HEAT TRANSFER STUDIES IN WAVY CORRUGATED PLATE HEAT EXCHANGERS

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ABSTRACT

In the present investigations heat transfer studies are made in three different types of corrugated plate heat exchangers having corrugation angles 30°, 40° and 50°. Water and Glycerol (40%, 50% and 60%) are taken as test fluid and water as the heating medium. The wall temperatures are measured along the length of the heat exchanger at seven different locations by means of thermocouples. The inlet and outlet temperatures of the test fluid and hot fluid are measured by means of four more thermocouples. Nusselt number is calculated from the experimental observations by calculating film heat transfer coefficient. These values are compared with different Reynolds numbers as well as corrugation angles. It is found from the experimental investigations that increase in corrugation angle has resulted in higher Nusselt’s number for a given Reynolds number and hence higher heat transfer rates. It is also found that 60% glycerol has higher heat transfer compared to 50%, 40% and water.

Keywords: Corrugated Plate Heat Exchanger, Corrugation Angle, Thermocouples, Heat Transfer Coefficient, Nusselt Number And Reynolds Number.

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1. INTRODUCTION
The purpose of the heat exchanger is to enhance the rate of heat exchange between different fluids. The rate of heat transfer can be increased by creating a large surface area for heat exchange, by increasing the driving force (i.e., temperature difference between hot & cold fluid), by increasing the time of heat exchange, by using cross current flow of fluids, by increasing the turbulence in fluids and so on. At present, a lot of research is being done on increasing the surface area for heat exchange as a part of which we have used the corrugated plate heat exchanger [3], [4]. The reason being in corrugated plate heat exchanger there is an enhanced surface area for heat transfer and increased turbulence level due to the corrugations. Pandey et. al. [2] conducted experiments to determine the heat transfer characteristics for fully developed flow of air and water flowing in alternate corrugated ducts. A test section was formed by three identical corrugated channels having corrugation angle of $30^\circ$ with cold air flowing in the middle one and hot water equally divided in the adjacent channels. He obtained various correlations of Nusselt number for water and air.

In this study the flow of fluid is operated in counter current flow pattern which gives approximately the same efficiency as given by cross current flow of fluids. The experiments were carried to study the variation of heat transfer characteristics of Glycerol and Water as test fluids in wavy type corrugated plate heat exchangers which have three different corrugation angles ($30^\circ$, $40^\circ$ and $50^\circ$). The obtained experimental data was used to plot the Nusselt number versus the Reynolds number to study the effect of corrugation angle on heat transfer rate for different concentrations of Glycerol (60%, 50% and 40%). The range of Reynolds number is found to be 126 to 6500 and that of Nusselt number was found to be 1 to 980.

2. EXPERIMENTAL METHODOLOGY AND MATERIALS USED

2.1 EXPERIMENTAL SETUP
The experiments were conducted on the setup shown in Fig.1 and the setup consists of a test box, test fluid tank, test fluid collection tank and hot water tank. Each test box consists of two wavy corrugated plates welded together to form a horizontal channel. The flow through these two channels is controlled using Rotameters. The flow pattern is countercurrent. The setup is fitted with thermocouples to measure wall temperature at different locations and for the measurement of fluid temperatures at inlets and outlets.

<table>
<thead>
<tr>
<th>TABLE 1 Dimensions of the corrugated plate heat exchanger test box.</th>
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</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Test fluid channel spacing</td>
</tr>
<tr>
<td>Corrugation angles</td>
</tr>
</tbody>
</table>
The corrugated plate consists of three layers forming two channels, one for the test fluid (cold) and the other for the hot fluid. The cold fluid flows through the bottom section and the hot fluid flows through the upper section. The corrugation angle is taken with reference to the horizontal plane as shown in the below Fig.3, where $\theta$=different angles of corrugations ($30^0$, $40^0$ and $50^0$).
2.2 MATERIALS USED
The test fluids used for the experimentation are Glycerol of different concentrations and water.

<table>
<thead>
<tr>
<th>TABLE 1 The properties of the test fluids are given below.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPERTIES AT 35°C</td>
</tr>
<tr>
<td>DENSITY (kg/m³)</td>
</tr>
<tr>
<td>VISCOSITY (NS/m²)</td>
</tr>
<tr>
<td>THERMAL</td>
</tr>
<tr>
<td>CONDUCTIVITY (W/m-K)</td>
</tr>
<tr>
<td>SPECIFIC HEAT(KJ/Kg-k)</td>
</tr>
</tbody>
</table>

3. EXPERIMENTAL PROCEDURE
For all the experiments, hot water temperature and flow rate are maintained constant for heating test fluids. For each experimental reading, the inlet and outlet temperature of the fluids, as well as the wall temperatures are noted with the help of thermocouples. The test fluids are pumped into the bottom channel through the rotameter with different flow rates. For all heat transfer studies film heat transfer coefficient \( h_i \) is calculated by making an energy balance with the logarithmic mean temperature difference.

4. RESULTS & DISCUSSIONS:
The film heat transfer coefficient has been calculated by taking energy balance equation as given below.

Heat gained by test fluid, which can be written as

\[ Q = \dot{m} \cdot C_p \cdot \Delta T \]  

Where \( \dot{m} \) = mass flowrate of the test fluid,
\( C_p \) = Specific heat of the test fluid,
\( \Delta T \) = difference in cold fluid inlet and outlet temperatures.

Amount of heat is given by Newton’s Law of Cooling as

\[ Q = h_i \cdot A \cdot (\Delta T)_m \]  

Where \( h_i \) = film heat transfer coefficient,
\( A \) = area of heat transfer ,
\( (\Delta T)_m \)=logarithmic mean temperature difference.

\[ (\Delta T)_m = \frac{\left( T_{avg, C \text{in}} - T_{avg, C \text{out}} \right)}{\ln \left( \frac{T_{avg, C \text{in}}}{T_{avg, C \text{out}}} \right)} \]

From (1) & (2), film heat transfer coefficient can be calculated as,

\[ h_i = \frac{(\dot{m} \cdot C_p \cdot \Delta T)}{(A \cdot (\Delta T)_m)} - \]  

The above obtained film heat transfer coefficient is used to calculate the Nusselt’s number.

Reynold’s number is calculated from the below formula,

\[ Re = \frac{d_{eq} \cdot v \cdot \rho}{\mu} \]  

Where \( d_{eq} \) is the equivalent diameter,
\( v \) is the velocity of the test fluid,
\( \rho \) is the density of the test fluid,
\( \mu \) is the viscosity of the test fluid.

Equivalent diameter can be calculated from the below formulae as,

\[
d_{eq} = \frac{wb}{w+b}
\]

where, \( b \) = breadth of the channel
\( w \) = width of the channel

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The experimental data has been used to plot the Nusselt number vs Reynolds number graphs.

Nusselt number is plotted against Reynolds number for different corrugation angles for each concentration of glycerol and for water.

**Figure 4** Nu vs Re comparison for 40\% glycerol.

For 40\% glycerol the heat transfer is found to be higher for 50\(^0\) corrugation angle and lower for 30\(^0\) corrugation angle. R-square values were found to be ranging from 0.9802 to 0.9955.

**Figure 5** Nu vs Re comparison for 50\% glycerol.
For 50% glycerol the heat transfer is found to be higher for 50° corrugation angle and lower for 30° corrugation angle. R-square values were found to be ranging from 0.9794 to 0.9974.

![Figure 6 Nu vs Re comparison for 60% glycerol.](image)

For 60% glycerol the heat transfer is found to be higher for 50° corrugation angle and lower for 30° corrugation angle. R-square values were found to be ranging from 0.9933 to 0.998.

![Figure 7 Nu vs Re comparison for water.](image)

For water the heat transfer is found to be higher for 50° corrugation angle and lower for 30° corrugation angle. R-square values were found to be ranging from 0.9784 to 0.9956.

The corrugation angle is kept constant, the graph is plotted for Nusselt number vs Reynolds number for different concentrations of test fluid and water.
For $50^\circ$ corrugation angle the heat transfer is found to be higher for 60% glycerol and lower for water. R-square values were found to be ranging from 0.978 to 0.9998.

As the corrugation angle increases, the channel becomes serrated and results in increased turbulence even at a low flow rate. Due to increased turbulence the heat transfer from hot fluid to test fluid increases. This attributes to the fact that the percentage of the heat transfer is more in the corrugated plate than the flat plate heat exchanger.

As the viscosity of the test fluid increases the tendency of the liquid to flow decreases or the liquid’s resistance to flow increases, it results in increased residence time of the fluid and resulting in higher heat transfer.

It is observed that Nusselt number increases as Reynolds number increases. The Nusselt number on an average was found to be 18% higher for $50^\circ$ when compared with $40^\circ$ and 32% higher when compared to $30^\circ$. Also, it is noticed that Nusselt number was increasing with increase in viscosity of the solution.

5. GOODNESS OF THE FIT
Curve fitting has been done using a software, in which a 4$^{\text{th}}$ degree polynomial is found to be the best fit for the experimental data. The R-square value for each plot on an average is ranging between 0.978 to 0.9998.

6. CONCLUSIONS
It can be concluded from the experimental analysis that both the corrugation angle and the viscosity of the test solution affect the hydrodynamics of the flow in wavy type corrugated channels. From the experimental studies it has been found out that the heat transfer was higher for 60% test fluid solution and with the $50^\circ$ corrugation angle. Therefore, it can be concluded that heat transfer increases with increase in corrugation angle of the heat exchanger and viscosity of the test fluid solution. This study can be further extended to higher corrugation angles in corrugated plate heat exchangers and with different test fluids.
REFERENCES


