Design Heat Exchanger: Optimization and Efficiency

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***Abstract*—Modern commercial and residential buildings procure HVAC systems, to provide heating and cooling for designed open and enclosed spaces to dissipate throughout the accustomed zones. HVAC (heating, ventilating, and air conditioning) systems have become a required industry standard for the construction of new buildings. The objective is the optimization of a heat exchanger model by resolving common system concerns; efficiency, fouling, leakage, dead zones, and vibration. These issues are prevalent in the HVAC industry, which are critical to the under-performing heat exchangers. The heat exchanger was tested at only three different wind speeds (20, 40%, 60%) to take the temperature readings every 5 minutes to allow for maximal heat transfer. The efficiency of heat exchanger at the specified speeds was determined to be .7413 at 20%, .6463 at 40% and .6351 at 60%.**

Keywords-Heat Exchanger; Efficiency; Buildings; Design

I. INTRODUCTION

Mankind is about to install their 700 millionth air conditioner. This baffling number creates great opportunity for engineers because behind each air conditioner there is a heat exchanger doing the heavy lifting to bring comfort to billions of people. Heat exchangers have sought be an engineering challenge and still after 700 million there are still problems that can be resolved. Common problems that heat exchangers endure are fouling, dead zones, and leakage and tube vibrations. Fouling is the reduction of performance due to the build of undesired material. This can be the result of corrosion within the heat exchanger and the lack of filtration prior to fluid entering the heat exchanger. Dead zones can lead to significant fouling and are sections of the heat exchanger that the flow is notably less compared to the rest of the heat exchanger. In most cases dead zones are the result of baffles that most heat exchangers use. But in most cases the baffles are essential for the heat transfer so eliminating them cannot be discussed. Leakage occurs when there is a loss of fluid from the heat exchanger, this results in reduced efficiency. Typically, leakage is the result of faulty connections from poor welding or stressed joints. Tube vibrations can cause the most significant damage to heat exchanger. This can be the result of very high velocity axial and perpendicular flow applications. In addition to resolving common heat exchanger problems the end goal is to improve the efficiency of the heat exchanger. R.L Webb et al. focused on [1] four design cases: (1) reduced heat exchanger material; (2) increased heat duty; (3) reduced log-mean temperature difference; and (4) reduced pumping power. The novel method was presented by B. Linnhoff et al. [2], the method is the first to combine sufficient simplicity to be used by hand with near certainty to identify "best" designs, even for large problems. "Best" designs feature the highest degree of energy recovery possible with a given number of capital items. Previous work [3] showed that three rough tube applications are presented: 1. to obtain increased heat exchange capacity; 2. to reduce the friction power; and 3. to permit a reduction of heat-transfer surface area. Adrian [4] examined the coupling between losses due to heat transfer across the stream-to stream ΔT and losses caused by fluid friction using the concept of heat-exchanger irreversibility.

II. DESIGN AND ANALYSIS

Solid works was used to design different models of heat exchanger, Equation Engineering solver (EES) was used for calculations and analysis, the efficient prototype heat exchanger is shown in Figure 1. Table 1 shows the dimensions of the inner tube and the properties of the fluid (water).

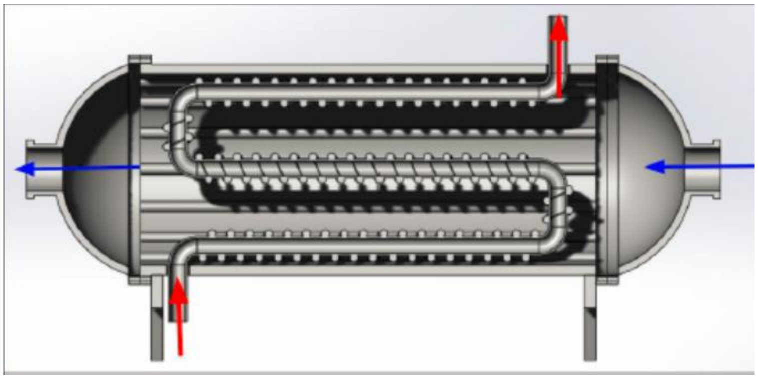

Figure 1. Sectioned SolidWorks model of shell and tube heat exchanger with copper coil and finned inner wall.

TABLE I. INTERNAL FLOW CALCULATIONS

Temperature Inside Pipe	Length	Inner Diameter	Volume Flow Rate	Temperature of Pipe	Average Temperature Between the Surface of the Pipe and Liquid
T_{hi} (C)	L (m)	D_i (m)	$\dot{V}$ $(\frac{m^3}{s})$	T_s (C)	T_{ave} (C)
75	1.397	.013843	.0000335	70	72.5

Properties of Water: Properties were found at the average temperature between the surface of the pipe and liquid and a pressure of 101.3 N/m^2, using Equation Engineering solver (EES) to write the code and solve for the amount of heat transfer.

TABLE II. EXTERNAL FLOW CALCULATIONS

Temp. of Air	Outer Diameter of the Pipe	Temp. of Outer Pipe	Velocity of Air	Vertical Distance Between Pipes	Horizontal Distance Between Pipes	Length the Air Travels	Average Temp. Between the Surface of the Pipe and Liquid
T_{ci} (C)	D_o (m)	T_{so} (C)	V_o $(\frac{m^3}{s})$	S_t (m)	S_l (m)	L_o (m)	T_{aveo} (C)
20	.015875	45	.222	.057785	.0127	1.9304	32.5

Initially the shell of the heat exchanger was going to be formed using sheet metal. With concerns of burn-through while welding the shell together it was determined that buying HVAC duct would reduce manufacturing time and eliminate concerns of sealing the shell together. The second difference between the prototype and the model is the use of fans to send air through the shell. Initially the plan was to incorporate fans within the shell that would send air through and out the other side. The main concern with this idea was if we were going to be able to vary the fan speed for calculation purposes. It was determined that a 4" flexible duct was attached from the heat exchanger to the wind turbine in Wentworth's Fluid Dynamics Lab where we would be able to vary wind speed during testing. Not only did this decision save money it also eliminated doubt from our calculations. The third difference is the overall length of the prototype. This work initially planned to make the shell 18" long with 6" diameter. While we kept the diameter the same, the heat exchanger is now 24" long due to the need for an additional connection piece for the HVAC duct that was not initially incorporated into the SolidWorks model.

III. Manufacturing Prototype Parts

The prototype consists of ten major part that will be assembled into a heat exchanger. The parts consist of the controller, pump, piping, valves, stand, reservoir, coil, slides, shell and caps. Out of these nine parts, the stand, reservoir and slides needed to be manufactured in the projects lab. This work manufactured all these parts on the Wentworth Campus in the Manufacturing Lab and Projects Lab.

The stand was manufactured in three major steps. First, we bout ¼ inch plywood and drew the dimensions that would sufficiently hold the tube and reservoir tank. The two vertical pieces were measure to the dimensions of 1' wide and 1.5' tall with a 6" diameter half circle cut at the top to hold the tube in place. The base piece was also dimensioned to be 1' wide and 2' long to hold the tube at the two ends. A small shelf to hold the pump and valves was dimensions to be 1' wide and 6" long. The second steps consisted of cutting all the pieces. This work used two tools to accurately cut the plywood, a circular and jig saw. The circular saw was used to cut the straight angles while the jig saw was used to cut the 6" diameter half circles. After the pieces were cut the stand could be assembled. The third step consisted of using 15 angle brackets, 60 screws and the three-stand pieces to assemble the stand. Three angle brackets were screwed into each inside portion of the base and vertical pieces with two angle brackets on the outside to ensure stability. The shelf was fastened in a similar manner to the outside of the vertical piece.

A. Reservoir

This work manufactured the reservoir using copper plates, angle brackets, screws, JB weld, and flex seal. First, it the precut copper plates and angled them against each other at 90 degrees to construct an open box, and screed the brackets in place at 3 points per corner. Next, with duct taped the outside of the box to ensure a tight seal between the two pieces and applied the JB weld to all the seams. After an hour of curing we applied flex seal to the entire surface of the inside. This sealed between the screws ensuing a waterproof reservoir.

B. Slides

The slides were manufactured using a Solidworks model, which was then converted over to a CAM file. The milling machines would have taken about 3 hours per slide, so we opted to use the LPM. The process with 26 minutes per part, which was a noticeable efficiency difference. The center hole was a quarter of an inch and was pressed out. The plate was then clamped down into the LPM and the larger holes began to mill. Then the circles were cut out from the existing material, with a helix pattern. A hole was drilled at both ends of the shell to allow the ends of the coil to protrude out so that we could connect the fluidics tubing. Once that was all done the end caps were placed on the ends of the shell which shrank the shell diameter from 6” to 4".

Figure 2. The heat exchanger prototype

After that insulation was put on the whole shell assembly to prevent any possible heat from escaping. With the whole shell finished it was time to put the rest of the manufactured parts together. The shell assembly was placed into the 6" diameter half circles in the wooden stand so that it could be supported horizontally. The copper reservoir was then placed underneath the shell assembly. Fluidics tubing was then connected from one of the ends of the copper coil from the shell to one side of the reservoir tank. This where the water will go after going through the heat exchanger. An overflow hole and tube were made in the reservoir to be directed back towards the sink. Electronic valve A was used to pull water from the hot sink water that was stored in a trash car and heated by a Bunsen burner. Piping from the trash can to Electronic Valve A, then the valve to the pump was made. Electronic Valve B was used to pull water from the reservoir tank. Piping from the reservoir tank to Electronic Valve B, then the valve to the pump was made. The final piping from the pump to the inlet part of the coil completed the piping system. Figure 2 shows the heat exchanger prototype.

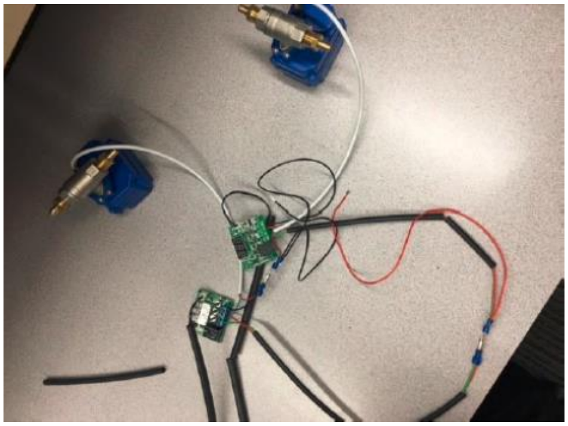

Figure 3. The electronic part of the heat exchanger

Two temperature controllers as shown in figure 3 were used to regulate the opening and closing of the valves. The wires from Electronic Valve A are connected to Controller A. The wires from Electronic Valve B are connected to Controller B. The source connection for the two controllers are to be wired together and connected to a DC source controller supplied by the Electrical Lab. Figure 4 shows testing the heat exchanger. Figures 5, 6 and 7 show the effect of time on the air outlet temperature.

Figure 4. Testing the heat exchanger

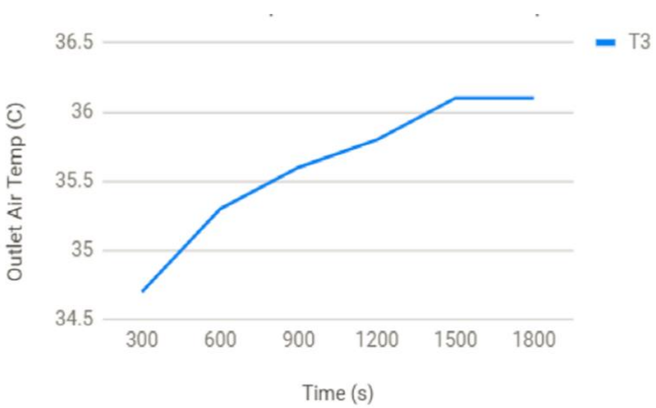

Figure 5. Time vs. outlet air temperature at 20% wind speed

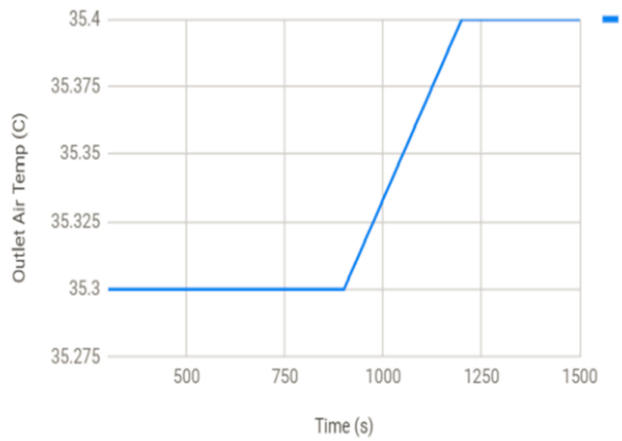

Figure 6. Time vs. outlet air temperature at 40% wind speed

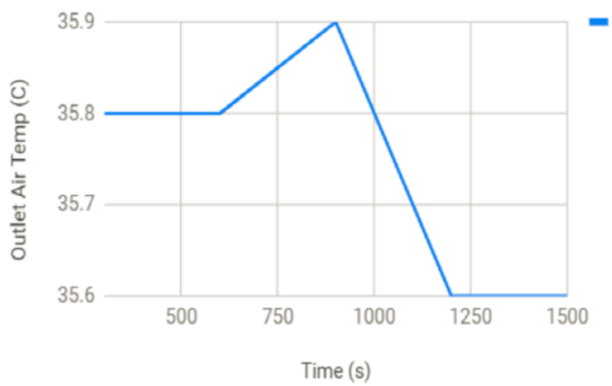

Figure 7. Time vs. outlet air temperature at 60% wind speed

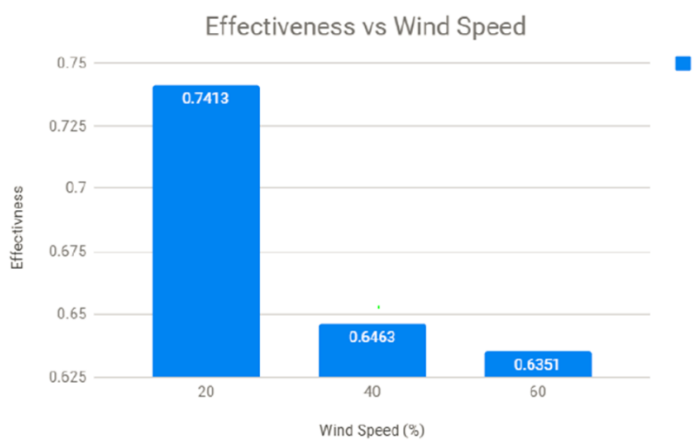

Figure 8. Effectiveness vs wind speed

Initially the heat exchanger was tested with fan speeds starting at 20% increasing up to 100% in increments of 10. However, it was determined that by increasing the fan speed percentage so rapidly there would not be enough time for maximal heat transfer. Knowing this, it was determined that the heat exchanger would be best to test at only three different wind speeds (20, 40%, 60%) and to take the temperature readings every 5 minutes to allow for maximal heat transfer. Before testing the heat exchanger for the second trial it was hypothesized that since slower fan speeds would allow the air to stay in contact with the inside of the heat exchanger longer the efficiency would be higher. Looking at the graphs above this hypothesis was proven to be correct. Every 5 minutes the inlet and outlet temperatures of both the air and the water were recorded based on the readings given from the thermocouples. While running the heat exchanger the pump sent the water through the copper coils at a constant velocity of .0667 m/s. For the three different fan speed percentages of 20, 40, and 60, the air velocities were measured at 2.2 m/s, 3.87 m/s, and 6.5 m/s. At each fan speed 5 temperature readings were taken, the temperature change between the 1st and 5th reading was then used to determine the efficiency of the heat exchanger at the specified air and water velocities with respect to the initial temperatures of both the water and air. By using the same equations that were used to analyse the initial four designs the effectiveness of the heat exchanger at the specified speeds was determined to be .7413 at 20%, .6463 at 40% and .6351 at 60% as shown in figure 8.

IV. CONCLUSION

After months of research, designing, building and testing we concluded that the heat exchanger provides an effectiveness that is below average compared to common industrial designs. Some variables that may have affected our results are the following; since it is the middle of the summer the outside temperature is quite high making it difficult to determine the true change in temperature since the inlet and outlet temperatures are quite close to one another. If this test was done in the winter are values could potentially be much better. Also, the reservoir tank had a hard time maintaining a warm enough temperature so that could start using the water from it rather than main water source. This may be due to the fact that we used Flex Seal to make sure the tank was water tight. The thermal conductivity of Flex Seal is much lower than copper which is what the tank is made out of. By spraying it everywhere the thermal conductivity of the tank as a whole might not be as high as thought. Overall heat exchanger did what wanted it to and by making these and other modifications the work believe can perform better.

ACKNOWLEDGEMENTS

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