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Conversion of Diesel Engine to CNG Engine and Emission Control

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Abstract: ***This paper presents the conversion of a Diesel engine to CNG engine with certain modifications in the engine such as replacing CRDI with gas injectors to maintain the injection pressure, modifying the inlet port and piston crown geometry to covert the swirl motion to tumble motion in the combustion chamber. In this paper, it is shown that with the altering of piston crown geometry and gasket thickness we can maintain the compression ratio in the range of 9:1 and 13:1. We have introduced Three-way catalytic convertor to reduce the emissions from the exhaust. To perform all these modifications, we have taken Tata Safari DiCOR as our baseline engine.***

Keywords: Conversion, Diesel engine, CNG engine, Three-Way Catalytic convertor**,** Compression Ratio.

1. Introduction

With emerging stringent pollution legislations and limited availability of liquid fossil fuels, demand for improving fuel efficiency and reduction of harmful emissions has become the most important job for the present engine researchers. Diesel engine has higher thermal efficiency; however, the emission of NOx and particulate matters remain a major concern. In recent years, direct injection gasoline engine has emerged to fulfill the need of improve fuel economy but still suffers from the problem of harmful PM emissions [1, 2]. With rising number of cars and decreasing of oil resources, it seems that the use of alternative fuels is inevitable in the future. To meet the required, demand the alternative fuels used in gasoline and diesel engines are becoming the subjects of interest today [3]. When evaluating different alternative fuels one must consider many aspects Adequacy of fuel supply, Process efficiency, Ease of transport and safety of storage, Modifications needed in the distribution/refueling network in the vehicle, Fuel compatibility with vehicle engine (power, emissions, ease of use, and durability of engine) [4]. However, CNG has some advantages compared to gasoline and diesel from an environmental perspective. It is a cleaner fuel than either gasoline or diesel as far as emissions are concerned. Compressed natural gas is an environmentally clean alternative to those fuels [5, 6].

2. Properties of CNG as compared to Diesel

Table 1: Comparison between Diesel and CNG [7]

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

The CO_2 emissions are lower for CNG engine when compared to diesel engine as shown in Table 1. The hydrogen content is more in case of CNG which increases its flammability.

3. Modifications

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

3.1 Modification of inlet port

Swirl motion is necessary in case of CI engines as it needs to mix with compressed air inside the combustion chamber, where as in case of SI engines the tumble motion is to be provided as it enters the combustion chamber mixed with air [8]. Hence, we are going to replace the helical inlet port with tangential inlet by machining to convert the swirl motion into tumble. The swirl and tumble motion is created in the cylinder as depicted in the Figure 1**.**

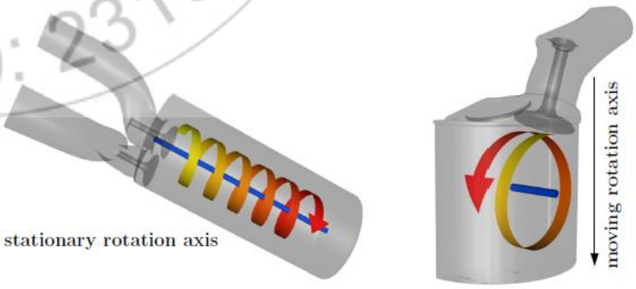

Figure 1: (Left) Stable, circulating flow pattern in a diesel engine designated as swirl motion, with the cylinder axis as the axis of rotation. The flow enters tangentially through the intake ports. (Right) Transient tumble motion in a gas engine. The axis of motion moves as the cylinder expands and stays halfway between the top cylinder wall and the piston head at the bottom (not shown) [8].

3.2 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 petrol engines to ignite the fuel air mixture. From Table 1 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 [9]. Hence, we are replacing the glow plug with spark plug by making necessary modifications in the cylinder head.

3.3 Replacement of CRDI

Basically, CRDI are used in diesel engines to inject the diesel into the combustion chamber with the required injection pressure, but this pressure is not suitable to inject CNG into the combustion chamber. Hence by the replacement of CRDI with gas injectors we can maintain the suitable injection pressure. The fuel injector sprays the fuel 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. Then gas is supplied into engine via gas injector [7].

4. Reduction of Compression Ratio

The compression ratio can be reduced by three different methods, which are listed below.

- Modifying the piston groove or bowl
- Modifying the length of the connecting rod
- Insertion of plate [Thicker gasket] onto the piston

The first method is usually constructed by milling the piston head to create a recessed bowl shape. The size of the bowl depends on the size of the piston. This method is chosen to reduce the compression ratio. We should remove a volume of 9200 mm^3 to reduce the compression ratio.

The second method is to reduce the length of the connecting rod. However, this method is very costly and complicated to be constructed. Improper design will cause vibration and thermal stress to build up in the piston.

The last method is chosen for the design of the piston in the combustion chamber to reduce the compression ratio. A plate with a thickness 2mm is added between the piston head and the cylinder block and act as a seal between the engine block and the piston head. The shape of the plate will follow the shape of the top of the piston head. It is chosen because of its lower construction cost and easier to be built compared to the other two methods explained earlier. Besides that, the design is much simpler and requires a simple calculation.

Table 2: Baseline engine Specification

Model	TATA SAFARI DICOR 2.2 VTT
Type	Water Cooled, Direct Injection, Common Rail, Turbocharged, Intercooled Diesel Engine
NO. of cylinders	4 inline
Bore/Stroke	85mm*96mm
Capacity	2179cc
Max. Engine Output	103kw @ 4000rpm
Max. Torque	320Nm(32mKg) at 1700-2700rpm
Compression Ratio	17.2:1

Considering the engine with specifications from Table 2, in this paper we are reducing the compression ratio from 17.2:1 to 10.806:1 by increasing gasket thickness and by milling the piston crown to create a bowl shape which also favors in the creation of tumble motion. Bowl shape piston geometry helps in increase of squish area and proper mixing of CNG with air. [7]

4.1 Calculations (for one cylinder)

$$Swept\ Volume, v_s = \frac{\pi \times b^2 \times s}{4}$$

$$= \frac{\pi}{4} \times 85 \times 85 \times 96$$

$$= 544752.166 mm^3$$

$$Clerance\ volume, v_c = \frac{\pi \times b^2 \times h}{4}$$

$$\text{Compression Ratio, CR} = \frac{v_s + v_c}{v_c}$$

From Table 2, we have

$$CR = 17.2$$

$$17.2 = \frac{v_s}{v_c} + 1$$

$$\frac{v_s}{v_c} = 16.2$$

$$v_c = \frac{v_s}{16.2}$$

$$= \frac{54475 2.166}{16.2}$$

$$= 33626.677 mm^3$$

Let us consider that the clearance volume obtained by milling bowl shape over the piston crown to be $v_{crown} = 9200 mm^3$.

The clearance volume obtained by increasing the gasket thickness, $v_{gasket} = \pi \times r^2 \times s$

$$= \pi \times 45^2 \times 2$$

$v_{gasket} = 12723.45 mm^3$

The new compression ratio obtained after the milling of bowl shape in piston crown and increasing the gasket thickness,

$$CR = \frac{v_s + v_c + v_{gasket} + v_{crown}}{v_c + v_{gasket} + v_{crown}}$$

$$CR = \frac{544752.166 + 33626.677 + 12723.45 + 92000}{33626.677 + 12723.45 + 92000}$$

$$= \frac{600302.293}{555 50.127}$$

New CR = 10.806:1

With the above demonstration, it is shown that with altering of crown geometry and gasket thickness we can control the compression ratio between 9:1 to13:1 [9].

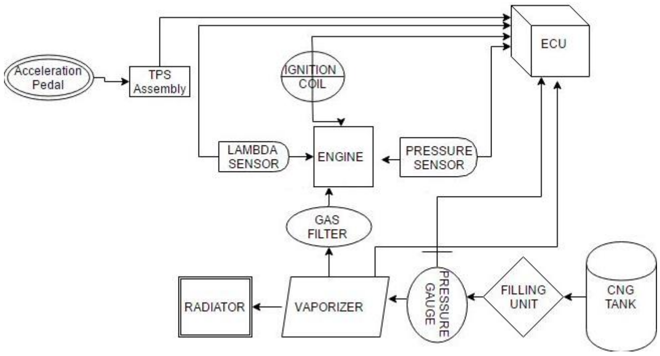

Figure 1: Block diagram of a CNG vehicle

5. Emission Control

Air pollution generated from mobile sources such as automobiles contributes major air quality problems in rural as well as urban and industrialized areas in both developed and developing countries. About 50 million cars are produced every year and over 700 million cars are used worldwide. Vehicle population is projected to grow close to 1300 million by the year 2030 [10]. The emissions of a CNG engine comprises of NOx, NMHC, PM, CO. [11]

5.1 Introducing Three-Way Catalytic Convertor (TWC)

TWCs have the advantage of performing the oxidation of carbon monoxide (CO), hydrocarbons (HC) and the reduction of nitrogen oxides (NO_x) simultaneously. Noble metals are usually used as the active phase in TWCs. Pd catalysts are especially attractive since Pd is by far the cheapest noble metal in the market and has better selectivity and activity for hydrocarbons. Rhodium the other essential constituent of three-way catalysts is widely recognized as the most efficient catalyst for promoting the reduction of NO to N_2. The TWCs performance in the emission control can be affected by operating the catalyst at elevated temperatures (> 600 °C). Reactions occurring on the automotive exhaust catalysts are very complex as listed below. The major reactions are the oxidation of CO and HC and the reduction of NO_x. Also, water gas shift and steam reforming reaction occur. Intermediate products such as N_2O and NO_2 are also found. The NO_x storage concept is based on incorporation of a storage component into the three-way catalyst (TWCs) to store NO_x during lean conditions for a time of minutes [12].

5.1.1. Reactions in Catalytic Converter [12]

Oxidation

$2CO + O_2 \rightarrow 2CO_2$

$HC + O_2 \rightarrow CO_2 + H_2O$

Reduction

$2CO + 2NO \rightarrow 2CO_2 + N_2$

$HC + NO \rightarrow CO_2 + H_2O + N_2$

$2H_2 + 2NO \rightarrow 2H_2O + N_2$

Water Gas Shift

$CO + H_2O \rightarrow CO_2 + H_2$

Steam reforming

$HC + H_2O \rightarrow CO_2 + H_2$

6. Conclusion

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 no better time to look for alternative ways to fuel our vehicles [13]. 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 three-way catalytic converter.

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