CFD ANALYSIS OF SINGLE CYLINDER HCNG ENGINE: A REVIEW

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Abstract - Hydrogen is being considered as a primary automotive fuel and as a replacement for conventional fuels. Some of the desirable properties of automotive fuels are high flame velocity & high calorific value, etc. Since hydrogen possess good combustion fuel it is used as a substitution fluid in internal combustion engines. The present paper is a review of a methodology intended to perform CFD analysis of C.I. Engine using mixture hydrogen and CNG as fuel. A multidimensional model of HCNG Engine will be developed using solid works based on which the flow, heat and pollutant analysis will be done using Fluent. Combustion performance, temperature characteristics, pressure and emission parameters of CO, HC and NO_x will be recorded and analyzed at various blends of HCNG ranging from 5% to 30% of hydrogen in CNG.CFD analysis will be carried out at different compression ratios based on the boundary conditions. Results will be compared to decide optimum blend of HCNG.

Key Words: IC Engine, CFD, Combustion, Turbulence, Emission.

1. INTRODUCTION

Increasing air pollution is one of the most important problems of world today. Exhaust emission from automotive has major contribution in increasing air pollution. Many experimentations and improvements have been done with engine design but it is is necessary to continue to work on alternative fuel technologies. It is important to produce alternative fuels from renewable sources and can be used directly without making much change in engine design. Hydrogen is probably the cleanest fuel known to man. Its combustion and emissions characteristics are superior to any other competing fuel and furthermore, its high-octane value permits high compression ratio, leading to higher thermal efficiency at full load conditions. Blending of Hydrogen with CNG provides a blended gas termed as HCNG. The Hydrogen blends in CNG can range from 5 to 30 % by volume. Any natural gas engine is compatible to run on HCNG and can do so with minimum modifications. HCNG has several benefits such as it can use existing CNG infrastructure, It produces lower NO_x and GHG emissions as compared to CNG. HCNG has higher energy storage density as compared to Pure Hydrogen, which allows lower fuel volumes to be carried on board.

In this study the lean burn combustion concept is to be evaluated for varying HCNG blends. Traditional process of prototyping is time consuming and cost consuming. Therefore CFD simulation of the combustion process is to be performed. Identification of optimum blend is one of the objectives of this study. It is also expected that HCNG fuel blends reduce NO_x emissions, hydrocarbons and CO_2 as compared to CNG. No PM emissions are observed in CNG or HCNG engines.

2. LITERATURE REVIEW

Thipse, S. S., Rairikar, S. D., Kavathekar, K. P and Chitnis, P. P. [1], the testing is carried out for the neat CNG and 5% blends of Hydrogen by volume with CNG. It is observed in the experimental work that the HCNG engines are more superior to CNG engines from fuel economy, power output and emission compliance point of view. The power improvement of 3% to 4%, torque improvement of 3% and fuel consumption reduction of 4% is observed in HCNG engine than the neat CNG engine. The HCNG engine increases the H/C ratio of the fuel, which drastically reduces the carbon based emissions such as CO, CO2 and HC. To increase the flame speed of HCNG engines, the ignition timing needs to be retarded; this results in reduction of NOx emissions. The HCNG reduced CO emissions by 40 to 50%, NMHC emissions by 45% and NOx emissions by 20 to 30% than the neat CNG operation.

Mariani A., Morrone B., Unich A. [2], In 2009 has done comparison between natural gas and a hydrogen-natural gas blend (HCNG in the following) in terms of exhaust emissions and fuel consumption. A passenger car has been tested on a chassis dynamometer according to the European emission regulations, without any change on engine calibration (i.e. spark advance). The HCNG blend used during the test has a 12% vol. of hydrogen content. CO emissions showed a reduction of about 19% when HCNG blend is used, while HC emissions remained constant. A 70% increase was observed for NOx emissions with CNG. A 3% reduction for CO_2 emission was observed using HCNG because of the lower carbon content in the blend and the reduced fuel consumption on a mass basis. There is not significant variation of fuel consumption on energy basis, probably

Mariani A., Morrone B., Unich A [3], In 2008. Developed a numerical engine model and carried out an investigation on HCNG blends with hydrogen content up to 30%. The authors stated that by employing a MBT spark advance, such HCNG blends exhibit improvements of engine brake efficiency compared with CNG, which are more relevant at part loads and for the highest hydrogen content. NOx emissions were reduced by means of exhaust gas recirculation system.

Khatri, D. S.Singh, V., Pal, N. K., Maheshwari, M., Singh, S and Chug, S.Rajendra Singh, Anup Bhat [4], Has experimentally studied to investigate the viability of HCNG as an automotive fuel. The effect of gas pressure and gas temperature on the duration gas injection has been considered in the control strategy. In the first phase the duration of injection, ignition timing were optimized using CNG, subsequently 18% Hydrogen by volume was mixed in CNG and used in this investigation. Different parameters like injector pulse width and ignition timing were optimized under idling and different load conditions. Detailed testing has been conducted on idling operation to analyze the idle stability and emission. Subsequently vehicle mass emission tests were conducted on chassis dynamometer with CNG and HCNG fuel. Test results indicate that COV in engine idle speed has been reduced from 1.1% to 0.5% with HCNG fuel as compared to CNG. CO emission has been reduced from 198 ppm to 15 ppm with HCNG as compared to Gasoline operation. HC emission has been also reduced from 67 ppm to 25 ppm with HCNG fuel as compared to gasoline. With HCNG mode NOx has increased significantly as compared to CNG mode. However, NOx was reduced by retarding the ignition timing by 30 crank angle with HCNG as compared to CNG operation during idling. CO2 is reduced by 19.47% with CNG as compared to gasoline and 31.74 % with HCNG as compared to gasoline during idling operation. During mass emission test CO, CO2 and HC were reduced with HCNG operation with respect to CNG operation. The driveability with HCNG fuel was observed to be fairly good.

David Serrano, Olivier Laget, Dominique Soleri, Stephane Richard, Benoit Douailler, Frederic Ravet Marc Moreau and Nathalie Dioc [5], has done experimental investigation of different methane/hydrogen blends between 0% and 40% vol. hydrogen ratio for three different combustion modes: stoichiometric, leanburn and stoichiometric with EGR. The main objectives are to identify the complex mechanisms involved in the combustion process and to define the optimal hydrogen ratio for each combustion mode. The study combines engine tests and 0D modeling. Tests were carried out on a spark-ignited single cylinder engine adapted to CNG operation with 2 different compression ratios 9.5:1 and 11.5:1. Computations allow studying separately the different phenomena linked to the progressive addition of hydrogen in the fuel. Hence, using 0D modeling, the effects due only to the combustion speed evolution, as a function of hydrogen ratio in the fuel, were then quantified using experimental results as comparison basis. The engine test results reveal that the impact of hydrogen is limited in stoichiometric conditions except for CO 2 savings. A ratio of 10 to 20 vol. % of hydrogen seems to be optimal to reach interesting HC emissions reduction without an excessive lowering of the operation range. The results are more encouraging for lean-burn operation as the lean limit of equivalence ratio is extended for more than 0,125 with 40 vol. % of hydrogen. NOx emissions and consumption were significantly reduced (−92% for NOx) while maintaining constant HC and CO emissions compared to methane operation. Hydrogen stabilizes and speeds up combustion especially in very diluted mixtures. Furthermore, hydrogen increases EGR tolerance for the same reasons as in lean-burn mode: in comparison, identical very-low NOx levels were reached with smaller consumption gains. Finally, the engine test results show that the highest tested ratio of hydrogen (up to 40%) in methane for much diluted mixtures with air or EGR drastically reduced.

J. Krishnara, C. Karthick kumar ,P.Vasanthakumar ,M.Palanisamy [6],has done a computational analysis of S.I. Engine using hydrogen gasoline blends. Different 3D model of piston head and combustion chamber were created model. This methodology combined three-dimensional model and CFD techniques with numerical optimization tools to compute the working, of IC engines. A computational model of IC engine is modeled and computational fluid dynamic analysis was carried out by using FLUENT. In the analysis, combustion parameters like fluid flow, mixing, turbulence and back pressure were analyzed using CFD software. Combustion performance, temperature characteristics, pressure and emission parameters of CO, HC and NOx were recorded and analyzed at various flow rates of hydrogen. In this work a methodology of various proposed designs of piston heads is modelled and based on the boundary conditions that model were analyzed. Output data of various models were compared to identify best optimum design which fulfils desired performance characteristics.

Irwin Osmond Toppo [7], In this work author used Computational fluid dynamics (CFD) code FLUENT to model the complex combustion phenomenon in compression ignition engine. Jathropha was used as a alternative fuel. CFD analysis was carried out for Nox produced and temperature profile inside the combustion chamber. CFD analysis was done for taking both Jathropha and conventional diesel as a fuel individually for comparison. . Simulation results obtained were validated experimentally for both Jathropha and conventional diesel on test diesel engine. Simulation was carried out in Ansys- fluent using Non-premixed combustion model to cater actual in cylinder combustion parameters. Two-dimensional combustion chamber with deformation mesh is used for simulation.

Hüseyin Turan Arat, Kadir Aydin, Ertuğrul Baltacioğlu ,Ergül Yaşar, Mustafa Kaan Baltacioğlu, Çağlar Conker And Alper Burgaç [8], has done contemporary research and given comprehensive overview on the HCNG fueled diesel engines. Main topics that were studied includes introduction and fundamentals of the combustion of hydrogen and compressed natural gas blends, history of the Hythane, details on the different mixture formation strategies and fuel properties. Engine performance and their emissions characteristics were analyzed to look through the benefits and challenges of HCNG for diesel engines.

P. Venu Gopal , Shaik Hussain [9], Author has used dual fuel natural gas (biogas) as fuel.A multidimensional 2D model of Dual Fuel IC Engine was developed using solid works based on which the flow, heat and pollutant analysis was done using Ansys IC Engine package. The meshing was done by tetrahedral element using copper tool. The results were analyzed to get the values of heat transfer rate, temperature, dynamic & average pressures, the torque generated and emissions of combustion process. To validate the Ansys ICE simulation the results were compared with the experimental values and also with Ansys Fluent simulation and found that the predicted values are in conformance with the experimental results.

Syed Kaleemuddin and G. Amba Prasad Rao [10], experimental investigations were carried out and upgradation of 395 cc air cooled engine to dual fuel (CNG/Gasoline) application was done. The original 395 cc direct injection naturally aspirated, air cooled diesel engine was first converted to run on Gasoline by addition of electronic ignition system and reduction in compression ratio to suit both gasoline and CNG application. CFX software was employed to calculate and improve the cooling capacity of engine with the use of CNG. Materials of major engine components were reviewed to suit CNG application. The engine was subsequently tuned with dual multi-mapped ignition timing for bi-fuel stoichiometric operation on engine dynamometer and then fitted on a 3-Wheeler vehicle. The vehicle was optimized on a chassis dynamometer to meet the proposed Bharat Stage-III norms. The engine has passed current BS-II emission norms with 48% margin in CO emission and 76% margin in NMHC (Non-Methane Hydrocarbons) and Extensive trials were conducted on engine and vehicle to optimize with CNG kit and minimum loaded three way catalytic convertor to finally to met proposed BS-III norms.

Shaik Magbul Hussain, Dr.B. Sudheer Prem Kumar, Dr.K. Vijaya Kumar Reddy [11], has done CFD analysis using Biogas-Diesel dual fuel. The combustion CFD analysis was carried out using FLUENT software to study the effect of Biogas substitution on turbulent kinetic energy, Turbulent Dissipation Rate, Combustion flame velocity, and NOx formation for five compression ratios. For Turbulence analysis, RNG κ−ε model were used, which is further modified for the dual fuel analysis. GAMBIT software was used for meshing of the combustion chamber, by tetrahedral element using cooper tool. To analyze the effect of compression ratio in dual fuel mode, compression ratios were varied along with Bio-gas substitutions. Experimental investigations were done to validate CFD results, which showed a good agreement between the predicted and experimental results.

M. Masood, M.M. Ishrat [12], has done simulation program for determining the mole fraction of each of the exhaust species when the hydrogen is burnt along with diesel. The proportion of hydrogen in the hydrogen–diesel blend affecting the mole fraction of the exhaust species is also simulated. Experimental investigations were carried out, in hydrogen–diesel dual fuel mode, which showed a good agreement between the predicted and experimental results.

Collier .K [13], have reported that Hydrogen addition to natural gas will extend the lean limit of combustion for natural gas in a CNG engine. It appears that approximately 30% hydrogen, by volume, will make a significant difference in the relationship between NOx and THC emissions as compared to natural gas alone. NOx emissions for a full size passenger car with this converted engine were reported as 0.01 g/mile and THC emissions were approximately 2 g/mile with the 30% hydrogen mixture and without catalytic treatment. With 30% hydrogen addition and a 0.65 mixture ratio, MBT was not well defined. BSFC was not a strong function of ignition timing. Retarding ignition timing with the 30% hydrogen mixture allowed NOx emissions to be controlled to extremely low levels over the range of power and engine speeds tested. Furthermore, the same trends held for the highest bmep that could be run on this naturally aspirated engine. It was confirmed that a standard CNG engine, with appropriate spark, air fuel ratio, and engine r/min control, could be converted to operate on mixtures of natural gas and hydrogen and produce NOx emissions below any currently proposed standard.

Munshi. [14], evaluated various HCNG blends on engines for city bus application. Their testing result indicates that 25 vol% H2 blend has the highest average NOx reduction. The optimization was carried out in real time with the engine running at constant torque while varying spark timing and lambda (relative air-fuel ratio) were varied. It was found difficult to maintain the pre-catalyst THC emissions exactly the same as the baseline level. Similarly an attempt was made to maintain the fuel consumption at the baseline level. The engine had closed loop air-fuel ratio control and was equipped with a waste-gate turbocharger and an electronically controlled intake throttle. These features allowed the engine to maintain torque under HCNG operation at higher air-fuel ratios and retarded spark timings by increasing the intake airflow, while keeping the fuel energy flow rate the same as the CNG operation. The engine torque curve and maximum performance was verified by comparing the torque curve. The torque curve demonstrated the capability of the engine to maintain full load under HCNG fueling. As was seen from the results the HCNG engine torque was equal or slightly higher than the CNG engine torque.

Maheboob Pasha, Yeshwanthray ashtagi, Rahul G Panchal [15], has used Species Transport Model of ANSYS FLUENT14.5 to find the complex phenomenon of in cylinder process of combustion, temperature and pressure distribution, CO2 and NOX emissions etc. The process was carried out at different injection timing of the Diesel liquid, the cases considered were Injection at two degree after TDC, Injection at five degree bTDC, and Injection at ten degree bTDC. After getting optimized value of Injection than 10 % of ethanol was added in order to increase the efficiency of the combustion and reduce the NOx emissions.

C. Ajay Sekar [16], study has been carried out for different proportions of hythane and diesel blends using a computational approach. To understand the combustion characteristics of these blends, the total pressure and temperature distribution in combustion chamber was studied which will help in understanding heat release rate during combustion process while the emission characteristics of these blends was studied using NOx, Soot, CO concentrations after combustion. The results obtained from fluent were then compared with emission characteristics of actual diesel engine, to check on the feasibility of use of such blends as an alternative fuel for gas turbines.

3. PROPOSED WORK

The methodology for the present work is as follows.

- Solid modeling of the intake manifold and cylinder geometry with valves using SOLIDWORKS
- Mesh generation. Solution of the governing equations with appropriate boundary conditions.
- Comparison of the simulated results with the various compression ratios.

The study is expected to explore the potential of using CFD tool for identifying the use of HCNG as fuel. The CFD code ANSYS FLUENT and ANSYS IC ENGINE PACKAGE is used for the analysis of flow. The CFD package includes user interfaces to input problem parameters and to examine the results. The code contains three elements

1. Pre-Processor
2. Solver
3. Post Processor

Preprocessor mainly involves the creation of basic 3D model, grid generation and fixing of the boundary conditions. Modeling and meshing is done in ANSYS MESH and is exported to ANSYS FLUENT for completing the process.

3.1. PROPOSED 3D MODEL

Fig 1. Front view of assembly of valves, piston, intake manifold and combustion chamber.

Fig 2. Top view of assembly of valves, piston, intake manifold and combustion chamber.

Fig 3. Side view of assembly of valves, piston, intake manifold and combustion chamber.

Fig 4. Isometric view of assembly of valves, piston, intake manifold and combustion chamber.

4. CONCLUSIONS

This review has considered C.I. Engine and the combustion performance of Engine using hydrogen and CNG blends as a fuel. Computational fluid dynamics (CFD) code FLUENT along with ANSYS 16 ICE will be used for this study. Simulation will be performed by varying proportion of hydrogen in CNG and at different compression ratios. Solution of the governing equations with appropriate boundary conditions will be obtained from simulation. From the above review, optimum blend of HCNG will be identified along with investigation of combustion characteristics and exhaust emission. Hence it is concluded that from the literature review, using HCNG as fuel for single cylinder C.I. engine will increase performance of engine with minimum exhaust emissions.

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