Experimental Investigation and CFD Analysis on Effect of Turbulators on Performance of Heat Exchanger

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Abstract: Heat exchanger is an important device in all the thermal systems. The heat exchanger is widely used equipment in different industries such as process, petroleum refining, chemicals, pharmaceutical and paper etc. After studying different literature about heat exchanger and double pipe heat exchanger problem is identified as to perform simulation and experimental investigation of double pipe heat exchanger with inner twisted tape inserted different mass flow rate. The system has followed different types of flow arrangement and geometric dimension with circular tape to attain heat transferred in experimental result and compare with simulation result. The objective of these experiments is Performance analysis of double pipe heat exchanger with inner and outer twisted tape at different mass flow rate. The experimental set up consists of double pipe heat exchanger experiment. The apparatus includes tube-within-a-tube heat exchangers and twisted tape type inserted threaded thermocouple at each end, a water pump and electric motor. These methods used to find out the heat transfer rate from the surface and related temperature of fluid motions also used to find the effectiveness.

I. INTRODUCTION

Heat exchangers are widely used in chemical, power generation and petroleum refining industry. Shell and tube heat exchanger have the ability to transfer large amount of heat in relatively low cost, serviceable designs. The important variable in reducing the size and cost of a heat transfer device are pressure drop and heat transfer coefficient. Therefore, it is good to developed method to improve the heat transfer coefficient. The twisted tape insert as flow turbulator’s have been widely applied due to their promising performance. Many researchers have reported their influence of tube insert on heat transfer improvement. The promising challenge for design of heat exchanger is to reduce the pumping power while increased heat transfer rate. Therefore it is essential to develop theory and technique about increased heat transfer in the double pipe heat exchanger to optimize the performance of heat exchanger. The presence of twisted tape lowers the hydrodynamic and thermal boundary layer thickness, leading to greater convective heat transfer. Though pumping power may increase meaningfully and ultimately the cost of pumping is more. Therefore to achieve a desired heat transfer rate with minimum pumping power, the design of twisted tape with proper geometry is necessary. Twisted tapes are normally inserted into the tube to generate swirl motion of fluid for greater heat transfer. This also leads to improve flow velocity, thermal boundary layer, hydrodynamic boundary layer, heat transfer rate, fluid mixing. However more pumping power is required when twisted tapes are inserted to inner tube. Classification of improvement method - Heat removal improvement method mention to the development of thermo hydraulic performance of heat exchanger. These improvement method is categorized in generally three categories. They are as below

A. Active method
In these Methods, exterior power is used to effect the need flow statement and related important in rate of heat transfer.

B. Passive Method
These methods do not necessary have any direct input of exterior power.

C. Compound Method
A compound important method is the one wherever more than one of the above stated method is used in mixture by the purpose of further improving the rate of heat transfer.

II. METHODOLOGY

Work being considered is to perform experimental investigation and simulation of double pipe heat exchanger with and without twisted tape inserted.
The study the heat transfer performance of heat exchanger with and without insert twisted tape different geometry. Calculation of its heat transfer performance.
Heat transfer coefficient for all cases.
Nusselt number for all cases.
Reynolds Number for all cases.
Compare in mode of the result of found from experimental analysis and simulation type twisted tape.

A. Proposed Experimental Set-Up

B. Components With Specification

The following is a list of all pieces of equipment and their specifications for the double-pipe heat exchanger.

1) Double-Pipe Heat Exchange
Inside pipe Material copper
Outside pipe material steel
Length 1.4m
INSIDE PIPE
inside pipe dia 0.0198m
outside pipe dia 0.0028 m
outside pipe thickness 0.003m
HOT WATER
Pass 1
COLD WATER

1) Pass

2) Valves
   Ball Valves
   Location: Process Valves, Tank Valve, Drain Valve, Bypass valves

   3) Temperature indicating control
   Input: RTD – PT100
   wire range 0 to 200 deg C
   Display: 3 1/2 digit red LED 13 mm Height
   Accuracy: 1% F.S.
   Set point: 1 Potentiometric
   Output: INO/NC, 3A
   Control mode: ON/OFF
   Power: 230VAC 50Hz +/- 10%
   Size: 96 x 96 x 85 mm DIN ABS Cabinet
   Panel cutout: 92 x 92 mm

4) Multipoint Temperature Indicator
   Input: RTD-PT100, 3 Wires
   Display: 3 1/2 Digit Red LED 3mm Height
   Range: 0 to 400 Deg.
   Power: 230V AC, 50 Hz.
   Size: 96 x 96 x 80 mm DIN
   Panel Cutout: 92 x 92 mm
   Model: MPTI

5) Electrical Heater
   Type: Emersion type
   Body: SS304
   Capacity: 1.5KW
   Power: 230VAC 50Hz

6) Pumps
   Type: Centrifugal
   Capacity: 1/5HP
   Discharge: 2000LPH
   Foot mounting
   Power: 250VAC 50 Hz
   Size: 1”

7) U tube manometer
   MOC: Acrylic
   Range: 250 – 0 - 250mm WC

8) Temperature Sensor
   Type: RTD-PT100 3 wire
   Assembly: Transition type
   Range: 0 to 300Deg C
   Diameter: 6mm
   Length: 100 mm
   Cable: 3mtr. Teflon/Teflon Cable

9) Rota meter
   MOC: Acrylic
   Range: 100-1000LPH
   Media: Water
   Connection: ½”
Float : SS316

10) **Power relay**
Power: 250VAC 50Hz
Output: 1NO
Size: Wall mounting

11) **Tanks in MS with powder coating Size: 400 x 350 x 350mm**

**C. Formulae use**

1) **Properties of hot water:** Calculated at mean bulk temperature
   \[ T_{bh} = \frac{Th_1 + Th_2}{2} \]
   Where
   \[ T_{bh} = \text{mean bulk temperature hot water in } ^\circ C \]
   \[ Th_1 = \text{inlet temperature of hot water in } ^\circ C \]
   \[ Th_2 = \text{outlet temperature of hot water in } ^\circ C \]
   \[ T_{bh} = \frac{335+325}{2} = 330^\circ C \]

2) **Properties of cold water**
   \[ T_{bc} = \frac{Tc_1 + Tc_2}{2} \]
   Where
   \[ T_{bc} = \text{mean bulk temperature cold water in } ^\circ C \]
   \[ Tc_1 = \text{inlet temperature of cold water in } ^\circ C \]
   \[ Tc_2 = \text{outlet temperature of cold water in } ^\circ C \]
   \[ T_{bc} = \frac{300+308}{2} = 304^\circ C \]

3) **Heat given by hot water**
   \[ Q_h = m_m \cdot C_{ph}(T_{h1} - T_{h2}) \]
   Where
   \[ Q_h = \text{heat given by hot water in } \text{kw} \]
   \[ m_m = \text{mass flow rate of water in } \text{kg/s} \]
   \[ C_{ph} = \text{specific heat of water at constant pressure in } \text{kJ/kg}^\circ C \]
   \[ T_{h1} = \text{inlet temperature of hot water in } ^\circ C \]
   \[ T_{h2} = \text{outlet temperature of hot water in } ^\circ C \]
   \[ Q_h = 0.1667 \times 4.187 (335-325) = 6.9797 \text{kw} \]

4) **Heat given by cold water**
   \[ Q_c = m_c \cdot C_{pc}(T_{c2} - T_{c1}) \]
   Where
   \[ Q_c = \text{heat given by cold water in } \text{kw} \]
   \[ m_c = \text{mass flow rate of water in } \text{kg/s} \]
   \[ C_{pc} = \text{specific heat of water at constant pressure in } \text{kJ/kg}^\circ C \]
   \[ T_{c1} = \text{inlet temperature of cold water in } ^\circ C \]
   \[ T_{c2} = \text{outlet temperature of cold water in } ^\circ C \]
   \[ Q_c = 0.1667 \times 4.187 (308-300) = 5.5837 \text{kw} \]

5) **Average heat transfer**
   \[ Q_{avg} = \frac{Q_h + Q_c}{2} \]
   \[ Q_h = \text{heat given by hot water in } \text{kw} \]
Q_c = heat given by cold water in kw

\[
Q_{avg} = \frac{6.9797 + 5.5837}{2} = 6.2817 \text{ kw}
\]

6) **Overall heat transfer coefficient**

\[Q_{avg} = U \cdot A_s \cdot \Delta T_m\]

Where

- \(U\) = overall heat transfer coefficient between two fluid w/m² °c
- \(A_s\) = effective heat transfer area m²
- \(\Delta T_m\) = approximate means of temperature difference

\[A_s = \frac{(\pi/4) \times d_i^2}{4} = 3.14 \times 0.0198^2 = 0.0003077\]

\[\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{335 - 325}{\ln(335/325)} = 2.2723 \text{°c}\]

\[Q_{avg} = U \cdot A_s \cdot \Delta T_m = 6.2817 \text{ kw} = U \times 0.0003077 \times 2.2723\]

\[U = \frac{8984.295 \text{KW/m}^2\text{°c}}{2.2723}\]

7) **Reynolds number**

\[Re = \frac{p v d_i}{\mu}\]

- \(p\) = density of water
- \(v\) = velocity of water
- \(d_i\) = diameter of inner pipe
- \(\mu\) = viscosity of water

\[\nu = \frac{V}{PA_s} = \frac{0.1667}{1000 \times 0.0003077} = 0.5417 \text{m/s}\]

\[Re = 1000 \times 0.05417 \times 0.0198 = 8.90 \times 10^4\]

\[= 12052.67\]

\[\Delta p = pg \Delta h = 1000 \times 9.8 \times 0.132 = 1293.6 \text{N/m}^2\]

For mass flowrate = 0.1667 kg/s

\[Re = 12052.67\]

\[Nui = 0.023 (Re)^{0.8} (Pr)^{0.3}\]

\[Nui = 0.023 (12052.67)^{0.8} (5.42)^{0.3} = 70.27\]

\[f = \frac{16}{Re} = 16/12052.67 = 0.00132\]

Same as calculate for all mass flow rate
For mass flowrate = 0.1667 kg/s
Re = 12052.67
\[ \frac{\text{Nui}}{h \cdot d} = \frac{4189.66 \times 0.0198}{0.6} = 138.26 \]

\[ f = \frac{\Delta p d_i}{2P \text{L}^2} \]

\[ f = \frac{1294.6 \times 0.0198}{2 \times 1000 \times 1.4 \times 0.5417^2} = 0.03197 \]

Same as calculate for all mass flow rate

Sample observation table 1.1

<table>
<thead>
<tr>
<th>Sr. no</th>
<th>Cold water Mass flow rate (m)</th>
<th>Cold water Inlet temp (°c)</th>
<th>Cold water Outlet temp (°c)</th>
<th>Cold water Mass flow rate (m)</th>
<th>Hot water Inlet temp (°c)</th>
<th>Hot water Outlet temp (°c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0833</td>
<td>300</td>
<td>308</td>
<td>0.0833</td>
<td>335</td>
<td>325</td>
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<tr>
<td>2</td>
<td>0.1112</td>
<td>300</td>
<td>308</td>
<td>0.1112</td>
<td>335</td>
<td>325</td>
</tr>
<tr>
<td>3</td>
<td>0.1388</td>
<td>300</td>
<td>308</td>
<td>0.1388</td>
<td>335</td>
<td>325</td>
</tr>
<tr>
<td>4</td>
<td>0.1667</td>
<td>300</td>
<td>308</td>
<td>0.1667</td>
<td>335</td>
<td>325</td>
</tr>
<tr>
<td>5</td>
<td>0.1945</td>
<td>300</td>
<td>308</td>
<td>0.1945</td>
<td>335</td>
<td>325</td>
</tr>
<tr>
<td>6</td>
<td>0.2223</td>
<td>300</td>
<td>308</td>
<td>0.2223</td>
<td>335</td>
<td>325</td>
</tr>
<tr>
<td>7</td>
<td>0.2361</td>
<td>300</td>
<td>308</td>
<td>0.2361</td>
<td>335</td>
<td>325</td>
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<tr>
<td>8</td>
<td>0.2561</td>
<td>300</td>
<td>308</td>
<td>0.2561</td>
<td>335</td>
<td>325</td>
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<tr>
<td>9</td>
<td>0.2638</td>
<td>300</td>
<td>308</td>
<td>0.2638</td>
<td>335</td>
<td>325</td>
</tr>
</tbody>
</table>

**TABLE 1.2 Plain tube**

<table>
<thead>
<tr>
<th>Sr. no</th>
<th>Mass flow rate (m)</th>
<th>Reynolds number (Re)</th>
<th>Nusselt number (Nu)</th>
<th>Friction factor (f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.0833</td>
<td>6022.53</td>
<td>40.34</td>
<td>0.00256</td>
</tr>
<tr>
<td>2.</td>
<td>0.1112</td>
<td>8039.93</td>
<td>50.83</td>
<td>0.00199</td>
</tr>
<tr>
<td>3.</td>
<td>0.1388</td>
<td>10035.45</td>
<td>60.69</td>
<td>0.00159</td>
</tr>
<tr>
<td>4.</td>
<td>0.1667</td>
<td>12052.67</td>
<td>70.27</td>
<td>0.00132</td>
</tr>
<tr>
<td>5.</td>
<td>0.1945</td>
<td>14062.65</td>
<td>79.50</td>
<td>0.00113</td>
</tr>
<tr>
<td>6.</td>
<td>0.2223</td>
<td>16072.63</td>
<td>88.47</td>
<td>0.00099</td>
</tr>
<tr>
<td>7.</td>
<td>0.2361</td>
<td>17070.39</td>
<td>92.83</td>
<td>0.00093</td>
</tr>
<tr>
<td>8.</td>
<td>0.2561</td>
<td>18516.42</td>
<td>99.07</td>
<td>0.00086</td>
</tr>
<tr>
<td>9.</td>
<td>0.2638</td>
<td>19073.15</td>
<td>101.26</td>
<td>0.00083</td>
</tr>
</tbody>
</table>
Table 1.3 Twist tape

Graph represent between Reynolds number and nusselt number of twist tape or without twist tape inserted in heat exchanger
In below figure
T.R represent the twist ratio
\[ \text{Twist ratio} = \frac{\text{pitch}}{\text{Width of tape}} \]
C. **Above Figure**

plot between Nusselt number and Reynolds number for without twist tape and twisted tape with various twisted ratio inserted, concludes that nusselt number and Reynolds number. Nusselt number rise with rise in reynolds number; hence rate of convective heat transfer is more with higher reynolds number. Further, it can concluded that, twisted tapes with higher twist (with lesser twist ratio) give increase nusselt number for particular reynolds number. heat transfer rate is batter with twisted tape of lower twist ratio.

Graph between renold number and fraction factore is shown below

![Graph between renold number and fraction factore](image)

Heat exchanger modelling and analysis are carried out on ansys workbench Above figure plot drawn between factor of friction and Reynolds number with varying twisted tape ratio, one can easily observe the change fraction factor with varying twisted ratio with increase in fraction, Reynolds number also increase.

D. **Cfd analysis**

1) **Modelling**: Start ANSYS WORKBENCH

![Fig model of heat exanger](image)

First we describe part of model with dimension

2) **wisted Tape**

![Fig model of heat exanger](image)

Dimension of twisted tape
- Length of twist tape: 1.4m
- Pitch of twisted tape: 4.2mm
Cross section of twisted tape rectangular (0.7x0.5)

Procedure for twisted tape 
For this open the Ansys workbench, and select the x-y plane, then drawing rectangle 0.7*0.5, after that again taken y-z plane making second sketch drawing line start with centre of rectangle with length is 1.4m and exist 2d work bench go modelling sweep command use, for this select the first profile as rectangle then select line as path, then go twist and given the pitch 40 mm, the generate

diameter of the tube : 0.0198m

tube thickness : 0.0028m

D. Procedure
For this select x-y plane and making circle with diameter is 0.0198m, again drawing circle with diameter 0.0226m in same sketch, then extrude with frozen with height 1.4m the generate

Fluid filling in outer tube 
Fill outer tube with cold fluid as shown as belo Then we describe of outer tube filling fluid figure shown in below

E. Use Boolean operation
Here subtract Boolean Operators is used from outer fluid to inner fluid as shown in below

F. Meshing
After complete geometry, we need to mesh of the model figure shown in below
Fig 3.14 meshing of model Mesh outer edge

Fig 3.15 Mesing of outer Edge

All part meshing shown below

Fig 3.16 mesing of whole model 1.no of node 30933 2. elements no 58496

G. Processing
After the completion of meshing the design in ANSYS Fluent, fluent boundary conditions are given as per requirement and solution is initialized and calculation are iterated. After the calculation is converged, the contours are to be plotted. The Boundary conditions are under taken below:

Fluid domain is to be specified
Temperature
At inlet
Hot fluid – water (335k)
Cold fluid – water (300k)
In the analysis report the mainly reynolds number, pressure, velocity, temperature contour to be viewed the result obtain are to be tabulated

Boundary specifications
Outer surface: Adiabatic outer wall
Twist tape: wall
   Outer pipe: wall
   Inner pipe: wall
Cold water inlet: velocity
Hot water inlet: velocity
Cold water outlet: pressure outlet
Hot water outlet: pressure outlet
Cold domain: mass flow
Hot domain: mass flow

II. RESULTS AND DISCUSSION

First we compare temperature of cold fluid outlet with twist tape and without twist tape shown in below

With twist tape

![Contour of Static Temperature](image1)

Fig 4.1 temprature of hot fluid outlet with twisted tape inserted

B. Without twist tape

![Contours of Wall Temperature](image2)

Fig 4.2 Temprature of hot fluid outlet without twisted tape
in the above figure we can observe that the Reynolds number is increasing from inlet to outlet of the heat exchanger to the outlet of heat exchanger. This is because of the reason that during the flow of fluid over the twisted tape a disturbance is created in flow thus turbulence is created. This result is increase of the Reynolds number.
In above two figure the reynolds no of the hot fluid at inlet and outlet of heat exchanger .we observe that there is no much difference in the value , they remain almost constant .this is due to no turbulent in the flow

<table>
<thead>
<tr>
<th>Sr.no</th>
<th>Mass flow rate(m)</th>
<th>Reynolds number(Re)</th>
<th>Nusselt number(Nu)</th>
<th>Friction factor (f)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.2638</td>
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<td>171.8</td>
<td>0.01245</td>
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</table>

Fig 4.6 Reynolds number at outlet in heat exchanger without twist tape

Fig 4.8 velocity vector of heat exchanger with twisted tape
The above figure shown that the velocity & direction of the fluid element during the flowing of heat exchanger (with twist tape). We can observe that there is a rise in velocity of the fluid element when moving from inlet to the outlet this is due to the swirl created by the twisted tape.

The result obtain from CFD analysis are shown below

<table>
<thead>
<tr>
<th>Sr. no</th>
<th>Mass flow rate(m)</th>
<th>Reynolds</th>
<th>Nusselt</th>
<th>Friction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kg/s)</td>
<td>number(Re)</td>
<td>number(Nu)</td>
<td>(f)</td>
</tr>
<tr>
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<td>40.34</td>
<td>0.00256</td>
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<tr>
<td>2.</td>
<td>0.1112</td>
<td>8039.93</td>
<td>50.83</td>
<td>0.00199</td>
</tr>
<tr>
<td>3.</td>
<td>0.1388</td>
<td>10035.45</td>
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<td>0.00159</td>
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<tr>
<td>4.</td>
<td>0.1667</td>
<td>12052.67</td>
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<td>0.00132</td>
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<td>5.</td>
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<td>101.26</td>
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</tr>
</tbody>
</table>

Comparision is made between CFD analysis and experimental analysis for with and without twisted tape inserted

### III. CONCLUSION

CFD analysis is carried out by taking double pipe heat exchanger with cold and hot fluids with different boundary conditions by incorporating twist tape inserts. It can be concluded as follows: By using passive techniques that is by inserting twist tape inserts the heat transfer enhancement increased by 10–15% with the cost of reasonable allowable pressure drop. In this report we achieved enhancement of heat transfer effectively. Future work may be extended to:

A. Combination of techniques may be used to enhancement of heat transfer coefficient by compound techniques
B. Reduce the width of twist tape inserts with low Reynolds number
C. By varying low Reynol

### REFERENCES
