

# A Technical Review of Optimization Natural Gas SI Engine with Employing EGR Rate

Vijay C Patel<sup>1</sup> Bhavik B. Hirapara<sup>2</sup> Prof. M A Shaikh<sup>3</sup>

<sup>1,2</sup>P.G Student <sup>3</sup>Assistant Professor

<sup>1,2</sup>Department of Mechanical Engineering <sup>3</sup>Department of Automobile Engineering

<sup>1,2,3</sup>L. D. College of Engineering, Ahmedabad

**Abstract**— The research on alternative fuels for internal combustion engine has become essential due to depletion of petroleum products and its major contribution for pollutants, where Natural gas is one of the most promising fuel alternatives for the future. Compressed natural gas (CNG) has long been used in stationary engine as well as a transport engine fuel. There are various methods which use the compressed natural gas in IC engine with little modification. It is revealed that the performance characteristics are lower while the emission characteristics of CO, CO<sub>2</sub> HC are better for Natural gas compared to petrol or diesel. The compression ratio has a large influence on the engine performance, combustion, and emissions. However, the brake thermal efficiency is increased with a compression ratio up to a limit of 12 at high engine loads. The maximum cylinder gas pressure is increased with increase in the compression ratio. The exhaust hydrocarbon (HC) and carbon monoxide emissions decreased with increase in the compression ratio, while the exhaust nitrogen oxide (NO<sub>x</sub>) emission is increased with increase in the compression ratio. In this study, a natural gas spark-ignition engine employing cooled exhaust gas recirculation (EGR) strategy in a high pressure inlet condition was optimized. Both engine compression ratio and start of combustion timing were optimized in order to obtain the lowest fuel consumption accompanied with high power and low emissions. It was found that cooled EGR can significantly reduce NO<sub>x</sub> emission at high compression ratio conditions.

**Key words:** Alternative Fuel, CNG, SI Engine, Compression ratio, Performance, Exhaust Emission, EGR

## I. INTRODUCTION

The energy sector in India has been receiving high priority in the planning process. The growth of an economy, with its global competitiveness, hinges on the availability of cost-effective and environmentally benign energy sources. Even the level of economic development has been observed to be reliant on the energy demand. In the recent years, the government has rightly recognized the energy security concerns of the nation and more importance is being placed on energy independence.<sup>[1]</sup>

Natural gas being the cost-effective and environmentally benign energy source suffices to be the fuel of 21st century. Investing in the natural gas industry is not only a smart business decision, but also an essential environmental choice and expanded use and export of natural gas technologies offers significant macroeconomic benefits.

As, India prepares to be a developed nation it needs to take note of environmental issues with the economic development. Natural Gas being cleanest, most efficient fossil fuel provides greater environmental security. The increased use of natural gas could help the nation meet its

environmental, economic and national security goals. Increasingly stringent environmental regulations will spur switch to cleaner burning natural gas. Using more natural gas will help ease a number of environmental concerns – greenhouse gas emissions, acid rain, smog, solid waste and water pollution.<sup>[2]</sup>

## II. CNG AS AN ALTERNATIVE FUEL

CNG (Compressed Natural Gas) is a mixture of hydrocarbon consisting of approximately 80 to 90 % methane in gaseous form. Due to its low energy density, it is compressed to a pressure of 200 to 250 kg/cm<sup>2</sup> (to enhance the vehicle on-board storage in a cylinder) and hence the name Compressed Natural Gas. Natural Gas is colourless, odourless, non-toxic but inflammable lighter than air. CNG is not a liquid fuel and is not the same as LPG (Liquefied Petroleum Gas) which consists of Propane and Butane in liquid form. Natural Gas is normally transported from the source up to the users by pipelines. Besides widespread industrial use as a clean fuel for applications ranging from electric power generation, feedstock for fertilizer plants to furnaces etc., it is becoming a fuel of choice in domestic and commercial sectors.<sup>[3]</sup>

### A. Benefits of CNG as an Alternative Fuel:

#### 1) Economics:

On an energy-equivalent basis, Natural Gas costs less than petrol and diesel. Natural gas is a clean burning fuel that reduces maintenance such as extended interval of oil change and standard spark plugs last longer. Natural Gas, unlike liquid fuels, cannot be siphoned off from a vehicle.

#### 2) Emissions:

Natural Gas is the cleanest burning alternative fuel. Exhaust emissions from CNG fuels are much lower than those from petrol/diesel powered engines. Reduction in IDC mass emission with CNG retrofitted as certified ARAI/VRDE<sup>[3]</sup>.

#### 3) Greenhouse Gases:

Per unit of energy, natural gas contains less carbon than any other fossil fuel, and thus produces lower level of CO<sub>2</sub> emissions per vehicle km travelled. While CNG vehicles do emit methane another principal greenhouse gas, any slight increase in methane emissions would be more than offset by a substantial reduction in CO<sub>2</sub> emissions compared to other fuels.

CNG vehicles also emit very low levels of carbon monoxide and volatile organic compounds. Although these two gases are not greenhouse gases, they play an important role in helping to break down methane and some other greenhouse gases in the atmosphere, and thus increase the global rate of methane decomposition.

#### 4) Safety:

Compressed natural gas, unlike gasoline, dissipates into the atmosphere in the event of an accident. Petrol

pools/accumulates on the ground which creates a fire hazard. The fuel storage cylinders used in CNG vehicles are much stronger than petrol fuel tanks. The design of CNG cylinders are subjected to a number of “severe abuse” tests, such as heat and pressure extremes, gunfire, dynamite, collisions and fire.

The high ignition temperature and limited flammability range make accidental ignition or combustion of natural gas unlikely. Natural gas is not toxic or corrosive and will not contaminate ground water.

### B. Use of CNG in IC Engine <sup>[4]</sup>

Many investigations were carried out in order to use of CNG as an alternative fuel in an engine could be divided into three main types according to their fuel usage and they are: Dual Fuel, Bi-Fuel, and Dedicated/Mono Fuel.

#### 1) Dual Fuel:

This is a development from conventional diesel engine. In this type of engine, both diesel and natural gas were introduced into the engine cylinders during compression. As natural gas will not ignite under compression alone, the diesel is required to act ignite the gas/air mixture. When natural gas refuelling points are not available, the engine can revert to conventional operation.

#### 2) Bi-Fuel:

This type of engine development is based on the conventional petrol engines where the fuel system has been modified to operate either petrol or gas. When natural gas refuelling is not available, normal running on petrol is possible.

#### 3) Dedicated/Single Fuel:

This is a specialized engine type, which has been designed and optimized to operate only on natural gas. This enables the characteristics of natural gas to be fully exploited without the need to compromise in design to enable other fuel usage.

### C. Properties of CNG as an Automotive Fuel:

#### 1) Combustion Related Properties of Gasoline & CNG <sup>[4]</sup>

Properties	Gasoline	CNG
C-Content (% weight)	85-88	75
H-Content (% weight)	12-15	25
Density kg/m <sup>3</sup> (Ambient, 25°C)	730	0.66
Vapour density, (compared to air)	Heavier	Lighter
Boiling point (Temp °C)	27-225	-162
Flame propagation (Speed m/s)	0.5	0.43
Motor octane number	80-90	120
Research octane number	92-98	120
Molar mass (kg/mol)	110	16.04
Stoichiometric air-fuel ratio	14.6	17.3
Stoichiometric mixture density (kg/m <sup>3</sup> )	1.38	1.24
Lower heating value (MJ/kg)	43.6	47.377
Lower heating value of stoichiometric mixture(MJ/kg)	2.83	2.72
Flammability limits (vol% in air)	1.3-7.1	5-15
Spontaneous ignition temperature (°C)	257	540

Table 1: Combustion related properties of gasoline & CNG <sup>[4]</sup>

### III. EGR (EXHAUST GAS RECIRCULATION) SYSTEM

A widely adopted route to reduce NO<sub>x</sub> emissions is Exhaust Gas Recirculation (EGR). This involves recirculating a controllable proportion of the engine's exhaust back into the intake air. A valve is usually used to control the flow of gas, and the valve may be closed completely if required. The substitution of burnt gas (which takes no further part in combustion) for oxygen rich air reduces the proportion of the cylinder content available for combustion. This causes a correspondingly lower heat release and peak cylinder temperature, and reduces the formation of NO<sub>x</sub>.

The exhaust gas acts as an inert gas in the combustion chamber, it does not participate in the combustion reaction. This leads to a reduction of the combustion temperature by different effects. The fuel molecules need more time to find an oxygen molecule to react with, as there are inert molecules around. This slows down the combustion speed and thus reduces the peak combustion temperature, as the same amount of energy is released over a longer period of time.

#### A. Advantages of EGR:

- Reduced NO<sub>x</sub>.
- Potential reduction of throttling losses on spark ignition engines at part load.
- Improved engine life through reduced cylinder temperatures.

#### B. Disadvantages of EGR:

Since EGR reduces the available oxygen in the cylinder, the production of particulates is increased when EGR is applied. This has traditionally been a problem with diesel engines, where the trade-off between NO<sub>x</sub> and particulates is a familiar one to calibrators.

The deliberate reduction of the oxygen available in the cylinder will reduce the peak power available from the engine. For this reason the EGR is usually shut off when full power is demanded, so the EGR approach to controlling NO<sub>x</sub> fails in this situation.

#### C. EGR in spark-Ignited Engines:

The exhaust gas, added to the fuel, oxygen, and combustion products, increases the specific heat capacity of the cylinder contents, which lowers the adiabatic flame temperature.

In a typical automotive spark-ignited (SI) engine, 5% to 15% of the exhaust gas is routed back to the intake as EGR. The maximum quantity is limited by the need of the mixture to sustain a continuous flame front during the combustion event; excessive EGR in poorly set up applications can cause misfires and partial burns. Although EGR does measurably slow combustion, this can largely be compensated for by advancing spark timing. The impact of EGR on engine efficiency largely depends on the specific engine design, and sometimes leads to a compromise between efficiency and NO<sub>x</sub> emissions. A properly operating EGR can theoretically increase the efficiency of gasoline engines via several mechanisms:

- Reduced throttling losses.
- Reduced heat rejection.
- Reduced chemical dissociation.
- Reduced specific heat ratio.

#### IV. PERFORMANCE AND EMISSION CHARACTERISTICS

B.B.Ghosh, P.K.Bose, Ranajitkumar Chakrabarti and Kalyankumar Das (2003)<sup>[7]</sup>: Laboratory work at IIT Delhi in developing CNG fuelled spark ignition engine, results of the work have shown that maximum level of carbon monoxide emissions was 0.325 %, NOX emission concentrations achieve the peak value around an equivalence ratio of 1.1, whereas if it reduces the leaner and richer mixtures, Result of the work showed an improvement in the performance and emission characteristics of the CNG fuelled engine using a specially designed Electro Mechanical Fuel (EMF) system. Results showed that the light load lean-limit misfire region of natural gas begins at an air fuel ratio between 140-150 % of stoichiometric. Changes in ignition timing significantly influenced emission of nitrogen oxides and hydrocarbons but had little effect on CO emission. It is the proper time to go for dedicated CNG engines which can be operated at higher compression ratio in order of 14 to have very good engine efficiency.

M.K. Hassan, I. Aris, S. Mahmud and R. Sidek (2010)<sup>[8]</sup>: The objectives of the experiments are to study the influence of injection and ignition towards brake torque, brake power and emission at maximum brake torque (MBT) interval. Most of researched on CNGDI engine are focused on diesel engine cycle but diesel engines emit high emission especially particulate matter. The diesel engine uses compression heating for ignition while the gasoline engine uses spark plug for ignition. The only car manufacturer that proposed and developed CNGDI diesel cycle engine is ISUZU. They developed CNGDI with glow spark plug ignition with hot surface system mounted on cylinder head, which will improve engine efficiency.

Ignition angle was varied between 24° BTDC up to 36° BTDC. The torque and power trend indicate an arc with a gradient after 29° BTDC. Thus, it is a sign of that maximum brake torque (MBT) occurs at 29° BTDC. The timing which is advanced or retarded from 29° BTDC gives lower torque. If an engine is to retard the ignition timing 1-3 degrees from the MBT avoid the engine damage. For example, in this particular exercise, the best ignition timing laid between 25° BTDC to 27° BTDC. Higher NO<sub>x</sub> occurred at more advanced ignition timing. Ignition timing has not shown much effect on the HC but proper ignition timing must be set, the HC concentrated is becoming lower. The lowest CO concentration occurs at late injection 300° CA at 25° BTDC of ignition timing. It is clearly shows that spark ignition timing is one most influential factor to the CO sources, thus is strongly related to the mixture of air-fuel Ratio. The more advanced ignition angle implemented, the lesser CO emission formed. The lowest percentage of CO is 0.011% occurs during the 30° BTDC.

R. Chandra, V.K. Vijay, P.M.V. Subbarao, T.K. Khura (2011)<sup>[9]</sup>: carried out the Performance evaluation of a constant speed IC engine on CNG, methane enriched biogas and biogas. On a 5.9 kW stationary diesel engine which was converted into spark ignition mode and run on compressed natural gas (CNG), methane enriched biogas (Bio- CNG) and biogas produced from bio methanation of jatropha and pongamia oil seed cakes. The performance of the engine with 12.65 compression ratio was evaluated at 30°, 35° and 40° ignition advance of TDC. They observed that power losses due to conversion of diesel engine into spark ignition

engine. The engine test results obtained in terms of brake power output, specific gas consumption and thermal efficiency on methane enriched biogas containing 95% methane has showed that the engine performance is almost similar to that of compressed natural gas. Thus, the gaseous fuel methane enriched biogas is as good as natural gas.

E. Ramjee and K. Vijaya Kumar Reddy (2011)<sup>[10]</sup>: worked on experimental investigations on a single cylinder 4-stroke air cooled type Bajaj-Kawasaki petrol engine to compute performance and exhaust emissions of the test engine. All tests have been carried out under steady state conditions for both petrol and CNG fuels and the results have been compared. They found that for all range of speeds, the volumetric efficiency is reduced and various between 10-14%; Except thermal efficiency the other performance parameters viz BMEP, Torque, Power and BSFC are decreased for CNG fuelled engine compared to petrol fuelled engine; Except NO<sub>x</sub> the other emission characteristics such as CO, CO<sub>2</sub>, and HC are decreased.

Amr Ibrahim, Saiful Bari, (2010)<sup>[11]</sup>: EGR in a supercharged natural gas SI engine. The use of lean burn technology in spark-ignition engines has been dominant; however, lean burn technique can not economically satisfy the increasingly restricted future emission standards. Consequently, alternative combustion techniques need to be investigated and developed. In this paper, the use of the

Stoichiometric air-fuel mixture with exhaust gas recirculation (EGR) technique in a spark-ignition natural gas engine was experimentally investigated. Engine performance and NO emissions were studied for both atmospheric and supercharged inlet conditions. It was found that the use of EGR has a significant effect on NO emissions. NO emissions decreased by about 50% when EGR dilution increased from zero with an inlet pressure of 101 kPa to close to the misfire limit with an inlet pressure of 113 kPa. In addition, the use of EGR effectively suppressed abnormal combustion which occurred at higher inlet pressure. The use of higher inlet pressure in the presence of EGR improved engine performance significantly. Engine brake power increased by about 20% and engine fuel consumption decreased by about 7% while

NO emissions decreased by about 12% when 5% of EGR dilution was employed with an inlet pressure of 113 kPa compared to using undiluted stoichiometric inlet mixture with an inlet pressure of 101 kPa.

Ibrahim A, Bari S, (2008)<sup>[12]</sup>: In this paper, the use of EGR strategy was experimentally investigated in a natural gas spark-ignition engine. Engine performance and NO emissions were studied for both atmospheric and supercharged inlet conditions and the following conclusions have been obtained:

The increase of the percentage of EGR dilution in the inlet mixture decreases the oxygen concentration, and consequently, it decreases the combustion rate significantly. For instance, the increase of EGR dilution from 0% to 10% at atmospheric inlet conditions increased the total combustion duration from about 74° to 95°. The increase of EGR dilution in the inlet mixture decreases both the maximum cylinder temperature and oxygen concentration which leads to a significant reduction in NO emissions. For instance, NO emissions decreased by about 50% when EGR dilution increased from zero with an inlet pressure of 101

kPa to close to the misfire limit with an inlet pressure of 113 kPa.

The engine tolerance to EGR increases with the increase of inlet pressure. The maximum tolerable EGR dilution limit increased from about 10% to 12% when the inlet pressure increased from 101 to 113 kPa. Engine performance can be significantly improved when the EGR dilution strategy is employed at higher inlet pressure. Engine brake power increased by about 20% and engine fuel consumption decreased by about 7% while NO emissions decreased by about 12% when 5% of EGR dilution was employed with an inlet pressure of 113 kPa compared to using undiluted stoichiometric inlet mixture with an inlet pressure of 101 kPa.

#### V. CONCLUSION REMARKS

Optimized the parameter of CNG in ignition advance- 30° BTDC and higher CR- 12.4 is required for maximum power, maximum thermal efficiency, low brake specific fuel consumption and less emission.

When the engine run with the use of higher CR it gives higher Brake Power but it is lead to increasing the NOx emission and more fuel consumption.

So, Engine performance can be significantly improved when the EGR dilution strategy is employed at higher inlet pressure for Engine brake power increased and engine fuel consumption and NOx emissions decreased.

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