CFD Modelling and Analysis of Dual Fuel (Diesel + Methanol) Combustion Engine with various blend grade using ANSYS (Fluent)

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ABSTRACT - In order to develop design guidelines for optimum operations of internal combustion engines fuel with alternative fuels, comprehensive understanding combustion behaviour and the pollutant formation inside the cylinder are needed. The first part of this study aimed to numerically study the combustion performance in a CI engine fuel (Diesel) with Ethanol and Methanol. Advanced simulations were performed using multi- dimensional software Fluent coupled with CHEMKIN. Formation rates of nitrogen oxides (NOx) within the engine were accurately predicted using the extended chemkin mechanism. Multi fuel combustion is not a mature technology when compared to CI and SI combustion. Because of this it is expected that not all challenges and limitations have been encountered and documented, much less fully understood. The objective of this project is to identify, investigate and attempt to overcome known and unknown limits to dual fuel operation. Alternative fuels have been getting more attention as concerns escalate over exhaust pollutant emissions produced by internal combustion engines, higher fuel costs, and the depletion of crude oil. Various solutions have been proposed, including utilizing alternative fuels as a dedicated fuel in spark ignited engines, diesel pilot ignition engines, gas turbines, and dual fuel and bi-fuel engines.

Among these applications, one of the most promising options is the diesel derivative dual fuel engine with Alternate fuel as the supplement fuel. In present study we are using Ethanol as alternate fuel with Diesel to investigate the Dual fuel model with non-premixed & premixed combustion and compare on the basic of combustion efficiency and pollutant emissions rate like carbonic oxides and nitric oxides. Ethanol and Methanol is taking as an Alternate fuel which is cheaper in cost and easily available as compare to the conventional fuels. CFD Results shows an excellent flow phenomenon which is stable in nature and due to this the accuracy of the simulation results are higher for layer formation system in combustion. The pollutant emissions (Carbonic oxides) are decreasing in higher percentages of alternate fuels as compare to the lower one that shows the complete combustion rate is increased. NOx emissions are also decreasing in d70 model (Diesel 70% + Ethanol 15%+ Methanol 15%) model as compare to the d90 model. In second part of the study we are using chemkin mechanism for the evaluation of N0x percentages of different blends, simulation results shows that it is also decreasing with higher no of alternate fuels.

Kew words: Dual fuel engine , Diesel , Methanol, Emissions, CI engine, CFD, and Fluent etc.

1. INTRODUCTION

The demand for energy, specifically the demand for petroleum fuels around the world is increasing every day. From 2012 to 2015, 41% increase in global energy consumption is forecasted, 30% and 52% increase over last ten and last twenty years respectively. Non-OECD economies will account for 95% of this growth, half of which is expected to come from China and India. Compared to 2012, 69% higher energy will be used in 2035 in the non-OECD economics. Due to having benefits such as adaptability, high combustion efficiency, availability, reliability as well as the handling facilities, fossil fuels results in most energy consumption. Shares of the major fossil fuels are converging, with natural gas, oil and coal each contributing 27% of the total mix by 2035 and the remaining share supplied by nuclear and renewable energy. Table 1 shows the primary energy consumption by fuel type between 2012 and 2035. Burning of fossil fuels produces emissions that have serious effect on both the environment as well as human health. Fuel, coal and gas each contributes 38% of the increase in emissions and 24% increase is coming from oil. It is predicted that by 2035 global CO2 emissions from energy use will increase 29%. Compared to 1990, global emissions will be nearly double in 2035. Price hiking of the petroleum products, world-wide environmental concerns as well as the rapid depletion of fossil diesel fuel have encouraged researcher to search for alternative fuel sources which will provide cleaner combustion of diesel engines. Therefore, it has become a global agenda to develop clean alternative fuels which are domestically available, environmentally acceptable and technically feasible. According to the Energy Policy Act of 1992 (EPACT, US), natural gas, biofuel, electricity and methanol are the most suitable substitute to fossil fuels that can reduce global warming, fossil fuels consumption and exhaust emissions. As an alternative fuel, biofuel such as ethanol, biodiesel are the best choices due to having properties such as environment friendly behaviour and similar functional properties with diesel fuel. In both developing and developed countries biofuel are at the top of their agendas and thus it is predicted that world biofuel production will be quadruple by 2020.

Blended Fuel

Under section 1.8 of the National Greenhouse and Energy Reporting (Measurement) Determination 2008 (NGER Measurement Determination)) a blended fuel is a fuel that is a blend of fossil and biogenic carbon fuels. For example, E10 is a blend of gasoline (fossil fuel) and up to 10 per cent ethanol (biogenic carbon fuel).

The NGER Measurement Determination defines 'biogenic carbon fuel' as energy that is:

a) Derived from plant and animal material, such as wood from forests, residues from agriculture and forestry processes and industrial, human or animal wastes, and

b) Not embedded in the earth, like coal oil or natural gas.

Examples of biogenic carbon fuels under the NGER legislation are listed in items 10–16 and 28–30 of Schedule 1 of the National Greenhouse and Energy Reporting Regulations 2008 (NGER Regulations).
The NGER legislation does not define fossil fuels. However, taking the ordinary meaning of the term, a fossil fuel is a carbon-based fuel from fossil hydrocarbon deposits, including coal, oil and natural gas.
The problem with crude oil depletion has arisen in the last years. There has been intensive research to find out alternatives to fossil fuels. Alternative fuels are derived from resources other than petroleum. When these fuels are used in internal combustion engines, they produce less air pollution compared to gasoline and most of them are more economically beneficial compared to oil. Last but not least, they are renewable. The most common fuels that are used as alternative fuels are natural gas, propane, ethanol, methanol and hydrogen. Lots of works have been written on engines operating with these fuels individually; but a small number of publications have compared some of these fuels together in the same engine [1–4]. The idea of adding low contents of ethanol or methanol to gasoline is not new, extending back at least to the 1970s, when oil supplies were reduced and a search for alternative energy carriers began in order to replace gasoline and diesel fuel. Initially, methanol and ethanol were considered the most attractive alcohols to be added to gasoline. Methanol and ethanol can be produced from natural products or waste materials, unlike gasoline which is a non-renewable energy resource [5, 6]. One of the important features is that the ethanol and methanol can be used directly without requiring any major changes in the structure of the engine. Among the various alcohols, ethanol and methanol are known as the most suitable fuels for spark ignited (SI) engines. The use of fuel additives is very important because many of these additives can be added to fuel in order to improve its efficiency and its performance. Some of the most important additives to improve fuel performance are oxygen containing organic compounds (oxygenates). Several oxygenates have been used as fuel additives, such as methanol, ethanol, tertiary butyl alcohol and methyl tertiary butyl ether [7]. The use of oxygenated fuel additives provides more oxygen in the combustion chamber and has a great potential to reduce emissions from SI engines.

2. LITERATURE REVIEW

M. Mofijur [1] Ever increasing drift of energy consumption due to growth of population, transportation and luxurious lifestyle has motivated researchers to carry out research on biofuel as a sustainable alternative fuel for diesel engine. Biofuel such as biodiesel and ethanol, produced from renewable feedstocks, are the most appropriate alternative of petroleum fuels. However, direct using of ethanol in diesel fuel face some technical problem especially in cold weather, due to low cetane number, lower flash point and poor solubility. Biodiesel can be blended with both ethanol and diesel fuel and biodiesel–alcohol–diesel blends can be used in diesel engines. The aim of this review paper is to discuss the effect of mixed blends of biodiesel alcohol and diesel on engine performance and emission parameters of a diesel engine. Most of the researchers reported that adding ethanol into biodiesel-diesel blend in diesel engines significantly reduce HC, PM, NOx and smoke emissions but slightly increase fuel consumption. The study concluded that biodiesel-diesel-ethanol blend can be used as a substitute of petro-diesel fuel to reduce dependency on fossil fuel as well as the exhaust emissions of the engine.

Chunhua Zhang et.al [2] The diesel-LNG (liquefied natural gas) dual-fuel combustion mode was conducted on a high-pressure common-rail six-cylinder diesel engine to find an assistant parameter to assess the brake thermal efficiency (ge) and nitrogen oxides (NOx) emission of the diesel-LNG dual-fuel engine. The results show that the diesel injection timing has a prominent impact on the centroid angle of combustion duration (α) which is closely related to ge and NOx emission. At low and medium loads, when a is near to top dead center (TDC) and is after TDC, the ge and NOx emission are higher. Nevertheless, when α is before TDC, the result of NOx emission is opposite. Therefore, for optimal ge and NOx emission at low and medium loads, it would be the best way altering diesel injection timing to retard a to ATDC and ensuring a in 1–2 °CA ATDC.

Aman Hira [3] This paper is based on experimental investigation of performance and emissions of CI engine. Due to exponential growth in industrialization the demand for conventional automotive fuels is also increased sharply which adversely affects not only the economy but also the environment. This makes the search for an alternative fuel more important today. In this research the blends of ethanol & biodiesel with diesel in varying proportions are used. The performance& emission levels has been investigated under the various parameters like Brake Thermal efficiency, BSFC, BSEC, Smoke density, HC, CO & exhaust temperature. The experimental results show that the BE20 fuel gives the best performance in comparison to conventional diesel fuel along with fairly reduced exhaust emission.

Jeongwoo Lee et.al [4] Reactivity controlled compression ignition (RCCI) is one of representative dual-fuel combustion concepts for low NOx, soot emissions and high thermal efficiency. Overall lean and highly premixed auto-ignition combustion make low combustion temperature and the reduction of heat transfer loss. Although premixed compression ignition (PCI) combustion using a single fuel, i.e., diesel, also shows low emissions and higher thermal efficiency, combustion characteristics of RCCI (dual-fuel PCI) are different from single-fuel PCI due to reactivity gradient from two different fuel characteristics as well as local equivalence ratio due to the fuel distribution. Therefore, it is necessary to know the influence of above two factors on the dual-fuel combustion characteristics for better understanding of dual-fuel combustion and its effective utilization. In this research, the characteristics of dual-fuel combustion are evaluated comparing to single-fuel combustion. Also, dual-fuel combustion modes are classified according to the analysis of heat release rate (HRR) shapes. Major factors in the classification of dual-fuel combustion modes are the degree of fuel reactivity gradient and the local equivalence ratio in the cylinder. Thus, the diesel injection timing, diesel and port injected gasoline fuel ratios and the overall equivalence ratio were selected as the main variables to characterize each dual-fuel combustion mode. The result emphasizes that the dual fuel combustion could be classified as three types by HRR shapes, and it was mainly affected by reactivity gradient and overall equivalence ratio.

M.Srinivasnaik [5]The fuel which is used in Internal Combustion engines meant for transportation applications will satisfy all the requirements of cost effectiveness, maximum thermal efficiency, excellent engine performance, and still remain clean enough to protect the environment. Alcohol fuels such as methanol (CH_3OH), Ethanol (C_2H_5OH) are favorable for IC Engines because of their high octane rating, burning velocities, and wider flammability limits. Alcohols can be considered as attractive alternative fuels because they can be obtained from both natural and manufactured sources. The air quality deterioration is a vital issue that needs to be seriously monitored and limited. The transportation system is a major air pollution contributor due to the exhaust emissions such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NOx), carbon dioxide (CO_2), and particulate matter (PM). Extensive research and development is difficult to justify until the fuels are accepted as viable for large numbers of engines. Liquid fuels are preferred for Internal Combustion Engines because they are easy to store and have reasonably good calorific value. The main alternative is the alcohol. Methanol and ethanol are two kinds of alcohols that seem most promising fuels and will likely play an increasingly important role in the future. In this review, the physical and the combustion characteristics of alcohols have been discussed briefly after comparing with the diesel. The production methods of alcohols have been discussed. The safety aspects of alcohols have also been discussed.

Carmelina Abagnale et.al [6] the effect of different fuel ratios on the performance and emission levels of a common rail diesel engine supplied with natural gas and diesel oil. Dual fuel operation is characterized by a diesel pilot injection to start combustion in an intake port premixed NG/air mixture. The combined numerical – experimental study of the dual fuel diesel engine that is carried out in this paper aims at the evaluation of the CFD potential to predict the main features of this particular engine operation. The experimental investigations represent a tool for validating such a potential and for highlighting, at the same time, the major problems that arise from the actual engine operation with different NG / diesel oil fuel ratios.

3. OBJECTIVE OF THE STUDY

The purpose of this study is to seek out the proportion of NOx after the combustion of Dual fuels. From this study our main interest is which can facilitate to reduce the formation of air pollution and acidic rain and lots of alternative harmful effects. computational fluid dynamics may be a widely used tool in optimizing fossil fuel burners, for example, emission problems and also the method of combustion of fossil fuel to sight the NOX formation like mass fraction of NO, NO_2 and N_2O. In order to save lots of procedure time, the flow is sculptured with an axis-Symmetrical formulation in fluent Ansys 14.5. In current study we will investigate the proper mixing of chemical species and the combustion of dual fuel (Diesel +Methanol) with various blend grade like M5, M10, M15, M20 and M25. Present study we use one conventional and other is Alternate fuels due to challenges in power sector. A cylindrical combustor burning (Diesel + Methanol) in air is studied using the eddy-dissipation model in ANSYS (Fluent). Our main objective of the study is to analyze the dual fuel combustion model with both type of mixing method Premixed and non-premixed type of combustion and compared on the basic of emissions (COx & NOx) and combustion efficiency.

PROBLEM FORMULATION

The cylindrical combustor considered in Present study is shown in Figure 1. The flame considered is a turbulent diffusion flame. A small nozzle in the centre of the combustor introduces (Diesel + Methanol) at 80 m/s. Ambient air enters the combustor coaxially at 0.5 m/s .The overall equivalence ratio is approximately 0.76 (approximately 28% excess air).The high-speed methane jet initially expands with little interference from the outer wall and entrains and mixes with the low-speed air. The Reynolds number based on the dual fuel jet diameter is approximately $5.7x10^{-3}$ mm.

METHODOLOGY

5. 1 Basic Steps to Perform CFD Analysis

5.1.1 Pre-processing: CAD Modeling: Creation of CAD Model by using CAD modeling tools for creating the geometry of the part/assembly of which you want to perform FEA.CAD model may be 2D or 3d.

5.1.1.1 Meshing: Meshing is a critical operation in CFD. In this operation, the CAD geometry is discretized into large numbers of small Element and nodes. The arrangement of nodes and element in space in a proper manner is called mesh. The analysis accuracy and duration depends on the mesh size and orientations. With the increase in mesh size (increasing no. of element), the CFD analysis speed decrease but the accuracy increases.

5.1.1.2 Type of Solver*:* Choose the solver for the problem from Pressure Based and density based solver.

5.1.1.3 Physical model: Choose the required physical model for the problem i.e. laminar, turbulent, energy, multi-phase, etc.

5.1.1.4 Material Property: Choose the Material property of flowing fluid.

5.1.1.5 Boundary Condition: Define the desired boundary condition for the problem i.e. temperature, velocity, mass flow rate, heat flux etc.

5.2 SOLUTION

- **Solution Method :** Choose the Solution method to solve the problem i.e. First order, second order
- **Solution Initialization:** Initialized the solution to get the initial solution for the problem.
- **Run Solution:** Run the solution by giving no of iteration for solution to converge.

5.3 Post Processing: For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

5.4 CFD METHOD APPLIED

The model was simulated and the required geometry configurations were pre-processed in ANSYS 14.5. This following section illustrates the method used in the CFD simulations in this particular study.

STEP I GEOMETRY OR MODEL FORMATION

The study focuses on the to calculate the NOx percentage and the geometry used for the simulations is therefore only a part of the whole exhaust gas system in order to save computational time. The generation of the model by using ANSYS shown below:-

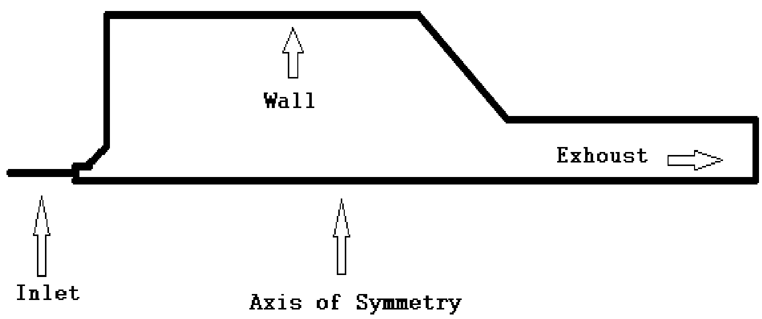

Figure 5.1 CAD MODEL

STEP 2 Mesh Generation:

Figure 5.2 MESH MODEL

STEP 3 CHECK THE MESH: -

Various checks on the mesh and reports the progress in the console. Also check the minimum volume reported and make sure this is a positive number select mesh to mm.

METHODS

1. Pressure based

2. 2D Model is used.

3. Gravity is enabling

4. Select Axisymmetric in the 2D Space list.

MODEL

1. Energy equation is enabled.
2. K-Epsilon turbulence model used.
3. Non-Premixed condition is used.
4. P-1 radiation model is used, since it is quicker to run. However DO radiation model can be used for more accurate results in typical models.
5. Finite rate / eddy dissipation in turbulence chemistry. Interactions are used for species model.

STEP 4 SIMULATION SET UP

5.5 Boundary conditions

1. Mass Flow Air inlet: - Mass flow rate is 0.5 kg/s,
2. Mass flow Fuel inlet – 0.05 kg/ s of Mixture
3. Outlet – pressure based.

5.6 MATERIAL

1. Diesel+ Ethanol + Methanol- In Present study we have used five different type of blends and analyze by CFD tools on the basis of temperature, velocity, pressure and emissions like Cox and NOx.

2. Mixture: - Species I H_20, II-O2, III-Fuel **-EG**, IV-CO_2, V-N2

Reactants	Stoichmetric Coefficient	Rate exponent	Products	Stoichmetric Coefficient	Rate exponent
Fuel	1	1	CO2	1.022	0
O2	7.52	1	H2O	20.22	0

1. Mixing law is used.

2. Thermal conductivity: - Define two polynomial coefficients

(a) 0.0054289 (b) $7.45178*10^{-6}$

3. Polynomial coefficient for viscosity

(a) 6.4152e-06 (b) 4.9148e-8

4. For absorption coefficient take stable domain.

5. Scattering coefficient is 1.1e-7.

STEP 5 SOLUTIONS

Method

1. Coupled
2. Presto model is used:-

Presto model is often used for buoyant flows where velocity vector near walls may not align with the wall due to assumption of uniform pressure in the boundary layer so presto can only be used with quadrilateral.

NOTE: - Higher time scale size is used for the energy and species equation to converge the solution in less number of iterations.

SOLUTION INITIALISATION: - The solution is initialized

RUN CALCULATION: - Start the calculation for 2000 iterations.

6. RESULTS

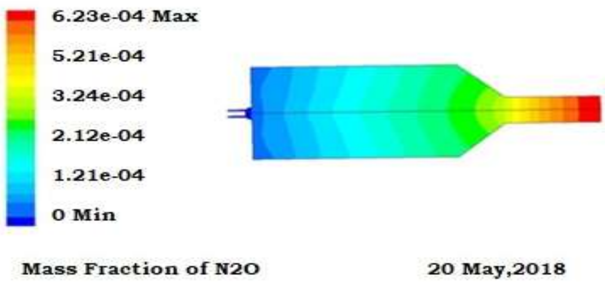

Figure 1: D70 Mass Fraction of N2O

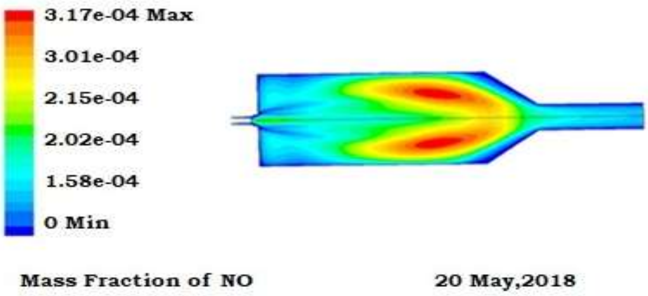

Figure 2: D70 Mass Fraction of NO

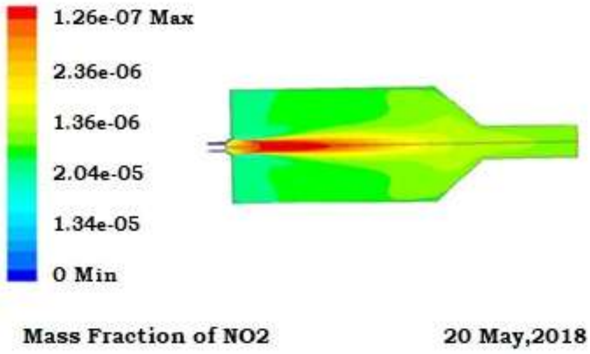

Figure 3: D70 Mass Fraction of NO2

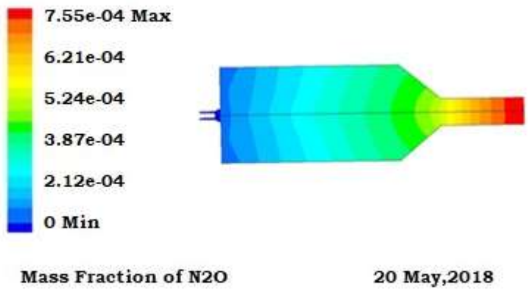

Figure 4: D80 Mass Fraction of N2O

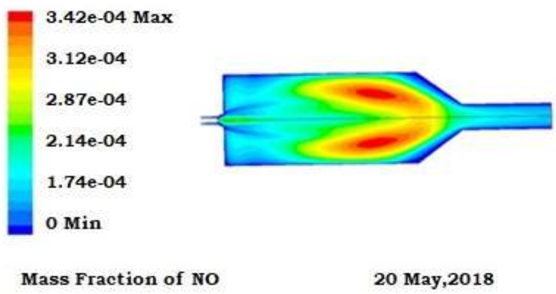

Figure 5: D80 Mass Fraction of NO

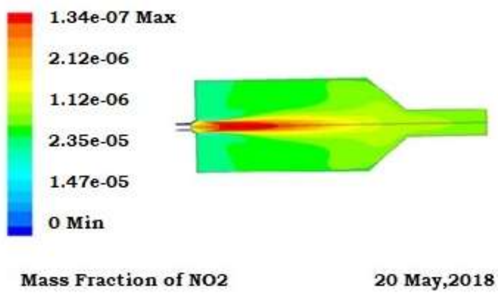

Figure 6: D80 Mass Fraction of NO2

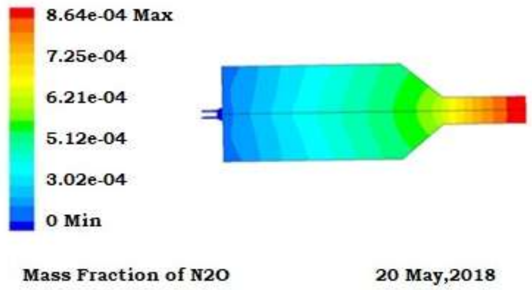

Figure 7: D90 Mass Fraction of N2O

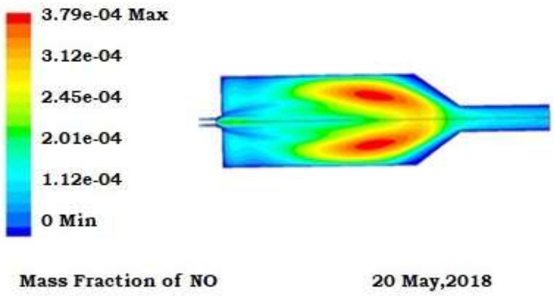

Figure 8: D90 Mass Fraction of NO

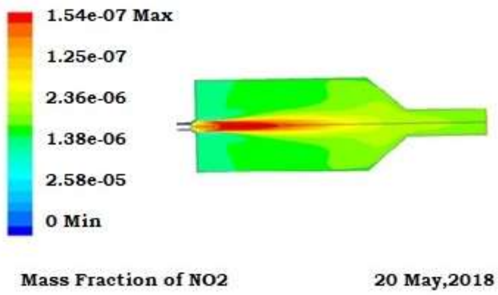

Figure 9: D90 Mass Fraction of NO2

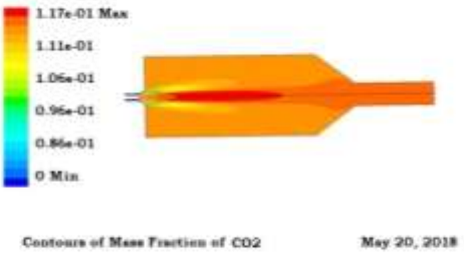

Figure 10: MASS FRACTION CO2 D70

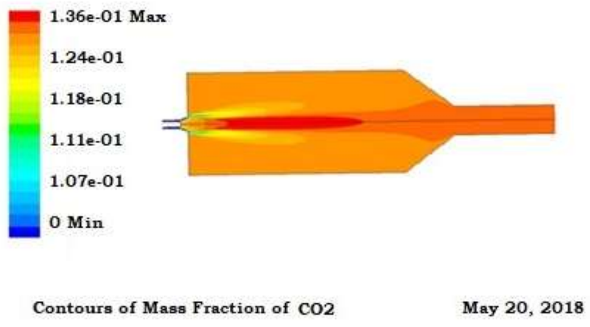

Figure 11: MASS FRACTION CO2 D80

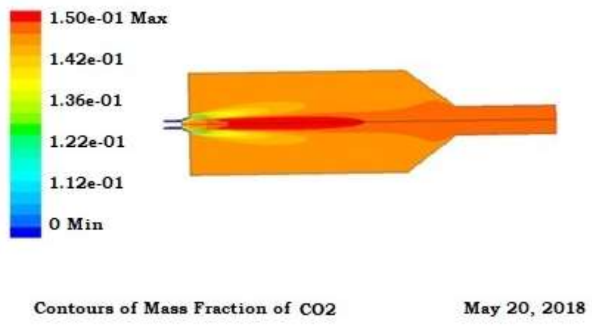

Figure 12: MASS FRACTION CO2 D90

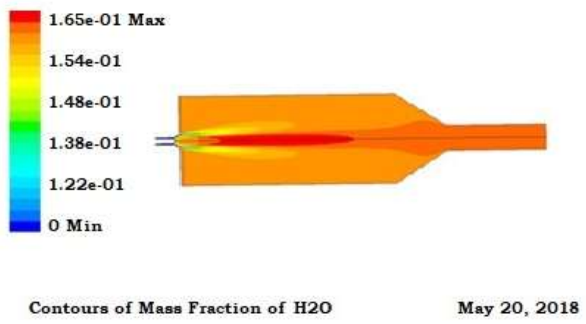

Figure 13: MASS FRACTION H2O D70

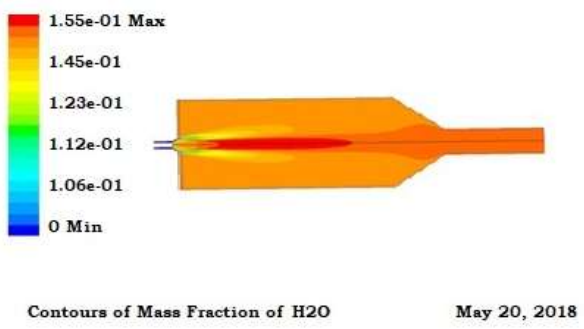

Figure 14: MASS FRACTION H2O D80

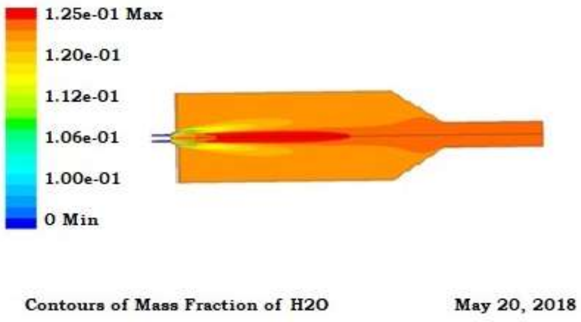

Figure 15: MASS FRACTION H2O D90

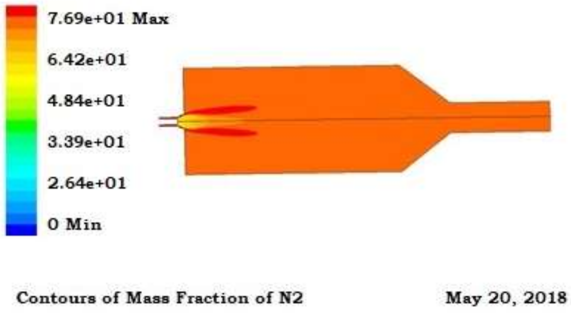

Figure 16: MASS FRACTION N2 D70

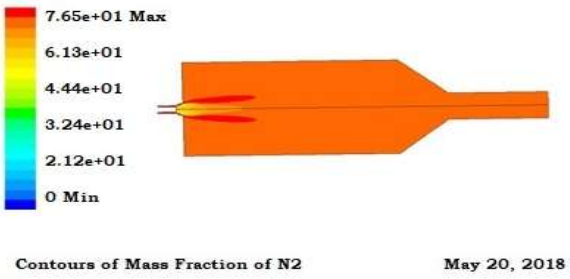

Figure 17: MASS FRACTION N2 D80

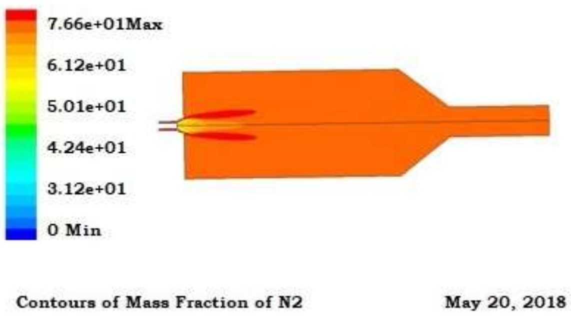

Figure 18: MASS FRACTION N2 D90

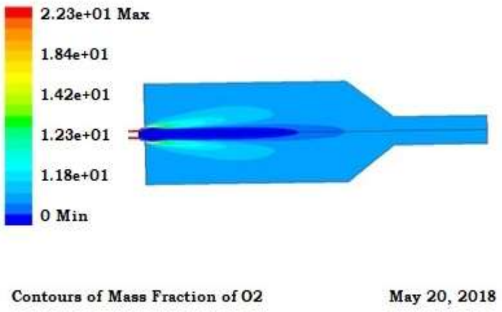

Figure 19: MASS FRACTION O2 D70

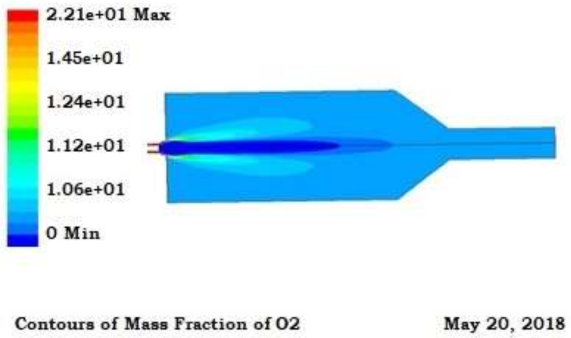

Figure 20: MASS FRACTION O2 D80

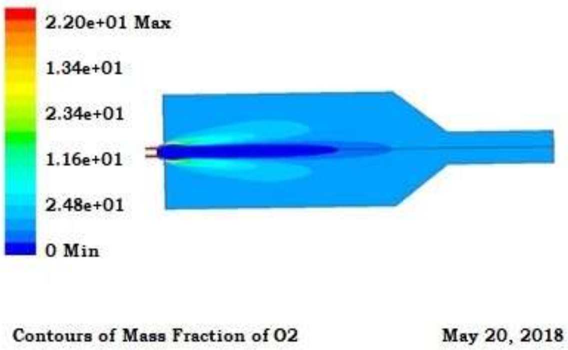

Figure 21: MASS FRACTION O2 D90

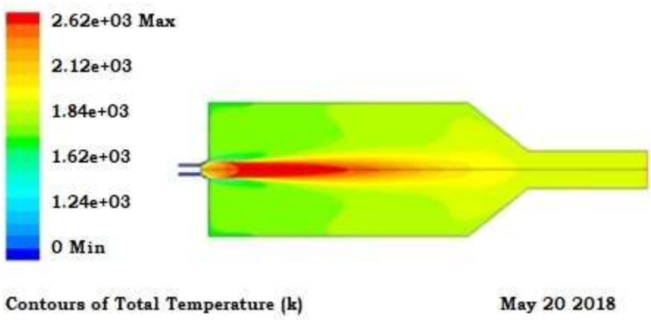

Figure 22: TEMP D70

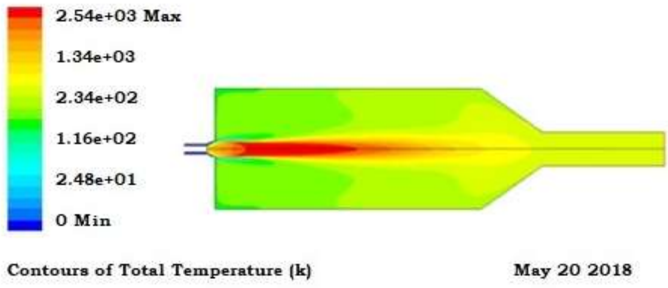

Figure 23: TEMP D80

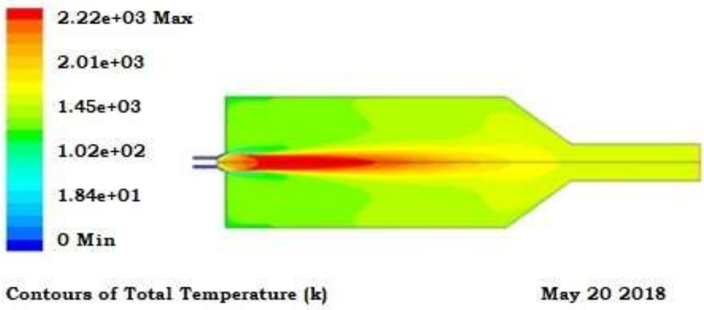

Figure 24: TEMP D90

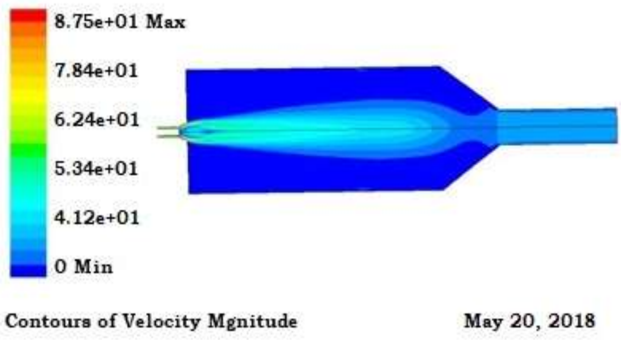

Figure 25: Velocity D70

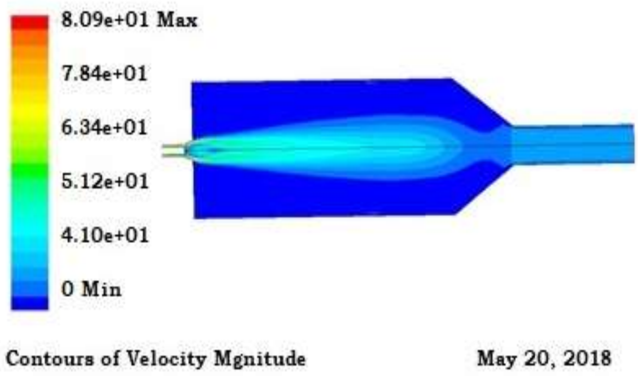

Figure 26: Velocity D80

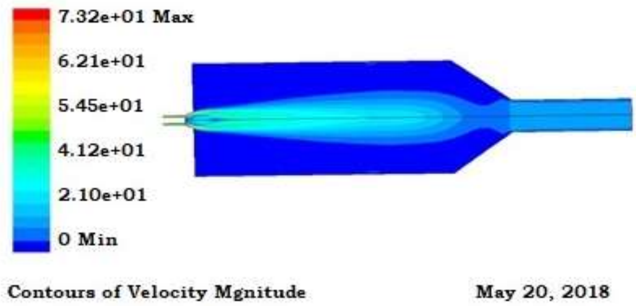

Figure 27: Velocity D90

RESULTS TABLE No.1

Dual fuel (Diesel+Methanol)	Diesel 90%+Ethanol 5%+Methanol 10%)	Diesel 80%+Ethanol 10%+Methanol 10%)	Diesel 70%+Ethanol 15%+Methanol 15%)
Total Temperature (K)	2.22e+03	2.54e+03	2.62e+03
Velocity (m/s)	7.32e+01	8.09e+01	8.75e+01
Mass fraction of N2	7.66e+01	7.65e+01	7.69e+01
Mass fraction of O2	2.20e+01	2.21e+01	2.23e+01
Mass fraction of H2O	1.25e-01	1.55e-01	1.65e-01
Mass fraction of CO2	1.50e-01	1.36-01	1.17e-01

RESULTS TABLE No. 2

Dual fuel (Diesel+Ethanol)	Diesel 90%+Ethanol 5%+Methanol 5%)	Diesel 80%+Ethanol 10%+Methanol 10%)	Diesel 70%+Ethanol 15%+Methanol 15%)
Mass fraction of NO_2	1.54e-07	1.34e-07	1.26e-07
Mass fraction of NO	3.79e-06	3.42e-06	3.17e-06
Mass fraction of N_2O	8.64e-04	7.55e-04	6.23e-04

CONCLUSION

In present study we investigate the Multi fuel system (Diesel + Ethanol+ Methanol) with premixed model and compare the results basic of Temperature, Flame phenomenon, Stability and Pollutant emissions like carbonic oxides and Nitric oxides. Simulation results shows in table no. 1 that temperature is increasing with increase in percentages of alternate fuels and rapid mixing is occurred. The pollutant emissions (Carbonic oxides) are decreasing in higher percentage of alternate blends as compare to the lower one that shows the complete combustion rate is increased. In second part of the study we are using Chemkin (Chemical kinetic) mechanism for evaluating the NOx pollutant which is responsible for thermal NOx. CFD Simulation results in Table no. 2 are clearly shows that mass fraction of NO, NO2 and N2O is decreasing as we increasing the percentages of ethanol and methanol. In current work we are taking Ethanol and Methanol as a Alternate fuel which is cheaper in cost and easily available as compare to the conventional fuels.

REFERENCES

1. M. MofijurRecent Developments on Internal Combustion Engine Performance and Emissions Fuelled With Biodiesel-Diesel-Ethanol BlendsProcedia Engineering 105 (2015) 658 – 664.

2. Kamaltdinov V.G.Modeling the combustion process of a powerful diesel engineProcedia Engineering 129 (2015) 488 – 494

3. AmanHiraPERFORMANCE & EMISSION CHARACTERISTICS OF CI ENGINE USING BLENDS OF ETHANOL AND BIODIESEL WITH DIESEL International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 5, July - 2012 ISSN: 2278-0181

4. MuruganSivalingamValidation of some engine combustion and emissionparameters of a bioethanol fuelled DI diesel engineusing theoretical modellingAlexandria Engineering Journal (2015) 54, 993–1002

5. M.SrinivasnaikAlcohols as Alternative Fuels for Diesel Engines:A REVIEWI international Journal for Research in Applied Science & EngineeringTechnology (IJRASET) Volume 3 Issue VI, June 2015 IC Value: 13.98 ISSN: 2321-9653

6. Haozhong HuangThe potentials for improving combustion performance andemissions in diesel engines by fuelingnbutanol/diesel/PODE3-4 blendsEnergy Procedia 105 (2017) 914 – 920ScienceDirectThe 8th International Conference on Applied Energy – ICAE2016

7. Scott L. Springer Experimental Evaluation of Alternative Fuels for Internal Combustion Engines Session ETD 445 Proceedings of the 2013 Conference for Industry and Education Collaboration.

8. MidhatTalibiCombustion and exhaust emission characteristics, and in-cylinder gascomposition, of hydrogen enriched biogas mixtures in a diesel engineEnergy 124 (2017) 397e412.

9. Kamaltdinov V.G.Modeling the combustion process of a powerful diesel engineProcedia Engineering 129 (2015) 488 – 494

10. MuruganSivalingamValidation of some engine combustion and emissionparameters of a bioethanol fuelled DI diesel engineusing theoretical modellingAlexandria Engineering Journal (2015) 54, 993–1002

11. Haozhong HuangThe potentials for improving combustion performance andemissions in diesel engines by fuelingnbutanol/diesel/PODE3-4 blendsEnergy Procedia 105 (2017) 914 – 920ScienceDirectThe 8th International Conference on Applied Energy – ICAE2016

12. MidhatTalibiCombustion and exhaust emission characteristics, and in-cylinder gascomposition, of hydrogen enriched biogas mixtures in a diesel engineEnergy 124 (2017) 397e412.

13. HimsarAmbaritaPerformance and emission characteristics of a small diesel enginerun in dual-fuel (diesel-biogas) modeCase Studies in Thermal Engineering 10 (2017) 179–191

14. FtwiYohanessHagosEffect of Air-fuel Ratio on the Combustion Characteristics of Syngas(H2:CO) in Direct-injection Spark-ignition EngineEnergy Procedia 61 (2014) 2567 – 2571Peer-review under responsibility of the Organizing Committee of ICAE2014doi: 10.1016/j.egypro.2014.12.047The 6th International Conference on Applied Energy – ICAE2014

15. Daniel CarderEmissions Control Challenges for Compression Ignition EnginesProcedia IUTAM 20 (2017) 103 – 1114th International Congress of Theoretical and Applied Mechanics

16. YanuandriPutrasariThe 8th International Conference on Applied Energy – ICAE2016Energy Procedia 105 (2017) 1743 – 1750

17. SakdaThongchaiInfluence of Injection Strategy on a Compression Ignition Engine Fueled with GasolineEnergy Procedia 105 (2017) 1757 – 1763The 8th International Conference on Applied Energy – ICAE2016

18. Vu Dinh NamStudy on Auto-Ignition Characteristics of Gasoline-Biodiesel Blend Fuel in a Rapid Compression Expansion MachineEngineering Science and Technology, an International Journal 19 (2016) 438–443

19. P. BaskarEffects of oxygen enriched combustion on pollution and performance characteristics of a diesel engineEngineering Science and Technology, an International Journal 19 (2016) 438–443