Effect Of Ignition Parameters For Enhancement Of Performance And Emissions Of A Four Stroke Single Cylinder SI Engine Fueled With CNG: A Technical Review

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***Abstract** - A* **review is given of the contemporary research on CNG fuelled Spark ignition engine. The emphasis is on light to medium duty engine research. We first describe CNG engine fundamentals by examining the engine specific properties of CNG Fuel. Here, it will be shown that due to lower volumetric efficiency and lean effect in CNG Fuelled SI engine, the maximum torque generated is diminished compared to gasoline fuelled engines. We showed that the torque reduction can be recovered and performance of CNG engine can be enhanced by modifying ignition system. Finally, we selected few ignition parameters that have to be optimized when Gasoline fuelled SI engine is made to run on CNG.**

Keywords – SI Engine, CNG Engine, Bi-Fuel Vehicles, Ignition system.

1. Introduction

The use of alternative fuels for engine is regarded as one of the major research areas for the age. Gaseous fuels in general are promising alternative fuels due to their economical costs, high octane numbers and lower polluting exhaust emissions. Natural gas is one of the major combustion fuels used throughout the country. The natural gas has different chemical and physical properties when compared to gasoline. Natural gas consists of a high percentage of methane and varying amounts of ethane, propane, butane, and inert (typically nitrogen, carbon dioxide, and helium). The potential for CNG fuelled Spark Ignition engines as less polluted and more efficient power plants for automobiles is now well established.

Natural gas can be compressed, so it can be stored and used as compressed natural gas (CNG). CNG requires a much larger volume to store the same mass of natural gas and the use of very high pressure on about 200 bars or 2,900 psi. Natural gas is safer than gasoline in many respects. The ignition temperature for natural gas is higher than gasoline and diesel fuel. Additionally, natural gas is lighter than air and will dissipate upward rapidly if a rupture occurs. Gasoline and diesel will pool on the ground, increasing the danger of fire. Compressed natural gas is non-toxic and will not contaminate groundwater if spilled. Advanced compressed natural gas engines guarantee considerable advantages over conventional gasoline and diesel engines. Compressed natural gas is a largely available form of fossil energy and therefore non-renewable. 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 considered to be an environmentally clean alternative to those fuels [2].

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. Natural Gas is the cleanest burning alternative fuel.

Exhaust emissions from CNG fuels are much lower than those from petrol/diesel powered engines. Per unit of energy, natural gas contains less carbon than any other fossil fuel, and thus produces lower level of CO_2 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_2 emissions compared to other fuels. 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.

2. CNG Engine Fundamentals

The high auto ignition temperature of CNG (540°C) means that CNG is more suitable as a fuel for spark ignition (SI) engines. Natural gas, commonly referred to as gas, is a gaseous fossil fuel consisting primarily of methane (CH4), the shortest and lightest hydrocarbon molecule. It is lighter than air, and so tend to dissipate.

Table 1: Combustion related properties of gasoline & CNG [3,4,5]

Properties	Gasoline	CNG
H-Content (%weight)	12-15	25
Density kg/m3 (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/m3)	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

2.1 Use of CNG in IC Engines

Almost any petrol vehicle can be converted to operate on CNG with special kit fitment. Vehicles with catalytic convertors can also be fitted with CNG kit without any difficulty as CNG does not contain lead.

Diesel Engines can also be converted on CNG, either by installing dual fuel kit or converting the existing into spark ignition engine. In the second type of diesel conversion existing diesel engine will become CNG engine.

2.1.1 Bi-Fuel Vehicles

A bi-fuel vehicle can run on either natural gas or petrol. With a flip of a switch mounted on a dashboard one can change from CNG to petrol mode and vice-versa. Many are designed to switch automatically to petrol when the natural gas fuel tank reaches empty or when rpm of the engine reaches to ascertain value. It has problems with low power output and combustion instability under lean-burn condition [8].

2.1.2 Dual-Fuel Vehicles

A vehicle that runs either on diesel fuel only, or diesel fuel and natural gas simultaneously is called Dual-Fuel vehicles. In a dual-fuel vehicle the combustion of the diesel fuel serves to ignite the natural gas. The mixture of CNG and air is drawn inside the engine cylinder by conventional manner and a jet of diesel is then sprayed inside the engine cylinder to initiate the ignition of the fuel. It needs Two Fuel Supply System and still has problem with high HC emissions [8].

2.1.3 Dedicated Vehicles

A dedicated CNG vehicle runs on natural gas only. Dedicated CNG vehicles can be petrol-fueled vehicles that have been converted to run on natural gas. Most dedicated CNG vehicles in India, however, are produced by conversion of SI engines into after-market retrofit conversion kits.

2.2 Performance and Emissions of a 4-stroke SI engine using CNG as a Fuel

Natural Gas has considerably higher Octane Number than petrol and has very low Cetane Number when compared with diesel fuel [5]. Hence it is more suitable for SI engine rather than CI engine [1]. An SI engine can be easily converted into dedicated CNG engine, while converting a CI engine into CNG engine is more complicated as an ignition system has to be added to initiate the ignition. Hence, a single cylinder four stroke SI engine is to be converted into CNG engine by retrofitted conversions.

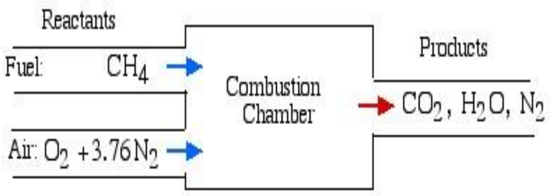
The combustion characteristics of natural gas is different from that of petrol, which eventually affects the engine performance. A Four stroke SI engine running on CNG has a lower volumetric efficiency as compared with Petrol fuelled engine. As Gaseous fuels displace more incoming air than liquid fuels, which are only partially evaporated in the intake system [9].

The exhaust gas temperature, piston crown, spark plug body, exhaust valve and cylinder head temperature in natural gas and gasoline fuelled engine was measured. The results showed that, at wide open throttle conditions and at stoichiometric fuel-air ratios, the temperature of combustion chamber for natural gas fuelling was lower than that for gasoline fuelling. The exhaust gas temperature was lower for natural gas operation than that for gasoline operation. The exhaust valve temperature with gasoline fuelling was higher than that with natural gas fuelling [11].

For all range of speeds, 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 NOx the other emission characteristics such as CO, CO_2, and HC are decreased [10].

2.3 Combustion Characteristics of CNG Fuelled SI Engine

CNG used in SI engine can be approximated by methane (CH_4). Consider the stoichiometric combustion of methane (CH_4) in atmospheric air. Equating the molar coefficients of the reactants and the products we obtain:



$$CH_4 + 2(O_2 + 3.76N_2) \Rightarrow CO_2 + 2H_2O + 7.52N_2$$

The minimum m amount of air which will allow the complete combustion of the fuel is called the Theoretical Air (also referred to as Stoichiometric Air). In this case the products do not contain any oxygen. If we supply less than theoretical air then the products could include carbon monoxide (CO), thus it is normal practice to supply more than theoretical air to prevent this occurrence. This Excess Air will result in oxygen appearing in the products.

The standard measure of the amount of air used in a combustion process is the Air-Fuel Ratio (AF), defined as follows:

$$AF = \frac{m_{air}}{m_{fuel}}$$

Thus considering only the reactants of the methane combustion with theoretical air presented above, we obtain [12]:

$$\underset{\text{fuel}}{CH_4} + \underset{\text{2 kmol air}}{2(O_2 + 3.76N_2)} \leftrightarrow \text{ Reactants}$$

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{2(4.76)\,[\text{kmol}]\ 29\left[{}^{kg}/_{kmol}\right]}{1\,[\text{kmol}]\ (12+4)\left[{}^{kg}/_{kmol}\right]}$$

$$AF = 17.3\,\frac{\text{kg - air}}{\text{kg - fuel}}$$

The chemically correct stoichiometric air-fuel ratio by mass for CNG is considered 17.3:1. As discussed earlier, the stoichiometric ratio of CNG is higher than Petrol (14.6) [5].This results into the lean burning of fuel in the SI engine when it is fuelled with CNG.

The lean burning of natural gas has the advantages of high efficiency, low NO_x emissions, thermal loading close to diesel operation and increased safety. The lean combustion results in loss of flame speed [4] and it can be observed in combustion variation from one cycle to the next. Non-optimal combustion phasing, partial burns and misfires cause cycle-to-cycle variation. Combustion phasing means that the spark timing is not properly adjusted to achieve maximum brake torque; partial burns occur when the flame speed is quenched before the whole mixture is ignited; misfires occur when the mixture is too diluted to be ignited by a spark plug [13].

Following steps can be taken to reduce the negative effects of lean combustion:

1) Spark timing can be further advanced to compensate for the effect of loss of flame speed which will result in less partial burns and cycle-to-cycle variation and maximum brake torque can be achieved.

2) As lean mixture requires high energy to ignite, high Intensity spark is to be produced to decrease the misfire that occurs due to the too diluted mixtures. To achieve that ignition system has to be modified.

3. Effect of Ignition Parameters on SI engine

Various parameters that affect the performance of the ignition system for SI engines are as under:

3.1 Ignition advance

The pressure versus spark timing curves are shown in the figure-1 shows that engine torque varies as spark timing is varied relative to TC. If the start of the combustion process is progressively advanced before TC, the compression stroke work transfer increases. If the end of the combustion process is progressively delayed by retarding the spark timing, the peak cylinder pressure occurs later in the expansion stroke and is reduced in magnitude. These changes reduce the expansion stroke work transfer from the cylinder gases to the piston. The optimum timing which gives the maximum brake torque, or MBT, occurs when the magnitudes of these two opposing trends just offset each other. Timing which is advanced or retarded from this optimum gives lower torque. The optimum spark timing will depend on the rate of flame development and propagation, the length of the flame travel path across the combustion chamber, and the details of the flame termination process after it reaches the wall.

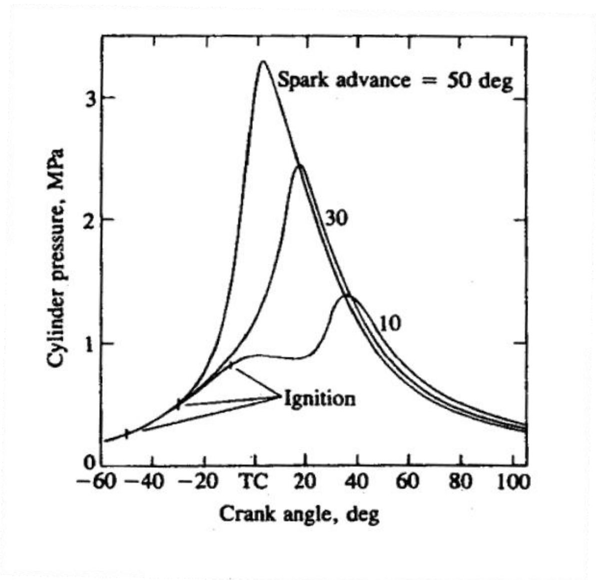


Figure-1 Cylinder pressure versus crank angle for over advanced spark timing (50°), MBT timing (30°) and retarded timing (10°) [1]

Figure-2 shows the effect of variations in spark timing on brake torque for a typical Spark-ignition engine. The maximum is quite flat.

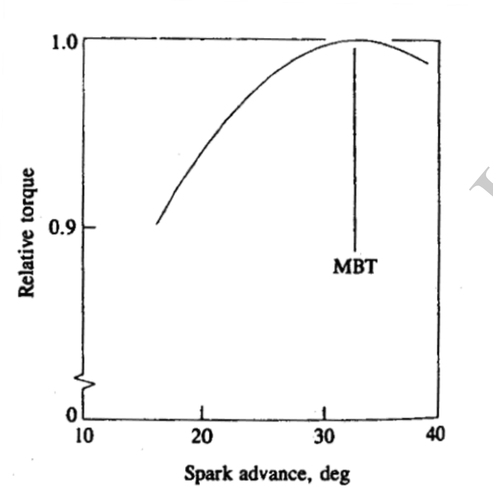


Figure-2 Effect of spark advance on brake torque at constant speed and air-Fuel ratio, at wide open throttle [1]

CNG has lower flame speed when compared with petrol engine, hence the end of the combustion process is delayed and spark timing has to be further advanced for the better performance of the SI engine. For SI engine running on CNG, the spark timing has to be changed for maximum brake torque conditions [14].

3.2 Spark Plug electrode size

The reduction in size of spark plug electrode is the most basic and effective means of responding to high performance. However, a reduction in size also substantially reduces wear resistance. This causes maintenance problems. It has been extremely difficult to both reduce size and maintain wear resistance [15]. As the centre electrode diameter decrease the lean limit of the fuel increases. The effect of spark plug electrode size on lean limit of the engine is shown in the figure 3.

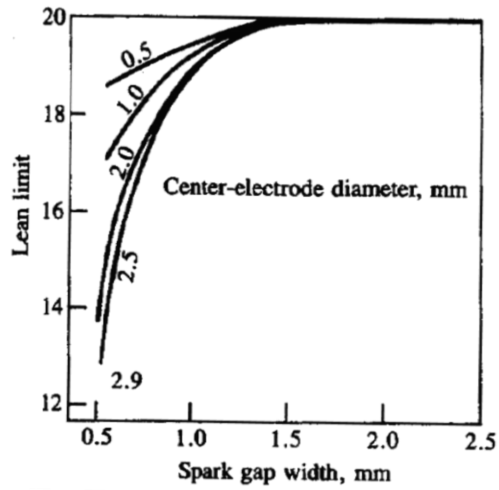


Figure-3 Effect of spark plug electrode diameter and plug gap on lean limit of the engine. Baseline conditions: 30mJ spark energy, 3.5mm projection, centre electrode diameter 2.5 mm, 40° BTC spark timing, 1600 rev/min, intake pressure 300mmHg[1].

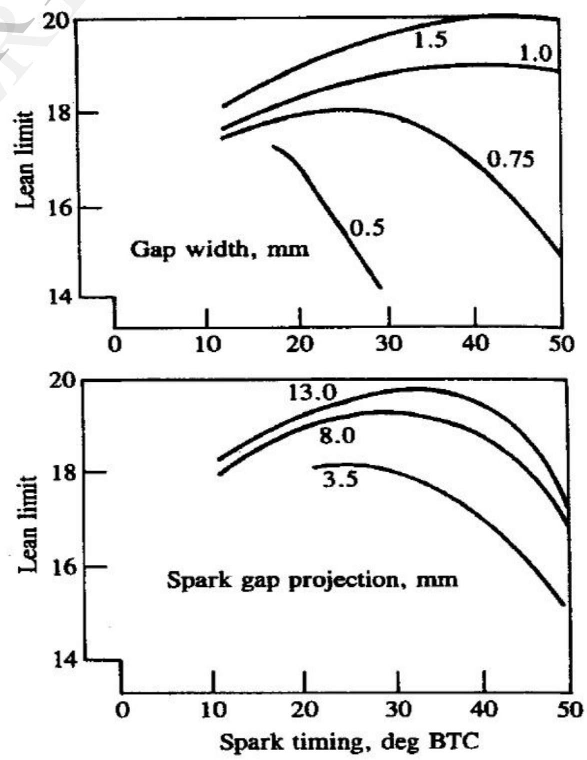


Figure-4 Effect of spark plug gap and spark timing on engine's lean stable operating limit [1]

3.3 Spark Gap Width and Spark Projection

There are many different designs of spark plugs. These use different geometry electrodes, =gap widths, and gap arrangements. The effects of the major plug electrode design features on the engine's stable lean operating limit are illustrated in Figure 3 and 4. Ignition system effects are important when misfire due to the quenching effect of the spark plug electrodes determines the stable operating limit. Thus, smaller spark plug centre-electrode diameters, larger electrode gap widths and higher electrode temperatures, all extend the lean stability limit to leaner mixtures for the more advanced spark timings and smaller gap widths. For spark Timing closer to TC and for larger gap widths, these data show the lean stability limit to be much less sensitive to plug geometry or spark energy.

For lean mixture combustion, the torque and efficiency of the engine increases with increase in spark plug gap and after certain value of gap it starts decreasing again [16]. For CNG fuelled SI engine this optimum spark plug gap has to be achieved.

As the flame speed of the CNG fuel is less compared with petrol the spark projection can be increased further so that flame propagation to the engine cylinder becomes fast. This results in less knocking and better performance and less emissions of the engine.

3.4 Spark Plug Intensity

Spark plug intensity depends upon the voltage supplied to the spark plug from the ignition system. The higher the voltage supplied the higher will be the energy available at the spark plug electrode. High breakdown voltage will result in better flame kernel growth [17]. This will result in improvement of the lean limit of the engine

For CNG fuelled engine, the spark plug intensity is to be increased to eliminate the problem of misfiring. Also, the high intensity spark will result in flame kernel increase.

4. Conclusion

Most of the CNG fuelled vehicles in India are aftermarket retrofitted conversions from the existing SI engine vehicles. These conversions don't include the modifications in Ignition system. As CNG has lean combustion effect on the SI engine ignition system has to be modified for the batter performance and to optimize the power loss and drivability problems caused by conversions.

Ignition system Parameters such as ignition timing, spark plug gap, spark plug intensity, spark plug design, spark plug projection is to be modified for the optimization of the ignition system in the CNG fuelled SI engine.

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