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Numerical Analysis of Heat Transfer for Double Pipe Heat Exchanger with and Without Fin

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ABSTRACT

In this paper, the heat transfer enhancement analyzed using ANSYS FLUENT both in finned and unfinned condition. The numerical analysis went through different inlet velocities. As the cold fluid passed through the outer pipe surrounding the hot fluid in inner pipe, there was temperature fall in hot fluid. And that rate was found greater in finned condition comparing with unfinned one. Optimum number of fins were determined by analyzing the heat transfer through numerical computation. The effectiveness was found to reduce with the increase in flow velocity. For extended surface area in finned setup the overall heat transfer coefficient reduced. The reducing rate was found 28.88% for counter flow and 28.90% for parallel flow, for the flow velocity 0.001 m/s. The LMTD values were found 30.06 for parallel, 28.91 for counter flow in finned heat exchanger and 45.38 for parallel, 43.53 for counter flow in unfinned heat exchanger.

Keywords: Fin, Effectiveness, Parallel and Counter flow.

1. Introduction

The heat exchanger is a device which facilitates heat transfer between two medium of hot and cold without mixing both the medium since both mediums are separated with a solid wall generally. The temperature gradient, or the differences in temperature, facilitate this transfer of heat. In recent time, there are versatile use of different types of heat exchanger in daily life. Steam power plants, chemical processing plants, building heating, air conditioning, refrigerators, car radiators, radiators, for space vehicles etc. are well known sectors of use of heat exchanger. The main purpose of using a heat exchanger is to get an efficient method of transferring heat from one fluid to another. The heat transfer occurs by mainly three modes which are: Conduction, Convection and Radiation. Conduction takes place when the heat flows from a high temperature fluid to a low temperature fluid through the surrounding solid walls. Convection is the mode of heat transfer in which the heat transfer takes place between the adjacent layers of fluid. Convection mainly occurs in fluids and plays a major role in the performance of heat exchanger. Radiation does not play a significant role in the heat transfer in heat exchanger and hence it is neglected.

Many researches had been worked to find the best way to heat transfer in heat exchanger. Heat transfer enhanced in a heat exchanger tube by installing fins on the outer surface of hot water tube [1]. The results were compared between the two designs for counter flow. According to results, it concluded that in case of fin using, effectiveness also increases. The reason behind maximum effectiveness was that due to use of fins, turbulence was increased as they allow more mixing of fluid layers and resulted in increase of heat transfer through the heat exchanger tube. But there was no concern about the mass flow rate change in the cold fluid region.

A parallel flow heat exchanger and a corresponding ribbed tube heat exchanger is modeled and numerically analyzed. While investigating it was found that the effectiveness of the ribbed heat exchanger is more than that of simple heat exchanger [2]. Due to the ribbed helical shape of the tube the flow of fluid is not parallel but in swirls and there also increase in surface, which increases turbulence and thereby increasing the effectiveness.

Heat transfer coefficient of heat exchanger increasing with the logarithmic mean temperature difference, the mass flow of the shell side, and the mass flow of the tube side. Also shows that the heat transfer coefficient of tube side is higher usually than the shell side [3].

Velocity distribution is minimum to enhance the heat transfer rate. From the temperature path lines the temperature distribution is in the maximum scale range, which shows the perfect heat transfer rate [4].

As the fin thickness increases the value of heat transfer is increasing. For copper, heat transfer is maximum value when compared to other materials and steel is having the least value of heat transfer [5].

CFD analysis of different fluids and different pipe materials were investigated on parallel and counter flow in concentric tube heat exchanger [6]. The first stage was a modified Graetz problem model where velocity and temperature profiles were analyzed for fluid flow in a tube of 1.0 m in length. Both turbulent and laminar flow was considered for the analysis. These findings proved it is more important for engineers and developers to focus for the best choosing materials. But there was no concern for the improvement of heat exchange.

Experimental investigation of heat transfer and friction factor characteristics with different flow rates was done by means of CFD simulation. The work is conducted by the double pipe heat exchanger with counter flow direction. The data acquire from the plain tube double pipe heat exchanger with the CFD simulation and ensured the validation results. The plain tube with dissimilar mass flow rates were also studied for

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comparison assessment. A commercial CFD package, Ansys CFD analysis was used in this study and 3D models of double pipe heat exchanger was generated in this simulation [7].

2. Methodology

2.1 Governing Equations

The continuity equation or the equation for conservation of mass can be written as:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho U_1}{\partial x_1}+\frac{\partial \rho U_2}{\partial x_2}+\frac{\partial \rho U_3}{\partial x_3}=0 \qquad (1)$$

The momentum equation in tensor notation for a Newtonian fluid can be written as:

$$\frac{\partial U_i}{\partial t}+U_j\frac{\partial U_i}{\partial x_j}=\frac{1}{\rho}\frac{\partial P}{\partial x_i}+\upsilon\frac{\partial}{\partial x_j}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right) \qquad (2)$$

The total energy can be defined as the sum of all these energies:

$$h=h_m+h_T+h_c+\varphi \qquad (3)$$

The standard k-epsilon model was chosen as the turbulence modelling. The first transported variable is turbulent kinetic energy, k. The second transported variable in this case is the turbulent dissipation, **ε**.

Effectiveness may be defined as:

$$\varepsilon^{'}=\frac{Q}{Q_{\max}} \qquad (4)$$

Here, Q =Actual heat transfer rate

$Q_{\max}$ =Maximum possible heat

Transfer rate:

$$Q=m_h c_{ph}(T_{h,in}-T_{h,out})=m_c c_{pc}(T_{c,out}-T_{c,in}) \qquad (5)$$

$$Q_{\max}=(m\ c_p)_{\min}(T_{h,in}-T_{c,in}) \qquad (6)$$

As both hot and cold fluid are water liquid:

$$m_h c_{ph}=m_c c_{pc}=(m\ c_p)_{\min}=(m\ c_p)_{\max} \qquad (7)$$

$$\varepsilon^{'}=\frac{T_{h,in}-T_{h,out}}{T_{h,in}-T_{c,in}} \qquad (8)$$

Again overall heat transfer coefficient:

$$U^{'}=\frac{Q}{A\Delta T_{\ln}} \qquad (9)$$

Here, Log mean effective temperature:

$$\Delta T_{\ln}=\frac{\Delta T_o-\Delta T_L}{\ln\left(\frac{\Delta T_o}{\Delta T_L}\right)} \qquad (10)$$

2.2 Geometrical Modelling

Heat exchanger geometry had been generated in the ANSYS workbench design modeler. Both heat exchangers: with and without fin was designed. In this CFD analysis, two heat exchangers had been simulated with different types of flow i.e. parallel and counter flow.

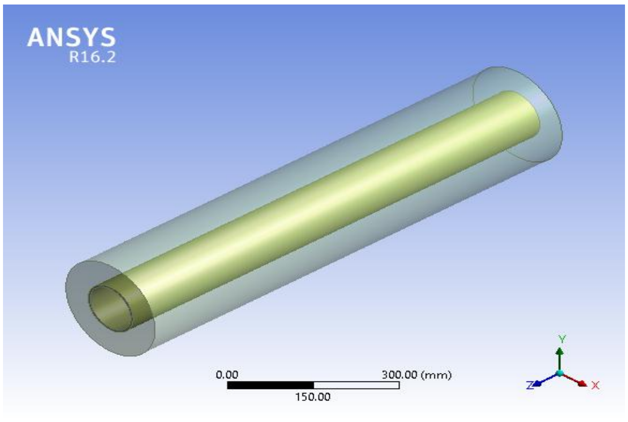

Fig.1 Geometrical model of heat exchanger without fin

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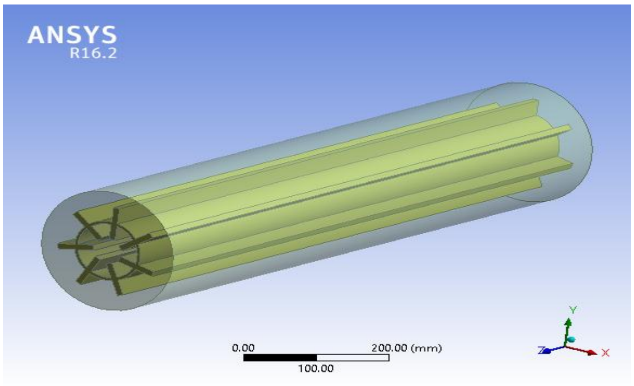

Fig.2 Geometrical model of heat exchanger with fins.

Table 1 Dimensions of both heat exchanger.

No.	Description	Without Fin	With fin
1	Length of heat exchanger	1000 mm	1000 mm
2	Inner pipe diameter	100 mm	100 mm
3	Outer pipe	220 mm	220 mm

	diameter		
4	Tube pitch	5 mm	5 mm
6	Height of the fins		60 mm
7	Width of the fins		10 mm

2.3 Software Validation

For software validation, a paper's data and setup considered from a recognized journal [6]. The same data setup were run through the present software for transformer oil and water. Comparing the results there was no major difference between the two software's outputs. The temperature deviation between the two, were found ranging from 0.166% to 0.045% for transfer oil throughout the pipe length. And for water it ranged from 0.169% to 0% throughout the pipe length. Hence, it proves the validity of the present software.

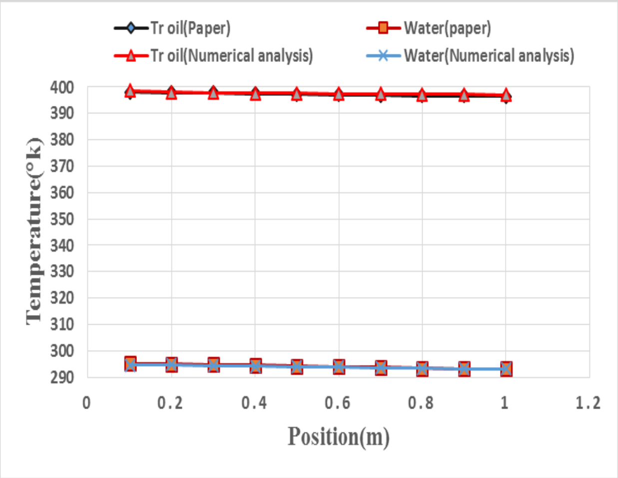

Fig.3 Turbulent counter flow heat exchanger temperature change.

3. Results and Discussion

In simple double pipe heat exchangers there occurs pressure drops, temperature distribution and velocity distribution throughout the pipes as the two fluids flows through the pipe. For different inlet velocities i.e. different mass flow rate there is various heat transfer phenomena occurs for the same arrangement of heat exchanger. Parallel and counter flow systems gives different types of heat transfer results.

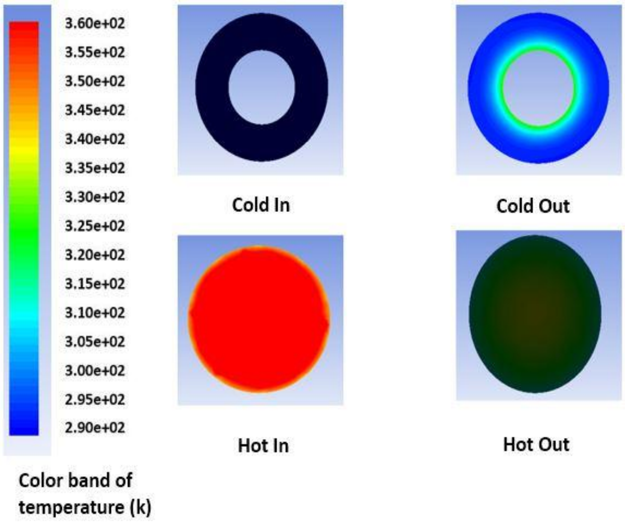

Fig.4 Temperature contour: counter flow (without fin).

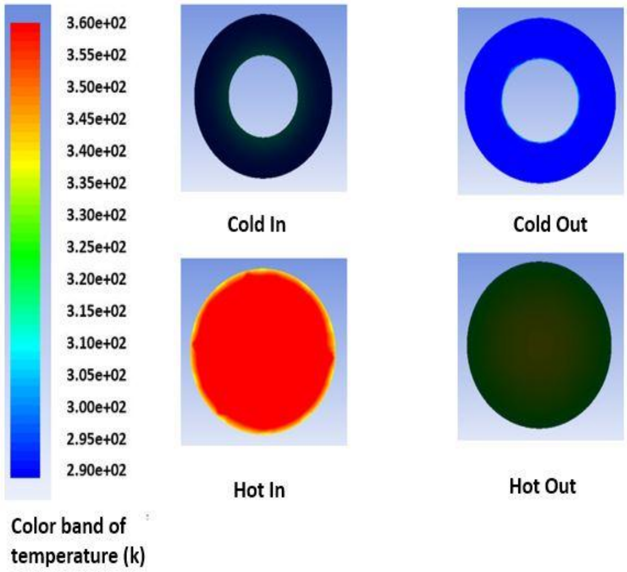

Fig.5 Temperature contour: parallel flow (without fin).

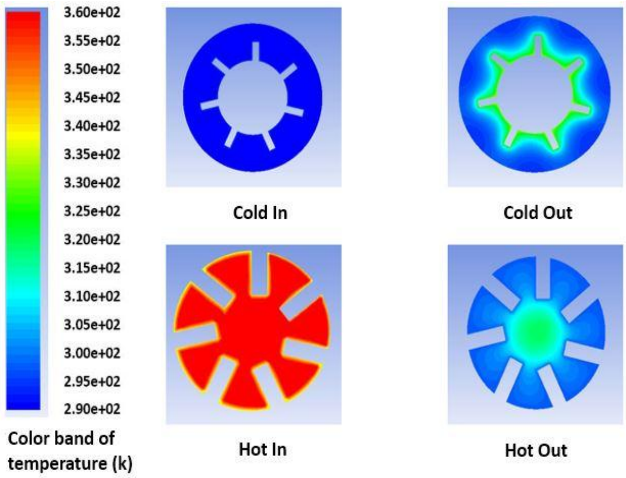

Fig.6 Temperature contour: counter flow (with fin).

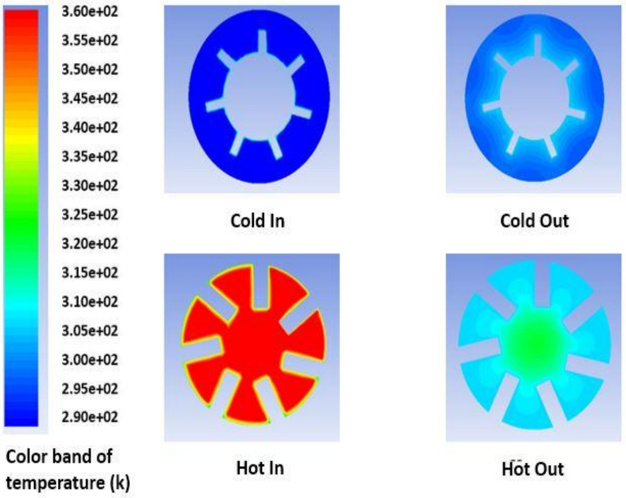

Fig.7 Temperature contour: parallel flow (with fin).

Above figures indicates the phenomena that the hot fluid temperature falling till the outlet section and cold fluid temperature rising consequently for heat transfer from hot to cold region. And the rate is greater in finned pipe as extended surfaces facilitates the heat transfer.
For velocity 0.001 m/s:

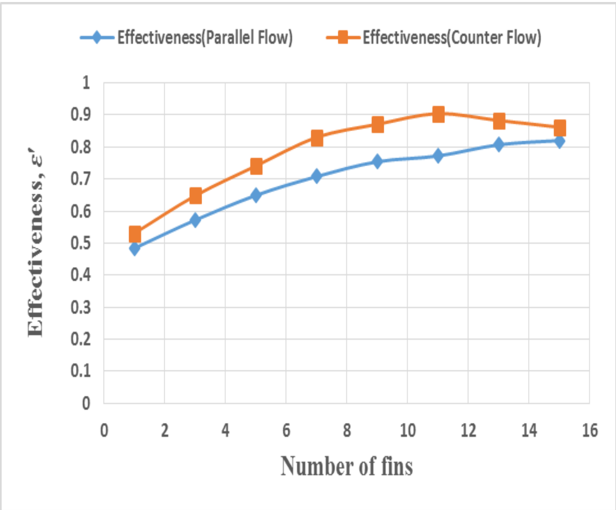

Fig.8 Effectiveness vs. Numbers of fin.

From the graph it is visible that the effectiveness gradually increases with the increased number of fins used. But it is not desirable to fill the whole pipe with fins so that less fluid flows. From the graph it is visible that the effectiveness rate increases at high rate till 7 number of fins and then gradually decreases, so the optimum number of fins considered as 7 fins.
For velocity 0.001 m/s:

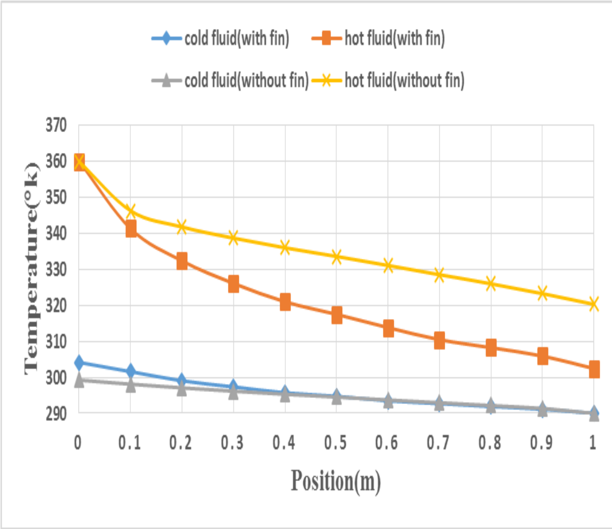

Fig.9 Temperature vs. Position for counter flow.

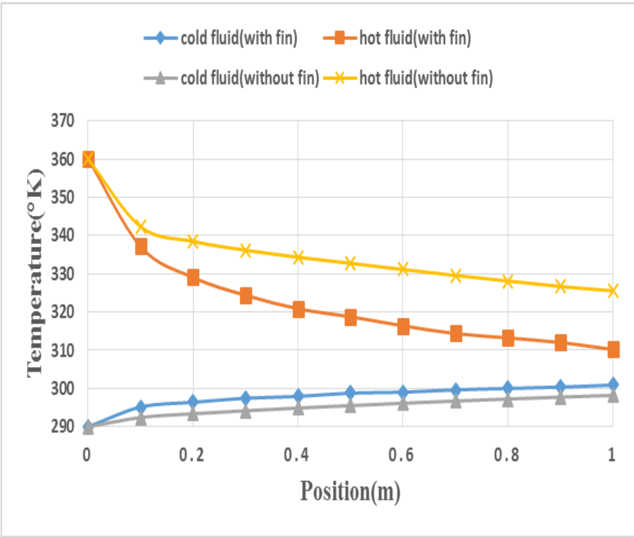

Fig.10 Temperature vs. Position for parallel flow.

From the above figures, it is visible that finned curve falling degree is greater than unfinned for hot fluid and rising degree is greater in cold fluid in finned heat exchanger. So the heat transfer is faster in finned heat exchanger than unfinned heat exchanger for both parallel and counter flow types.

Table 2 Effectiveness of double pipe heat exchanger with fins.

Inlet velocity (ms^{-1})	Effectiveness (ε')			
	With Fin		Without Fin	
	Parallel Flow	Counter Flow	Parallel Flow	Counter Flow
0.001	0.711	0.822	0.492	0.567
0.005	0.498	0.542	0.283	0.305
0.01	0.376	0.396	0.195	0.204
0.05	0.138	0.141	0.067	0.068

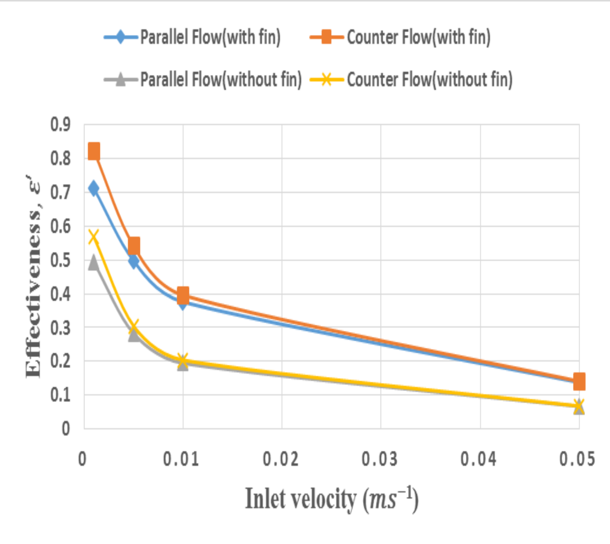

Fig.11 Effectiveness vs. Inlet velocity.

The effectiveness of double pipe heat exchanger with fin is greater than the effectiveness without fin. The highest effectiveness of heat exchanger is achieved in finned heat exchanger for counter flow setup and lowest is achieved in heat exchanger without fin for parallel flow heat exchanger setup for the same velocity.

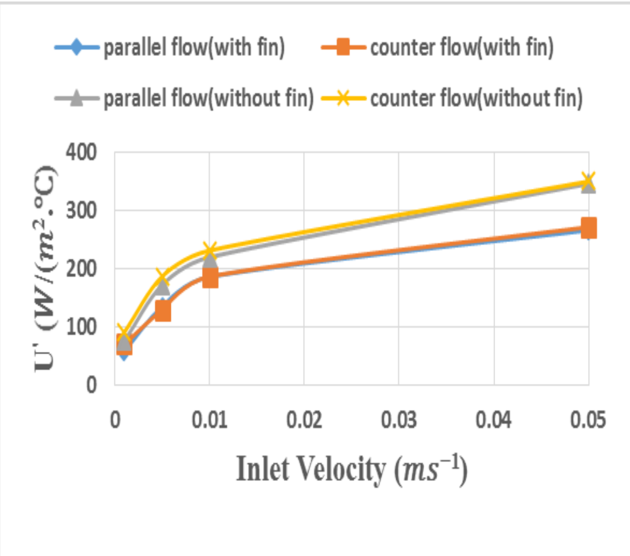

Fig.12 Overall heat transfer coefficient vs. Inlet velocity.

For both parallel and counter flow types the overall heat transfer coefficient is increasing with velocity. The log mean effective temperature is low for lower velocities. Thus the overall heat transfer coefficient is increasing with higher velocities. The heat transfer rate is greater in counter flow than the parallel flow. So the overall heat transfer coefficient is slightly greater in counter flow.

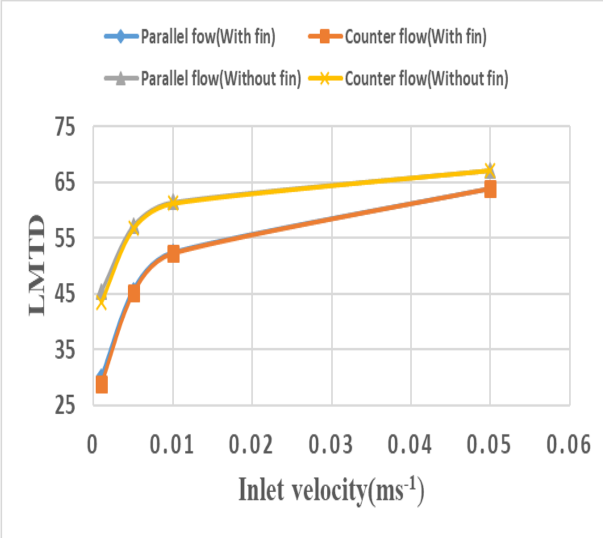

Fig.13 LMTD vs. Inlet velocity.

4. Conclusion

For double pipe heat exchanger flow characteristics and heat transfer was analyzed with and without fin for parallel and counter flow type through the numerical computation using ANSYS FLUENT16.2. The analysis was done on basis of different inlet velocities. The major findings are:

- Seven rectangular fins were considered as the optimum number of fins, as the effectiveness flux was maximum at that arrangement. The effectiveness rising rate was about 14.35% for seven number of fins, which was the maximum rate.
- With the rise in velocity, the outlet temperature difference decreased. 10.92 °K for parallel and 12.45 °K for counter flow found in finned heat exchanger while 8.22 °K for parallel and 9.24 °K for counter flow analyzed for unfinned one, for velocity 0.001 m/s. Thus the effectiveness also reduced with the increase in velocity.
- The LMTD for unfinned setup was greater than that of the finned setup for same directional flow or counter directional flow depending on outlet temperature difference. The overall heat transfer coefficient was reducing in finned for enhanced surface area. Reducing rate was 28.88% for counter flow and 28.90% for parallel flow, for the velocity 0.001 m/s.
- Finally it can be said that the finned arrangement obviously reduces the hot fluid temperature than that of simple double pipe heat exchanger without fin. So when the purpose is to reduce the hot outlet temperature, then finned heat exchanger may be used.

NOMENCLATURE

A	: Area (m^2)
C_p,Cv	: Heat capacity at constant pressure, volume (J/kg-K)
h	: Heat transfer coefficient (W/m^2-K)
P	: Pressure (Pa)
U	: Free-stream velocity (m/s)
T	: Temperature (K)
t	: Time (s)
ω	: Specific dissipation rate (s^{-1})
υ	: Kinematic viscosity (m^2/s)
$\varepsilon^{'}$	: Effectiveness
$U^{'}$	: Overall heat transfer coefficient (W/m^2.℃)

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