EFFECT OF DIFFERENT TYPES OF TURBULATOR USED IN HEAT EXCHANGER TO INCREASE HEAT TRANSFER

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Abstract: A heat exchanger is a device that exchanges the heat between two or more flowing fluids. In simper words one flowing fluid is at the lower temperature, called the cold fluid, and the other fluid is at the higher temperature, called the hot fluid, from which heat has to be extracted. The fluid with the lower temperature flows inside the geometry of the heat exchanger to extract heat from the hot fluid flowing with the higher temperature. Different types of turbulators with different pitch ratio were used to increase heat transfer rate inside the heat exchanger. Turbulators were used to increase turbulence and contact time which helps in increasing heat transfer rate. Here in this work it calculated the effect of different diameter circular helical turbulator to increase heat transfer, for analyzing the effect of different diameter of circular turbulator here it considered three different diameters that are 0.5, 1 and 2 mm. In this work it also calculates the effect of different shape of helical turbulator, for analyzing the effect of different shapes of helical turbulator here it considered three different shapes of turbulator with same cross sectional area that is circular, Square and rectangular shape turbulator. Through analysis it is found that heat exchanger with rectangular helical turbulator shows maximum value of heat transfer as compared to other.

Keywords: heat exchanger, Turbulator shape, heat transfer, temperature distribution and Nusselt number

1. Introduction
Heat exchangers are moreover that comforts the heat alteration among two solutions which are at diverse temperature though having them since intercourse with another. heat exchanger are normally utilized in practice in a wide variety of application, from heating as well as air conditioning systems in a domestic, to chemical processing as well as power production in large plant. A heat exchanger in which two fluids exchange heat by coming into straight interaction called direct contact heat exchanger. The wall may be an easy level wall or tube or a complex arrangement comprising fins, baffles and tubes multiple passes. These units, also called surface heat exchanger, are ordinary utilized as they can be created with huge heat transfer area in somewhat lesser volume and are fit for heating, cooling, evaporating or condensing applications. A periodic flow type heat exchanger called a regenerator. In this type of heat exchanger, the identical space of it consecutively engaged by hot and cold gases between which heats exchanged. Regenerator may discover its assertion in preheaters for condensation influence firm, blast furnaces, oxygen manufacturers, and many more.

Here in this work it performs the numerical analysis of tube in tube heat exchanger having turbulator inside the inner tube. Here in this work turbulator having 39 mm pitch were introduced inside the inner tube and measure the value of heat transfer. In order to measure the effectiveness of turbulator here it performs numerical analysis on both kind of geometries that is heat exchanger with helical turbulator and heat exchanger without turbulator. The heat exchanger used by Akyurek et.al [23] for the experimental analysis were considered to perform numerical analysis.

2. Development of solid model
The geometrical parameters used to develop solid model of heat exchanger is shown in the below table.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube length</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Inner tube diameter</td>
<td>12 mm</td>
</tr>
<tr>
<td>Tube wall thickness</td>
<td>2 mm</td>
</tr>
<tr>
<td>Outer tube diameter</td>
<td>33 mm</td>
</tr>
<tr>
<td>Pitch of turbulator</td>
<td>39 mm</td>
</tr>
</tbody>
</table>

Based on the above geometric parameters it developed the solid model of nano fluid heat exchanger. The solid model of heat exchanger is shown in the below fig.
After analyzing the heat exchanger without turbulator, it analyzed the effect of use of turbulator in heat exchanger to increase the heat transfer rate. The solid model of heat exchanger having helical turbulator inside the inner tube is shown in the below fig.

3. Meshing
To perform the numerical analysis of heat exchanger with or without turbulator it is necessary to discretize heat exchanger in to number of body and element. During numerical analysis, it calculates the result on element and nodes. In order to test the independency of number of nodes and elements, here we have discretized the body with different number of nodes and element and found that, result does not depends on number of elements and nodes. In order to improve the mesh different tools were used to refine the mesh. Mesh of the heat exchanger with and without turbulator is shown in the below fig.
4. Material Used
Here in this work water is used as a hot fluid as well as cold fluid, whereas the inner tube of heat exchanger is made of aluminium and outer tube is made of polyethylene the properties of these materials are shown in the below section. Here in this work hot water is flowing in the outer tube and cold fluid is flowing in the inner tube. Turbulator is placed in inner tube to increase turbulence.

4.1 Water
Here in this work water is used as a working fluid which is flowing inside the heat exchanger. The properties of water used during the analysis is mention in the below table.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density ($\rho$) kg/m$^3$</td>
<td>998</td>
</tr>
<tr>
<td>Specific heat ($C_p$) J/kg-K</td>
<td>4182</td>
</tr>
<tr>
<td>Thermal Conductivity (K) W/m-K</td>
<td>0.6</td>
</tr>
</tbody>
</table>

4.2 Aluminium
Here in this analysis aluminium is used to manufacture inside tube of heat exchanger.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity(Wm$^{-1}$K$^{-1}$)</td>
<td>202.4</td>
</tr>
<tr>
<td>Density (Kg/m$^3$)</td>
<td>2719</td>
</tr>
<tr>
<td>Specific heat (J/kg K)</td>
<td>871</td>
</tr>
</tbody>
</table>

4.3 Polyethylene
Here in this work outer tube of the heat exchanger is made of polyethylene. The properties of the material is shown in the below table.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity(Wm$^{-1}$K$^{-1}$)</td>
<td>0.33</td>
</tr>
<tr>
<td>Density (Kg/m$^3$)</td>
<td>970</td>
</tr>
<tr>
<td>Specific heat (J/kg K)</td>
<td>1900</td>
</tr>
</tbody>
</table>

5. Mathematical model
In order to calculate the performance of heat exchanger nusselt number and overall heat transfer coefficient. With the help of CFD analysis temperature of hot and cold fluid at inlet and outlet where measured. After measuring the temperature of hot and cold fluid value of nusselt number and overall heat transfer coefficient where calculated with the help of following mathematical model

5.1 Heat transfer from hot water fluid
\[ Q_h = C_{pw} \times m_w (T_{inw} - T_{outw}) \] .......................... (1)

Where \( Q_h \) is the heat transfer from water, \( C_{pw} \) is the specific heat of water, \( m_w \) mass flow rate of water, \( T_{outw} \) is the temperature of water at exit and \( T_{inw} \) is the temperature of water at inlet.

### 5.2 Heat transfer to cold fluid

\[ Q_c = C_{pc} \times m_c (T_{oute} - T_{inc}) \] .......................... (2)

Where \( Q_c \) is the heat transfer to cold fluid, \( C_{pc} \) is the specific heat of cold fluid, \( m_c \) mass flow rate of cold fluid, \( T_{oute} \) is the temperature of cold fluid at exit and \( T_{inc} \) is the temperature of cold fluid at inlet.

In order to calculate the properties of nano fluid following mathematical model formulas were used.

### 5.3 The average heat transfer rate

\[ Q_{avg} = \frac{Q_h + Q_c}{2} \] .......................... (3)

The overall heat transfer coefficient

\[ Q_{avg} = UA_1 \Delta T_{lm} \] .......................... (4)

Where \( U \) is the overall heat transfer coefficient, \( A_1 \) is the surface area of inner pipe, \( \Delta T_{lm} \) is the logarithmic mean temperature difference.

\[ \Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)} \] .......................... (5)

\[ \Delta T_1 = T_{hi} - T_{co} \] .......................... (6)

\[ \Delta T_2 = T_{ho} - T_{ci} \] .......................... (7)

Heat transfer coefficient for cold fluid

\[ h_c = \frac{Q_{avg}}{\pi DL(\Delta T_{lm})} \] .......................... (8)

Where, \( h_c \) is the heat transfer coefficient of cold fluid.

Calculation of nusselt number for cold fluid

\[ Nu_c = \frac{h_cD}{K_c} \] .......................... (9)

### 6. Boundary condition

Here in this work hot water is flowing in the outer tube, whereas the cold fluid is flowing in inner tube. The inlet temperature of hot water is 343 K whereas the inlet temperature of cold fluid is 293 K. the velocity of hot fluid is considered as 0.0084 m/s as considered in base paper. The velocity of cold fluid changes as the Re number of cold fluid changes.

### 7. Result

Here in this work the performance of heat exchanger depends on the turbulator used inside the heat exchanger. In order to increase the performance of heat exchanger different types of turbulators can be used inside the heat exchange. Here in this work it considered three different wire coil diameter that is 0.5, 1 and 2 mm circular turbulators. It also analyzed the effect of different turbulator wire coil shape, to analyzed the effect of different shape of turbulator here it considered three different shapes of wire used as a circular helical turbulator inside the inner tube that is circular, square and rectangular which is having same cross sectional area.

#### 7.1 Without helical turbulator

- **For Re = 4000**

Here in this section cold fluid is flowing at a Re 4000. Whereas the hot fluid is flowing at a speed of 0.0084 m/s. the temperature contour of heat exchanger for this Re number is shown in the below fig.
Fig. 5 shows the temperature contours of heat exchanger for Re = 4000

Fig. 6 shows the temperature at the exit of heat exchanger

Through CFD analysis we have calculated the value of temperature of hot and cold fluid at inlet and outlet for Re = 4000. The temperature of hot and cold fluid at inlet and exit where mention in the below section. On the basis on temperature at the exit and inlet, here we have calculate the value of nusselt number and overall heat transfer coefficient using eq. 1, 2, 3, 4, 5, 6, 7, 8 and 9 as mention in chapter 3.

From CFD $T_{hi}$ (temperature of hot fluid inlet) = 343 K, $T_{ho}$ (Temperature of hot fluid outlet) = 312.5 k, $T_{ci}$ (Temperature of cold fluid inlet) = 293 k, $T_{co}$ (Temperature of cold fluid outlet) = 336 k

Heat transfer from hot fluid

$$Q = \dot{m} C_p \Delta T$$

Where, $\dot{m}$ is the mass flow rate, $C_p$ is the specific heat of water and $\Delta T$ is the change in temperature of hot fluid

$$Re = \frac{\rho V D}{\mu}$$

Reynolds number is shown in the below table.

Likewise the above calculation for Re = 4000, we have calculated the value of overall heat transfer coefficient and Nusselt number for different Re numbers. The value of overall heat transfer coefficient for heat exchanger without turbulator at different Reynolds number is shown in the below table.

Comparison of value of overall heat transfer coefficient values calculated with the help of numerical analysis with the value of overall heat transfer coefficient obtained from the experimental analysis performed by Akyürek et.al [23].
Table 5 Comparison of value of overall heat transfer coefficient

<table>
<thead>
<tr>
<th>S.No</th>
<th>Reynolds Number</th>
<th>Overall heat transfer coefficient (U) W/m²K calculated through numerical analysis</th>
<th>Overall heat transfer coefficient (U) W/m²K from base paper</th>
<th>Percentage error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4000</td>
<td>1007</td>
<td>980</td>
<td>2.7</td>
</tr>
<tr>
<td>2</td>
<td>8000</td>
<td>1225</td>
<td>1170</td>
<td>4.7</td>
</tr>
<tr>
<td>3</td>
<td>12000</td>
<td>1316</td>
<td>1260</td>
<td>4.4</td>
</tr>
<tr>
<td>4</td>
<td>16000</td>
<td>1408</td>
<td>1340</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>20000</td>
<td>1426</td>
<td>1360</td>
<td>4.8</td>
</tr>
</tbody>
</table>

7.2 For Heat exchanger having different circular helical turbulator

After validating the CFD model of heat exchanger, here we have used solid model of heat exchanger having different helical turbulator inside the inner tube of heat exchanger. The helical turbulator is made on the basis of geometrical pitch that is 39 mm as mentioned in the base paper; turbulator is mainly used to increase the turbulence inside the heat exchanger. Here in this case water is flowing in both tubes that are in outer tube and inner tube. The velocity of water flowing in the outer tube is same as considered during without turbulator case that is 0.0084 m/s. for analyzing the effect of different core diameter of circular turbulator on heat transfer here we have considered three different core diameter that is 0.5, 1 and 1.5 mm.

7.3 Comparison of different coil diameter of circular helical turbulators

Here we have compare the value of overall heat transfer coefficient and Nu number at different Reynolds for coil diameter circular helical turbulators. The comparison of different performance parameters of heat exchanger shown in the below fig.
From the above fig. it is conclude that the value of overall heat transfer coefficient is higher in case of 2 mm coil diameter as compared to 0.5 and 1 mm coil diameter. Above fig. also shows that the variation of overall heat transfer coefficient for different coil diameters at particular Re number start decreasing as the Re number increases and minimum for Re number 20000.

From above graph it is found that the value of Nu number increases with increase in Re number and it is higher for 2 mm coil diameter. After analyzing the circular coil turbulators of different diameter, here we have also analyzed the effect of different shapes of coil used for helical turbulators. In order to analyze the effect of different shapes of helical turbulator here we have considered circular, square and rectangular turbulaotrs inside the inner tube of heat exchanger and calculate the value of overall heat transfer coefficient and nusselt number. Here cross sectional area of all three turbulators are same, during circular shape coil analysis 2 mm diameter coil shows maximum overall all heat transfer coefficient so here we have considered the cross section area same as cross sectional area of 2 mm circular coil that is 3.141 mm².
7.4. Square coil helical turbulators

Fig. 10 shows the square shape coil helical turbulator

7.5. Rectangular coil helical turbulators

Here in this section rectangular shape coil is used to make helical turbulator inside the heat exchanger. The solid model of rectangular shape helical coil is shown in the below fig.

Fig.11 rectangular shape coil helical turbulator
Form the above analysis it is found that the value of overall heat transfer coefficient for rectangular shape turbulator is high as compared to other shape of helical turbulator. Through analysis it is found that the value of Nusselt number for rectangular turbulator is high as compared to other.

8. Conclusion

- Develop the numerical analysis of heat exchanger with different shapes of helical turbulator.
- Through analysis it is found that the value of nusslet number and overall heat transfer coefficient increases with increase in Reynolds number.
- Heat exchanger with circular shape turbulator with 2 mm core diameter shows higher value of overall heat transfer coefficient and nusslet number.
- It means that heat exchanger with 2 mm core diameter shows maximum heat transfer as compared to other core diameter helical turbulator.
- After analyzing different shapes of helical turbulator it is found that the value of Nusslet number and overall heat transfer coefficient is high for heat exchanger having rectangular shape turbulator.
- Through analysis it is conclude that heat exchanger with rectangular shape helical turbulator shows maximum heat transfer as compared to other shapes of helical turbulators.
REFERENCES


