines to be driven directly from the camshaft. In some systems, injection pressures can be as high as 200 MPa (30,000 PSI).

Baseline Engine Specification

ISC8.3 for Medium-Duty Truck (EPA 2010)

Specifications

Advertised Horsepower	260-350 hp
Peak Torque	660-1000 lb-ft
Governed Speed	2200 rpm
Clutch Engagement Torque	500 lb-ft
Number of Cylinders	6
Oil System Capacity	6.3 U.S. gallons
System Weight	1,830 lb
Engine (Dry)	1,630 lb
Aftertreatment System*	200 lb

Diesel Combustion

Diesel fuel is a mix of higher-order hydrocarbon molecules (i.e. mainly containing Carbon and Hydrogen with number of nine or more carbon atoms). These hydrocarbons are classified as saturated (CnH2n+2) and unsaturated (CnH2n and CnH2n-2). The range of the mixed molecules is between C10H20 to C15H28, but the dominant molecule is C12H23, and that is what the diesel fuel is usually chemically formulated with.The combustion is then can be easily written as a chemical equation of the diesel with oxygen (O2) or air (O2+3.76 N2). The balance is done accordingly based on either the assumption of complete combustion or a realized percentage of incomplete combustion components (CO and/or fuel molecules are not burned). Let's presume a complete combustion case with Oxygen only; the equation is supposed to be like this:

4 C12H23 +71 O2 –> 48 CO2 + 46 H2O

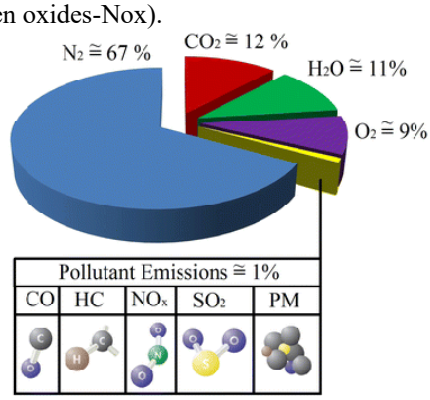
CNG Combustion

CNG is compressed natural gas. Natural gas is basically methane (CH4). In combustion, hydrocarbon is burnt in excess of air to form carbon dioxide and water. The Combustion process consists of a reaction between methane and oxygen. When this reaction takes place, the result is carbon dioxide (CO_2), water (H_2O), and a great deal of energy.

$CH_4[g] + 2\ O_2[g] \rightarrow CO_2[g] + 2\ H_2O[l] + 891$ kJ

Emissions produced by Diesel Engine

Diesel engines have high efficiency, durability, and reliability together with their low-operating cost. In addition to the widespread use of these engines with many advantages, they play an important role in environmental pollution problems worldwide. Diesel engines are considered as one of the largest contributors to environmental pollution caused by exhaust emissions, and they are responsible for several health problems as well. Many policies have been imposed by Cummins worldwide in recent years to reduce negative effects of diesel engine emissions on human health and environment. Many Cummins researches have been carried out on both diesel exhaust pollutant emissions and after treatment emission control technologies. In this paper, the emissions from diesel engines and their control systems are reviewed. The four main pollutant emissions from diesel engines (carbon monoxide-CO, hydrocarbons-HC, particulate matter-PM and nitrogen oxides-Nox).

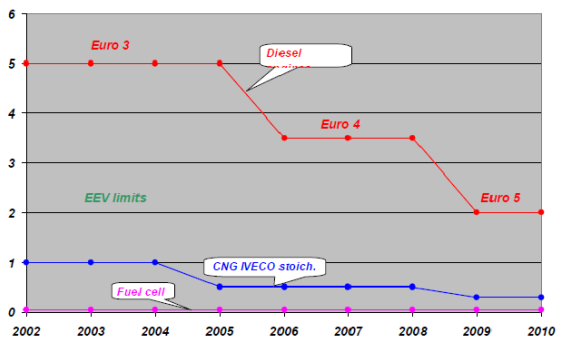


Emissions produced by CNG Engines

Compared with vehicles fuelled with conventional diesel engine, the compressed natural gas vehicles can produce significantly lower amounts of harmful emissions such as nitrogen oxides, particulate matter, and toxic and carcinogenic pollutants as well as the greenhouse gas carbon dioxide. Transit buses in Delhi equipped with the model year 2014 CNG engines

produced 49% lower nitrogen oxides emissions and 84% lower particulate matter emissions versus transit buses equipped with the model year 2014 diesel engines. Nitrogen oxides and particulate matter are the primary emissions of concern for heavy-duty vehicles. In a study of CNG and diesel Indian delivery trucks, CNG trucks produced 75% lower carbon monoxide emissions, 49% lower nitrogen oxides emissions, and 95% lower particulate matter emissions than diesel trucks of similar age. The Indian Protection Agency calculated the potential benefits of CNG versus diesel based on the inherently cleaner-burning characteristics of compressed natural gas, summarized in Clean Alternative Fuels.

- Produce half the particulate matter of average diesel vehicles
- Significantly reduced carbon monoxide emissions
- Reduced nitrogen oxide and volatile organic hydrocarbon emissions by 50% or more
- Potentially reduced carbon dioxide emissions by 25% depending on the source of the natural gas
- Drastically reduction of toxic and carcinogenic pollutants



CONCLUSION

On average the reduction of CO, CO2 and HC emission are 20-98%, 8-20%, and 40-87% respectively by CNG, as compared to the existing Cummins diesel engine. Natural Gas (CNG) represents almost a 50% savings over petroleum products such as gasoline and diesel fuel. Over the last decade, the average cost per gallon of gasoline in the United States has risen approximately 140%. In 2004, the average price per gallon of gasoline was $1.50, today the average price is around $3.60, and the costs are expected to continue to rise. In a very competitive economy, there is better time to look for alternative ways to fuel Cummins powered vehicles. The modifications in the engine were carried out theoretically and the compression ratio is successfully reduced to maintain in the range of 9:1 and 13:1. The emissions from the engine are controlled with the help of the three-way catalytic converter. After converting the Cummins diesel engine to CNG powered engines, both the manufacturing cost of the engine and the engine weight reduces, which directly gives profit to both to the manufacturer and its customers. As converting the diesel engine to CNG the weight of the engine decreases which increases the fuel efficiency of the engine or we can say decreases the emissions from the commercial vehicles. As in the coming future the amount of petrol and diesel available is going to decrease due to its excessive use and on present there cost per litre is very high, therefore by using the landfill gasses which decrease the cost of CNG to about Rs. 15/- per lit is an effective way. The land fill are those which are obtained from landfills by decomposing the inorganic and organic waste having large amount of methane gas which is then highly compressed to a smaller volume and fill in the CNG cylinders and can be used in the CNG diesel engines. Also after converting Cummins commercial vehicle diesel engine to CNG engine the company can improve its business market as today the amount of CNG is approx Rs 40/- per lit , therefore having lower cost as compared to diesel and gasoline people will always prefer to buy low cost CNG diesel engines. Also as the CNG gas is a eco friendly gas and causes very low amount of pollution therefore the company will get full support in view of business from the Organizations of pollution world wide.

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