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

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Abstract— CNG is one of the most feasible and accessible option as a replacement of conventional fuels likes 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. Debnath, 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].

K.Kadirgama, M.M.Noor, A.R.N.A. Rahim, R.Devarajan, M.R.M.Rejab and N.M.Zuki N.M (2008) have performed design optimization of mixer design based on chemically correct A/F ratio and concluded parameters affecting design are: Inlet and outlet diameter, Throat diameter, Inlet and outlet angle, Size and number of holes at throat section, CNG inlet tube size [7].

D. Ramasamy, S. Mahendran, K. Kadirgama and M. M. Noor (2010) have investigated flow characteristics through mixer using software simulation and mentioned key point to design are: Pressure drop, Mass fraction and Velocity of flow [9].

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.

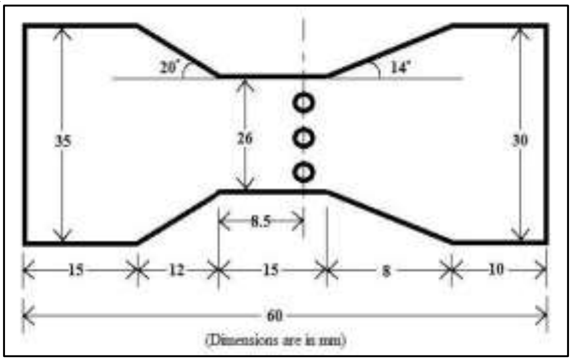

Fig. 1: Model 1 (20° Convergence, 26 mm throat)

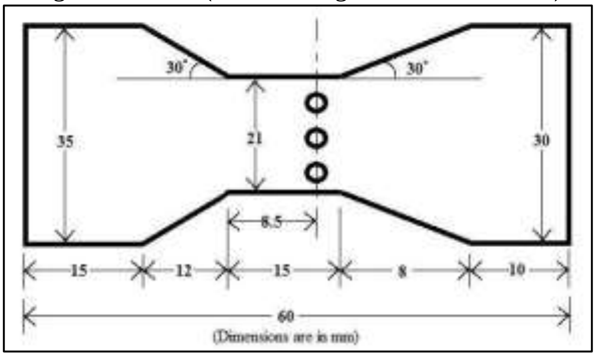

Fig. 2: Model 2 (30° Convergence, 21 mm throat)

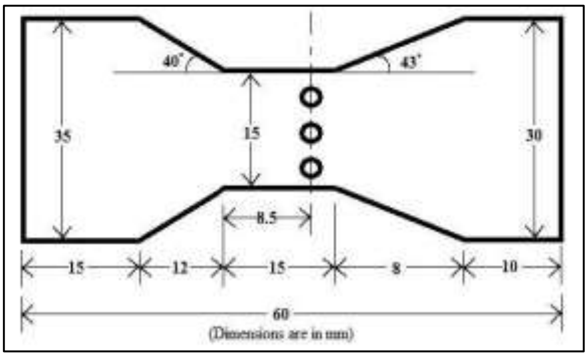

Fig. 3: Model 3 (40° Convergence, 15 mm throat)

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

Fig. 4: Photograph of Experimental Setup

Engine	Kirloskar (AVI)
Bore (mm)	87.5
Stroke (mm)	110
Displacement (cc)	661
Compression Ratio	17.5
R.P.M.	1500
Volumetric Efficiency	80%

Table 1: Engine Specification

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]:

$$A = \int_0^R \int_0^{2\pi} U\,V\,W\; d\theta\; dr \quad B = \int_0^R \int_0^{2\pi} U^2\,R\; d\theta\; dr$$

$$SN = \frac{A}{B}$$

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)

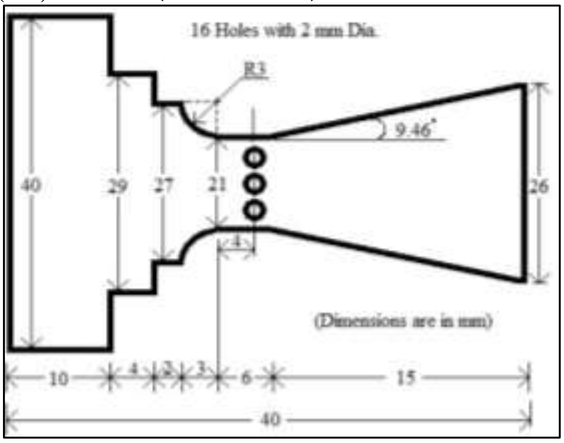

Fig. 5: Design of Adopted Actual model

By conducting experimental testing using both models i.e. Model 2_8 (Model shown in Fig. 2 with 8 holes) and model shown in Fig. 5, performance of engine is observed and recorded in terms of output parameters like BSFC and Air-fuel ratio by keeping engine speed constant 1500 rpm with constant loading of 60% of full load condition. As engine speed and load remains constant for experiment, brake power also remains same for both mixer and is 2.215 KW but for producing that much of power fuel consumption reduced by using mixer having high swirl intensity.

After performing experiment detailed observation table is obtained and performing various calculations, result table for three output parameters Brake Specific Fuel Consumption (BSFC), A/F ratio and Brake Thermal Efficiency (BTE) is comparing for two optimized model i.e. Model 2 (Fig. 2) with 8 holes at throat section and Actual adopted model (Fig. 5).

Model	BSFC (kg/KW.hr)	A/F ratio	BTE (%)
Model 2 (8 holes)	1.0329	18.3	8
Actual adopted model	0.9564	17.2	9

Table 2: Result 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.

References

[1] Abhilash M Bharadwaj, K Madhu, Seemanthini J, Vismay K G, Anand M Shivapuji & Aravind T (Dept. Of Mechanical Engineering, Atria Institute of Technology, Bangalore and Indian Institute of Science, Bangalore) presented on “Study of swirl and tumble motion using CFD”, ISSN: 2319 – 3182, Volume-2, Issue-1, 2013.

[2] Vinodh Kumar B, Sivagaminathan N and Gopalakrishnan N (Larsen and Toubro Limited, IES), Scott Morton and Paul Radavich (Mercury Marine Pvt. Ltd, India) presented on “Air flow and charge motion study of engine intake port” (2007).

[3] E. Porpatham (School of Mechanical and Building Sciences, VIT University, Vellore 632 014, India), A. Ramesh and B. Nagalingam (IC Engines Laboratory, Indian Institute of Technology Madras, Chennai 600 036, India) presented on “Effect of swirl on the performance and combustion of a biogas fuelled spark ignition engine”, Energy Conversion and Management 76 (2013) 463–471, Elsevier, July 22, 2013.

[4] M.M. Noor, Kumaran Kadirgama and Ramasamy Devarajan (University Malaysia Pahang, Malasia), T.F. Yusaf (University of Southern Queensland, 487/521-535 West St, Darling Heights QLD 4350, Australia) presented on “Development of a high pressure Compressed Natural Gas mixer for a 1.5 litre CNG-diesel dual engine”, National Conference on Design and Concurrent Engineering, 2008.

[5] Mr. Prasanna Sutar (PG Scholar, M.Tech I.C. Engines, Vel Tech University Chennai – ARAI Academy, Pune) presented on “CFD optimization of venturi mixer design in bi-fuel gas engines”, IRF-International Conference Organized by Institute of Research and Journals in association with: COE, Bharti Vidyapeeth, Deemed University, Pune (2010).

[6] Yvonne S. H. Chang, Z. Yaacob and R. Mohsin (Proceedings of the World Congress on Engineering and Computer Science, San Francisco, USA) presented on “Computational Fluid Dynamics simulation of injection mixer for CNG engines”, Proceedings of the World Congress on Engineering and Computer Science 2007, WCECS 2007, October 24-26, 2007, San Francisco, USA.

[7] K.Kadirgama, M.M.Noor, A.R.N.A. Rahim, R.Devarajan, M.R.M.Rejab and N.M.Zuki N.M. (Malaysian Technical Universities Conference on Engineering and Technology, Putra Palace, Perlis, Malaysia) presented on “Design and simulate mixing of Compressed Natural Gas with air in a mixing device”, Proceedings of MUCET2008, Malaysian Technical Universities Conference on Engineering and Technology March 8-10, 2008, Putra Palace, Perlis, Malaysia. (ISBN: 978-983- 42358-4-0).

[8] Thesis work by Devarajan A/L Ramasamy on “Development of a compressed natural gas (CNG) mixer for a two stroke internal combustion engine” for the degree of Master of Engineering (Mechanical), University Technology, Malaysia (October, 2005).

[9] D. Ramasamy, S. Mahendran, K. Kadirgama and M. M. Noor (Faculty of Mechanical Engineering, University Malaysia, 26300 UMP, Kuantan, Pahang, Malaysia) have presented on “Design of compressed natural gas mixer using computational fluid dynamics”, National Conference in Mechanical Engineering research and postgraduate students (1st NCMER 2010), 26- 27 May, 2010.

[10] Bhaskor J. Bora and Biplab K. Debnath (PhD Student), Ujjwal K. Saha (Professor), Niranjan Sahoo (Associate Professor) from Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, India and Nikhil Gupta (B.Tech Student, Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat ,Gujarat - 395007, India) presented on “Investigation on the flow behaviour of a venturi type gas mixer designed for dual fuel diesel engines”, International Journal of Emerging Technology and Advanced Engineering Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 202-209.

[11] Mardani Ali Sera, Rosli Abu Bakar and Sin Kwan Leong presented on, “CNG Engine Performance Improvement Strategy through Advanced Intake System”, University Technology Malaysia, JSAE 20030229, SAE 2001-01-1937, Japan (2003).

[12] “FLOW IN THE CYLINDER” by John L. Lumley, Cornell University (excerpt from his book: Engines – an introduction, Cambridge University Press, 1999).

[13] Introduction to Modelling and Simulation (Part-1) by Dr. Cagatay Undeger (Bilkent Univetsity, Ankara, Turkey (2008)).

[14] Gupta A.K., Lilley D.G., Syred N. (1984), “Swirl Flows”, Abacus Press.

[15] Dr. Rosli Abu Bakar, Mr. Mardani Ali Sera and Mr. Sin Kwan Leong (University Technology Malaysia) have presented on “Design and development of a new CNG (Compressed Natural Gas) engine” (2002).

