Optimization of Gasoline to CNG Engine Conversion using Computer aided Engine Simulation

Pankaj Rajput*, Shreya Singh**
*(Department of Mechanical and Aerospace Engineering, Polytechnic Institute of New York University, Brooklyn, NY 11201, USA)
**(Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA)

ABSTRACT

Among all the alternative fuels available in the market, CNG has so far proved to be the most promising. However, most of its use is limited to retrofitted engines, which has lead to improper utilization of CNG as a spark ignition fuel. This study focuses on efficient utilization of the high calorific value and other desirable properties of CNG by making slight design and operational changes. Performance of engine is studied using a computer aided engine simulation model that evaluates the performance of engine in a virtual working environment. Effect of various parameters on the engine operation is also studied and the valuable data collected in the process is used to alter the operational and design parameters of the engine. In this way engine is tuned for optimum utilization of CNG and its performance is enhanced as compared to the conventional CNG conversion kits.

Keywords - CNG, Engine Conversion, Engine Simulation, Parametric optimization, Well to Wheel.

I. INTRODUCTION

More than 99% of energy supply for modern day transportation in OECD countries comes from crude oil[1]. While there is an ever increasing demand for alternative fuels that can be economically viable and environment friendly, major alternative fuels, LPG(0.9%) and natural gas (0.05%)hold negligible shares[2].

The pollution that comes with this fossil energy consumption is recognized around the world and this has lead to implementation of stricter emission norms and an exponential increase in the number of Compressed Natural Gas (CNG) driven vehicles. Most of these automotive systems employ conventional conversion kits to run Gasoline engine on CNG. However, majority of these kits are incapable of tapping the potential of CNG as a spark ignition fuel[2]. This study focuses on achieving the maximum output from CNG with minimal design changes.

In the first section, the use of CNG is justified as a favorable alternative with the help of "Well to Wheel" concept. Then, in the next section using computer aided engine simulation, the performance of conventional kits is analyzed and compared with the engine operation with Gasoline creating a benchmark for further comparison. This is followed by a detailed analysis of previous studies related to the effect of various parameters such as speed, ignition timings, gas composition, equivalence ratio and compression ratio and changes were incorporated accordingly in the simulation model, which is then compared with the previously obtained results. The final section concludes the results of our study.

II. WELL TO WHEEL CONCEPT

A large number of criteria for measuring the performance of a fuel is related to its energy output or emissions only while it is being burned or otherwise consumed in a vehicle's engine[1]. This is also true for fuel safety and cost evaluation. Very little attention is given to the technology or the infrastructure that is needed at each stage in the life cycle of the fuel to produce it from its raw source. There can be cases where fuels that show very low emission characteristics from the vehicle may emit highly during their production phases. Similarly, fuels very suitable for use in combustion engines may be difficult and costly to transport and store. Therefore, a fair comparison among automotive fuels demands taking into account the entire history of the fuel, from the raw material to its combustion in an engine. Many recent studies focus on this "Well to wheel" approach for a more holistic comparison[1].

A fuel’s history in the complete “well-to-wheel” fuel chain has five stages:

1.Feedstock production,
2.Feedstock transportation,
3.Fuel production,
4.Fuel distribution and,
5.Vehicle use.

Distilling data from previous studies[1][2], we look consistently at the entire chain to examine all the aspects of fuel production and use, including feedstock, energy consumption, emissions, safety, technology, costs and infrastructure. Figure1. shows the comparison of most commonly used alternative fuels using this concept.

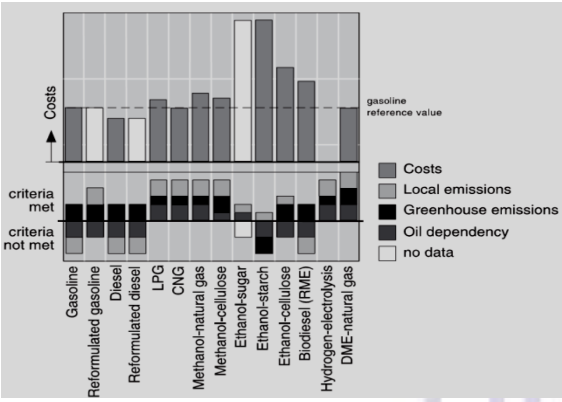

Figure1: Comparison of Alternative Fuels. [1]

This figure shows well-to-wheel fuel costs relative to gasoline. The lower part shows whether fuels meet criteria on local emissions, greenhouse emissions and reducing oil dependency. Half-size blocks indicate that fuels may meet the criteria under certain conditions. Based on this study, CNG met the criteria and was a low cost alternative. It was therefore selected for the engine conversion process and analyzed.

III. Engine Model and Specifications

Computer aided engine simulation was used to study the performance of CNG and its comparison with that of Gasoline. Operating parameters of the engine were varied with each simulation and their effect on the performance of the engine was studied. The valuable data thus generated was used for tuning engine to a desired performance.

Feasibility study on engine conversion to a CNG operation was performed on an already existing gasoline engine. The main engine operation parameters were first calculated and the obtained values were checked/ tested during engine operation in a virtual working environment created according to the input conditions in which the engine was going to work.

The major specifications of the engine used for performance comparison are as given in Table1.

Table1. Engine Parameters used for the study.

No.	Parameter	Value
1.	Swept Volume	1.20 ltr
2.	Bore	87.00 mm
3.	Stroke	84 mm
4.	Max RPM	7000
5.	C.R.	10.5
6.	Con-rod length	130.00 mm
7.	No of cylinders	4
8.	Firing order	1-3-4-2
9.	IVO	15 deg BTDC
10.	IVC	60 deg BTDC
11.	EVO	40 deg BTDC
12.	EVC	20 deg BTDC
13.	Valve throat dia	28 mm

IV. Engine Simulation

We constructed a 1-Dimensional model of the engine using the data provided in Table1 in Lotus Engine Simulation to study the Steady State performance of the Engine with Gasoline. This created a benchmark for performance comparison of Gasoline operation with that of CNG. The one dimensional engine model created for the study is as shown in Fig.2.

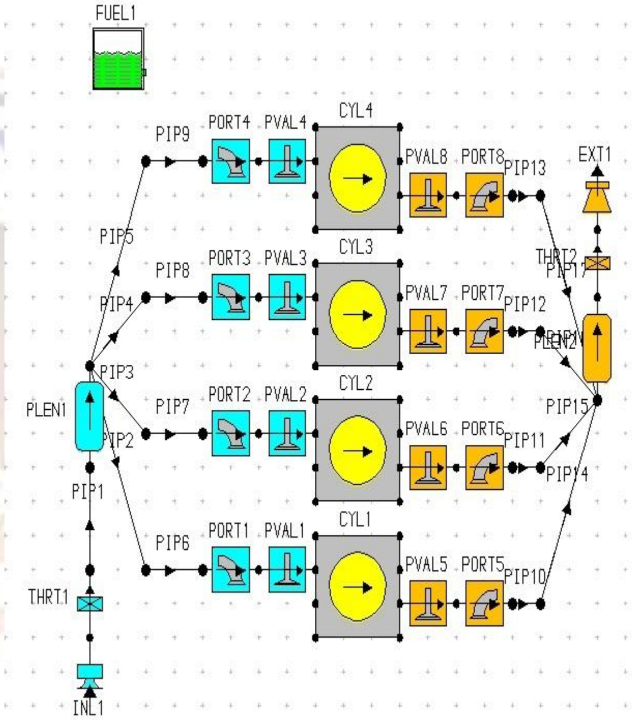

Figure2: 1 Dimensional Engine Model

After running the simulation for gasoline and CNG (without any design/operational modification) the following performance summary was plotted as shown in Fig. 3.

As can be seen there is a noticeable difference between Gasoline and CNG operations. The Power in the case of CGN operation is lower compared to that of gasoline and this deteriorates as the engine is pushed for higher RPM. Similar characteristic is observed for Torque. Brake Specific Fuel Consumption(BSFC) is same for both gasoline and CNG. This is undesirable as CNG, with a high calorific value should have lower BSFC. This implies that the CNG is not being utilized efficiently in the current SI engine model. So in order to study the effect of various parameters on engine performance the following cases were analyzed.

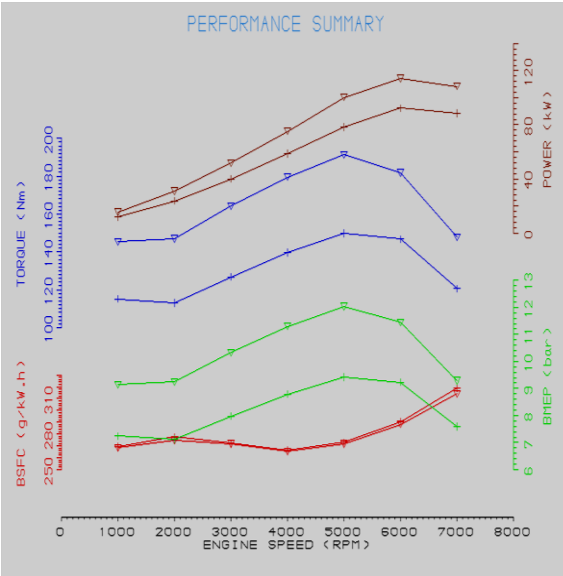

Figure 3. Engine performance comparison for Gasoline and CNG operation (without any modification) (Note: + - CNG, ∇-Gasoline)

4.1 EFFECT OF SPEED AND IGNITION TIMINGS

Previous investigations have revealed that gasoline engine performance is inferior with natural gas operation (without any design changes)[3]. It was found that through careful selection of spark timing, the maximum brake power and lower BSFC can be obtained over the entire range of operation as shown in Fig.4. This is similar to the behavior observed in Fig. 3.

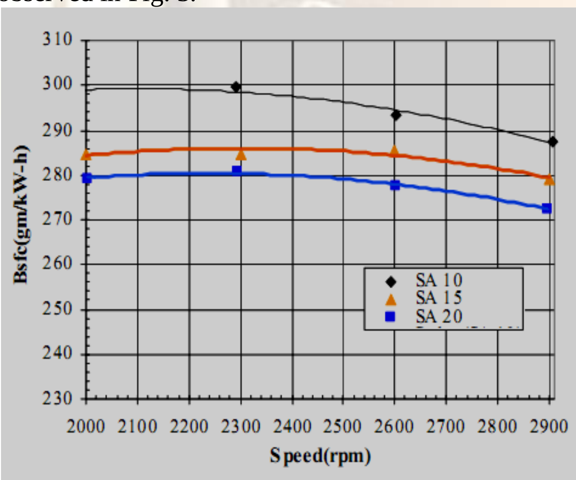

Figure 4. BSFC vs. Speed for CNG[3]

Moreover, as the pressure rise is moderate in the case of CNG operation, chances of knocking at higher speeds decrease significantly, Fig. 6.

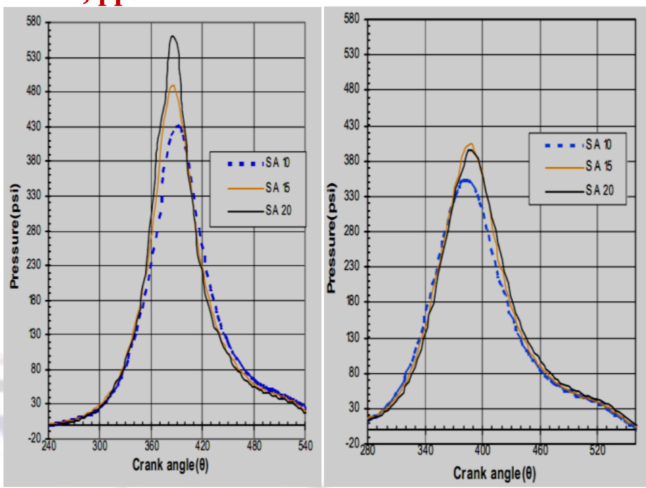

Figure 5. Pressure rise comparison of Gasoline and CNG[3]

4.2 EFFECT OF GAS (CNG) COMPOSITION

It has been studied that the engine power is proportional to the Wobbe Index(WI) value of the gas used, as it is an indicator of combustion energy output[4]. Also, it is expected that the gases having higher WI will have lower BSFC. However, BSFC is not inversely proportional to WI values of the gas as shown in the initial simulations(Fig.3). This abrupt behavior was explained by Min et al. (2002)[5], by using the C_p values and the amount of nitrogen contained in the gas.

According to the study, the spark timing for a gas with low C_p value needs to be advanced, allowing sufficient time for flame front propagation and development[5]. Also, the amount of nitrogen present in the gas affects the flame front, as it hinders the flame propagation [5]. Therefore, frequent adjustments of spark timings, depending upon corresponding changes in fuel composition become necessary to keep the engine operating at the same power.

4.3 EFFECT OF EQUIVALENCE RATIO AND COMPRESSION RATIO

It was observed that the compression ratio is directly proportional to in-cylinder pressure [6]. Also, lean mixtures lead to low in-cylinder pressures when compared to stoichiometric and rich mixtures. This is due to the low energy density of CNG.

Moreover, the peak temperature remains constant for all compression ratios, but it is attained at later crank angles for higher compression ratios (Fig.) [6]. The variation of peak temperature with equivalence ratio is similar in nature to that of pressure, i.e. that lean mixtures resulted in low in cylinder temperatures compared to stoichiometric and rich mixtures[6].

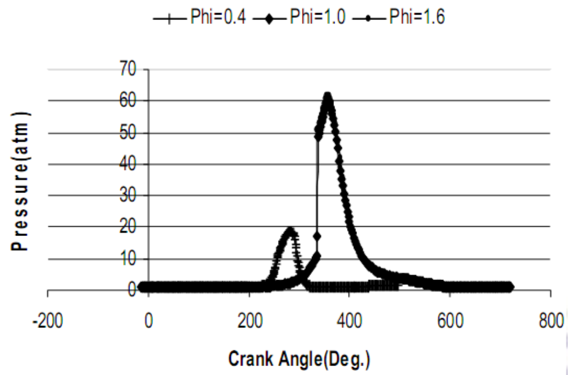

Figure6. Variation of In-cylinder pressure with E.R.[6]

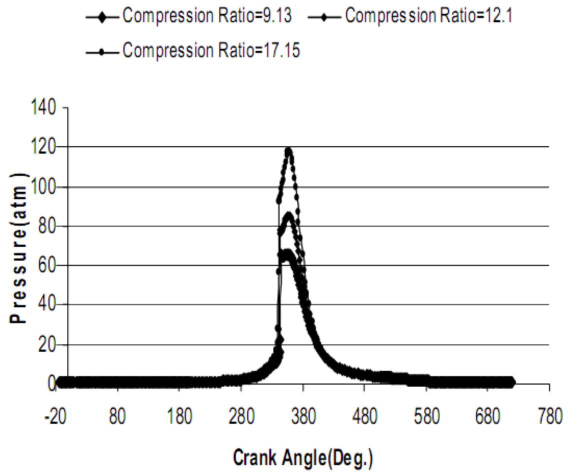

Figure7. Variation of In-cylinder pressure with C.R.[6]

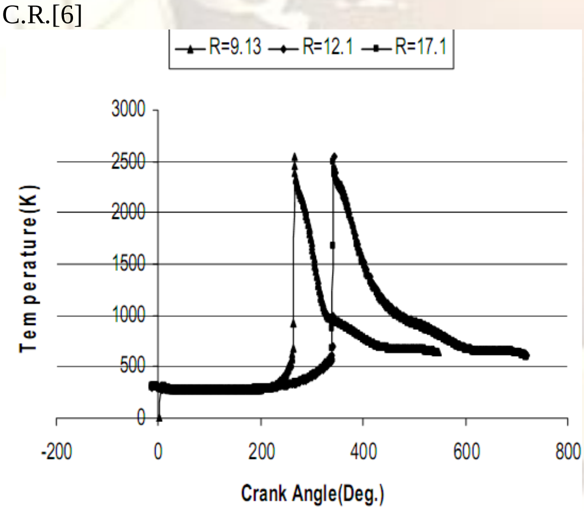

Figure 8. Variation of Temperature with C.R.[6]

V. SUGGESTED CHANGES IN ENGINE PARAMETERS

Based on the studies mentioned in the previous sections, the simulation model was adjusted for performance optimization of the engine and capacity utilization of CNG as a spark ignition fuel. After several design iterations the following changes were incorporated in the existing computer model.

1. CR increased from 11 to 15. (Higher CR leads to higher in-cylinder pressures and thus higher power output.)
2. Inlet port Diameter increased from 28 to 35. (Energy density of CNG is lower compared to Gasoline, this allows more fuel to enter the cylinder, thus increasing the volumetric efficiency)
3. IVO changed from 15 deg BTDC to 25 deg BTDC. (Same reason as above)
4. Spark advanced to 20 deg BTDC. (Fig.4)
5. Equivalence Ratio increased to 1.6. (Fig 6)
6.

VI. RESULTS AND DISCUSSION

Once the simulation model modified to our assessment, the obtained values were tested during engine operation in a virtual working environment. The results were plotted against those obtained in the case of gasoline for comparison as shown in Fig 9.

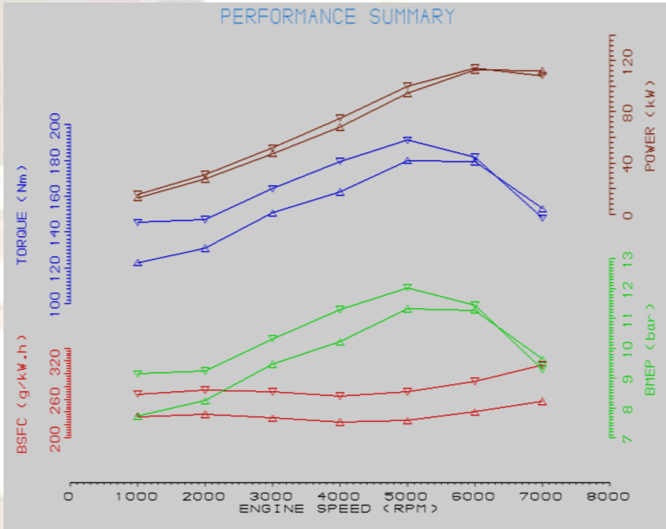

Figure 9. Engine performance comparison for Gasoline and CNG (with modifications) operation (Note: Δ - CNG, ∇-Gasoline)

As can be seen from Fig.9, the changes incorporated in the design and operating parameters of the engine improved the performance. Power of the engine improved from 80 kW to 115 kW at 600rpm and closely resembles that of Gasoline engine operation. Also, the BSFC reduced from 280g/kWh to 238g/kWh, which suggests efficient utilization of CNG, as it has higher calorific value than Gasoline.

VII. CONCLUSION

CNG proves to be a better alternate fuel for gasoline powered engines compared to other fuels according to the well to wheel analysis. However conventional conversion kits are unable to tap the high calorific value of CNG and hence the power output and performance of such retrofitted engines is found to be lower than that of gasoline operation. But with slight adjustment to the operational and design parameters, it is possible to match the performance of CNG operation to that with gasoline.

Moreover, with the help of modern technologies such as Engine Control Unit and in built sensor technology, such operational parameters can be easily varied. For eg. spark timings can be varied so as to allow optimum combustion time for CNG. Similarly, depending upon the WI of the gas and the amount of nitrogen present in the composition, spark timings can be adjusted to allow engine operation at a constant power output.

Although our study is aimed at optimizing the performance of a gasoline Engine fuelled with CNG, it did not cover all the aspects and parameters, and hence there is still scope for further optimization.

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