CFD ANALYSIS ON HEAT TRANSFER ENHANCEMENT IN A PIPE IN PIPE HEAT EXCHANGER WITH TANGENTIAL INJECTION

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Abstract: - Heat transfer enhancement is a significant requirement in process industries. There are various passive and active methods available to reinforce the heat transfer. In the present study, tangential injection and its effect on the advancement in heat transfer rate are analysed. This is an active technique for enhancing heat transfer accompanied by negligible increment in pressure drop. Design and operating parameters like geometry, pipe material, working fluid, and flow rate play a vital role in heat transfer characteristics. Taking into account the design and operating parameters, the present study is aimed to optimize the orientation of the injecting nozzle. FLUENT software is employed to simulate the heat transfer and flow characteristics. A thorough grid independence study has been administered, and the present results are validated using the author’s previous experimental work. The tangential orientation considered is 30°, 45°, and 60°. The results show 60° inclination of the nozzle for parallel flow gives maximum overall heat transfer coefficient.

Keywords: Heat Exchanger, Tangential Injection, Heat Transfer Enhancement

1. INTRODUCTION

The heat exchanger is a device used for efficient heat transfer between multiple mediums which are at different temperatures. Heat exchanger employs the fact that energy flow occurs whenever there is a temperature difference between two mediums. So, the thermal energy flows from high energy medium to a low energy medium. They are widely employed in refrigerators, air conditioners, power plants, chemical process industry, food processing industry, and ice making plants. The general sample of a heat exchanger is car radiator which works as an across flow heat exchanger which takes away the heat energy from the coolants and gives away the heat to the environment, it works as a cooling device in cars.

A. Classifications of heat exchanger
Classification according to construction:
1. Tubular-Pipe in Pipe, Shell & tube, Spiral tube
2. Plate type
3. Extended surface
4. Regenerative

B. Pipe in pipe heat exchanger
A simplest heat exchanger is a circular duct inside another larger circular duct as shown in Figure 1, where one fluid flows through the inner duct and the other fluid flows over the annulus space between the two ducts. The wall between the two fluids acts as a heat transfer surface. It can be operated as parallel flow as well as counter flow, but the counter flow gives more efficiency.
C. Heat transfer improvement techniques

Heat transfer improvement techniques are very crucial for laminar flow as the heat transfer rates are low for laminar flow in a plane duct. The heat transfer rate can be typically enhanced by instigating turmoil in the flow which can be attained by including twisted tape or turbulator inserts in the duct. The Enhancement techniques can be divided into three different categories:

1. Passive Techniques.
2. Active Techniques.
3. Compound Techniques.

Passive technique uses internal design modification by introducing inserts or other obstacles. The inserts or obstacles introduce disturbance in the fluid flow results in increase in the heat transfer coefficient with the consequence of pressure drop. Due to the extended surface the heat transfer area increases. In the Passive Technique no external power is required. The heat transfer improvement by this technique can be attained by using:

- Inserts
- Treated Surfaces
- Rough surfaces
- Extended surfaces
- Additives for liquids

The active technique is much compound when it comes to designing the heat exchanger it as it requires external power for fluid input to give improved flow pattern to enhance the heat transfer rate. It has limited applications due to the requirement of external sources. Enhanced heat transfer rate by active technique can be attained in the following ways:

- Mechanical Aids
- Surface vibration
- Fluid vibration
- Electrostatic fields
- Injection
- Jet impingement

The compound technique represents the amalgamation of active or passive technique with the sole objective to provide an improved thermohydraulic effect on heat exchanger.

Different works have been done by numerous specialists on heat transfer augmentation in heat exchanger. Akpinkar et al. [1] experimentally studied the pipe in pipe heat exchanger with a swirl generator at the inlet. The heat transfer rate in the heat exchanger with a swirl generator is 30 % more compared to the normal pipe. He concluded the pipe gives a higher heat transfer rate with a number of holes with a smaller diameter. Baig M et. al. [2] experimentally studied a concentric tube heat exchanger with twisted tape, twisted tape with a hole, and baffles to increase the heat transfer rate. It
can be concluded that, there is an 8.9% more heat transfer rate with twisted tape inserts, while inserts with hole and baffles gives a slighter rate compared to simple twisted tape. [2] Jawarneh [3] experimentally studied the system by giving swirl motion at the entrance of the pipe in the annulus space, from the experiment it is concluded that the swirls parameter at the entrance of the pipe have positive effect on the heat transfer characteristics. Swirl motion give better mixing of the fluid. The thermal and fluid property in the annular space was studied by finite volume method. Vijay K. Dhir et. al. “experimentally investigated a process for improving the efficiency of heat exchanger in which multiple tubes are arranged in one tube and incorporating injectors along the circumference to give tangential flow at the inlet. The injectors are provided to each of the inner tubes along the circumference to give tangential flow to the fluid. A notable improvement in the heat transfer rate was noticed due to modification in the design.” [4]. Kreith et.al. [5] experimentally investigated the heat transfer enhancement in double tube heat exchanger using inserts which increase the Nusselt Number by 25%. Abdullah [6] experimentally studied the double pipe heat exchanger with convergent divergent with twisted tape insert which and concludes that the concentric convergent and divergent profile and twisted tape was 52% to 280% greater than the plain heat exchanger. Chang et al. [7] experimentally investigated the heat transfer in pipe having a tangential injection of air through the nozzle having a uniform the temperature at the outer pipe, he concluded that tangential injection gives swirl motion to the fluid results in an increase in performance.

From the above literature it can be perceived that turbulence in fluid flow gives more heat transfer rate. The method with insert and system with tangential injection was studied from which twisted tape gives high heat transfer rate with an increase in pressure drop. The working fluid can be water, air, or any nanofluids. The rate of increase of heat transfer rate depends on Nusselt number and the mass flow rate or Reynolds number, it also depends on the material used, geometric structure, twist ratios in inserts, etc.In the present scenario, the productivity is a key strategy’s for the manufacturing industries to compete in the competitive world or in the global markets. The main aim to achieve increase the productivity with the availability of the raw materials and some of the very good high precession technologies and maintenance system used in the world-class industries.

2. PROBLEM STATEMENT

Heat transfer improvement in a pipe in pipe heat exchanger with multiple tangential entries through the nozzle at different angles along the length of the pipe with water as a working fluid.

3. COMPUTATIONAL DOMAIN/GEOMETRY

Cylindrical concentric pipe heat exchanger with pipe made of aluminium is used as an inner pipe, PVC as an outer pipe having insulation at the top with water used as a working fluid. The fluid is injected in the annulus space with the nozzles on the outer pipe with cold fluid as inlet and inner pipe having hot fluid as working a medium. Six nozzles are used as a cold fluid inlet.

Length-1000 mm  Outer radius-21.08 mm
Inner radius-10.75 mm  Nozzle Diameter- 4.5 mm  No. of Nozzles- 6
4. MATHEMATICAL MODEL

The flow in the pipe is considered as incompressible, turbulent, and steady. The heat transfer between the hot water to the cold region is modelled as conjugated heat conduction with fluid flow. The wall material and working fluid properties were fixed depending on the working temperature, and the vapor density of the working fluid followed the perfect-gas law.

The elliptic class of the conservation equations are solved as a single domain conjugate problem. Body force and gravity terms were neglected.

It follows mass, momentum and energy conservation equations.

Mass Conservation Equation
\[ \nabla \cdot \vec{V} = 0 \]  
\[ \text{Momentum Equation} \]  
\[ \rho (\nabla \cdot \vec{V}) = -\nabla p + \nabla \cdot (\mu \nabla \vec{V}) \]  
\[ \text{Energy Equation} \]  
\[ \rho C_p (\nabla \cdot \vec{V}) = k \nabla^2 T \]  

Heat Transfer in hot and cold fluid section
\[ Q_h = m_h \times C_{ph} \times (T_{hi} - T_{ho}) \]  
\[ Q_c = m_c \times C_{pc} \times (T_{co} - T_{ci}) \]  

Log mean temperature difference
\[ \Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln \left( \frac{\Delta T_1}{\Delta T_2} \right)} \]  
Where,
\[ \Delta T_1 = T_{hi} - T_{ci} \]  
\[ \Delta T_2 = T_{ho} - T_{co} \]  

Overall heat transfer coefficient
\[ U_o = \frac{Q_{avg}}{A \times \Delta T_m} \]  
Where,
\[ A = \pi \times d_o \times L \]

\[ V = \text{Volume (m}^3) \]  
\[ k = \text{Thermal Conductivity} \]  
\[ C_p = \text{Specific Heat (j/K)} \]  
\[ \rho = \text{Density (kg/m}^3) \]  
\[ m_h, m_c = \text{Mass flow rate} \]  
\[ T_{hi} = \text{Hot inlet temperature (K)} \]  
\[ T_{ho} = \text{Hot outlet temperature (K)} \]  
\[ T_{co}, T_{ci} = \text{Cold fluid inlet and outlet Temperature} \]  
\[ A = \text{Surface Area (m}^2) \]  
\[ \Delta T_m = \text{LMTD} \]  
\[ U_o = \text{Overall Heat Transfer Coefficient} \]

5. SIMULATION SETUP AND BOUNDARY CONDITION

Flow and turbulent equations are solved simultaneously to capture the flow field. The energy equation is solved to obtain the temperature field. Appropriate thermophysical properties are assigned for the fluids. Hot fluid flows through the inner pipe with a constant 300 LPH flow rate whereas cold fluid flows through the annular space with flow rate varying from 300 LPH to 600 LPH. The pressure outlet condition is given at the outlet for both cold and hot fluids. The outer pipe is insulated to prevent heat loss.
6. RESULTS AND DISCUSSION

Temperature distribution along the length of the pipe. With hot fluid inlet 0.1111 kg/s and outlet fluid inlet as 0.125 kg/s. Thermal and Material properties were defined for each material from property chart.

The thermal energy from the hot fluid through aluminium pipe transfers to cold fluid which results in an increase in the temperature of the cold fluid. LMTD is calculated by the outlet and inlet temperatures of cold and hot fluids respectively. Averaged heat transfer coefficient values are calculated at the surface using CFD post and related temperature variation graphs were plotted.

Figure 3 shows the temperature distribution on the mid plain of the pipe the inner tube temperature decreases along the length and the temperature of cold water increases through the length of the pipe in annulus space. Figure 4 shows the streamline through the annulus space showing a swirl motion around the hot pipe to extract more heat when compared to the normal fluid flow.

Figure 5 display the validation of numerical results using experimental results taken at nozzle with an inclination of 60° with a parallel flow configuration which gives a maximum deviation of 2.17% for 600 LPH cold water flow rate.

Figure 6 shows the comparison of overall heat transfer coefficient with flow rate for tangential nozzle inclined at 60° configuration. It is noticed that, the average overall heat transfer coefficient increases, with the increment in mass flow rate. For 60° angle tangential entry for parallel flow give more overall heat transfer coefficient compared to counter flow, for higher Reynolds number the overall heat transfer coefficient is almost the same with a small deviation.
Figure 5: Validation of numerical results with experimental results at 60° inclination parallel flow.

Figure 6: Correlation of overall heat transfer coefficient with flow rate at 60° inclination at cold inlet.

Figure 7: Correlation of overall heat transfer coefficient with flow rate at 30° inclination at cold inlet.

Figure 8: Correlation of overall heat transfer coefficient with flow rate for 45° inclination at cold inlet.

Figure 9: Correlation of overall heat transfer coefficient with flow rate for parallel flow at different inclination angle at cold inlet.

Figure 10: Correlation of overall heat transfer coefficient with flow rate for counter flow at different inclination angle at cold inlet.
**Figure 7** shows the correlation of overall heat transfer coefficient with the flow rate for the tangential nozzle inclined at 30° configuration. It is noticed that, the overall heat transfer coefficient increase with the increment in mass flow rate. For 30° angle tangential entry, counterflow gives a more overall heat transfer coefficient to that for parallel flow at lower flow rate. Overall heat transfer coefficient is almost the same with a small deviation with the increment in mass flow rate. A little hike in the overall heat transfer coefficient for 550 LPH for counter flow is observed.

**Figure 8** shows the correlation of overall heat transfer coefficient with the flow rate for tangential nozzle inclined at 45° configuration. It is noticed that, the average overall heat transfer coefficient increases with the increment in mass flow rate.

**Figure 9** shows the correlation of overall heat transfer coefficient with flow rate for tangential nozzle inclined for parallel flow configuration. It is noticed that, the average overall heat transfer coefficient increases with the increment in mass flow rate. While comparing with different inclination angles, parallel flow at 60° gives 2.7 % more overall heat transfer rate than 45° inclination and 11.66 % more than 30° inclination.

**Figure 10** shows the correlation of overall heat transfer coefficient with flow rate for tangential nozzle inclined for counterflow configuration. It is noticed that, the average overall heat transfer coefficient also increases with the increment in mass flow rate. For counterflow the efficiency is more for 60° angle of injection compared to 45° and 30°, it gives 10.8 % more overall heat transfer coefficient matched with 30° inclination.

### 7. CONCLUSION

Overall heat transfer rate can be augmented by giving turbulence inflow which gives better mixing and gives more convective heat transfer coefficient. From the present and previous studies, it can be concluded that heat exchanger with tangential injection gives 35.95 % more heat transfer coefficient than simple circular duct heat exchanger for parallel flow configuration and gives 33.58 % for counterflow configuration. Whereas, 60° parallel flow configuration gives more heat transfer coefficient compared to other computed cases like 30° and 45° (both parallel and counter flow configuration) and also this 60° configuration gives a maximum of 10.8% more overall heat transfer coefficient than 300 configuration.

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