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CFD analysis of heat transfer enhancement in double pipe heat exchanger using single and double triangular tape as inserts

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ABSTRACT

The need to increase the thermal performance of heat transfer equipment (for instance, heat exchangers), 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. 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 were obtained first for the smooth pipe and then for the pipe with a single/double triangular tape insert in the Reynolds number range and Prandtl number. Calculated values (obtained from empirical equations available in literature) were compared with CFD values. Comparisons were also made between the smooth tube results and the single/double triangular tape results to establish the heat transfer augmentation due to the use of the insert. Simulations were carried out using commercial CFD software ANSYS.

Keywords— *Heat transfer, Double pipe heat exchanger, CFD analysis*

1. INTRODUCTION

The heat exchanger is a device that exchanges the heat between two fluids of different temperatures that are separated by a solid wall. The temperature gradient or the differences in temperature facilitate this transfer of heat. Transfer of heat happens by three principal means radiation, conduction and convection. In the use of heat exchangers, radiation does take place.

However, in comparison to conduction and convection, radiation does not play a major role. Conduction occurs as the heat from the higher temperature fluid passes through the solid wall. To maximize the heat transfer, the wall should be thin and made of a very conductive material. The biggest contribution to heat transfer in a heat exchanger is made through convection.

The double-pipe heat exchanger is one of the simplest types of heat exchangers. It is called a double-pipe exchanger because one fluid flows inside a pipe and the other fluid flows between that pipe and another pipe that surrounds the first. This is a concentric tube construction.

Flow in a double-pipe heat exchanger can be co-current or counter-current. There are two flow configurations: co-current is when the flow of the two streams is in the same direction, countercurrent is when the flow of the streams is in opposite directions.

Conditions in the pipes change: inlet temperatures, flow rates, fluid properties, fluid composition, etc., the amount of heat transferred also changes. This transient behavior leads to a change in process temperatures, which will lead to a point where the temperature distribution becomes steady. When heat is beginning to be transferred, this changes the temperature of the fluids. Until these temperatures reach a steady state their behavior is dependent on time.

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In this double-pipe heat exchanger, a hot process fluid flowing through the inner pipe transfers its heat to cooling water flowing in the outer pipe. The system is in a steady state until conditions change, such as flow rate or inlet temperature. These changes in conditions cause the temperature distribution to change with time until a new steady state is reached. The new steady state will be observed once the inlet and outlet temperatures for the process and coolant fluid become stable. In reality, the temperatures will never be completely stable, but with large enough changes in inlet temperatures or flow rates, a relatively steady state can be experimentally observed.

2. PROBLEM DEFINITION

2.1 Problem Definition

To obtain optimum heat transfer rate for a pipe heat exchanger by using triangular tape insert with the following cases:
(a) A heat exchanger using single tape insert
(b) A heat exchanger using double tape insert
(c) A heat exchanger using without tape insert

2.2 Objective of the project

Enhancement of heat transfer in a heat exchanger is widely applied in industries due to the need for a more compact heat exchanger, a lower operating cost, energy saving as well as ecological benefit. Among many heat transfer enhancement techniques, utilization of perforated twisted tape and delta-wing/delta-winglet vortex generators is a promising method. The approach possesses not only an effective heat transfer enhancement but also the advantage of a low cost and ease of installation. Heat exchangers with different tapes configuration have been used as heat transfer enhancing devices in heat exchangers. The important effects induced by the tapes inserted are:
(a) Turbulent flow which improves fluid mixing.
(b) An increased heat transfer area.
(c) An increase in the heat transfer coefficient.
(d) Reduction of cost in industrial sectors.
(e) Reduction in the size of the heat exchanger.

All the effects mentioned above are directly responsible for the improvement of heat transfer within the heat exchanger. And for these reasons, this experimental research work has been chosen.

2.3 Aim of the work

The main goal of these researches is to reduce the thermal resistance and improve the performance of thermal devices. Among various studies, passive heat transfer enhancement using twisted tapes have significantly shown good results. In our study, we developed a numerical facility to observe the heat transfer properties for forced convection heat transfer through the circular tube with different tape geometries used as an insert where the fluid was passed at various flow rates.

3. METHODOLOGY

3.1 Basic Approach to using CFD

Computational Fluid Dynamics is used as a tool for evaluation of the solution of fluid flow problems by means of computer simulation. It involves a set of partial differential equations describing conservation laws for transport of mass, momentum and energy.
(a) Identify the process or equipment to be evaluated.
(b) Represent the geometry of interest using CAD tools.
(c) Use the CAD representation to create volume a volume flow domain.

3.1.1 Flow phenomena: Create a computational mesh in the flow domain

3.1.2 Solver

(a) Identify and apply conditions at the domain boundary.
(b) Solve the governing equations on the computational mesh using analysis software.

3.1.3 Pre-processor

(a) Interpreting the results Post-process, the completed solutions to highlight findings.
(b) Interpret the prediction to determine design iterations or possible solutions, if needed.
(c) Analysis and display of results.

3.2 Mathematical Model

In order to simulate the flow and heat transfer characteristic of Double pipe heat exchanger, k-ε RNG turbulence model with enhanced wall heat treatment is used. Considering some simplifying assumptions, the mechanism which governs the fluid flow and heat transfer is due to conservation of mass, momentum and energy. The energy and turbulence model is considered for capturing the fluid flow and thermal behaviour of Double pipe heat exchanger. These assumptions and equations for incompressible flow are discussed in this section.

3.3 Assumptions

(a) Flow is considered to be steady and incompressible.
(b) All the walls have no-slip momentum conditions and adiabatic conditions applied for all other wall being insulated.
(c) The pressure force and viscous force only drive the flow.

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(d) No source terms are included in the model.
(e) No phase change and heat generation within the heat exchanger.

3.4 Numerical Model
Selection of an appropriate computational domain is an important step in the analysis of a heat exchanger. In order to execute the investigation, a commercially available CFD code (ANSYS Fluent 16.0) has been used to simulate the fluid flow and temperature field of EGR cooler. The exercise consists of geometry creation, the physics-based meshing of the domain, selection of schemes and setting and post-processing. The investigation is supported by the grid independence test and validation of key parameters with the available test and theoretical results.

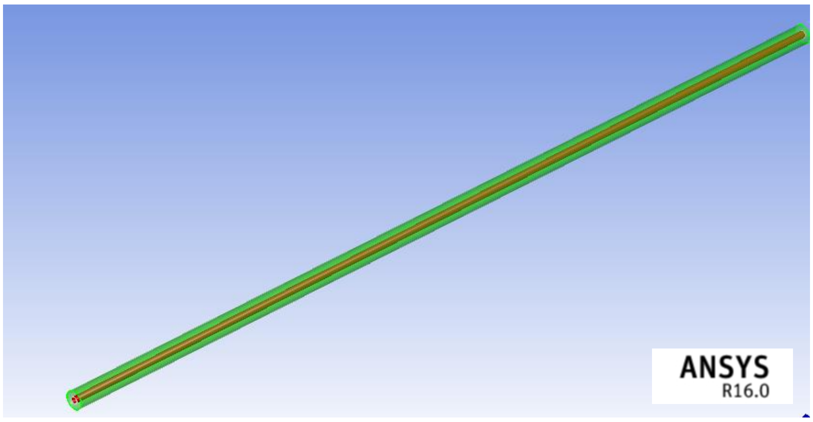

Fig. 1: Three dimensional modelling of the pipe heat exchanger

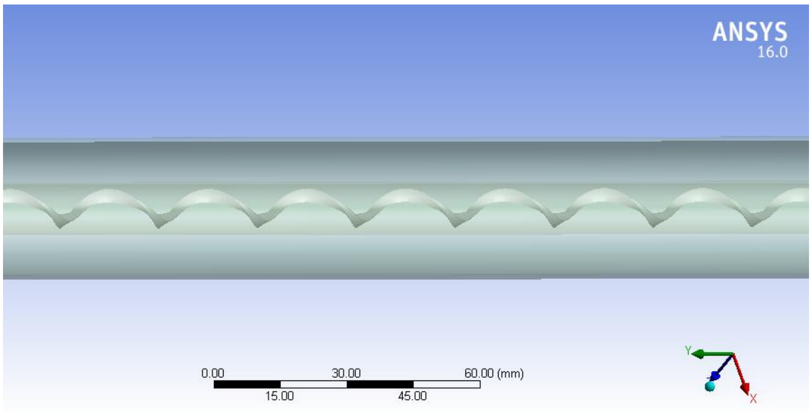

Fig. 2: Three dimensional modelling of the double pipe heat exchanger with single tape insert

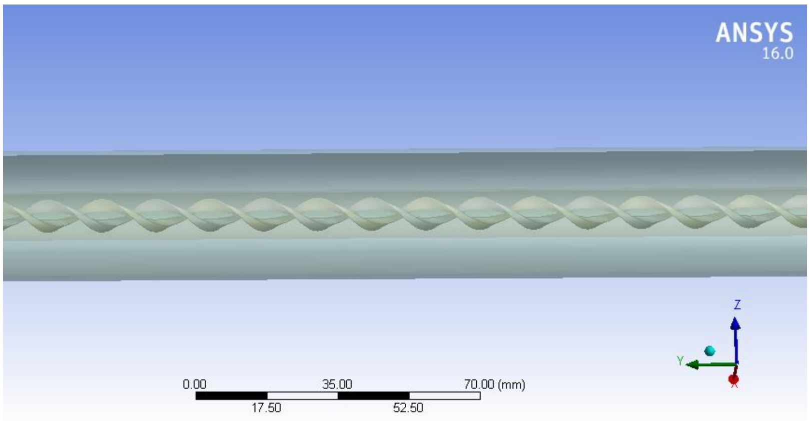

Fig. 3: Three dimensional modelling of the double pipe heat exchanger with double tape insert

In order to get complete information of processes which involve variations of temperature within solids and fluids, due to thermal interaction between them, a three-dimensional model of the simple double pipe heat exchanger and double pipe heat exchanger with tape insert of various geometry as shown in figure 1, figure 2, figure 3 respectively. The ANSYS Geometry section is used for 3-D modelling.

The hot water is flowing through the inner pipe and cold water is flowing in the annulus which can be admitted at any one of the ends enabling the heat exchanger to run as a counter flow exchanger. In the double pipe heat exchanger, the cold-water flow over the tape which is inserted in the annulus part of geometry while the hot water is flowing through the inner pipe.

3.5 Numerical set-up
The following process is employed in numerical set up are:

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(a) All the walls have a no-slip momentum condition. The thermal conditions were coupled for tube walls and headers, with adiabatic conditions for all the other walls being insulated.
(b) Cold Water and hot water was employed as working fluids with Fluent's default properties.
(c) The calculated Reynolds number of hot water in this work is more than 2300. Therefore, the "turbulent" property of water flow was defined. K epsilon–RNG turbulent model was used, with the near wall treatment "enhanced wall treatment.
(d) A pressure-based solver was used with the SIMPLEC pressure-velocity coupling scheme. Momentum and turbulence equations were solved with the high-order upwind scheme.

The numerical set up for the current investigation applied over the two-discretized computational domain i.e. simple double pipe heat exchanger and double pipe heat exchanger with tape insert. In the numerical technique of solving the problem the mechanism of the problem is first defined using some basic laws of science which are then represented in the form of mathematical equations. But the mathematical equations are in differential and integral form. In order to get the solution, these equations are discretized and converted to algebraic equations. After discretization, the equations are solved iteratively on individual nodes of mesh to get a solution. The accuracy of the solution depends on the number of data points considered before the particular node for which solution is solved. ANSYS Fluent offers some schemes such as first order, second order, third order up the winding, power law, QUICK etc. Convergence of solution is ensured by choosing appropriate controlling factors during the iterative process. These solution controls are called as relaxation factors.

4. RESULTS

4.1 CFD Results

Table 1: Coldwater outlet temperature for normal and tapes inserted heat exchanger in counterflow

S. no	Condition	Mass Flow rate (kg/s)	Normal geometry (K)	Single tape geometry (K)	Double tape geometry (K)
1	$\dot{m}_c$ constant at 0.02 kg/s and $\dot{m}_h$ varying	0.02	307.68	311.85	311.15
2		0.04	308.6	314.45	313.48
3		0.06	309.03	316.13	314.91
4		0.08	309.28	317.35	315.95

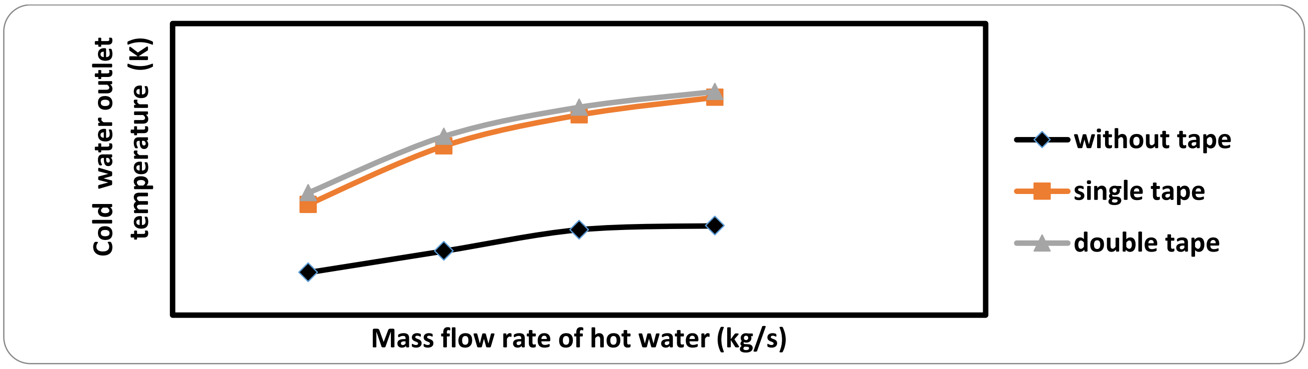

Fig. 4: Variation of cold water outlet temperature with mass flow rates of hot water in counter flow.

Figure 4 indicates the plot of cold water outlet temperature vs. mass flow rates of the hot water for counter flow. In the case of tapes inserted tube, the rise is not uniform and smooth as the entire flow field is being disturbed along the length single tape inserted tube shows a marginal improvement over the other types.

Table 2: Heat transfer calculations for normal and tape inserted heat exchanger in counter flow

S. no	Condition	Mass Flow rate (kg/s)	Normal geometry (Watt)	Single tape geometry (Watt)	Double tape geometry (Watt)
1	$\dot{m}_c$ constant at 0.02 kg/s and $\dot{m}_h$ varying	0.02	408.10	425.986	535.94
2		0.04	472.4	486.1814	610.393
3		0.06	509.188	520.874	727.025
4		0.08	530.09	535.9116	826.58

Table 2 indicates the heat transfer rate for different simulated conditions for the tape inserted and normal tubes. It can be revealed that the heat transfer rate increases with the increase in mass flow rate and tape inserted tubes show a higher value than the bare condition.

Table 3: Variation of annulus heat transfer coefficient with varying mass flow rates of Hot water in counter flow

S. no	Condition	Mass Flow rate (kg/s)	Normal geometry (W/m^2K)	Single tape geometry (W/m^2K)	Double tape geometry (W/m^2K)
1	m_c constant at 0.02 kg/s and m_h varying	0.02	594.403	638.808	979.67
2		0.04	706.032	744.803	1127.145
3		0.06	781.475	820.05	1600.47
4		0.08	826.63	856.205	2097.752

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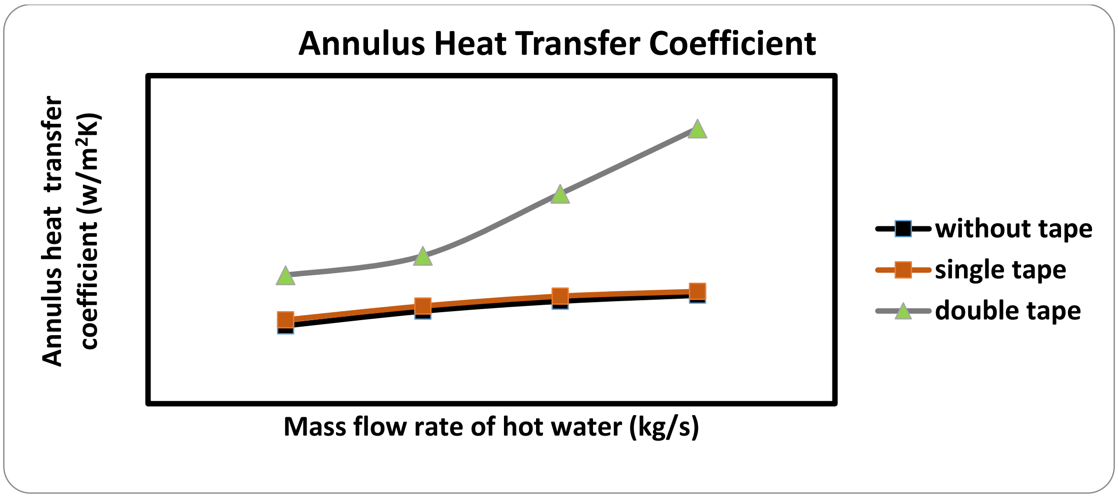

Fig. 5: Variation of annulus heat transfer coefficient with varying mass flow rates of hot water in counterflow

Figure 5, table 3 shows the variation of annulus heat transfer coefficient for different varied $\dot{m}_h$ keeping $\dot{m}_c$constant at 0.02 kg/s. It is observed that the annular heat transfer coefficient increases for tape inserted tubes than the bare tube. Further on comparing the values for different tape profiles it is observed that double tape profiles show the heat transfer coefficient is slightly higher than the others at all mass flow rate conditions for counterflow.

Table 4: Variation of pressure drop with varying mass flow rates of cold water.

S. no	Condition	Mass Flow rate (kg/s)	Normal geometry (Pa)	Single tape geometry (Pa)	Double tape geometry (Pa)
1	m_c constant at 0.02 kg/s and m_h varying	0.02	0.577	29.699	19.77
2		0.04	0.577	29.699	19.77
3		0.06	0.577	29.699	19.77
4		0.08	0.577	29.699	19.77

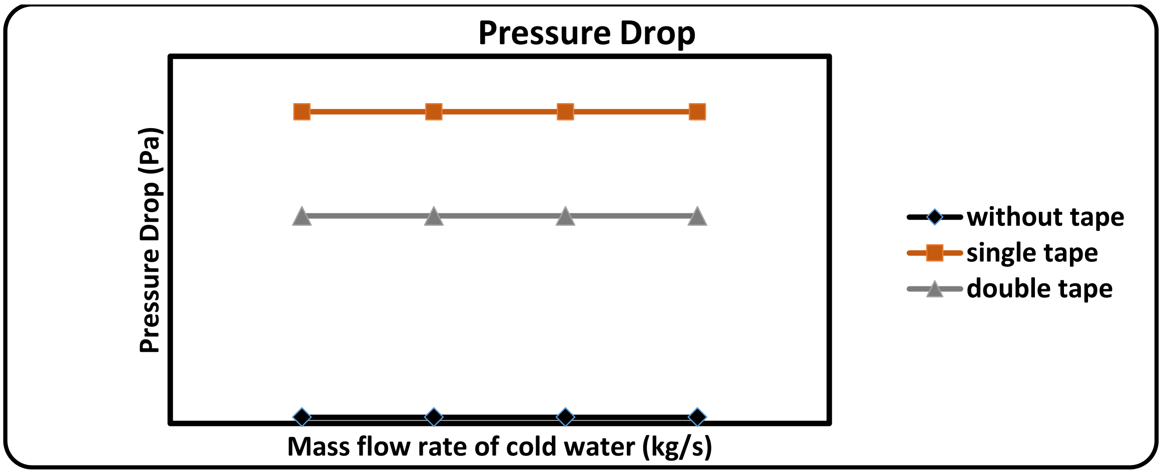

Fig. 6: Variation of pressure drop with varying mass flow rates of cold water.

Figure 6 and table 4 represents the pressure drop variation for bare and the triangular tape inserted tube for various mass flow rates of hot fluid. It can be seen that pressure drop for the bare tube is lesser than the tape inserted tubes. In case of a tape inserted tubes, the pressure drop was observed constantly for varying the mass flow rate of hot fluid in case of all two types of washers with a triangular shape. Higher pressure losses increase the pumping power. Since the pressure losses are more in case of single triangular tape inserted the pumping power required will be more when compared to the double triangular tape inserted tube. Marginally reduced performance of single triangular tape inserted tubes is compensated by reduced weight and reduced pressure losses. Considering all these factors single triangular tape is preferred over the other types since required pumping power and weight of the inserted structure will be reduced with the sacrifice of a marginal benefit of heat transfer characteristics.

Table 5: Variation of tape effectiveness with varying mass flow rates of hot water and cold water remains constant in counterflow

S. no	Condition	Mass Flow rate (kg/s)	Normal geometry (%)	Single tape geometry (%)	Double tape geometry (%)
1	m_c constant at 0.02 kg/s and m_h varying	0.02	10.16	17.4	21.4
2		0.04	18.16	20.1	21.66
3		0.06	20.1	21.83	26.56
4		0.08	20.93	23.26	26.7

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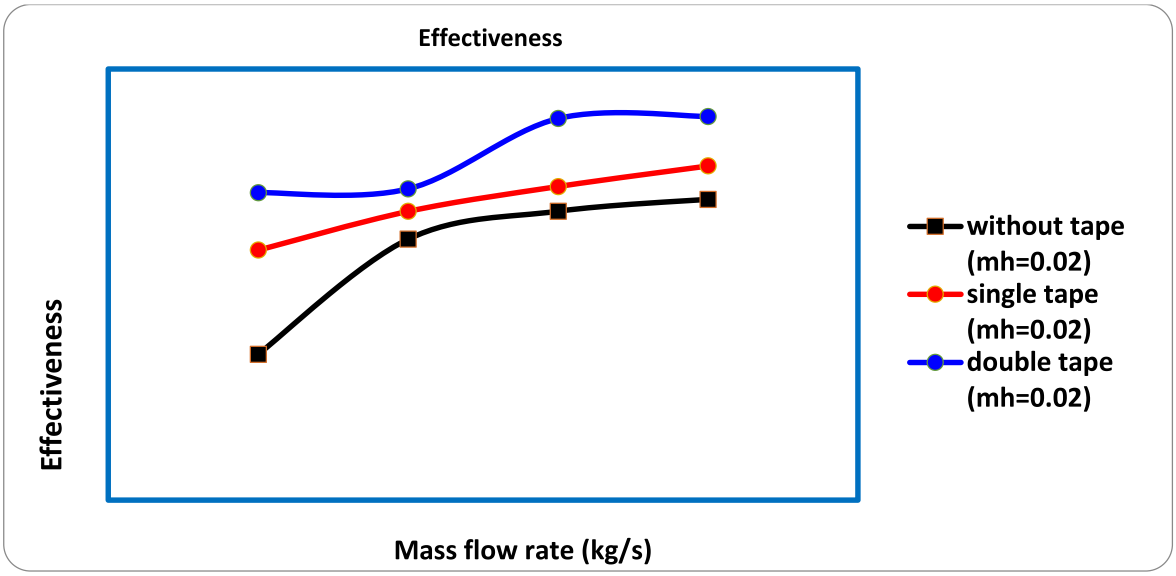

Fig. 7: Variation of tape effectiveness with varying mass flow rates of cold water and hot water remains constant in counterflow

For a constant value of $\dot{m}_c$ of 0.02 kg/s, as $\dot{m}_h$ was increased the effectiveness of the tape inserted heat exchanger and double tape inserted heat exchanger showed the highest efficiency among the different types. At higher mass flow rates, the flow field is being disturbed severely when compared to the bare tube. Hence heat transfer capability of the tape inserted tube decreases causing reduction in effectiveness. In order to have better performance by tape for heating a liquid flowing in annulus region, the mass flow rate of liquid in annulus should be minimum and mass flow rate of hot liquid flowing inside the inner tube should be maximum.

Table 6: Variation of Nusselt number with varying mass flow rates of Hot water and Coldwater remains constant in counterflow

S. no	Condition	Mass Flow rate (kg/s)	Normal geometry	Single tape geometry	Double tape geometry
1	m_c constant at 0.02 kg/s and m_h varying	0.02	13.8	18.75	28.75
2		0.04	15.58	21.86	33.08
3		0.06	16.699	24.07	46.97
4		0.08	17.33	25.13	61.57

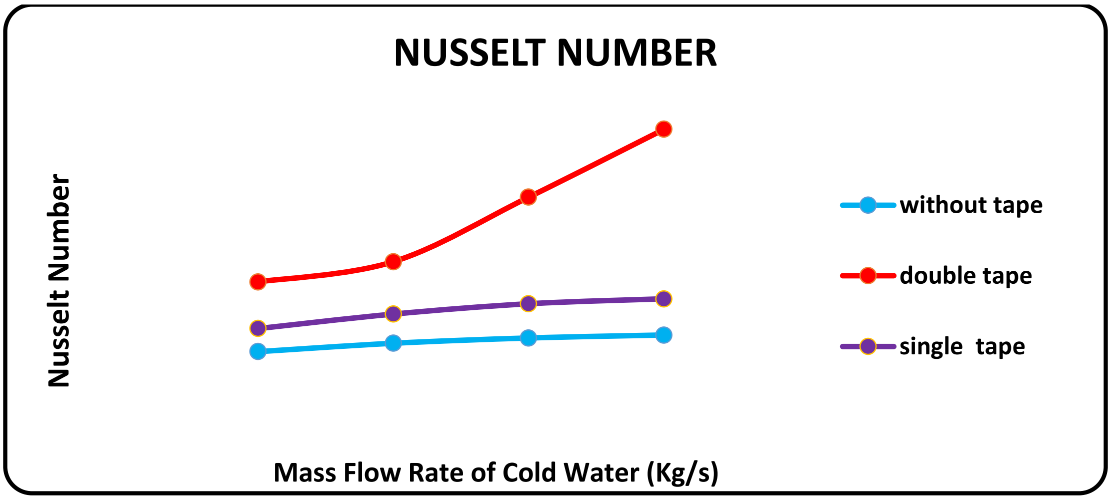

Fig. 8: Variation of Nusselt number with varying mass flow rates of cold water and hot water remains constant in counterflow

Figure 8, table 6 shows the Nusselt number is gradually increasing with increase in mass flow rate of hot water from 0.02 Kg/sec to 0.1 Kg/sec and cold-water flow rates for constant 0.02 Kg/sec for counterflow.

5. CONCLUSIONS

In the present study numerical simulation of triangular tape insert heat exchanger is done with hot fluid flowing in the inner tube and cold fluid in the annulus. After validating the results for a bare heat exchanger with the experimental results Simulation was done using single and double triangular tapes configurations inside the tube on the outer body of the inner tube. The results indicated tape configurations shows an overall improvement in the thermal characteristics compared with bare one. For better Performance, the mass flow rate of the cold fluid should be kept low whereas that of the hot liquid should be high. Single triangular tape configuration shows a marginal improvement over the other in terms of temperature rise, heat transfer rate and heat transfer

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coefficient. For a constant value of $\dot{m}_c$ of 0.02 kg/s, as $\dot{m}_h$ was increased, the effectiveness of the tapes inserted tube is increased and the single triangular tape showed the highest effectiveness is 25.41% and 46.64 % higher than double triangular tape for counterflow. In addition to this even they provide the advantage of lesser material and hence reduced weight.

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