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Thermal Analysis of flow through Serpentine Tube in Tube Heat Exchanger

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Abstract:*The serpentine tube in tube arrangement is very effective for various applications such as heat exchanger and chemical reactors thermal power plant etc. This serpentine tube in tube arrangement can provide accommodations a large passive type heat exchanger. During heat transfer, area in small space with high heat transfer coefficients due to these arrangements. This study deals with the analysis of heat transfer for flowing fluid through tubes using experimentally and Computational Fluid Dynamics. The experimental and computation results are compared with numerically and the temperature contours, the effectiveness and nusselt number of heat exchangers are calculated and plotted. For the construction of serpentine tube, copper is choosing. Water is flowing through the inner tube and also at the outer shell of the serpentine tube in tube heat exchanger. In this precise study, an effort is made to evaluate the effect of counter flow only.*

I. Introduction

The heat transfer happens by three principles: 1) Conduction 2) Convection 3) Radiation etc. Heat transfer through a heat exchanger due to radiation is not considered and it is negligible compare with conduction and convection. The heat transfer take lace due to conduction by fluid is flowing through a nearby solid wall. By go for a least thickness of wall of a very conductive material the conductive heat transfer is maximized. But convection plays a major role in transfer of heat through a heat exchanger.

In the heat exchanger enactment augmentation of heat transfer is better technique. The aim of energy saving and to make a compact design for mechanical and chemical industries and process plants etc. The important feature of designing a heat exchanger is improvement in heat transfer.

The enhancement technique in heat exchanger is generally divided in two types.

1. Passive technique
2. Active technique

In the passive technique the improvement in heat transfer rate does not require any external energy or source. By the adapting the geometrical change in exchanger, by altering appearance of surface or flow modification, by supplements or extra devices which increases the heat transfer rate in heat exchanger. For example: Additives for gases, displaced enhancement devices, extended surfaces, swirl flow devices, Coiled tubes, treated surfaces, rough surfaces, and additives for liquids.

In the active technique the improvement in heat transfer rate is require some external energy or source. For example Jet impingement, Fluid vibration, Surface vibrations, Electrostatic fields (DC or AC), Mechanical aids.

Serpentine Tube in Tube Heat Exchanger :Enlargement in heat transfer due to serpentine pipe is stated by many investigators, great available experimental or theoretical study of a serpentine tube heat exchanger bearing in mind fluid-to-fluid heat transfer are obtainable. Heat transfer appearances intimate a serpentine tube for several boundary conditions are measured. The heat exchanger is examined as conjugate heat transfer and temperature needy properties of heat transport media.

Problem Statement: To study and examined the serpentine tube in tube heat exchanger, which arrangements with the study of heat transfer region and estimate quantity of heat transfer between two fluids. Copper is used as tube material, and determine the amount of heat transfer for the definite materials considering several properties. Altered systems will be used for various outcomes for thermal parameter for checking the extent of heat transfer such as experimental method and numerical method by CFD analysis etc.

Calculate all thermal parameters through experimentally for specially design compact heat exchanger and find the maximum heat transfer rate by making proper inlet and outlet temperature and flow rate through exchanger. On other hand calculate thermal parameters also by numerically. The temperature range from 25-

700C considered without phase change process and heat transfer is sensible heat. So these things are to be considered.

II. Experimental Setup

The trial set up is shown in fig. 1 and set up is properly set for counter flow arrangement and also for parallel flow arrangement.

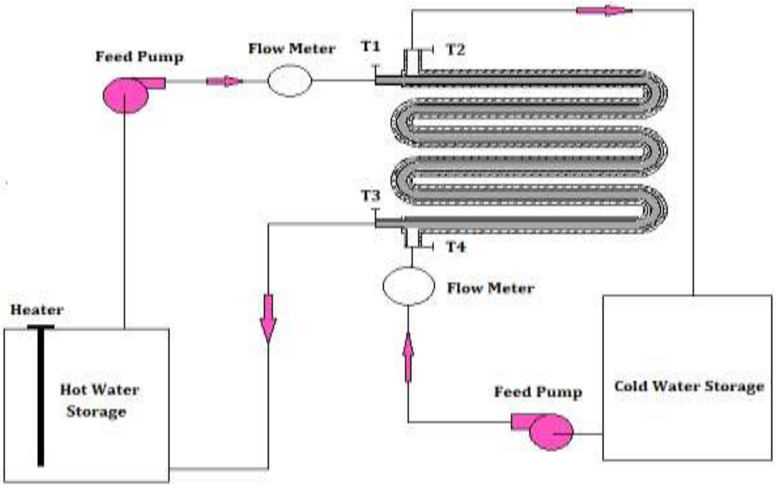

Fig. 1 Experimental rig

Set the bulk flow rate of both cold water and hot water to a suitable computing instrument. Using a digital thermometer, measure the inlet and exit temperature of hot and cold water and remarks are noted and outcomes are estimated. The graphs are planned to permit to the attained results. Dimensional parameters of serpentine tube in tube heat exchanger is shown in Table 1 as follows,

Table 1 Dimensional parameters of serpentine tube in tube heat exchanger

Sr No.	Dimensional Parameter	Dimension (mm)
1	Inner diameter of tube	12.7
2	Outer diameter of tube	12.8
3	Inner diameter of shell	38.1
4	Outer diameter of shell	38.4
5	Length (L)	460

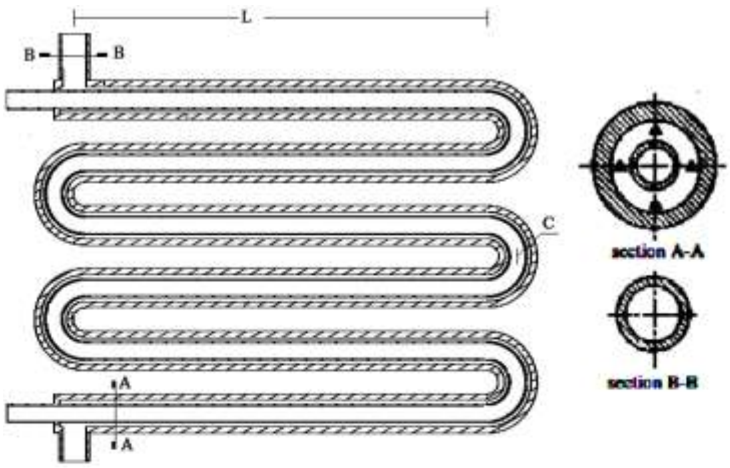

Fig. 2 Schematic diagram of serpentine tube in tube heat exchanger

The experiment is to be carried out on the different series of flow rate and results are collected. Fig. 2 illustrates the presentation of the serpentine tube in tube heat exchanger. The experiment is to be carried out on deciding on proper values, and also the assessment is to be taken concerning the approach of heat transfer.

III. Mathematical Analysis

Analytical Calculations: As flow geometry involve different correlation be used to achieve heat transfer coefficients and calculations of Nusselt number is carried out using this relationship given by Keys Xin and Roger for curved pipe arrangement Correlation is given by Roger is as follows,

$$\mathrm{Nu} = 0.023\mathrm{Re}^{0.84}\mathrm{Pr}^{0.4}\,\partial^{0.1} \tag{1}$$

For Re > 2000

In curved pipes, the heat transfer coefficient inside the tube in the presence of heat transfer, the various empirical correlations proposed in the numerous literatures is chosen the most widely used being that by Xin and Ebadian. An empirical correlation is developing by Xin and Ebadian for the average fully developed flow, using this, estimate the heat transfer coefficient inside a curved tube. The correlation as follows,

For Laminar flow,

$$\mathrm{Nu} = (2.153 + 0.318\mathrm{De}^{0.643})\mathrm{Pr}^{0.177} \tag{2}$$

$20 < De < 2000$, $07 < Pr < 175$, $0.0267 < \delta < 0.088$

For turbulent flow,

$$\mathrm{Nu} = 0.00619\mathrm{Re}^{0.92}\mathrm{Pr}^{0.4}(1 + 3.455\,\delta) \tag{3}$$

$5\times103 < Re < 105$, $0.7 < Pr < 5$, $0.0267 < \delta < 0.0884$

In the calculation the heat transfer coefficient at ho based, the empirical correlation is given by Keys is applied in Incropera and Dewitt as follows,

$$Nu = 3.66 + \frac{0.0668\left(\frac{D}{L}\right)Re\,Pr}{1+0.04\left[\left(\frac{D}{L}\right)Re\,Pr\right]^{2/3}} \tag{4}$$

The Effectiveness of heat exchanger is calculated as,

$$\varepsilon = \frac{Q}{Q_{max}} = \frac{C_h(T_{h1}-T_{h2})}{C_{min}\,(T_{h1}-T_{c1})} = \frac{C_c(T_{c2}-T_{c1})}{C_{min}\,(T_{h1}-T_{c1})} \tag{5}$$

IV. Numerical Calculations

Steady state implicit pressure based solver using Ansys15 environment is being allowed for the numerical solution. For steady state streams for mass and momentum are explained by the major partial differential equations. Using second order up wind scheme, the discretization is complete. Mean Flow Equations are presented in Cartesian tensor notation as follows,

Continuity equation,

$$\frac{\partial}{\partial x_i}(\rho V_i) = 0 \tag{6}$$

Momentum Equation,

$$\frac{\partial}{\partial x_i}\left(\rho V_i V_j\right) = \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial V_i}{\partial x_j}\right) + \left(\frac{\partial V_j}{\partial x_i}\right)\right] - \rho\overline{v_i v_j} \tag{7}$$

Energy Equation,

$$\frac{\partial}{\partial x_i}(\rho\, V_i T) = \frac{\partial}{\partial x_j}\left[\frac{\mu}{Pr}\frac{\partial T}{\partial x_j} - \rho\, V_i\, t\right] \tag{8}$$

The geometric model of the serpentine tube was constructed using workbench in ANSYS 15 environment. Three-dimensional computational domain modeled is shown in fig. 3. And this geometry is mesh by using hexagonal mesh is as shown in fig. 4. Initially a reasonably coarser mesh is made. The whole domain of serpentine tube consists of ≈7.8 lakes elements and straight tube consists of ≈5.6 lakes elements. For checking the validity of the quality of the mesh in the results are achieved by grid independent test. Further adaptation did not alter the results by more than 0.87% which is occupied as the applicable mesh quality for computation.

A boundary condition such as constant wall temperature is executed on the wall of the tube. Fluid is ready to become cold as it flows through the tube by isolating a wall temperature of 300 K. Pressure outlet boundary conditions are applied at the outlet of both hot and cold fluid. Conservation calculations were committed for the control volume to capitulate water flow in the tube for velocity and temperature fields.

There is two inlet condition and two outlet condition because here two tubes are used. Copper is separated two fluid flows. The inner fluid is taken as hot liquid flow and outer fluid as cold liquid flow.

Boundary Conditions: Boundary condition is used permitting to the requisite of the model as mass flow inlet and pressure outlet is well defined at inlet and outlet condition of the hot and cold fluid. The walls are independently identified with corresponding to boundary conditions. No slip condition is deliberated for every single wall. Zero heat flux condition is established at respective wall with the exception of the inner tube wall. The above table demonstrations all boundary condition.

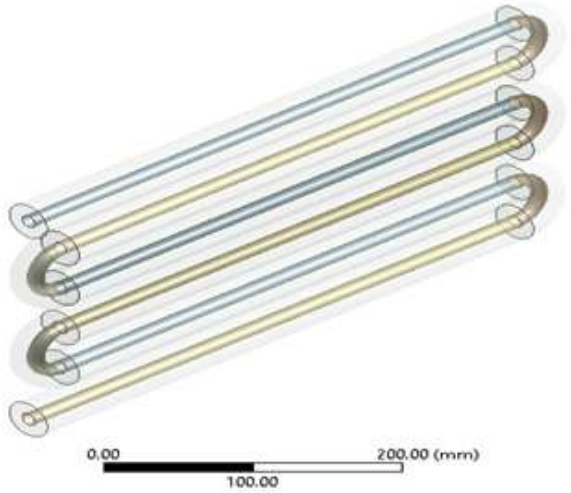

Fig. 3 3D computational domain modeled

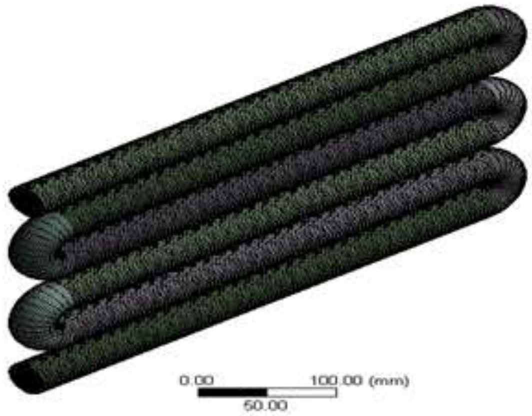

Fig. 4 Mesh modeled

Table2 Boundary conditions

	HotInlet	HotOutlet	ColdInlet	ColdOutlet
Boundary Condition Type	Mass Flow Inlet	Pressure Outlet	Mass Flow Inlet	Pressure Outlet
Mass Flow Inlet (kg/s)	0.01-0.03	-	0.05	-
Temperature (k)	333	-	300	-
Turbulent Kinetic Energy (m^2/s^2)	0.01	-	0.01	-
Turbulent Dissipation Rate (m^2/s^2)	0.1	-	0.1	-

Table-4 Properties of the Copper

Description	Density	Specific heat capacity	Thermal conductivity
Value	8978 kg/m^3	381 J/kg-K	387.6 W/m-K

V. Result And Discussions

Fig. 5 illustrates the effect of Reynolds number on Nusselt number. While calculating Nusselt number a different scientist gives correlations to deliberate various parameters. Hence, five different curves for each correlation were plotted. From above graphs for same Reynolds number, it can be seen that a value of the Nusselt number given by Xin and Ebadian for a curved tube arrangement and is higher than straight tube arrangement. According to Roger, for calculation of nusselt number they consider the curvature rations and its results are increased heat transfer due to secondary turbulence occurs at curvature. Thus, the values given by Roger are considered for comparison.

The schematic diagram of experimental setup is shown in Fig.-2. The setup is a well instrumented single phase heat exchange system with a hot water stream flowing inside the tube side is cooled by a cold water stream flowing in the shell side. The main parts of the system are tube in tube heat exchanger, centrifugal pump, storage tank, and heater. The heat exchangers include a copper tube and an insulated shell. The dimensions of the heat exchangers are illustrated in table - 1. The water in storage tank is heated using an electric heater. Reaching to a prescribed temperature, pump is started to circulate the hot water in the system.

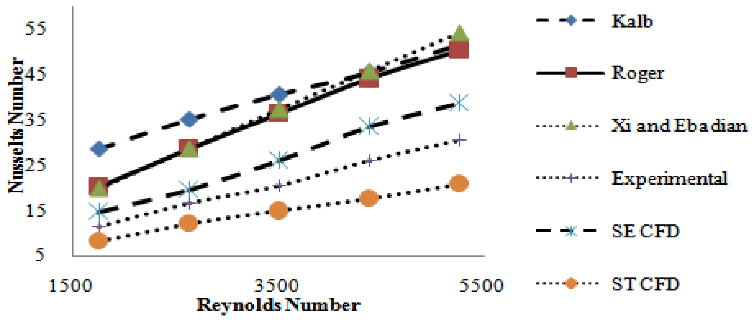

Fig. 5 Reynolds number vs Nusselt number

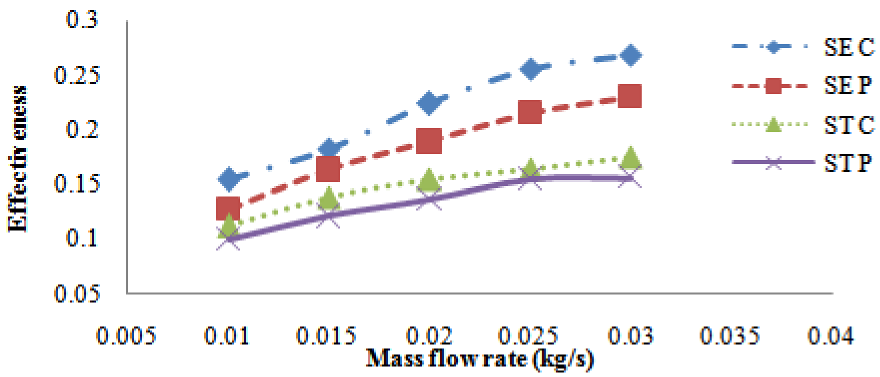

Fig. 6 Mass flow rate Vs Effectiveness for 0.05 kg/s cold fluid flow

fig.- 7 represent variation of mass flow rate over overall heat transfer coefficient for counter flow heat exchanger.

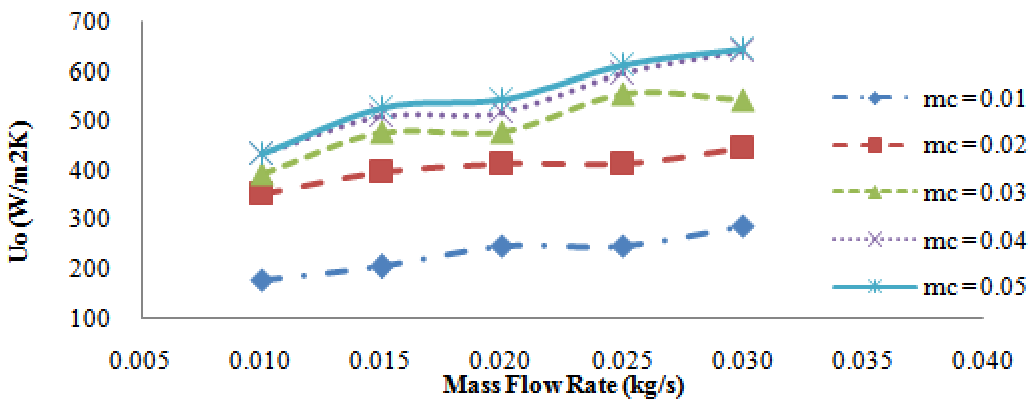

Fig. 7 Mass flow rate vs Uo counter flow

As the mass flow rate of hot water increases the average heat transfer rate increases gradually for each corresponding mass flow rate of cold water when it is kept constant for set of five readings. From fig.- 8 Where represent variation of mass flow rate over length through serpentine tube and straight tube in counter flow heat exchanger respectively.

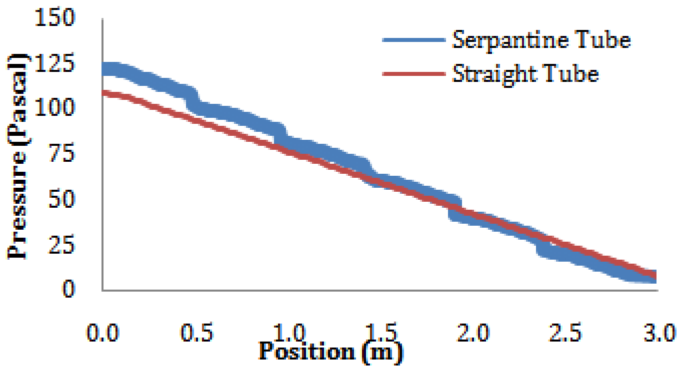

Fig. 8 Variation of total pressure in serpentine tube and straight tube

Fig. 9 and 10 illustrate temperature distributions in a serpentine tube and straight tube with a counter. This shows temperature is reducing more at curved section than a straight one.

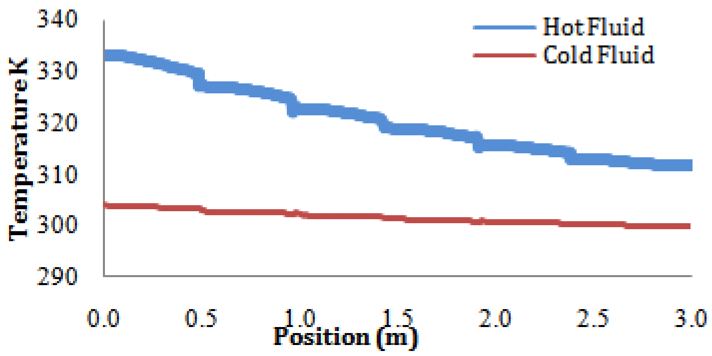

Fig. 11 Temperature distributions in serpentine tube with counter flow

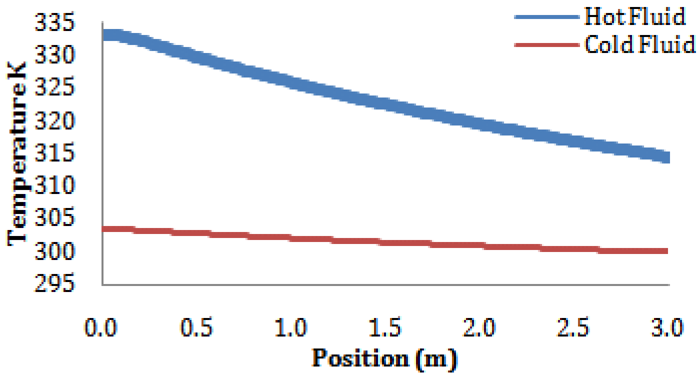

Fig. 12 Temperature distributions in straight tube with counter flow

VI. Conclusions

An intensity of secondary flow developed goes on increasing within curvature ratio based on the experiments. This increase in turbulence causes major mixing of fluid inside the tube which increases heat transfer coefficient. Heat transfer is attained at the out flow of pressure drop over a length higher in the serpentine tube in tube heat exchanger than the straight tube in tube heat exchanger tolerable limits as per previously research in a parallel field.

The study offered that there is an excessive alteration in the heat transfer enactments of the serpentine tube configuration over straight tube configurations. From the numerical data, Nusselt numbers at different points along the tube length are determined. The model was carried out for fluid to fluid heat transfer features and at a different inlet temperature, Nusselt number for the serpentine tubes is established to be changing from 3-100.

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