CFD Simulation of Triangular Shape and Circular Shape Concentric Triple Tube Heat Exchanger

Abstract. In the current study, the investigation of heat transfer and fluid flow characteristics of pure water when pass through an inner annulus triangular shape and circular shape triple tube heat exchanger (CTTHX). This investigation has been conducted across various Reynolds number to gain insights into their performance also conducted a computational fluid dynamics (CFD) simulation using the ANSYS-FLUENT software. Result obtained was validated by comparing to empirical correlation data found in the existing literature. The investigation considered various operating variable as Reynolds Number and temperature across the inner, intermediate, and outer tubes. Specifically, the Reynolds Number of 2000 at 305 K, a range of 2000 to 4500 at 340 K, and 2000 at 295 K for the respective tubes. Key findings are that friction factor of triangular shape is increase by 10.5% and for circular shape by 2.69% as compared to correlation in existing literature. And Nusselt number (Nu) for triangular shape increase by 39.19% and for circular shape by 13.30% as compared to correlation in the range of Reynolds Number (Re) from 2000 to 4500. The effectiveness was increased by 16.67% and 7.6% for triangular shape and circular shape respectively as compared to existing literature.

Keywords: CFD, Thermal performance, Concentric, Triple Tube Heat Exchanger.

1. Introduction

to extract. If the current population growth rate continues, we’ll need 50 percent more energy to sustain life application to meet the today’s demand of energy

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The triple tube heat exchanger, formed by adding an intermediate tube, outperformed the double concentric fluid heat exchangers enabling efficient thermal energy exchange between either identical or distinct fluid streams. Through numerical analysis, researchers demonstrated that utilizing the triple tube heat exchanger yields a higher heat transfer rate compared to the double tube configuration. The results revealed an 18% increase in the percentage of combustion heat transferred in the cold heat exchanger's thermal performance is optimized with higher rib height, smaller rib pitch, and greater nanoparticle concentration, while energy efficiency is achieved with smaller rib height, lower rib pitch, and highest nanoparticle concentration.

2. Material and Methods
2.1 Definition of Heat Exchanger and nanofluids

![Diagram of heat exchanger flows](image)
2.2 Design Modular Geometry of triangular triple tube heat exchanger

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner tube inner diameter(di,i)</td>
<td>22mm</td>
</tr>
<tr>
<td>Inner tube outer diameter(di,o)</td>
<td>30mm</td>
</tr>
<tr>
<td>Middle tube inner side(Sm,i)</td>
<td>34mm</td>
</tr>
<tr>
<td>Middle tube outer side(Sm,o)</td>
<td>47mm</td>
</tr>
<tr>
<td>Outer tube inner diameter(do,i)</td>
<td>70mm</td>
</tr>
<tr>
<td>Outer tube outer diameter(do,o)</td>
<td>78mm</td>
</tr>
<tr>
<td>Length of heat exchanger(L)</td>
<td>500mm</td>
</tr>
</tbody>
</table>

Figure 2: 3D Design Modular Geometry.

2.3 Data calculation methodology

The computed variables and parameters are used to analyse the friction factor and Nu number in the TTHX when nanofluids are used [26-28]. These variables provide detailed insights into the data results.

The following formula can be taken to express the heat quantities for the TTHX's cold, normal, and hot fluid sides:

\[ Q_\text{h} = \dot{m}_h \cdot c_h (T_{h0} - T_{hi}) \] (1)

\[ Q_\text{c} = \dot{m}_c \cdot c_c (T_{c0} - T_{ci}) \] (2)

\[ Q_\text{n} = \dot{m}_n \cdot c_n (T_{n0} - T_{ni}) \] (3)

\[ Q_{\text{avg}} = \frac{Q_\text{h} + Q_\text{c} + Q_\text{n}}{3} \] (4)

\[ Nu = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\sqrt{\frac{f}{8}}(Pr^{\frac{3}{2}} - 1)} \] (6)

Where \( f = (1.82 \log Re - 1.64)^{-2} \) (7)
\[
\frac{Q_{av}}{Q_{max}} = \frac{Q_{av}}{mc_{min}(T_{hi} - T_{ci})} \tag{8}
\]

2.4 Numerical CFD modelling

In the pursuit of unveiling the enigmatic heat transfer and fluid flow characteristics of the remarkable TTHX (Triple Tube Heat Exchanger), the governing equations find solace through the meticulous application of FVM. The study employed a FVM with a (RNZ)k-ε turbulence model for simulating turbulent flows, accounted for conjugate heat transfer, used a pressure-velocity coupling method with the SIMPLE algorithm, applied a standard pressure discretization scheme, and utilized second-order upwind schemes to solve momentum and energy equations [29-31]. This comprehensive numerical approach allowed for investigation of the fluid flow characteristics and heat transfer within the TTHX, taking into consideration the complex interplay between heat transfer and fluid flow.

2.5 Grid Generation

Mesh generation is the process of dividing the computational domain into a number of distinct regions known as control volumes [32-34]. These control volumes serve as the focus of seeking the solution within the domain. In this work, we have generated a structured mesh. It is a grid or network of geometrically regular and interconnected cells or elements that cover a physical domain. Each cell in a structured mesh is typically of the same shape (e.g., quadrilaterals in 2D or hexahedra in 3D), and the arrangement of cells follows a well-defined pattern or structure.

Table 2

<table>
<thead>
<tr>
<th>Mesh matrix</th>
<th>No. of elements</th>
<th>Maximum skewness</th>
<th>Elemental quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>0.6</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A 3D view of meshing is shown in figure 3 and mesh description is available in table 2 in which number of elements, maximum skewness and Elemental quality are tabulated.

3. Result and Discussion
The heat transfer rate was optimized, ensuring effective exchange between the hot and cold fluids. The pressure drop was within acceptable limits, indicating smooth flow. Additionally, the temperature distribution analysis helped identify areas for potential improvement and achieving a more uniform heat distribution. These findings contribute to enhancing the heat exchanger’s design and industrial applications.

3.1) Validation and Verification of Data for TTHX

As the Re Number increases, the f decreases. This is because the Re number represents the ratio of inertial forces to viscous forces in a fluid flow. At higher Reynolds numbers, inertial forces dominate over viscous forces, resulting in a smoother flow with lower friction. Essentially, the fluid particles are better able to overcome resistance and move more freely through the system, causing a reduction in friction. This phenomenon can be attributed to the fluid’s increased ability to maintain momentum and exhibit more streamlined behaviour. At a Reynolds Number (Re) of 2500 a 2.69\% and 10.5\% deviation occur for circular shape and triangular shape respectively from the correlation in existing literature.

3.2) Nusselt number for TTHX

When the Re number increases, the Nu number also tends to increase. The Nusselt number is a nondimensional parameter that relates the convection heat transfer rate to the conduction heat transfer rate in a fluid flow. As the Re number increases, the flow becomes more turbulent and chaotic. This turbulence promotes better mixing and increase the convective heat transfer. fluid flows in a manner that creates eddies and swirls, increasing the contact between the fluid and the solid surface. This increased contact area allows for more efficient heat transfer. Furthermore, the higher Reynolds number leads to the formation of a thinner boundary layer, which is the region of flow closest to the solid surface where velocity changes occur. A thinner boundary layer implies reduced thermal resistance and improved heat transfer. Nusselt number (Nu) for triangular shape increase by 39.19\% and for circular shape by 13.30\% as compared to correlation in the range of Reynolds Number (Re) from 2000 to 4500. Overall, the increased turbulence, improved mixing, larger contact area, and thinner boundary layer that accompany higher Reynolds numbers result in greater convective heat transfer. Consequently, the Nu number improve as the Re number increases.
The effectiveness of a heat exchanger tends to reduce with an improvement in Re number. The effectiveness of a heat exchanger refers to its ability to transfer heat efficiently between two fluids. At higher Re numbers, the flow inside the heat exchanger becomes more turbulent and chaotic. Turbulence enhances convective heat transfer but also increases pressure drop and fluid mixing. Turbulence results in a reducing the temperature difference between the two fluids, reducing the overall effectiveness of heat transfer. The turbulent flow causes a higher rate of heat transfer near the surface of the heat exchanger, but it also leads to increased resistance to flow and reduced thermal gradients. Consequently, the temperature driving force for heat transfer diminishes, resulting in less efficient heat exchange between the fluids. Additionally, the increased turbulence can lead to flow maldistribution, where the fluid distribution becomes uneven across the heat exchanger's surface, further impacting heat transfer effectiveness.

3.3) Effectiveness of TTHX

![Graph showing Nusselt Number vs Reynolds Number](image)

![Graph showing Effectiveness vs Reynolds Number](image)
and circular shape respectively as compared to existing literature. Overall, the rise in Reynolds number leads to increased turbulence, reduced temperature gradients, flow maldistribution, and greater pressure drop, all contributing to a decrease in the effectiveness of the heat exchanger.

3.4) Temperature Contour for TTHX

![Temperature Contour for TTHX](image)
Figure 7-10 has shown about the temperature contour of TTHX. In a heat exchanger, the temperature distribution refers to how the temperature varies across the heat exchanger's surfaces and the fluids flowing through it. As the fluids flow through the exchanger, heat is transferred between them. This results in a gradual change in temperature along the flow path. The temperature distribution depends on the heat exchanger design, flow rates of the fluids, $Nu$, and the thermal properties of the fluids. Achieving a uniform temperature distribution is desirable to ensure efficient heat transfer and to prevent thermal gradients that could lead to thermal stress or inefficiencies in the system.

As the Reynolds number increases in a heat exchanger, the temperature change becomes less significant. Higher Reynolds numbers correspond to increased fluid turbulence, which enhances heat transfer but also reduces the hot and cold fluids temperature gap. This decrease in temperature change can limit the overall effectiveness of heat exchange in the system.

4. Conclusion

The hot and cold water flow in a triple tube heat exchanger facilitates effective heat transfer between the two fluids. The arrangement of the triple tube design allows for enhanced thermal efficiency. The hot water flows through the inner tube, transferring its heat to the surrounding cold water flowing in the annular space between the inner and outer tubes. This configuration maximizes the surface area for heat exchange and promotes efficient energy transfer.

The counter-current flow configuration improves heat transfer even more by maintaining a temperature gradient down the length of the exchanger. Overall, the triple tube heat exchanger design promotes efficient heat exchange between the hot and cold water streams. The specific conclusions are listed below:

• Friction factor of triangular shape is increased by 10.5% and for circular shape by 2.69% as compared to correlation in existing literature.
• Nusselt number ($Nu$) for triangular shape increases by 39.19% and for circular shape by 13.30% as compared to correlation in the range of Reynolds Number ($Re$) from 2000 to 4500.
References:


