Annulus Water Jacket Cooling of An Induction Motor.

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Abstract –

This project aims to describe the heat transfer analysis of annulus water jacket cooling of AC-50 induction motor using Open FOAM software. The objective of this project is to study the final temperature of inner wall which is in contact with motor and to compare results with different geometries and meshes.

It also aims to find the outlet temperature of fluid and final temperature of the motor. This AC-50 induction motor finds its application in electric vehicles which replaces the IC engines in near future.

Keywords: *OpenFoam, BuoyantSimpleFoam, Annulus, Cooling, Salome.*

I. INTRODUCTION

Electric motor heats up when operated under extreme load and may reduce the efficiency of the vehicle. At high load the motor runs at 65^{0}C. According to the specifications the motor, it produces peak power of 60 HP which is equivalent to 45 KW. The efficiency of the is around 75-90 %. Assuming 90 % efficiency, the heat generated is 10 % which is 4500 W Further when safety factor included it comes to 5500 W [1]. The cooling medium is ethylene glycol.

A. Geometry

The CAD geometry of the annulus was created using SALOME (Version 8.3.0) which is an opensource software. The outer diameter of the annulus is taken as 0.27 m and the inner annulus diameter is taken as 0.22 m. The length of the annulus cylinder is taken as 0.23 m. The inlet and outlet radius are taken as 0.01 m and the length of the jacket is taken as 0.1 m.

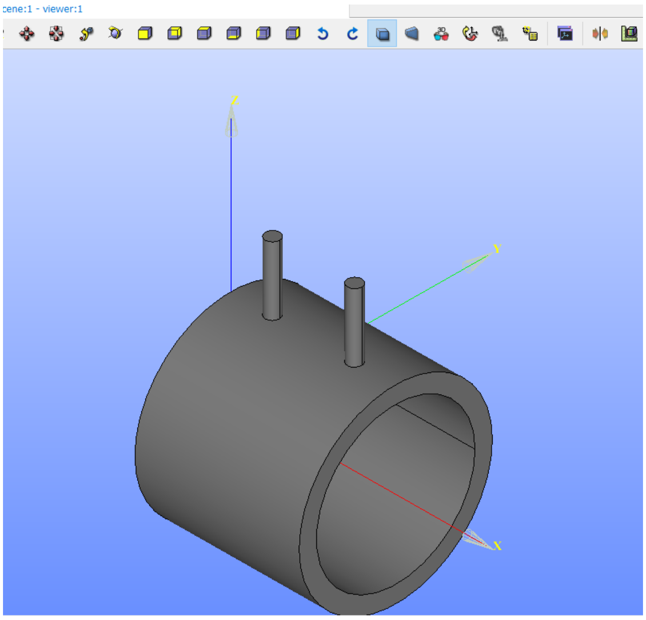

Figure 1: 3D Model of Annulus Geometry

Another geometry of annulus is created using SALOME. Dimensions of annulus are same as previous case. The inlet and outlet geometry are square prism. The dimensions of both inlet and outlet is 0.0177*0.0177. The cross-section area of both circular and square are same. The length of the jacket is 0.1 m

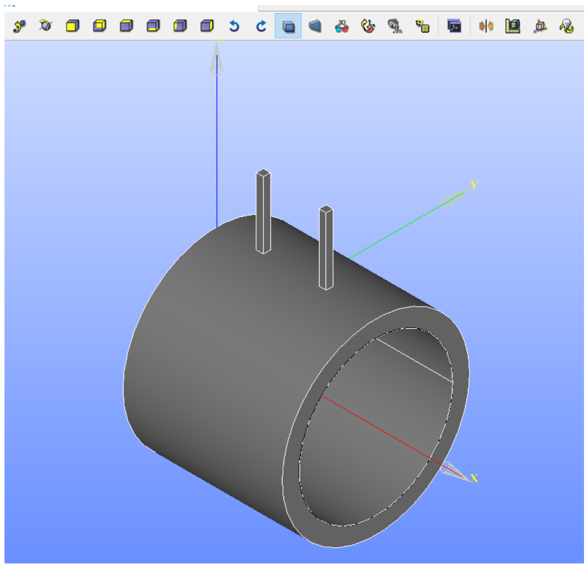

Figure 2: 3D Model of Annulus Geometry with square cross section jacket (Square Geometry).

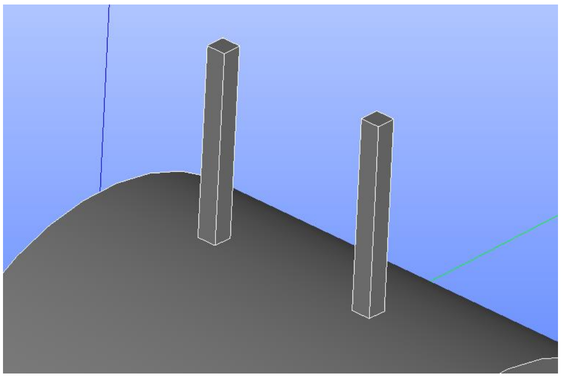

Figure 3: Zoomed View of Square inlet and outlet

B. *Meshing*

The meshing for simulation was also done by SALOME (Version 8.3.0). NETGEN Algorithm is used to mesh the geometry. For the circular geometry the mesh is fine.
The maximum element size is given as 0.005 m and minimum element size is given as 0.001 m. The fineness ratio is given as 0.6.

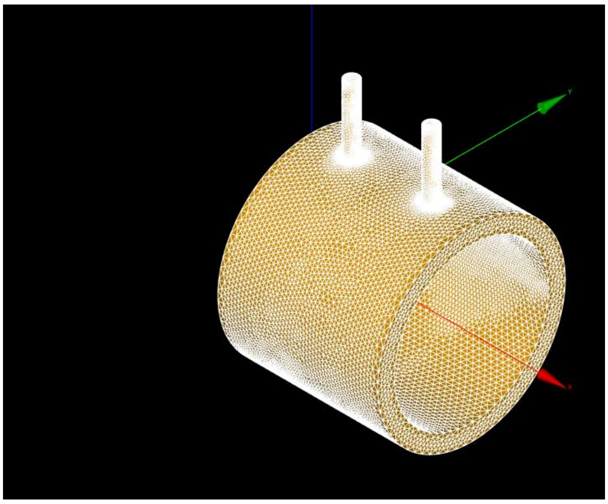

Figure 4: Meshing of Annulus Geometry (Circular)

Total Number of cells	193071
Tetrahedrons	193071
Hexahedrons	0
Pyramids	0
Prisms	0
Hexagonal Prisms	0
Polyhedrons	0

Table 1: Mesh Statistics of Annulus geometry (Circular)

For the square geometry, the fine mesh has been applied. The NETGEN algorithm is also used in this case. The maximum cell size is given as 0.009 m and the minimum cell size is given as 0.004 m. The fineness ratio is given as 0.9.

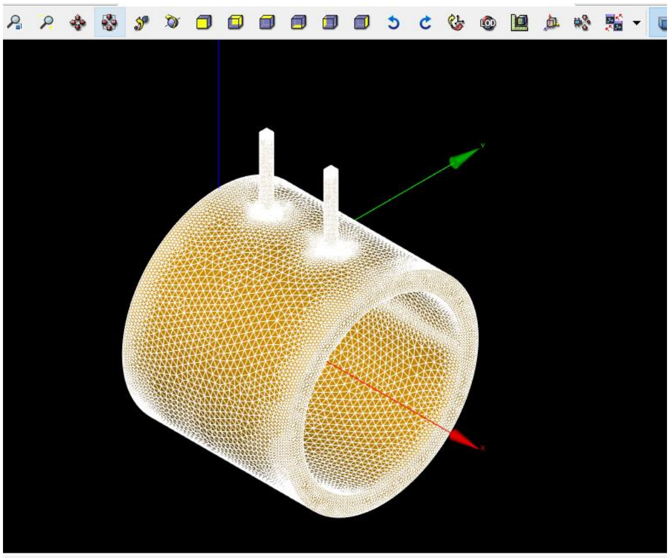

Figure 5: Meshing of Annulus Geometry (Square)

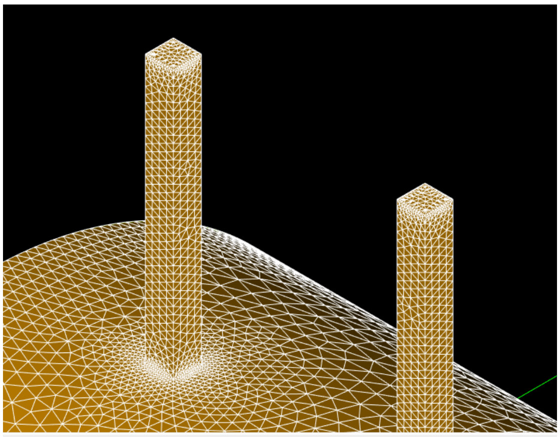

Figure 6: Meshing of Annulus Geometry (Zoomed View)

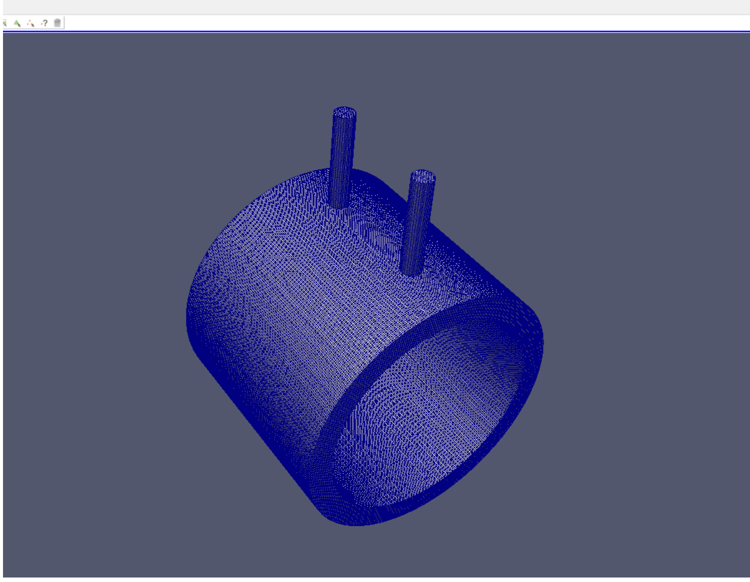

Figure 7: SnappyHexMesh of Annulus Geometry (circular)

Total Number of cells	158164
Tetrahedrons	158164
Hexahedrons	0
Pyramids	0
Prisms	0
Hexagonal Prisms	0
Polyhedrons	0

Table 2: Mesh Statistics of Annulus geometry (Square)

The circular geometry is again meshed using snappyhexmesh. For snappyhexmesh, the 3D geometry is converted into 2D STL geometries and imported to the triSurface. For snappyhexmesh, a utility called BlockMesh is used to create a block based fully structured hexahedral mesh. The block consists of 8 vertices. The surfaceFeatureExtract utility is used to extract sharp edges from STL geometries. The snappyhexmesh utility is used to create high-quality Hex-dominant meshes based on arbitrary geometry. It is also responsible for the addition of wall layers in geometry. [2].

Total Number of cells	389028
Tetrahedrons	0
Hexahedrons	275196
Pyramids	0
Prisms	57967
Wedges	0
Polyhedrons	55865

Table 3: Mesh Statistics of Annulus geometry (snappyHexMesh Circular)

II. ANALYSIS

The CFD analysis of the annulus water jacket cooling was done using blueCFD - Core which provides source code and related open source projects to windows operating systems.

A. Boundary Conditions

Both inlet and outlet pressure are kept at atmospheric pressure. The velocity of ethylene glycol enters at 0.5 m/s normal to the inlet surface. The temperature of the inlet is given as 270C (300 K). The inner wall which is in contact with motor is given in heat flux. The heat flux is found to 34.684 W/m2. Inlet and outlet are defined as a patch and the remaining walls are defined as walls. Since Reynolds number is less than 2300, flow is considered to be laminar.

B. The SIMPLE Solver

This case comes under steady-state laminar flow. Since it also involves heat transfer, we can use buoyantsimpleFOAM solver. BuoyantSimpleFOAM solver uses SIMPLE (Semi-Implicit Method for Pressure Linked Equations) algorithm.

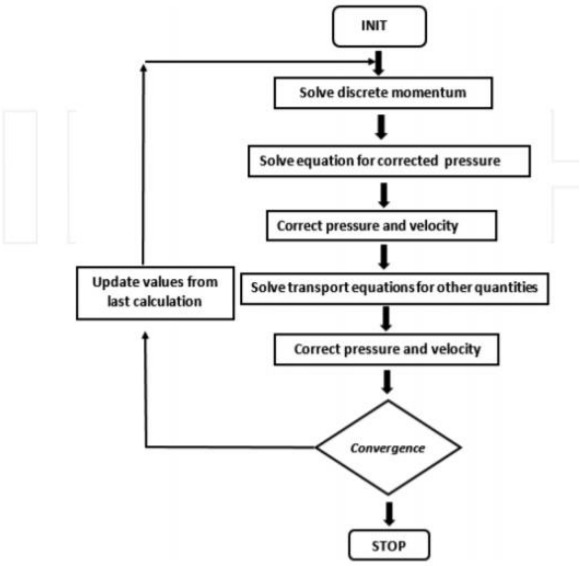

Figure 8: Working of SIMPLE algorithm [3].

III. RESULTS

A. ParaView

ParaView is an open-source post processing tool used for multi-platform data analysis and visualization application.

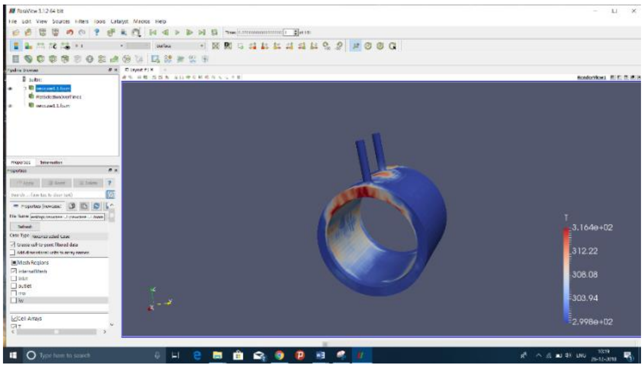

Figure 9: ParaView interface

B. Post Processing

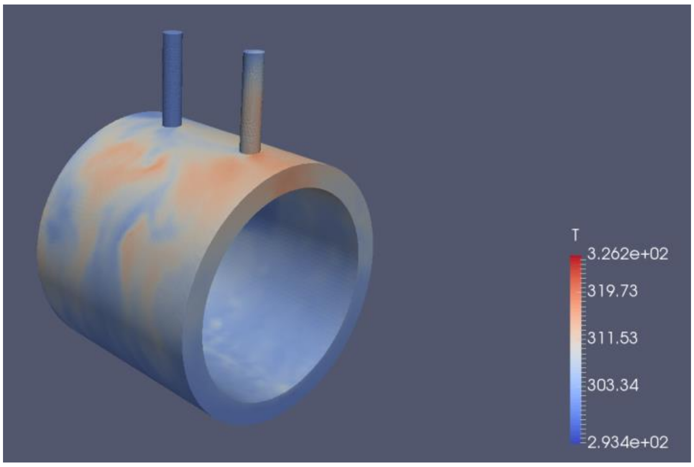

Figure 10: CFD Analysis of Annulus (Tetra Mesh)

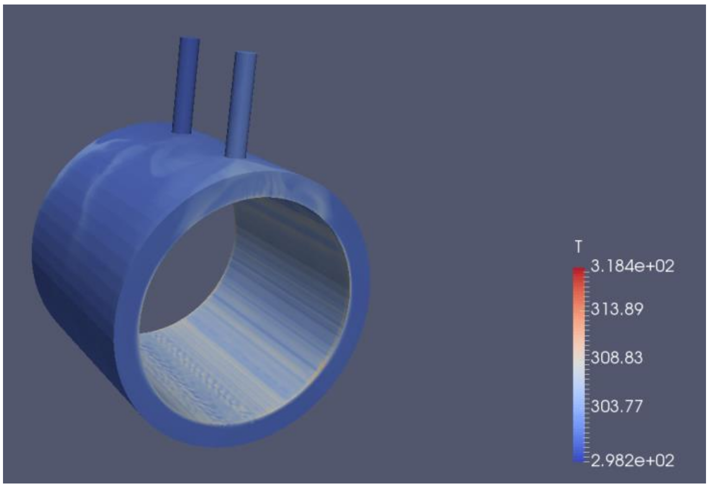

Figure 11: CFD Analysis of Annulus (Snappy Hex-Mesh)

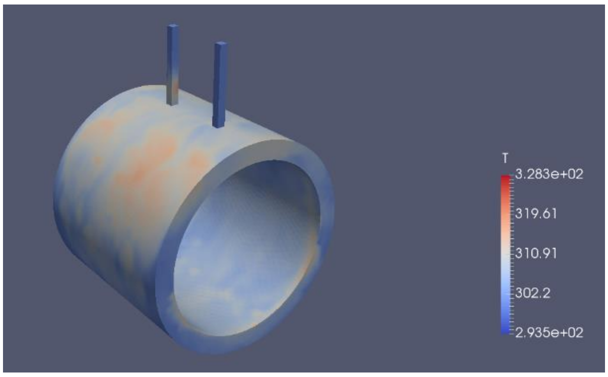

Figure 12: CFD Analysis of Annulus (Square Geometry)

C. Plots

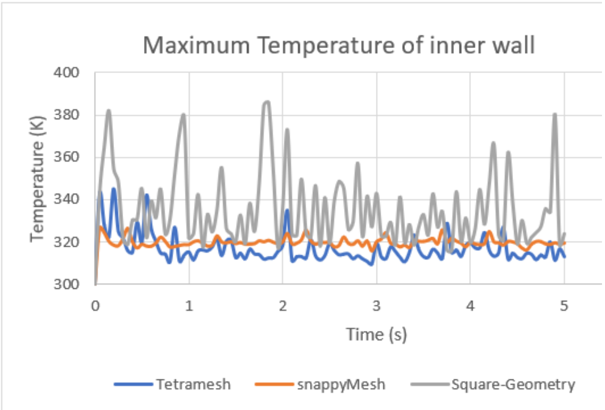

Figure13: Plots of Average Temperature of inner wall

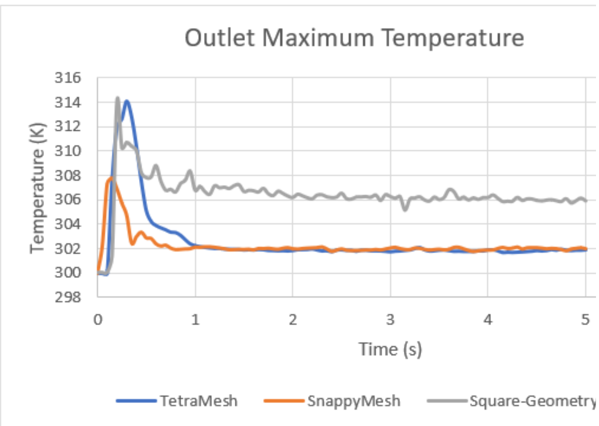

Figure14: Plots of Average Temperature of outlet

Inference from plots

Cases	**CFD Validation**	**Theoretical Validation**
Inner wall Temperature (circular Tetra)	39.8^0 C	40^0 C
Inner wall Temperature (Circular Snappy)	46.63^0 C	40^0 C
Inner Wall Temperature (Square Tetra)	50.69^0 C	Not Applicable
Maximum outlet Temperature (circular Tetra)	14.02^0 C	Less than 15^0 C
Maximum outlet Temperature (circular Tetra)	7.82^0 C	Less than 15^0 C
Maximum outlet Temperature (square Tetra)	14.02^0 C	Less than 15^0 C

Table 4: CFD results vs Theoretical validation

- *For circular tetramesh the maximum temperature of inner wall which is contact with motor is 312.95 K (39.8^0 C). While for snappyHexMesh the temperature is 319.37 K (46.63^0 C). The optimum temperature for the electric motor is 40^0 C [1].*
- *For square geometry the maximum temperature of inner wall is 323.84 K (50.69^0 C). Hence it is ineffective for cooling motors.*

- *The number of cells in tetramesh is lesser than Hexmesh. But the results are quite comparable.*
- *The temperature difference between inlet and outlet for all cases is less than 15^{0}C.*
- *This value is also in accordance with theoretical value [1].*

IV. REFERENCES

[1]. Zainal Ambri Abdul Karima and Abdul Hadi Mohd Yusoff. Cooling System for Electric Motor of an Electric Vehicle]Propulsion: Advanced Materials Research Vol 903 (2014) pp 209-214

[2].https://openfoamwiki.net/images/f/f0/Final-AndrewJacksonSlidesOFW7.pdf

[3]. Alejandro Alonzo-García, Claudia del Carmen Gutiérrez-Torres and José Alfredo Jiménez-Bernal. Computational Fluid Dynamics in Turbulent Flow Applications