Experiment HT – 310: Plate Heat Exchanger

Background:

A plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids. This has a major advantage over a conventional heat exchanger in that the fluids are exposed to a much larger surface area because the fluids spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of the temperature change.

The plate heat exchanger normally consists of corrugated plates assembled into a frame. The hot fluid flows in one direction in alternating chambers while the cold fluid flows in true co-current flow in the other alternating chambers. A schematic diagram of the flow is shown in Figure 1. The fluids are directed into their proper chambers either by a suitable gasket or a weld depending on the type of exchanger chosen. Traditionally, plate and frame exchangers have been used almost exclusively for liquid to liquid heat transfer.

![Figure 1: Plate heat exchanger setup](image)

Advantages of Plate Heat Exchanger (PHE):

- PHE offers a very high heat transfer coefficient on both sides of plates.
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Disadvantages of Plate Heat Exchanger (PHE):

- If steam is used as heating medium, rapid fluctuation in steam temperature & pressure reduces gasket life.
- Pressure drop is very high (because flow passage is less).

Therefore in this configuration it is of interest to understand the relationship between flow regime and heat transfer.

Aim:

**To understand relationship of heat transfer and flow regime in a plate heat exchanger geometry through the following:**

1. To determine the overall heat transfer coefficient in a plate heat exchanger.
2. To study its scaling dependence on the hot fluid flow rate and flow regime.
3. To derive a correlation function for laminar/turbulent flow and verify with literature.

Theory:

The heat transfer correlation for a fluid flow past a solid surface is expressed in a dimensionless form is given as:

\[
Nu = Nu(Re, Pr) \tag{1}
\]

Where \( Nu \) is the (Nusselt No) non dimensional heat transfer coefficient \( Nu = \frac{h \cdot D_e}{k} \), For a heat transfer in a laminar fluid flow past a solid surface, with constant fluid properties, the steady state temperature profile is a function only of \( Re \) and \( Pr \), The heat transfer coefficient is a function of the temperature profile, this expression is often used in situations where the properties vary with temperature, and for turbulent flows.

For fully developed laminar flows, we expected the Nusselt number \( Nu \) to be constant however for a developing flow it is expressed as:

\[
Nu = C_1 Re^{\alpha} Pr^{\beta} \tag{2}
\]

The heat transfer coefficient appearing in the Nusselt number can be calculated from the overall heat transfer coefficient \( U \), which is given by

\[
\frac{1}{U} = \frac{1}{h_h} + \frac{\Delta x}{k} + \frac{1}{h_c} \tag{3}
\]

Where \( h_h \) is the hot fluid heat transfer coefficient and \( h_c \) is the cold fluid transfer coefficient, \( k \) is the thermal conductivity of the metal plate and \( \Delta x \) is its thickness.
Thus, the overall heat transfer coefficient will depend upon the value of the hot fluid heat transfer coefficient alone. If the bulk mean temperature does not differ much for different flow rates, then all the physical properties will remain nearly the same and Eq. (3) can be re-written in combination with Eq. (2) as

\[
\frac{1}{U} = \frac{1}{h_h} + C = \frac{m}{u^{\alpha}} + C
\]  

(4)

Where \( m \) and \( C \) are constants \( h_h \) can therefore be evaluated from the intercept of the plot of \( 1/U \) vs. \( 1/u^\alpha \). Since the value of \( \alpha \) is not known, it has to be estimated first. Differentiating and taking logarithm of equation (4) we got.

\[
\frac{d\left(\frac{1}{U}\right)}{du} = -\frac{\alpha m}{u^{\alpha+1}}
\]  

(5)

\[
\ln\left\{\frac{d\left(\frac{1}{U}\right)}{du}\right\} = \ln\left[-\alpha m\right] - \left[\alpha + 1\right] \ln u
\]  

(6)

A plot of \( \ln d(1/U)/du \) vs. \( \ln(u) \) will give the slope \(- (\alpha + 1)\). \( \alpha \) can be evaluated from the slope, then a plot of \( 1/U \) vs. \( 1/u^\alpha \) provides \( C \) as the intercept which is then used to calculate the heat transfer coefficient from Eq. (4). The Nusselt number correlation can then be found.

**Procedure:**

1. **Make a list of apparatus used in experiment and schematic of setup.**

2. **Zero correction**

   The zero correction of the thermometers are determined by measuring steady the fluid inlet and outlet temperature under the following conditions (without switching on the heater).

   a. Stationary (Assuming the equipment is at equilibrium, before the start of the experiment, all the thermometers should indicate the same temperature. Any deviation indicates the error of the thermometer/sensor combination)

   b. Allow minimal flow of the hot fluid (30 lph) and measure any temperature difference (which is more than the above error). If the outlet temperature is greater, it indicates viscous dissipation.

   c. Set the pump to maximum capacity flow rate (500 lph), and measure the temperature difference between the outlet and inlet of the hot fluid.
3. **Determination of characteristic steady state time:**

Adjust the set point temperature to a temperature around \( T = 60 \, ^\circ C \). Set the flow rate to the minimum flow rate possible. Throughout the measurement, make sure the flow rate is at this value. Measure the inlet and outlet temperatures for about 15 minutes at 30 second intervals. Use a graph sheet to plot the variation in temperature. Use this plot to obtain an estimate of the time; it takes for the inlet and outlet temperatures to attain steady state. Therefore, set the time you must wait before taking readings.

4. **Determination of the overall heat transfer coefficient:**

i. Set the inlet temperature to a high value (65 °C).

ii. Set the flow rate to the highest possible value. Note down the value and maintain it constant (see above on how to do this).

iii. Wait for the predetermined characteristic settling time, and then note down the steady inlet and outlet temperatures of both the fluids.

iv. Repeat steps from 2 (at constant temperature) for at least 8 different flow rates ranging from a maximum of about 500 lph to a minimum of about 100 lph. It is useful to place the interval in the flow rate in a geometric progression (GP), which will give equally spaced data in a logarithmic scale.

**Observations:**

**The heat exchanger specifications are to be noted.**

- Height of plate \( H = \) cm
- Width of plate \( W = \) cm
- Gap between two plates \( b = \) mm
- Number of plates \( N = \)
- Number of hot fluid chambers \( N_h = \)
- Number of cold fluid chambers \( N_c = \)
- Cold fluid flow rate = lph
Zero correction:

Zero error correction of hot fluid digital thermometers $\delta T_z = ^\circ C$

Observation table

<table>
<thead>
<tr>
<th>Obs. No.</th>
<th>Flow rate $V$ (lph)</th>
<th>Hot Fluid Temperature ($^\circ C$)</th>
<th>Cold Fluid Temperature ($^\circ C$)</th>
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<tr>
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<td>Inlet ($T_1$) Outlet ($T_2$)</td>
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Parameter Estimation:

- Total heat transfer area of heat exchanger $A = N*H*W$  
  $A = N H W = \ldots$  
- Cup mean temperature ($T_m=1/2*(T_1+T_2)$)  
  $T_m = \ldots$  
- Density of ethylene glycol at $T_m$  
  $\rho = \ldots$  
- Specific heat of Ethylene glycol at $T_m$  
  $C_p = \ldots$  
- Viscosity of Ethylene glycol at $T_m$  
  $\mu = \ldots$  
- Thermal conductivity of Ethylene glycol at $T_m$  
  $K = \ldots$  
- Prandtl number for hot fluid  
  $Pr = C_p*\mu/K = \ldots$  
- Equivalent diameter  
  $De = 2*W*b / (W+b) = \ldots$

(Properties of the fluid can be found out from Perry’s Chemical Engineer’s Handbook, 8th Ed.)

Results and discussion:

Sources of Errors:

Questions:

- Show calculation for calculating LMTD and how a propagation of uncertainty. Express LMTD as $x\pm y$.
- Show calculation for calculating $U$ and how a propagation of uncertainty. Express $U$ as $x\pm y$.  

Assume sum of resistance in wall and cold fluid is (a) negligible and (b) constant. Calculate \( h \) using both methods. Which is more conservative and why? Use the “more conservative” value of \( h \) to calculate \( \text{Nu} \).

Using \( \text{Nu} \) Vs \( \text{Re} \) data make an appropriate plot to derive the correlation function. Compare the two values for \( \alpha \) and discuss.

Based on experiment write Dittus Boelter equation for flow regime and explain how to get the value of \( \beta \).