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Experimental Investigations and Numerical Modelling of Compression Ignition Engine Fuelled With Diesel and Biodiesel Blend

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Abstract

In this study, diesel fuel and two hundredth by volume of synthesised biodiesel from waste coconut oil (WB20) were used as fuel in unmodified, naturally aspirated, single cylinder compression ignition engine to study their performance and combustion characteristics at full load condition. Numerical studies were carried out with the use of CFD and compiled with the experimental results. FORTE software was used for CFD simulation. Methyl-palmitate (MPA) and Dodecane ($C_{12}H_{26}$) were used as surrogate fuels for biodiesel and diesel fuel respectively. The variation of special parts for diesel fuel and WB20 with CI engine in-cylinder pressure, in- cylinder temperature and mass fraction of O_2, CO and NO emission at 10p and 20p ATDC were analysed. The mass fraction contours of in-cylinder temperature, O_2, CO and NO for diesel fuel and WB20 were found to be decreased with increase in crank angle from 10º to 20º ATDC. The maximum BTE, in-cylinder pressure, in-cylinder temperature, O_2, CO_2 and NO were obtained for WB20 at 10º ATDC.

Keywords: *Dual fuel, waste coconut oil, CFD, FORTE, Performance.*

1.0 Introduction

Compression ignition (CI) engines are generally utilized in all transport, locomotive, domestic, agricultural and other applications. Therefore, the demand for the diesel fuel is increasing which leads increase in the pollution to the environment. The emission, combustion and performance characteristics of CI-engine can be improved by blending biodiesel with diesel fuel. The dependence and environmental pollution can be reduced significantly by using optimised biodiesel blends with no engine hardware modification [Bafghi et al. 2015]. Methyl ester is synthesized from naturally available feedstocks and has from some environmental and economical benefits. The presence of oxygen (O_2) in the biodiesel decreases hydrocarbon (HC) and carbon monoxide (CO) emissions and increases nitric oxide (NO) emissions in the exhaust [Kumar et al. 2018]. The cost of the biodiesel can be significantly reduced by using low cost feedstock in the synthesis of biodiesel [Thakur et al. 2020]. Computational fluid dynamics (CFD) is one of the powerful tools that can be used to analyse the engine parameters such as in-cylinder pressure, fuel consumption, temperature and HC, NO and CO emissions. However, the cost involved in measuring devices and experimental set up is high and consumes more time to study detailed emission

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and combustion parameters [Masimalai et al, 2017; Mauro et al. 2018; Hawi et al. 2017]. The physicochemical properties of biodiesel such as viscosity, density, thermal conductivity, boiling point, specific heat and latent heat have considerable impact on combustion and emission modelling which improves accuracy of numerical prediction combustion characteristic parameters [Luka Lešnik et al. 2014]. Shaik mull and Karishma et al. [2022] used various concentration of apricot biodiesel in diesel fuel to study their performance in four stroke, direct injection, single-cylinder, naturally aspirated CI engine. As a result, it was found that the blend B20 of apricot oil exhibits encouraging effects on emission and performance compared to other blends. C. Anuradha et al. [2015] used STAR-CD CFD package to simulate CI engine in order to understand the effect of fuel injection pressure, they found that in-cylinder pressure, temperature and heat release rate were increased with increasing injection pressure. 20% of biodiesel in diesel–biodiesel mixture was found to be ideal for the CI engine as suggested by most of the researchers, which is recommended in terms of physicochemical properties closer to diesel fuel. In this research, diesel and WB20 were used as fuels. The experiments were conducted on compression ignition (CI) engine at full load condition with no engine hardware modifications. The performance and combustion characterises of the test fuels such as break thermal efficiency (BTE) and in-cylinder pressure were determined experimentally. However, oxygen (O_2), in-cylinder temperature, carbon monoxide (CO) and nitric oxide (NO) were determined with the use of CFD simulation. In the current research work, numerical studies were carried out with the use of CFD and compiled with the experimental results obtained.

Table 1. Engine specification

Parameters	Specification
Type AV1 (Kirloskar)	
Bore diameter (mm)	80
Stroke length (mm)	110
Swept volume (cc)	552
Length of the Connecting rod (mm)	234
Inlet valve closing (deg)	35.5
Exhaust valve open (deg)	35.5
Injection pressure (bar)	220
Injection nozzle diameter (mm)	0.15
Number of injection nozzle	3

FORTE software is used for CFD simulation. Emission, combustion and turbulence model can be used to precisely analyse the engine performance in comparison with other research tools. The study of literature shows that the methyl ester can be used directly in existing compression ignition engine with no hardware modifications [Garcia et al. 2010]. Also there was short note on IC engine simulation analysis with the use of CFD was reviewed [Kannan et al. 2020; Govindan et al. 2014; Maurya et al. 2017]. It showed that CFD is one of the best tools for analysing performance and emissions from the engine to decide optimisation.

2.0 Materials and Experimental Methodology

The two hundredth by volume of synthesised biodiesel from waste coconut oil (WB20) is used for experimental investigations.

In the current theoretical study, a single cylinder, four-stroke compression ignition engine was used. ANSYS FORTE 19.2 were used to simulate the CIengine while chemkin pro software was used to create standard chemical kinetic file (Figure 1). The engine specification is presented in Table 1. The engine tests were carried out at full load condition at a constant speed of 1500 rpm. Figures 2 and 3 show the flow map of engine test and photographic view of diesel engine respectively.

2.1 Solver details

2.2 Fuels surrogate used in CFD simulation

Diesel fuel and biodiesel are the mixture of variety of hydrocarbons and ester compounds respectively.

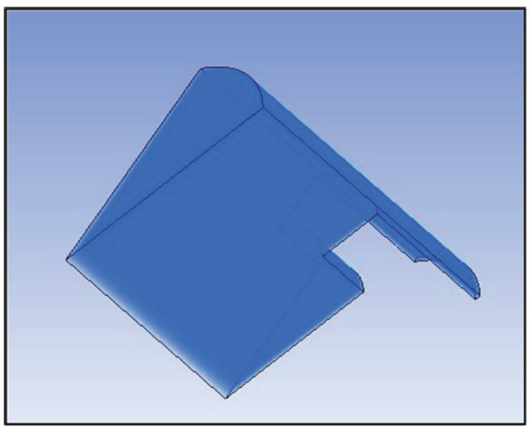

Figure 1: CFD Model of engine cylinder

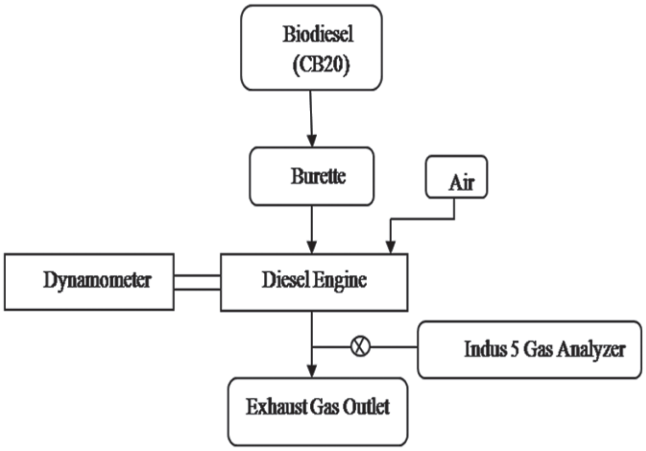

Figure 2: Flow map of the engine tests

Figure 3: Photographic view of diesel engine

Generally surrogate fuels are used instead of actual composition in order to avoid complexity in selection of fuels. In the present research, dodecane ($C_{12}H_{26}$) and methyl-palmitate (MPA) are used as surrogate fuels for diesel fuel and biodiesel respectively. Kinetic file and thermal data are obtained from the literature [Rakopoulos et al. 1998; Ayyaswamy et al. 2019], and is converted into standard chemkin file format by using chemkinpro 19.2 software. Chemkin file consists of 582 species and 21174 reactions.

2.3 Mesh generation in ANSYS forte

Geometry required for ANSYS FORTE simulator is generated by using FORTE sector mesh generator. The 45^o geometry sector model is developed with the use of basic inputs like engine bore, stroke, crevice width and squish. Bowl topology is provided according to engine bowl geometry. Simulation is carried out at constant engine speed of 1500rpm and at full load condition. According to FORTE mesh report, geometry consists of 19020 nodes and 18478 elements. Initial pressure and temperature are equal to 1.63 bar and 380 K respectively. Maximum RAM memory of 1028 MB is used during simulation.

3.0 Simulation Special- Temporal Analysis

The variation of special parts for diesel fuel and WB20 with CI engine in-cylinder pressure, in-cylinder temperature and mass fraction of O_2, CO and NO emission at 10p and 20p ATDC were analysed. The temperature distribution of diesel fuel and WB20 are as shown in Figure 4. It can be observed from the figure that the temperature is decreasing with the increase in crank angle ATDC. The maximum temperature was found to be for WB20. This could be

Table 2: Presents the simulation of CFD codes of model in CFD package

Phenomena	Model	Phenomena	Model
Turbulence	RNS k-ε	Atomization	Taylor-Analog- Breakup
Droplet breakup	Kelvin Helmholtz/Rayleigh-Taylor breakup	Droplet collision model	Radius of influence model
Combustion	G-equation	NO_x mechanism	Extended zeldovich mechanism
Fuel chemistry	Skeletal n-heptane mechanism	Soot	Optional Semi-empirical
Law of wall	Wall modes	Solid cone breakup	Gas-jet

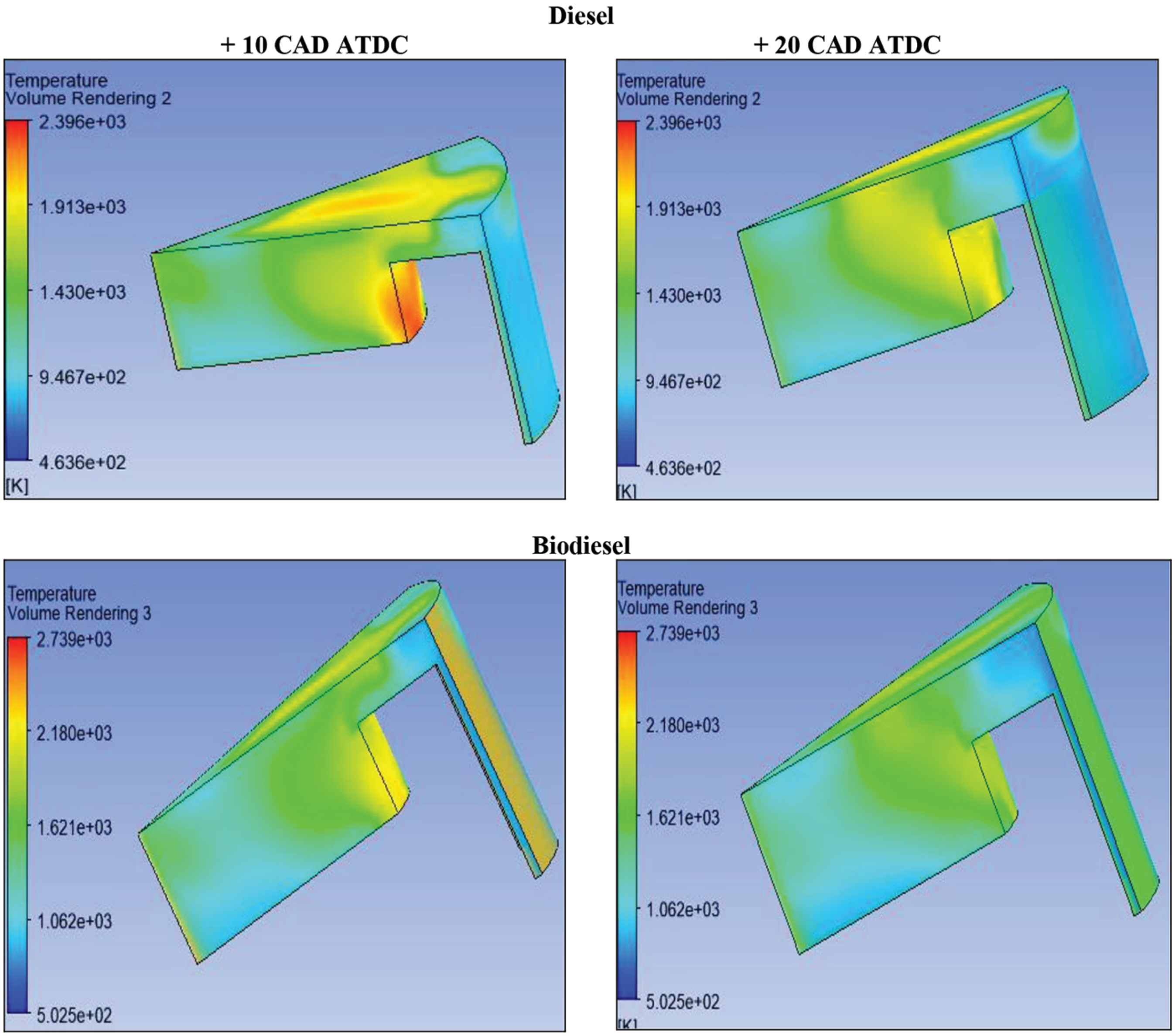

Figure 4: In-cylinder temperature of spatial plots for diesel and biodiesel.

due to the higher density of WB20 and presence of inbuilt oxygen in biodiesel. The mass fraction contours of O_2 for diesel fuel and WB20 is presented in Figure 5. O_2 decreases with increase in crank angle from 10° to 20° ATDC. Higher oxygen traces can be observed for the WB20 compared to that of diesel fuel.

Figure 6 shows the mass fraction contours of NO for diesel and WB20 at different crank angle position. NO decreases with the increase in crank angle ATDC. This could be due to decrease in in-cylinder temperature. High NO formation was predicted for WB20. Because WB20 have more oxygen content as compared to that of diesel fuel. Figure 7 presents the mass fraction contours of CO for diesel and WB20 at different crank angle position. It can be seen from the figure that CO emission for WB20 is lower than that of diesel fuel. Because WB20 have more oxygen concentration has compared to that of diesel fuel. Thus, fuel burns as a leaner mixture in WB20 causing less CO concentration.

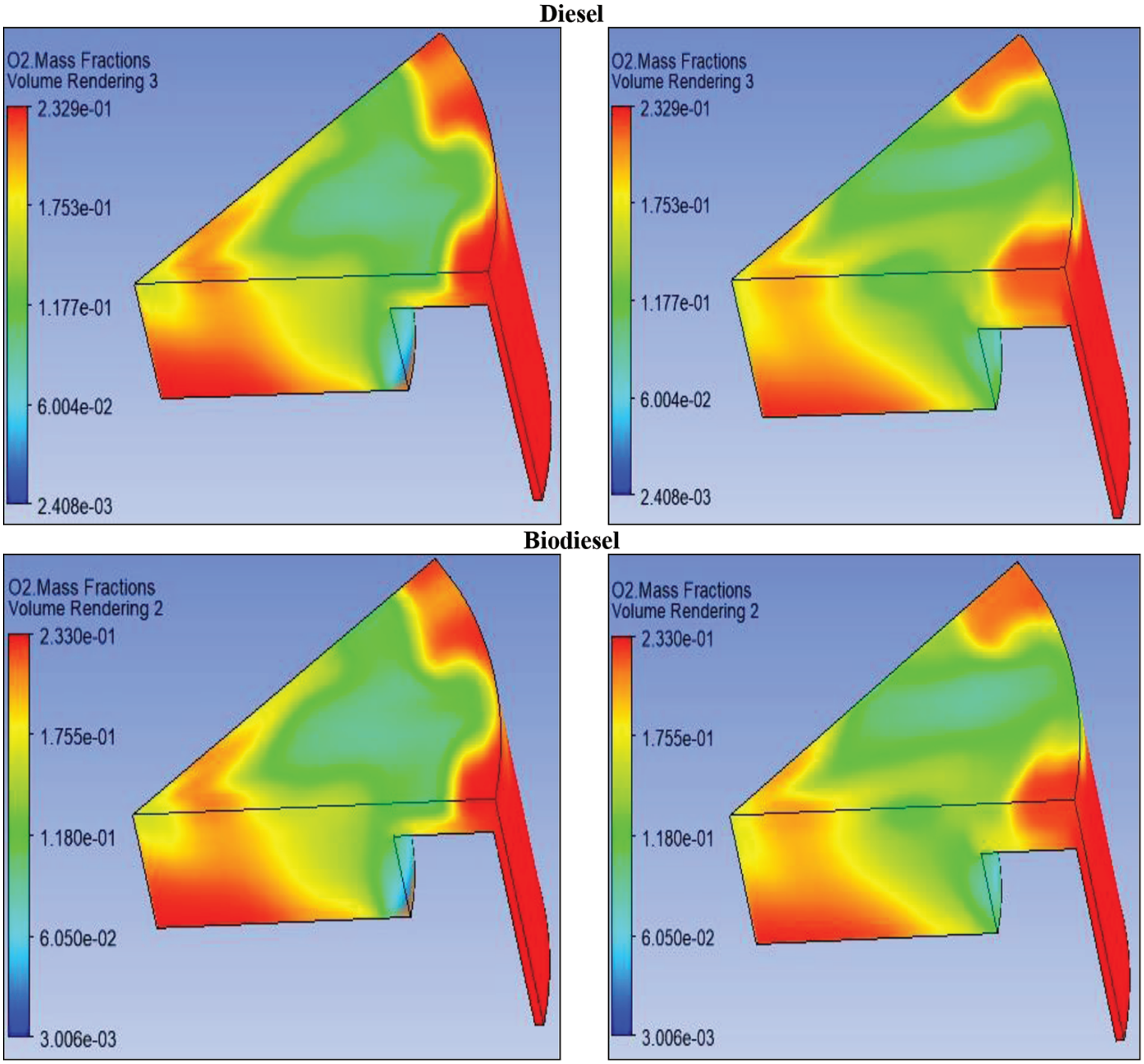

Figure 5: O_2 mass fraction for diesel and biodiesel fuels

3.1 Effect of break thermal efficiency

Comparison of experimental and simulated BTE with regard to diesel fuel and WB20 at full load condition is presented in Figure 9. It can be seen from the figure that WB20 simulated results was found to be 0.03% higher than that of experimental outcomes. However, D100 simulated results was found to be 0.04% higher than that of experimental results. This could be due to presence of inbuilt oxygen content in the biodiesel leads complete combustion of the fuel. The maximum BTE acquired in WB20 was noted for both simulated CFD and experiment outcomes. It can be seem from the figure that simulated CFD findings are more than experimental outcomes. This is because of no energy loss in CFD simulations like experiments.

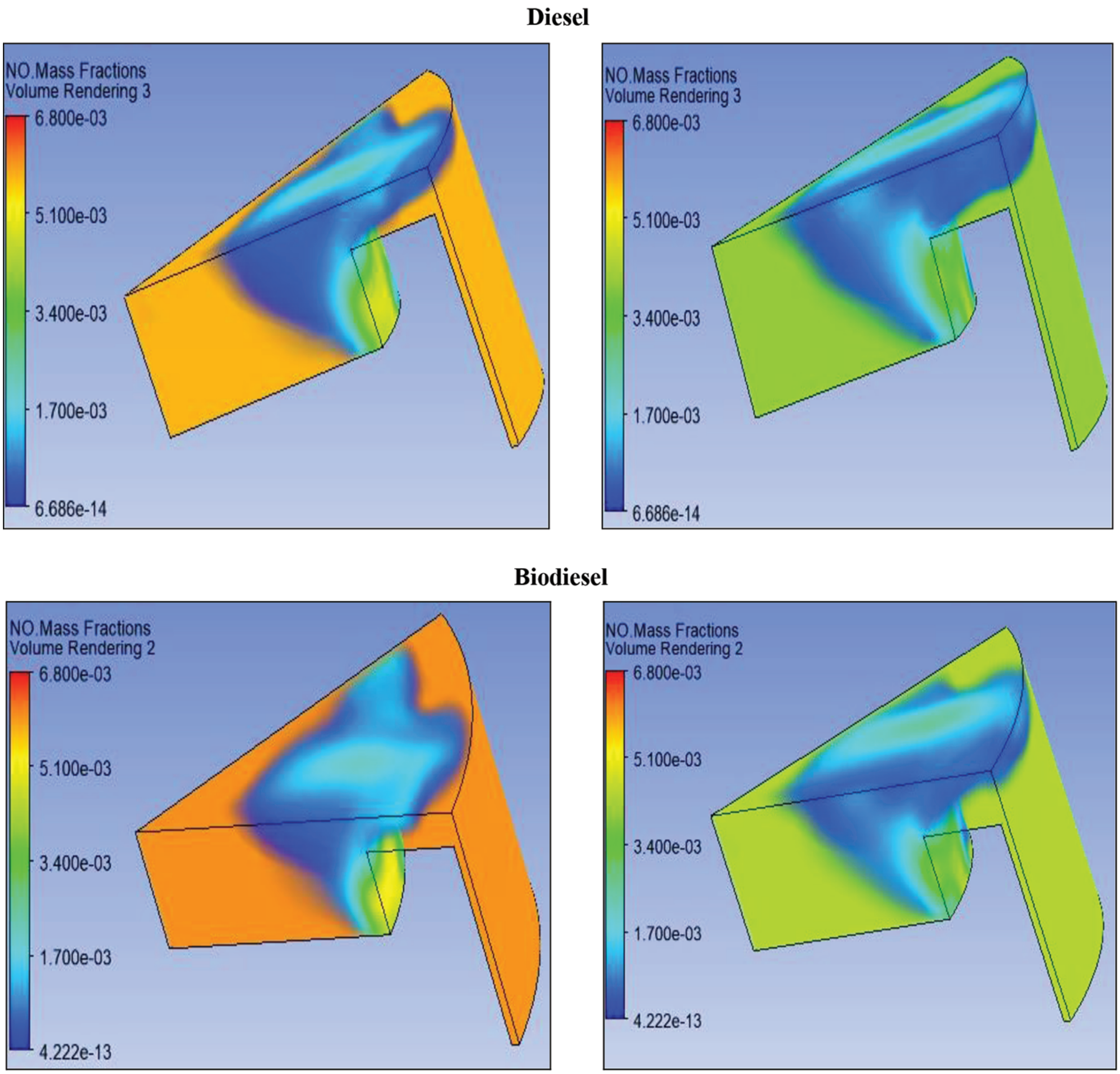

Figure 6: NO mass fraction for diesel and biodiesel fuels

3.2 In-cylinder pressure-crank angle diagram

Comparison of simulated and experimental in-cylinder pressure with regard to diesel fuel and WB20 at full load condition is presented in Figure 8. It shows the highest in-cylinder pressure in WB20 simulated outcomes. It can be seen from the figure that WB20 simulated results was found to be 0.032% higher than that of experimental outcomes. However, D100 simulated results was found to be 0.019% higher than that of experimental results. Because biodiesel contains inbuilt oxygen content leads to complete combustion of the fuel.

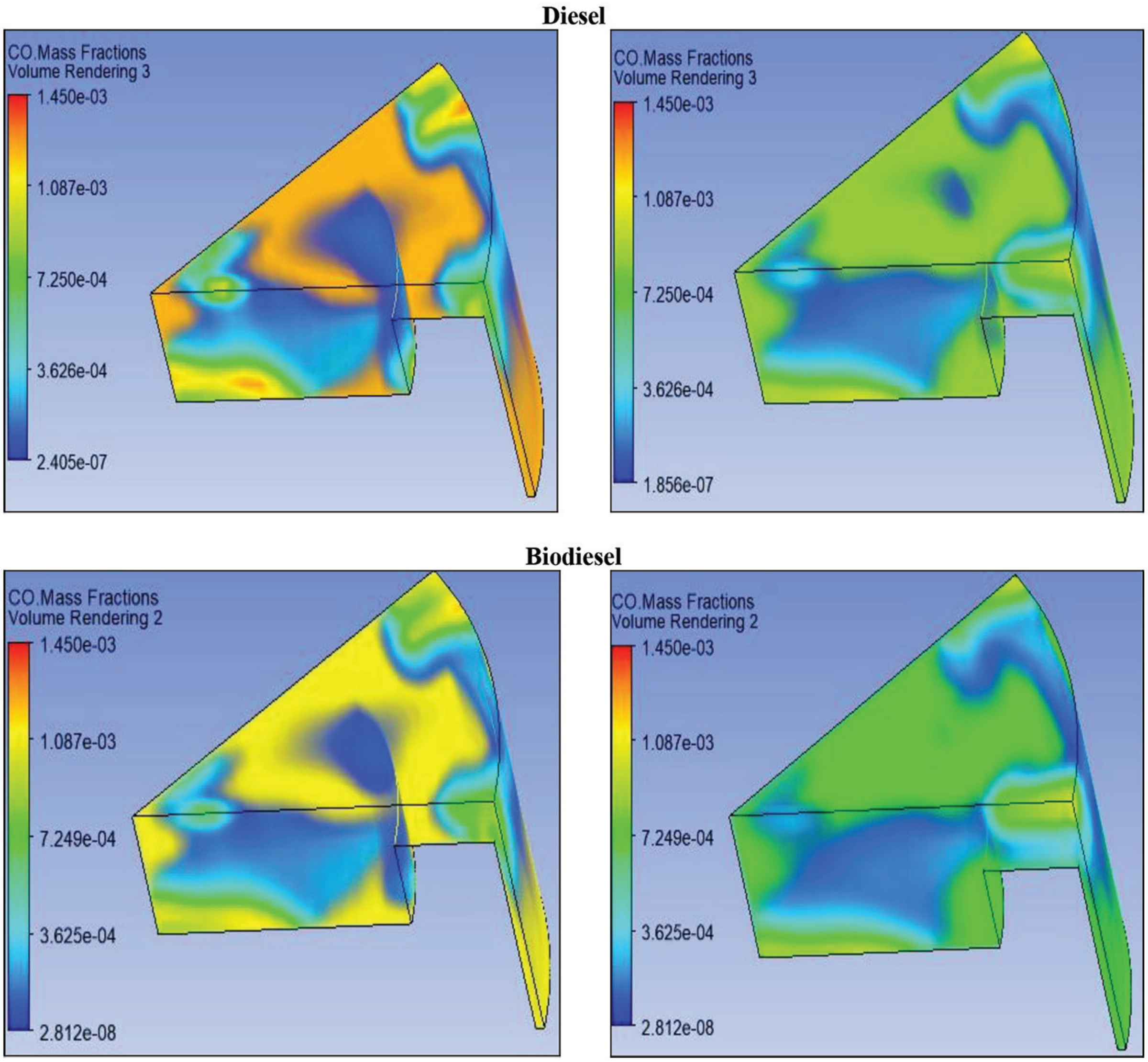

Figure 7: CO mass fraction for diesel and biodiesel fuels

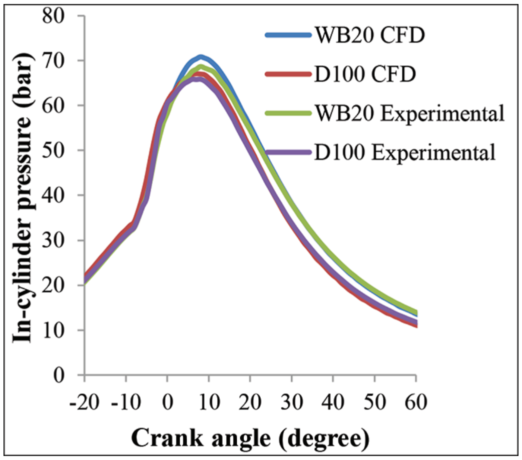

Figure 8: Comparison of experimental and simulated in-cylinder pressure

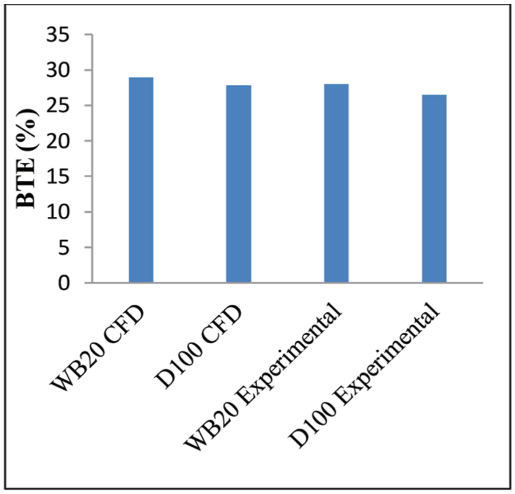

Figure 9: Comparison of experimental and simulated BTE

4.0 Conclusions

The following conclusions are drawn from the present research work.

- Numerical studies were carried out with the use of CFD and compiled with the experimental results obtained. FORTE software was used for CFD simulation. Dodecane ($C_{12}H_{26}$) and methyl-palmitate (MPA) are used as surrogate fuels for diesel fuel and biodiesel respectively. Numerical results obtained were in good agreement with the experimental results.
- The variation of special parts for diesel fuel and WB20 with CI engine in- cylinder temperature, pressure and mass fraction of O_2, CO and NO emission at 10º and 20º ATDC were analysed.
- The mass fraction contours of in-cylinder temperature, O_2, CO and NO for diesel fuel and WB20 were found to be decreased with increase in crank angle from 10º to 20º ATDC.
- The maximum BTE, in-cylinder temperature, in-cylinder pressure, O2 and NO were obtained for WB20 at 10º ATDC.
- Simulated CFD findings were found to be more than experimental outcomes due to no energy loss in CFD simulations like experiments.

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