Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 4, Issue 7; October-December, 2017, pp. 555-560
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http://www.krishisanskriti.org/Publication.html

Numerical and Experimental Comparison of Diesel Combustion in CI Engine

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Abstract—*The combined CFD analysis – experimental study of the diesel engine that is carried out in this paper, aims at the evaluation of the CFD potential to predict the complex combustion inside the IC engine. The IC engine test rig chosen is Kirloskar TV1 having power 5.20 kW @ 1500 rpm which is multi Cylinder, Four stroke, Constant Speed, Water Cooled, Diesel Engine with computerized panel to record the results along with an eddy current dynamometer with a working r.p.m. upto 5000.It is an effort to compare the computational results obtained using CFD with the experimental results. Two dimensional computational geometry is used which is decomposed and used for computational analysis. Velocity and temperature contours obtained computationally represent the insight which is important in understanding the complex combustion phenomena. Non premixed combustion model is used along with conservation of mass and momentum equation for obtaining the results though CFD. Results obtained are pressure-volume, mass fractioned burned, net heat release, rate of pressure rise and mean gas temperature vs crank angle. Results obtained computationally were in close resemblance with CFD results. Same trends regarding peaks and troughs were observed in results obtained experimentally and in CFD. The study concludes that the computational geometry and model used can be used for evaluating and predicting the engines combustion performances.*

Table 1: Keywords

TDC	Top Dead Centre
BDC	Bottom Dead Centre
SOC	Start of Combustion
CFD	Computational fluid dynamics
CI	Compression Ignition

1. INTRODUCTION

The theory of combustion is a very complex subject and it has been a topic of wide spread discussion and research for many years. The major problems arise with the fact that the actual combustion process cannot be observed unless with a costly set up. In recent years a lot of intensive research has been done into this field but in spite of this, not much is known about the phenomenon of combustion. There are four stages of combustion in CI Engines .Its divided into the ignition delay period, the period of rapid combustion, the period of controlled combustion and the period of after burning. To observe the Combustion characteristics of the CI Engine the IC engine rig on which tests were performed was Kirloskar TV1 having power 5.20 kW @ 1500 rpm which is 4 Cylinder, Four stroke, Constant Speed, Water Cooled, Diesel Engine . Results obtained are pressure-volume, mass fractioned burned, net heat release, rate of pressure rise and mean gas temperature vs crank angle. IC engines involve complex fluid dynamic interactions between air flow, fuel injection, moving geometries, and combustion.. Various design problems are encountered including but not limited to port-flow design, combustion chamber shape design, variable valve timing, injection and ignition timing, and design for low or idle speeds.

There are several tools which are used in practice during the design process. These include experimental investigation using test or flow bench setups, 1D codes, analytical models, empirical/historical data, and finally, computational fluid dynamics (CFD). Of these, CFD has the potential for providing detailed and useful information and insights that can be fed back into the design process. This is because in CFD analysis, the fundamental equations that describe fluid flow are being solved directly on a mesh that describes the 3D geometry, with sub-models for turbulence, fuel injection, chemistry, and combustion. Several techniques and sub-models are used for modeling moving geometry motion and its effect on fluid flow .We used two dimensional computational geometry which was decomposed for computational analysis.

2. EXPERIMENTAL SETUP

2.1. Test Rig

The study was conducted on a multi-cylinder, four strokes, 661.45cc, 5.20 kW, Constant speed, Water cooled Kirloskar TV1 Diesel Engine. The engine set up used is shown in Figure 1. The engine was run on a steady state condition before generating the performance report.

Figure 1. Experimental Setup

Table 2. Engine Details.

Type	4-stroke,multi cylinder, Compression ignition engine
Make	Kirloskar TV1
Rated Power	5.20 kw @ 1500 r.p.m.
Bore & Stroke	87.50 mm*110.00 mm
Compression Ratio	17.50
Cylinder Capacity	661.45cc
Fuel	Diesel
Connecting Rod Length	234.00 mm

Table 3. Combustion Parameters.

Specific Gas Const (kJ/kgK)	1
Air Density (kg/m^3)	1.17
Adiabatic Index	1.41
Polytrophic Index	1.26
Auto-ignition Temperature (deg. Celsius)	210

Table 4. Engine Parameters and Fuel Properties

Orifice Diameter (mm)	20.00
Orifice Coefficient Of Discharge(mm)	0.60
Dynamometer Arm Length(mm)	185
Fuel Pipe diameter (mm)	12.40
Ambient Temp. (Deg C)	27
Autoignition Temperature(Deg C)	210
Fuel Density (Kg/m^3)	830
Calorific Value Of Fuel (kj/kg)	42000

2.2. CFD Modeling

Two dimensional computational geometry is used which is decomposed and used for computational analysis. Velocity and temperature contours obtained computationally represent the insight which is important in understanding the complex combustion phenomena. Non premixed combustion model is used along with conservation of mass and momentum equation for obtaining the results though CFD.

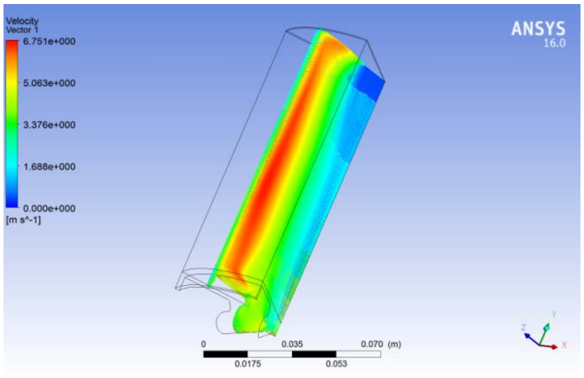


Figure 2. CFD Model

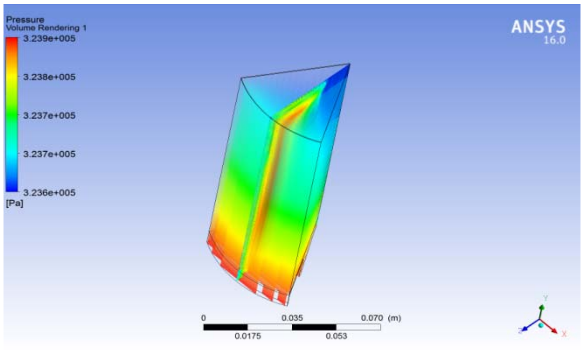


Figure 3.CFD Model

3. RESULTS

3.1 Experimental Results

Cylinder Pressure is the pressure in the engine cylinder during the 4 strokes of engine operation (intake, compression, combustion and expansion, and exhaust).The cylinder pressure vs. crank angle graph shows that the increase in pressure starts before the SOC due to the intake stroke, after SOC the graph rises sharply due to the combustion, reaching its peak 10 degrees after TDC.

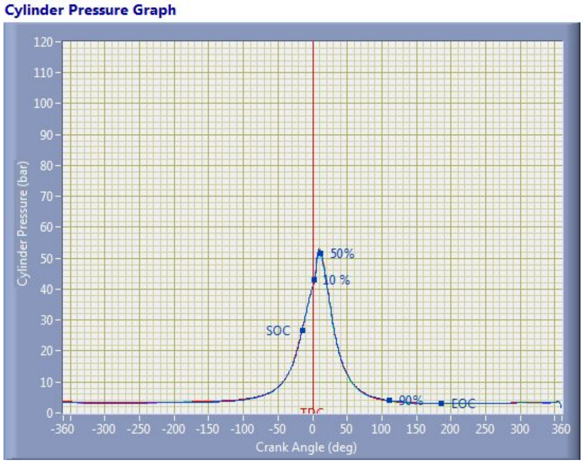


Figure 4. Pressure versus crank angle graph

All heat engines are characterized by a pressure-volume diagram, also known as pV diagram, which basically shows the variation of the pressure in the cylinder function of its volume, for a complete engine cycle.

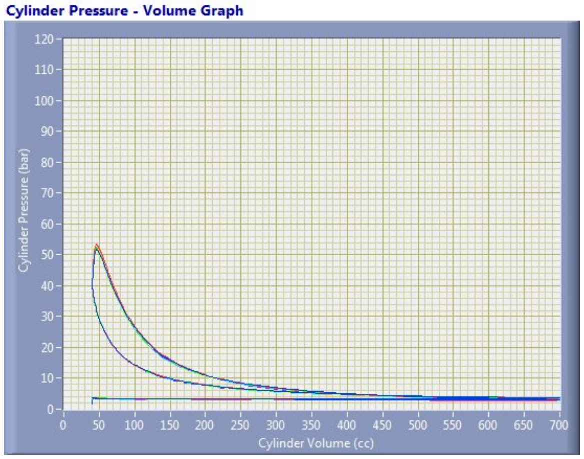


Figure 5. Pressure vs. Volume graph

The compression and heat addition strokes are defined by a single curve and the expansion by other. The exhaust and suction stroke have very less change on the pressure -volume diagram but act as changing points.

The most common method of defining cumulative combustion is with a mass fraction burned curve. Mass fraction burned is the ratio of the cumulative heat release to the total heat release

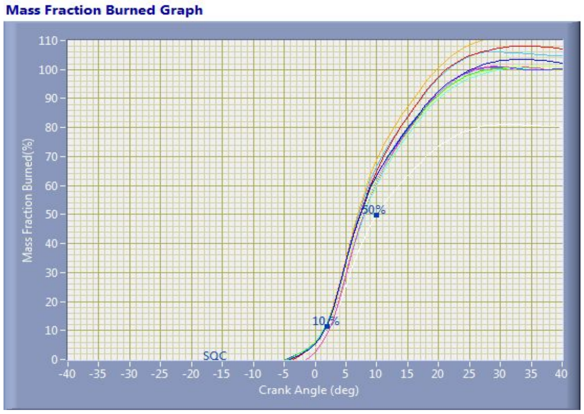


Figure 6. Mass fraction burned vs. crank angle

On the basis of first law of thermodynamics the heat release model is given in figure 5.

$$\frac{dQ_n}{d\theta}=\frac{\gamma}{\gamma-1}p\frac{dV}{d\theta}+\frac{1}{\gamma-1}V\frac{dp}{d\theta}, \qquad \text{where} \quad \frac{C_p}{C_v}=\gamma, R=C_p-C_v$$

Figure 5.Formula for heat release

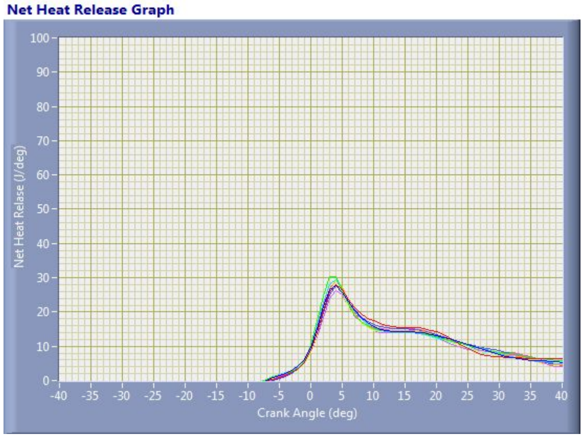


Figure 7.Net heat release vs. crank angle graph

The heat starts getting released before the piston reaches TDC .The max heat is released about 4 degrees after TDC, the heat keeps on being released to about 40 degrees after TDC

The rate of pressure rise shows that the rate increases just before reaching TDC, peaks at TDC and then dips sharply.

Figure 8.Rate of Pressure rise vs. crank angle graph

The mean gas temperature curve ascends before TDC and reaches its peak at about 20 degrees after TDC. Then it starts declining.

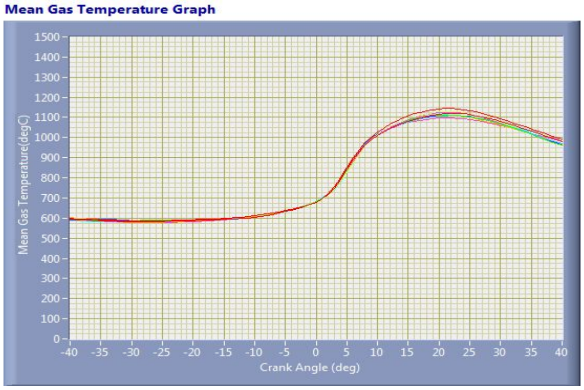


Figure 9.Mean Gas Temperature vs. crank angle

3.1.2. Simulation Results

The average pressure vs crank angle graph peaks at the TDC and steadily decreases .The graph follows the experimental data and is also validated by it, same trends are observed regarding peaks and troughs.

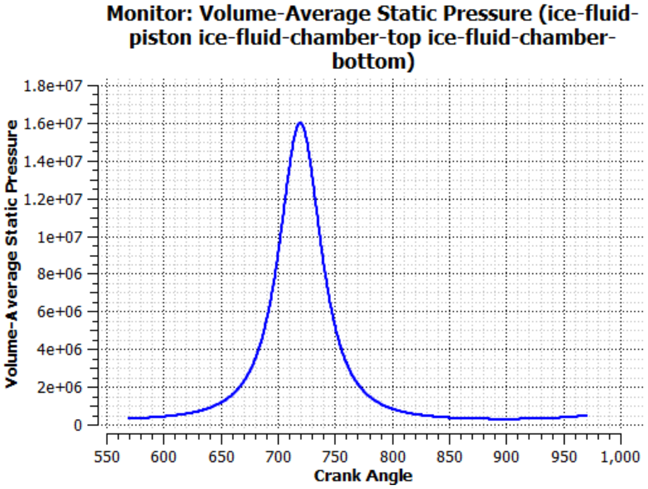


Figure 10.Average pressure vs. crank angle

The AHRR vs. crank angle graph shows that AHRR drops significantly at BDC and keeps dropping till combustion at TDC ,where it peaks.

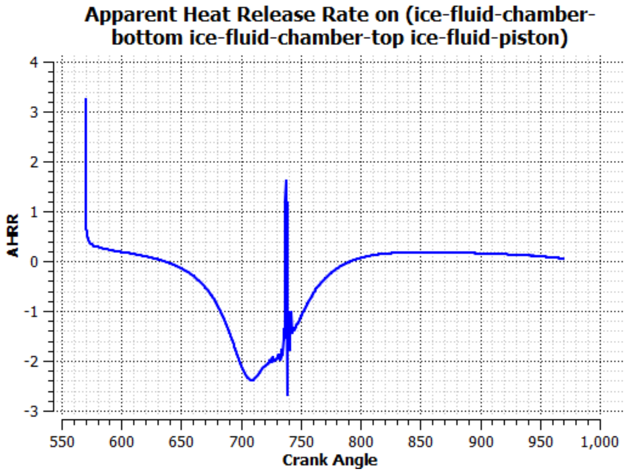


Figure 11.AHRR vs. crank angle

The average kinetic energy vs. crank angle graph peaks just before the TDC pr before combustion.

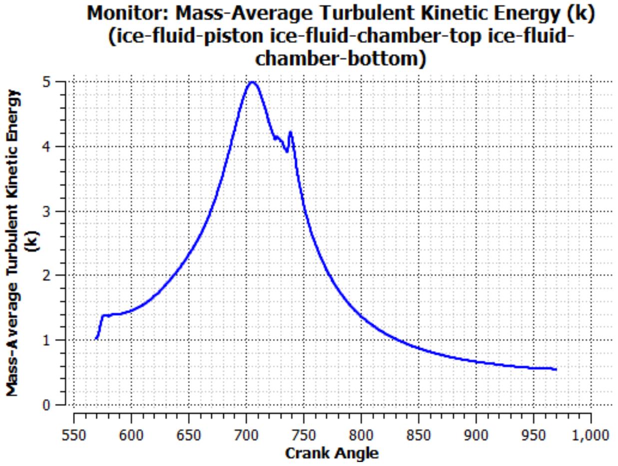
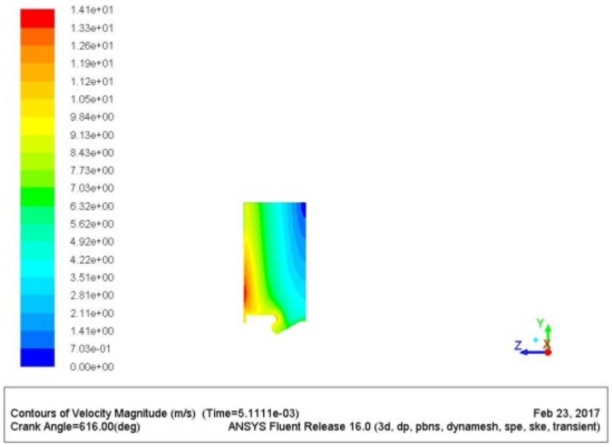
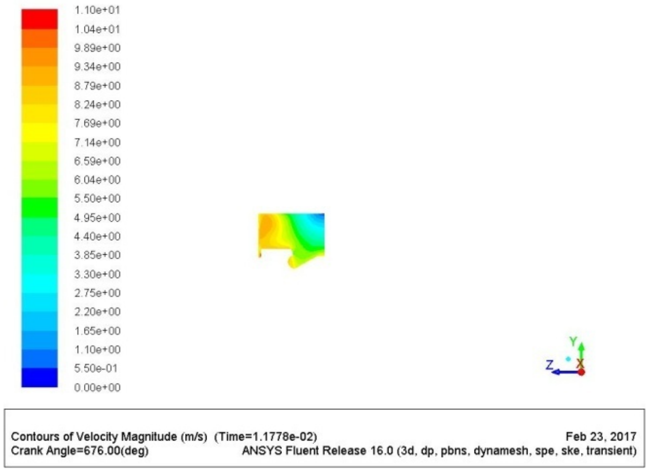


Figure 12. Average KE vs. crank angle



Contours of Velocity Magnitude (m/s) (Time=5.1111e-03) Feb 23, 2017
Crank Angle=616.00(deg) ANSYS Fluent Release 16.0 (3d, dp, pbns, dynamesh, spe, ske, transient)



Contours of Velocity Magnitude (m/s) (Time=1.1778e-02) Feb 23, 2017
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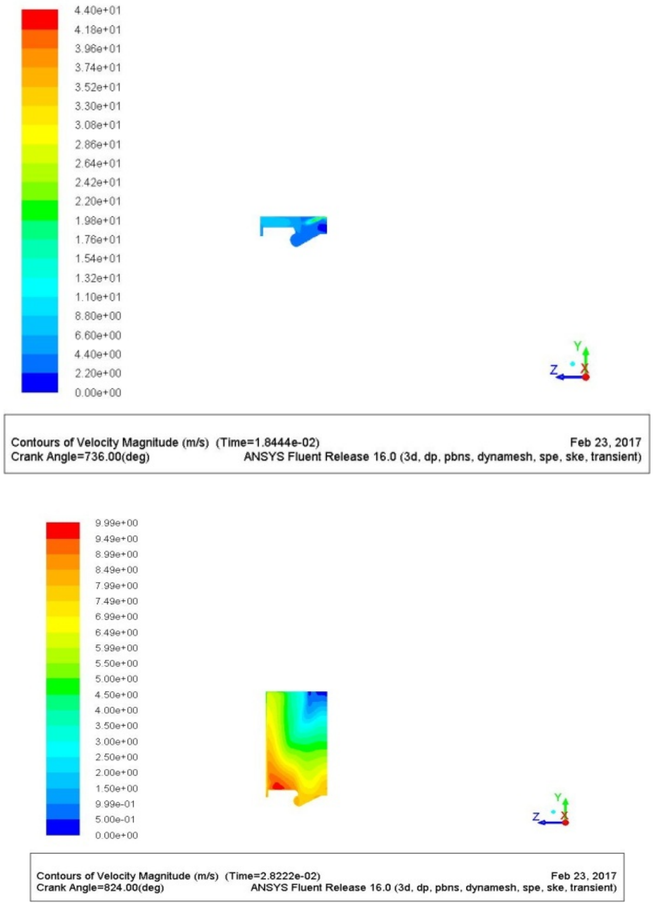
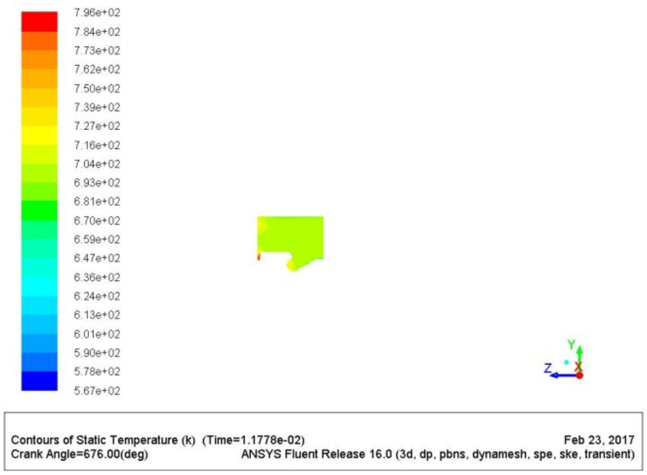


Figure 13. Contours of Velocity Magnitude

The velocity contours chart depict the change in velocity of the fluid in the piston, relative to change in crank angle .The velocity and temperature contours provide an insight to the internal fluid flow and heat change inside the piston.



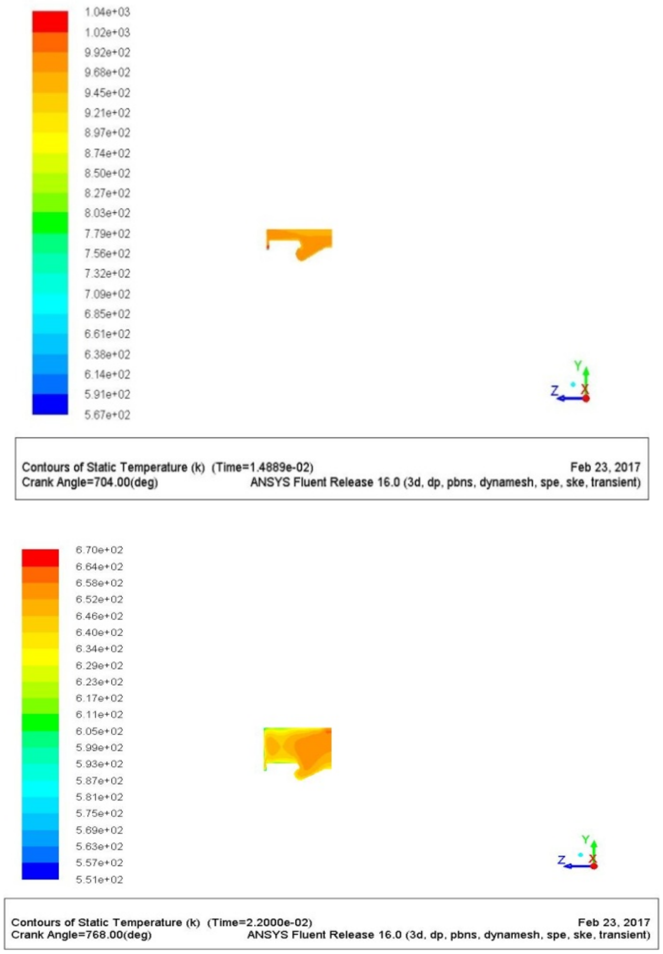


Figure 14.Contours of Static Temperature

These contour charts are validated by the actual experimental data observed by us thorough the test rig.

4. CONCLUSIONS

When the results through the analysis our CFD model and the experimentally performed data were compared, the following points were observed:-

1) Our CFD results were validated by our experimental data, thus our CFD model can be used for analysis and study.
2) Same trends regarding peaks and troughs were observed in results obtained experimentally and in CFD.
3) In the net heat release graph the peak points are observed to be occurring at the same crank angles.

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