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Jaikumar Methre[1], Sharanappa Godiganur[2] and Rajeesh S[3]

[1]Reserach scholar, Department of Mechanical Engineering, REVA Institute of Technology & Management, Bengaluru, 560064 Karnataka, India
*Email: jamethre@gmail.com , Phone: +91 8066226622

[2]Professor & Dean (R&D), KK University Campus, Berauti, Nepura, Biharsharif, Nalanda, Bihar, India
[3]Assistant Professor, Department of Mechanical Engineering, Ramaiah Institute of Technology, Bengaluru, Karnataka, India

ABSTRACT

The present numerical study examines the combustion characteristics (CCs) of four stroke Kirloskar CI engine fueled with 20% chicken fat biodiesel by volume blended to diesel fuel (CB20) for three different compression ratios (CRs) of 14, 16.5 and 18. Experimental work is carried out for engine CCs measurements with CB20 fuel, such as peak pressure inside the cylinder, volume consumed during compression stroke and retained in expansion stage with piston movement for each CRs. Numerical investigation is used to predict the behavior of pressure, volume, heat release rate (HRR) and temperature during piston movement inside the combustion chamber at different stages of crank angles using ANSYS IC Engine model as a simulation tool. The percentage variation of peak pressure was 7.24, 6.83 and 14.7 bar from simulation is observed for CR 14, 16.5 and 18 respectively as compared to experimental values. Also, the volume profile and temperature inside the cylinder for different CRs indicates that CB20 fuel can be used within the CI engine with no modification to the engine.

Keywords: Computational fluid dynamics, Chicken fat biodiesel, Combustion characteristics, CI engine, Compression Ratio.

INTRODUCTION

The need of diesel oil is increasing in the current situations from several industries and vehicles simultaneously because of its high compression ratio it increases the pollution to the environment. The addition of biodiesel to diesel improve the performance and emission characteristics of a diesel engine. The optimized biodiesel mix can reduce some important portion of fuel dependency and surroundings from pollution with none modification to the diesel engine [1]. Biodiesel is created from natural resource and has some environmental benefits. The oxygen content presence in biodiesel reduces the carbon monoxide and hydrocarbons emissions and it increases the NOx formation at the exhaust [2].

The cost involved in experimental set up is high for required measuring devices and consume more time to study detailed combustion and emission parameters. Therefore, CFD (Computational fluid dynamics) analysis is playing important role to predict results accurately by proper modeling of the simulation. The biodiesel physical and chemical properties such as density, specific heat, viscosity, latent heat, thermal conductivity and boiling point have great impact on modeling of combustion and fuel spray which improve the accuracy of numerical prediction of CCs parameters. L. Lešnik et al. [3] described the sub models from new empirical by using AVL BOOST program to predict the parameters of combustion model. It was observed that increase in blend ratio results in lower calorific value of the fuel reduces ignition delay, torque and engine power. Around 10% variation in in-cylinder pressure is noticed from experimental and numerical modeling for 2000rpm.

Ganji, P.R. et al. [4] focused on response surface methodology to optimize the combustion parameters using design of experiment and CONVERGE ics simulation tool. The turbulence, fuel spray and combustion were modeled by defining the fuel properties from the main type of ester which is present in the biodiesel. Edwin E et al. [5] worked on thermophysical properties of different oils and developed the correlations to predict the properties within the range of temperature. The statistical analysis from 299.15 to 433.15 K temperature were evaluated by using coefficient of determination, residual analysis and level of significance. The thermal conductivities and heat capacities were calculated for the highest percentage present in oil from fatty acid compositions are Miristic, Palmitic, Estearic, Oleic, Linoleic, and Linolenic.

C. Anuradha et al. [6] carried out the CFD simulation to study the influence of injection pressure on CI engine. The 45° sector model is considered for the combustion analysis and calculation of velocity and mass flow rate calculation was done for three different injection pressures 150, 200 and 250 bars. The simulation results showed that increase in cylinder pressure, temperature and HRR with increase in injection pressure with STAR-CD tool.

Rajesh Govindan et al. [7] used Ansys FLUENT to analyze engine combustion using Thumba biodiesel. Explained that there are very a lesser number of species availability for oxidation of biodiesel substitute and shortage of chemical kinetics mechanism to accomplish satisfactory results from simulation. The fuel properties for the simulation were taken from fatty acid composition of biodiesel. The 30° injector angle to the vertical and three nozzles with 0.15mm diameter were considered. The fuel start and end of injection were 23° crank angle (CA) BTDC (before top dead center) and 7° CA ATDC (after top dead center) with three different mesh sizes to study the effect of grid independent on the combustion parameters of pressure, volume, HRR and temperature inside the cylinder. The similar trend was observed between experimental and simulation results and noted that HRR starts earlier at an CA by 2 to 3° for biodiesel compared to diesel fuel. The temperature and pressure from simulation were predicted more in biodiesel than diesel during combustion. Also, found that in cylinder pressure increases with increase in blending ratio.

Umakant Kongre et al. [8] used CFD code FLUENT software to validation of combustion in direct ignition engine fueled with diesel. The RNG k-ε model is implemented to confine in cylinder turbulence. They observed that, the peak pressure is 66.16 bar from CFD modelling and 63.55 bar experimental at CA 366°. Similarly, the peak heat release rate is 79.01 J/ degree from CFD modelling and 77.34 J/ degree from experimental at CA 364° operating at full load condition. Ajay Kolhe et al. [9] carried out combustion modeling with CFD in CI engine fueled with pongamia biodiesel. The CFD commercial code FLUENT was used to account the effect of turbulence using RNG k-ε model. For the spray modelling, droplet collision and Taylor Analogy Breakup (TAB) sub models were used and in-cylinder combustion was modeled to predict the combustion parameters inside the cylinder by using finite rate chemistry and species transport models. The results obtained from modeling were similar pattern with higher values in compare with experimental values.

Many investigations were carried out to simulate combustion chamber using different CFD codes availability. From the literature, most of the researchers were chosen 20% by volume of biodiesel for their research work and which is recommended in terms of physical and chemical properties closer to diesel fuel. Also, it was found that good agreement between experimental and numerical study in comparing the combustion parameters with accepted percentage variation of results. In this paper both experiment and CFD analysis of diesel engine CCs with CB20 fuel is presented for three different CRs 14, 16.5 and 18 to see the behavior of combustion parameters in the four-stroke single cylinder Kirloskar VCR engine at 83.3% of engine load.

MATERIALS AND METHODOLOGY

The two hundredth by volume of extracted biodiesel from chicken fat (CB20) is used for experimental CCs investigation. The engine was operated to measure CCs parameters for three different CRs 14, 16.5 and 18 with varying load at constant speed. The droplet properties of CB20 are shown in “Table 1”. The properties are taken on the basis of percentage peak area measured from fatty acid composition test of biodiesel [10, 11].

Table 1. Droplet properties of CB20 fuel

Droplet Properties	CB20
Density (kg/m^3)	855
Viscosity (kg/m-s)	0.003
Calorific value (kJ/kg)	42375
Specific heat (j/kg-k)	2076
Thermal conductivity (w/m-k)	0.164
Latent heat (j/kg)	269600
Boiling point (K)	484

In the current paper Oleic acid occupied more percentage area in the biodiesel is around 40.78% and properties have been taken at temperature at 300 K for CB20 [12]. The engine specification of single cylinder four stroke CI engine is shown in “Table 2”. The study was carried out by varying loads at the constant speed of 1500 rpm for different fuels. The peak pressure, volume was evaluated for the fuel CB20 at CR 14, 16.5 and 18. "Figure 1” illustrates the flow chart of engine test set up for different CRs.

NUMERICAL MODEL SET-UP

CFD analysis is carried out for CR 14, 16.5 and 18 to study CCs of engine. The 3D sector with 120^o angle in-cylinder model of CI engine is considered for the analysis. Preprocessing of in-cylinder geometry from inlet valve closed to exhaust valve open is modeled using Design Modeler ANSYS tool and grid generation is done for three different models of CRs 14, 16.5 and 18 [13].

Table 2. Engine specifications

Parameters	Specification
Type	AV1 (Kirloskar)
Cylinder bore diameter	80 mm
Stroke length	110 mm
Swept Volume	552 cc
Connecting rod length	234 mm
Inlet valve closing, IVC	35.5° ABDC
Exhaust valve open, EVO	35.5° BBDC
Injector orifice diameter	0.15 mm
Injector pressure, bar	220

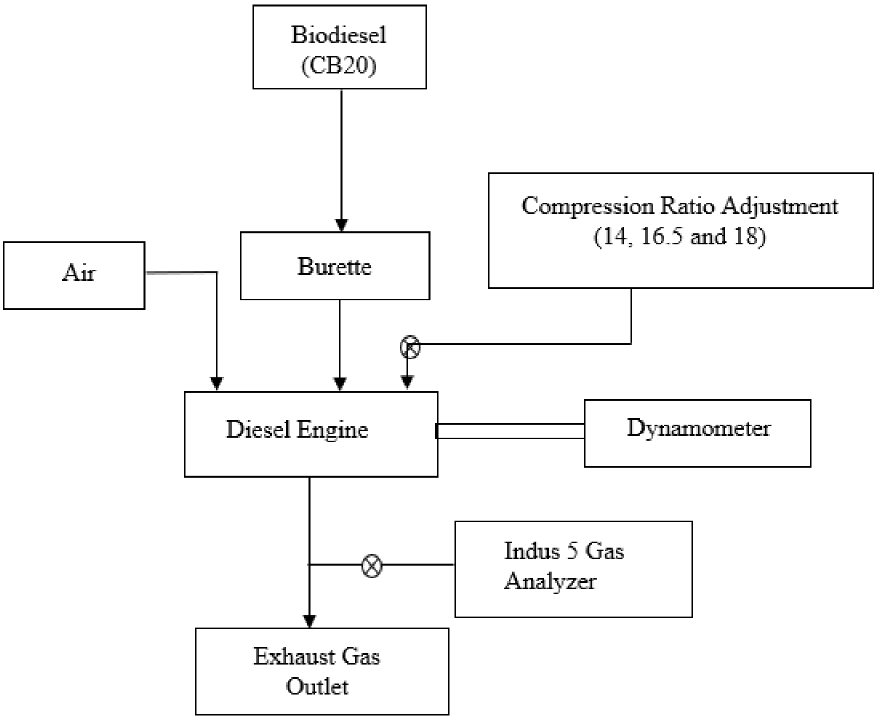

Figure 1. Experimental Set Up in Diesel Engine

“Figure 2” shows the numerical CAD model set up for CR 14, 16.5 and 18 with grid size 2mm. “Table 3” shows the total elements and skewness after grid generation for CR 14, 16.5 and 18. There are three nozzle holes of diameter 0.15 mm and a sector with one hole is considered which is 15° inclined to the vertical. No valves have been modeled for combustion chamber analysis. The engine has hemispherical piston bowl with diameter of 48mm. The CA 23° BTDC and 7° ATDC were fixed and a mass profile was used for fuel injection. Analysis of CI engine fueled with CB20 were evaluated with a total mass flow rate of 8.7e-5 kg/s for CR 14, 16.5 and 18 to measure peak pressure, HRR, volume behavior, temperature profile in the combustion chamber.

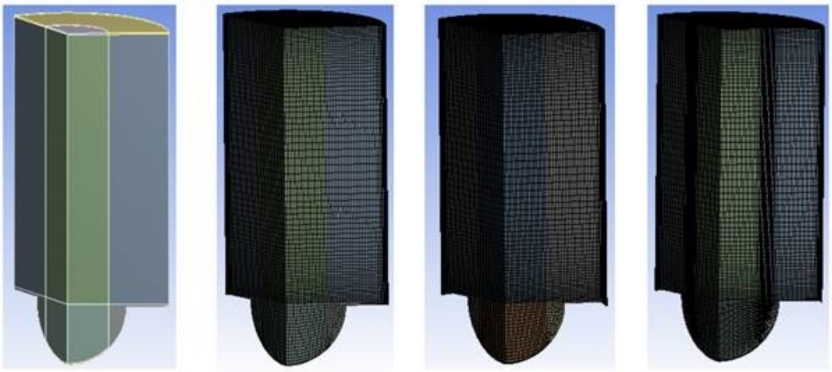

Figure 2. Numerical Set Up with 120° Sector CAD Model and Grids for CR 14, 16.5 and 18

Table 3. Grid elements and skewness

Compression Ratio	Number of elements	Volume skewness
14	142572	0.83
16.5	155134	0.836
18	179940	0.847

RESULTS AND DISCUSSIONS

Pressure vs. Crank angle (P-CA) Diagrams

“Figure 3” to “Figure 5” shows the comparison of Pressure (P) vs. CA diagram obtained from the experimental & CFD analysis for different CRs. The “Figure 6” shows the peak pressure values from the experimental & CFD analysis for different CRs.

The peak pressure developed in the cylinder at CR 14 are 54.21 (at crank angle 369°) and 58.44 bars (at crank angle 365.7°) for Experimental and CFD analysis respectively. Similarly, 66.82 (at crank angle 367°) and 71.72 bars (at crank angle 365.3°) at CR 16.5 and 71.31 (at crank angle 367°) and 83.6 bars (at crank angle 365.25°) at CR 18 for experimental and CFD analysis respectively. The results exhibit that in CFD simulation, there is a small change in CA for the peak pressure at all CRs as compared to experimental analysis combustion crank angles. In the conventional engine as the crank angle varies, the change in the volume of the cylinder changes the properties of biodiesel leads to different stages of combustion with different ignition delay for each CR. Where as in CFD simulation, the biodiesel properties will change linearly based on energy and mass conservation equations with initial boundary condition.

The peak pressure developed in the cylinder increases with increase in CR, whereas ignition delay decreases with increase in CR [14]. The fuel-burning rate in the early stage of combustion is higher in the case of biodiesel due to higher content of oxygen with larger cetane number present in it along with higher operating temperature in the fuel with increase in CR, which bring the peak pressure more closely to TDC. Thus, reduces the ignition delay period [15].

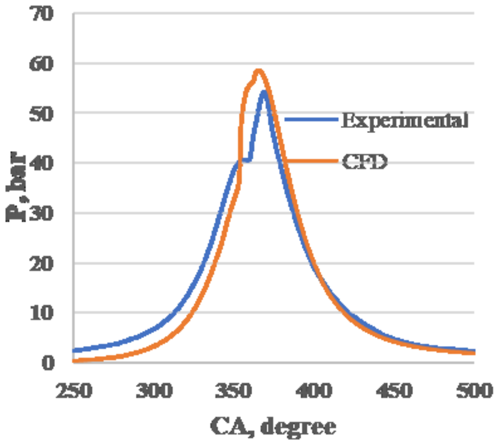

Figure 3. P vs. CA for CR 14

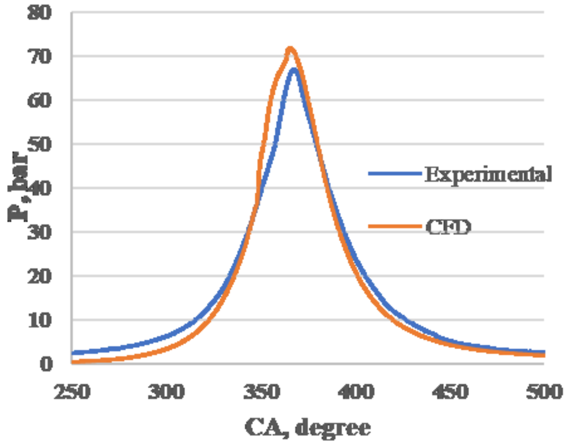

Figure 4. P vs. CA for CR 16.5

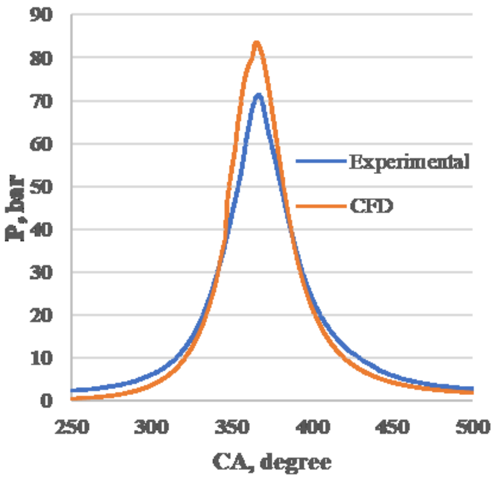

Figure 5. P vs. CA for CR 18

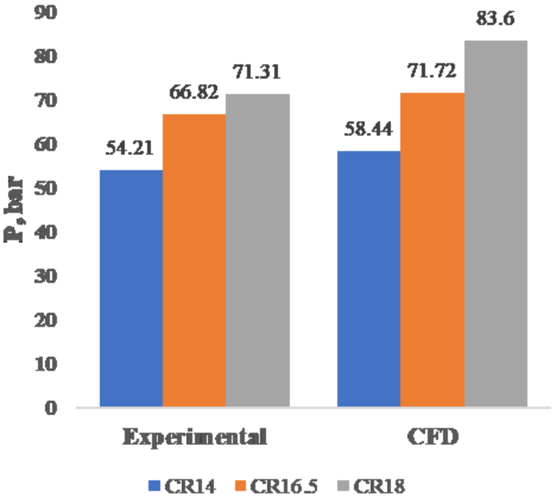

Figure 6. Peak P in bar at different CR

The relation between experimental & CFD result for P-CA diagram required for validation result is given in "Table 4".

Table 4. Percentage difference between CFD and experimental peak pressure

CR	Experimental Vs CFD (%)
14:1	7.24
16.5:1	6.83
18:1	14.7

Pressure vs. Volume (P-V) Diagrams

In the CI engine during the compression stroke the volume inside the cylinder consuming and at the same time the cylinder pressure increases till the piston top surface reaches to TDC. The experimental and CFD analysis for P-V diagram at CRs 14, 16.5 and 18 is shown in “Figure 7” to “Figure 9”. It is observed that there is a little deviation of curve at the compression and expansion stroke of the engine inside the cylinder and modeled exhaust valve opening is before 35.5° CA. So, simulation curve is not closed.

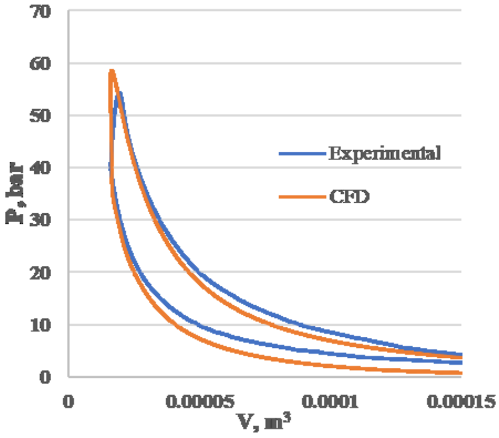

Figure 7. P- V diagram for CR 14

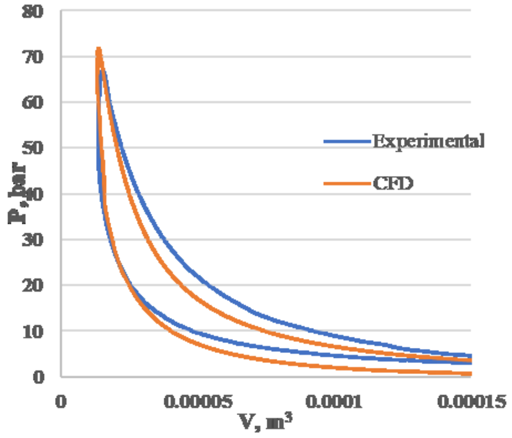

Figure 8. P- V diagram for CR 16.5

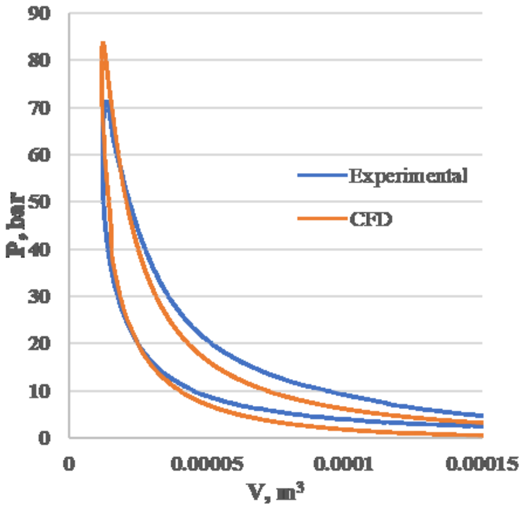

Figure 9. P- V diagram for CR 18

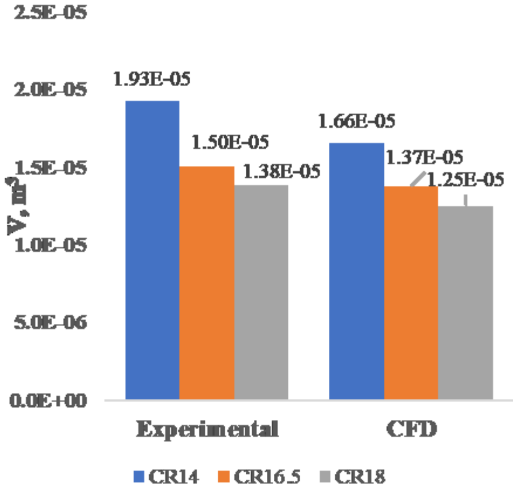

Figure 10. Volume at P for different CRs

The volume (V) from “Figure 10” at which highest peak pressure inside the cylinder from both experimental and CFD analysis is observed. It is noticed that highest peak pressure with more volume consumption is observed in CFD analysis as compared to experimental. Which could be due to the leakage between piston and cylinder during compression stroke in the experimental case at CRs 14, 16.5 and 18.

Heat Release Rate (HRR)

The variation in HRR for different crank angle at different CRs for CB20 obtained from CFD is shown in “Figure 11”. It is observed that, the HRR in the cylinder at CR 14, 16.5 and 18 are 36.33 J at CA 364, 32.85 J at CA 364 and 27.54 Joules at CA 363 for CFD analysis respectively. The occurrence of peak HRR is due to the injected fuel portion mixed and vaporized with air during the premixed combustion phase. The peak HRR near to TDC with HR increases then the compressed air increases the temperature of the fuel which results in increased intensity of combustion [16]. The variation of HRR due to continuous injection of fuel, addition of heat due to combustion and heat lost due to work done and cooling of engine.

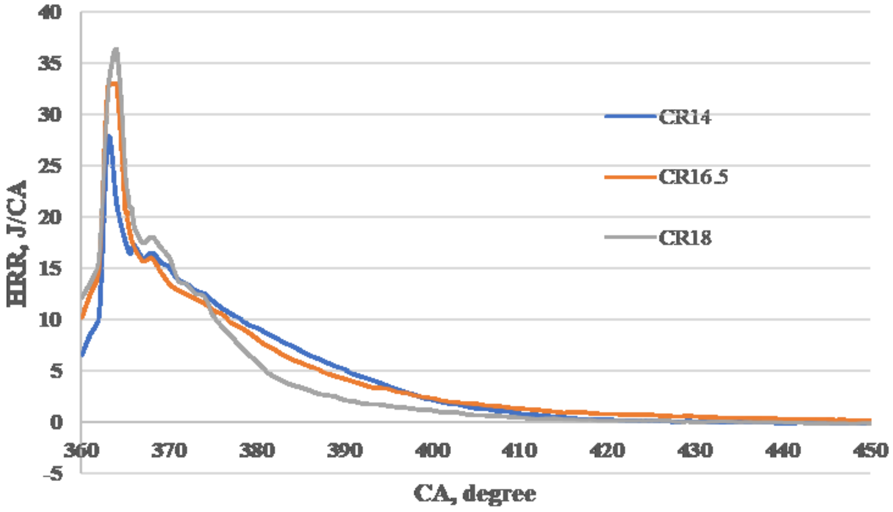

Figure 11. CFD HRR at different CRs

Variation of Temperature with Crank angle (T-CA)

The temperature (T) vs. crank angle (T-CA) diagram also plays a vital role in understanding the combustion process. Four stages of combustion period also depend on the temperature inside the cylinder and corresponding crank angle.

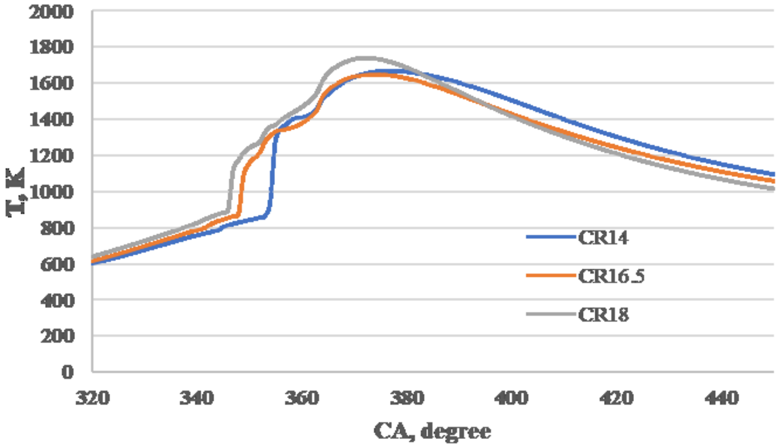

Figure 12. CFD simulation of T-CA diagram at different CRs

The variation of temperature observed from the CFD analysis with CA at different CR 14, 16.5 and 18 respectively as shown in "Figure 12". It is noted that from CFD analysis the volume average temperature developed in the cylinder are 1666.53 K, 1652.63 K and 1740.96 K for CR 14, 16.5 and 18 resulted at crank angles 377°, 374° and 372° respectively. The results indicate that higher the temperature increases NOx emission at higher CR and minimum for CR14 [17].

CONCLUSIONS

It is observed that slight and accepted variation of peak combustion pressure between experimental and numerical investigation with the use of CB20 fuel. CFD analysis predicted the pressure and volume inside the chamber during combustion at different CRs. Peak pressure reduces as the compression ratio decreases from 18 to 14. High HRR is observed for higher CR and low for CR14 from CFD simulation. Temperature is increased after the combustion and resulted maximum for CR 18 and decreases with CA during the expansion phase. Overall, it is concluded that there is a strong correlation between experimental & CFD results for diesel engine CCs parameters at CR 14, 16.5 and 18 respectively. Thus, the CFD analysis is useful for studying the CCs of CI engine. From the literature, it is found that only few are attempted earlier this kind of CFD analysis. This could be a useful model for the future researchers for validating results by saving cost of measurement device and time.

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