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NUMERICAL PREDICTION FOR FLUID FLOW AND HEAT TRANSFER IN DUCTS USING TWISTED TAPE TURBULATORS

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ABSTRACT

The present work focuses on numerical simulation of the augmentation of laminar flow heat transfer in a horizontal circular tube by means of twist tape inserts with water based cuprous oxide Nano fluid as the working fluid. Computational fluid dynamics (CFD) techniques were also employed to perform optimization analysis of the twisted tape inserts. The horizontal tube along with tube inserts was modelled in STAR CCM+ with fine meshing and analysed using same and the analysis is done for the different cases like 90,45 and 30 degree twist angle of twist insert. CFD analysis was performed initially for plain tube and the results are compared with experimental values for validation.

Key Words: Nano Fluid-CuO, Twisted Turbulators, Heat Transfer Coefficient, Nusselt Number

1. INTRODUCTION

The development of the high performance thermal system has stimulated interest in method to heat transfer. The method of improving heat transfer is referred as heat transfer enhancement or heat transfer augmentation.

Heat exchanger is the apparatus providing heat transfer between fluids and they can be classified according to the mode of flow of fluid or their construction methods. Heat exchangers with the convective heat transfer of fluid inside the tubes are frequently used in many engineering applications. Heat transfer augmentation techniques (passive, active or a combination of passive and active methods) are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. Passive techniques, where inserts are used in the flow passage to augment the heat transfer rate, are advantageous compared with active techniques, because the insert manufacturing process is simple and these techniques can be easily employed in an existing heat exchanger.

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The present work is emphasized in dealing with twisted tape inserts because they are known to be economical heat transfer augmentation tool and water based cuprous oxide Nano fluid because the thermal conductivity of the Nano fluid is good compare to the water. The use of the twisted tape inserts provides simple passive technique for enhancing convective heat transfer by introducing swirl in bulk flow and by disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. It has been explained that such tapes induce turbulence and superimposed vortex motion (swirl flow) causing a thinner boundary layer and consequently resulting in a high heat transfer coefficient and Nusselt number due to repeated changes in the twisted tape geometry.

2. GEOMETRIC MODELLING AND NUMERICAL GRID GENERATION

The required model for the analysis of the present work is modelled in CATIA V5 R19. The below figures shows the circular tubes with twist insert with some standard dimension. In this present work dimension of the twisted insert same for all the different case only the twist angle is changed and circular tube is also changed. The generation of the grid for the present work is done Star CCM+. The generation of the grid is nothing but the discretization of the model. The finesse of the mesh resulting in good numerical results. The meshing is done in Star CCM+ by selecting appropriate element size. Meshing is done individually for all the different cases to compare results and to decide the optimized design. The below figure shows meshed model of the circular tube with the twisted insert for the particular case and same procedure is followed to extract volume and meshing for the other case also.

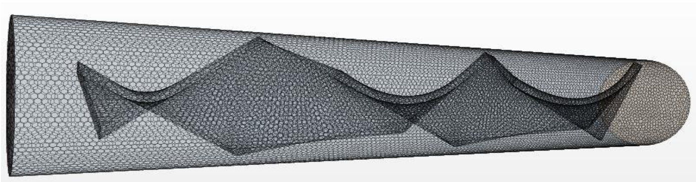

Fig.2.1. Meshed model

3. MATHEMATICAL MODELLING AND NUMERICAL PROCEDURE

These notes will cover the general topic of heat transfer to a laminar flow of fluid that is moving through an enclosed channel. This channel can take the form of a simple circular pipe, or more complicated geometries such as a rectangular duct or an annulus. It will be assumed that the flow has constant thermos-physical properties (including density). We will first examine the case where the flow is fully developed. This condition implies that the flow and temperature fields retain no

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history of the inlet of the pipe. In regard to momentum Conservation, FDF corresponds to a velocity profile that is independent of axial position in the pipe. In the case of a circular pipe, u=u (r) where u is the axial component of the velocity and r is the radial position. The momentum and continuity equations will show that there can only be an axial component of velocity that is zero radial components, and that

$$U(r) = 2u_m\left(1-\left(\frac{r}{R}\right)^2\right)$$

With the mean velocity is given by

$$u_m = \frac{1}{A}\int_A u\,dA = \frac{2}{R}\int_0^R u r\,dr$$

The convection law of internal flow is given by

$$q_s''.h\,(T_s - T_m) = K\left.\frac{\partial T}{\partial r}\right]^R = -K\frac{(T_s - T_m)}{R}\left.\frac{d\bar{T}}{d\bar{r}}\right]^1$$

The governing differential equation for the temperature distribution in the field is given by

$$\rho C_p u.\frac{\partial T}{\partial x} = k.\nabla^2 T = k\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{d^2T}{dr^2}\right)$$

Numerical procedure as follows-

The commercial CFD package STAR CCm+8.02 was used to perform three-dimensional numerical calculations of the plain tube and twisted tape inserts in a constant heat-fluxed tube using the following governing equations.

(1) Continuity equation for an incompressible fluid:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho\bar{\upsilon}) = S_m.$$

The above equation is the unsteady, three-dimensional mass conservation or a continuity equation at a point in a compressible fluid. The first term on the left-hand side is the rate of change of density with time. The second term describes the net flow of mass out of the element across its

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boundaries and is called the convective term. For an incompressible fluid (i.e. a liquid) the density ρ is constant and the above equation becomes

$$\mathrm{Div}\ \bar{\upsilon} = S_m .$$

3.1 CONSERVATION OF MOMENTUM:

Newton's law of motion states that the rate of change of momentum is equal to the sum of all the forces acting on the fluid particle. That is Rate of increase of momentum on fluid particle is equal to the sum of all the forces acting on the fluid particle. The forces acting on the body are of two types. They are. Surface force and Body force

$$\frac{\partial \upsilon}{\partial t} + \rho\,(\bar{\upsilon}.\nabla)\bar{\upsilon} = -\nabla P + \rho\bar{g} + \nabla\tau_{ij} + \vec{f}$$

3.2 CONSERVATION OF ENERGY:

The energy equation can derive from the First law of thermodynamics, which states that the rate of change of fluid particle is equal to the rate of work done on the fluid particle and heat addition to the fluid particle.

$$\rho\frac{\partial}{\partial t}(\rho E) + \nabla\{\vec{U}(\rho E + \rho)\} = \nabla\{K_{eff}\nabla T - \Sigma h_i(\overrightarrow{\tau_{eff}}.\vec{U}) + S_h$$

The commercial CFD package Star ccm+8.02 was used to solve the above mentioned governing equations based on the defined boundary conditions. The solution sequential algorithm (segregated solver algorithm) has been chosen for this study and solver setting includes implicit formulation, steady (time independent) calculation, viscous laminar model, and energy equation. The SIMPLE algorithm has been selected as the pressure-velocity coupling method and the first-order upwind scheme was used for the energy and momentum equations solution.

4. RESULT AND DISCUSSIONS

This section presents the computational results for flow through a circular tube with and without twisted insert. All the simulations were carried out using CFD commercial software Star CCM+ 8.02. The objective of these computations is primarily to understand the proper flow of water and water based CuO fluid in circular tube with and without twisted insert and to see the temperature distribution and velocity of flow.

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The flow through a circular tube with twisted insert has been analysed in different cases and computational results of these cases are discussed here. Temperature contour and velocity contour at Reynolds number 2000 of all cases are presented and discussed with appropriate explanation.

4.1 Circular tube with water:

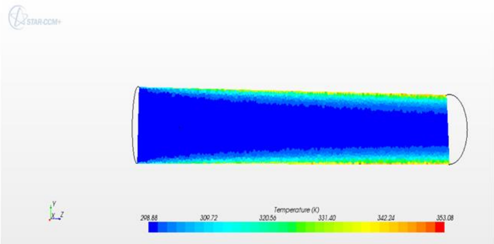

Fig 4.1.1: Temperature contour at Reynolds number 2000

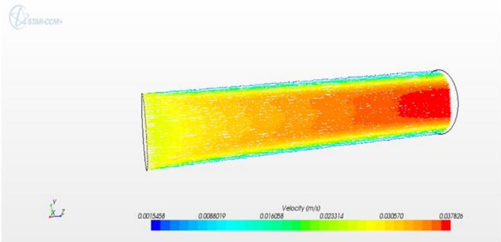

Fig 4.1.2: Velocity contour at Reynolds number 2000

The test has been conducted using water as fluid with its default properties and applied appropriate boundary conditions. After extracting the fluid volume from circular tube, the cut section was extracted to see the proper flow fluid and temperature distribution in the fluid domain and set the convergence criteria to find heat transfer rate in the domain.

4.2 Circular tube with water based CuO Nano-Fluid:

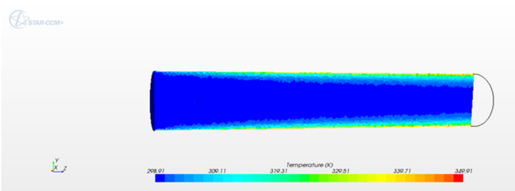

Fig 4.2.1: Temperature contour at Reynolds number 2000

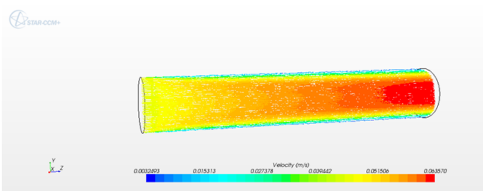

Fig 4.2.2: Velocity contour at Reynolds number 2000

The same above test has been reconducted using water based CuO Nano-fluid to check the flow and to check the convergence criteria to find heat transfer rate in the domain.

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4.3 Circular tube with water based CuO Nano-Fluid and Twisted Insert:

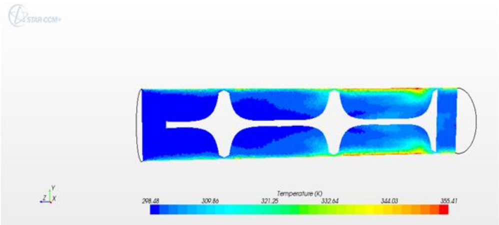
Fig 4.3.1: Temperature distribution Contour

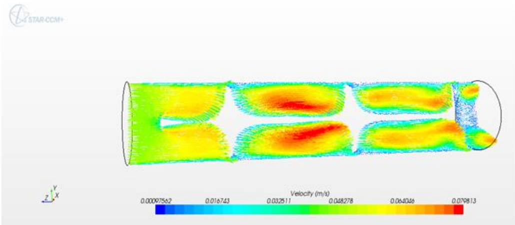
Fig 4.3.2: Velocity distribution Contour

As we can see from the figures 4.3.1 and 4.3.2 insertion of Twisted Tape Turbulators in the flow passage increases the fluid residence during the flow. This creates the boundary layer and increases the rate of fluid flow. Since we used Nano-fluid in this work which is having a enhanced property compared to water, this case gives more enhanced heat thranfer coefficeint for Reynolds Number of 2000.

The heat transfer comparison has been made for the Numerical results obtained for all the cases keeping the Reynolds number of 2000 is shown below in the below figure 4.3.3. In the below graph the maximum heat transfer for the Reynols number 2000 is obtained in 90 degree angle of twist (Different Twist Configurations).

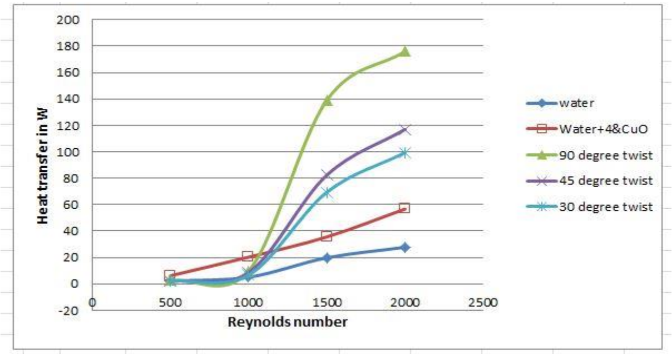

Fig 4.3.3. Heat Transfer V/S Reynolds number

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The Nano fluid gives the better results in comparing to the Water because of the good thermal properties. For the given mass flow rate of water and water based Nano fluid property, we can compare the Heat transfer results is as shown in figure 4.3.4.

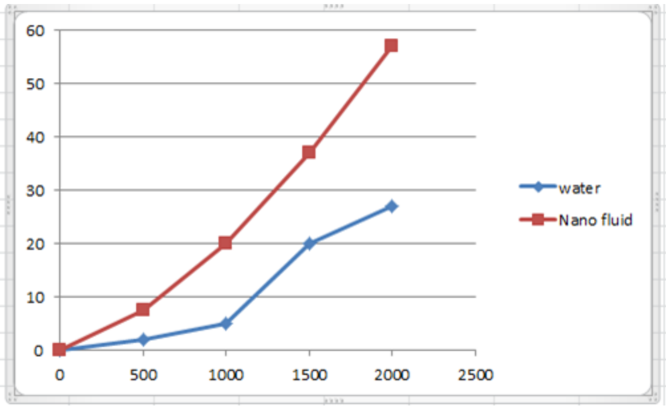

Fig.4.3.4 Heat transfer comparison between water and CuO Nano-Fluid

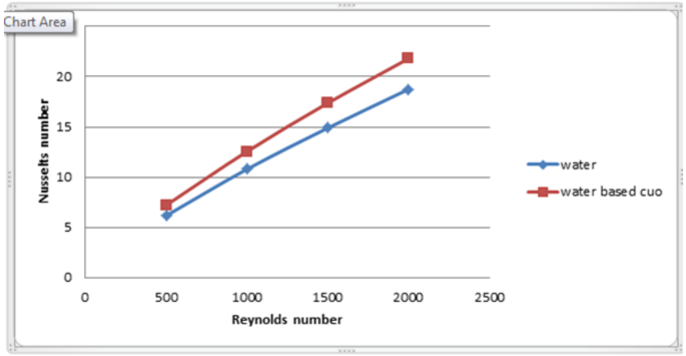

Fig 4.3.5. Nusselts number V/S Reynolds number

The thermal conductivity of the water based Cuprous oxide Nano fluid is higher compared to that of water because Nusselts number will be good for Nano fluids as compare to water is as shown in figure 4.3.5.

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5. CONCLUSIONS

Based on simulation results obtained, the following conclusions are drawn:

- Instead of using water in the heat exchanger can use water based cuprous oxide Nano fluid as working fluid which yields better result in heat transfer rate for the given mass flow rate.
- Because of using the twisted tabulators in the heat exchanger will create turbulence in the flow field. Hence good heat transfer rate can be obtained
- Based on our simulation results we can conclude that 90^0 twisted insert is the optimized design which gives a better heat transfer rate as compared to the other twisted insert like 45^0 and 30^0V.

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