ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

CFD Simulation of Dual Fuel Natural Gas Based IC Engine Using Ansys ICE Package

P. Venu Gopal
PG student (M.Tech Thermal Engineering),
Department of Mechanical Engineering,,
Malla Reddy Engineering College,
Hyderabad, Telangana, India.

Shaik Hussain
Associate Professor,
Department of Mechanical Engineering,,
Malla Reddy Engineering College,
Hyderabad, Telangana, India.

ABSTRACT:

A Dual Fuel IC Engine is designed on the concept of the injection of a liquid fuel to start the combustion of the working mixture of a gaseous fuel and air in the engine cylinder. Due to stricter air pollution controls and the rise in the cost of fuels in general and relatively reduced availability of liquid fuels of right quality, the demand for gas-fuelled engine applications began increasing, mainly in the stationary electric power generation and commercial vehicle sectors. However the design and development of such engine needs a lot of time and costs for the conventional prototyping and experimental setup of any IC Engine. These time and cost constraints can be overcome by doing CFD simulation using Ansys Fluent and Ansys IC Engine packages. These simulation packages helps to design and development of efficient IC Engines by predicting the heat transfer rate along with temperature, pressure and pollutants.

Also by understanding the in-cylinder combustion process of dual fuel combustion engine helps us to develop low emission engines. 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

Keywords:

CFD simulation, Ansys IC Engine, Natural-gas based, Dual Fuel IC Engine, Rate of Heat transfer, Combustion modeling, Diesel combustion.

I.INTRODUCTION TO CFD SIMULATION

With the increased computational power of modern computers, the CFD has become useful to many applications using diesel engine research, design and development. Hence it reduces the time and costs involved in conventional prototyping and testing the engine prototype to design and develop fuel efficient and low emission engines. Usually CFD analysis is done by using Ansys Software's Fluent or CFX Modules. However it needs lot of expertise and takes more time to do the setup and complete the simulation. Ansys's ICEngine module is gaining momentum as it takes very less time compared to other simulation techniques and also we can performs port flow simulation, combustion simulation, cold flow simulation with ease. In addition the Ansys IC Engine is user friendly and has intuitive interface. It also has the capability to predict the gas flow pattern, Fuel spray patters and other features similar to Fluent. It helps in understanding the Heat Transfer in IC Engine which causes thermally induced stresses impacting the life of engine parts and thereby it helps in designing and developing better engines for more durability and efficiency.

II ANSYS IC ENGINE SETUP, GEOMETRY AND MESHING

The first step for simulation is creating the geometry of the Engine cylinder & valves. This geometry was created using Solidworks in 3D and the geometry and saved as .STEP file. The simulation was started by dragging the ICE Module from the left side of the Ansys panel into the right panel. The properties of ICEngine are set suitably as below:

Simulation type: Combustion simulation
Connecting rod length: 122 mm
Crank radius: 20.5 mm
Piston offset wrench: 75 mm
Engine speed: 1800 RPM
Minimum lift: 2 mm
Inlet Valve Closing: 542 degrees
Exhaust Valve Opening: 460 degrees

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Fuel Type: Mixture of natural gas + air + other minor constituents
Next , the Valve Lift profile was uploaded.

Next, the Geometry menu of the ICE instance was double clicked to open the Design Modeler (DM) window. Here the previously created Geometry STEP file was imported into the Modeler and the Generate button was clicked to get the Geometry appeared in the DM window. Then a spark point is created with appropriate co ordinates like x, y, z. Then the Input Manager was added to the Design view. In the InputManager the configuration was done to select the two of cylinder faces, Inlet valve and Exhaust Valve. In the Inlet Valve button the Valve body and two faces are selected and necessary parameters such as spray height, spray radius, pilot ignition pipe angle etc were applied. Similarly, the Exhaust valve is also added and corresponding valve body and two faces were selected. The Geometry was updated and then it is decomposed by clicking on Decompose button. Next in the 'Mesh' section of the ICE the meshing parameters such as mesh type = Medium, Element length=10 mm etc with Tetrahedral meshing option were set and chosen Animate option to 'yes'. The Generate option will create the generation of Mesh on the selected surfaces.The Final step, is setting up the solver and running Calculation

Figure: 1 Running calculations in Ansys IC Engine CFD simulation

III SOLVER SETUP

The solver setup menu is available next to the generate mesh menu. Below are various settings and parameters in each setting that were used to run the solution to solve the equations. Basic settings: Autosave type: Crank
Angle and ICE Swirl Number: 1.3
Physics settings: Species
Model: Laminar Flow rate,
Material Input: Ansys ICE Fluent
Mixture Material: Natural gas-air
Boundary Conditions: ice-outlet-exvalve, ice-outlet-invalve
Monitor settings: vol-mon, vol-avg-temp-mon, vol-avg-press-mon, max-vel-mon,max-temp-mon, max-pres-mon,mass-mon, mass-avg-tke-mon
Initialization parameters such as: x,y,z co ordinates, Temperature=300 K, Turbulent K.E, Turbulent Dissipation Rate, c7h16 and below other parameters are setup
Location of spray: Height: 22 mm from the top of the cylinder,
Spray radius: 15 mm,
Inlet valve angle: 14 degrees,
Pilot injection pipe angle: 90 degrees,
Pilot injection time: 1.5 sec

Engine specifications used:

Bore: 84 mm
Stroke length 82 mm
Connecting rod length: 122 mm
Crank radius: 20.5 mm
Displacement: 1817cc
Engine speed=1800 RPM
Compression Ratio: 16:1. For this study the main fuel used is the mixture of natural gas with air. The Diesel was used for pilot ignition purpose with an ignition time of 1.5 seconds.

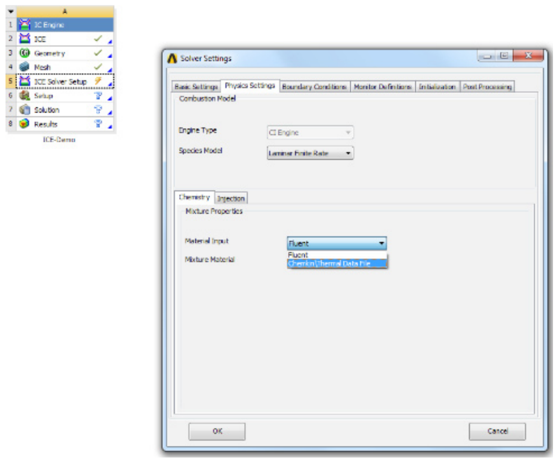


Fig: 2 Setting up of solver

IV FLUID FLOW SIMULATION & RATE OF HEAT RELEASE

The distribution of temperature and other thermal quantities under a transient thermal analysis is conducted to obtain the values of Heat transfer rate at various mass flow rates of the natural gas + air fuel mixture.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

The rate of heat transfer, pressures, temperature contours and torque are obtained for various mass flow rates. These observations were in turn used to calculate the Efficiency and Brake power.

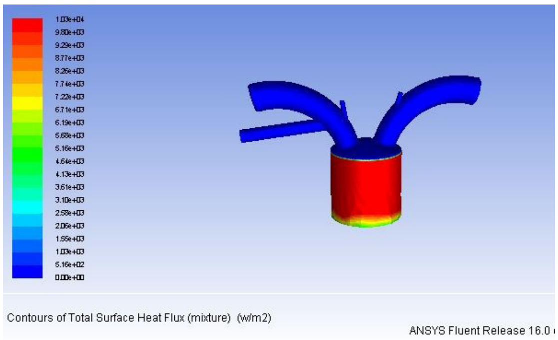


Figure 3: Total Heat Release rate

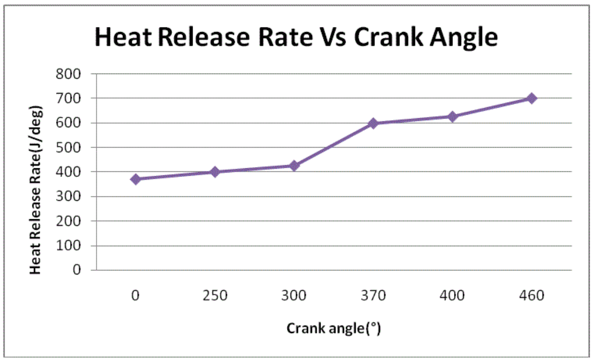


Figure 4.1: Total Heat Release rate Vs Crank Angle

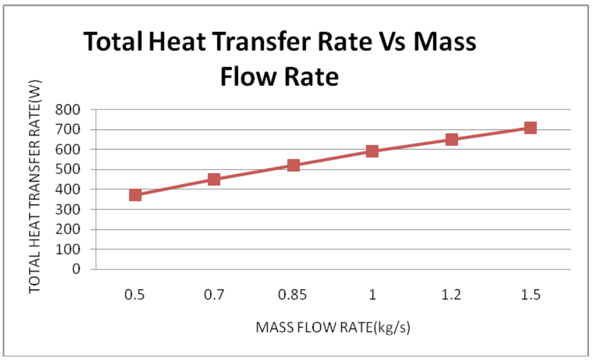


Figure 4.2: Total Heat Release rate Vs Crank Angle

COMPOSITION OF BIOGAS

The composition of biogas depends on a number of factors such as the process design and the nature of the substrate that is digested. A special feature of gas produced at landfills is that it includes nitrogen. The table below lists the typical properties of biogas from landfills, digesters and a comparison with average values for Danish natural gas for 2005.

		Landfill gas	Biogas from AD	Natural gas
Calorific value, lower	MJ/Nm³	16	23	40
	kWh/Nm³	4.4	6.5	11
	MJ/kg	12.3	20.2	48

Figure 4.3: Composition of Biogas

WHAT IS THE ENERGY CONTENT OF BIOGAS?

A typical normal cubic metre of methane has a calorific value of ca. 10 kWh, while carbon dioxide has none at all. The energy content of biogas is therefore directly related to the methane content. Thus, if biogas comprises 60 % methane, the energy content is ca. 6.0 kWh per cubic metre.

The energy content of different fuels:
1 Nm³ biogas (97 % methane) = 9.67 kWh
1 Nm³ natural gas = 11.0 kWh

Figure 4.4: Energy Content of Biogas

V. COMBUSTION SIMULATION

In the simulation of Dual Fuel Engines, the combustion modeling mainly deals with three processes, the first two being of the pilot ignition of Diesel Fuel [3] and third process is of the main combustion of the mixture of natural gas and air. The intermediate species produced by auto ignition in the first process trigger high temperature reactions subsequently in the second process which releases some heat energy. In case of Dual Fuel Engines, the heat released from the above second process ignites the main fuel consisting of natural gas + air mixture. which triggers high temperature reactions and causes the main heat release as well as further release of complete and incomplete combustion products. By choosing time scale combustion model, we can ensure the significance of effect of turbulence on the combustion process.

This combustion of dual fuel i.e. Diesel + Mixture of natural gas and air was simulated using Ansys IC Engine package. A single cylinder, single zone, multidimensional Combustion model was applied. The natural gas composition, Diesel and air properties were copied from various web resources, for combustion analysis. This combustion model includes both laminar and turbulent time scales to calculate the equilibrium concentration of each species. The major species like Methane, Ethane, Propane, Butane and other minor species like Pentane , Hexanes, Nitrogen, Carbon Dioxide, Oxygen etc were used for combustion species [2] and corresponding contours of pollutants such as HCN, NH3, NOx, CO2 etc were obtained.

VI. RESULTS AND DISCUSSIONS

1. HEAT TRANSFER RATE AT VARIOUS MASS FLOW RATES AND CRANK ANGLES

The Heat Transfer data obtained from the modeled cylinder is shown in fig.3. From the graph the heat transfer co-efficient is in the order of 1.08*102 W/m2K and the maximum heat transfer of 700 watts at a mass flow rate of 1.5 kg/sec.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

The total heat transfer rate at various mass flow rates and the total heat release rate at various crank angles were obtained. These heat values [Fig 4.1 & 4.2] were found to be comparable with the extrapolated experimental results of natural-gas based dual fuel engine1 [1]. The results of natural gas + air combustion are also in agreement with the energy content of bio gas[7] [Fig 4.3 & 4.4]. Also the maximum cycle temperature is observed to be 2160 K.

2. TORQUE VS EFFICIENCY:

After running the calculations in the post processing->Function Calculator, the torque values are obtained and observed results are plotted in a graphical format as shown below in Fig 5. Here the efficiency of the engine is calculated theoretically. Based on maximum torque of about 29 to 30 N-m.

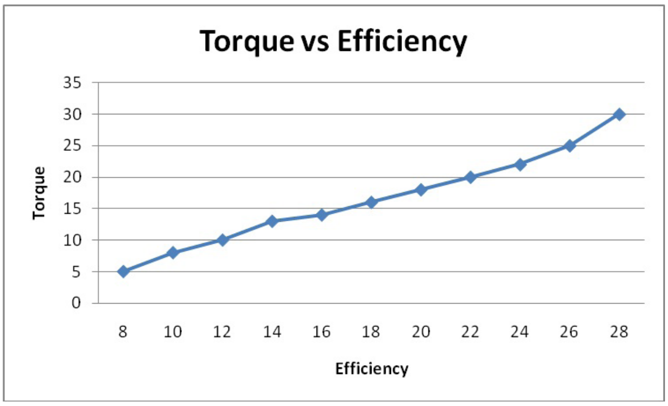


Figure 5: Torque Vs Efficiency

3. IN CYLINDER PRESSURE AND MASS FRACTION

The maximum pressure observed to be about 10.5 bars approximately as shown in the Fig. 6. The average dynamic pressure is observed to be about 50 bars as shown in the Fig. 7. A graph is drawn between mass flow rate and dynamic pressure which is shown in the Fig. 8. The contours of mass fraction are shown as in Figure 9

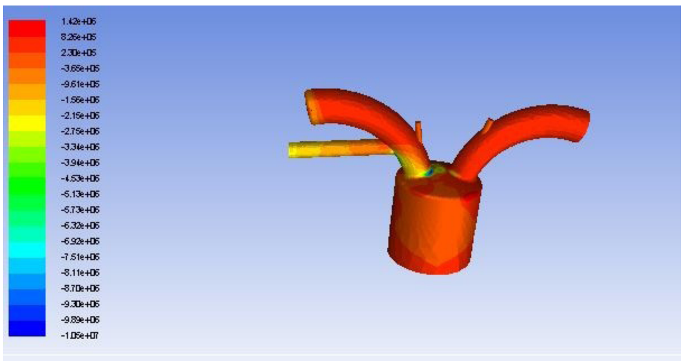


Figure 6: In cylinder pressure and Mass fraction

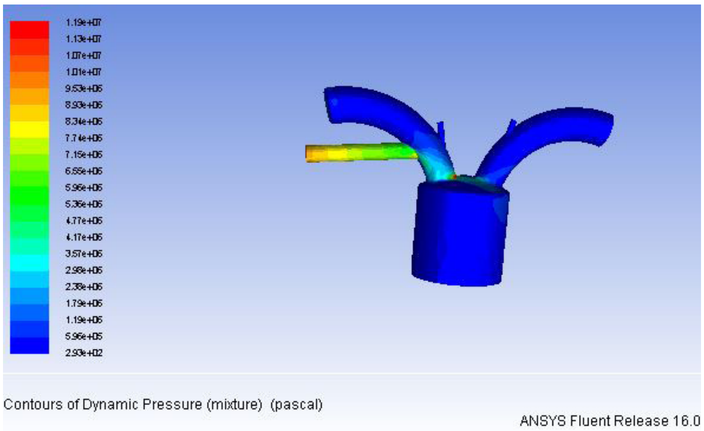


Figure 7: Average Dynamic pressure

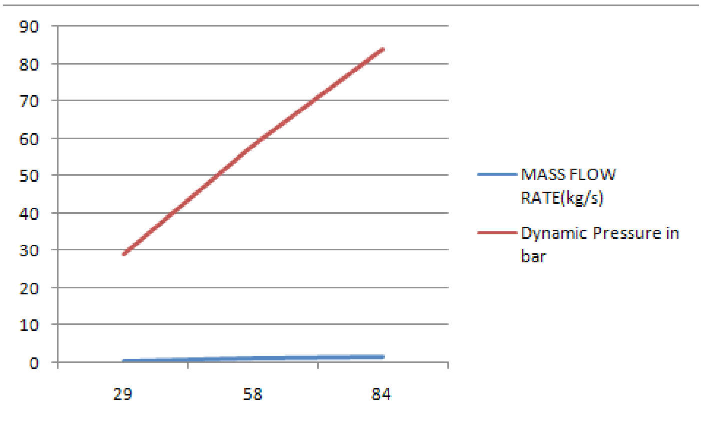


Figure 8: Average Dynamic pressure

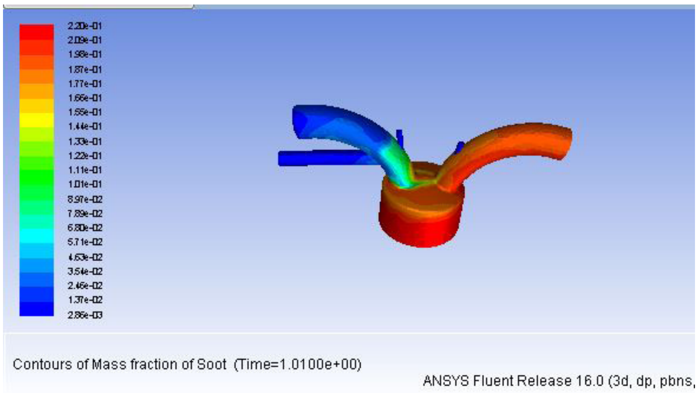


Figure 9: Contours of Mass fraction of soot

4 TEMPERATURE PROFILES

The temperatures contours are derived from the premixed combustion inside the cylinder as shown in Figure 10. Also the maximum cycle temperature is observed to be 2160 K.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

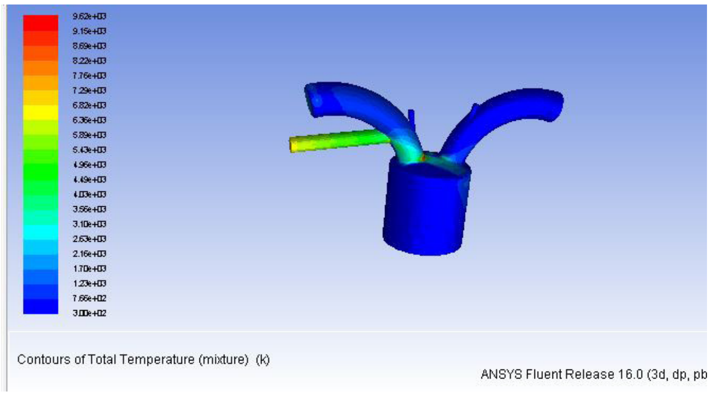


Figure 10: Contours of Total Temperature

5 COMPARISION OF BRAKE POWER OF CFD SIMULATION WITH EXPERIMENTAL SETUP

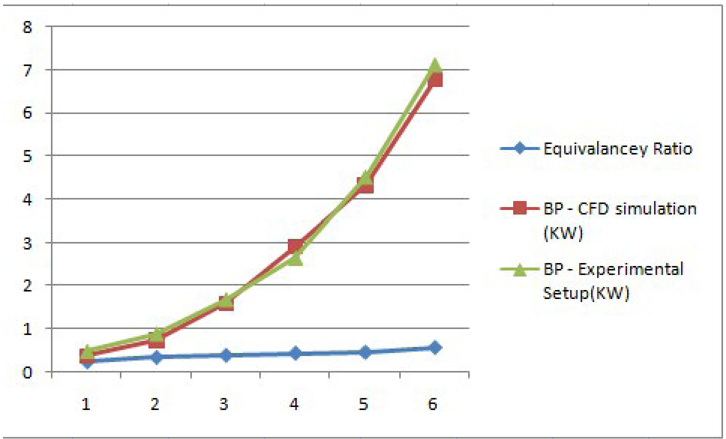
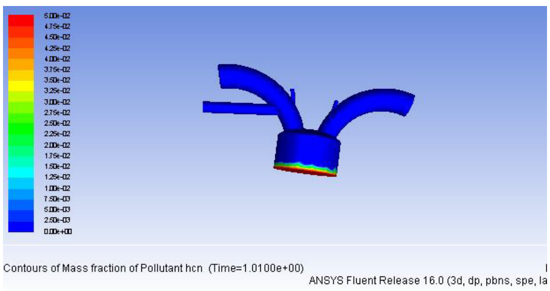
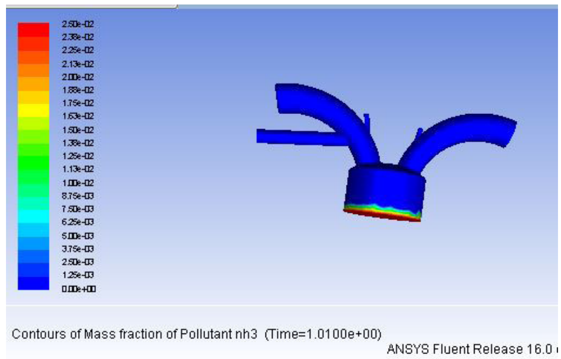


Figure 10: Comparison of Brake power of CFD Simulation with Experimental setup

6. THE MASS FRACTION OF POLLUTANTS

HCN, NH3, NOx Pollutants are observed to be as per the below figure 11, 12 &13.





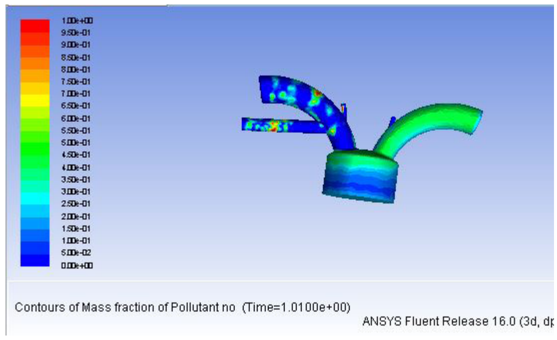


Figure 11, 12, 13: Mass fraction of Pollutants (HCN, NH3, NOx)

VII. CONCLUSIONS:

1.The model was created using Solid works, and the Heat transfer rate and combustion phenomenon was analyzed using Ansys 16 ICE. The results shows values of Heat Release, Pressure and Temperature are comparable with the Experimental Setup of dual fuel engine working on Natural Gas[1] for the same given equivalence ratio and output power. Hence the developed model is suitable for predicting the Heat transfer analysis and combustion characteristics of a Dual Fuel IC engine.

2.In the Dual Fuel ICEngine with combustion of Natural gas and air mixture, for the given compression ratio of 16:1, the heat transfer rate is observed to be about 700 Joules at about 460 degrees of crank Angle. At about 350 degrees of crank angle, the heat release rate is about 580 Joules [1], which is much higher than the heat release rate of 370 Joules as per the experimental setup of Bio-gas air mixture used for comparison[2]. The same can be verified from the fact that the Calorific Value of natural gas is about 48 MJ/Kg, which is much higher when compared to that of Biogas which is about 20.2 MJ/kg [7] as shown in figures 4.3. Similarly the energy content of natural gas is about 11 KWh for 1 Nm3 when compared with 9.67 KWh for 1Nm3 of biogas as shown in Fig 4.4.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

The results data from CFD simulation is nearly close with both the experimental and statistical information. Hence CFD simulation is a good alternative for designing and developing Dual Fuel IC engine when compared to prototyping and experimental setup which is expensive and time consuming process.

3.From the results of simulation it can be observed that the average dynamic pressure is about 50 bars at 1800 RPM in this study of natural gas-diesel duel fuel engine. The combustion pressure of LPG-Diesel dual fuel engine is about 57 bars at 1300 RPM itself [3] which support the fact that the LPG engines are poor knock resistance. Also, LNG engines have higher thermal efficiencies compared to LPG Engines [8]. Hence the Natural gas-Diesel based dual fuel engines are much preferable for the commercial vehicles & heavy engine applications.

4. The results of CFD simulation of natural-gas-diesel engine shows that the CO2 emissions are almost negligible when compared to 0.0048 as in case of Diesel only engine. Hence it is proved that the dual fuel engines are less polluting and recommended for better environment Also the Natural gas engines produce less emissions particularly NOx and other particulates. Hence the Natural-gas-Diesel can be considered as a choice for dual fuel engine compared to Diesel only engines.

5.The results of CFD simulation using Ansys 16 ICEngine package are comparable with Ansys 15 Fluent package. Hence the Ansys ICE can be used as an alternative to the Ansys Fluent to leverage the benefits already explained at the beginning of this paper.

6.The simulation results of this study with natural-gas diesel engine such as average pressure and mean temperatures are observed to be much higher when compared with a naturally aspirated gasoline direct engine[9]. Hence sufficient care is to be taken in the aspects of engine vibrations, cooling system for the engine, lubrication of engine components etc for natural-gas diesel dual fuel Engine.

7.It is possible to export the results like the heat transfer co-efficient, temperatures etc to Ansys Finite Element Solver to find the thermally induced stresses to come up with better materials to manufacture robust engines to with stand high pressures and temperatures

REFERENCES:

[1] Miqdam Tariq Chaichan et. al, Combustion of Dual Fuel Type Natural Gas/Liquid Diesel Fuel in Compression Ignition Engine e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 6 Ver. IV (Nov- Dec. 2014), PP 48-58 page | 51

[2] Shaik Magbul Hussain1*, Dr.B. Sudheer Prem Kumar2, Dr.K. Vijaya Kumar Reddy3 et. al, CFD analysis of combustion and emissions to study the effect of compression ratio and biogas substitution in a diesel engine with experimental verification, IJEST, ISSN: 0975-5462 Vol. 4 No.02 February 2012,pp2, 489, fig 25&26.

[3] B. Ashok, S. Denis Ashok, C. Ramesh ,et. al, LPG diesel dual fuel engine – A critical review Alexandria Engineering Journal (2015) 54, 105–126 | Page 105

[4] S Gavudhama Karunanidhi, Melvinraj C R, Sarath Das K P, G Subba Rao et.alCFD Studies of Combustion in Diesel Engine International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 4, Jul-Aug 2013, pp.827-830 , 828

[5] Weaver, C. and Turner, S. et. al Dual Fuel Natural Gas/Diesel Engines: Technology, Performance, and Emissions, SAE Technical Paper 940548, 1994, doi:10.4271/940548.

[6] Pawlak, G. et. al The Concept of a Dual Fuel Highly Efficient Internal Combustion Engine, SAE Int. J. Fuels Lubr. 3(2):135-141, 2010, doi:10.4271/2010-01-1480.

[7] Swedish Gas Technology Center, Basic Data on Bio Gas. http://www.sgc.se/ckfinder/userfiles/files/BasicDataonBiogas2012.pdf

[8] P. M. Darade, R. S. Dalu et al Investigation of Performance and Emissions of CNG Fuelled VCR Engine ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 1, January 2013

[9] T. Morauszki, P. Mandli, Z.Horvath, M.R Dreyer Simulation of Fluid Flow, Combustion and Heat transfer process In Internal Combustion Engines et.al Hungarian journal of Industrial chemistry Vol 39(1) pp 27-30 (2011)

[10] John J. Kargul, Director of Technology Transfer, National Center for Advanced Technology Efficient, Use of Natural Gas Based Fuels in Heavy-Duty Engines

[11] Ansys Inc, Internal Combustion Engine workbench technical guide et al https://www.academia.edu/12969241/ANSYS_Internal_Combustion_Engines_Tutorial_Guide.pdf