Lab 4: Heat Exchanger

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1: Abstract

The purpose of this lab is to measure the effectiveness of a heat exchanger. This is done by comparing the measured effectiveness to the calculated NTU effectiveness. A heat exchanger consisting of a water reservoir, piping, a radiator, and an air duct is used to collect data. The data and known variables lead to comparable effectiveness values. Error within the lab could be from equipment failure, inexact flow rates, or collection errors. The effectiveness values both yielded expected values, but had inverse relationships to each other.

2: Introduction

Heat exchangers can be found in many aspects of everyday life. This can include central air, refrigerators, and internal combustion engines [1]. A heat exchanger works by using a cold fluid and a warm fluid in passing, specifically a cross flow in our exchanger. Heat travels from the hot fluid to the cold fluid, and the exchanged heat is proportional to the temperature changes between the fluids.

The heat exchanger in this experiment passes hot water from a tank through a water pump that leads to a radiator used to cool the water. It then passes from the outlet of the radiator back to the water tank, and the cycle begins again. Along the pipes and other components are heating elements, cooling elements, sensors, and valves to control flow.

The effectiveness of this system will be found. Two methods of finding effectiveness will be used - the first of which being the NTU method, which would use the inlet and outlet temperatures to calculate theoretical effectiveness. The second method would be calculated based on the data collected through the system. It is hypothesized that there will be a significant energy loss, resulting in an efficiency much lower than 100%.

3: Methods

The Heat exchanger system used in this experiment is large, and requires lots of different components. The water reservoir is a stainless-steel tank, and it is used to heat the water. It consists of the tank itself, a heating element, a level sensor to keep a consistent amount of water, and a temperature sensor. Within the other non-cooling part of the system, there is a pressure regulator, a variable speed pump, a valve to regulate the hot water flow, a valve to regulate cold water flow, a hot water flow sensor, cold water flow sensor, many ball valves, and inlet and outlet temperature sensors. The cooling system consists of a fan, a radiator, an air inlet and outlet temperature sensor, and an air velocity sensor. The Ebidon SCDAA VI software is used to collect data.

The experiment is begun by opening the software program and selecting TCIF. Two of the valves along both the water reservoir and pipes must be opened - V-1, V-6, V-7, and V-8. The temperature of the tank is set to 65 degrees Celsius, and it can be observed using the data acquisition system.

Once the system reaches 65 degrees Celsius, the hot water flow can be set to 1.5 liters per minute. This may not be achievable because of how the software works, so as close as possible to 1.5 (1.4, 1.6) will also suffice. The fan is set to maximum airflow rate. The air velocity through the outflow duct is recorded. The average velocity can be found using the following equation.

$$V_{avg} = \frac{\sum_{i=1}^{n} V}{n} \quad (1)$$

The same will be done for flow values at or close to 1.7, 1.9 and 2.1 liters per minute. Many other data points must be recorded - the hot water inlet and outlet temperature, the air inlet and outlet temperature, the hot water flow rate, and the average air velocity.

Once all of this data is collected, many related values can be calculated. Experimental effectiveness can be calculated by using equation 2, in which q represents the true heat transfer and q_{max} represents the maximum.

$$\varepsilon = q/q_{max} \quad (2)$$

Heat transfer by the hot water can be found using equation 3, in which m_h represents the hot water mass flow rate, $c_{p,water}$ represents the specific heat capacity of water, $T_{h,out}$ represents the temperature at the hot water outlet, and $T_{h,in}$ represents the temperature at the hot water inlet.

$$q_h = \dot{m}_h c_{p,water}(T_{h,out} - T_{h,in})$$

(3)

Next, the log mean temperature difference between hot water and cold air, represented by ΔT_{lm} will be calculated through equation 5. In the equation F represents the correction factor (found in figure 1), and $\Delta T_{lm,counterflow}$ represents the log mean temperature difference of the counterflow. However, $\Delta T_{lm,counterflow}$ must be found first, using equation 4, in which T represents the temperature at either the hot inlet, hot outlet, cold inlet, or cold outlet, relating to the respective subscript.

$$\Delta T_{lm} = F\Delta T_{lm,counterflow} \quad (4)$$

$$\Delta T_{lm,counter,flow} = ((T_{h,out} - T_{c,in}) - (T_{h,in} - T_{c,out}))/(\ln((T_{h,in} - T_{c,in})/(T_{h,in} - T_{c,out})))$$

(5)

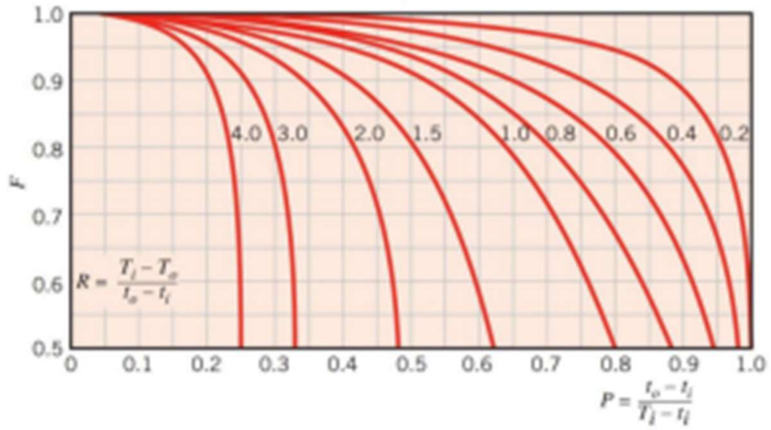

Figure 1: Correction factor chart

Next, UA must be calculated, which can be done using equation 6, where U represents the heat transfer coefficient, and A represents the heat transfer area. q_c represents the flow rate of the cold fluid.

$$UA = q_c * \Delta T_{lm} \tag{6}$$

Next the number of transfer units, represented by NTU, is found using equation 7, in which C_{min} represents the minimum heat capacity.

$$NTU = UA/C_{min} \tag{7}$$

Next, the ratio of heat capacities, C_r can be found using the following equation, where C_{max} represents the maximum heat capacity.

$$C_r = C_{min}/C_{max} \tag{8}$$

Lastly, the second, and theoretical efficiency is found through the following equation using the previously found values.

$$\varepsilon_{NTU} = 1 - exp((1/C_r)(NTU)^{0.22}(exp(-C_r(NTU)^{0.78}) - 1)) \tag{9}$$

4: Results and Discussion

The table below includes values obtained from the heat exchanger during the experiment. These are averaged values taken at one time interval but it should be noted that the values fluctuated. The values include, temperature, flow rate and air stream velocity.

Table 1: Measured Values

Measured	Test 1 - 1.5 lpm	Test 2 - 1.7 lpm	Test 3 - 1.9 lpm	Test 4 - 2.1 lpm
Hot water Tank Temperature ST16 (C)	64.2	64.2	64	64.3
Hot water Tank Temperature ST1 (C)	52.8	54.6	55.4	56.2
Hot water Tank Temperature ST2 (C)	40	42.8	44.1	45.3
Air inlet Temperature ST3 (C)	22.9	22.5	22.4	22.3
Air Outlet Temperature ST4 (C)	38.3	40.9	42.1	43.2
Hot water Flow Rate SC1 l/min	1.4	1.7	1.9	2.1
Average air Velocity SV-1 (m/s)	1.8	1.8	1.8	1.8

Heat exchangers use temperature difference between two working fluids to create heat transfer and either warm or cool a desired fluid. In the case of this heat exchanger the water is cooled by the flow of air across flowing tubes. Seen in table 1 the water and the air start at a significantly high temperature difference and end relatively close to each other. It is important to note that the temperatures approach each other but due to the laws of thermodynamics the water can never be cooler than the air without the introduction of work into the system.

Table 2 uses values from table one to calculate desired variables and characteristics of the heat exchanger using experimental calculation and the NTU method.

Table 2: Heat Exchanger Properties and Calculations

	Test 1	Test 2	Test 3	Test 4
Effectiveness	0.480	0.467	0.486	0.505
Heat Transfer (W)	1.340	1.400	1.498	1.597
Delta T (K)	12.93	11.75	9.44	8.76
UA (W/K)	0.111	0.146	0.195	0.223
NTU	1.191	1.566	2.087	2.385
C	0.893	0.788	0.705	0.638
Effectiveness (NTU)	0.441	0.419	0.407	0.369
T hot (C)	41.014	44.009	45.919	48.225
T cold (C)	36.094	35.937	35.845	34.800
F	0.82	0.7	0.55	0.5

The table begins with the values obtained from the experimental analysis of the heat exchanger. The first value of the effectiveness of the exchanger is used to compare the actual heat transfer rate of the exchanger to the theoretical maximum rate that the exchanger allows. If the effectiveness of the exchanger were to exceed one, there would be an error in the calculation of either q or q_{max}. The heat transfer from the water to the air is the next calculated value which uses the change in temperature of the water along with the mass flowrate and the c_p. The delta T value is calculated using the correction factor and the counterflow log mean temperature difference for a heat exchanger. If this value is incorrect for the correction factor is misread, the entire NTU method can be inaccurate and unusable. Due to the values of C and R calculated to use figure 1, the log mean temperature difference may not be accurate as the correction factor was difficult to approximate. While not required in the table the q_h values were compared to the heat transferred into the air and the values were not equal indicating some inefficiency in the exchanger. One reason for the heat transferred into the air to be larger than the heat transferred out of the water is that the air may have acquired some thermal energy from the surrounding air.

UA, NTU and C_r are all values that are used in the NTU method to calculate the efficiency of a heat exchanger. These values produced an inverse trend from the experimental values of efficiency as the flow rate increased. The effectiveness calculated from the NTU method uses equation 9 relating the previous three variables to find the effectiveness of a heat exchanger. $T_{h,o}$ and $T_{c,o}$ are values calculated using the NTU method based on the effectiveness and C_r temperatures can also be predicted if the effectiveness is known and temperature desired. Lastly the correction factor is determined from figure 1 using the equation for a counterflow heat exchanger's log mean temperature difference to adjust the value for a cross flow exchanger.

The average temperature values of the temperature for the water outlet when compared to the calculated NTU outlet temperatures are very similar and only differ by a degree or two. This demonstrates the power of the NTU method as temperatures can be calculated and predicted. While the water outlet temperatures are accurate the air outlet temperatures are inaccurate and decrease as flow rate is increased but the true values increase. This may be credited to potential inaccuracies in the calculation and determination of the correction factor.

5: Conclusion

Both the NTU method and experimental analysis are valid ways of calculating various parameters and characteristics of heat exchangers. While both of the methods are accurate, they can both serve useful during different scenarios. In an experimental environment where all of the inlet and outlet temperatures of the heat exchanger are known and recorded, using the q and q_{max} to solve for the efficiency of the exchanger is much more efficient and useful. Due to all of the temperatures being known equations one and two can be used. In the case of designing a heat exchanger or trying to calibrate one, the NTU method may prove more use4ful and efficient. Using the NTU method, a desired effectiveness can be given as an initial condition and then used to predict what the outlet temperatures of the exchanger need to be.

Both methods of examining a heat exchanger are powerful and useful, but it is imperative that the calculations be done accurately and precisely as one mistake will make all of the predictions inaccurate. In the case of this experiment it is possible that the calculation and conversion of the log mean temperature difference to fit a cross flow heat exchanger model were inaccurate due to inaccuracies with the conversion factor. This inaccuracy can also cause the effectiveness to decrease as the flow rate increases which is the inverse of what is supposed to happen. One way to eliminate this error in the calculator is to have a computing platform or website interpret the chart with the given temperature values. This would provide an accurate conversion factor and provide a usable log mean temperature difference.

In addition to calculation error in the NTU method it is inevitable that measurement error occurs during the experiment. Some common sources of measurement error include the recording of the temperature of the air as it is recorded by a thermocouple in the flow regime. This temperature may vary while also being impacted by the ambient air. Another uncertainty in the experiment is the flow rate. In the Edibson file the flow rate sensor varies constantly and the manual indicates that the flowrate will not be exactly the recommended value. This uncertainty impacts the accuracy of the heat transfer rates calculated in the experimental examination and leads to uncertainty in the effectiveness of the heat exchanger. To combat this uncertainty either a more consistent pump may be used to regulate flow ar and averaged flow rate based on the data reading from the computer.

6: Sources

(1) “What Is a Heat Exchanger? (Cost, Uses and Examples).” *TWI*, www.twi-global.com/technical-knowledge/faqs/what-is-a-heat-exchanger#:~:text=Heat%20exchangers%20are%20used%20in%20a%20range%20of%20applications%20including,sewage%20treatment%2C%20and%20space%20heating. Accessed 23 Mar. 2024.

(2) M. Huber, B Weber “Applied Measurements Laboratory.” *ME 3264 - Laboratory #4 - Heat Exchanger*. Spring 2023. Accessed March 20, 2024

(3) *“Flat Plate Heat Exchanger”,* Science Direct. J.D Spitler, M.S. Mitchell. Chapter 8, *Surface Water Heat Pump Systems”*. 2016. Accessed March 24 2024.