INVESTIGATIONS ON RECEIVER OF PARABOLIC TROUGH COLLECTOR

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Abstract : ***Parabolic trough solar technology is the most widely used and lowest cost large scale solar power technology available today. Corrugation is one of the important methods involved in the passive techniques of enhancement. This report provides an evaluation of numerical simulation studies on heat transfer enhancement, in the corrugations specifically in corrugated tubes which includes the turbulent flow regions. The flow and heat transfer characteristics in a symmetric outward convex corrugated tube has been investigated through numerical simulations based on the Reynolds stress transport (RST) model. In this report validation of the obtained results of RST modeling and the existing results of RST modeling simulation by Feng-Chen Li has been carried out. The simulation results, including velocity and temperature distributions for different profiles between carried out and existing simulation match well.***

On this basis, the same procedure of RST modeling simulation is applied to research the detailed flow and heat transfer mechanism in proposed corrugated receiver tube model. In one corrugation of the model, detailed study of mean velocity, mean temperature and Reynolds stress at different profiles is carried out. It is found that, in the proposed model of corrugation structure the velocity fluctuation intensity greatly increases, as a result of that there is increase in heat transfer rate which leads to increase in the efficiency of thermal power plant application.

IndexTerms - Symmetric outward convex corrugated tube, Reynolds stress transport model, Numerical simulation, Heat transfer enhancement, axisymmetric, Two-dimensional.

I. INTRODUCTION

The use of energy resources is irreversible. But the supplies of traditional fossil fuels are running out fast. Hence from many years more attention is given to the energy resources like oil, natural gas and the ways to increase energy efficiency. Now a day there is increasing demand of renewable energy resources. Solar energy is one of them.

Heating with solar energy is not as easy as we think. The solar energy that reaches the earth is spread out over the large amount area. Hence Capturing sunlight and putting it to work is hard [1].

A collector is a tool for converting the energy in solar radiation into usable or storable shape. Concentrating collectors use reflected surfaces to concentrate the sun's energy on an absorber called a receiver. Concentrating collectors additionally obtain high temperatures, however in contrast to evacuated-tube collectors; they are able to accomplish that only when direct sunlight is available. The mirrored surface focuses sunlight gathered over a large area onto a smaller absorber place to reach high temperatures. Sun energy is concentrated onto a focal point in some designs, while others concentrate the solar rays alongside a thin line referred to as the focal line. At the focal point or along the focal line, the receiver is situated. A heat transfer fluid flows through the receiver and absorbs heat.

The receiver, being the key component of a Concentrated Solar Power (CSP) plant, has a decisive influence on the overall efficiency of the plant. The conventional receivers in Parabolic Trough Collectors (PTC) are giving good results referring to solar energy collector. Still there is a scope to enhance thermal performance of the receiver by reducing various thermal losses. In the Parabolic Trough Collector (PTC), the receiver has to withstand with drastic temperature changes and mechanical stresses. Because of that, the various thermal losses occur in the receiver of PTC. Therefore, by modifying the shape of the receiver this losses can be reduced and in turn increase the heat transfer and thereby increase in efficiency of PTC.

Therefore in this study, the shape of the receiver tube of parabolic trough collector was modified in order to increase the heat transfer surface area of the receiver tube without changing the length and carried out the comparative study of thermal performance of modified receiver tube of Solar Parabolic Trough Collector (PTC) with that of the conventional receiver tube. The aim of this study is to increase the heat transfer rate and thereby increase in efficiency of PTC.

II. METHODOLOGY

The various types of losses in conventional receiver had been identified. Methods of reducing these losses had been studied. For the enhancement of heat transfer rate and efficiency of PTC, the shape of the receiver tube is modified. The proposed shape is designed to increase heat transfer surface area. Then, the proposed model is simulated in ANSYS Fluent 18.2. Compared the results of simulation of proposed model with the existing corrugated receiver tube model.

III. SIMULATION PROCEDURE

1] Geometry of proposed symmetric outward convex corrugated receiver tube model and meshing system

Schematic diagram of proposed symmetric outward convex corrugated receiver tube model is as shown in figure 1. The design parameter of model includes Length of receiver tube (L) = 200 mm, Diameter of receiver tube (D) = 20 mm, Thickness of receiver tube (t) = 3 mm, Height of corrugation (H) = 3 mm, Corrugation crest radius (R), Corrugation trough radius (r) as shown in figure 2. Helium gas is used as a heat transfer fluid in tube and material for tube wall used is steel [2]. Material properties of working fluid and tube wall are shown in the table 1:-

Table 1 : Material properties of working fluid and tube wall.

Variable	Unit	Helium	Steel
Density (ρ)	kg/m3	2.1659	-
Specific heat (Cp)	J/(kg k)	5191	8030
Thermal conductivity (λ)	W/(m k)	0.2724	502.48
Dynamic viscosity (μ)	kg/(m s)	3.46 x 10-5	16.27

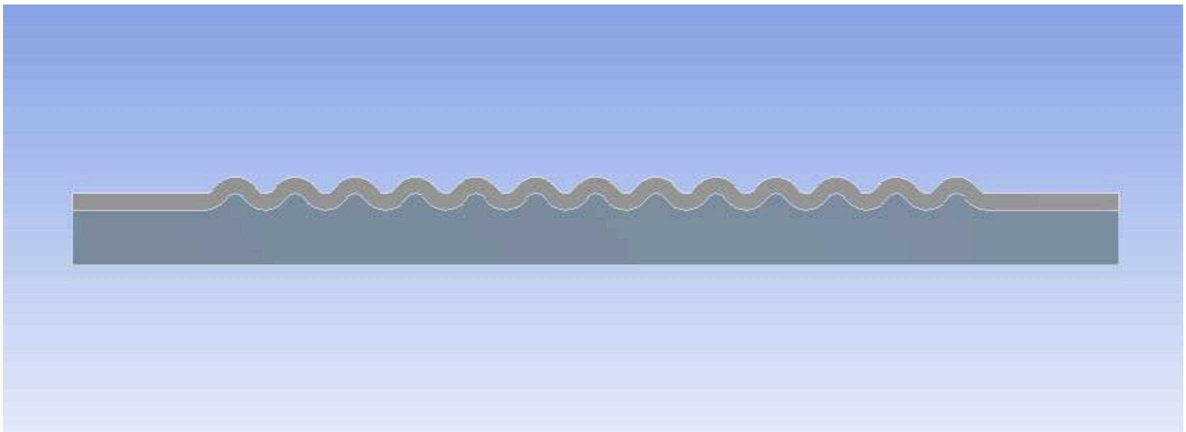


Figure 1 : Schematic diagram of proposed model.

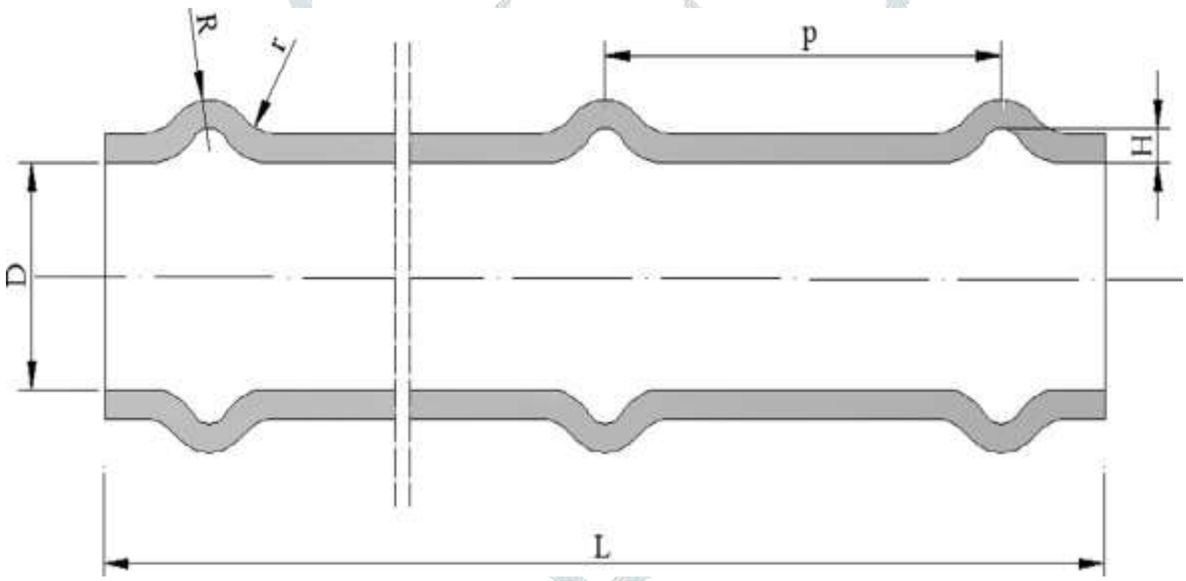


Figure 2 : Diagram of model showing all design parameters.

Following assumptions are used for numerical simulations: helium properties remain constant as given in Table 1; gravitational force is neglected and the flow is incompressible. Two-dimensional axisymmetric model is used for numerical simulation.

A MultiZone Quad/Tri method is used for meshing in order to accurately control size and number of cells in the domain as shown in figure 3. The region near wall represents the most important velocity and temperature gradients and hence, to resolve velocity and temperature boundary layers inflation is given near walls with growth rate of 1.2.

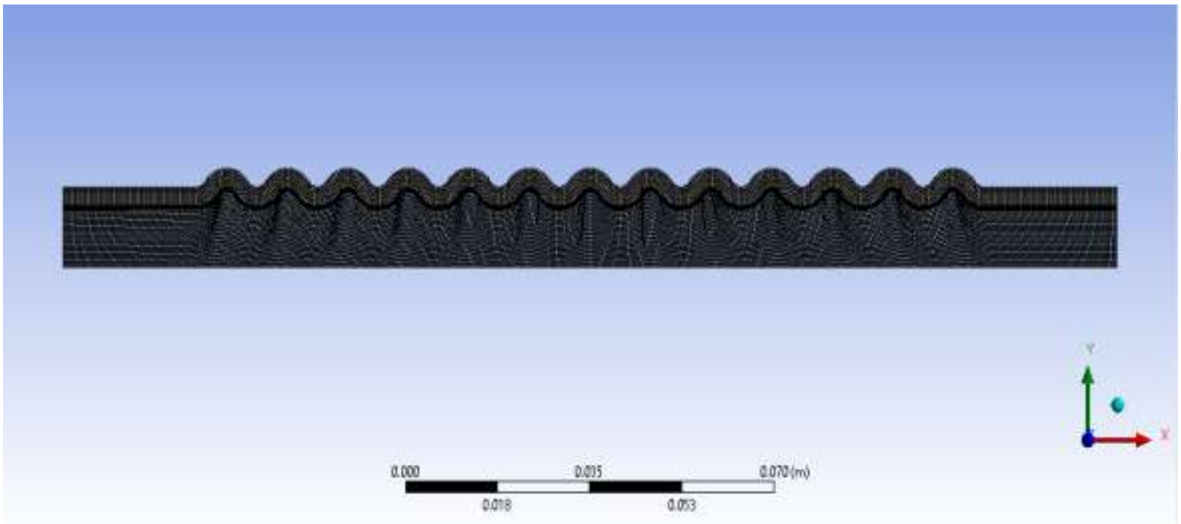


Figure 3 : Schematic diagram of the mesh in the proposed model.

2] Initial conditions and boundary conditions

Following Boundary conditions used for both existing model and proposed model:-

1. Inlet conditions for the tube are:- Inlet velocity Uin = 42 m/s, Inlet temperature Tin = 663.15 K, Turbulent intensity (%) = 5, Turbulent viscosity ratio (μt/μlam) = 5.
2. Outlet conditions for the tube are:- Pressure = 3 MPa, Turbulent intensity (%) = 5, Turbulent viscosity ratio (μt/μlam) = 5.
3. Wall conditions:- A constant wall temperature is applied on outer wall of the tube. No slip boundary condition is applied on the inner wall. Temperature of the wall = 600 K.

Five different profiles in one corrugation are used to capture the different flow and heat transfer characteristics caused by the corrugation pitches as shown in figure 4.

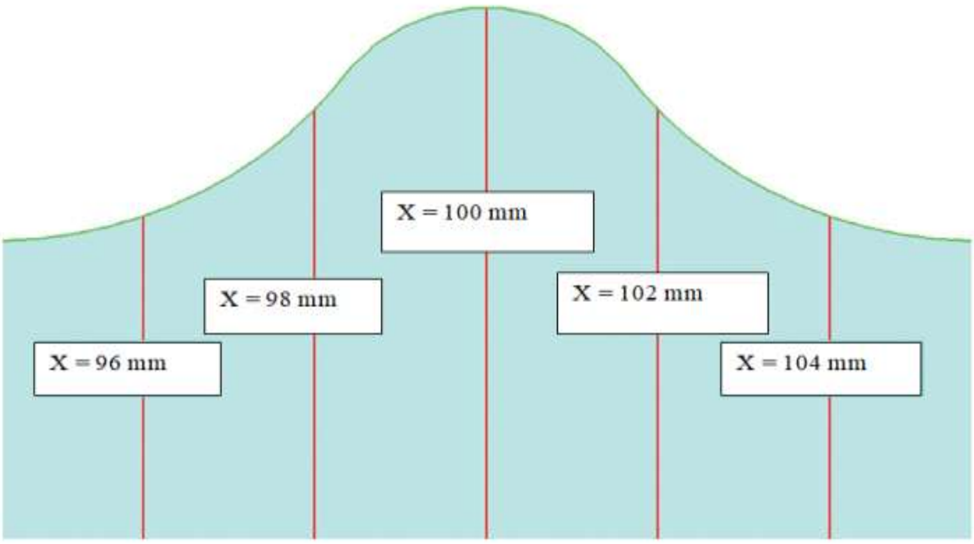


Figure 4 : Schematic diagram of acquired profiles in the corrugated tube.

3] Numerical procedure

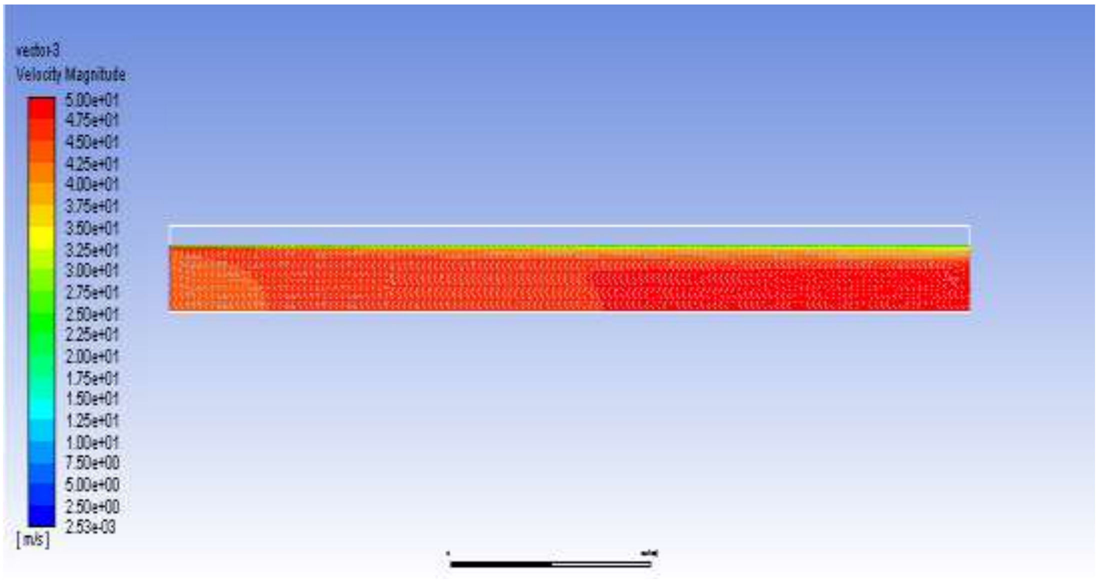
The pressure-velocity coupling is achieved by using SIMPLE scheme. For the momentum and energy equation second order upwind discretization is used. The two-dimensional computations are carried out using CFD package ANSYS FLUENT 18.2.

IV. Simulation results and discussion

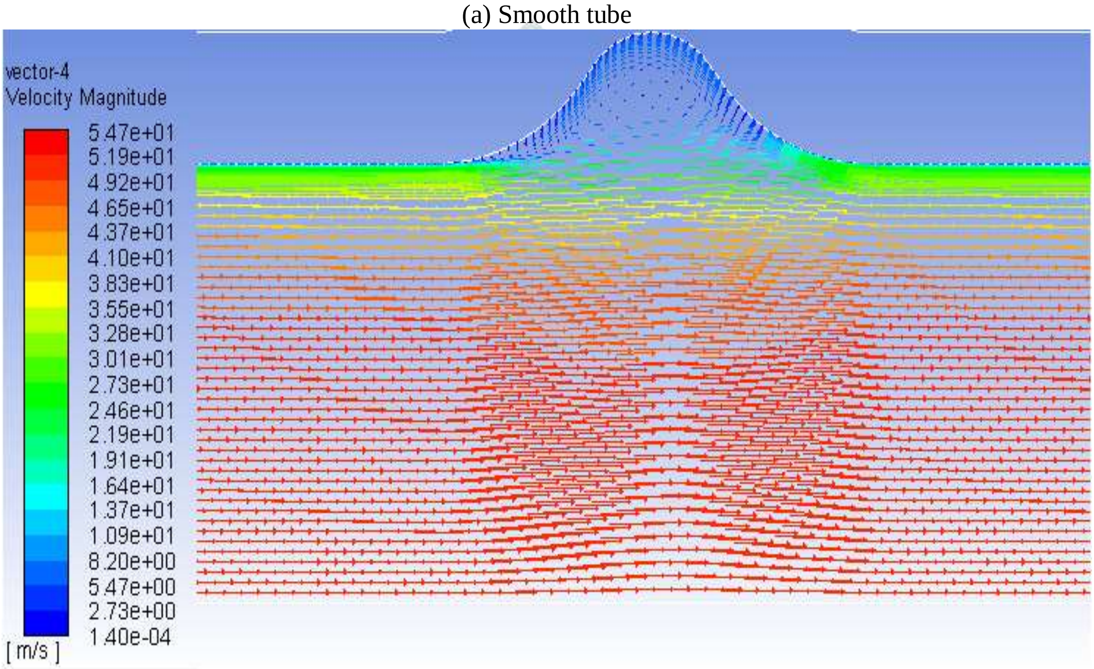
The Reynolds stress transport model with enhanced wall function is used for analysis of both existing and proposed model. Five different models including one smooth tube and four having different corrugation pitches are simulated in ANSYS FLUENT 18.2. The case with parameter set of R = 5 mm, r = 5 mm and H = 3 mm is used to get the plot of velocity vector, temperature contours in the meridional plane which is shown in figure 5 and 6 respectively.

1] Analysis of flow of fluid

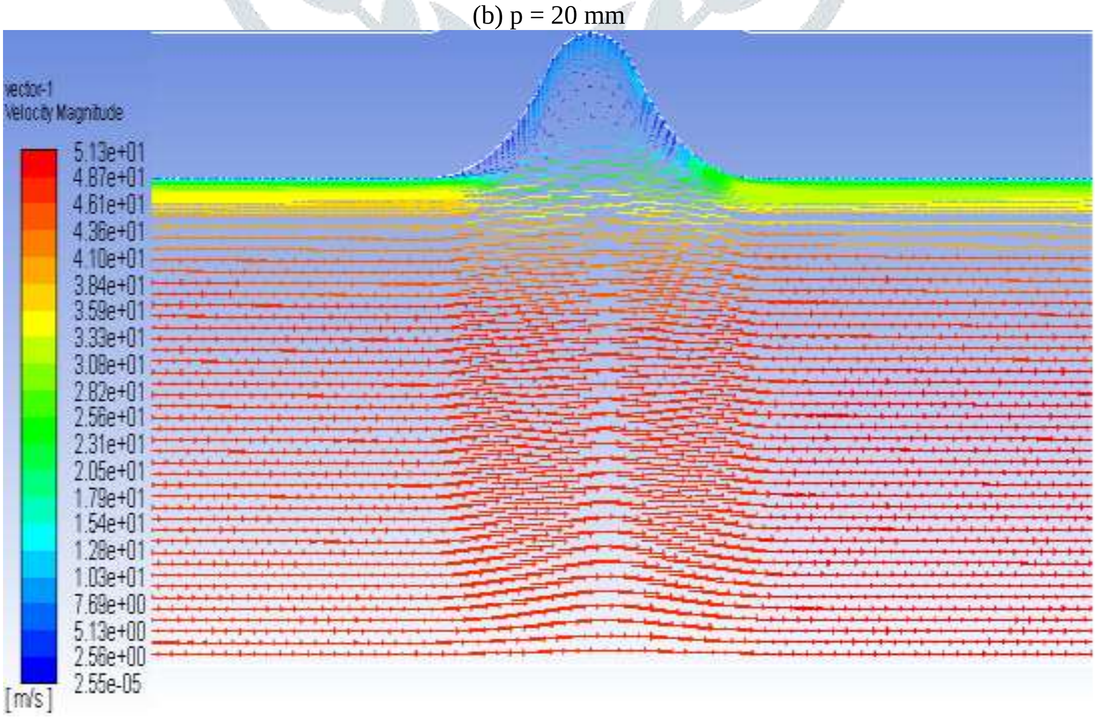
The figure 5 shows the velocity vector distributions in a corrugation for different corrugation pitches.



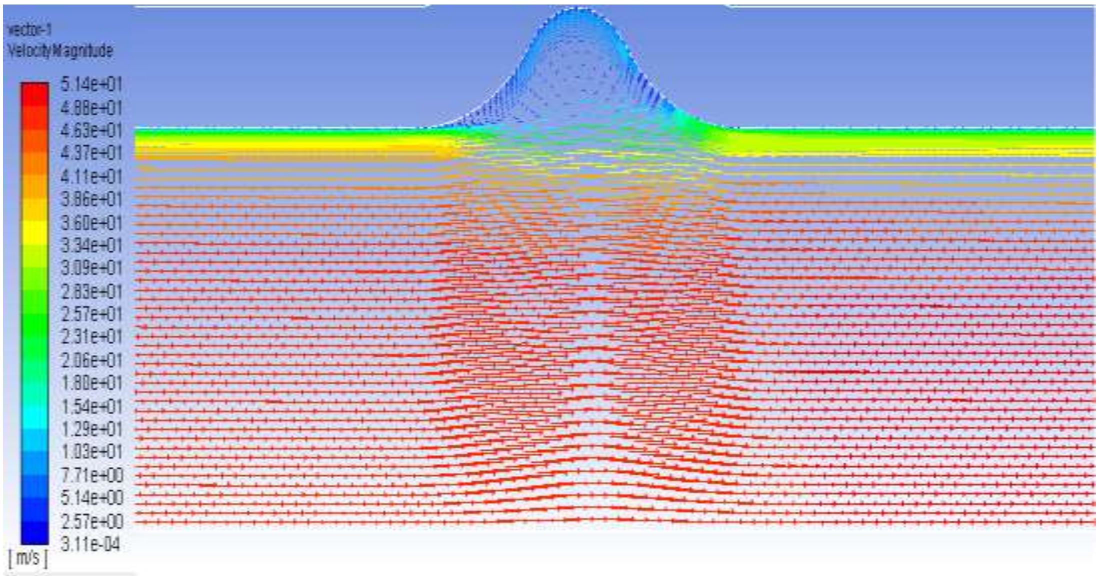
(a) Smooth tube



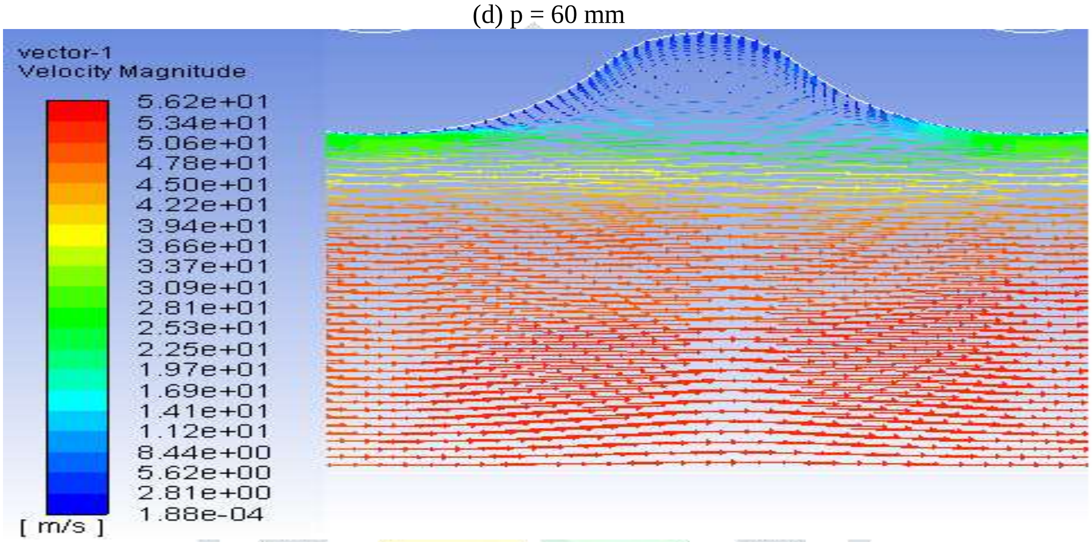
(b) p = 20 mm



(c) p = 40 mm



(d) p = 60 mm



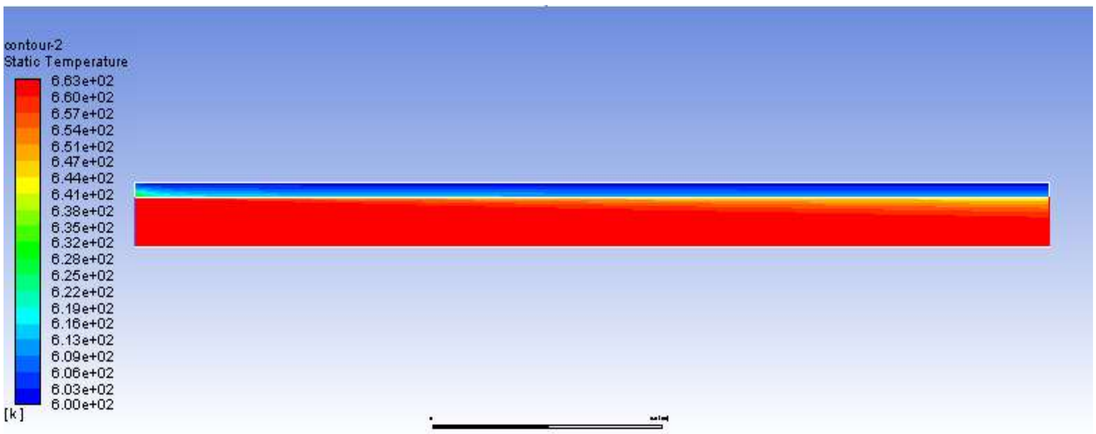
(e) Proposed model

Figure 5 : The velocity vector distributions in a corrugation with different pitches.

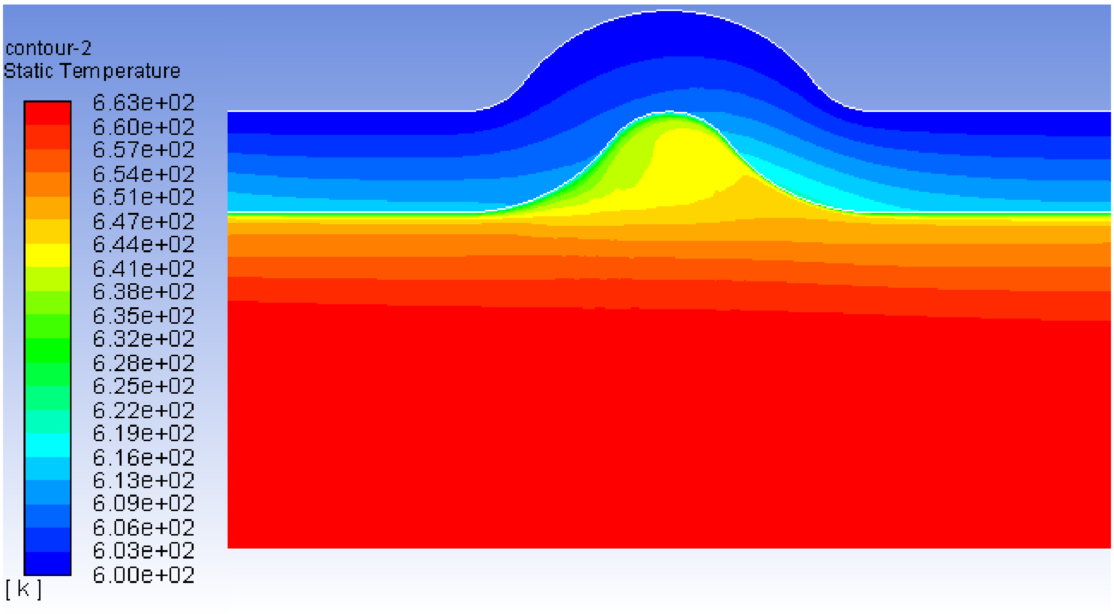
From the figure 5, it can be seen that the main feature in a corrugation is the existence of separated flow. Because of corrugation, there exists boundary layer separation as shown in figure 5. At the separation point, this boundary layer moves away from the surface and forms a free shear layer. At the inflection point of the mean velocity profile, intensity of velocity fluctuations reaches its maximum value. The vortex formed by the mixture at the boundary layer disturbs the flow and thermal fields inside the tube which is the main reason of enhancing the heat transfer rate in the tubes. At the central region of corrugation swirl is formed. A region with very large velocity gradients close to the wall is the indication of redevelopment of the boundary layer during reattachment.

2] Analysis of temperature fields

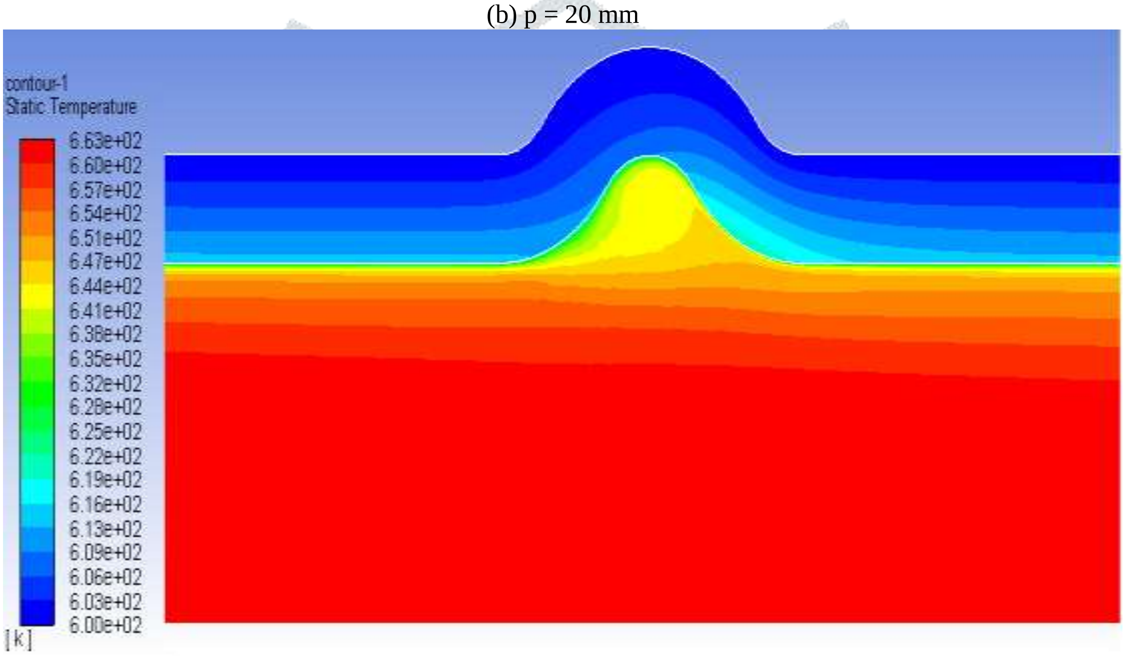
The figure 6 shows distribution of temperature contour for different models.



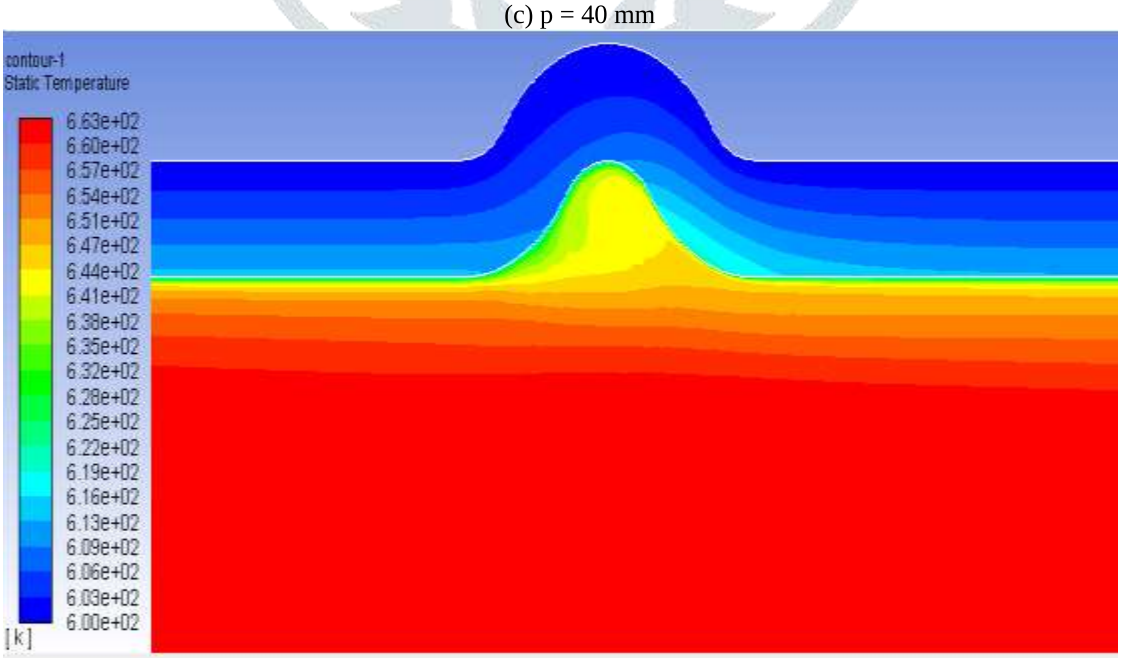
(a) Smooth tube



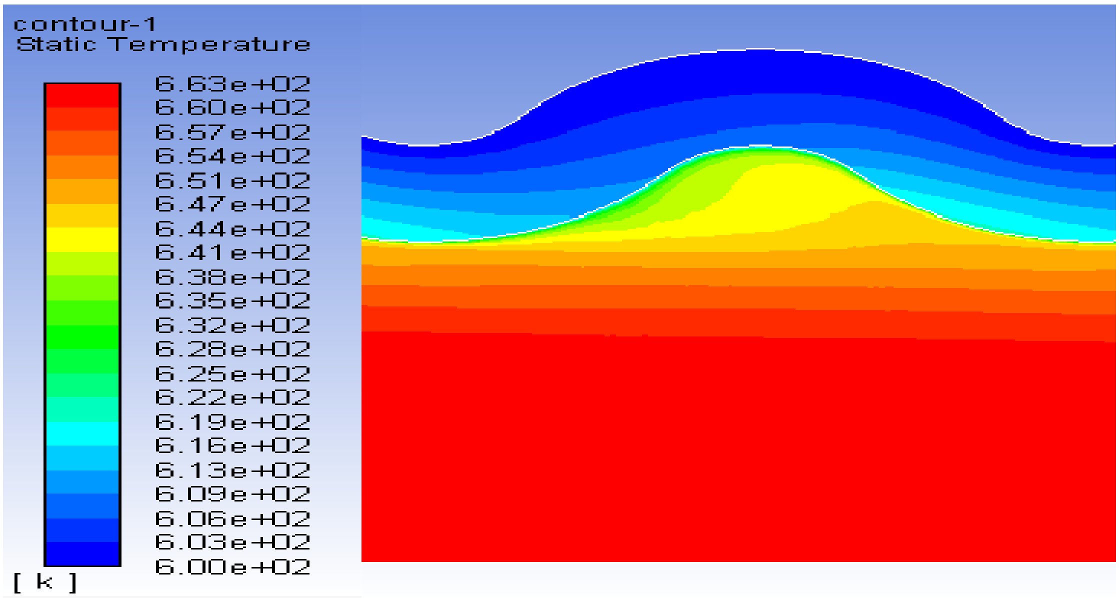
(b) p = 20 mm



(c) p = 40 mm



(d) p = 60 mm



(e) Proposed model

Figure 6 : The temperature contours for different corrugation pitches.

From the figure 6, it can be seen that the thickness of thermal boundary layer changes in the various region of a corrugation. It is thicker in the upstream region, thinner near the wall and again gets thicker in the smooth segment region due to the redevelopment of thermal boundary layer in the downstream region of corrugation. This change in the thickness of boundary layer formation leads to increased heat transfer in the corrugated tube. It can also be seen that the flow pattern and thermal boundary layers are nearly similar for all corrugation pitches. Therefore, the amount of corrugation in a unit length is responsible for the increase of heat transfer performance at various corrugation pitches.

3] Analysis on surface heat transfer coefficient distribution

The figure 7 shows convective surface heat transfer coefficient distribution along the tube wall for different corrugation pitches.

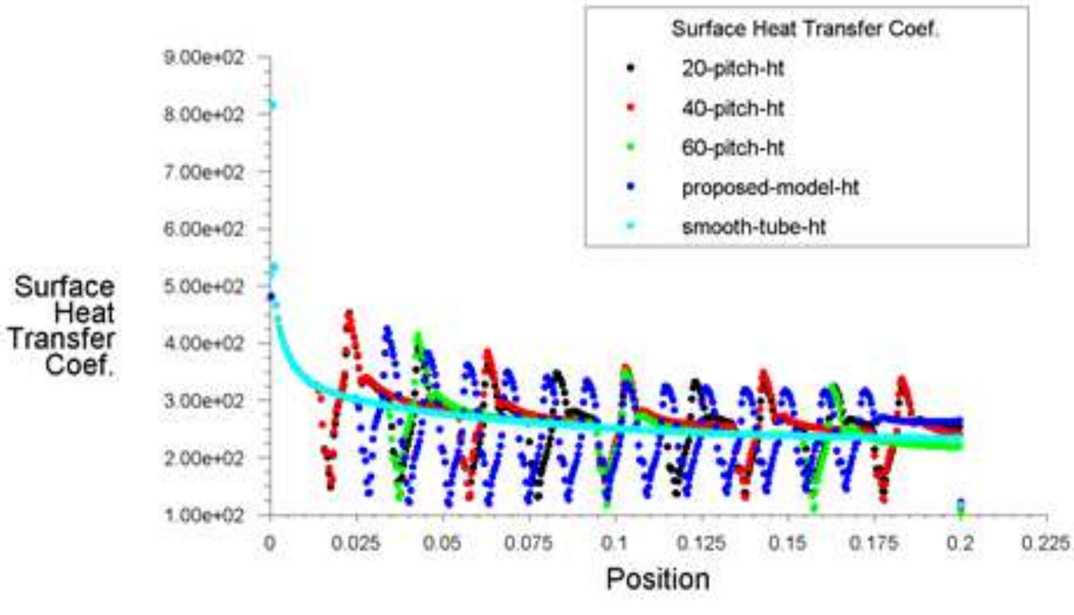


Figure 7 : Surface heat transfer coefficient distribution along the tube wall.

The figure 7 shows significant enhancement in the convective heat transfer of turbulent flow in the proposed model as compared to the smooth tube and other corrugated tube models. Therefore, it is concluded that the enhancement of heat transfer performance in corrugated tube depends upon the number of corrugation within a unit length.

4] Validation and comparison of obtained results

The obtained results of simulation of existing model shows good agreement with that of in research paper of one researcher. In order to achieve the aim of this work that is to achieve the better heat transfer rate the shape of existing model is modified and simulated using same material and boundary conditions. From the above graph of velocity distribution it is concluded that the proposed model shows increase in velocity fluctuations as compared to existing model which is the main reason of enhancement in heat transfer.

V. CONCLUSION AND FUTURE SCOPE

The proposed model shows more flow separation and then the boundary layer reattachment of turbulent flow in the corrugation as compared to the existing model, which results in increase in the Reynolds shear stress and it is the main reason that the proposed model is able to give the better heat transfer performance as compared to the existing model.

As increase in overall efficiency of thermal power plant is very essential; the heat transfer performance in proposed model can also be increased by using dimples, protrusions, fins and increase in height of corrugation.

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