

Lab 3d: Heat Exchanger Performance Measurement – Shell and Tube vs. Plate

Introduction

This lab allows you experiment with a shell and tube (S&T) and plate heat exchanger (HX). The HXs can be set up so that the flow is countercurrent or cocurrent. The flow rates of the hot and cold water can be changed to see how this affects the heat transfer, and can be read directly off of the control console. The temperature of the hot water entering the HX can be controlled. Thermocouples are placed at the inlets and exits of the HX and are read directly off of the control console.

Main Objective of This Lab:

- To experiment with plate and shell and tube (S&T) heat exchangers and learn differences between the two.
- Demonstrate the difference between countercurrent flow and cocurrent flow and the effect on heat transfer.
- Investigate the effects of changing the flow rates of the hot and cold fluids.
- Determine the Overall Heat Transfer Coefficient for the plate and S&T heat exchangers.

See attached brochure from manufacturer for more details on equipment.

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PROCEDURE:

DAY 1

- a) Read pages 8 through 11 in the instruction manual of the HT30X to become familiar with the location of certain values and switches.
- b) Place the S&T HX onto the HX Service Unit and hook up the HX in countercurrent flow as shown in Fig. 1.

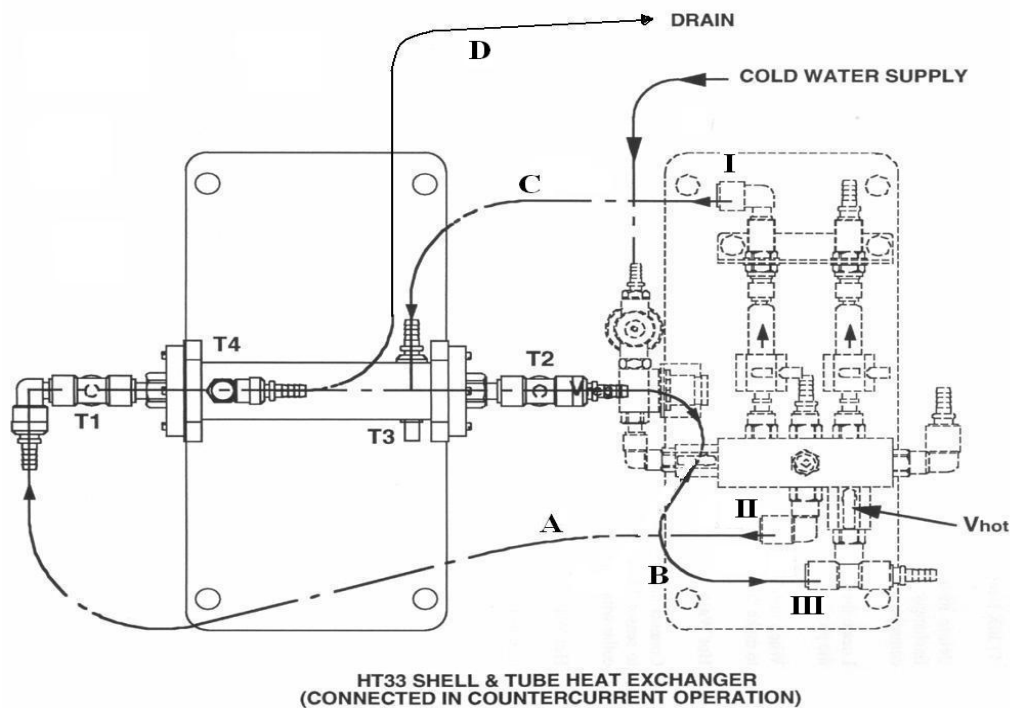


Fig. 1. S&T HX countercurrent flow setup.

- c) Turn on the main switch (in the lower right corner) to power the Service Unit.
- d) **Hit the set button on the control console and make sure the temperature is set to 25 °C.** If the water heats at too high of a temperature without the pump running, it will cause the pump to not run.

- e) Make sure the cold water valve is closed (14 in Fig. 2). Pull the grey knob (the pressure regulator – 13 in Fig. 2) out and turn all the way counterclockwise. Change the knob for the flow meter reading to F_{cold} . It should read zero. Turn on the cold water from the facet. Now open the cold water valve fully and gradually turn the pressure regulator until water begins to flow. Continue doing so until the flow meter reads 3 liters/min. Then push in the grey knob.

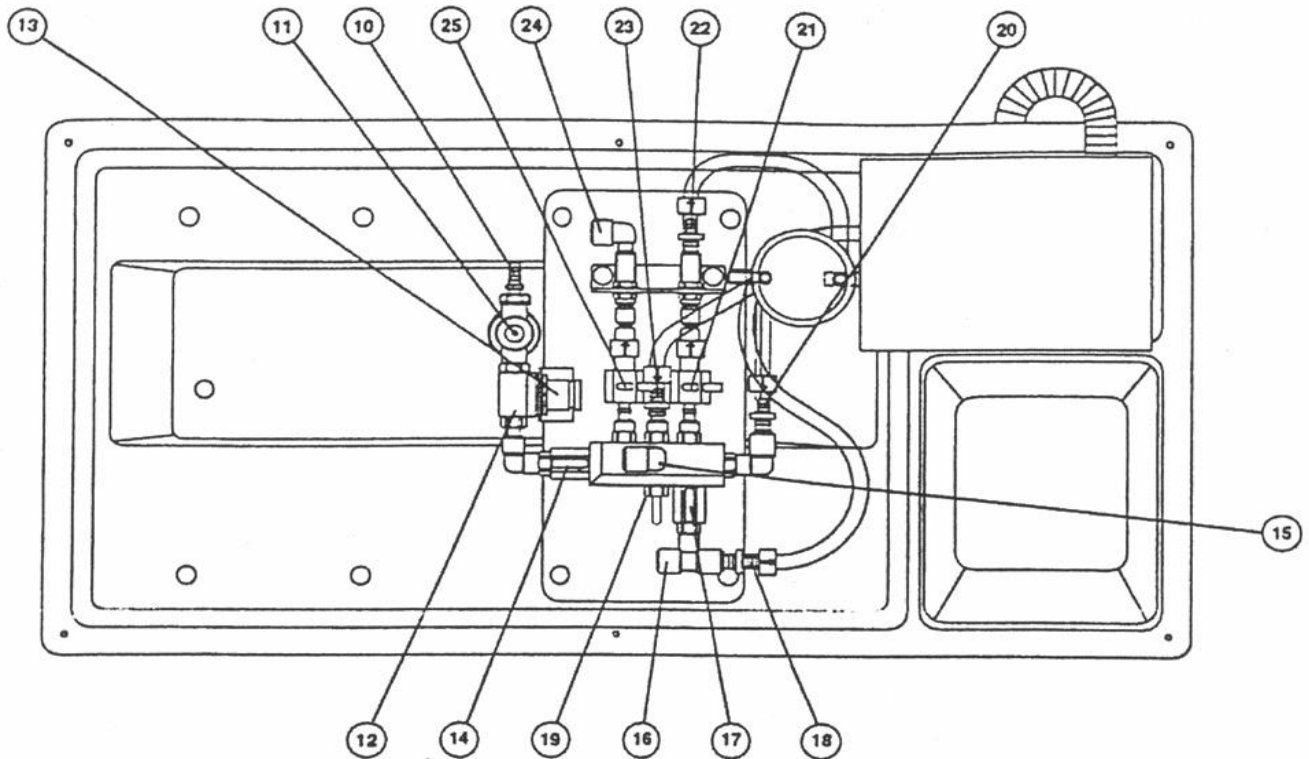


Fig. 2. Top view of Service Unit.

- f) Calibrate the cold water flow meter. With the cold water flowing at 3 liter/min, drain the cold water hose (hose D in Fig. 1) into an empty cylinder. Measure how long it takes to fill the container to 0.150 liter with a stopwatch. Repeat the measurement 5 more times (for purposes of uncertainty analysis). Repeat this at flow rates of 2 and 1 liter/min, but only repeat the measurement 3 times at each flow rates (instead of 6 times). Do the calibration and uncertainty analysis later. Assume that this calibration applies for the hot water flow meter also.
- g) Determine the accuracy of the K type thermocouple.
- Use the PC to the right of the cooling tower. Open DasyLab and open the file K_Type_Thermocouple_Calibration.DSB located at: C:/Program Files/DasyLab5.5/Worksheets. The top display is the standard deviation of the thermocouple and the second display is the mean.
 - Set the Omega CL351A to 35 °C and press the yellow button in so that it lights up.
 - Place the K type thermocouple and Omega HH41 thermometer probe into the CL351A.
 - Make sure the thermocouple is connected to channel 2.

- Record the temperature from DasyLab and from the Omega HH41 10 times.
 - Perform the precision and accuracy analysis for the thermocouple outside of the lab.
- h) If time permits, practice priming the system. The instructions for this are shown in the appendix.
- i) **Hit the set button on the control console and make sure the temperature is set to 25 °C.**

DAY 2

- a) Setup the S&T HX in countercurrent flow as shown in Fig. 1.
- b) **Hit the set button on the control console and make sure the temperature is set to 25 °C.**
- c) Prime the system.
- d) Set the temperature controller to a set point of 50 °C. Turn on the hot water circulating pump. (Fill the plastic priming vessel with distilled water if water is below half full.)
- e) Set flow indicator to F_{cold} and adjust cold water control valve (14 in Fig. 2) to give 1 liter/min.
- f) Set flow indicator to F_{hot} and adjust hot water control valve (17 in Fig. 2) to give 2 liter/min.
- g) Allow temperatures to stabilize and record T_1 , T_2 , T_3 , T_4 , F_{cold} , F_{hot} . Be sure to note what the T 's are (i.e. T_1 = hot water into HX) because these will change at some point).
- h) Repeat steps d) through f) for the four other flow rates given in the table below:

F_{cold}	F_{hot}
1	2
1	1.5
2	2
2	1
3	1

- i) Turn off the hot water circulating pump. Let the system cool down for a few minutes. Change connections so system is in cocurrent flow (i.e. switch hose A to location III and hose B to location II). Note now that T_2 = hot water into HX and T_1 = hot water leaving HX.
- j) Repeat steps c) through g) with the system in cocurrent flow.
- k) Turn off hot water circulating pump. Let the system cool down for a few minutes. Remove the S&T HX (unscrew the studs and unplug the thermocouples) and install the frame HX

(screw down the studs and plug in the thermocouples) in countercurrent flow as shown in Fig. 3. Make sure additional hose is connected to hose D (the hose that goes to the drain) if this hose does not reach the drain.

- l) Prime the system again.
- m) Repeats steps c) through g). Note: it will take longer for the temperatures to stabilize, and the temperature of the heated water (hot water entering the HX) may never reach the set point of 50 °C.
- n) Turn off hot water circulating pump. Let the system cool down for a few minutes. Change connections so system is in cocurrent flow (i.e. switch hose A to location III and hose B to location II).
- o) Repeat l) with system in cocurrent flow.
- p) **Hit the set button on the control console and make sure the temperature is set to 25 °C.**

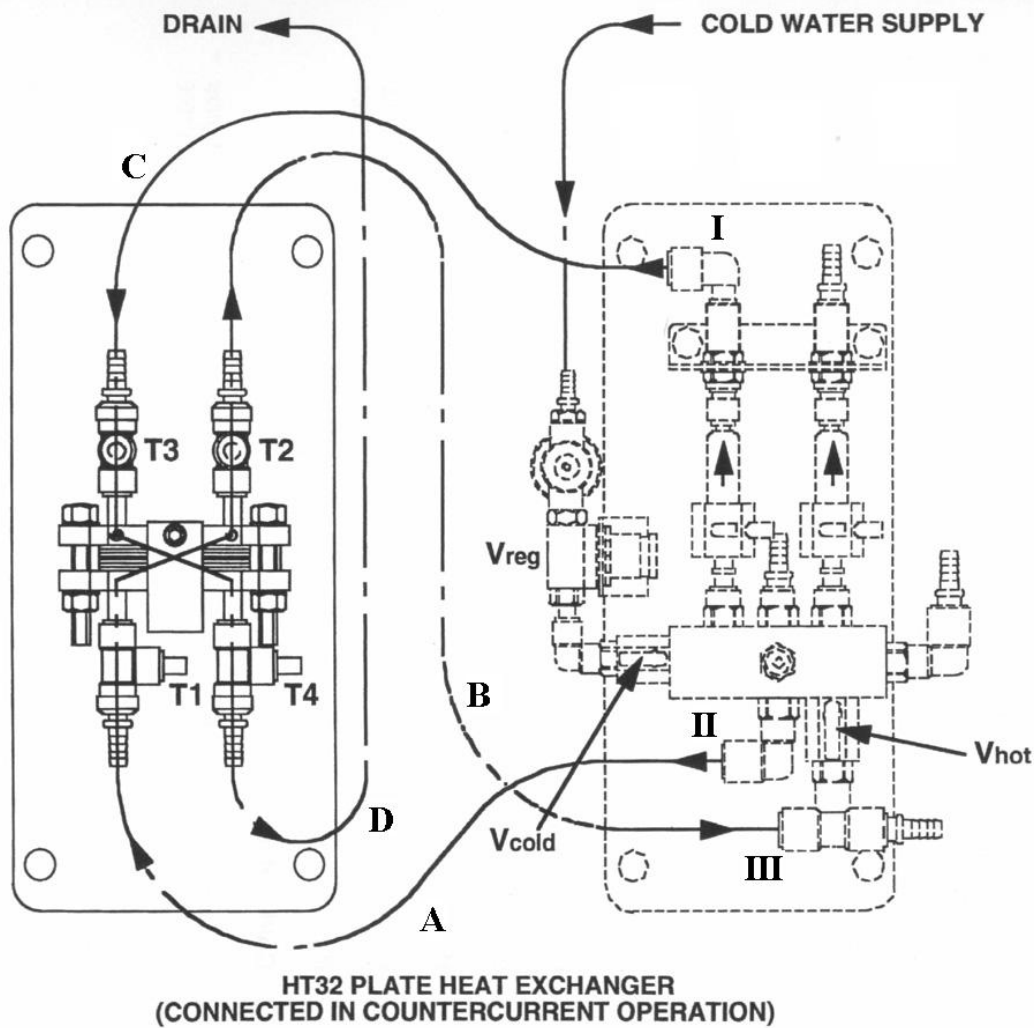


Fig. 3. Frame HX countercurrent flow setup.

- q) Once finished, you should have 20 different measurements for T1, T2, T3, Therefore, you will have 20 different cases to examine.
- r) Make sure to close the cold water valve and turn off the facet. Turn off the hot water circulating pump.

ANALYSIS:

Do the following calculations in Microsoft Excel

- 1) Change the volumetric flow rates (q_v) into m^3/s .
- 2) Calculate the average hot water and average cold water temperature for each case.
- 3) Using the tables below, find the specific heat and density for both the hot and cold water. Use the average temperature calculated in 2) in the charts.
- 4) Calculate the mass flow rate ($\dot{m} = q_v \rho$) in kg/s.

TABLE 1
Specific Heat Capacity of Water (C_p kJ/kg $^\circ$ K)

$^\circ\text{C}$	0	1	2	3	4	5	6	7	8	9
0	4.1274	4.2138	4.2104	4.2074	4.2045	4.2019	4.1996	4.1974	4.1954	4.1936
10	4.1919	4.1904	4.1890	4.1877	4.1866	4.1855	4.1846	4.1837	4.1829	4.1822
20	4.1816	4.1810	4.1805	4.1801	4.1797	4.1793	4.1790	4.1787	4.1785	4.1783
30	4.1782	4.1781	4.1780	4.1780	4.1779	4.1779	4.1780	4.1780	4.1781	4.1782
40	4.1783	4.1784	4.1786	4.1788	4.1789	4.1792	4.1794	4.1796	4.1799	4.1801
50	4.1804	4.1807	4.1811	4.1814	4.1817	4.1821	4.1825	4.1829	4.1833	4.1837
60	4.1841	4.1846	4.1850	4.1855	4.1860	4.1865	4.1871	4.1876	4.1882	4.1887
70	4.1893	4.1899	4.1905	4.1912	4.1918	4.1925	4.1932	4.1939	4.1946	4.1954

TABLE 2
Density of Water (ρ kg/m 3)

$^\circ\text{C}$	0	2	4	6	8
0	999.8	999.9	999.9	999.9	999.9
10	999.7	999.5	999.2	998.9	998.6
20	998.2	997.8	997.3	996.8	996.2
30	995.7	995.0	994.4	993.7	993.0
40	992.2	991.4	990.6	989.8	988.9
50	988.0	987.1	986.2	985.2	984.2
60	983.2	982.2	981.1	980.0	978.9
70	977.8	976.6	975.4	974.2	973.0

- 5) Calculate the power emitted by the hot water (Q_e) and the power absorbed by the cold water (Q_a). Compare the results.

Countercurrent Flow:

$$Q_e = m_h (c_p)_h (T1 - T2)$$

$$Q_a = m_c (c_p)_c (T4 - T3)$$

Cocurrent Flow:

$$Q_e = m_h (c_p)_h (T2 - T1)$$

$$Q_a = m_c (c_p)_c (T4 - T3)$$

- 6) Calculate the temperature efficiency for the hot water (η_h), the temperature efficiency for the cold water (η_c), and the mean temperature efficiency (η_m).

Countercurrent Flow:

$$\eta_h = \frac{T1 - T2}{T1 - T3} \times 100\%$$

$$\eta_c = \frac{T4 - T3}{T1 - T3} \times 100\%$$

$$\eta_m = \frac{\eta_h + \eta_c}{2}$$

Cocurrent Flow:

$$\eta_h = \frac{T2 - T1}{T2 - T3} \times 100\%$$

$$\eta_c = \frac{T4 - T3}{T2 - T3} \times 100\%$$

$$\eta_m = \frac{\eta_h + \eta_c}{2}$$

- 7) Calculate the average temperature difference, called the Logarithmic Mean Temperature Difference.

$$\Delta t_{lm} = \frac{(T1 - T4) - (T2 - T3)}{\ln\left(\frac{T1 - T4}{T2 - T3}\right)}$$

- 8) Calculate the Overall Heat Transfer Coefficient (U):

Plate HX:

$$U = \frac{Q_e}{AF\Delta t_{lm}}$$

$A = aN$ = heat transmission area

$a = 0.008 \text{ m}^2$ = projected heat transfer area of each plate

$N = 5$ = number of plates with hot and cold fluids on opposite sides

$F = 0.95$ = correction factor

S&T HX:

$$U = \frac{Q_e}{A\Delta t_{lm}}$$

$A = \pi d_m L$ = heat transmission area

$d_m = \frac{d_o + d_i}{2}$ = mean diameter

$L = nl$ = heat transmission length

$N = 7$ = number of tubes

$l = 0.144$ m = heat transmission length of each tube

$d_o = 0.00635$ m = tube outer diameter

$d_i = 0.00515$ m = tube inner diameter

9) Comment on the results of the analysis.

PRELAB:

A S&T HX in countercurrent flow is used to heat up water from a temperature (T3) of 9 °C to a temperature (T4) of 14.6 °C. The hot water used to heat up the cold water enters at a temperature (T1) of 61.2 °C and leaves at a temperature (T2) of 48.4 °C. The cold and hot water have a volumetric flow rate of 1 and 2 liter/min, respectively.

From this information and the formulas provided in the analysis, determine:

- a) Average hot and cold water temperatures.
- b) Density and specific heat capacity for both the hot and cold water.
- c) The power emitted by the hot water and the power emitted by the cold water.
- d) The hot and cold water temperature efficiency and the mean temperature efficiency.
- e) The log mean temperature difference.
- f) The Overall Heat Transfer Coefficient.

APPENDIX: Priming Instructions

Note: the hand written additions to the instructions refer to Figs. 1, 2 and 3 of the write up.

PRIMING THE HOT AND COLD WATER CIRCUITS

Note: To disconnect the flexible tubing from a quick release connector, push the grey collet hard against the body of the connector while pulling the flexible tubing away from the connector. (Do not allow the collet to move away from the body of the connector while pulling the flexible tubing). Refer to the diagrams on Page 25 for further information.

Fit the required heat exchanger:

- 1) Attach the HT33 heat exchanger to the HT30X Heat Exchanger Service Unit.
- 2) Confirm the required direction of flow through the hot water circuit of the heat exchanger (if necessary refer to the appropriate practical training exercise in the exchanger teaching manual for details).
- 3) For the purpose of priming only, connect the heat exchanger hot water inlet (appropriate flexible tube with red collar) to the quick release cold water outlet connector (blue collar with arrow pointing left) at the rear of HT30X. *Connect hose A to location I*
- 4) Connect the heat exchanger hot water outlet (appropriate flexible tube with red collar) to the quick release hot water inlet connector on HT30X (red collar with arrow pointing right) at the front of HT30X. *connect hose B to location III*

Prime the hot water circuit:

- 5) Ensure that the bypass valve in the hot water circuit is fully closed (right-hand valve with black handle at 90 degrees to valve body). *17 in Fig. 2*
- 6) Ensure that the cold water pressure regulator is set to minimum pressure. (Pull the grey knob upwards – towards the right - then turn the knob fully anticlockwise, looking at end of knob). *13 in Fig. 2*
- 7) Open the cold water flow control valve fully (left-hand valve with black handle in line with valve body). *14 in Fig. 2*
- 8) Gradually adjust the pressure regulator by turning the grey knob clockwise until cold water is heard / seen to flow steadily through the flexible tubing of the hot water circuit.

Connect hose C to location II so water doesn't flow everywhere

- 9) Wait until water flows into the clear plastic priming vessel and all air bubbles have been expelled from the flexible tubing. Note: Water will flow from the hot water outlet connector at the front of HT30X before priming is complete. This is normal and the water will drain in the central channel.
- 10) When the system has primed, close the cold water flow control valve (left-hand valve with black handle at 90 degrees to valve body).
- 11) Disconnect the flexible tube (to the heat exchanger) from the cold water outlet connector (blue collar with arrow pointing left) then reconnect the same flexible tube to the hot water outlet connector (red collar with arrow pointing left). *Connect hose A to location II*
- 12) Fill the clear plastic priming vessel with clean water to the level of the overflow then replace the lid on the vessel.
- 13) Switch on the hot water circulating pump. Any remaining air bubbles will be expelled via the priming vessel. Open and close the hot water bypass valve (right-hand valve with black handle) several times until no air bubbles are seen travelling along the flexible tubing. If the level falls below mid height in the priming vessel then it will be necessary to top it up with clean water.

Set the cold water pressure regulator:

- 14) *connect hose C to location I*
Connect the heat exchanger cold water inlet (appropriate flexible tube with blue collar) to the cold water outlet connector (blue collar with arrow pointing left) at the rear of HT30X, ensuring that the flow of water is in the required direction through the exchanger. Connect the remaining cold water flexible tube from the heat exchanger to a suitable drain.
- 15) Set the flow selector switch on the console to F_{cold} . Open the cold water flow control valve fully (left-hand valve with black handle in line with body) then adjust the grey knob on the pressure regulator until the display indicates 3.00 litres/min.
- 16) Push the grey knob on the pressure regulator down – towards the left - to lock the setting. Close the cold water flow control valve (left-hand valve with black handle at 90 degrees to valve body).