CFD ANALYSIS OF HEAT TRANSFER AUGMENTATION FOR FLOW THROUGH A MICROTUBE

Jamal Reddy Saleem
Research Scholar JJT University
Email Id - Seelam312@Gmail.Com

Dr. S. Chakradhar Goud
Principal Of Sana Engineering College
Email Id – Cgsakki@Gmail.Com

Abstract
This project deals with the analysis of heat transfer augmentation for fluid flowing through pipes using CFD. Using CFD codes for modeling the heat and fluid flow is an efficient tool for predicting equipment performance. CFD offers a convenient means to study the detailed flows and heat exchange processes, which take place inside the tube. Friction factor and Nusselt number for water flowing through the specified pipe (internal diameter = 0.022 m, length = 2.5 m) were obtained first for the smooth pipe and then for the pipe with a wire coil insert in the Reynolds number range of 250 to 25,000 and Prandtl number of 6.97. Three wire coils with pitch 0.033 m, 0.044 m and 0.0484 m, and coil diameter 0.00154 m, 0.00187 m and 0.002 m respectively were considered.

Keywords: *CFD, heat applications,wire coil inserts.*

INTRODUCTION

The conversion, utilization, and recovery of energy in industrial, commercial, and domestic application usually involve a heat transfer process. Improved heat exchange, over and above that in the usual or standard practice, can significantly improve the thermal efficiency in such applications as well as the economics of their design and operation. The need to increase the thermal performance of heat based equipment's (for instance, heat ex changers), thereby effecting energy, material, and cost savings as well as a consequential mitigation of environmental degradation has led to the development and use of many heat transfer enhancement techniques. These methods are referred to as augmentation or intensification techniques. Enhancement techniques essentially reduce, for example, the thermal resistance in a conventional heat ex-changer by promoting higher convective heat transfer coefficient with or without surface area increases (as represented by fins or extended surfaces). As a result, the size of a heat exchanger can be reduced, or the heat duty of an existing exchanger can be increased, or the exchanger's operating approach temperature difference can be decreased. The latter is particularly useful in thermal processing of biochemical, food, plastic, and pharmaceutical media, to avoid thermal degradation of the end product. On the other hand, heat exchange systems in spacecraft, electronic devices, and medical applications, for example, may rely primarily on enhanced thermal performance for their successful operation.

Objective

In the present work, heat transfer enhancement for fluid flowing through a pipe with wire coil inserts is to be analyzed using Computational Fluid Dynamics (CFD). The impressive improvements in computer performance, matched by developments in numerical methods, have resulted in a growing confidence in the ability of CFD to model complex fluid flows. CFD techniques have been applied on a broad scale in the process industry to gain insight into various flow phenomena, examine different equipment designs or compare performance under different operating conditions.

METHODOLOGY

(a) A smooth copper pipe 2.5 m in length and 0.022 m internal diameter is considered. Water flows through it with inlet temperature 25˚C. Wall temperature is assumed constant at 100˚C.

Properties of water at 25˚C are as follows:

Density, ρ = 995.7 kg/m3

Thermal conductivity, K = 0.618 W/m.K

Viscosity, μ = 801.2x10-6 kg/m.s

Specific heat, Cp = 4.174 kJ/kg.K

Nusselt number and friction factor values were calculated from empirical equations taking different velocity values in the laminar and turbulent regions. These were then compared with the values obtained from CFD simulation.

(b) Same procedure was repeated for pipe with wire coil insert in it. Three different wires were considered for the calculations and simulations with different pitch and wire diameters as shown below:

specifications of the wire coils used:

Coil no.	Pitch p(m)	Coil diameter e(m)	Tube diameter d (m)	p/d	e/d	p/e	p2/ed
1	0.0330	0.00154	0.022	1.5	0.0700	21.43	32.143
2	0.0440	0.00187	0.022	2.0	0.0850	23.53	47.059
3	0.0484	0.00200	0.022	2.2	0.0909	24.20	53.240

Smooth tube:

Equations used:-

- Reynold's number, Re = ρvDi/μ
- Friction factor, f:
- Laminar flow: f = 16/Re
- Turbulent flow: f = 0.079(Re)-0.25 (Blassius equation)
- Nusselt Number, Nu:
- Laminar flow(Re<2100):
- For Gz<100, Hausen's equation is used:
- For Gz<100, Hausen's equation is used:
- Nu = 3.66 + [0.085Gz/(1 + 0.047Gz2/3)](μb/μw)0.14
  where Gz = Re.Pr.(D/L)
- Pr = Cpμ/K
- For Gz>100, Sieder Tate equation is used:
- Transition region (2100<Re<10000):
- Nu = 0.116(Re2/3-125)Pr1/3[1 + (D/L)2/3] (μb/μw)0.14
- Turbulent flow (Re>10000):
- Sieder Tate equation is used:
- Nu = 0.023Re0.8Pr1/3(μb/μw)0.14

Design Analysis Input parameters

The experimental study on passive heat transfer augmentation using twisted aluminium angles and twisted tapes were carried on in a double pipe heat exchanger having the specifications as listed below:-

Specifications–

Inner pipe ID = 21mm
Inner pipe OD=25mm
Outer pipe ID =42mm
Outer pipe OD =48mm
Material of construction= Cu.
Heat transfer length= 1.5m

Pressure tapping to pressure tapping length =2m

Inserts used:

The aluminium angles of size 19mm, thickness about 1mm and length 366cm were first cut into 3 equal length (122cm) .About 2.5 cm on each side was clipped into a flat tape and a hole of about 5mm was drilled in it. Then the ends were tightened in the clamps and fixed on the lathe – one end being fixed on the tool part side and the other on the chuck side. The chuck was then rotated slowly by hand, while the angle was being held in tension, to give it a desired twist. Four angle tapes with varying twist ratios were fabricated as shown in fig. The end portions of the fabricated tapes were cut and drilled to join the tapes by thin high tension wires. Three tapes with the same twist ratio and twist in the same direction were joined to give a length of around2m, which was sufficient for the heat exchanger used for the experimental study. The inserts tapes are shown in figure 3,4 and 5 respectively.

Fig. 3 Wire Type

Fig. 4 Screw Type Insert

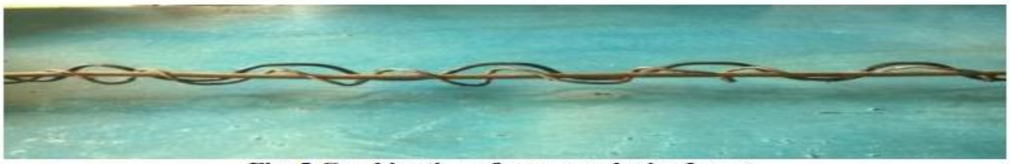

Fig. 5 Combination of screw and wire Insert

MODEL & MESHING

Introduction to CATIA:

CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CADAM software to develop Dassault's Mirage fighter jet. It was later adopted in the aerospace, automotive, shipbuilding, and other industries. Computer Aided Three dimensional Interactive Application(CATIA) is well known software for 3-d designing and modeling for complex shapes.Commonly referred to as a 3D Product Lifecycle Management software suite, CATIA supports multiple stages of product development (CAX), including conceptualization, design (CAD), engineering (CAE) and manufacturing (CAM). CATIA facilitates collaborative engineering across disciplines around its 3DEXPERIENCE platform, including surfacing & shape design, electrical, fluid and electronic systems design, mechanical engineering and systems engineering.CATIA facilitates the design of electronic, electrical, and distributed systems such as fluid and HVAC systems, all the way to the production of documentation for manufacturing.

MESHING

- The Figure shown is the meshed model of rigid flange coupling in the ANSYS analysis for the static structural process. To analyse, the FEM triangular type of mesh is used for the rigid flange coupling in the ANSYS environment.
- The number of elements used in this meshing is 71441and the number of nodes is 122228.In this process regular type of meshing is done to analyse the process.
- Using the working condition of the coupling a relative rotational movement between the shafts comes into picture consequently.

The CFD values follow the same trend as the values obtained from the empirical equations available in literature with deviations varying in the range of + 18% for friction factor and -20 to 28 % for Nusselt number. The deviation of the CFD values from the calculated ones can be due to a few reasons. Firstly, the correlations used for calculation are not universal laws or formulae, rather they are the empirical correlations developed by a particular group of researchers based on their experimental investigations. So, the values calculated may not be the true values. Secondly, CFD calculates the values by iteratively solving the discretized energy and momentum equations by the finite volume method. So, the accuracy depends on the number of iterations. Increasing the number of iterations would increase the accuracy. Another method to get better results would be to go for higher order meshing. However, increasing the number of elements during meshing can lead to very high computation time. Moreover, the commercial CFD software used for the current work did not simulate the model for very high order meshing. Hence, overcoming these problems could lead to even better results. As can be seen, the wire coils provide moderate friction factor increase for pure laminar flow but in the transition and turbulent regions, much higher increment was observed. The increment is maximum in the transition region and again drops as Re increases and flow becomes more turbulent. Similar observations were made for Nusselt number also. The plots also indicate an early onset of turbulence at Reynolds number around 750 to 1000 due to the use of wire coils. Higher the pitch, lower is the roughness and higher the coil diameter, higher is the roughness. The wire coils used are in increasing order of pitch as well as coil diameter. This leads to counter acting effect on roughness because of which there's not much difference in the increment of friction factor and Nusselt number for the three coils. The dimensionless number p2/ed is a measure degree of roughness. Lower its value, higher is the roughness. Thus, coil 1 having the lowest p2/ed value i.e. 32.143 has highest roughness and hence, as expected the friction factor values for coil 1 are slightly higher than the other coils.

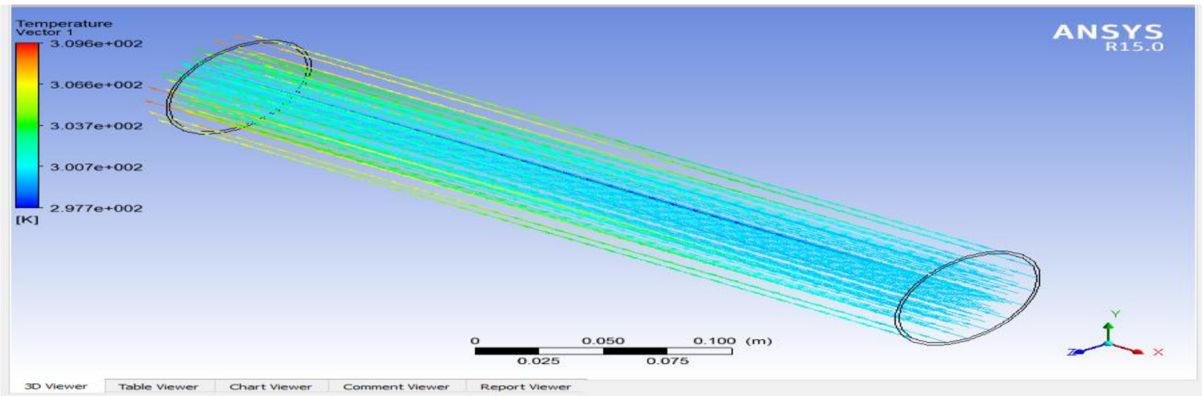

Figure shows the temperature difference flow inside when a strip is present in a tube.

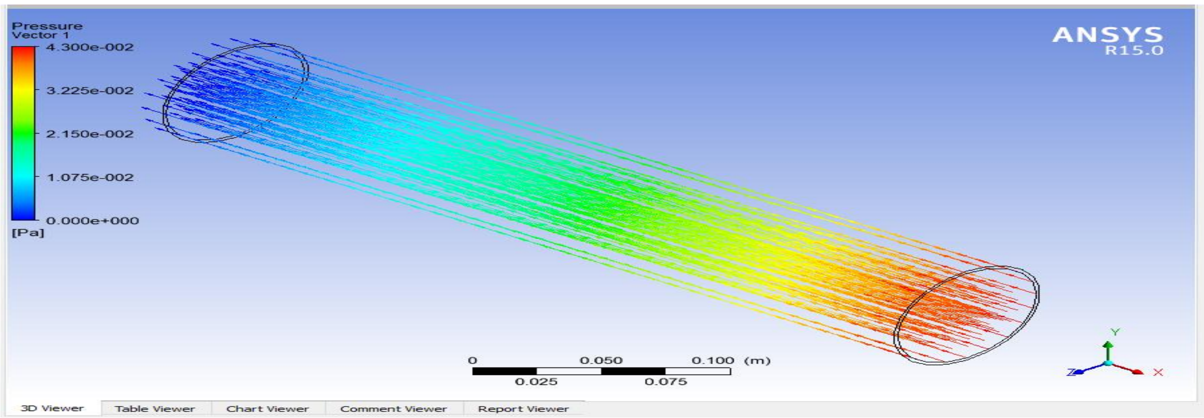

Figure shows the pressure flow inside the tube when a strip is present in a tube

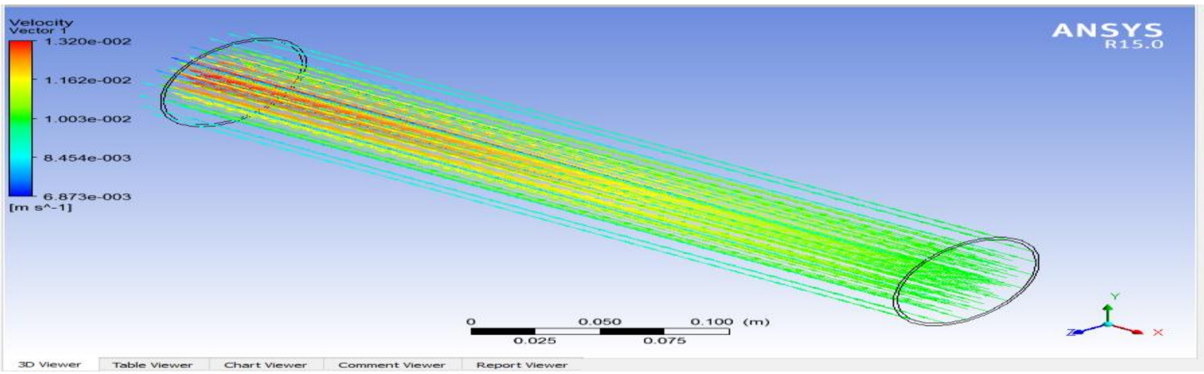

Figure shows the velocity flow inside the tube when a strip is present in a tube

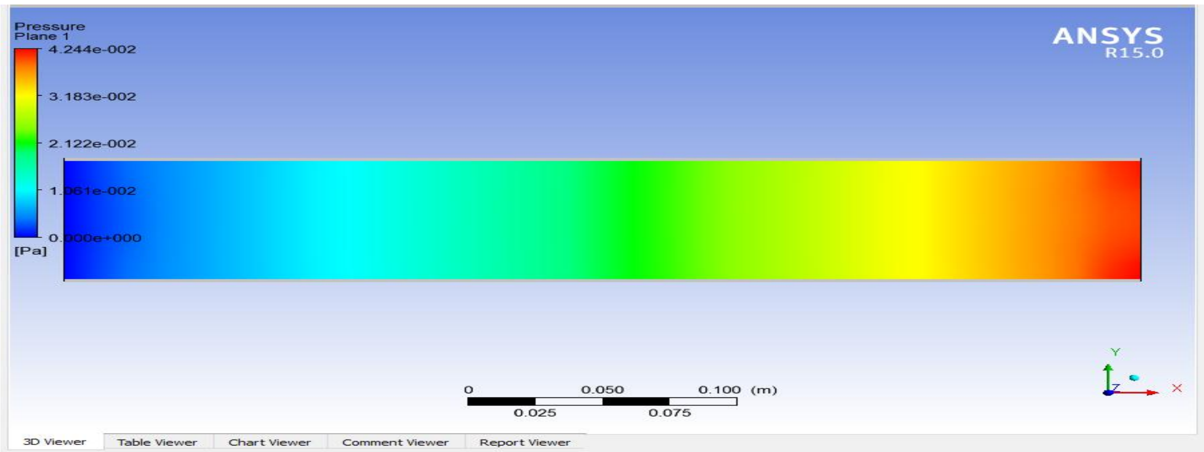

Figure shows the pressure flow in a plane inside the tube when a strip is present in a tube.

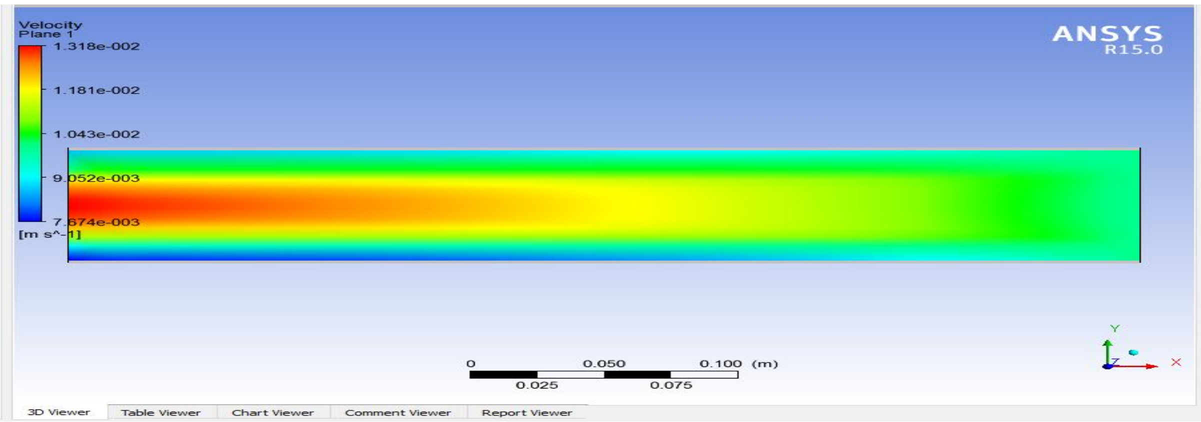

Figure shows the velocity flow in a plane inside the tube when a strip is present in a tube.

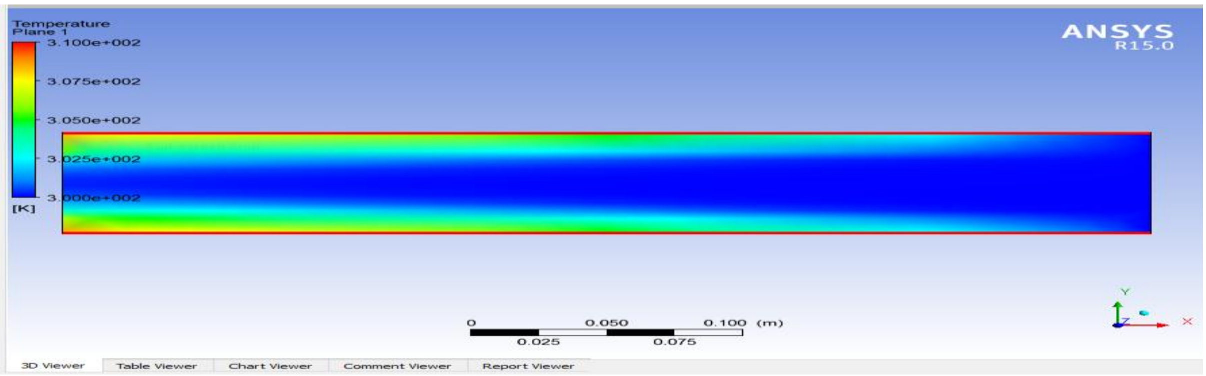

Figure shows the temperature flow in a plane inside the tube when a strip is present in a tube.

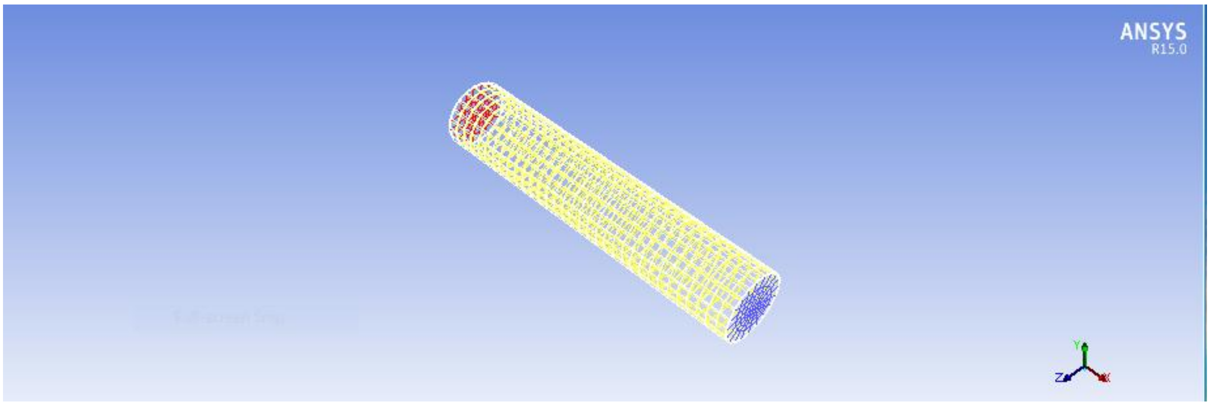

Figure shows the static structural design of a hallow tube in ANSYS.

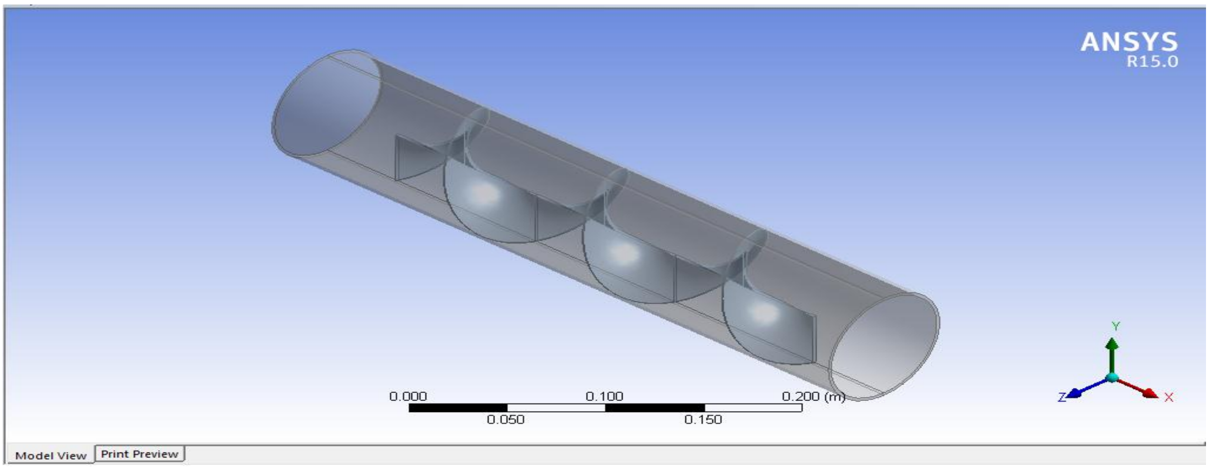

Figure shows the static structural present of a strip inside a tube of a circular shape design.

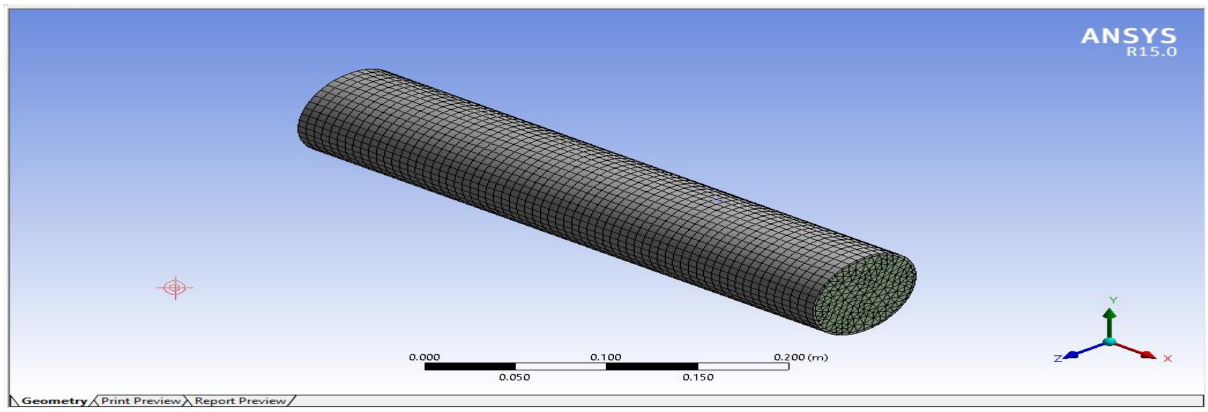

Figure shows the total meshing on the outer side of the tube in ANSYS.

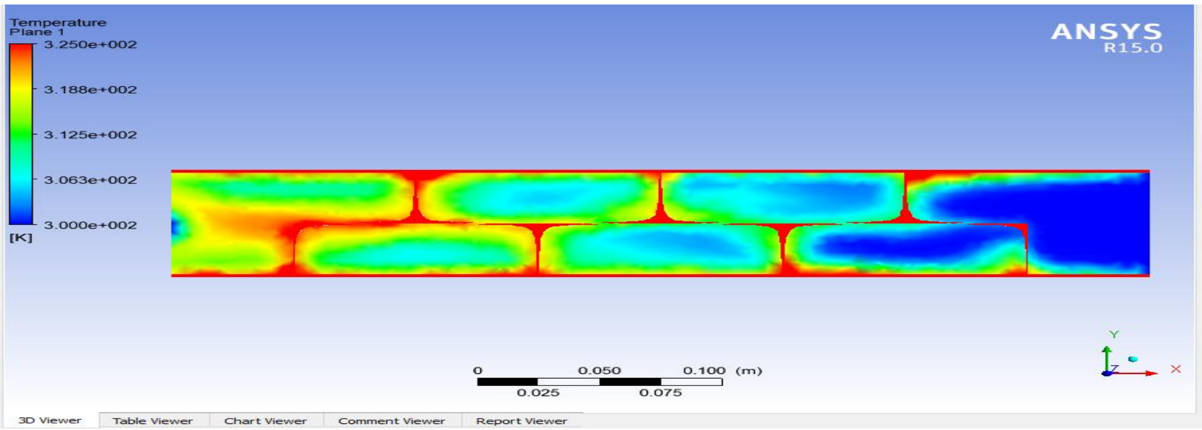

Figure shows the temperature varience outside the tube at given conditions

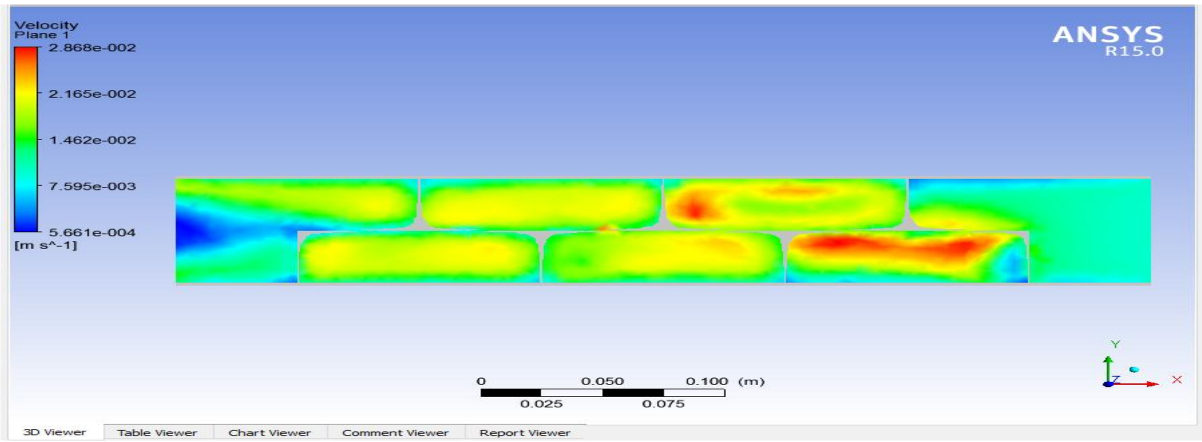

Figure shows the velocity variation outside the tube at different condition.

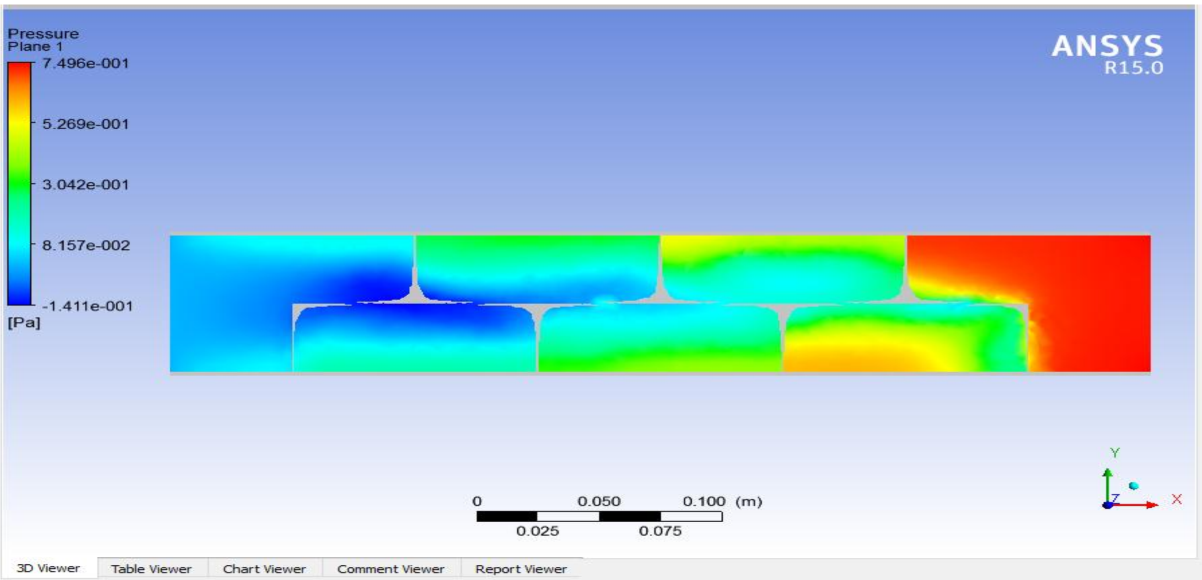

Figure shows the pressure flow outside the tube

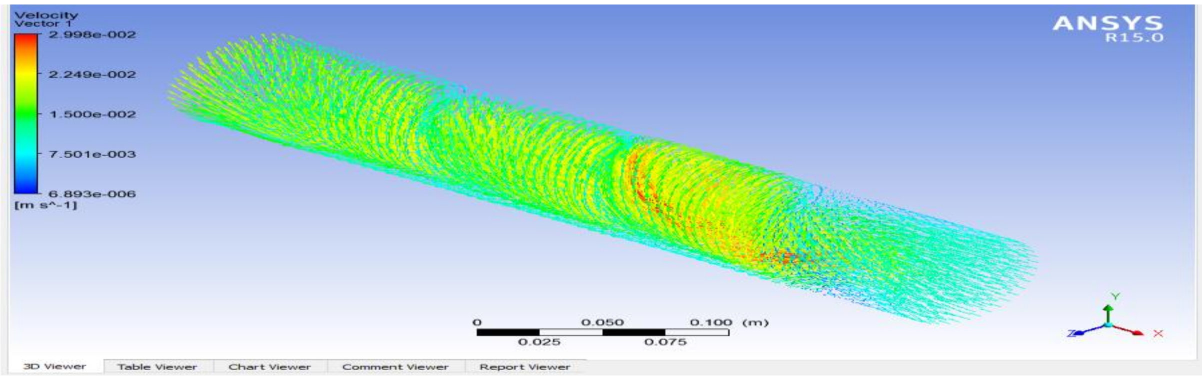

Figure shows the velocity flow at the outer side of the tube at different condition.

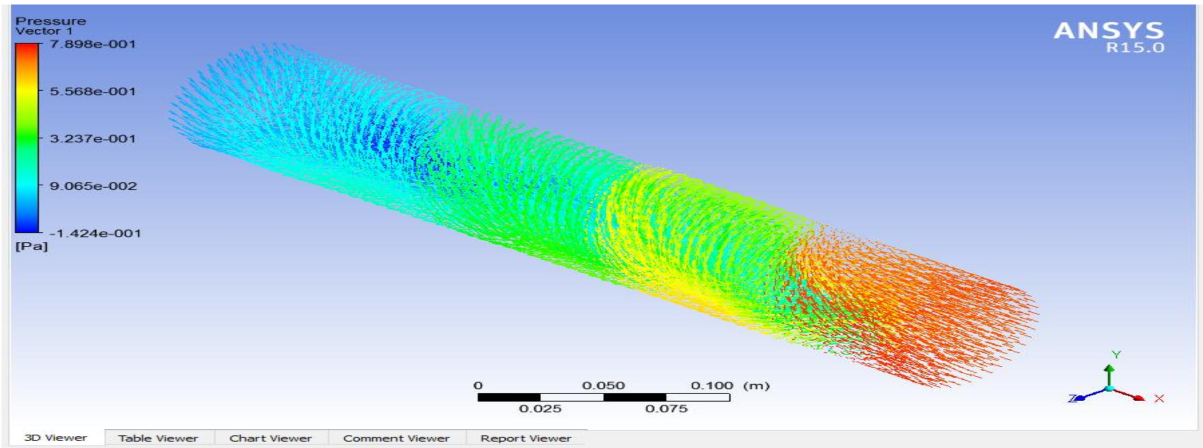

Figure shows the pressure difference when a strip is present in a tube

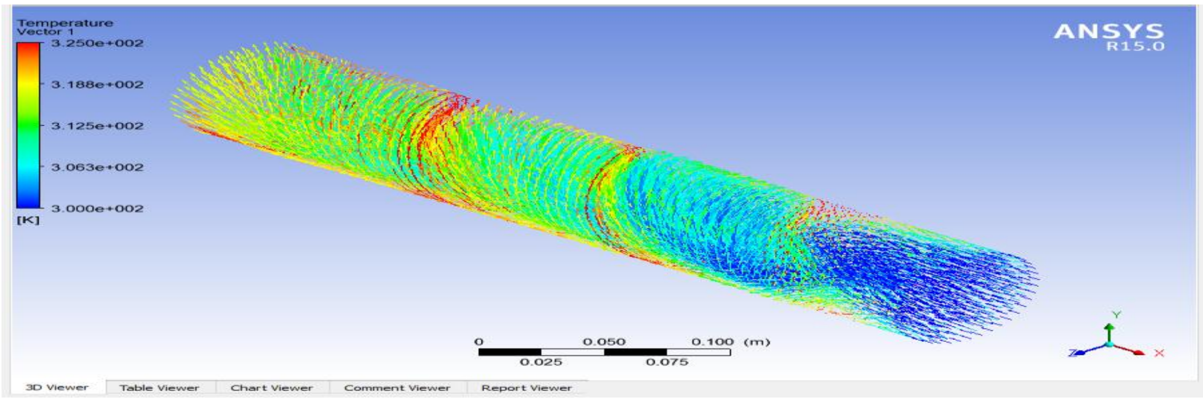

Figure shows the temperature difference when a strip is present in a tube.

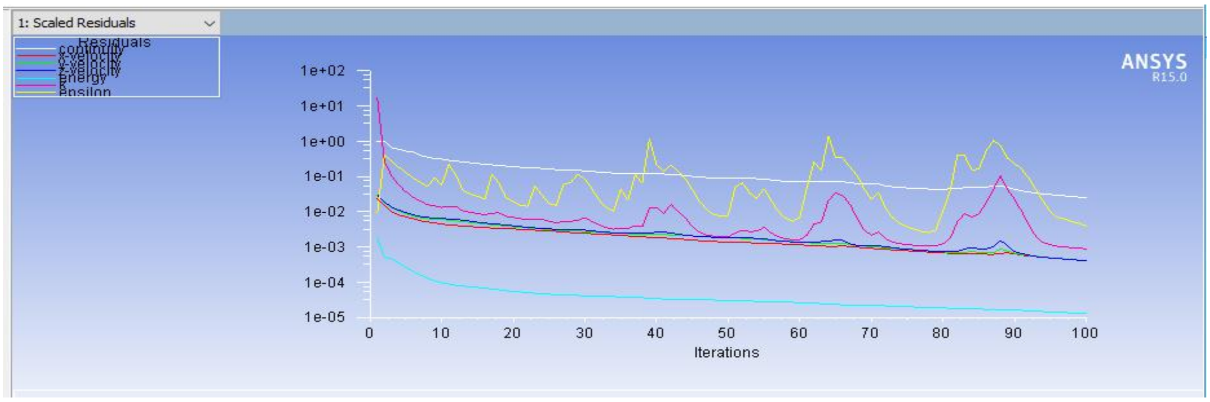

Figure shows the scared residuals of temperature graph results.

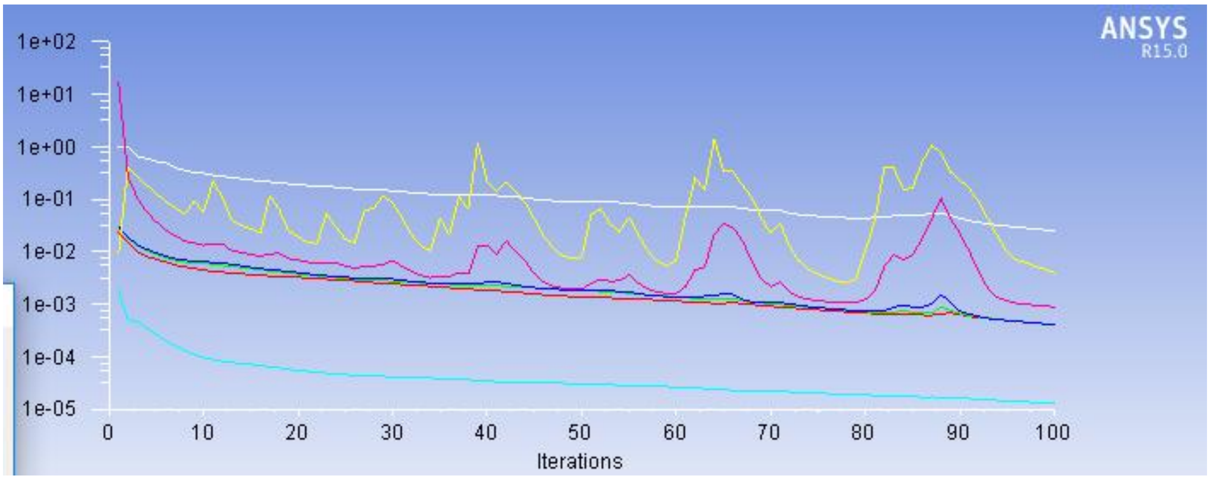

Figure shows the scared residuals of pressure graph results.

Discussions

Heat transfer analysis for water flowing through a smooth tube as well as a tube with a wire coil insert was done by calculation of friction factor and Nusselt number at the specified conditions using the empirical equations available in literature. CFD simulations were carried out for the same problem using commercial CFD software ANSYS 15.0. Results revealed that in laminar flow, wire coils mostly behave as a smooth tube with moderate increase in friction factor and Nusselt number values.

However in turbulent flow, considerable increase in friction factor and Nusselt number are observed, especially for coil 1 with lowest p2/ed ratio, i.e highest degree of surface roughness. Moreover use of wire coils gives the advantage of early onset of turbulence (at Reynolds number around 750 to 1000). It was seen that the friction factor increment i.e. f_c/f_0 varied from 1.2 to 8.5 with coil 1 giving the maximum value of 8.5 at a Reynolds number of 2250. Similarly, the Nusselt number increment i.e. Nuc/Nu0 varied in the range of 1.3 to 4.9, again with coil 1 giving the maximum value of 4.9 at the same Reynolds number of 2250. CFD simulation for the heat transfer augmentation in a circular tube equipped with classical and Parabolic-cut twisted tape (PCT) for 2% and 4% volume fraction of CuO nanofluid was carried out using FLUENT version 6.3.26. The data obtained by simulation are matching with the literature correlations of plain tube for validation with the discrepancy of less than ±8% for the Nusselt number and ±10% for friction factor. The results show that the Nusselt number increased with the increase of the nano particle volume fraction, Reynolds number, and twist tape decreases. The results also revealed that the twist tape with twist ratio y = 2.93 and cut depth (w = 0.5 cm) was more dominant than those of (w = 1 and 1.5 cm) for all the Reynolds number. Furthermore, the Parabolic-cut twisted tape (PCT) with 4% CuO nanofluid offers about 10% more enhancement of the Nusselt number with significant increases in friction factor than that of Classical twisted tape.

Conclusions

The heat transfer augmentation, Pressure drop variation, friction factor and overall thermal performance of a tube inserted with wire coil inserts alone, twisted tape inserts alone and the combined devices between the twisted tape and constant or periodically varying wire coil pitch ratio are studied. Many of researchers have developed The correlations of the Nusselt number and friction factor for all parameters studied are also developed. The results of smooth tube test are studied and the results from the combined devices are also compared with those from each device alone. Their result shows that twisted tapes are good with heat transfer improvement but are poor with friction factor analysis. But in all for low Reynolds number, the experimental results shows that the compound devices of the Twisted Tape and DI-coil, shows the highest thermal performance which is higher than the wire coil alone, the TT alone, the TT with uniform wire coil, and the TT with D-coil.

The heat transfer augmentation, pressure drop variation and overall thermal performance of tube inserted with wire coil insert alone, twisted tape insert alone and combine devices between twisted tape and constant or varying wire coil pitch ratio and varying diameter of wire coil are studied. The relation between Nusselt number and friction factor for all parameter are also studied. From studying all paper it concluded that the swirl flow helps decrease the boundary layer thickness of hot water flow and increase the residence time of hot water which result increases in heat transfer augmentation. The heat transfer augmentation and Nussult number is increases with decreases in pitch of wire coil. Studies on the heat transfer characteristics in a circular tube fitted with pierced twisted tape and wire coil for various twist ratio has been done experimentally. The results indicate that the nusselt number increases with decrease in the twist ratio. The thermal performance factor is more than 1.44 while using the pierced twisted tape with lower twist ratio and lower wire coil ratio.

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