CFD ANALYSIS OF COMBUSTION ENGINE WITH DUAL FUEL

Sanjiv Khare[1], Dr. Nitin Shrivasatav[2]

[1]Research Schalar, Department of Mechanical Engineering, RGPV Bhopal

[2]Prof., Department of Mechanical Engineering, RGPV Bhopal

Abstract: The combustion research is more extensive, diverse and interdisciplinary due to a powerful modelling tool like the Computational Fluid Dynamics (CFD). In CI engine, the in-cylinder multiphase fluid dynamics like fuel spray, chemical reaction kinetics influence the combustion. The fluid flow in an internal combustion engine presents one of the most challenging fluid dynamics problems to the model. In the present study we have used Methanol 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 etc.

Keywords: CFD, Dual Fuel, Combustion, CI Engine, Emission

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. 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 CO_2 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 methanol, 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.

2. PROBLEM FORMULATION

Diesel engines are used widely around the globe as power plants for various purposes due to their excellent drivability and economy. But they are also the major contributors of air pollutants such as CO, NOx, PM and other harmful compounds. At the same time the global fuel crises and increase in fuel prices have led us to the need of developing an alternate fuel that would give a solution to these problems. For about a decade researches and investigations were conducted on the use of methanol-diesel blend as a fuel in diesel engines. Many proposals were made and few are commercially implemented. Many of the results comes to a conclusion that methanol diesel blend could solve the problems mentioned above. The aim of this work is to find the optimum methanol-diesel blend that suits the diesel engines presently available in the market and could be used without much modification in the engine.

3. COMPUTATIONAL DOMAIN

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 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.

4. BOUNDARY CONDITIONS

The models have been used for the combustion are classified as zero-dimensional, single zone to multi-zone and multi-dimensional models. The Two zone flamelet model is a fractal-based combustion model which considers the possible finite pre-combustion air/fuel mixing and is therefore able to cope with both premixed and non-premixed burning conditions. It also has the advantage of high computational efficiency [2]. The Richardo two zone flame let (RTZF) combustion model is based on a “Two-Zone” assumption whereby each computational cell is notionally divided into burned and unburned zones; the unburned zone is further divided into segregated and mixed regions. It is assumed that only in the mixed region that the air and fuel are mixed at the molecular level and ready for chemical reactions [1,4]. In non-premixed combustion, non-premixed fuel and air are located in the segregated region in the unburned zone, their mixing is continuously calculated. The newly mixed reactants are transferred into the mixed region where they are consumed by combustion. The combustion products are finally passed into the burned zone. In purely premixed combustion, the calculation of mixing process is not required.

5. MATERIAL

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

2. Mixture: - Species I H_2O, II-O_2, III-Fuel -EG, IV-CO_2, V-N_2

Reactants	Stoichmetric Coefficient	Rate exponent	Products	Stoichmetric Coefficient	Rate exponent
Fuel	1	1	CO_2	1.022	0
O_2	7.52	1	H_2O	20.22	0

6. RESULTS AND DISCUSSION

6.1 TEMPERATURE DISTRIBUTION

The initial flame occurs from the centre of the model and propagated towards the wall. At the early stage of combustion have certain characteristics of premixed burning. The spray and flame reaches the edge of piston bowl very quickly. It was observed from the temperature profile that the remaining unburnt fuel mixture burns at the end of the working stroke. The temperature at the end of working stroke increases slightly due to burning of small quantities of unburnt mixture

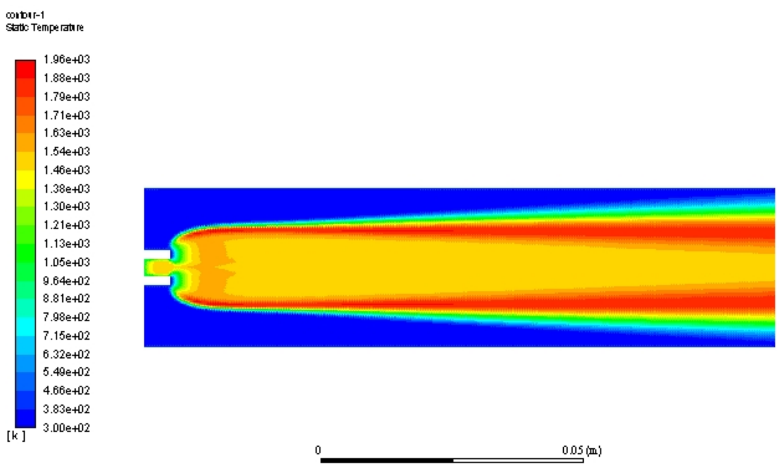

Fig. 1: Temperature contour with 100% Diesel

Figure 1 shows the temperature distribution in engine. The peak heat release rate increases with an increase in methanol concentration in the diesel. The methanol as an oxygenator improves combustion for all fuel blends and faster laminar flame speed of methanol that results in sudden heat release rate than that of diesel. The heat release curve has slightly negative depression during the ignition delay period. This is due to loss of heat from the cylinder during fuel vaporization phase. During the premixed combustion, higher heat is released with methanol blend than diesel due to higher ignition delay, which may be due to higher latent heat of evaporation and lower cetane number of methanol in the blend.

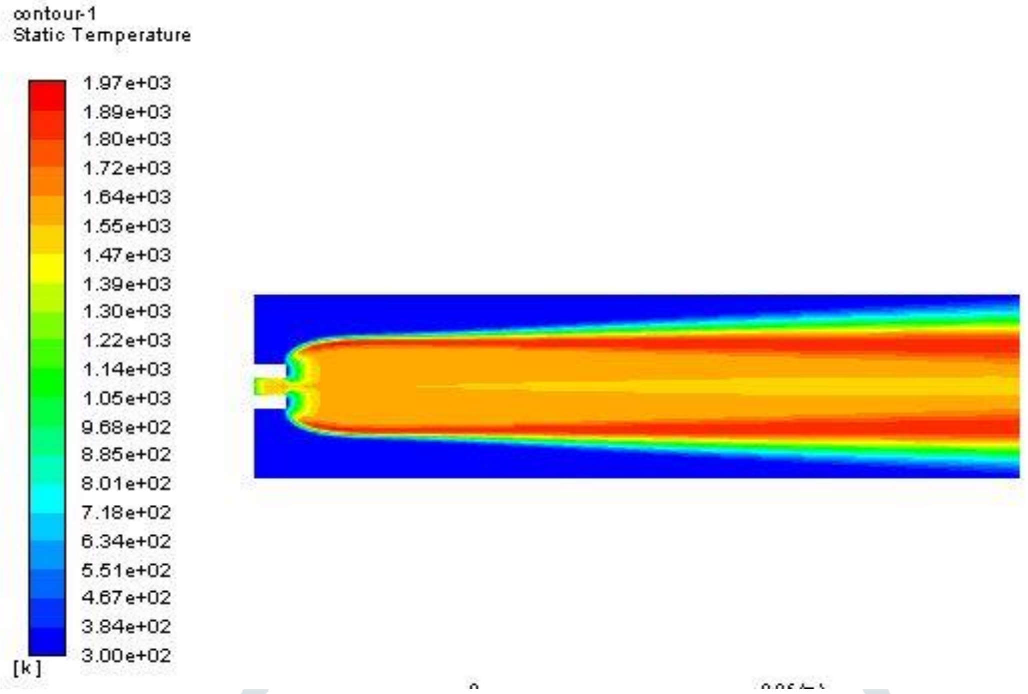

Fig. 2: Temperature contour with 20% methanol and 80% diesel

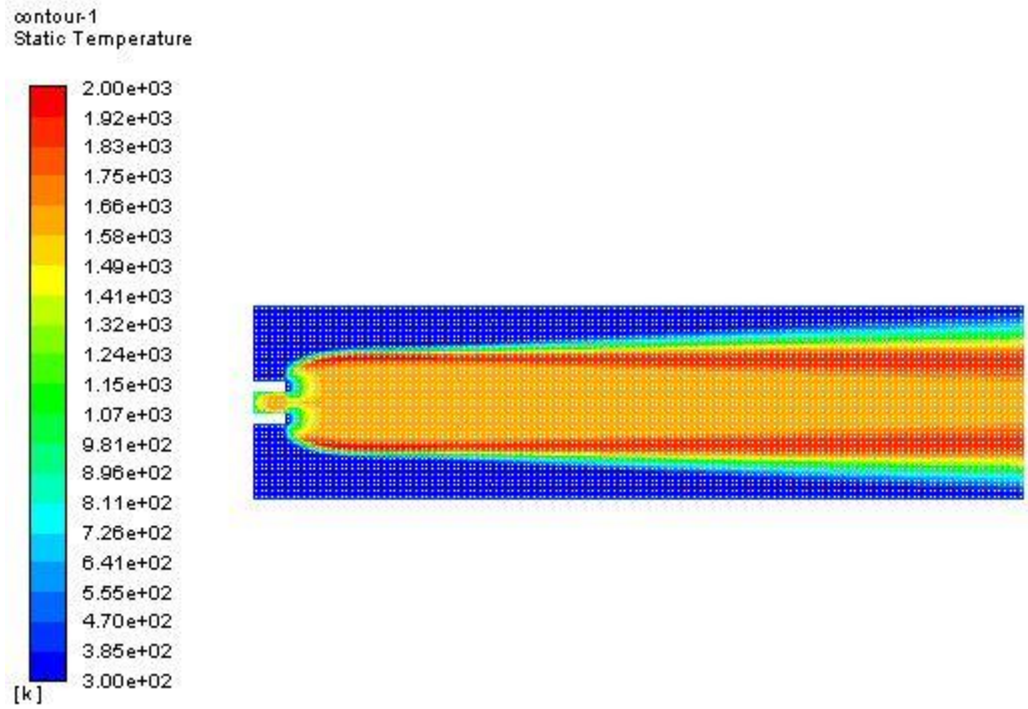

Fig. 3: Temperature contour with 40% methanol and 60% diesel

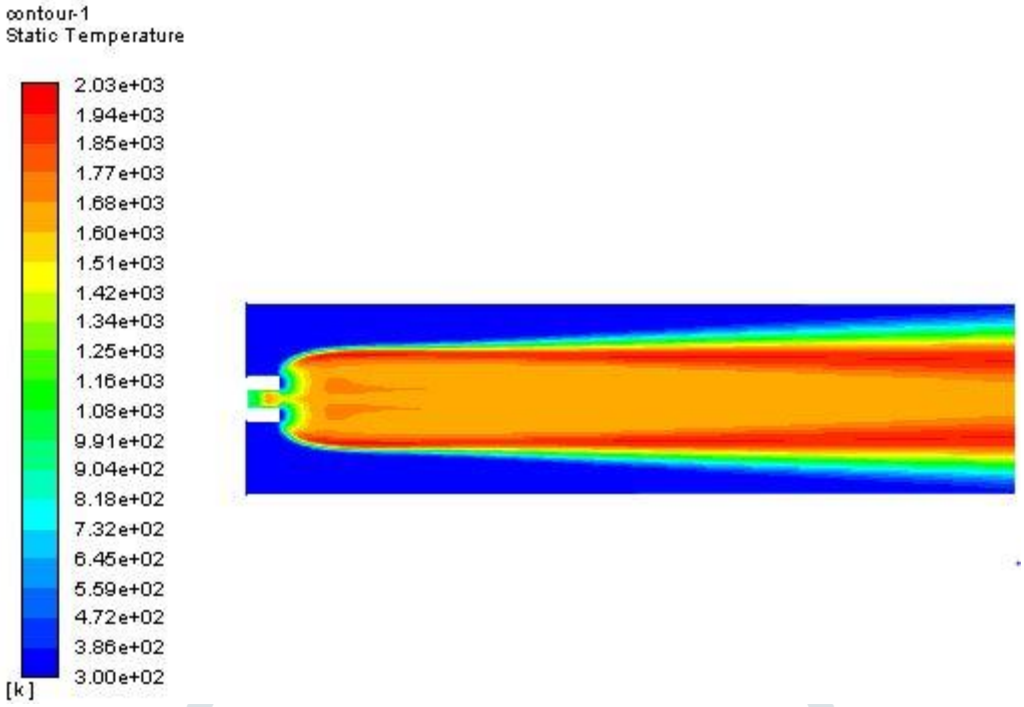

Fig. 4: Temperature contour with 60% methanol and 40% diesel

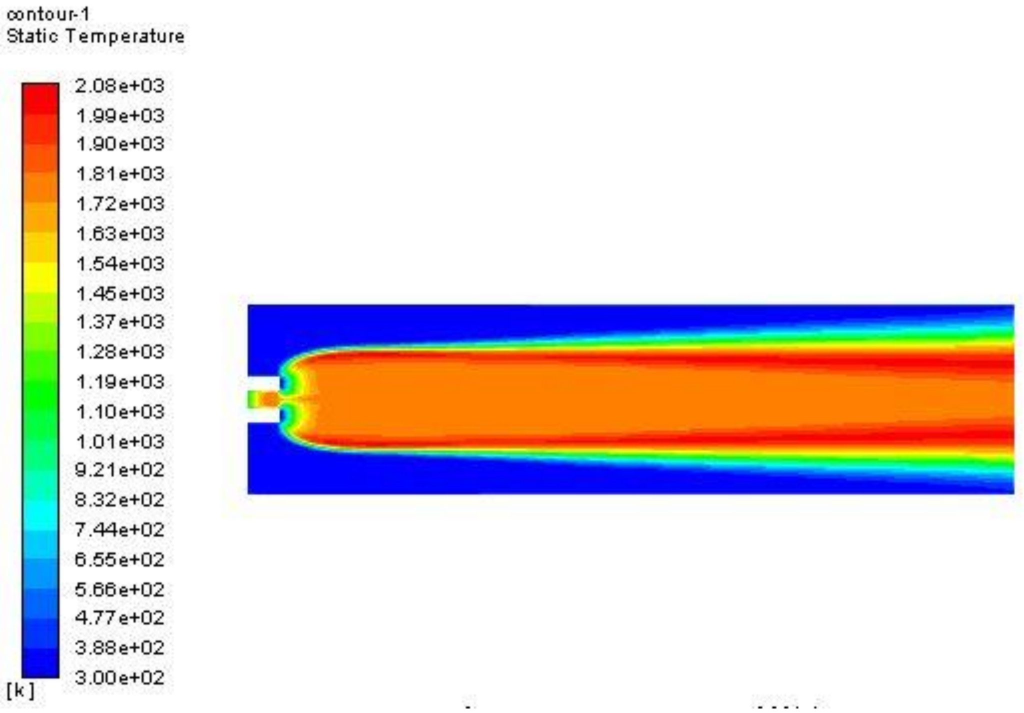

Fig. 5: Temperature contour with 80% methanol and 20% diesel

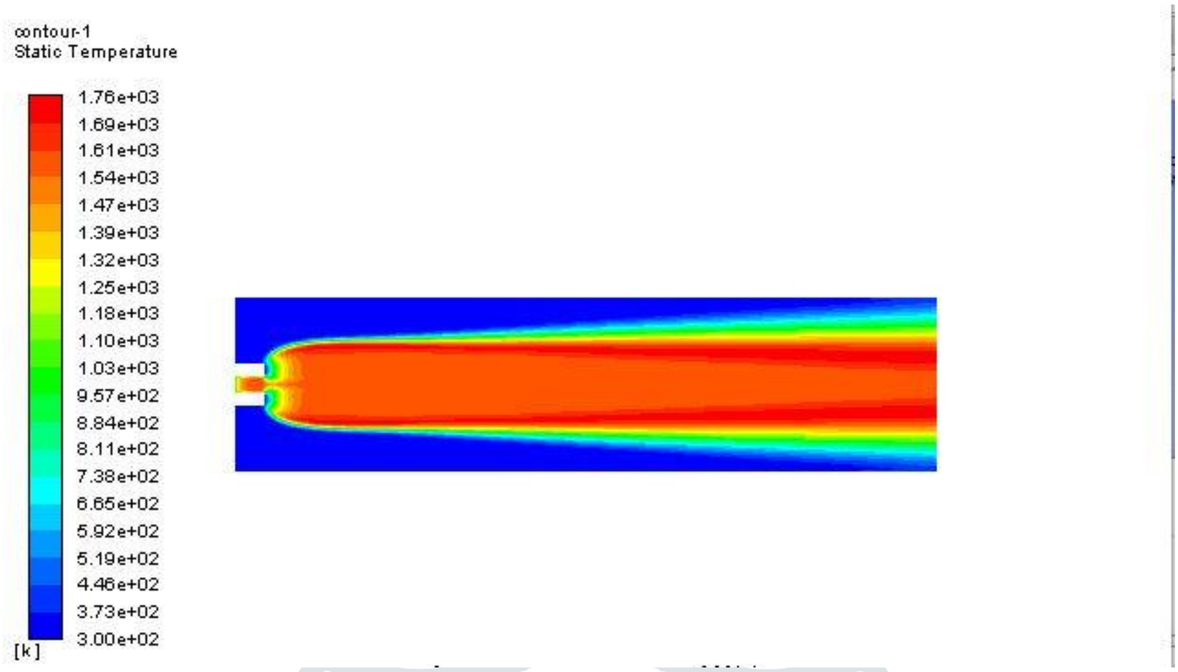

Fig. 6: Temperature contour with 100% methanol

Figure 6 shows the temperature distribution in engine. In this temperature contour diesels include 20% and methanol includes 80%. The peak temperature, predicted using a constant heat capacity is over 2080 K .This over prediction of the flame temperature can be remedied by a more realistic model for the temperature and composition dependence of the heat capacity. The mixture specific heat is largest where the fuel is concentrated, near the fuel inlet, and where the temperature and combustion product concentrations are large. The increase in heat capacity, relative to the constant value used before, substantially lowers the peak flame temperature.

6.2 TOTAL ENERGY DISTRIBUTION

The fixed length option is useful when the vector magnitude varies dramatically. With fixed length vectors, the velocity magnitude is described only by colour instead of by both vector length and colour. The entrainment of air into the high-velocity dual fuel mixture is clearly visible in the streamline display.

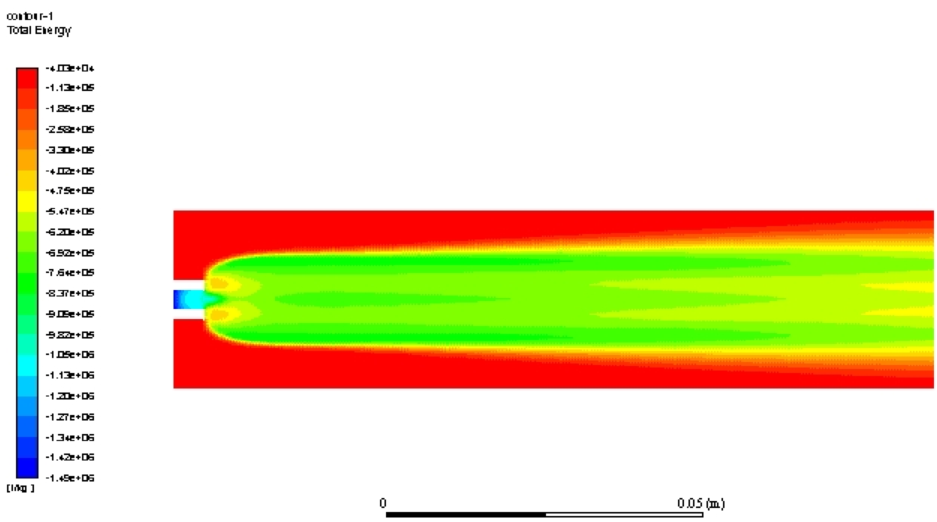

Fig. 7: Total energy when 100% diesel

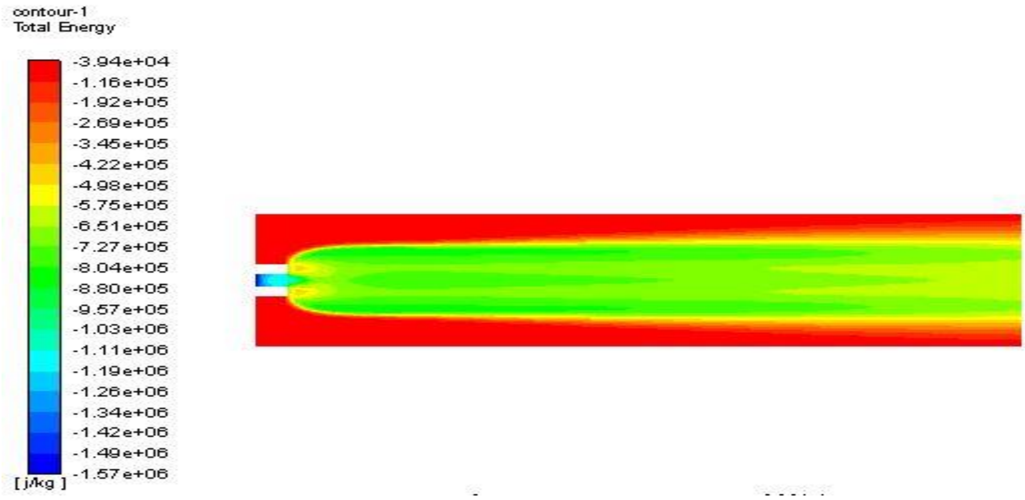

Fig. 8: Total energy when 20% methanol and 80% diesel

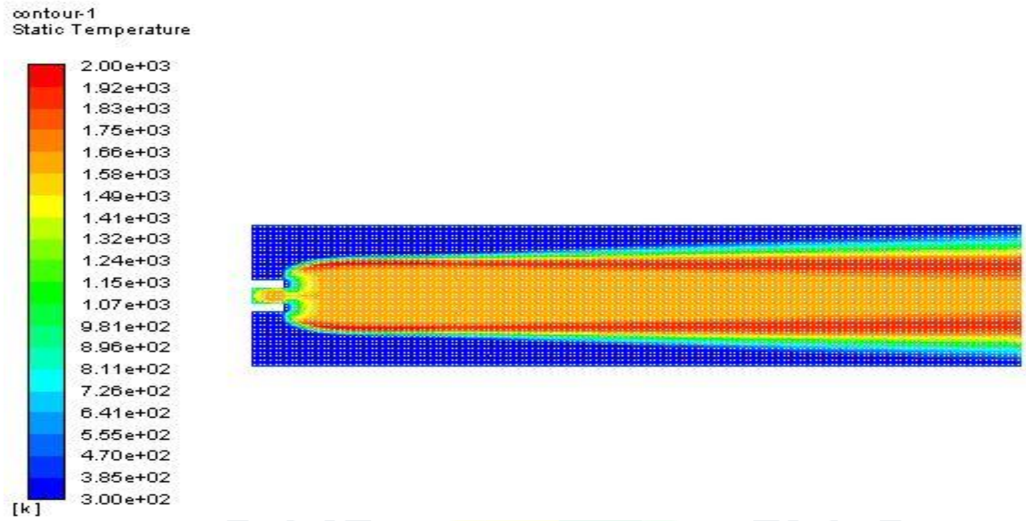

Fig. 9: Total energy when 40% methanol and 60% diesel

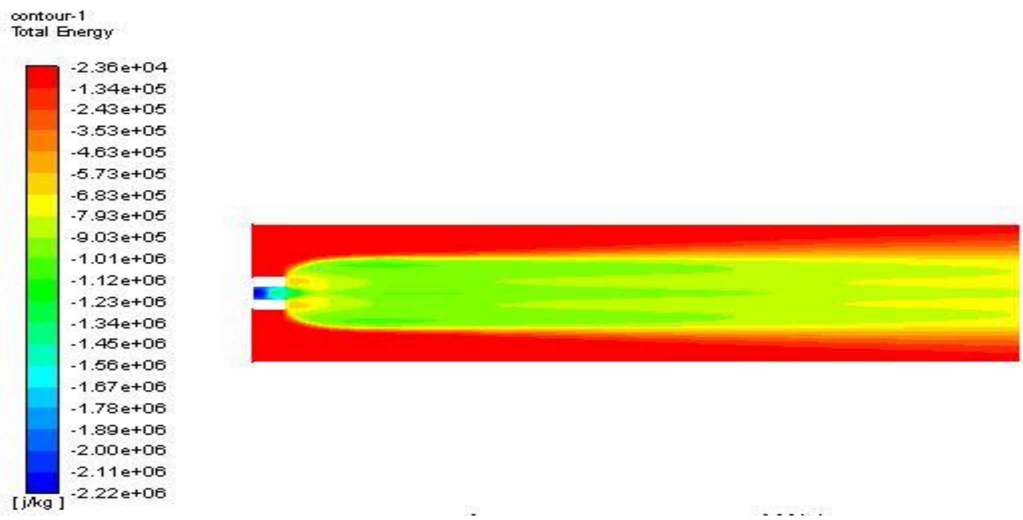

Fig. 10: Total energy when 60% methanol and 40% diesel

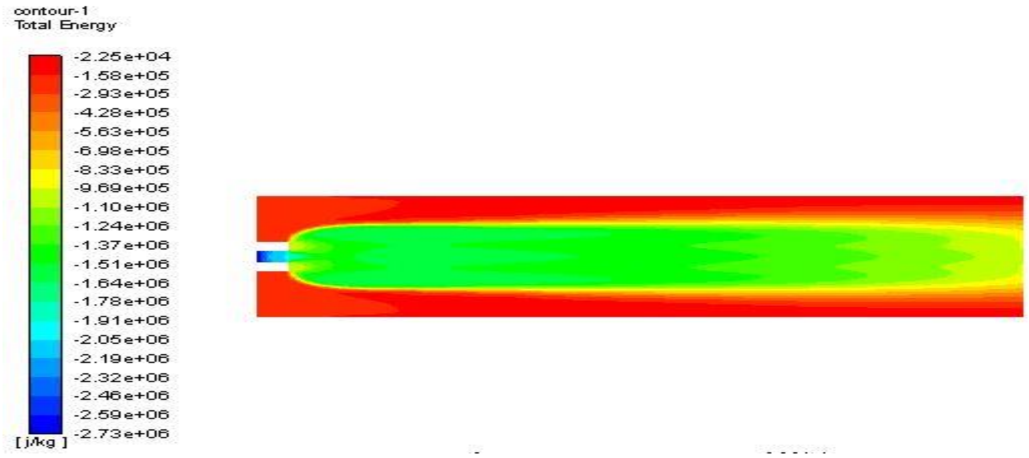

Fig. 11: Total energy when 80% methanol and 20% diesel

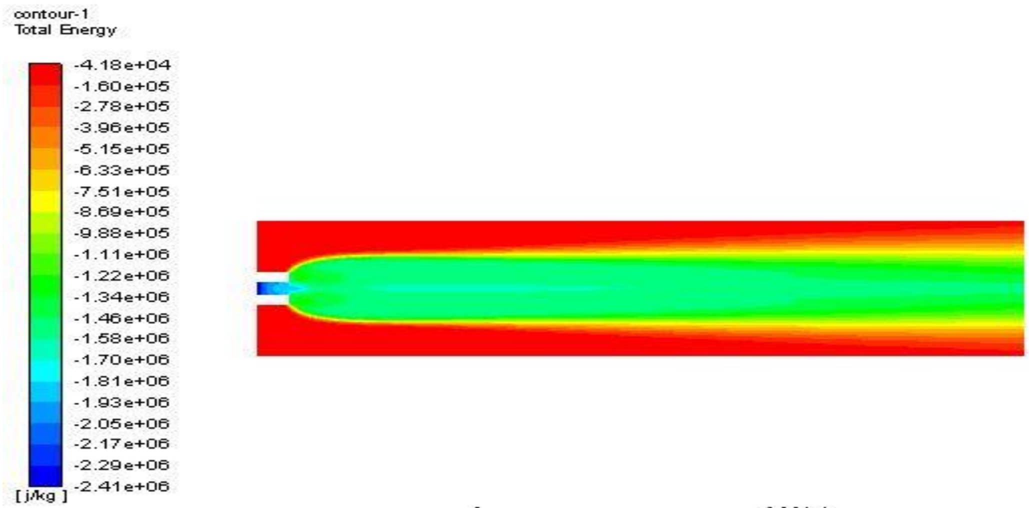

Fig. 12: Total energy when 100% methanol

6.3 EXHAUST GAS ANALYSIS

6.3.1 MASS FRACTION OF CO_2

Carbon dioxide is the product of complete combustion of fuels inside the combustion chamber. Figure 13 shows the variation of CO_2 emission for different diesel methanol blends. It can be seen from the figure that, the methanol blending, the emission of CO_2 is decreased. The main reason of CO_2 reduction is low C/H ratio and high oxygen content of the blends. Also the high oxygen content helps in better combustion and reduces the phenomena of dissociation due to decrease in temperature resulting in the increase in CO_2 emission.

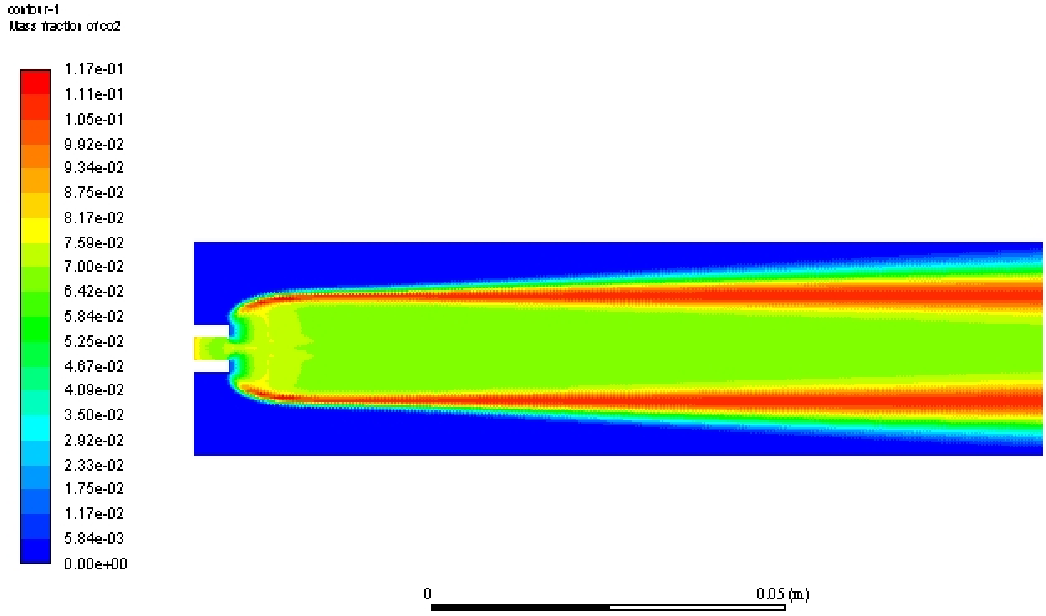

Fig. 13: Mass Fraction of CO_2 with 100% Diesel

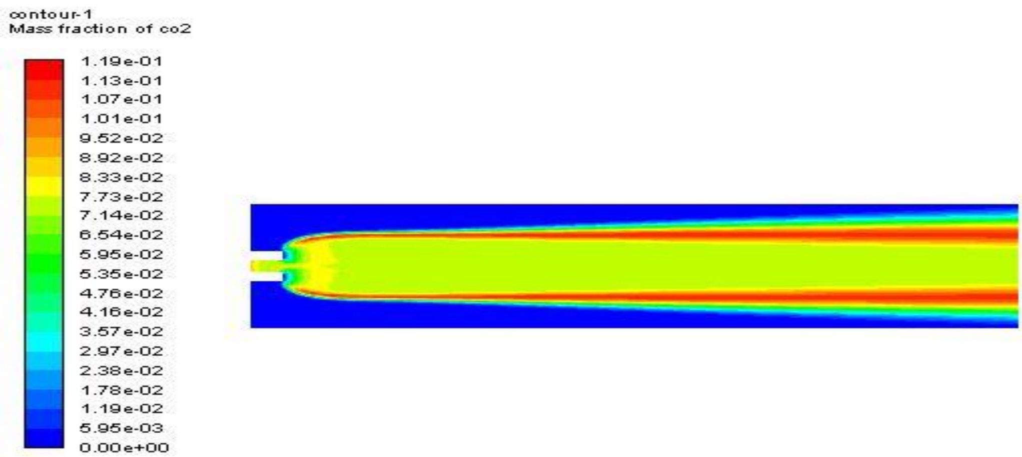

Fig. 14: Mass Fraction of CO_2 with 20% methanol and 80% diesel

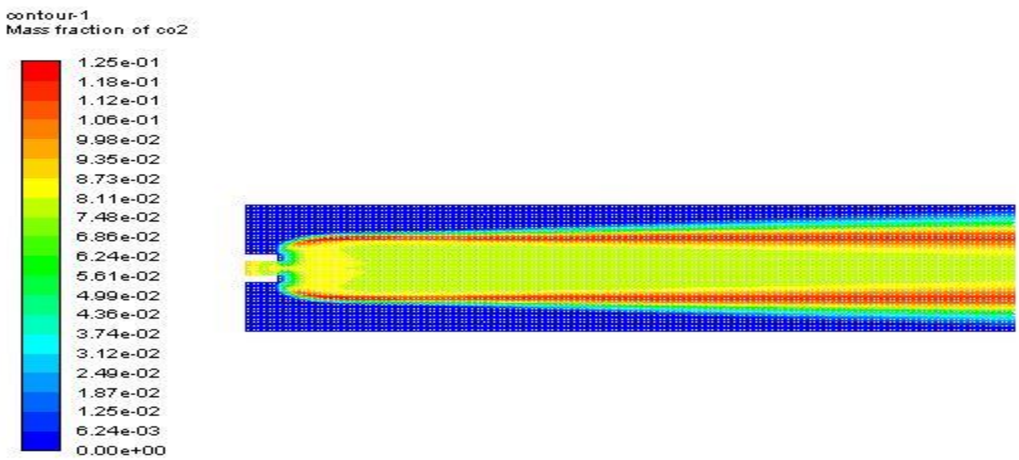

Fig. 15: Mass Fraction of CO_2 with 40% methanol and 60% diesel

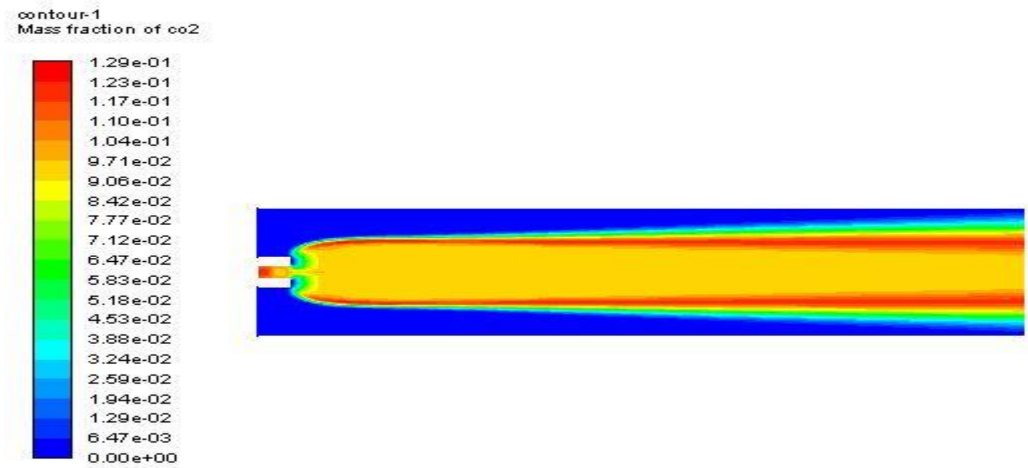

Fig. 16: Mass Fraction of CO_2 with 60% methanol and 40% diesel

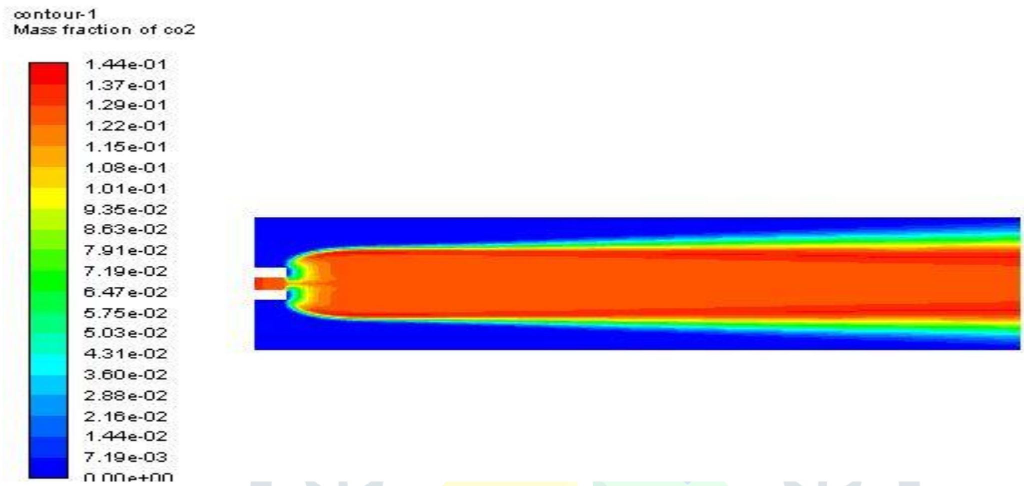

Fig. 17: Mass Fraction of CO_2 with 80% methanol and 20% diesel

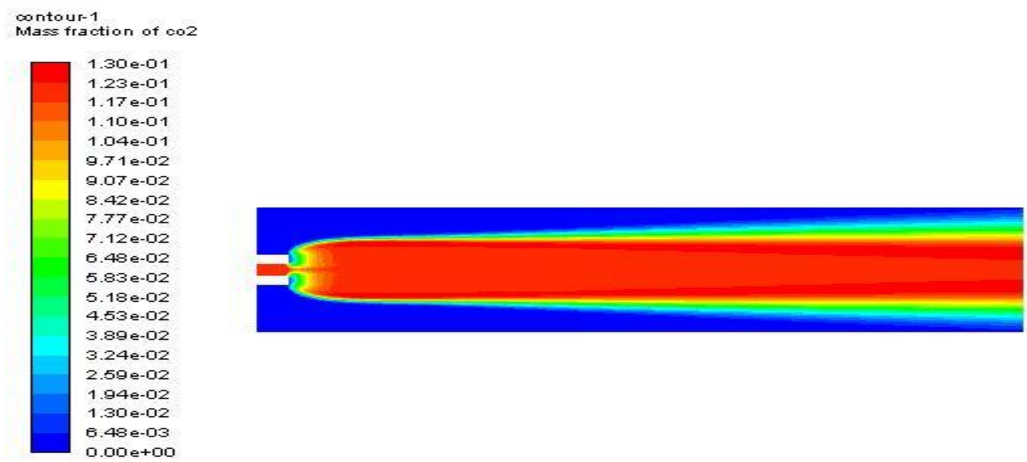

Fig. 18: Mass Fraction of CO_2 with 100% methanol

6.3.2 MASS FRACTION OF CO

The formation of carbon-dioxide leads to complete combustion and reduces CO emissions. One of the prime advantages of reaction is the hydrogen formation and its effect is very well explained by many researchers by using diesel, ethanol and methanol blends. Diesel and water combination has significant effect on performance and emissions of CI engines.

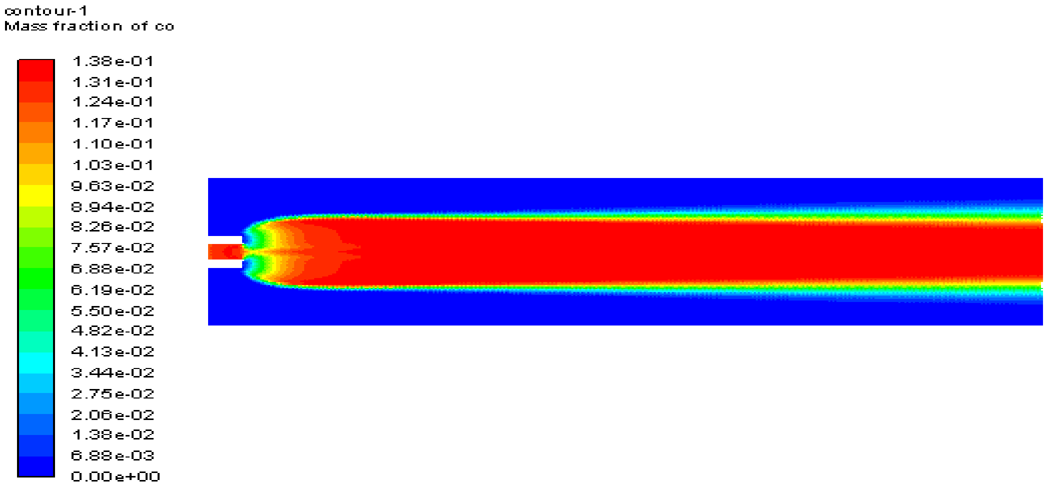

Fig. 19: Mass Fraction of CO with 100% Diesel

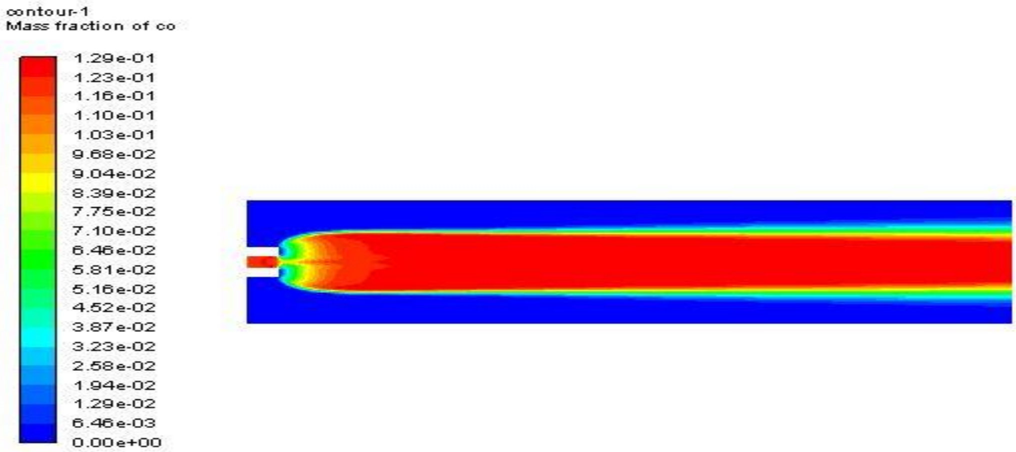

Fig. 20: Mass Fraction of CO with 20% methanol and 80% diesel

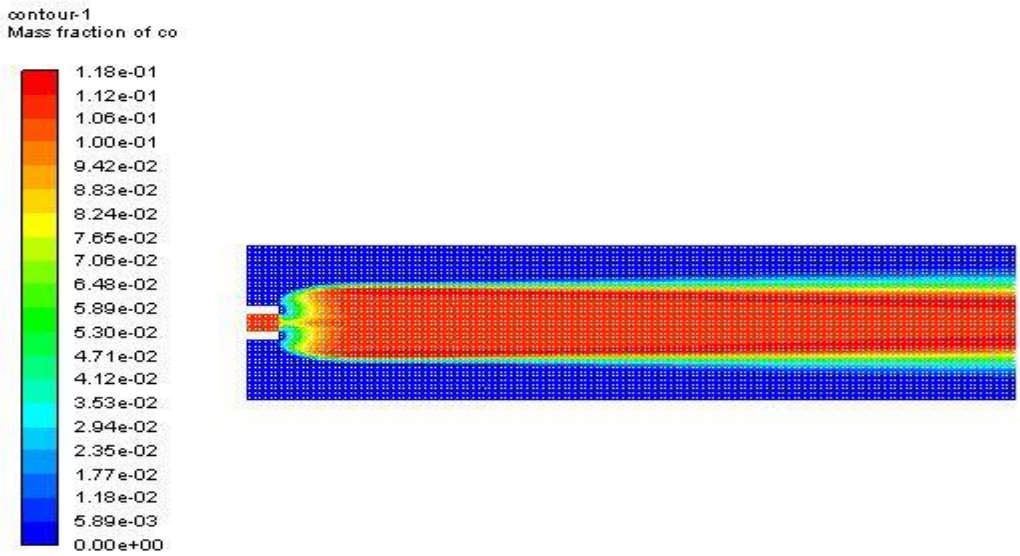

Fig. 21: Mass Fraction of CO with 40% methanol and 60% diesel

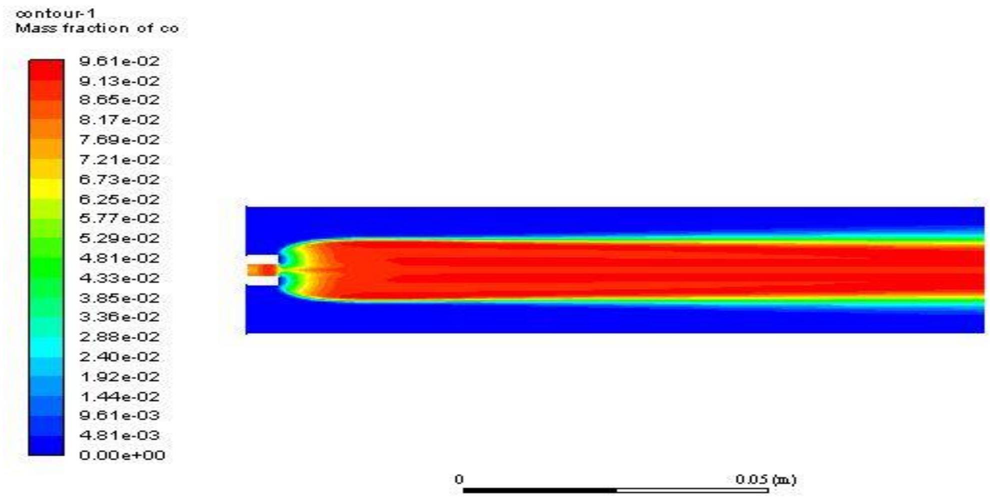

Fig. 22: Mass Fraction of CO with 60% methanol and 40% diesel

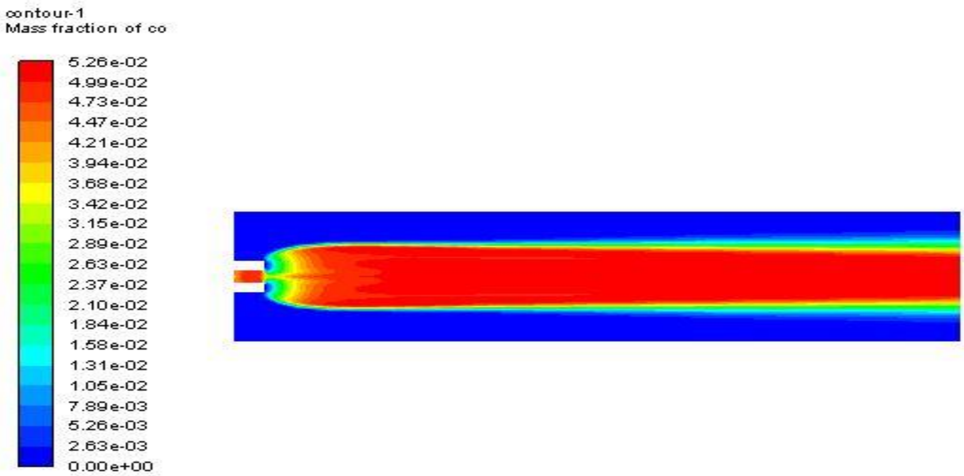

Fig. 23: Mass Fraction of CO with 80% Methanol and 20% diesel

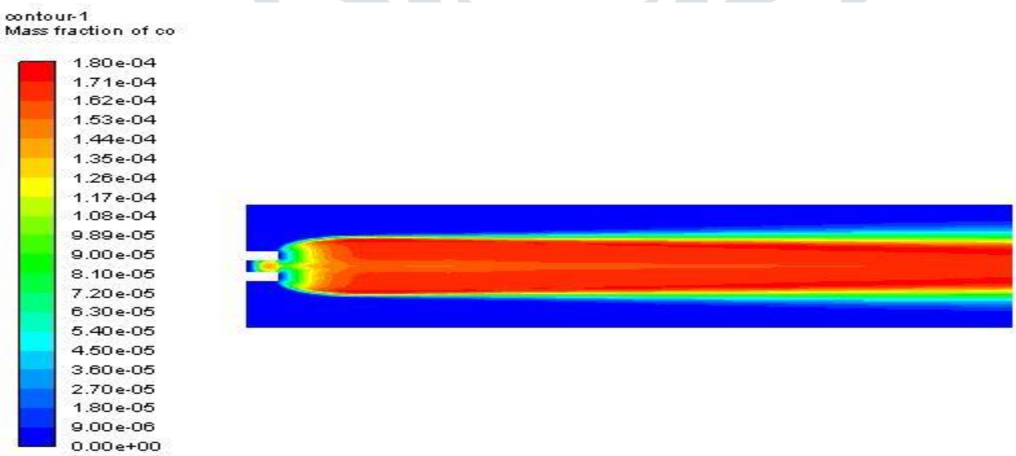

Fig. 24: Mass Fraction of CO with 100% methanol

Figure 24 shows the mass fraction of CO emission in engine. Combustion characteristics of diesel–water blend depend on the difference in boiling points of both the constituents. The boiling point of any constituent is directly related to the evaporation rate of the molecules. Evaporation of water particles is resulted in dispersion of tiny droplets inside the cylinder which is known as micro explosion. Micro explosion is also delineated as the secondary atomization which leads to fast evaporation and improved air fuel mixing. Besides that, micro combustion is also regulated by the heat utilization of water molecules to change into steam.

6.4 OVERALL RESULTS

Table 1: Overall result of Dual fuel (Diesel + Methanol)

Dual fuel (Diesel + Methanol)	100% Diesel	80% Diesel + 20% Methanol	60% Diesel + 40% Methanol	40% Diesel + 60% Methanol	20% Diesel + 80% Methanol	100% Methanol
Temperature (K)	1930	1970	2000	2030	2080	1760
Mass fraction of CO_2	0.117	0.119	0.125	0.129	0.144	0.130
Mass fraction of CO	0.138	0.129	0.118	0.0961	0.0526	0.0008

The table shows the analysis of Dual fuel (Diesel + Methanol). In this table value of Temperature (K) and Mass fraction of CO_2 and Mass fraction of CO is decrease after the addition of 80% methanol, so this is best blend. As the percentage of methanol increases in diesel from 20% to 100%, significant increment has achieved 65%, 68% and 56% in CO and CO_2 emission respectively with respect to diesel alone. Therefore, 60% Diesel + 40% Methanol blend may be considered as optimum blend in terms of emission reduction.

7. CONCLUSION

In present study investigation were done with the Multi fuel system (Diesel + Methanol) with premixed model and compare the results basic of Temperature, Flame phenomenon, Stability and Pollutant emissions like carbonic oxides. 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 Methanol. 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 work 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.

In current study investigation was done on the proper mixing of chemical species and the combustion of dual fuel (Diesel + Methanol) with various blend grades. Present study used 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.

1. The methanol participation in combustion process causes an increase in peak pressure value. It is also visible that the combustion process occurs in shorter time.
2. It can be stated that engine operated on 35% of energetic share of methanol the course of heat release rate is similar to course of classical diesel engine. There is visible both characteristic phases of combustion process, the premixed and diffusion phase.
3. In case of engine operated on 35% energetic share of methanol, the combustion process occurs faster but it still occurs in two stages.
4. Near and away from the nozzle the dissipation rate increases and it is dependent on turbulent kinetic energy.
5. Simulation results shows that temperature is increasing with increase in percentages of alternate fuels and rapid mixing is occurred.
6. 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 current work Methanol can be used as an Alternate fuel which is cheaper in cost and easily available as compare to the conventional fuels.

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