AN EXPERIMENTAL STUDY OF HEAT TRANSFER IN A CORRUGATED PLATE HEAT EXCHANGER

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ABSTRACT

In the present work an attempt has been made to investigate the performance of a corrugated plate heat exchanger by the first law and the second law of thermodynamics. Experiments were conducted to determine the laminar convective heat transfer characteristics for fully developed flow of hot and cold fluid in alternate ducts. Experiments were conducted on a three channel 1-1 pass corrugated plate heat exchanger. Hot fluid was made to flow in the central channel to get cooled by cold fluid in the top and bottom channels in parallel and counter flow arrangements. The average effectiveness of the system is 48% higher in counter flow arrangement than in the parallel flow arrangement. The average non-dimensional exergy loss ($E/Q_{\text{max}}$) of the system is also calculated and found 33% less in counter flow arrangement than in the parallel flow arrangement.

Keywords: Corrugated Plate Heat Exchanger, Effectiveness, Exergy Loss.

Nomenclature

- $A$: Cross sectional area, ($m^2$)
- $c$: Specific heat at constant pressure, (J kg$^{-1}$ K$^{-1}$)
- $C$: Heat capacity rate, (W K$^{-1}$)
- $D_h$: Hydraulic diameter, (m)
- $E$: Exergy loss, (W)
- $f$: Friction factor
- $h$: heat transfer coefficient, (W m$^{-2}$ K$^{-1}$)
- $L$: length, (m)
- $m$: Mass flow rate, (kg s$^{-1}$)
- $Q$: Heat transfer rate, (W)
- $R$: Capacity ratio
- $Re$: Reynolds number
INTRODUCTION

Heat exchangers are the devices which are used to transfer the heat between two flowing fluids. In the 1930s plate heat exchangers were introduced to meet the hygienic demand of the dairy industry. These days plate heat exchangers are widely used in many fields like automobile industry, power industry, dairy, food processing, chemical and petrochemical industries. In heat exchangers, there is usually no external heat and work interactions, typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid streams. The objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control process fluid. In a few heat exchangers, the fluid exchanging heat is in indirect or direct contact. In most of the heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperate. Common examples of heat exchangers are shell-and tube exchangers, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers. If no phase change occurs in any of the fluids in the exchanger, it is sometimes referred to as a sensible heat exchanger. There could be internal thermal energy sources in the exchangers, such as in electric heaters and nuclear fuel elements. Combustion and chemical reaction may take place within the exchanger, such as in boilers, fired heaters, and fluidized-bed exchangers. Mechanical devices may be used in some exchangers such as in scraped surface exchangers, agitated vessels, and stirred tank reactors. Heat exchangers are devices used to transfer heat between two or more fluid streams at different temperatures. Heat exchangers find widespread use in power generation, chemical processing, electronics cooling, air-conditioning, refrigeration, and automotive applications. A corrugated plate type heat exchanger, as compared to a similar sized tube and shell heat exchanger, is capable of transferring much more heat. This is due to the large area that plates provide over tubes. Corrugated plate heat exchangers are used for transferring heat for any combination of gas, liquid and two-phase streams. Fins or appendages added to the primary heat transfer surface (tubular or plate) with the aim of increasing the heat transfer area. The two most common types of extended surface heat exchangers are plate-fin heat exchangers and tube-fin heat exchangers. Consist of a stack of parallel thin plates that lie between heavy end plates. Each fluid stream passes alternately between adjoining plates in the stack, exchanging heat through the plates. The plates are corrugated for strength and to enhance heat
transfer by directing the flow and increasing turbulence. These exchangers have high heat-transfer coefficients and area, the pressure drop is also typically low, and they often provide very high effectiveness. However, they have relatively low pressure capability. A corrugated plate type heat exchanger consists of plates instead of tubes to separate the hot and cold fluids. It would be misleading to consider only capital cost aspect of the design of a heat exchanger, since high maintenance cost increase the total cost during the service life of the heat exchanger. Therefore, exergy analysis and energy saving are very important parameters in the heat exchanger design.

EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup established, to investigate the heat transfer characteristics in the corrugated channel for different flow conditions is shown in the basic components as numbered in the schematic and their names given along with the caption, of the experimental apparatus include a water loop and a measurement system. The water loop comprises a water tank containing a heater, a pump and a temperature controller; the flow rate is measured by noting time for collection of fixed volume. Importantly, the components in the water system are thermally insulated such that the wall temperature of the corrugated channel can be maintained at a nearly constant temperature. The test section of the corrugated plate heat exchanger has three ducts. The geometrical characteristics are given in the table 1.

Two different cases of parallel and counter flow arrangements have been made. Hot fluid was made to flow through the central channel and cold fluid through the two outer channels. Copper-Constantan thermocouples are used to measure the temperature of the fluids at the inlet and outlet of the heat exchanger.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Length of the test section, L</td>
<td>100 cm</td>
</tr>
<tr>
<td>2</td>
<td>Width of the test section, a</td>
<td>10 cm</td>
</tr>
<tr>
<td>3</td>
<td>High of the test section, b</td>
<td>5 cm</td>
</tr>
<tr>
<td>4</td>
<td>Corrugation angle</td>
<td>30°</td>
</tr>
</tbody>
</table>

Table 1: Geometrical characteristics of plate heat exchanger

Fig 1: Photograph showing Experimental setup
**Methodology**

The experimental data was used to calculate the heat transfer rate

\[ Q = m_h C_h (T_{hi} - T_{ho}) \]

Each channel has equal flow area and wetted perimeter given by,

\[ A_o = H \cdot W \text{ and } p = 2(W+H) \]

Heat capacity
\[ C_h = m_h c_{ph} \]
\[ C_c = m_c c_{pc} \]

LMTD = \[ \frac{[(T_{ho} - T_{ci}) - (T_{hi} - T_{co})]}{\ln[(T_{ho} - T_{ci})/(T_{hi} - T_{co})]} \]

\[ \varepsilon = \frac{C_c(T_{co} - T_{ci})}{C_{min} \ln(T_{hi} - T_{ci})} \]

The exergy changes for the two fluids are obtained as given below:

For hot fluid (i.e. water),
\[ E_h = T_e \cdot [C_h \ln (T_{hi}/T_{ho})] \]

And for cold fluid
\[ E_c = T_e \cdot [C_c \ln (T_{co}/T_{ci})] \]

Exergy loss for steady state open system can be found as a sum of individual fluid exergy
\[ E = E_h + E_c \]

**RESULTS AND DISCUSSION**

Fig. 1 shows the variation of effectiveness of the corrugated plate heat exchanger in parallel and counter flow arrangement at the different hot water temperature ranging from 50 °C to 70 °C at the interval of 5°C.

A maximum of 100% and a minimum of 3.3% higher effectiveness is observed in case of counter flow at hot water temperature of 50 °C and 65 °C respectively.
Fig 2: Variation of effectiveness at different hot water inlet temperatures for counter and parallel flow arrangements

![Graph showing variation of effectiveness](image-url)

Fig 3: Variation of Exergy loss at different hot water inlet temperatures for counter and parallel flow arrangements

![Graph showing variation of exergy loss](image-url)

Fig. 3 shows the variation of exergy loss at different hot water inlet temperatures for counter and parallel flow arrangements. It is observed that exergy loss is found more in parallel flow than in counter flow. A maximum of 39.5% and a minimum of 35.5% rise in exergy loss is calculated in counter flow arrangement than in parallel flow arrangement.

Fig 4: Variation of max heat transfer at different hot water temperatures for counter and parallel flow arrangements

![Graph showing variation of max heat transfer](image-url)

Fig 4: Variation of max heat transfer at different hot water temperatures for counter and parallel flow arrangements
Fig 4 shows that the maximum heat transfer increases with rise in hot fluid inlet temperature. The maximum value of heat transfer is at the maximum hot water temperature of 70°C in parallel and counter flow respectively. Maximum value of heat transfer is 5% greater in parallel flow than in the counter flow arrangement.

Fig. 5 shows the variation of $E/Q_{max}$ at different hot water inlet temperatures for counter and parallel flow arrangements. As the hot water inlet temperature increases, the non-dimensional exergy loss goes on decreases. The non-dimesional exergy loss is found more in parallel flow than in the counter flow arrangement. A maximum of 35% and minimum of 29% more exergy loss is found in the parallel flow arrangement than in the counter flow arrangement. Further it is observed that the rate of reduction in the exergy loss is more in the parallel flow than in the counter flow.

CONCLUSIONS

An experimental set up of heat exchanger was made of GI sheet for heat transfer study. The test section was formed by three identical channels with hot fluid in the middle and cold fluid in the adjacent channels. Plates had sinusoidal wavy surfaces having corrugation angle of 30°. Water-water fluid combinations are selected in parallel and counter flow arrangements of the heat exchanger. Bulk temperature of the hot fluid was in the range of 50°C to 70°C whereas cold fluid was in the range of 30°C to 40°C. It is observed that the log mean temperature difference of the system is 42% higher in parallel flow arrangement than in the counter flow arrangement. $Q_{max}$ of the system is 3.5% higher in the parallel flow arrangement than in the counter flow arrangement. Average exergy loss of the system is also calculated and found 37% higher in parallel flow arrangement than in counter flow arrangement.

REFERENCES


