

# CFD SIMULATION OF HEAT TRANSFER IN VERTICAL RIBBED TUBE

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**ABSTRACT:**-Computational Fluid Dynamics (CFD) simulation of heat transfer and fluid flow analysis in the turbulent flow regime in a spirally ribbed tube and a smooth tube in vertical orientation are simulated in this project using ANSYS Fluent. The ribbed tube has outside diameter of 25mm, maximum inner diameter of 18.80mm, minimum inner diameter of 17.50mm and pitch varied from 2m to 0.25m. The smooth tube has outside diameter of 26.7mm and inner diameter of 18.88mm. Both tubes were uniformly heated by passing an electrical current along the tube with a heated length of 1m. The CFD simulation is performed on a vertical orientation of the steel tubes (rifled and smooth) under six different inlet velocities of 0.893m/s, 1.786m/s, 2.38m/s, 2.976m/s, 3.57m/s and 4.166m/s. The main objective of this thesis is to determine the heat transfer and pressure drop in both vertical smooth and ribbed tubes. The fluid used is water and the initial temperature is 25°C. The heat flux that for heating the tube is equal to 150KW/m<sup>2</sup>. During the CFD simulation analysis it was found that for smooth tube at lower inlet velocity, the temperature increases from 298K to 310.4K while the pressure drop between inlet and outlet is equal to 598 Pa. At higher inlet velocity, the temperature for smooth tube is found increasing from 298K to 301.53K, with the pressure drop is equal to 7368.1 Pa. Smooth tubes results are validated again analytical calculation, it is agreed well with analytical results. For the ribbed tube at lower inlet velocity the temperature is increasing from 298K to 313.5K, with the pressure drop is found to be 622.1 Pa for 0.25m pitch. In the case of a higher inlet velocity, the temperature increase in ribbed tube is increasing from 298K to 304.5K, while the pressure drop is equal to 8087.1 Pa. It is clear that the temperature difference between ribbed and smooth tube at lower inlet velocity are equal to 15.5K and 12.4 K, respectively. While at higher inlet velocity there, temperature difference becomes 6.5 K, and 3.5 K respectively. This result indicates that the ribbed tube has higher heat transfer efficiency than the smooth tube. The pressure drop in the ribbed tube is found to be higher than that of the smooth tube. This clearly shows that the characteristic of ribbed tube is much better than smooth tube.

**Keyword:** Computational Fluid Dynamics, Computation Heat Flux Helix, angle Specific heat, Pressure.

## 1. INTRODUCTION

The problem of heat and mass transfer enhancement plays a dominant role in designing and manufacturing new energy systems, power plant devices, air conditioning equipment and heat exchangers. Among lots of augmentation techniques, flow swirling is the most simple, reliable and frequently used method of heat transfer enhancement in circular tubes. It is widely used in ducts of nuclear power stations, heat exchangers, refrigerators, radiators, airplane and space devices the proper designs of the tube inner wall will increase the heat transfer to the flowing water; hence it is one of the main factors for its successful usage in boiler. In order to increase the heat transfer and prevent damage to the inner wall of tube, ribbed tubes are applied instead of the smooth walled tubes. The heat transfer coefficient is one of the most important factors for the successful design and operation of inner tube wall to heat transfer on the flowing water. Analysis and modeling of the inner tube wall for boiler is very important, in order to keep the boiler operation below the critical stages.

In recent years, the high cost of energy and material has results an increased effort for producing more efficient heat exchange equipment. The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate and pressure drop.

## 2. OBJECTIVE AND SCOPE OF WORK

### 2.1 Objectives of Study

1. To determine the fluid flow characteristics in a vertical positioned tube (smooth and ribbed) by means of CFD.
2. To determine the heat transfer in a vertical tube (smooth and ribbed) by means of Computational Fluid Dynamics (CFD).
3. To determine the pressure drop in a Vertical tube (smooth and ribbed) by means of Computational Fluid Dynamics (CFD).

**2.2 Scope of Study**

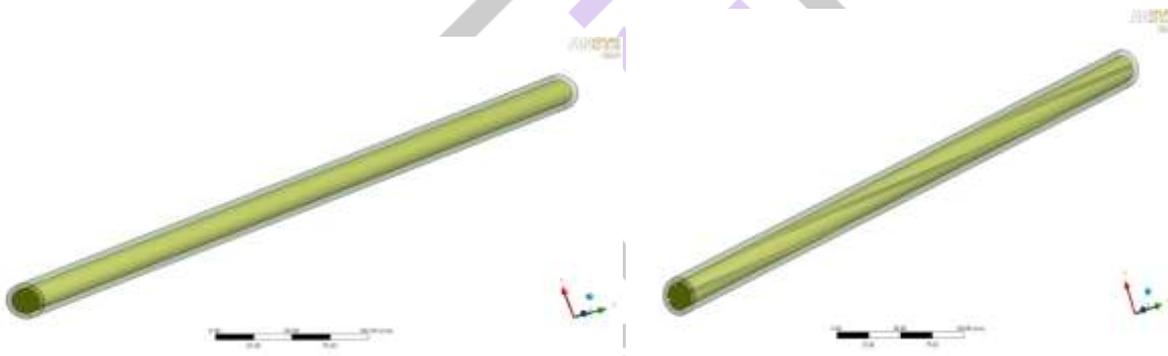
Computational Fluid Dynamics (CFD) will be used to determine the characteristics of fluid flow in the ribbed and smooth tube.

1. Water will be used as the fluid domain in Computational Fluid Dynamics (CFD).
2. Steel tube, (smooth and ribbed) will be analyzed by using Computational Fluid Dynamics (CFD).
3. The analysis by using Computational Fluid Dynamics (CFD) will be conducted with tubes placed vertical.
4. The fluid flow in this analyzed will be single phased.

**3. Geometry of smooth tube and ribbed tube**

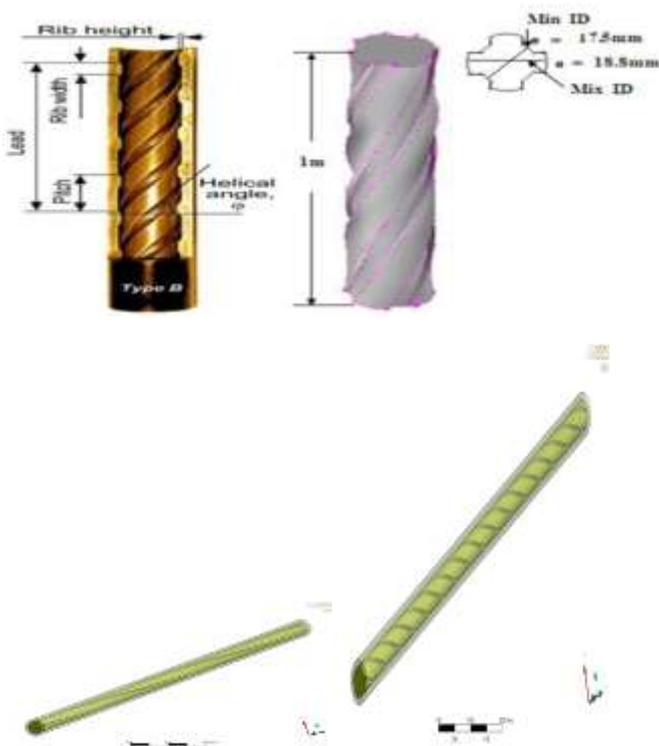
The commercial CFD code FLUENT 13.0 is used to analyze the model flow characteristics of smooth and ribbed tube. Modeling and mesh generation are however performed in ANSYS Design Modeler and ANSYS Meshing environment. Water is taken as the fluid medium. The schematic diagram of the smooth tube model show in figure 4.1, that comprise an outer diameter is 26.7mm, Inner diameter is 18.88mm, the wall thickness is 3.91mm, and the length of smooth tube is 1m.

Figure 4.1 shows the schematic diagram of the ribbed tube model that comprises a 25mm outer diameter, 18.8mm maximum inlet diameter and 17.5mm minimum inlet diameter. The length of the tube 1m, the rib height is 0.6835mm and the width is 9.25mm. The helix angle is 60o, and the number of starts is 4. The ribbed tube parameter used in this analysis is show in table 4.1. In this study the effect of helix pitch from 2m to 0.25 m is studied. Fig. 4.3 to 4.8 shows the Geometric model of ribbed tube Helix pitch 2m to 0.25m.



**Fig3.1 Geometric model of Smooth tube**

**Fig.3.2 Schematic diagram of a ribbed tube**



**Fig 3. 3 Geometric model of ribbed tube Helix pitch 1 m and .25m**

**4 Boundary conditions**

The present work set both the tubes is sited vertically and the flow inside the tube is assumed as fully turbulent flow. The water temperature is set at 25°C (298° K), with water properties at that temperature as shown in the table 3.3. Figure 3.5 shows the prescribed boundary condition for solving this flow problem numerically by using Fluent software. In that figure, q is representing the heat flux at constant rate which created by passing an electrical current (150 KW/m<sup>2</sup>) along 1 meter tube length. At the inlet station, the water velocity can be set for different value. The present study carries out six different inlet velocities at constant inlet temperature 25oC. Those six inlet velocities are: 0.893, 1.786, 2.38, 2.976, 3.57 and 4.166 m/s.

**Table 4.1 the properties of water at temperature at (298° K).**

Temperature (K)	Density $\rho$ (kg/m <sup>3</sup> )	Specific heat $C_p$ (j/kg.K)	Thermal conductivity $k$ (w/m.k)	Dynamic Viscosity $\mu$ (kg/m.s)
298	997.1	4180	0.6055	0.000891

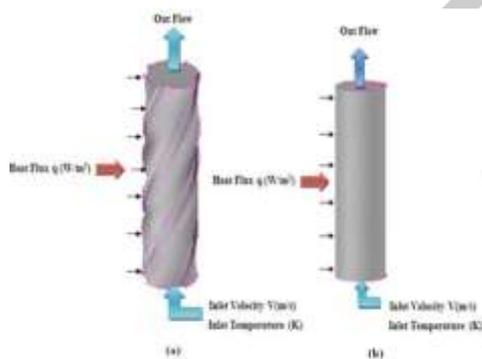


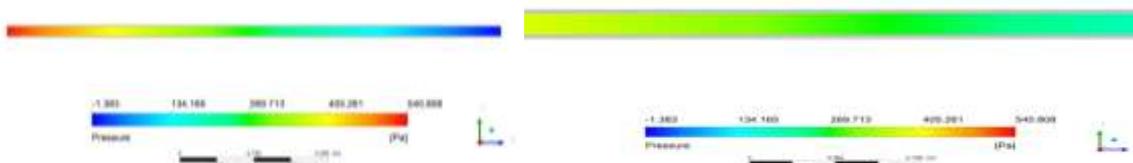
Fig 4.5 Boundary conditions, (a) ribbed tube, (b) smooth tube.

The tube uses a steel material and it had been found the material properties are a constant if the steel operated below 300° K and they will vary if the temperature above of it. The steel properties in term of density, the specific heat coefficient at constant pressure  $C_p$  and thermal conductivity  $k$  below 300° K are shown in the Table. 4.3

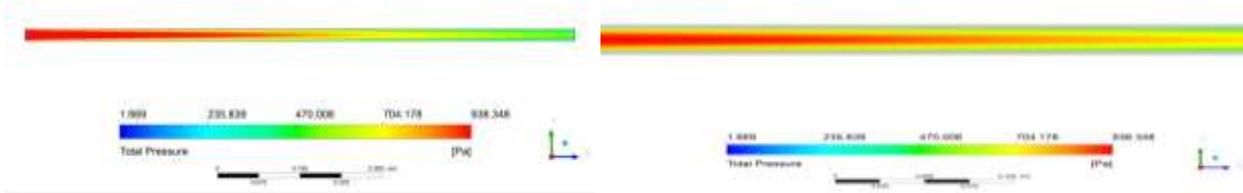
**6. Results Smooth tube- Velocity 0.83 m/s**

The CFD analysis studies by use of fluent software for the flow along the tube with heat transfer effects are presented. The CFD analysis applied for the case of internal flow problems through a vertically positioned smooth and ribbed tube in order to determine the heat transfer and pressure drop along the tube. Comparison result among of them will be carried out to determine the most suitable tube model in handling the heat transfer problem.

CFD simulation study was carried out using the smooth tube with six different inlet velocities at constant temperature (25°C) and heat flux (150 KW/m<sup>2</sup>). The result of Pressure shows 4.12 the linear variation in pressure drops from inlet to outlet.

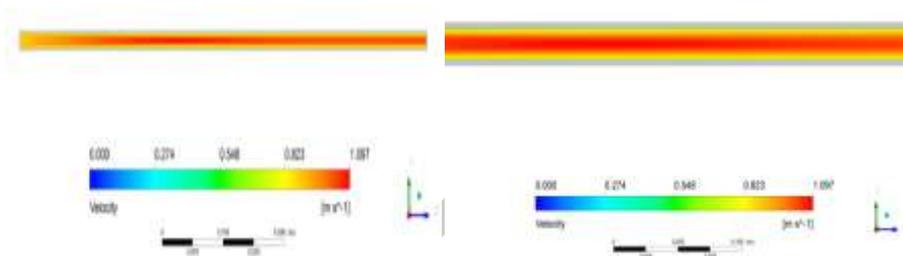


**Fig.4. 3 Pressure contours of smooth tube- Velocity 0.83 m/s**



**Fig.4. 4 Total Pressure contours of smooth tube- Velocity 0.83 m/s**

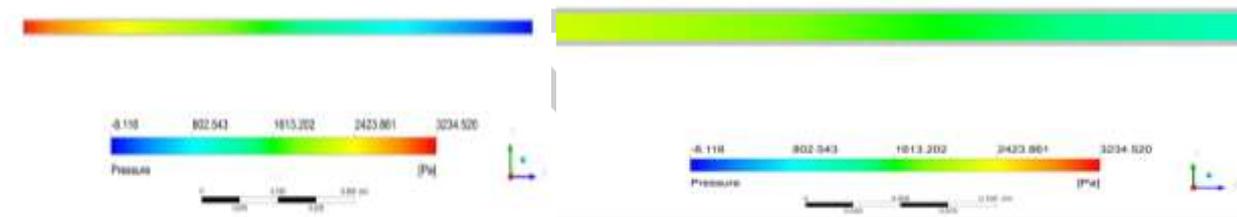
It is clear from figure 4.14 that the temperatures along the tube increased for all cases, but the highest temperature increment occurs at the small inlet velocity. At the inlet velocity equals to 0.893 m/s, the temperature rises from 298 K to 310 K , while at a higher inlet velocity, namely at velocity 4.166 m/s, the temperature increment is only 1 degree is from, 298K, to 301.53 K . This result indicates that a lower inlet velocity is better than a higher inlet velocity.



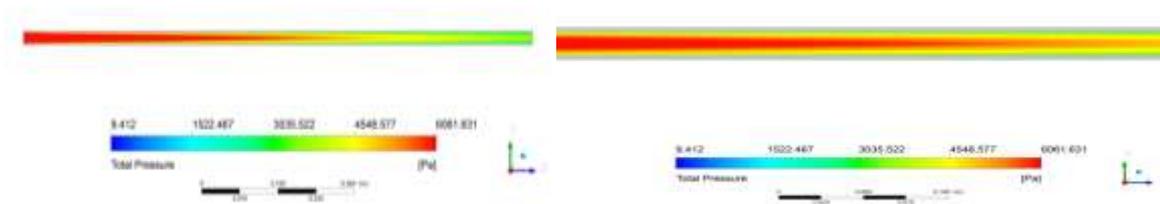
**Fig.4. 5 Velocity contours of smooth tube- Velocity 0.83 m/s**

**4.8 Results Inlet Velocity 2.38 m/s**

The result of Pressure shows 4.16 the linear variation in pressure drops from inlet to outlet for Velocity 2.38 m/s. The Pressure drop approximately 3532 Pa



**Fig.4. 6 Pressure contours of smooth tube- Velocity 2.38 m/s.**



**Fig.4. 7 Total Pressure contours of smooth tube- Velocity 2.38 m/s**

It is clear from figure 4.18 that the temperatures along the tube increased for all cases, but the highest temperature increment occurs at the small inlet velocity. At the inlet velocity equals to 0.2.38 m/s, the temperature rises from 298 K to 303.23 K , while

at a higher inlet velocity, namely at velocity 4.166 m/s, the temperature increment is only 3.5 degree is from, 298K, to 301.53 K . This result indicates that a lower inlet velocity is better than a higher inlet velocity.

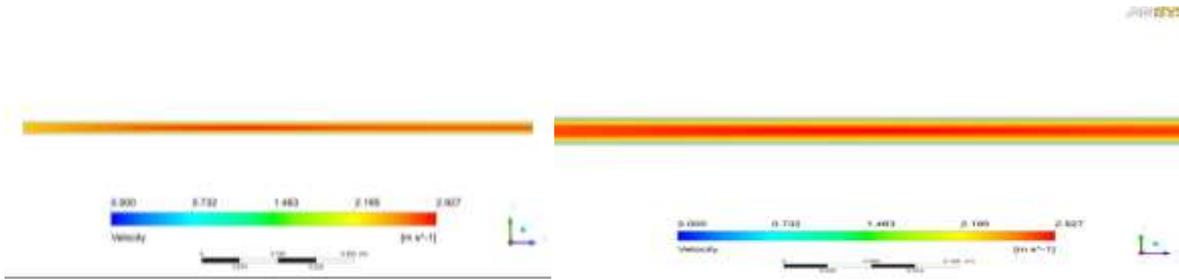


Fig.4. 8 Velocity contours of smooth tube- Velocity 2.38 m/s

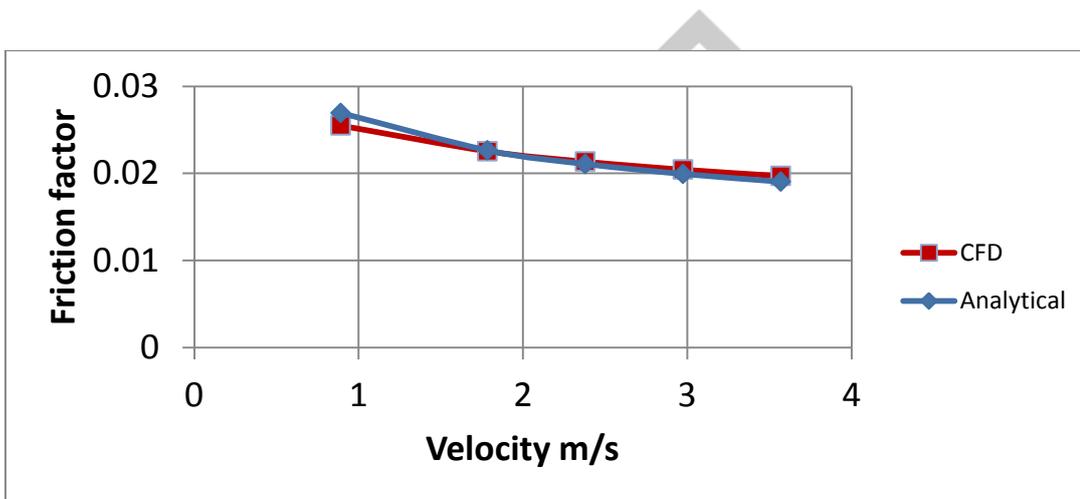


Fig. 9 Smooth Tube CFD and analytical Comparison of Pressure drop Vs velocity

Results Ribbed Tube

Table.5.1 Comparison of Pressure drop and Temperature Outlet

S.No	Velocity m/s	Helix Pitch mm	Pressure drop Pa	Temperature Outlet K
0	0.893	2000	622.1769	313.5464
1	1.786	2000	2182.804	308.0692
2	2.38	2000	3674.174	306.2633
3	2.976	2000	5509.847	305.225
4	3.57	2000	7662.782	304.5443
5	0.893	1500	635.5347	314.7031
6	1.786	1500	2219.131	308.4056
7	2.38	1500	3732.504	306.605
8	2.976	1500	5595.369	305.5384
9	3.57	1500	7773.213	304.8327
10	0.893	1000	649.2463	315.0022
11	1.786	1000	2246.4	308.6995
12	2.38	1000	3806.698	306.889
13	2.976	1000	5702.821	305.8224
14	3.57	1000	7933.464	305.1241
15	0.893	750	663.9655	315.6399
16	1.786	750	2313.487	309.3095

17	2.38	750	3887.84	307.5036
18	2.976	750	5824.368	306.4389
19	3.57	750	8093.217	305.7453
20	0.893	500	738.7884	316.2625
21	1.786	500	2575.044	309.8678
22	2.38	500	4331.424	308.0796
23	2.976	500	6492.072	307.0261
24	3.57	500	9024.9	306.3372
25	0.893	250	863.6719	316.5687
26	1.786	250	2998.398	310.2409
27	2.38	250	5040.178	308.4297
28	2.976	250	7555.756	307.3527
29	3.57	250	10513.19	306.6499

7. Ribbed Tube-Helix Pitch 2m -Velocity 0.83 m/s

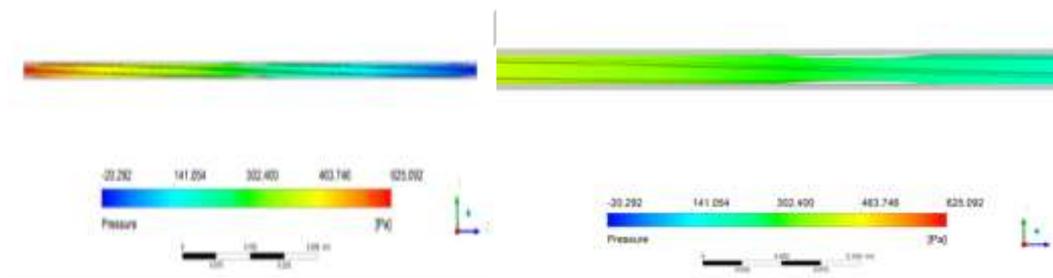


Fig.5. 1 Pressure contours of ribbed tube-Helix Pitch 2m- Velocity 0.83 m/s

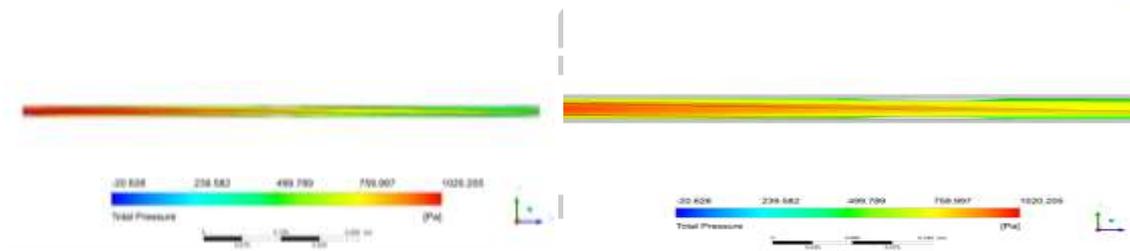


Fig.5. 2 Total Pressure contours of ribbed tube-Helix Pitch 2m- Velocity 0.83 m/s

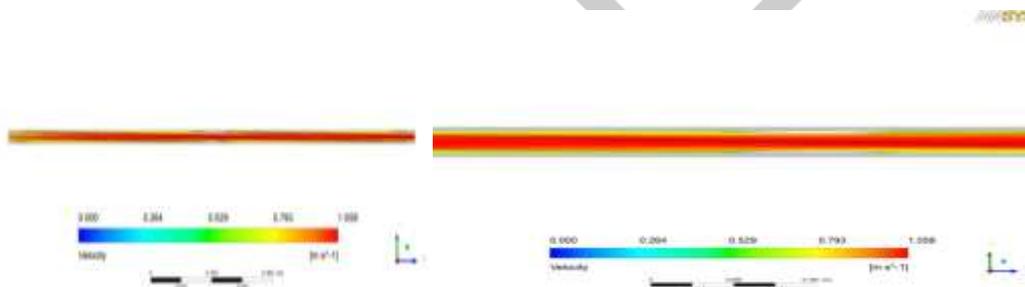


Fig.5. 3 Velocity contours of ribbed tube-Helix Pitch 2m- Velocity 0.83 m/s.

5.2 Ribbed Tube-Helix Pitch 2m -Velocity 2.38 m/s

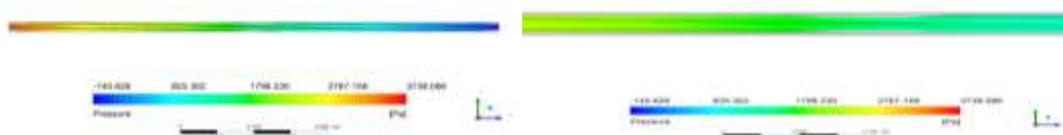


Fig.5. 4 Pressure contours of ribbed tube-Helix Pitch 2 m- Velocity 2.38 m/s

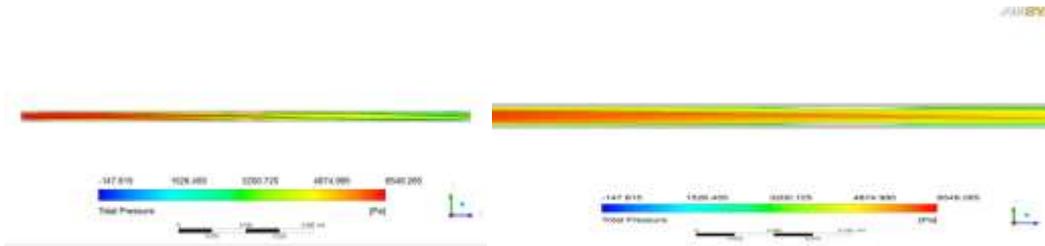


Fig.5. 5 Total Pressure contours of ribbed tube-Helix Pitch 2m-Velocity 2.38 m/s



Fig.5. 6 Velocity contours of ribbed tube-Helix Pitch 2m-Velocity 2.38 m/s

Ribbed Tube-Helix Pitch 1m -Velocity 0.83 m/s

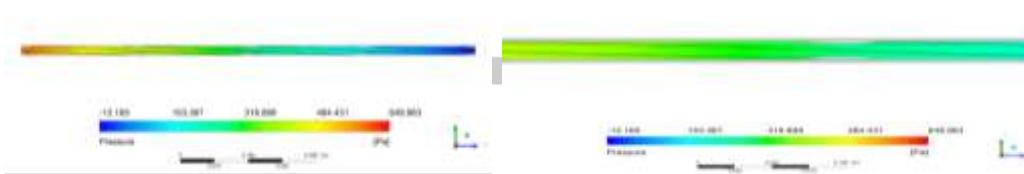


Fig.5. 7 Pressure contours of ribbed tube-Helix Pitch 1 m- Velocity 0.83 m/s.

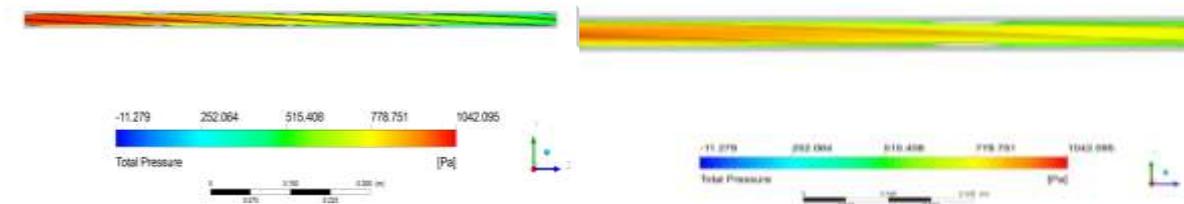


Fig.5. 8 Total Pressure contours of ribbed tube-Helix Pitch 1 m-Velocity 0.83 m/s.

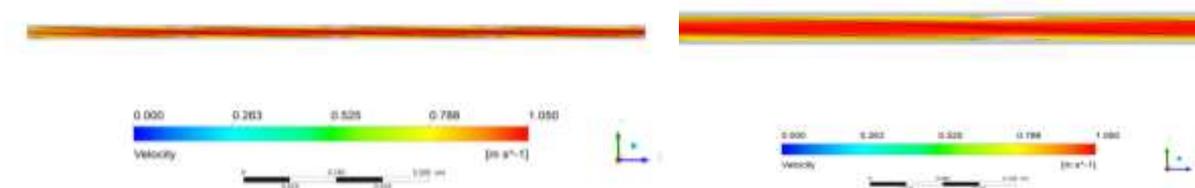


Fig.5. 9 Velocity contours of ribbed tube-Helix Pitch 1 m-Velocity 0.83 m/s

5.6 Ribbed Tube-Helix Pitch 1m -Velocity 2.38 m/s



Fig.5. 10 Pressure contours of ribbed tube-Helix Pitch 1 m- Velocity 2.38 m/s.

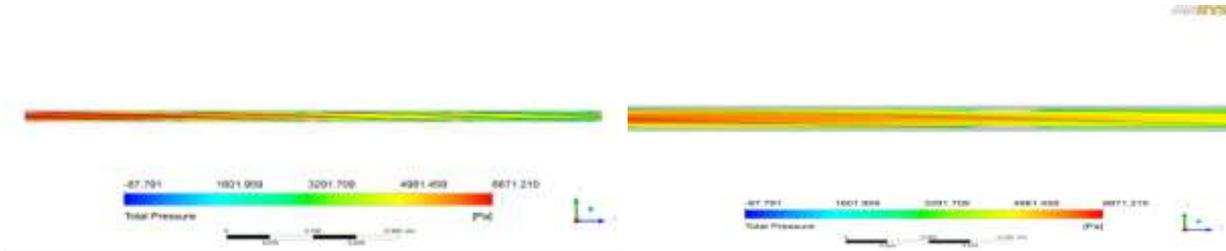


Fig.5. 11 Total Pressure contours of ribbed tube-Helix Pitch 1m-Velocity 2.38 m/s

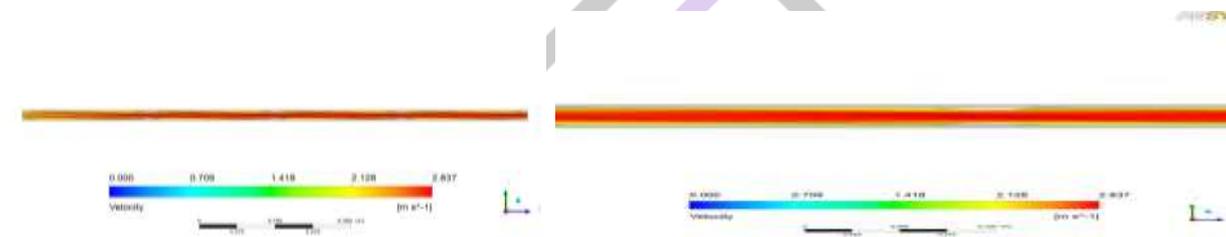


Fig.5. 12 Velocity contours of ribbed tube-Helix Pitch 1 m-Velocity 2.38 m/s

Ribbed Tube-Helix Pitch 0.25m -Velocity 0.83 m/s



Fig.5. 13 Pressure contours of ribbed tube-Helix Pitch 0.25 m- Velocity 0.83 m/s

5.12 Ribbed Tube-Helix Pitch 0.25m -Velocity 2.38 m/s

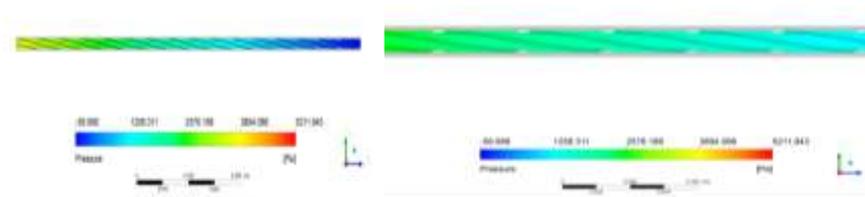


Fig.5. 14 Pressure contours of ribbed tube-Helix Pitch 0.25 m- Velocity 2.38 m/s

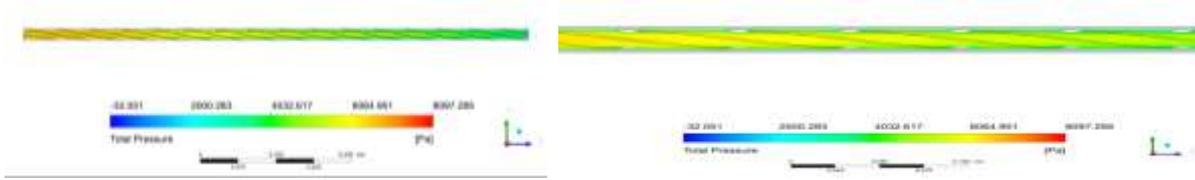


Fig.5. 15 Total Pressure contours of ribbed tube-Helix Pitch 0.25 m-Velocity 2.38 m/s

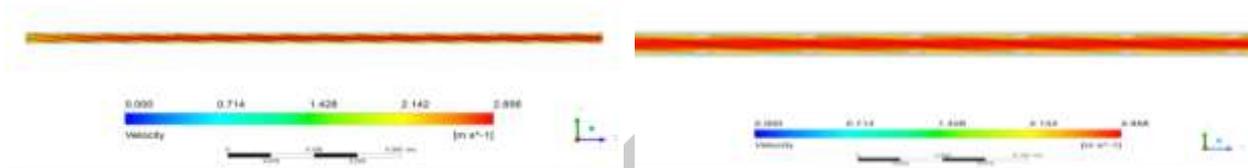


Fig.5. 16 Velocity contours of ribbed tube-Helix Pitch 0.25 m-Velocity 2.38 m/s

Graphs and Comparison

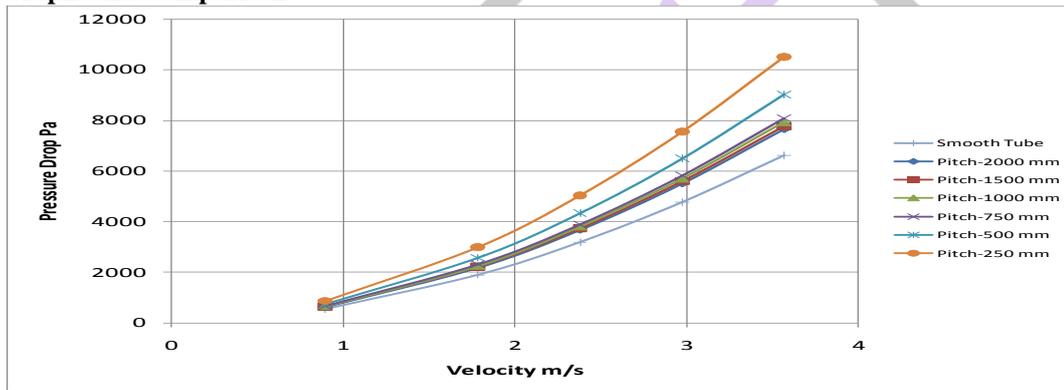


Fig.5. 17 Comparison Pressure Drop Vs Velocity

Fig.5.49 demonstrates the numerical and analytical results for the pressure drop vs. velocity number for different types of helix pitch from 2m to 0.25m. The ribbed tube results are represented using solid lines, while the corresponding analytical results are denoted by circular “+” symbols. It was found that the pressure drop for ribbed was 10–60% higher than that of plain tubes and that of 0.25m helix pitch shows 25–60% higher.

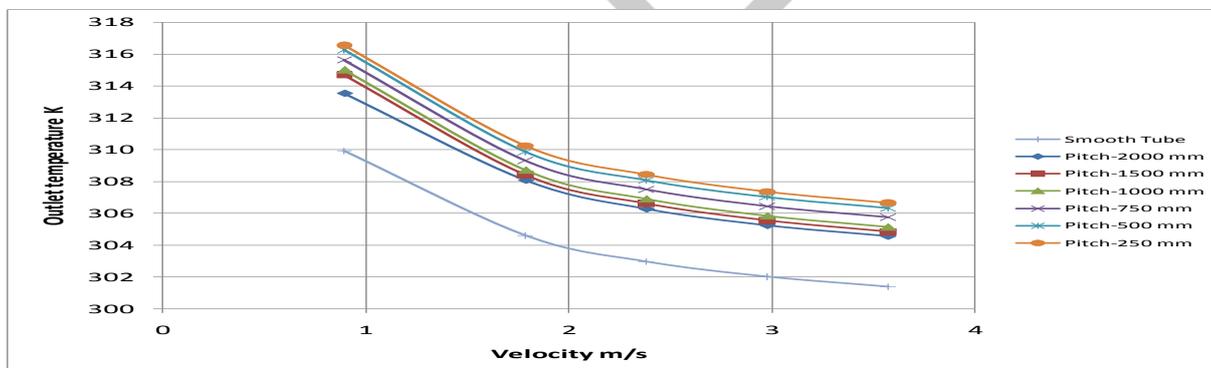


Fig.5. 18 Comparison Outlet temperature Vs Velocity

Fig.5.49 demonstrates the numerical and analytical results for the Outlet temperature vs. velocity number for different types of helix pitch from 2m to 0.25m. The ribbed tube results are represented using solid lines, while the corresponding analytical results are denoted by circular “+” symbols. It was found that the temperature rise for ribbed was 10–40% higher than that of plain tubes and that of 0.25m helix pitch shows 25–40% higher.

## CONCLUSIONS

Computational Fluid Dynamics (CFD) analysis of heat transfer and fluid flow analysis in the turbulent flow regime in a spirally ribbed tube and a smooth tube in vertical orientation are investigated using ANSYS Fluent. The Geometric model of the ribbed and smooth tube is created using ANSYS Design Modeler. CFD meshing is carried out using ANSYS Meshing Platform. The CFD simulation is performed on a vertical orientation of the steel tubes (rifled and smooth) under six different inlet velocities of 0.893m/s, 1.786m/s, 2.38m/s, 2.976m/s, 3.57m/s and 4.166m/s. The main objective of this thesis is to determine the heat transfer and pressure drop in both vertical smooth and ribbed tubes. The fluid used is water and the initial temperature is 25°C. The heat flux that for heating the tube is equal to 150KW/m<sup>2</sup>.

## REFERENCES

- [1] Lixin Cheng and Tingkuan Chen, Flow boiling heat transfer in a vertical spirally internally ribbed tube, HEAT AND MASS TRANSFER Volume 37, Numbers 2-3 (2001), 229-236, DOI: 10.1007/PL00013294
- [2] Wang, Weishu; Bi, Qincheng; Gu, Hongfang; Chen, Tingkuan; Luo, Yushan, An Investigation on Heat Transfer to Water Flowing in Vertical Upward Internally Ribbed Enhancement Tube at Supercritical Pressure, Advanced Science Letters, Volume 4, Numbers 6-7, June/July 2011 , pp. 2281-2288(8)
- [3] Ooi, G. Iaccarino, P.A. Durbin, M. Behnia Reynolds averaged simulation of flow and heat transfer in ribbed ducts, International Journal of Heat and Fluid Flow 23 (2002) 750–757.
- [4] Abdulati Muftah Mohamed Ibrahim, Bashir Rahuma Elhub, H. Abas A. Wahab, Experimental Study on Heat Transfer and Fluid Flow in Vertical Rifled, Advanced Materials Research (Volume 505), April, 2012.
- [5] L. Cheng<sup>1</sup>, T. Chen, Enhanced Heat Transfer Characteristics of Upward Flow Boiling of Kerosene in a Vertical Spirally Internally Ribbed Tube, Chemical Engineering & Technology Volume 29, Issue 10, pages 1233–1241, October, 2006.

