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ESTIMATION OF LOCAL WALL SHEAR STRESS IN CURVED PIPES USING CGNS MESH IN OpenFOAM

[1] Manuraj R ,[2]Sajomon Mathew

[1,2] Assistant Professor,
[1,2] Department Of Mechanical Engineering,
[1,2]College Of Engineering Adoor, Kerala, India

Abstract: CFD General Notation System (CGNS) provides an industry standard, portable and extensible scheme for the storage and retrieval of computational fluid dynamics mesh and data. The CGNS standard includes structured and unstructured grid information, boundary condition, multi-zone interface connectivity etc. Any complex mesh and data can be exported as CGNS file and this capability is provided by many CFD software. OpenFOAM, the powerful open-source CFD software, doesn't natively facilitate handling of CGNS mesh. In fact one of the drawbacks of OpenFOAM is generation of complex mesh to be used with it. It will be very useful to develop capability to import mesh data available in CGNS format in OpenFOAM, so that the code can be used for various industrial applications. In order to validate the mesh conversion, local wall shear stress under turbulent flow through straight pipe is analyzed then the flow through torus is analyzed.

***Index Terms* - OpenFOAM, CGNS, Wall shear stress, Tours**

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I. Introduction

The CGNS (CFD General Notation System) project originated during 1994 through a series of meetings that addressed improved transfer of NASA technology to industry. The specific purpose of CGNS was to provide a standard for recording and recovering computer data associated with the numerical solution of the equations of fluid dynamics. The intent was to facilitate the exchange of CFD data between sites, between applications codes, and across computing platforms, and to stabilize the archiving of CFD data. The format implemented by this standard was to be (1) general, (2) portable, (3) expandable, and (4) durable [1,2]. OpenFOAM, the powerful open-source CFD software, doesn't negatively facilitate handling of CGNS mesh. In fact one of the drawbacks of OpenFOAM is generation of complex mesh to be used with it.is present work, a module cgnsMeshToFoam is developed to import mesh from the CGNS format. It is built on CGNS library version 3.2.1 and can be used with OpenFOAM version 2.2.1. The converter will provide the necessary grid information through the files boundary, faces, neighbor, owner and points located in the polyMesh directory of the case under analysis. Using the imported mesh(ie cgns file), local wall shear stress under turbulent flow through a pipe is analyzed. Both straight pipe and torus pipe is analyzed.

Any real fluid moving along solid boundary will incur a shear stress on the boundary. The no-slip condition dictates that the speed of the fluid at the boundary(relative to the boundary) is zero, but at some height from the boundary the flow speed must equal that of fluid. Shear stress developed in the wall of the pipe will opposes the flow of the fluid.

II. SOLUTION PROCEDURE

The CGNS (CFD General Notation System) project originated during 1994 through a series of meetings that addressed improved transfer of NASA technology to industry. The specific purpose of CGNS was to provide a standard for recording and recovering computer data associated with the numerical solution of the equations of fluid dynamics. The intent was to facilitate the exchange of CFD data between sites, between applications codes, and across computing platforms, and to stabilize the archiving of CFD data. The format implemented by this standard was to be (1) general, (2) portable, (3) expandable, and (4) durable [1,2]. OpenFOAM, the powerful open-source CFD software, doesn't negatively facilitate handling of CGNS mesh. In fact one of the drawbacks of OpenFOAM is generation of complex mesh to be used with it.is present work, a module cgnsMeshToFoam is developed to import mesh from the CGNS format. It is built on CGNS library version 3.2.1 and can be used with OpenFOAM version 2.2.1. The converter will provide the necessary grid information through the files boundary, faces, neighbor, owner and points located in the polyMesh directory of the case under analysis. Using the imported mesh(ie cgns file), local wall shear stress under turbulent flow through a pipe is analyzed. Both straight pipe and torus pipe is analyzed.

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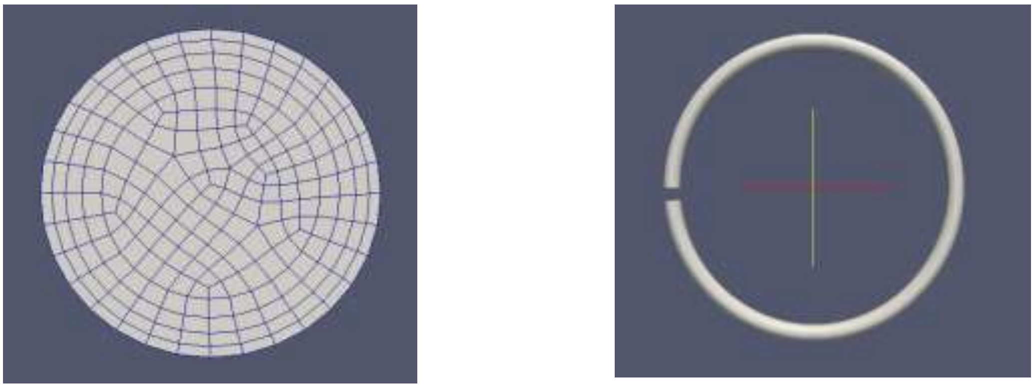


Fig.1. Grid used in analysis for straight pipe and torus pipe

In compressible solver simpleFoam of the OpenFOAM package is selected as the base solver for this problem. It is an implementation for steady flow using SIMPLE algorithm. The Navier-Stokes equation for a single-phase flow with constant density and viscosity are following

$$\nabla.(\rho U) = 0 \quad (2.1)$$

$$\frac{\partial U}{\partial t} + \nabla.(uu) - \nabla.(v.\nabla u) = -\nabla p \quad (2.2)$$

Eqn (2.1) is mass conservation for in compressible flow and eqn (2.2) steady flow momentum conservation. In simpleFoam the numerical schemes for term such as derivatives, interpolation procedure etc. are set in casename/system/fvSchemes file. In this file we specify that the case steady state by giving SteadyState value to the keyword timeScheme. The term $\nabla$and ∇^2controlled respectively by the keyword gradSchemes and laplacianSchemes have been set to value Gauss because we adopted the satndard finite volume discretization of Gaussian integration of values from cell centers to face centers. The divergent term∇ccntrolled by the key word divScheme has been set to UD to ensure boundaries. Standard k-epsilon turbulence model consisting of two transport equations for turbulent kinetic energy and turbulent dissipation is used with coefficients Cμ=0.09, C1=1.44, C2=1.92.Velocity is given as 0.3m/s and with zero pressure gradient at inlet. Outlet pressure is 0 pascal and velocity is zero gradient. In wall velocity is given as 0 m/s and pressure is 0 pascal.

In order to find out the wall shear stress along the pipe walls, a post processing utility in OpenFOAM is used. “SAMPLING”. For the extrication of wall shear stress along the surface using sampling utility we wanted supply coordinates of the points on the wall. For that a program is written to find out x,y,z coordinates of points on the walls of both straight pipe and torus pipe. SAMPLING utility extract wall shear stress in each points. Thus we can get a plot of wall shear stress along the wall of pipes[4,5].

III. VALIDATION

Flow analysis is made for Reynolds numbers 5000, 7000 and 9000. Variation of local wall shear stress as a function of distance from the entrance for Re = 9000 is given in Fig. 3. Value of the fanning frictional factor in the fully developed region is calculated using the data from graph and is found to be 8.10e-03. This value is compared against the friction factor obtained from the friction factor chart for smooth pipes and is closely matching. Similar results have been obtained for other Reynolds number also. These results confirm the CGNS mesh handling capability as well as validate the solver for estimation of wall shear stress and friction factors.

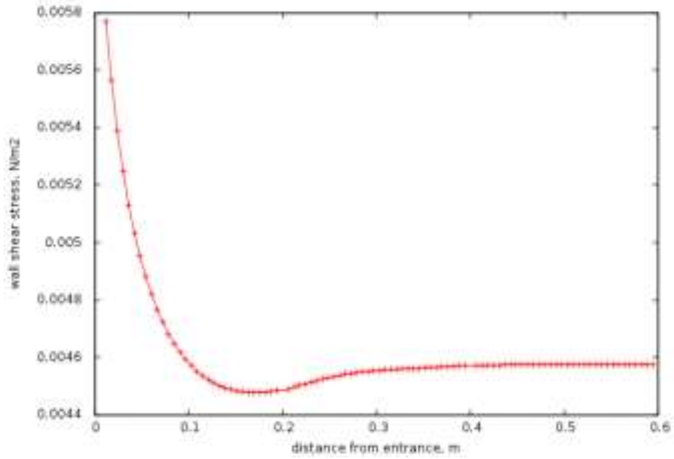


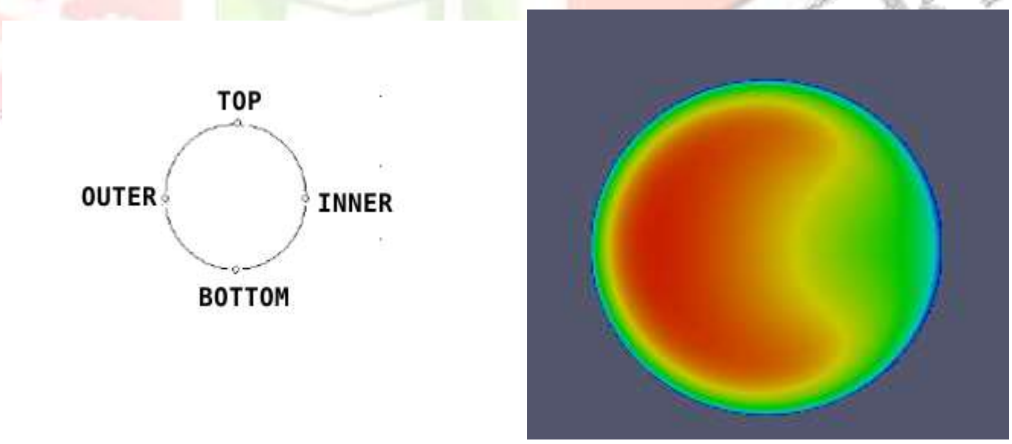
Fig.2. Wall shear stress vs axial distance (9000)

Table 1:Frictional factor from graph and chart

Reynolds Number	Frictional Factor from graph	Friction factor chart for smooth pipes	Percentage error
5000	6.5e-3	6.8e-3	4.6
7000	7.12e-3	7.4e-3	4.1
9000	8.10e-3	8.4e-3	3.5

Value of the fanning frictional factor in the fully developed region is calculated using the data from graph while calculating the entry length for the pipe it is obtained as 0.3m. From the Fig 2. it is clear that the value of wall shear stress becomes constant after 0.3m. So we can conclude that the value of wall shear stress is becomes constant after entry length or after which the flow becomes fully developed.

In the present analysis we consider torus with pitch radius 0.150m, angle 355 degree, and outer diameter 0.018m is created and meshed in Ansys and exported as CGNS file from Fluent as described in section2. Flow analysis is made for Reynolds numbers 5000, 7000 and 9000. Variation of local wall shear stress as a function of distance from the entrance is found. The velocity profile at exit section is shown in the Fig 3(b)



(a) (b)

Fig.3 Velocity profile at the exit section

Fig 3(a) shows the different location of pipe where the wall shear stress plotted. As the fluid flows through the torus pipe fluid particle undergo rotational motion[7,8]. The fluid particles also undergo movement from inner side of the coil to outer side. It can be noted that fluid particles are taking various trajectories and also move with different velocities. The particles which were forming a line to begin with are found to be totally scattered. When the flow approaches exit section, high velocity is concentrated outer wall of the tube. This due to centripetal force. Fluid particle get accelerated and moves outward.

Analysis of wall shear stress from entrance to exit section of the pipe is done. Wall shear stress plotted along the length of the pipe for both straight pipe and torus pipe.

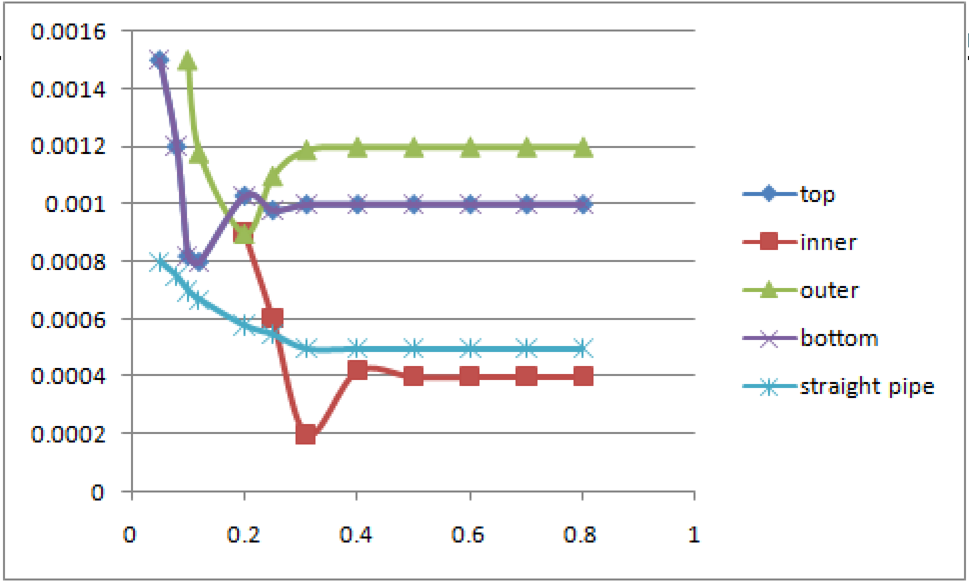
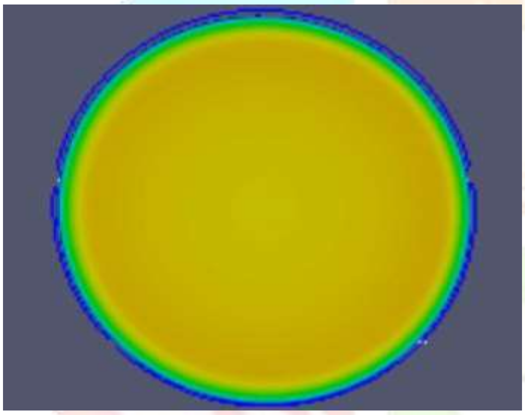
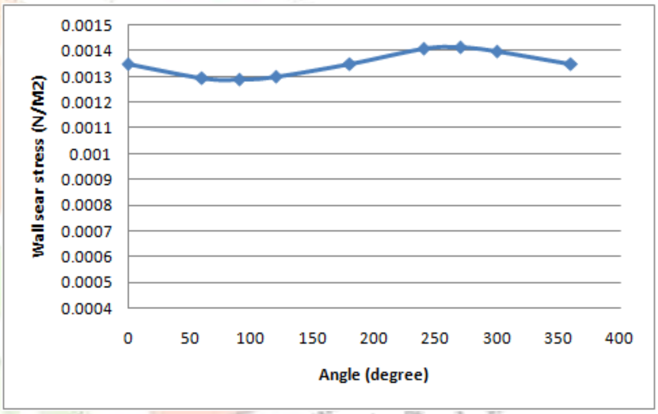
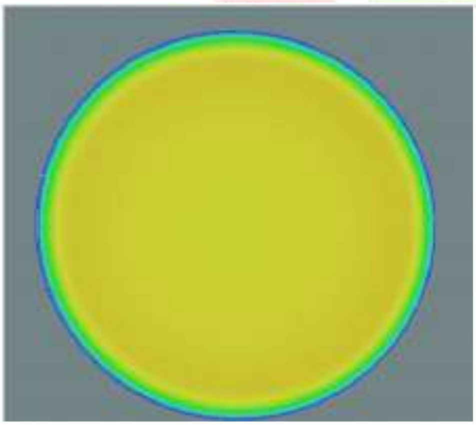


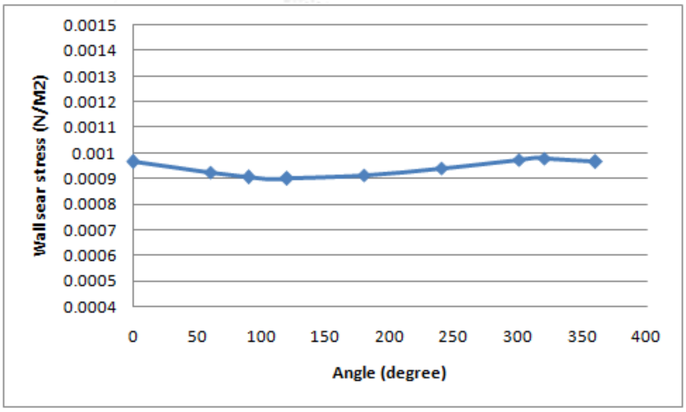
Fig .4.Wall shear stress at different locations (top, bottom, inner, outer) along the length for both straight pipe and torus pipe

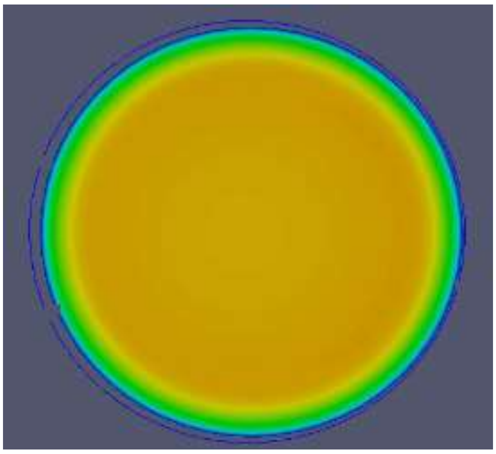
Wall shear stress at different locations (top, bottom, inner, outer) along the length for both straight pipe and torus pipe is plotted in Fig 4. Value of wall shear stress at different location (top, bottom, inner, outer) same for a straight pipe.In the case torus pipe it is different for inner and outer. But for top and bottom value is same. It is found that wall shear stress outer side of the coil is higher than those at any other location at the cross-section. Due to centripetal force, the velocity in the outer region is higher and this leads to higher velocity gradient in the outer wall[9]. In similar way, the wall shear stress inner periphery of the coil is lowest.

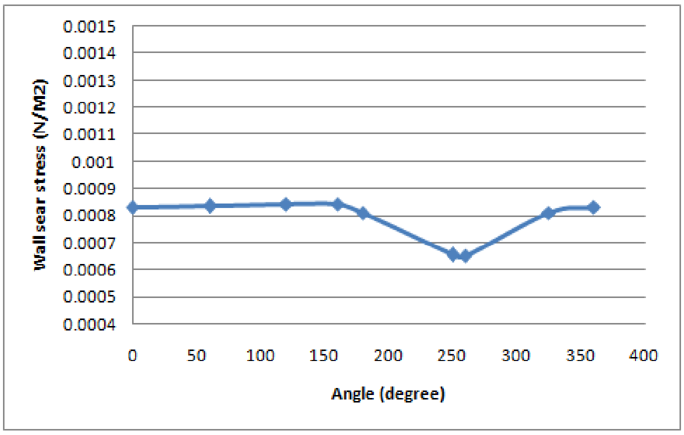








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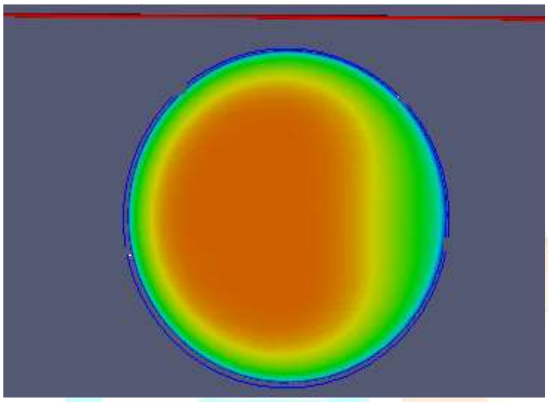

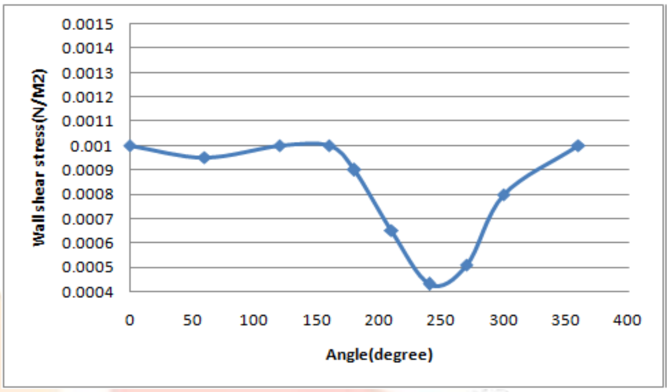
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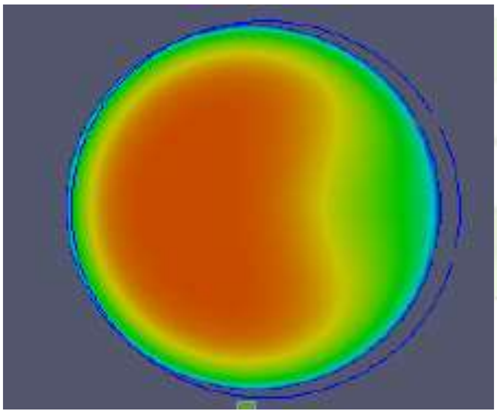

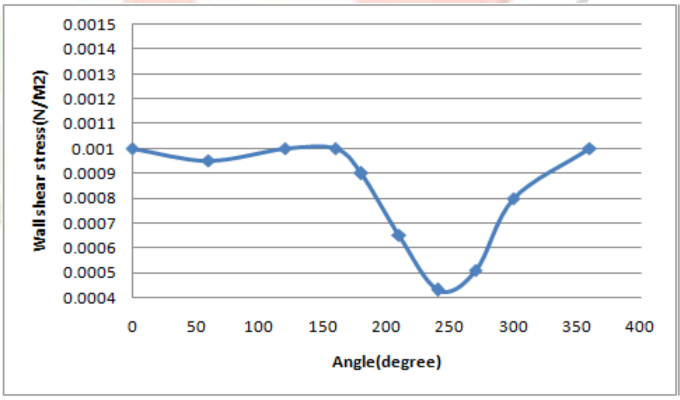
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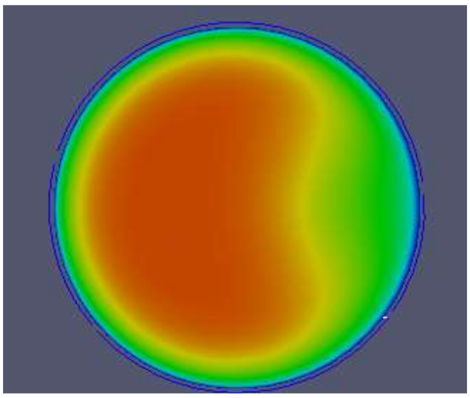

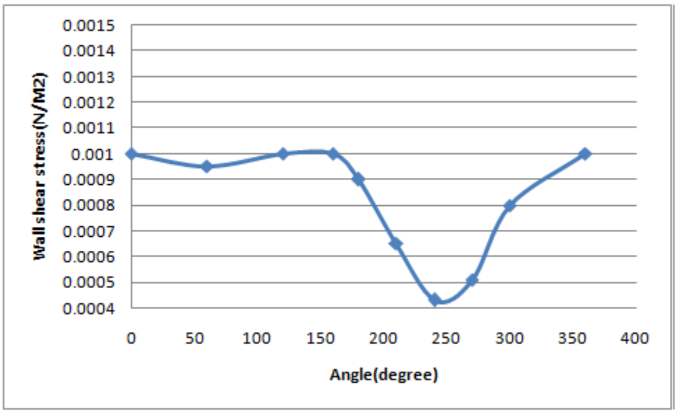
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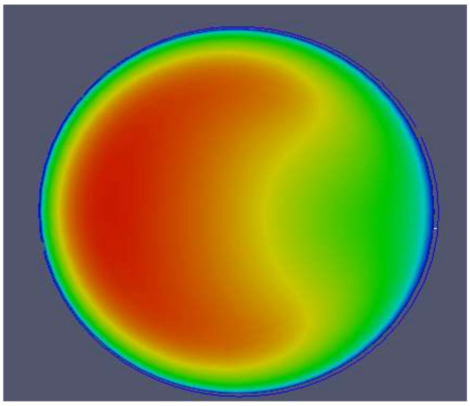

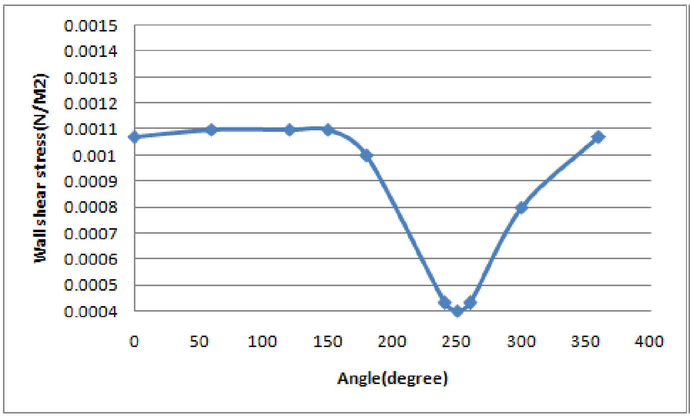
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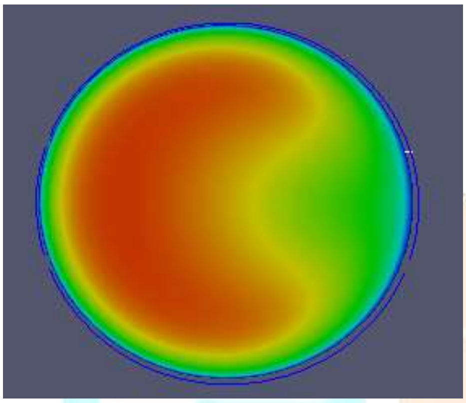

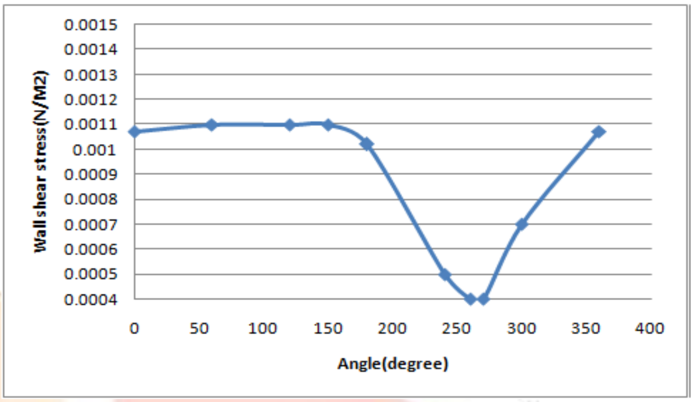
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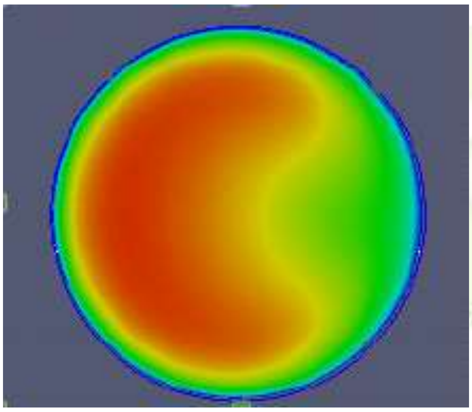

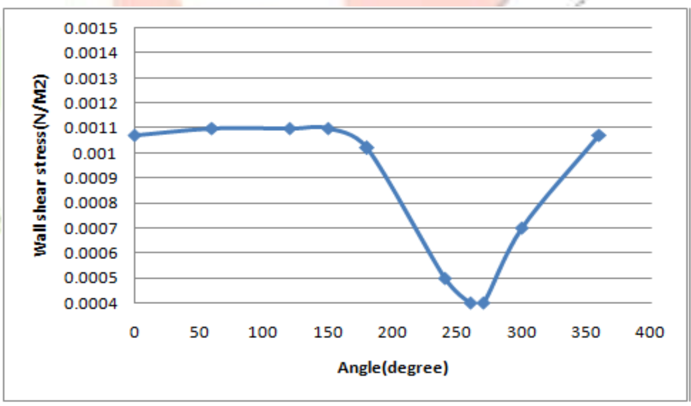
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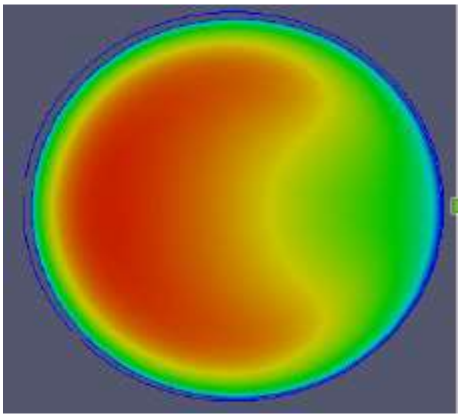

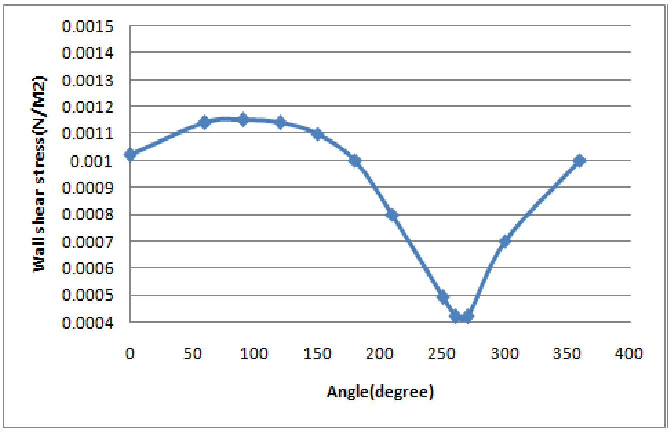
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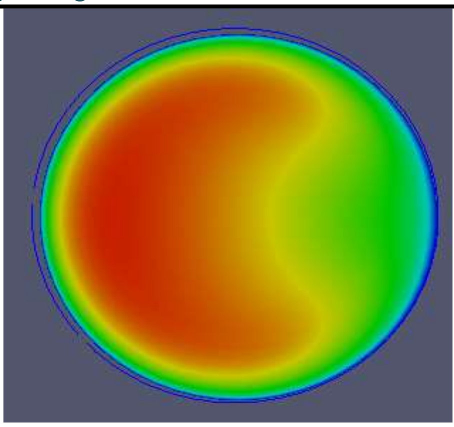

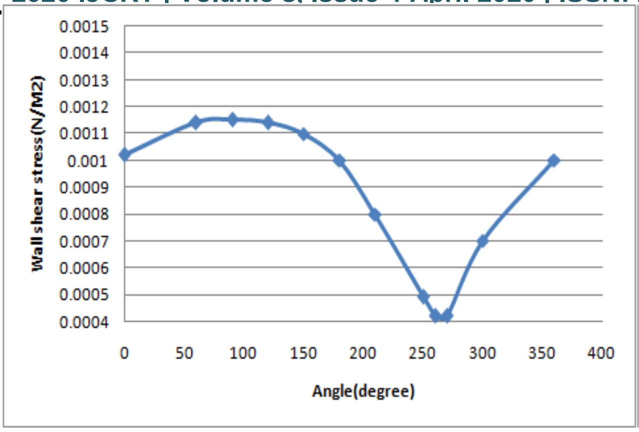

Fig 5:Wall shear stress with respect angle is plotted for different cross sections along the length of the pipe

Wall shear stress with respect angle is plotted for different cross sections along the length of the pipe. Wall shear stress does not showing much variation in entrance section of the pipe. When moving to the exit section of pipe we can see a considerable variation in wall shear stress on inner and outer section of the pipe. It is found that wall shear stress outer side of the coil is higher than those at any other location at the cross-section. Due to centripetal force, the velocity in the outer region is higher and this leads to higher velocity gradient in the outer wall. In similar way, the wall shear stress inner periphery of the coil is lowest. From the cross-section view in figure 4 it is clear that surface area covered by higher velocity fluid particle is greater than lower velocity fluid particles. The reason for this distribution is centripetal force. Due to this difference in the velocity distribution higher value of wall shear stress is distributed in more circumferential area and smaller value of wall shear stress lesser area.

IV Conclusion

Wall shear stress at various points along the length of the pipe was estimated. Simulation was done in OpenFOAM. Using the module cgnsMeshToFoam to import mesh from the CGNS format to OpenFOAM. Wall shear stress on the outer side of the coil is highest among all other points at specified cross section, while that at inner side is the lowest. Value of wall shear stress along a pipe becomes steady after the flow become fully developed.

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VI Nomenclature

U - Velocity M/s

ρ- Density Kg/m^3

P - Pressure N/M^2

t - Time s