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Study of The Effect of Spark Advance, Engine Speed Variation and Number of Spark Plugs on Engine Performance Using CFD Software

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ABSTRACT

CFD Models have been extensively validated and used to predict the performance and emissions of spark ignition (SI) engines and compression ignition CI engines. As opposed to experimental methods, numerical methods are often less expensive and faster. The present work is the numerical investigation of spark ignition SI engines using open source Computational Fluid Dynamics (CFD) tool OpenFOAM. The effect of spark advance, engine speed variation and number of spark plugs on engine performance is studied with OpenFOAM module engineFOAM. The standard k-ε turbulence model is used along with Reynolds Averaged Navier Stokes (RANS) equations for simulating flow field and heat transfer. The cylinder geometry is created in ICEM CFD and converted to OpenFOAM. The variation in pressure and temperature values in the cylinder with crank angle are plotted. Also contours for temperature distribution and reaction regress variable are plotted.

KEY WORDS: *OpenFOAM, Spark Ignition Engine (SI), kivaTest, Engine Combustion.*

NOMENCLATURE

CA Crank Angle
b Reaction Regress Variable
SI Spark Ignition
B Bore
N Speed in rpm
Φ Relative Air Fuel Ratio
Γ Compression Ratio
l connecting rod length

1.0 INTRODUCTION

Spark Ignition (SI) engines are employed across a broad range of scale and of applications. This variation of application is caused by varying requirements of power output as well as increasing concerns for emission legislations. To meet these requirements experimental as well as numerical research is carried out in the field. Extensive validation of CFD models has been carried out and used to predict the performance of spark ignition (SI) and compression ignition (CI) engines. The cost and time benefits of numerical methods far outweigh the experimental ones and have actually come to dictate the terms in experimental research. Additionally, simulations give much further information (mixture formation, combustion process, flow field, etc.) CFD codes such as STAR-CD, ANSYS Fluent, KIVA etc. are able to solve this kind of problem with their numerical contents and models. This dependence has given an impetus to the advancement in numerical methods and simulations.

OpenFOAM®, an open source CFD tool has been generating traction with researchers CFD analysis in various field. The application of OpenFOAM investigations to internal engines is limited. It has not been used like other commercial tools that are available in the market. Various developments are being carried out for engine simulation related solvers especially for solving diesel engine processes.

Application to SI engines is again limited. Kannan 2016, provides for preliminary simulations for SI engines using OpenFOAM. The present project work draws from this and extends towards applying OpenFOAM to cases of engine speed, spark advance and number of spark plugs variation in an engine.

2.0 LITERATURE RIVEW PAPER FORMAT

Kannan, B.T. [3] compared for Cold flow compression and combustion simulations in terms of temperature and pressure for various CA. The temperature contours were plotted on a vertical plane inside the cylinder indicates the rise in temperature due to combustion.

A computer simulation was performed by Ender HEPKAYA, Salih KARAASLAN [5] to visualize fluid flow and combustion characteristics of a single cylinder spark ignition engine. The complete engine cycle process (inlet, compression, expansion and exhaust strokes) in gasoline engine model was investigated using RANS (Reynolds Averaged Navier-Stokes) and CFM (Coherent Flame Model) approaches offered by Star-CD/es-ice.

Cho [6] et al. have carried out studies on a four-valve, direct-injection spark-ignition (DISI) engine, with the fuel injector located between the two intake valves. Measurement and simulation of wall film behavior of formation, transport, and vaporization on the surface is carried out.

Cornolti L [10] et al (2015) has worked on OpenFoam in CFD modeling of turbulent premixed combustion in SI engines covering all the stages of combustion process, starting from early flame kernel development to its fully developed phase.

Cupia L [11] et al have carried out experimental measurement on the performance on multi point spark engine operating on lean mixture. They have also modeled the engine in KIVA 3V fortran based CFD tool.

3.0 COMPUTATIONAL METHODOLOGY

3.1 *Engine Details*

Two engines are selected for the present work. Engine 1 is used to validate the openFOAM CFD with experimental results performed by researchers [2]. Subsequently the same CFD code is used for another engine Engine 2 to carry out further numerical study. The detailed specifications of both the engines are given in Table 1.

Table 1: Engine Specification

Sr.No	Engine Specification	Engine 1	Engine 2
1	Bore (B), mm	79.4	52
2	Stroke (2a), mm	111.2	46
3	Connecting rod length (l), mm	233.4	81
4	Compression Ratio (Γ)	7.4	4.8
5	Speed (N), rpm	2000@5HP	3600@1.8HP
6	Spark Timing in terms of Crank Angle	25 deg bTDC	25 deg bTDC
7	Intake Manifold Pressure (P_0), bar	1	1
8	Relative air fuel raitio (φ)	1	1
9	Fuel	C_8H_{18} (Gasoline)	C_8H_{18} (Gasoline)

3.2 Computational Domain and Boundary Conditions

Mesh is generated in ANSYS ICEMCFD. Multi block 'O' grid with hexahedral elements. The geometry consists of piston, cylinder Head and liner. Fine mesh is used in area near cylinder head.

Mesh is generated in such way that aspect ratio is not increased to very high level. Fine mesh is selected for clearance volume to capture combustion.

Once the mesh is generated, it is imported into openFOAM for further simulation operations.

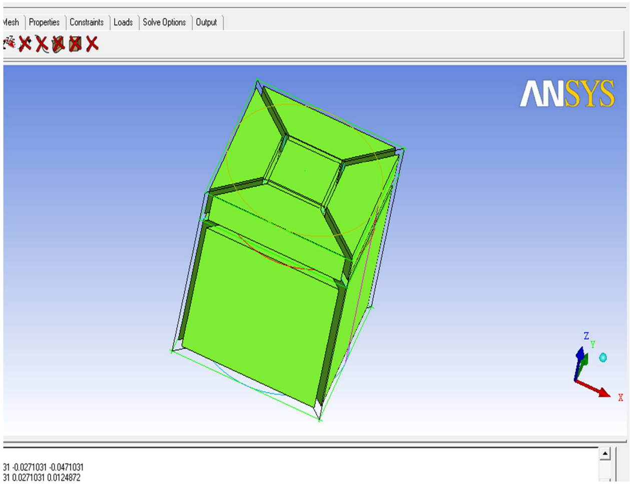

Figure 1: Creating blocks for meshing

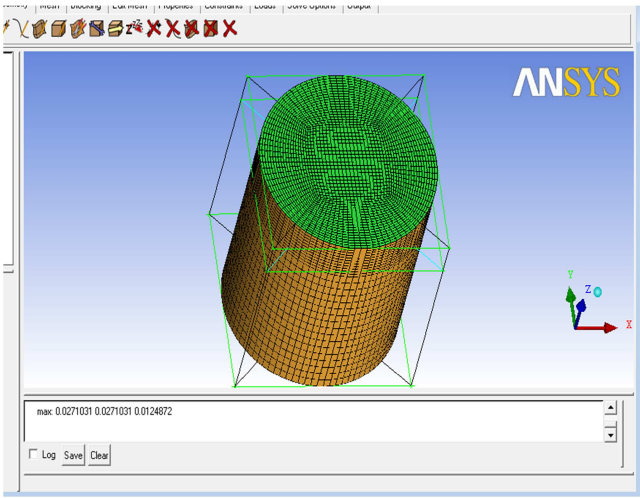

Figure 2: Meshing of cylinder Space

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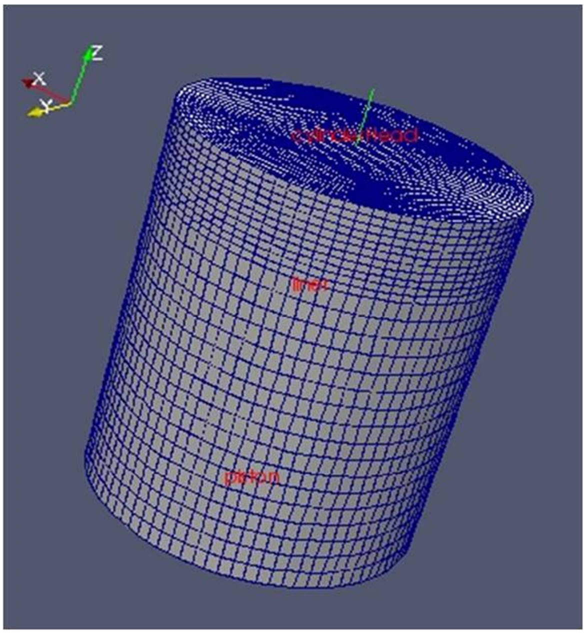

Figure 3: Mesh in openFOAM

3.3. Governing Equations And Other Details

Several Governing transport equations along with models of combustion are required for simulations of IC engines. The equations and models [2] to be used in the present work are as follows:

- RANS equations along with standard k—ε turbulence model for simulating the flow field
- Energy equation and transport equation for regress variable
- Transport model for Xi Gulder's correlation is used for laminar flame speed along with unstrained model.

Reaction Regress Variable: Reaction regress variable 'b' measures the extent of combustion reaction. Its value is 1-reaction progress variable.

4. RESULTS AND DISCUSSIONS

4.1 Case 1. Validation Of Computational Results With Experimental Data Performed By Researchers [1]

The reference [1] contains experimental data for the variation of cylinder pressure with respect to crank angle in a single cylinder petrol engine at different intake manifold pressures. Simulation in openFOAM was carried out for the similar computational setup and graphs for Pressure v/s Crank angle were plotted as follows. If it were to be assumed that the experimental results were performed with due diligence and the data is good [1] there exists a slight deviation between the values of peak pressure in experimental results. This deviation reduces as intake manifold pressure decreases. There is always some deviation in experimental results and simulation for a complex thermodynamic process such as IC engine combustion.

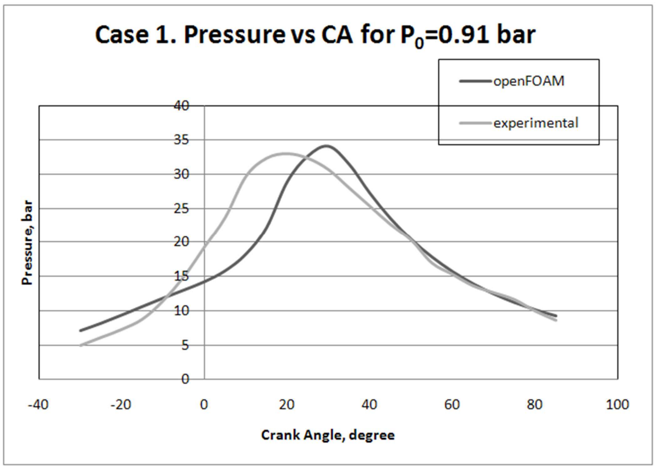

Figure 4: Pressure Vs Crank Angle graph for intake pressure 0.91 bar

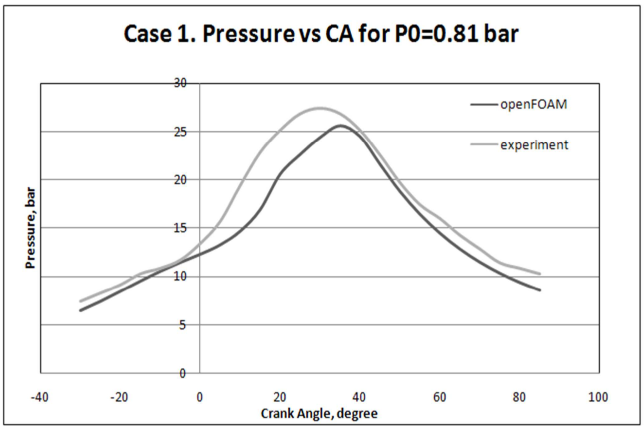

Figure 5:.Pressure Vs Crank Angle graph for intake pressure 0.81 bar

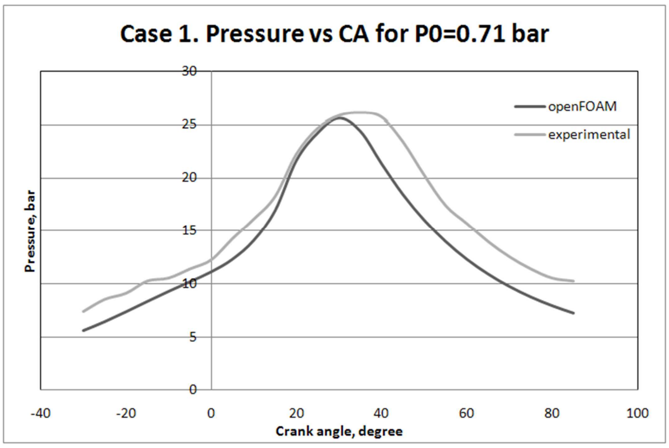

Figure 6:.Pressure Vs Crank Angle graph for intake pressure 0.71

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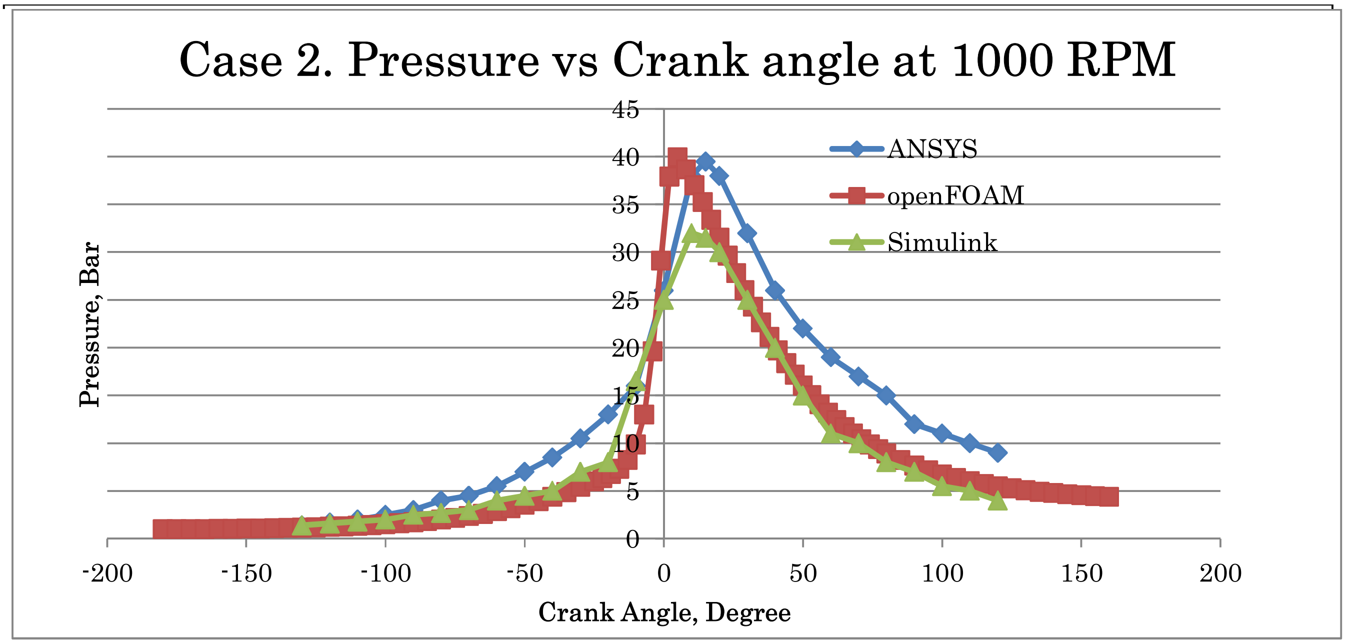

Figure 7: Pressure Vs Crank Angle graph for Case 2 at speed 1000 rpm

5.2 Case 2. Comparison of results in openFOAM with results from other simulation models.[4]

Chaudhari et al [4] have carried out simulations on same engine using simulink software and ANSYS. For similar conditions the present work has employed openFOAM and plotted the pressure VS Crank Angle Curves.

5.3 Case 3: Study the effect of spark advance at 5 degree intervals for six different spark advance angles.

Spark advance for the engine was varied from CA -30 deg to -5 deg and pressure vs CA graph is plotted. This is done to determine the effect of giving a spark advance to the engine. Three parameters viz variation of peak pressure, temperature distribution, and reaction regress variable for the values are studied.

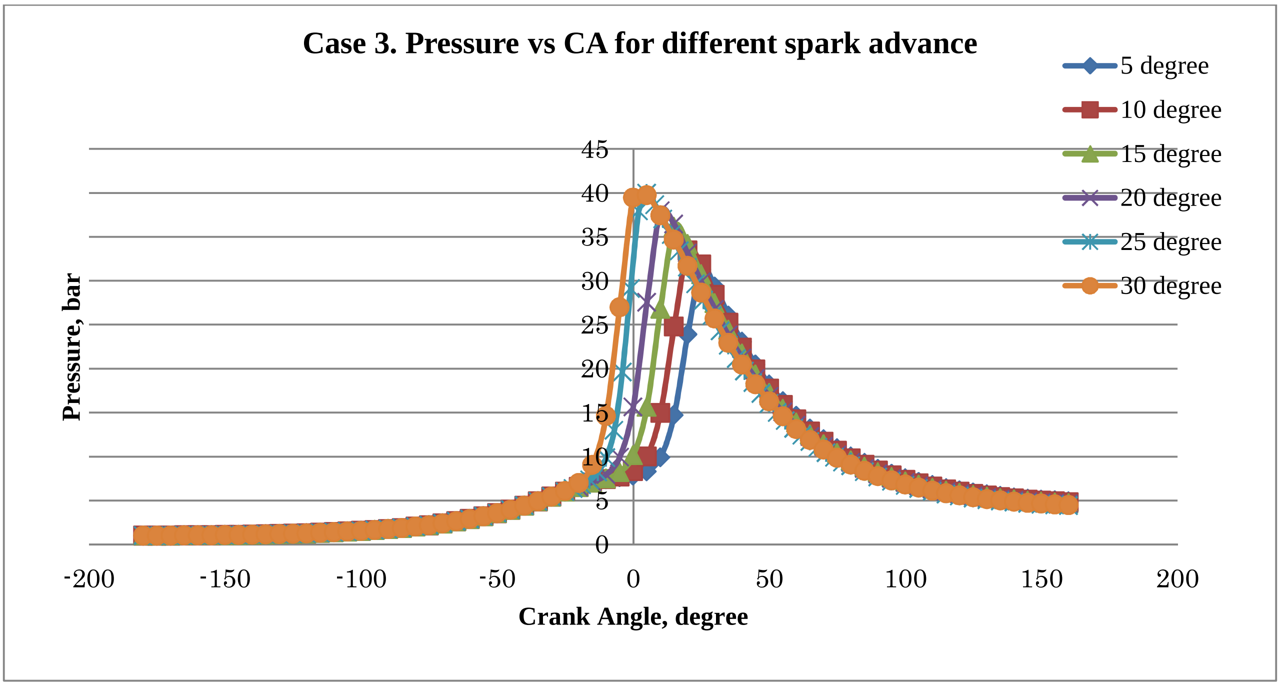

Figure 8: Pressure vs Crank angle graph for Spark advance case.

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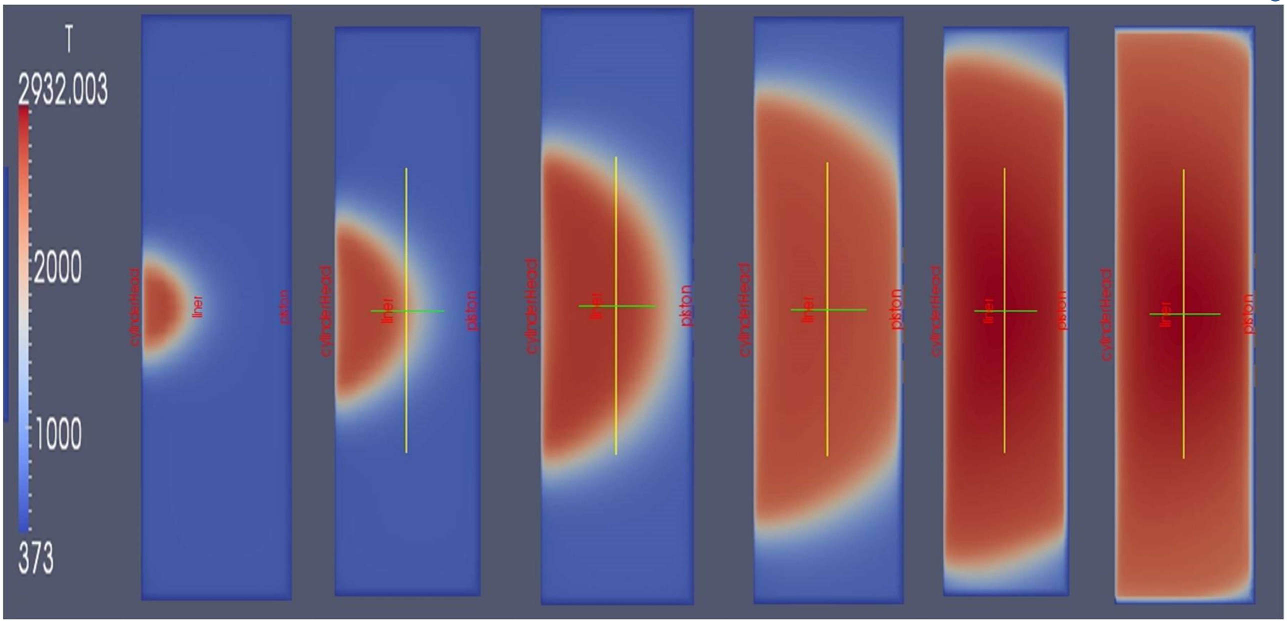

Figure 9: Temperature distribution plot in cylinder for spark advance (5 deg to 30 deg Left to Right)

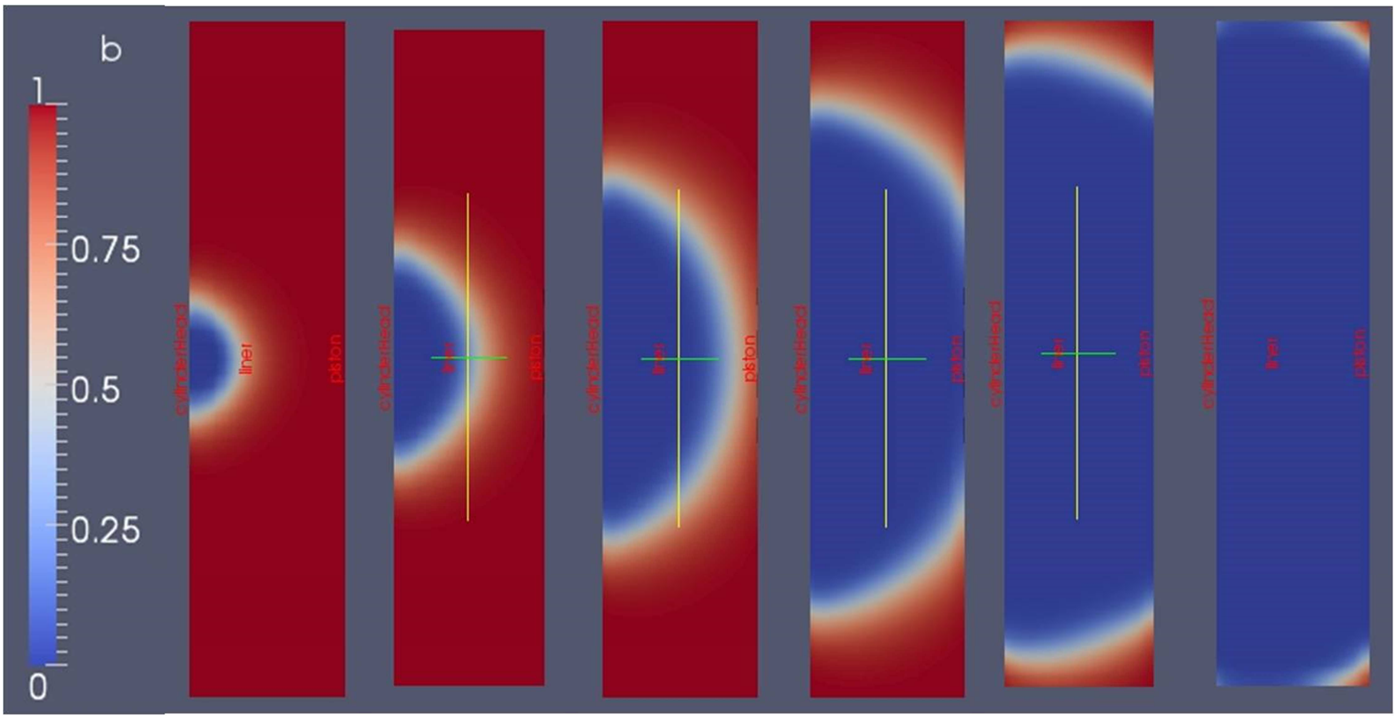

Figure 10: Reaction regress variable contour plot in cylinder for spark advance (5 deg to 30 deg. Left to Right)

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5.4 Case 4. Study of the effect of engine speed variation at a step of 200 rpm for five different speeds.

The engine speed was varied from 1500 rpm to 2500 rpm in a step of 200 rpm.

The pressure versus crank angle graph was plotted as follows. As in case 2, here also temperature distribution and reaction regress rate is plotted using contour plots.

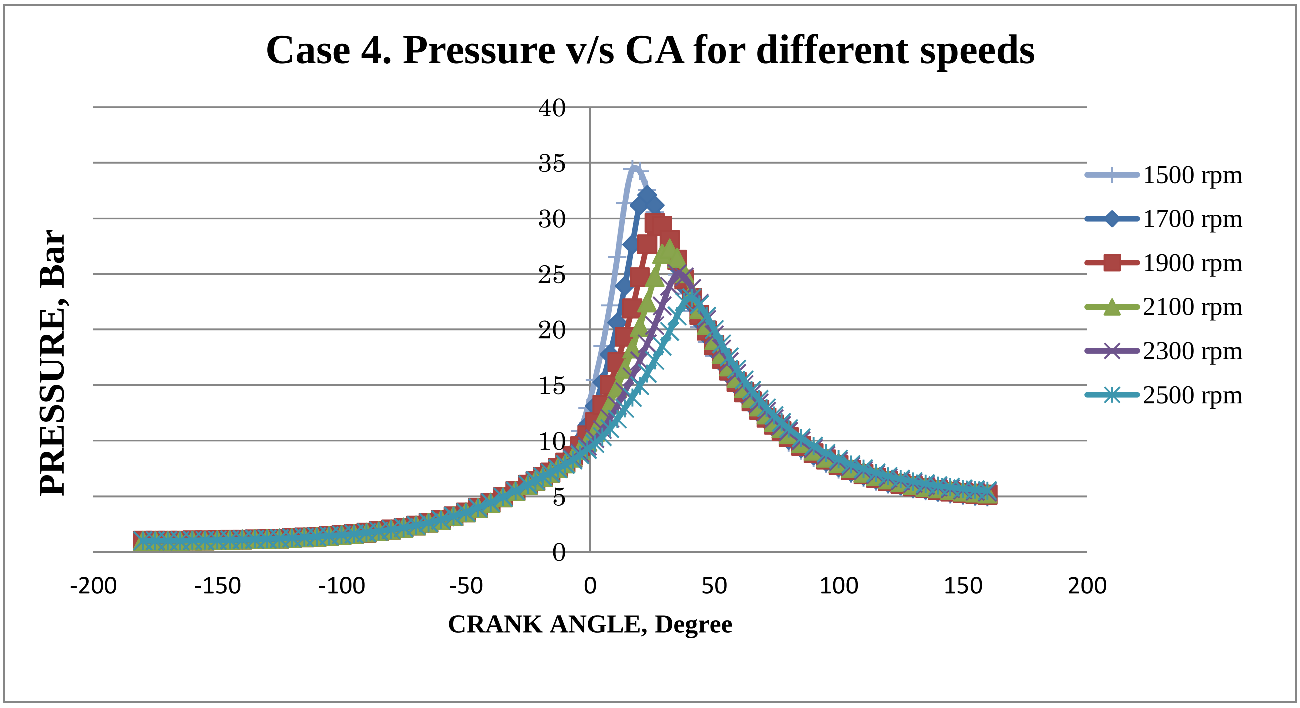

Figure 11: Pressure vs Crank angle graph for increasing engine speed

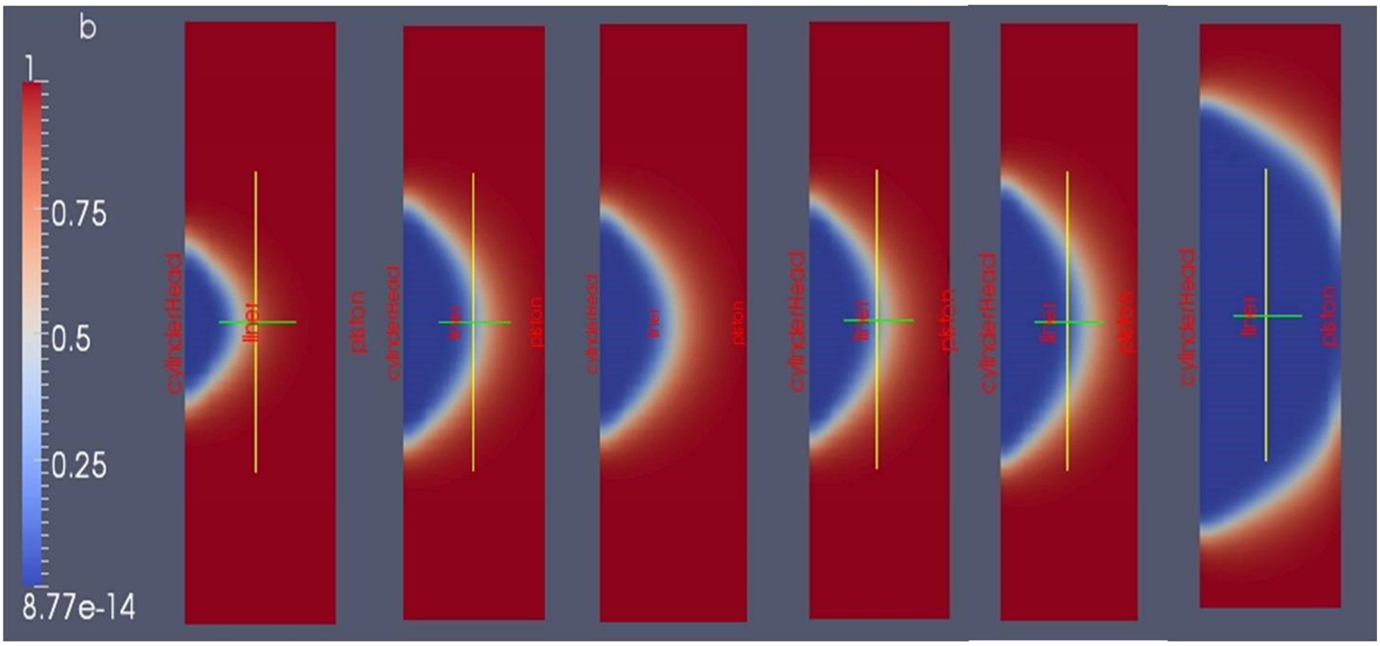

Figure 12: Reaction regress variable 'b' contour plot for engine speed from 1500 rpm to 2500 rpm

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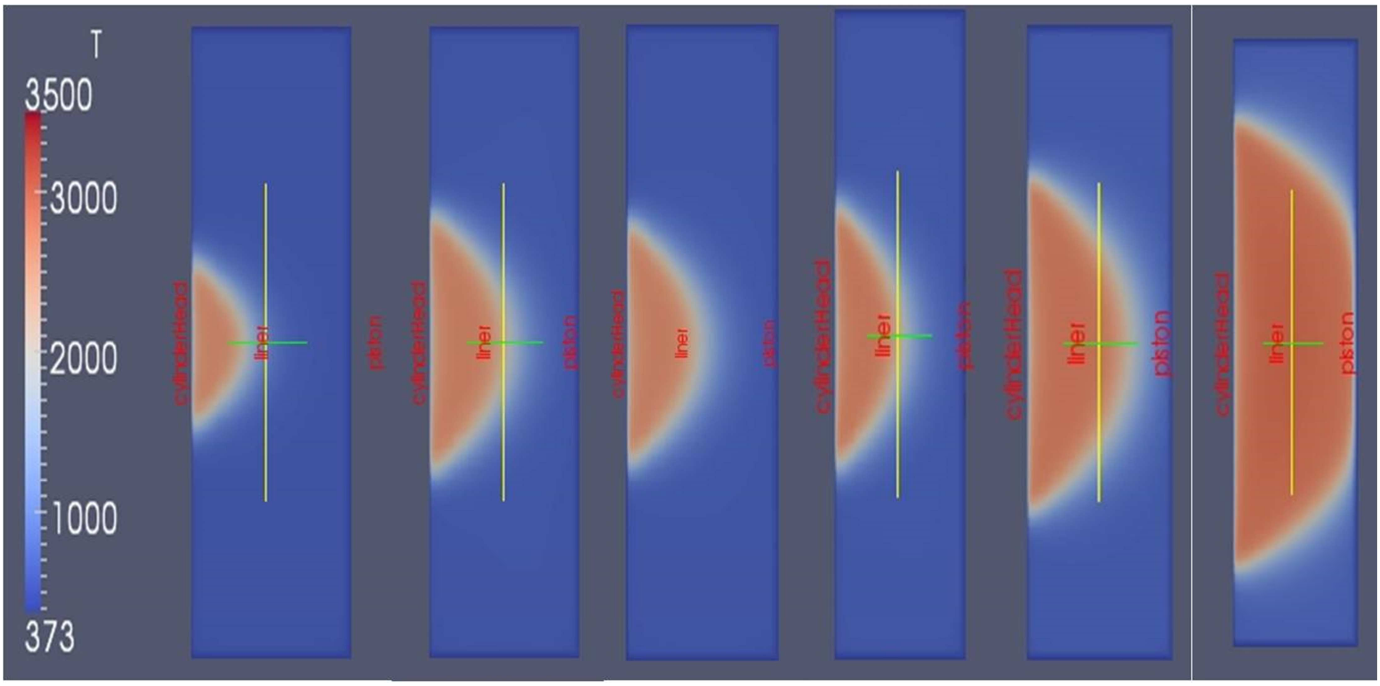

Figure 13: Temperature distribution plot for engine speed from 1500 rpm to 2500 rpm (Left to Right)

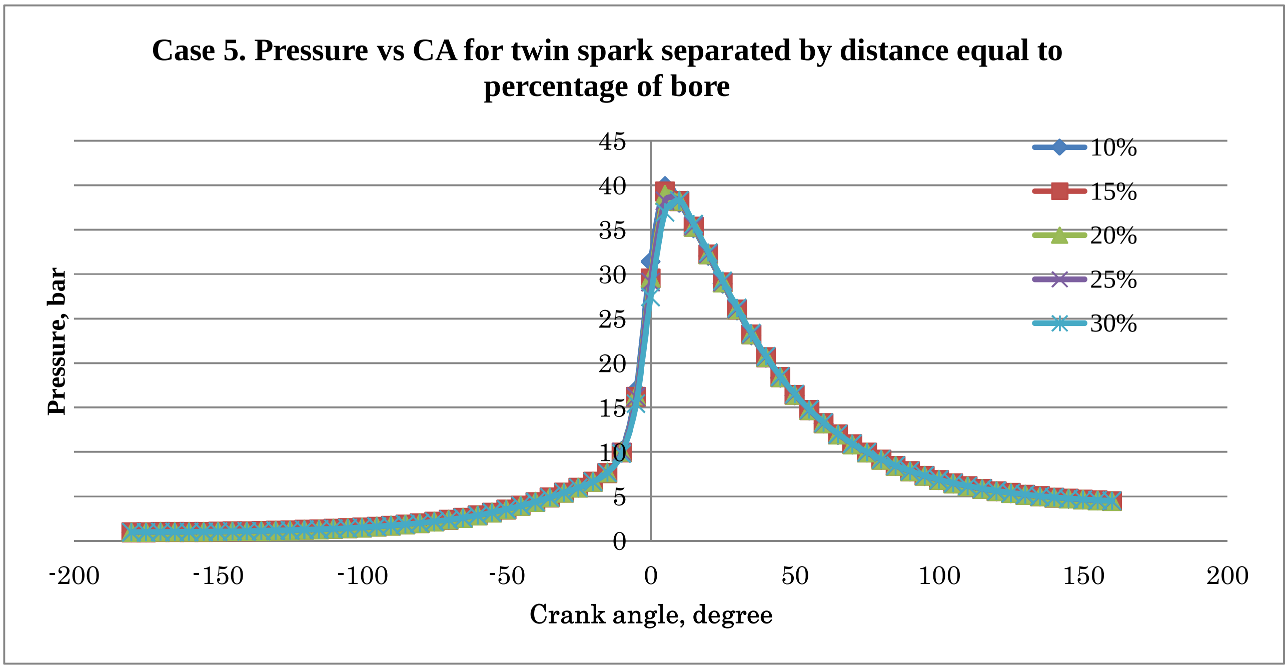

Figure 14: Pressure vs Crank angle graph for twin spark case

5.5 Case 5: Effect of twin spark plugs that are separated by a distance expressed as percentage of the bore

Simulations were run for a case involving two spark plugs (two ignition sites) from 10% to 30% in a five percent interval. The variation of pressure with respect to crank angle is plotted as follows.

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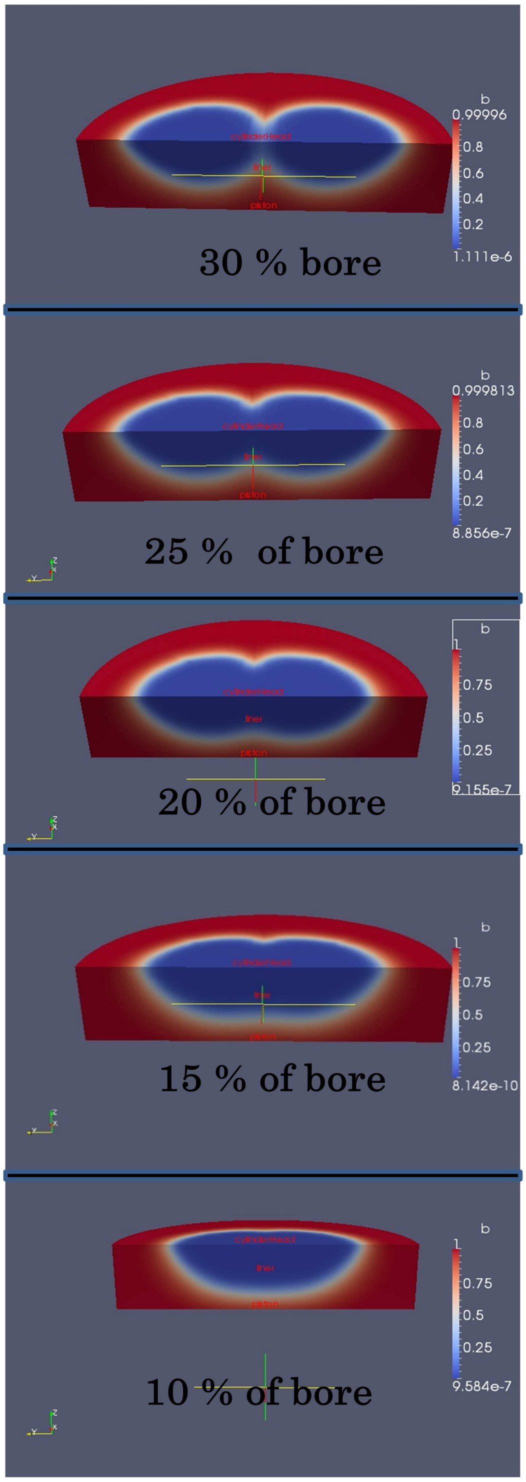

Figure 15: Reaction Regress Variable Plot for twin spark case

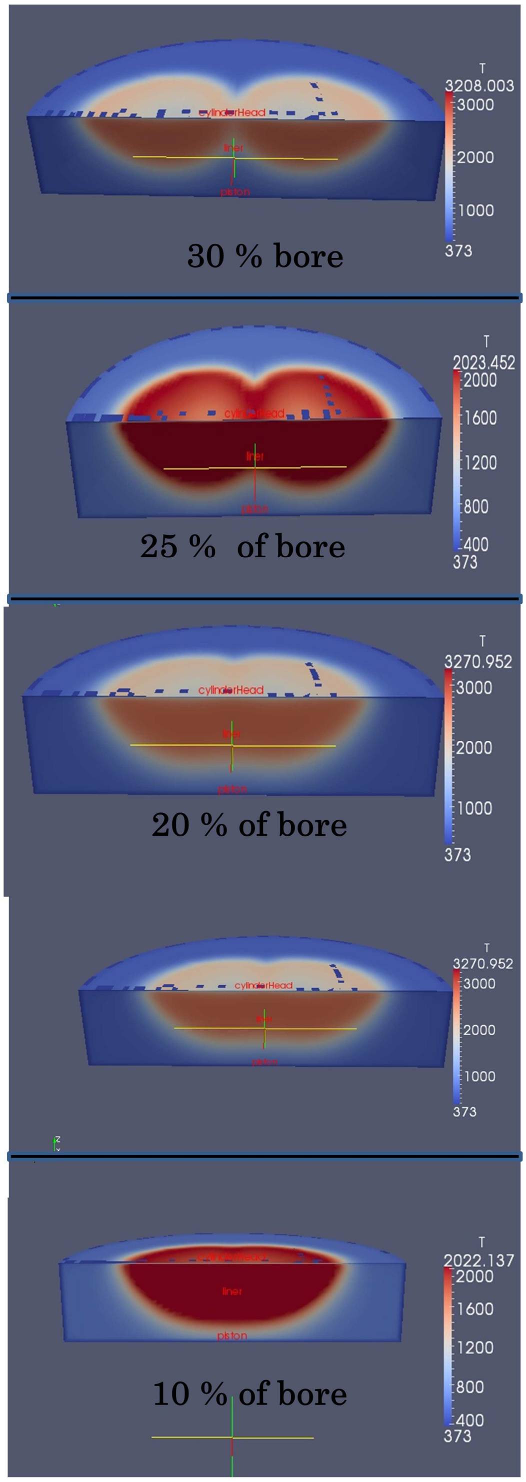

Figure 16: Temperature distribution contour plot for twin spark case

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5. CONCLUSION

The numerical results based on our geometry reported in this paper can provide flow field data for Spark Ignition (SI) engines using an open source CFD tool OpenFOAM. In this study, a computer simulation was performed, to visualize fluid flow and combustion characteristics of a spark ignition engine

Case 1 provided for validation of pressure variation in the engine with experimental data. The closeness of the two results makes a good case for openFOAM simulation for IC engines.

Case 2 which went for a comparison with ANSYS and Simulink results is a step ahead in checking as well as pitting openFOAM as a software alternative to existing commercial packages. There are some deviations which will be considered for further investigation of the complex phenomenon of combustion.

Case 3, which investigated the effect of spark advance on the engine, clearly demonstrates the rise in peak pressure as well as the progress of reaction. More is the spark advance, better is the reaction progress. However it comes at the cost of peak pressure therefore suitable combination of peak pressure requirement and reaction progress is employed.

Case 4 studied the effect of engine speed on the process. Here again the peak pressure clearly decreases with increasing engine speed. This is because of the reduction in time for combustion of the charge.

Case 5 is an investigation into the twin spark effects. The pressure regime shows very little deviation. However, the two distinct and strong flame fronts propel the reaction in the cylinder as is evident by the contour plots.

CFD tools have developed over the years to cater to the needs of research. OpenFOAM in engine simulations is an yet another step with the benefits of it being an open source CFD tool.

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