Safety Hazards
Thermal Systems Laboratory Rooms 106 & 110

HAZARD: Rotating Equipment

Be aware of pinch points and possible entanglement

Personal Protective Equipment: Safety Goggles; Standing Shields, Sturdy Shoes
No: Loose clothing; Neck Ties/Scarves; Jewelry (remove); Long Hair (tie back)

HAZARD: Projectiles / Ejected Parts

Articles in motion may dislodge and become airborne

Personal Protective Equipment: Safety Goggles; Standing Shields

HAZARD: Heating - Burn

Be aware of hot surfaces

Personal Protective Equipment: Safety Goggles**;** High Temperature Gloves;

HAZARD: Electrical - Burn / Shock

Care with electrical connections, particularly with grounding and not using frayed electrical cords, can reduce hazard. Use GFCI receptacles near water.

HAZARD: High Pressure Air-Fluid / Gas Cylinders / Vacuum

Inspect system integrity before operating any pressure / vacuum equipment. Gas cylinders must be secured at all times. Use appropriate equipment guards.

Personal Protective Equipment: Safety Goggles

HAZARD: Water / Slip Hazard

Clean any spills immediately.

HAZARD: Noise

Personal Protective Equipment: Use Rated Ear Plugs

ME 406: Experiment 6

Performance Test of a Concentric Tube Heat Exchanger

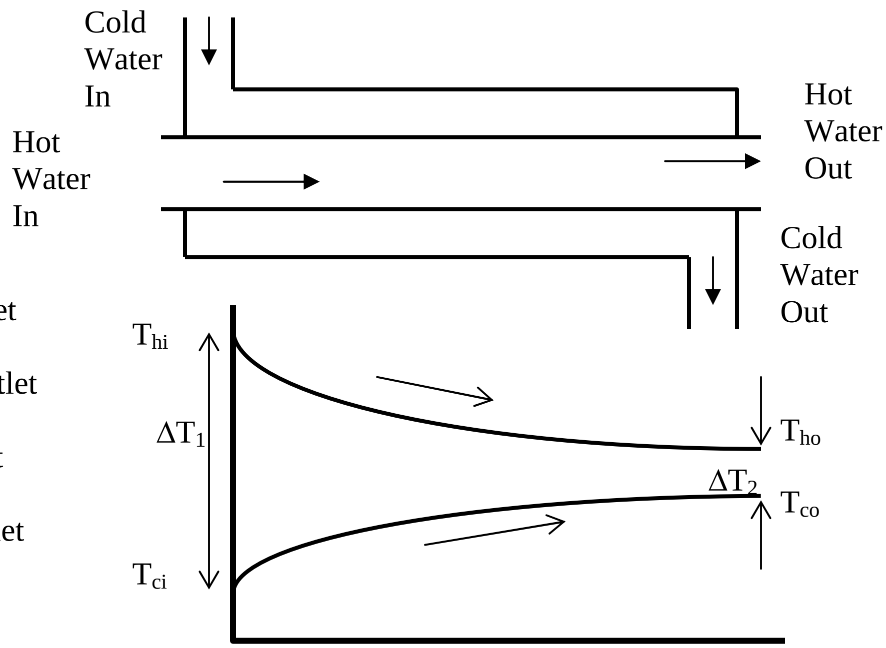
I. Objective:

To evaluate the performance of a concentric tube heat exchanger in parallel flow (cocurrent flow) and counter flow under variations of high temperature and low temperature flow rates.

II. Background

A concentric tube heat exchanger is composed of a tube, through which one fluid flows, located concentrically inside another tube. The other fluid flows through the annular region between the two tubes. In this heat exchanger, the hot fluid (water) flows through the inside tube and the cold fluid (water) flows through the annular space.

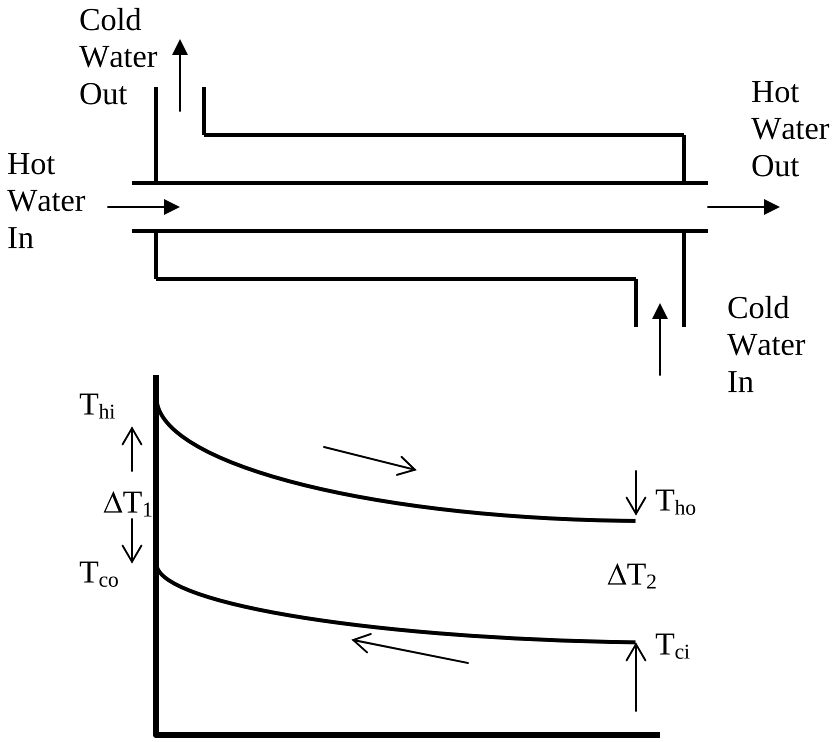
For parallel flow, both hot and cold water enters the same end of the heat exchanger.



T_{ci} = cold water inlet Temperature
T_{co} = cold water outlet Temperature
T_{hi} = hot water inlet Temperature
T_{ho} = hot water outlet Temperature

$\Delta T_1 = T_{hi} - T_{ci}$
$\Delta T_2 = T_{ho} - T_{co}$

For counter flow, the hot water enters one end of the heat exchanger, the cold water enters the opposite end.



Since the temperatures of the hot and cold water vary over the length of the tubes, the temperature difference, $\Delta T = T_h - T_c$, is not constant over the length. To account for the variation, a Log Mean Temperature Difference (LMTD) is used.

$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$$

The rate of heat transfer from the hot water to cold water is then given by;

Q = UA*LMTD　　Q = heat transfer rate (kJ/min)
U = overall heat transfer coefficient (kJ/min-m^2-^oC)
A = Hot water tube surface area (ft^2)

UA = Q/LMTD

NOTE: It is possible that for counter flow, $\Delta T_1 = \Delta T_2$. In that case, $Q = UA*(T_{hi} – T_{co})$ or $Q = UA*(T_{ho} – T)$.

Applying the First Law of Thermodynamics,

to the hot water side, $Q_h = M_hC_h(T_{hi} - T_{ho})$

to the cold water side, $Q_c = M_cC_c(T_{co} - T_{ci})$

M = mass flow rate of water (kg/min)
C = specific heat of water (kJ/min-kg-^oC)

With negligible losses to the surrounding air from the cold water, $Q_c = Q_h$

If the tube surface area is based on inside diameter, $(A_i = \pi D_iL)$,

then $U = U_i$.

If the tube surface area is based on outside tube diameter, $(A_o = \pi D_oL)$,

then $U = U_o$.

Using a 1 dimensional steady state analysis for cylindrical surfaces, the total thermal resistance, R_t, is the sum of the hot water convection resistance (R_h), the tube wall conduction resistance (R_w), and the cold water convection resistance (R_c).

$R_t = R_h + R_w + R_c$ $\quad$ $R_h = 1/h_hA_i$ (hot water convection resistance)

$R_w = \ln(D_o/D_i)/2\pi kL$ (tube wall conduction resistance)

$R_c = 1/h_cA_o$ (cold water convection resistance)

k = tube wall thermal conductivity
h = convection heat transfer coefficient

The convection heat transfer coefficients can be determined from empirical relations for Nusselt Number (Nu) for flow through a tube, (hot water side), and flow through an annulus, (cold water side).

The overall heat transfer coefficient is related to the total thermal resistance as,

$$U_iA_i = U_oA_o = 1/R_t$$

Heat exchanger effectiveness, ε, is defined as,

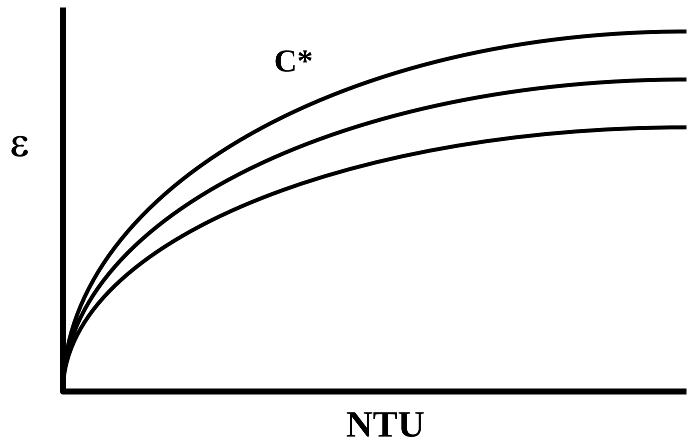
$$\varepsilon = \frac{M_hC_h(T_{hi} - T_{ho})}{MC_{min}(T_{hi} - T_{ci})} = \frac{M_cC_c(T_{co} - T_{ci})}{MC_{min}(T_{hi} - T_{ci})}$$

MC_{min} = minimum of either M_hC_h or M_cC_c.

The number of transfer units (NTU) for a heat exchanger is defined as,

$NTU = UA/MC_{min}$

The effectiveness of the heat exchanger is a function of heat exchanger NTU, represented typically by the graph below.



$C^{*} = MC_{min}/MC_{max}$

Empirical relations for the above are;

Parallel Flow

$$\varepsilon = \frac{1 - \exp[-NTU(1 + C^{*})]}{1 + C^{*}}$$

Counter Flow

$$\varepsilon = \frac{1 - \exp[-NTU(1 - C^{*})]}{1 - C^{*}\exp[-NTU(1 - C^{*})]}$$

In the special case of $C^{*} = 1$

Parallel Flow

$\varepsilon = ½ [1 – \exp(-2NTU)]$

Counter Flow

$\varepsilon = NTU/(1 + NTU)$

III. Equipment

Armfield HT30X Heat Exchanger Apparatus
- Hot Water Tube
- Di = 0.0083 m
- Do = 0.0095 m
- L = 0.660 m
- Stainless steel

Computer/Software
- Armfield HT31 Tubular Heat Exchanger
- Log in Username: student
- Log in Password: meclab

IV. Procedure

1. Make sure the drain valves for the refrigeration apparatus and convection apparatus are closed
2. Open drain valve for the heat exchanger apparatus
3. Check that the 3-way valve on the heat exchanger is in the cocurrent (parallel flow) arrangement. If not, set the valve that way.
4. Turn on the computer, log in, and open the HT31 Tubular Heat Exchanger.
5. Open exercise D – Overall Heat Transfer Coefficient.
6. Click through the, “Walk through presentation”, (procedure and questions can be ignored).
7. Make sure the hot water reservoir is primed (full). If not, fill the reservoir up to the overflow.
8. Turn on the power to the HT30X apparatus
9. Set the temperature controller on the HT30X to $60^{o}C$ by pressing SET and the up or down arrows.
10. Turn on the cooling water supply (main valve and heat exchanger apparatus water valve).
11. Switch on the hot water toggle switch (from 0 to 1) on the HT30X.
12. On the computer “Results” screen, make sure the radio button for flow orientation is set to the appropriate cocurrent (parallel flow) or counter-flow orientation.
13. Adjust the hot water flow valve to 1 L/min.
14. Adjust the cold water flow valve to 3 L/min.
15. Allow the temperatures to stabilize (monitor on the computer Results screen), then click on “Sample Now”.
16. Adjust the cold water flow valve to 2 L/min.
17. Allow the temperatures to stabilize (monitor on the computer Results screen), then click on “Sample Now”.
18. Adjust the cold water flow valve to 1 L/min.
19. Allow the temperatures to stabilize (monitor on the computer Results screen), then click on “Sample Now”.
20. Adjust the hot water flow valve to 2 L/min.
21. Repeat steps 14 to 19.
22. Adjust the hot water flow valve to 1 L/min.
23. Repeat steps 14 to 19.
24. Turn off the hot water toggle switch.
25. Turn off the cooling water flow valve.
26. Turn the 3-way valve to the counter-flow orientation, change the radio button to counter-flow.
27. Repeat steps 10 to 25.
28. Turn off hot water toggle switch, HT30X power, cooling water main supply valve and heat exchanger water supply valves.
29. The results in the “Results table” can be saved to a floppy disk or emailed.

V. Analysis

1. Calculate the Overall Heat Transfer Coefficient (U) using measured values. Compare these to the U's calculated using the empirical equations.
2. Determine the NTU and ε for each flow orientation and flow rate combination.
3. Plot the ε versus NTU for each flow orientation.
4. Compare the ε calculated from measured values to those calculated from empirical equations.