Optimization of Natural Gas Mixture Design Using Computational Method for HCCI Engine by Improving Swirl Effect

M. A. Shaikh¹ Aditya H. Shukla²
¹Assistant Professor ²Student
¹,²L. D. College of Engineering, Ahmedabad, Gujarat, India

Abstract—CNG is one of the most feasible and accessible option as a replacement of conventional fuels like Gasoline and Diesel nowadays. But major problem of using it as fuel for automotive purpose is reduced engine performance in terms of power and torque. Out of some parameters that may overcome this deficiency, “swirl motions of charge” in cylinder is emphasised in this study to enhance the performance of engine and so to negotiate mentioned difficulty. The component that prepares the charge by mixing CNG with air must be the primary source that imparts the swirling motion and so optimization of CNG Mixer design considering various factors is carried out. Using Computational Fluid Dynamics (CFD) most suitable Mixer design is selected that has highest tendency of producing swirl motion and testing that Mixer experimentally, the performance of engine is recorded. Thus by varying swirl intensity the enhancement in engine performance is obtained.

Key words: Compressed natural gas, Computational fluid dynamics, Mixer, Swirl and Tumble motion

I. INTRODUCTION

From study of current trends in mixer design Venturi burner type mixer is selected to deal with because it is proved that it had the value 5% closer to conventional fuel output already [11]. Different design of this type of mixer by varying its design parameters is modelled in CREO Parametric 2.0 and fluid flow analysis is carried out in ANSYS Workbench (CFX) 16.0. Based on Swirl Number criteria one of the designs if optimized and one another model is finalized, having better Swirl Number. Both this models is tested experimentally on setup in order to record engine performance.

II. LITERATURE REVIEW

Bhaskor J. Bora, Biplab K. Deb Nath, Nikhil Gupta, Ujjwal K. Saha and Niranjan Sahoo (2013) has investigated a newly designed gas mixer has been investigated with the help of computational fluid dynamics based software. The venturi type gas mixer seems to provide far better mixing of fuel biogas and air than the existing T-junction gas mixers [10].

E. Porpatham, A. Ramesh and B. Nagalingam (2013) have investigated the influence of swirl on the performance, emissions and combustion in a constant speed Spark Ignition (SI) engine and observed that there is an improvement in brake thermal efficiency and power output with increase in swirl level [3].

Mr. Prasanna Sutar (2010) has worked with geometric parameter of mixer design and it is evident that better mixing performance will also rely on: Number of holes at the throat section and Venturi convergence and divergence [5].

III. MIXER DESIGN

Analyzing different available designs in real scenario leads to the conclusion that some of the design parameters mentioned must have to be prefixed based on engine configuration requirements:

- Inlet Diameter = 35 mm,
- Outlet Diameter = 30 mm,
- Location of Holes (From inlet) = 35.5 mm
- Diameter of Holes at Throat = 3 mm and
- Total Length = 60 mm.

Thus only by changing Convergence angle (which consequently changes Throat Diameter and Divergence angle) basic three designs are prepared and after that varying number of holes in each of the design total 9 models are prepared to simulate.
Mentioned three basic models and each design by just varying number of holes 8, 10 and 12 at throat section is modelled and all those 9 models are simulated in order to find Swirl intensity to decide optimum design out of it. Boundary conditions mentioned is a calculated based on engine specification using simple venturi equations.

IV. EXPERIMENTAL SETUP

Table 1: Engine Specification

<table>
<thead>
<tr>
<th>Engine</th>
<th>Kirloskar (AVI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore (mm)</td>
<td>87.5</td>
</tr>
<tr>
<td>Stroke (mm)</td>
<td>110</td>
</tr>
<tr>
<td>Displacement (cc)</td>
<td>661</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>17.5</td>
</tr>
<tr>
<td>R.P.M.</td>
<td>1500</td>
</tr>
<tr>
<td>Volumetric Efficiency</td>
<td>80%</td>
</tr>
</tbody>
</table>

V. ANALYSIS AND RESULT

Models simulated will be optimized based on following criteria: (1) Overall velocity: Adequately lower (2) Turbulence Kinetic Energy (outlet): As high as possible [15] Optimized design out of all based on above criteria having detailed dimensions:

Inlet Diameter = 35 mm
Convergence-Divergence Angle = 30°
Throat Diameter = 21 mm
No. of holes = 8
Diameter of holes = 3 mm
Outlet Diameter = 30 mm
Total length = 60 mm
Swirl number can be calculated using following equations and values for mentioned model is [14]:

\[ SN = \frac{A}{B} \]

\[ A = \int_{0}^{R} \int_{0}^{2\pi} U V W \, d\theta \, dr \]
\[ B = \int_{0}^{R} \int_{0}^{2\pi} U^2 R \, d\theta \, dr \]

Resultant swirl number found is:
SN (Air) = 1.6142 (anticlockwise)
SN (CNG) = 1.6227 (anticlockwise)

One more design is adopted by keeping all engine restricted parameters aside and having swirl number better than this model.
SN (Air) = 1.9194 (anticlockwise)
SN (CNG) = 2.2526 (anticlockwise)

Table 2: Result Table

<table>
<thead>
<tr>
<th>Model</th>
<th>BSFC (kg/KW.hr)</th>
<th>A/F ratio</th>
<th>BTE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 2 (8 holes)</td>
<td>1.0329</td>
<td>18.3</td>
<td>8</td>
</tr>
<tr>
<td>Actual adopted model</td>
<td>0.9564</td>
<td>17.2</td>
<td>9</td>
</tr>
</tbody>
</table>

For BSFC, the value for adopted model is less than Model 2 by 8% (approx.). Similarly for A/F ratio for Model 2 value is quite leaner than stoichiometric A/F ratio for CNG i.e. 17.25 and that may cause functional problems but for actual model is very near to ideal value. As far as values of BTE is concern not much of improvement but still is 1% higher and comparatively 12.5% improvement.

So advantage in all mentioned factors is only effect of enhanced swirl intensity because during experiment all other parameters and conditions is same. Variation is just in
swirl intensity by optimizing the design parameters of Mixer.

VI. CONCLUSION

It is concluded that as Swirl tendency of charge increases within the cylinder, improvement in engine performance is observed and this is achieved only by means of design optimization of Mixer. By increasing swirl intensity from 1.62 (for Model 2-8 holes) to 2.25 (for adopted model) for fuel, achieved improvement in BSFC is 8%. BTE improvement is observed is around 12.5%. A/F ratio is reduced by 6% and come to chemically correct from leaner.

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