TUBULAR HEAT EXCHANGER

Objective

The objective of this laboratory exercise is to familiarize the student with heat transfer in tubular heat exchangers. Students will determine the heat transfer coefficient which is the measure of heat exchanger performance. The student will also learn about the different transducers used to detect and measure the physical properties used when calculating the heat transfer between the hot and cold media in the heat exchanger. A HT30XC Heat Exchanger Unit and HT31 Tubular (tube-in-tube) Heat Exchanger are used for this laboratory. The HT30XC and HT31 are test devices manufactured by Armfield Limited, England.

Introduction

The tubular heat exchanger is the simplest form of heat exchanger. It consists of two concentric (coaxial) tubes. The inner metal tube carries a hot fluid and the outer acrylic annulus carries the cold fluid, such that the inner tube's outer surface is in direct contact with the cold fluid. Any temperature difference across the metal tube wall will result in the transfer of heat between the two fluid streams. The hot water flowing through the inner tube will be cooled and the cold water flowing through the outer annulus will be heated. A thermocouple is placed at the center location along the heat exchanger length and at entrance and exit of both the hot and cold fluid streams. The temperature of the hot fluid and the flow rate of the cold and hot streams are controlled by the student during each exercise. Tubular heat exchangers may be configured where the flow of the two fluids enter at the same side of the exchanger and flow in the same direction (parallel flow) or made to flow in opposite directions (counter flow).

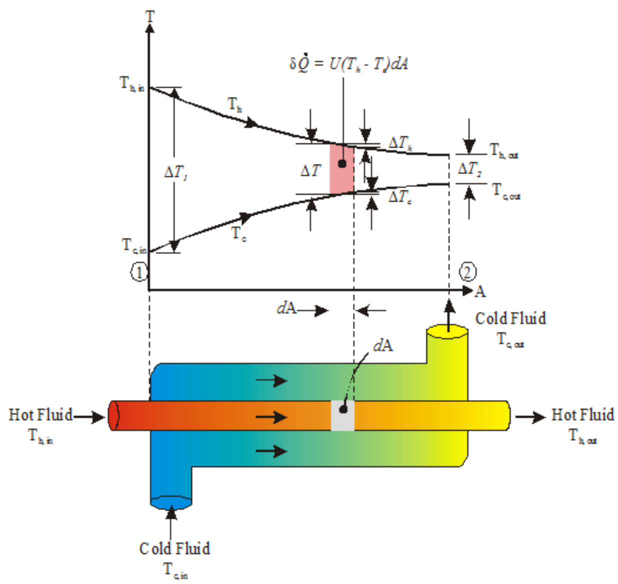

Figure 1: Parallel flow heat exchanger.

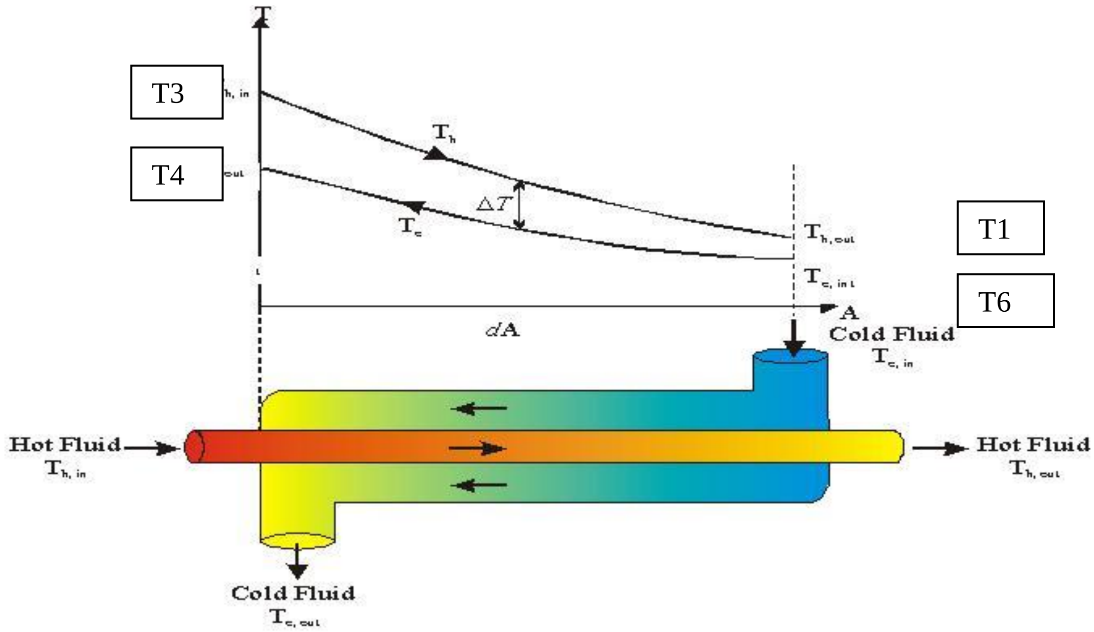

Figure 2: Counter flow heat exchanger

Counter flow is preferred, as the difference in temperature between the hot and cold fluids is relatively constant along the full length of the heat exchanger. This practice is also beneficial because extreme differences in temperature are eliminated that can thermally stress the heat exchanger material.

The following relationships will be used in this lab exercise.

Mass flow rate: m^{dot} = Volume flow rate (V^{dot}) $\times$ density of the fluid (ρ)
Heat power: $Q = m^{dot} \times c_p \times \Delta T$
c_p $\therefore$constant specific heat
Heat emitted from the hot fluid: $Q_e = m_h c_{p,h}(T_1 - T_3)$
Heat absorbed by the cold fluid: $Q_a = m_c c_{p,c}(T_6 - T_4)$
Overall Efficiency for the system: $\eta = (Q_a / Q_e) \times 100\%$
Theoretically, $Q_e = Q_a$. However, this does not hold true due to heat loss given by $Q_f = Q_e - Q_a$
Overall Heat Transfer Co-Efficient U= Q_e /(A * ΔT_{lm})
A= 0.02 m^2
ΔT_{lm}= (ΔT_1 - ΔT_2) / ln(ΔT_1/ΔT_2)
ΔT_1 = (T3 – T4)
ΔT_2 = (T1 – T6)

System Set-up

1. Ensure that the tubular heat exchanger HT 31 is properly mounted to the HT30XC Heat Exchanger Service Unit. Also make sure that HT30XC unit is connected to the computer through a USB port.

2. Prime the water cylinder manually. This just requires filling up the cylinder if it is empty or half-full.

3. Turn on the Main Power supply switch. The switch is a rocker switch located on the lower right front of the test set. Check that the green and red LEDs are illuminated. Depress the red Start/Stop button on the unit.

4. Complete the connections for Experiment as shown in **Figure 3.**
   - **Hot Water Inlet**
     Connect the flexible tube from the front left hand tapping on the sliding end plate (adjacent to sensor T1) to the quick release hot water outlet connector on the HT30XC (front connector with red collar).
   - **Hot Water Return**
     Connect the flexible tube from the rear right hand tapping on the fixed end plate (adjacent to sensor T3) to the quick release hot water return connector on the HT30XC (center connector with red collar.)
   - **Cold Water Inlet**
     Connect the flexible tube from the rear left hand tapping on the fixed end plate (adjacent to sensor T4) to the quick release cold water outlet connector on the HT30XC rear connector with blue collar).
   - **Cold Water Outlet**
     Connect the flexible tube from the front right hand tapping on the sliding end plate (adjacent to sensor T6) to a suitable drain.
   - **Temperature Sensors**
     Connect the miniature thermocouples plug from each of the six temperature sensors to the appropriate socket on the front of the service unit, ensuring that the numbers on the plugs and sockets are compatible/the same.
     As you can see hot stream starts/enters system with T1 follows by T2 (temperature of hot water in the middle of the stream) and ends with T3 (temperature of hot water at the exit). And cold water stream starts/enters the system with T4, follows by T5 and ends/leaves system by T6(temperature of cold water at the exit).

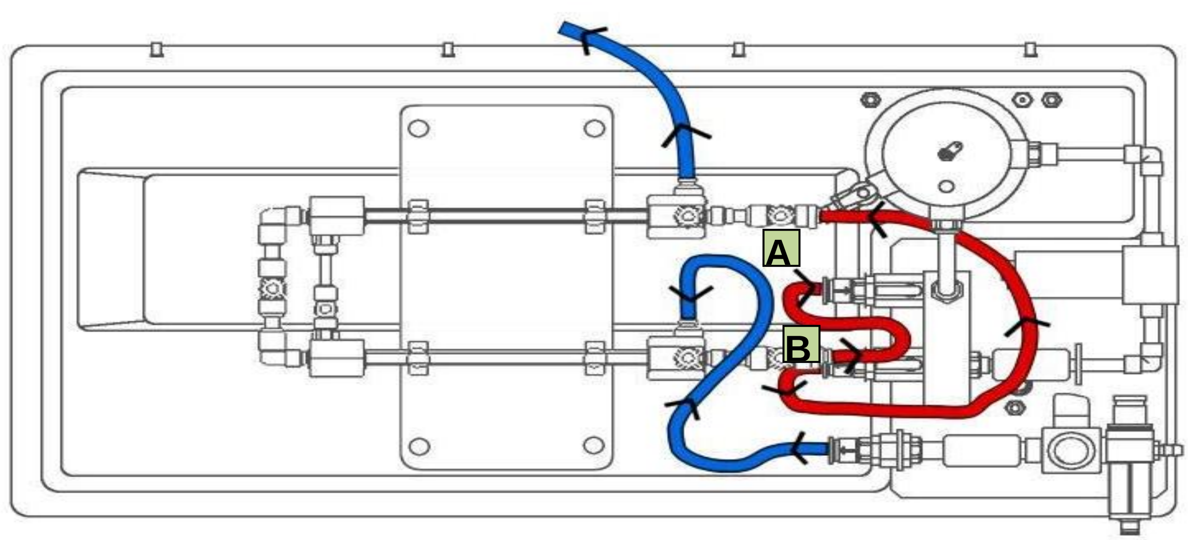

Figure 3. Connections for Experiment

Lab Exercise

The objective of this exercise is to perform an energy balance across a tubular heat exchanger and calculate the overall efficiency at different fluid flow rates. This will be done using thermocouples placed along the length of the tubes, one in the hot stream and one in the cold stream. The thermocouples will indicate the temperature of the fluid stream at each location. The energy transferred to and from each stream will be calculated and used to determine the overall efficiency.

Caution: be sure that the expected and actual placement of each thermocouple is the same in the theory as it is in the lab setup. If an error is found, notify the instructor.

Procedure

1. The starting point for all of the following tests assumes that the system has been primed as defined above in System Set-up.
2. Start the **Armfield HT31 Tubular heat exchanger** software from the Menu.
3. Select '**countercurrent flow'** and click on '**Load'** button.
4. Click on the '**view diagram'** icon.
5. Click on the '**hot water flow'** tab.
6. Select the mode of operation as '**automatic'**.
7. Set the hot water flow rate as **2.5 lit/min** in the '**set point'** tab.
8. Click on 'save' and then the '**apply'** button. Then, press '**OK'**.
9. On the right side of the main screen click on the '**heater'** tab.
10. Select the mode of operation as '**automatic'**.
11. Turn on the hot water inlet and outlet flow valves indicated as '**A'** and '**B'** in Figure 3.
12. Set the temperature at **50** degree Celsius.
13. Keep the remaining settings the same.
14. Click on 'save' and then the '**apply'** button. Then, press '**OK'**.
15. On the left side of the main screen in 'controls', press '**power on'**.
16. Now, the motor and heater will start.
17. Wait until the display indicates the temperature reaching the value set for the hot water in Step 11.
18. Once the set hot water temperature is achieved, turn on the main cold water supply valve on HT30XC.
19. Next, the cold water flow rate is adjusted by setting the percentage valve opening to 100% **and then opening the Main Valve (counter-clockwise), until the actual corresponding cold water flow rate from the 'cold water flow' box reads 4L/min (+/- .1). Note the actual rate.**
20. On the main screen, click the '**GO'** button. This will start enabling collection of data.
21. Press the 'view table' tab and save the data collected as shown on the screen.
22. Repeat the procedure (Steps 18 - 20) for **two** more different **cold water flow rates (2.5L/min, 1L/min (+/- .1))**. For this, keep the percentage valve opening at 100% and then slowly adjust the main valve to two different levels. Again, read and note down the corresponding cold water flow rates from '**cold water flow'** box.
23. This brings you to the end of the experiment. Make sure you have collected all the three sets of data. Turn the power off by pressing the '**power off'** button.
24. Disconnect all the connections and drain the water.

Data Reduction

1. Note the following for each set of data:
   a. Temperature T1
   b. Temperature T2
   c. Temperature T3
   d. Temperature T4
2. Calculate the following for each set of data:
   a. Hot fluid volume flow rate = $(F_{hot})(1.667\times10^{-5})$ m^3/min.
   b. Cold Fluid volume flow rate = $(F_{cold})(1.667\times10^{-5})$ m^3/min.
   c. $\Delta T_{hot} = T1 - T2$
   d. $\Delta T_{cold} = T4 - T3$.
   e. Heat emitted by the hot fluid: $Q_e = m_h c_{p,h} \Delta T_{hot}$
   f. Heat absorbed by the cold fluid: $Q_a = m_c c_{p,c} \Delta T_{cold}$
   a. The heat lost from the system.
   b. Heat transfer coefficient.
   c. The mean temperature efficiency.
   d. The overall efficiency for the system.
3. Graph the power emitted and absorbed for the three fluid stream rates on one chart.
4. Plot and graph
   a) flow rate Vs ΔT for both cold fluid and hot fluid and
   b) flow rate Vs overall efficiency of the system

Questions:

1. Did the heat exchanger remove more or less heat from the hot stream as the flow rate of the cold water decreased?
2. Did the system efficiency increase or decrease as the cold water flow rate decreased?
3. Why it is necessary to find the Heat Transfer co-efficient for heat exchanger?
4. Were there any systematic or random errors that affected your measurements? Discuss in detail and suggest innovative ways to minimize such errors.

Appendix

Table 1

°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

Specific heat capacity of water (Cp kJ/kg˚K)

Table 2

Density of water (ρ kg/m^3)

°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