

Heat Exchanger Laboratory Analysis

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Introduction

This investigation was undertaken in order to understand the key features and properties of a 32 tube, parallel flow heat exchanger and which variables effect its function. Air flow, water flow, and water temperature were varied independently of one another in 3 separate experiments in order to see how these changes effect performance and the results compared to theoretical knowledge.

Procedure

To begin experiment 1, the orifice of the air inlet was inspected, and the diameter measured and recoded before the water pump and the fan were turned on. The water pump causes a steady flow of temperature-controlled water to flow through the tubes of the heat exchanger, beginning at the bottom most tube, and flowing upwards. The fan passes a steady flow of air over the tubes containing the water. This air is at ambient temperature and enters the system through the orifice.

At this point the temperature of the water was set to a target temperature of 60°C and allowed to warm up. Whilst this was happening, the air pressure drop of 250 Pa (+/- 5 Pa) was set using the sliding valve.

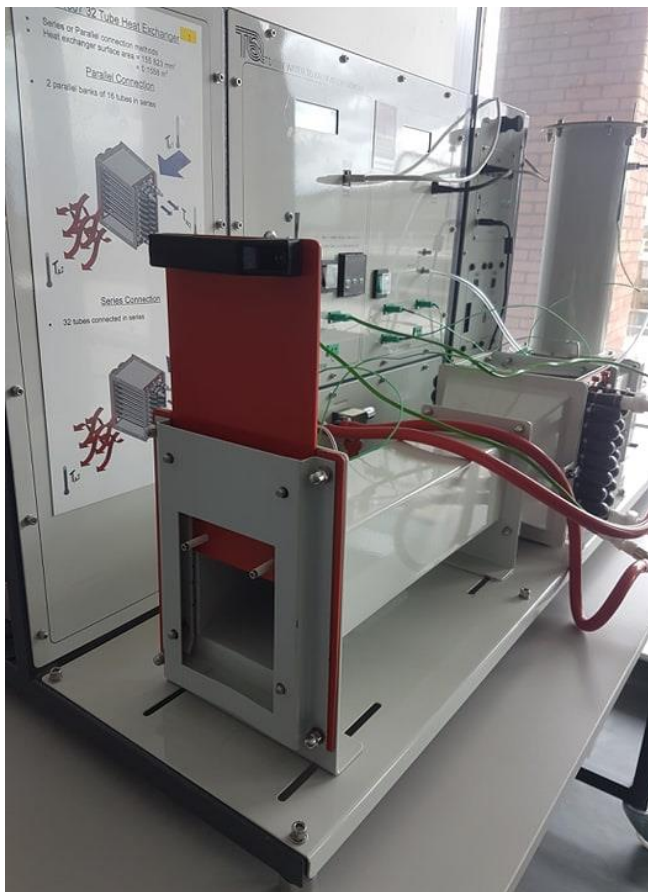


Figure 1 - Change in air pressure slider

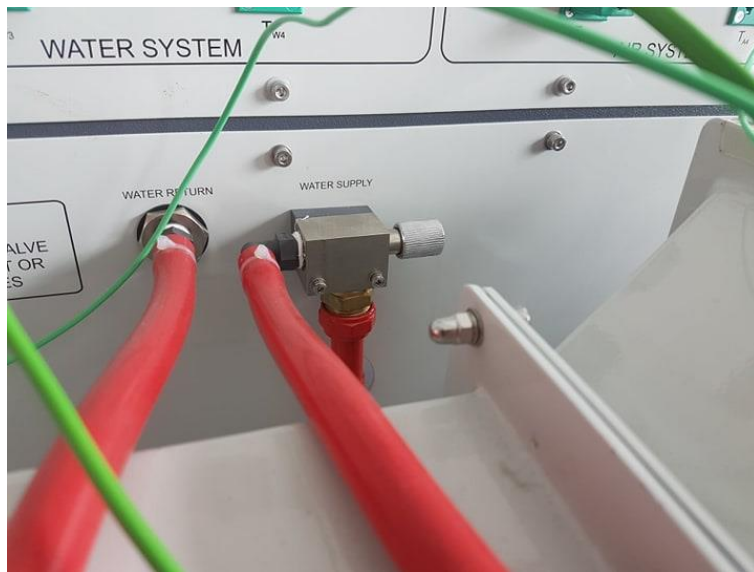


Figure 2 - Water flow regulator

Now the water flow rate was set using the manual flow valve in figure 2. The heat exchanger displays this as the volumetric flow rate (L/min) and was later converted to mass flow rate (kg/s). In the first experiment, this would be the controlled variable, changing from 2.25 to 0.25 at each repeat, whilst air flow and water temperature were kept constant as set out above.

The procedure for experiment 2 was similar to the procedure for experiment 1. The difference was that for this experiment, the flow rate was kept constant at 0.25 L/min, and instead the orifice pressure drop was changed at increments between 250 and 50 Pa using the sliding valve in figure 1.

Finally experiment 3 used the same procedure as experiment two. The only difference being that the temperature of the water was kept constant at 45°C as opposed to 60° (used in experiment 1 and 2). Then the air flow rate was again varied.

After any setting is changed, the system must be left to rest for at least 5 minutes, to allow changes in pressure, or temperature to settle, as reading values whilst fluctuating, could cause inaccurate readings. Whilst it is settling, it is important to ensure that all constants and control variable remain within tolerance. If they fluctuate outside the range of tolerance, they must be adjusted, and the resting cycle started again.

Experiment 1

This experiment investigated the effect of changing water flow on the performance of the heat exchanger. Of particular interest were the change in temperature and average temperature at each water flow rate. As well as this we were interested to investigate the effect of water flow rate on the specific heat capacity of water.

Results

To calculate the air mass flow rate the equation below was used.

$$\dot{m}_A = C_d \times A_o \sqrt{\Delta p \times 2 \times \rho_A}$$

$C_d = 0.6$

Ao = Area of the orifice (0.00787127m²)

Pa = Density of air (kg/m³)

The Change in air pressure Δp was measured as follows

$$\rho_A = \frac{p}{RT}$$

p = Air pressure (Pa)

T = Average Temperature (K)

R = Gas constant (287)

Water Flow (L/min)	Average Ta K	dP	Air Density	Air Mass Flow Rate
2.25	301.1	249	1.190756	0.115006421
1.75	301.0	249	1.191151	0.115025523
1.25	301.0	250	1.191151	0.115256267
0.75	300.7	248	1.192538	0.114861115
0.25	300.1	250	1.194724	0.115428964

Table 1

The equation below was used in order to convert the volumetric flow rate, to mass flow rate.

$$\dot{m} = (\dot{V}/60000) \times \rho$$

ρ = Density of Water (kg/m³)

Before this was possible, the density of water had to be calculated using the equation below.

$$\rho_w = \frac{(999.839 + 16.952T - 7.990 \times 10^{-3}T^2 - 46.241 \times 10^{-6}T^3 + 105.846 \times 10^{-9}T^4 - 281.030 \times 10^{-12}T^5)}{(1 + 16.887 \times 10^{-3}T)}$$

T = Average Temperature of Water (°C)

Both the calculations for density of water and mass flow rate were repeated at each volumetric flow rate

Water Flow (L/min)	Average Tw (°C)	Water Density (kg/m ³)	Water Mass Flow Rate (kg/s)
2.25	59.0	983.71829	0.036889436
1.75	58.4	983.99698	0.028699912
1.25	57.2	984.62358	0.020512991
0.75	55.0	985.70329	0.012321291
0.25	49.5	988.2694	0.004117789

Table 2

To find the specific heat capacity of water:

$$\frac{c_{pW}(\text{at } T^{\circ}\text{C})}{c_{pW}(\text{at } 15^{\circ}\text{C})} = 0.996185 + 0.0002874\left(\frac{T + 100}{100}\right)^{5.26} + 0.011160 \times 10^{-0.036T} \quad (7)$$

T = Temperature of water (°C)

Cp = Specific heat capacity (J/kg/K)

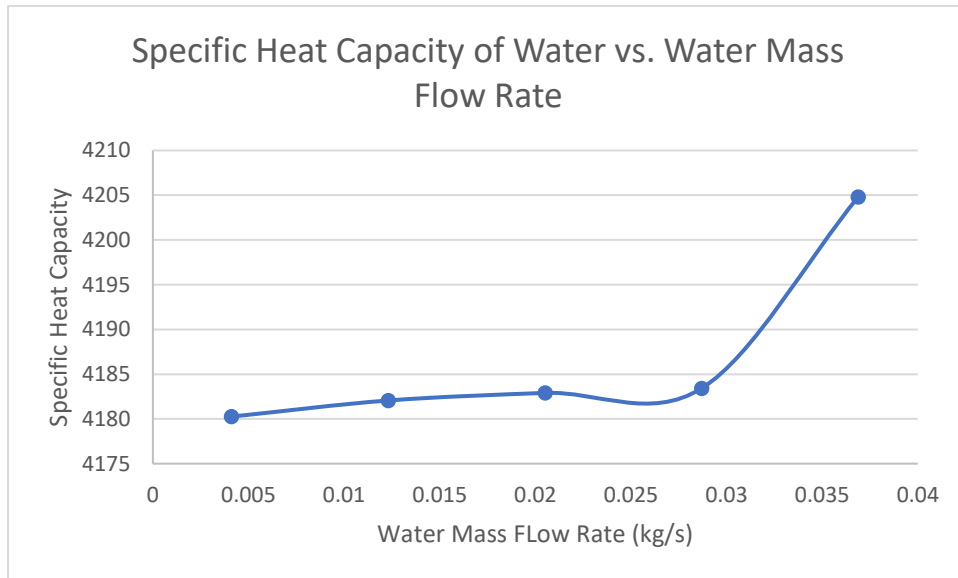


Figure 3 - Specific Heat Capacity of Water vs. Water Mass Flow Rate

Analysis

Since the purpose of this heat exchanger is to move the energy in the water, which is stored as heat, into the air (Thermex.co.uk, 2019), the energy emitted and absorbed could be an appropriate measure of the heat exchangers effectiveness.

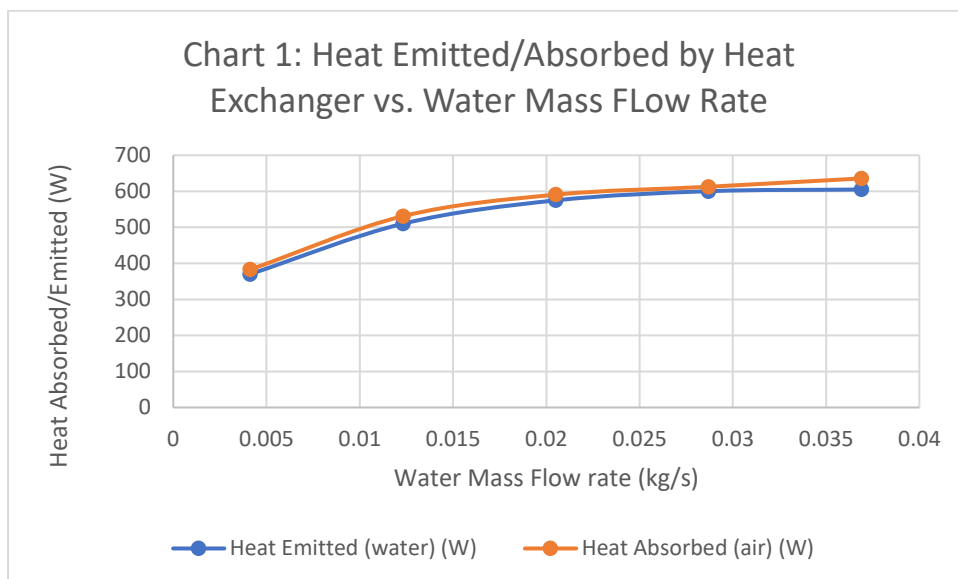


Figure 4 - Heat Emitted/Absorbed vs. Water Flow

The figure above shows how heat transfer is affected by the flow rate of the water. It is evident that the initial increase in mass flow rate has a far more significant impact on heat transfer, however this

increase drops of steadily, until at roughly 0.025 kg/s, continued increase in water mass flow rate has a seemingly negligible effect on the head transferred (emitted or absorbed).

It is also worth noting that there is potentially a cause of inaccuracy obvious here. Newtons laws of conservation of energy would suggest that the heat emitted should at each measurement be greater than the heat absorbed (Energyeducation.ca, 2019). The lost energy could easily be accounted for, when taking losses to the environment (both heat and sound) into consideration. However, the graph above suggests that energy is created, which we know is not possible.

Since the two lines in figure 4 follow very similar trends and have similar magnitudes, it could be assumed that there is high efficiency. The figure below shows the temperature efficiency of water and air, and the mean temperature efficiency, which shows how much energy is wasted (or lost) whilst transferring from the water to the air.

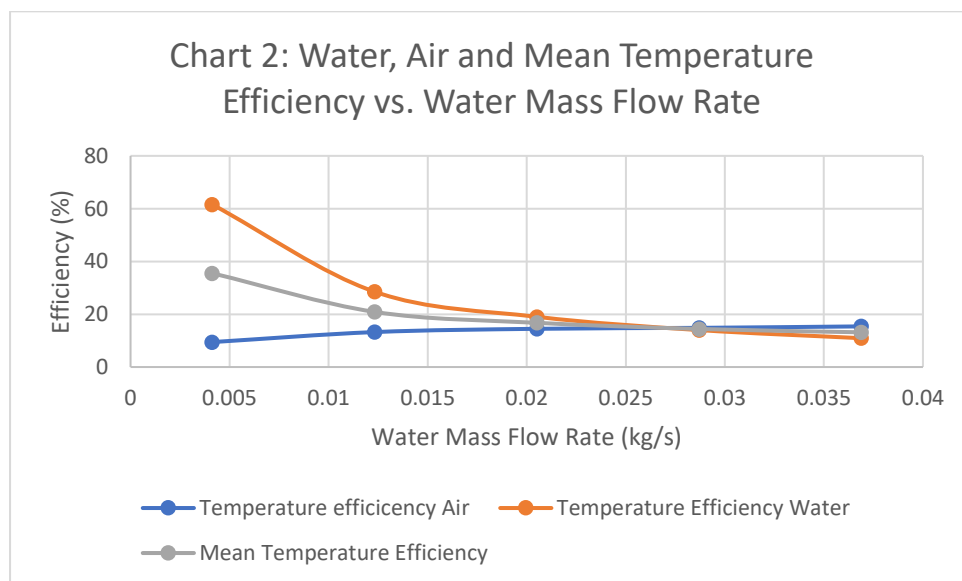


Figure 5 - Temperature Efficiency

The figure shows that at lower flow rates, the amount of energy retained in the water is significantly higher than the energy retained at higher flow rates. It also shows that the amount of energy received by the air only increases very slightly. At this point the effectiveness of increasing the flow rate would depend upon the intended use of the heat exchanger. If the purpose was to heat the air, whilst increasing the water flow rate would increase the air temperature efficiency to some extent, this improvement is very limited, whilst if the purpose is to cool the water, the increased rate has a more significant effect. As with figure 4, the change in efficiency decreases as the water mass flow rate increases.

Investigating the heat transfer coefficient gives further evidence that increasing the water mass flow rate, provides a more efficient means of heat transfer to some extent, and that the extent to which it increases effectiveness decreases as the flow rate increases. It shows that the heat transfer coefficient increases until roughly 0.023 kg/s flow rate, but then begins to reduce again. This would suggest that this flow rate is where the most efficient energy transfer occurs, and this is supported by the other graphs.

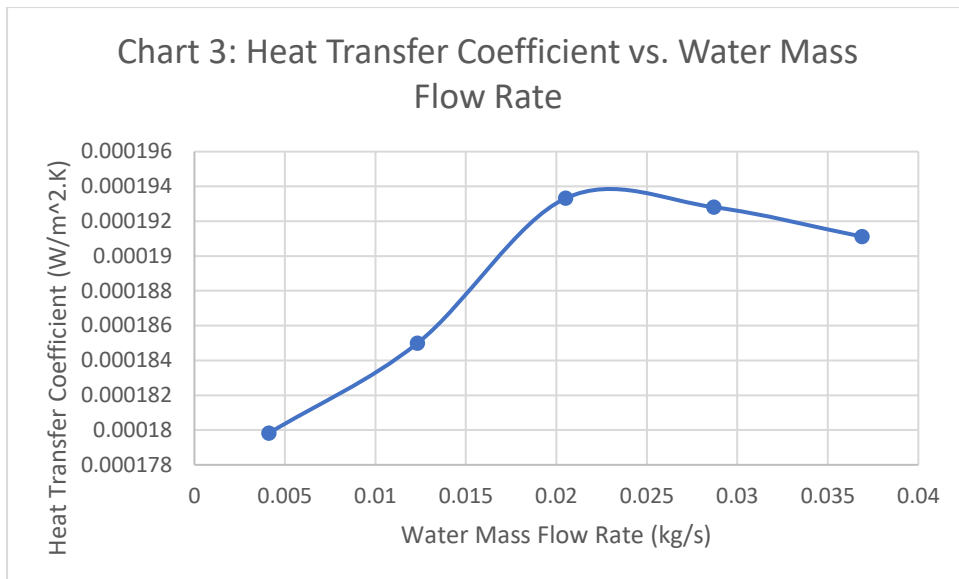


Figure 6 - Heat Transfer Coefficient

Experiment 2

The objective of this Experiment was to investigate the effect of changing the air flow rate, on the efficiency of the heat exchanger.

Results

To calculate the change in temperature and air mass flow rate in this experiment. The same equations and constants as in experiment 1 were used. The results can be seen in the table below.

Water Flow (L/min)	Average Ta K	dP	Air Density	Air Mass Flow Rate
0.25	300.0	250	1.195321	0.115457822
0.25	300.1	200	1.194923	0.103251406
0.25	300.3	149	1.194127	0.089090094
0.25	300.6	99	1.192935	0.072583352
0.25	301.2	50	1.190558	0.051531331
0.25	302.0	25	1.187207	0.036386839

Table 3

Water Flow (L/min)	Average Tw	Water Density	Water Mass Flow Rate
0.25	49.5	988.2694	0.004117789
0.25	48.6	988.67062	0.004119461
0.25	48.8	988.58193	0.004119091
0.25	49.4	988.29183	0.004117883
0.25	50.6	987.77176	0.004115716
0.25	51.8	987.1967	0.00411332

Table 4

Power Heat Absorbed (air)	Power Heat Emitted (water)	Temperature efficiency Air	Temperature Efficiency Water	Mean Temperature Efficiency	LMTD	Heat Transfer Coefficient
382.9158683	393.7449569	9.455587393	61.60458453	35.53008596	20.00078	126.3573576
342.4332875	369.723771	9.90990991	60.96096096	35.43543544	19.13361	124.0260628
295.467297	353.8278993	10.03039514	59.27051672	34.65045593	19.3067	117.6295916
269.9011956	340.0012604	11.17824773	56.79758308	33.98791541	19.75973	110.441418
233.0504443	307.0440305	13.55421687	51.5060241	32.53012048	20.54121	95.9416592
190.1576184	278.5039496	15.6626506	46.98795181	31.3253012	21.11989	84.63931897

As well as these, the overall heat transfer coefficient (U) was calculated for each flow. As the equation below shows, in order to calculate U, first heat emitted, heat absorbed, mean temperature efficiency and LMTD need to be calculated.

$$U = \frac{\dot{Q}_w}{A \times LMTD}$$

$$\dot{Q} = \dot{m} \times c_p \times \Delta T$$

$$LMTD = \frac{(T_{W2} - T_{A2}) - (T_{W1} - T_{A1})}{\ln\left(\frac{T_{W2} - T_{A2}}{T_{W1} - T_{A1}}\right)}$$

Table 5

Analysis

Looking again at how heat transfer is affected, this time it is being compared to varying rates of air flow. When compared to the results seen in figure 4, we can see that heat transfer in the figure below, follows a different trend when the air flow rate is changed. The figure suggests a near linear correlation, however further investigation with a wider range of air mass flow rates, would be required to determine if this is true at any rate, or if the correlation changes.

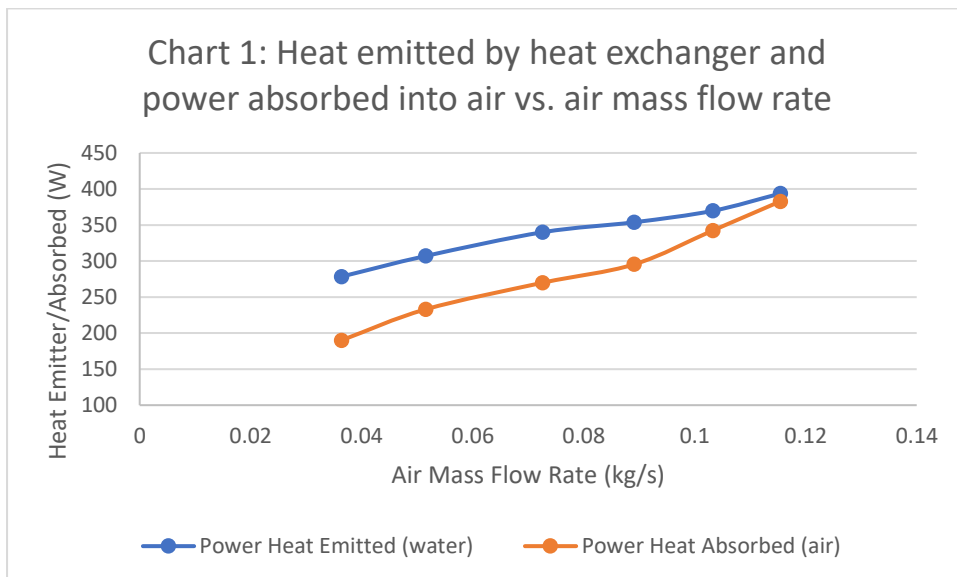


Figure 7 - Heat Transmitted vs. Air Mass Flow Rate

These results do not seem to suffer the same issues that were evident when evaluating the heat transfer for experiment one. As expected, there is a greater power emitted than absorbed. This would suggest that the issue seen earlier was as a result of a zeroing error, rather than a calculation or data gathering error.

Another trend that is noticeable in figure 7, is the tendency of the two lines to converge. This would suggest a higher efficiency in energy transfer, and this is confirmed by the data that can be seen in figure 8. We can see that the mean temperature efficiency increases as the air mass flow rate increases.

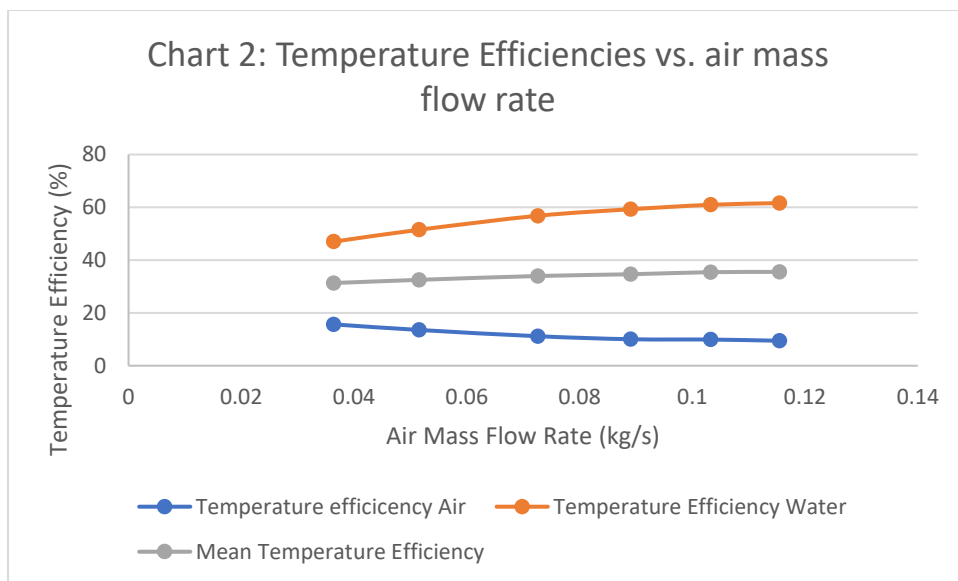


Figure 8 - Temperature Efficiency vs. Air Mass Flow Rate

It is worth noting that whilst the mean temperature increases as the air flow rate increases, this is not true for the temperature efficiency of air, which sees a decrease. This would suggest that there are also greater losses as the air mass flow rate increases.

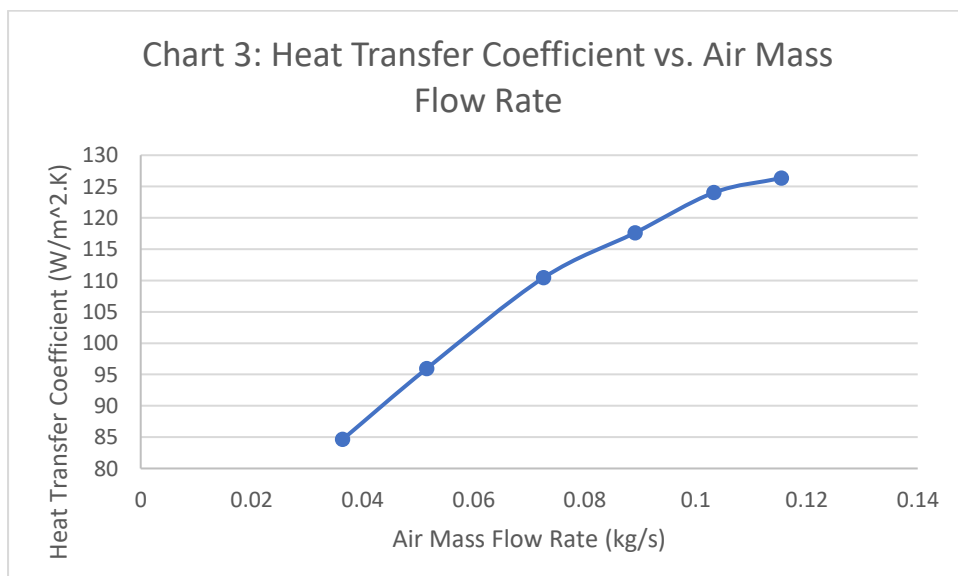


Figure 9 - Heat Transfer Coefficient vs. Air Mass Flow Rate

The results seen in figure 9 seem to suggest what figure 7 shows. They both show a positive linear correlation between the heat transfer and the air flow rate, and figure 9 shows more clearly that eventually this correlation seems to level off, suggesting that increasing air flow will not improve efficiency once a certain point is reached.

Experiment 3

In this experiment, the aim was to investigate the effect of temperature of the hot water supply, on the performance of the heat exchanger.

Results

All results for experiment 3 were calculated in the same way as in experiments 1 and 2.

Water Flow (L/min)	Average Tw	dP	Air Density	Air Mass Flow Rate
0.25	41.4	250	1.197517	0.115563822
0.25	41.5	200	1.196917	0.103337542
0.25	41.7	150	1.196318	0.089171804
0.25	42.2	100	1.19552	0.072661968
0.25	43.0	50	1.193531	0.051595619
0.25	43.7	25	1.191349	0.036450259

Table 6

Water Flow (L/min)	Average Tw	Water Density	Water Mass Flow Rate
0.25	41.4	991.66102	0.004131921
0.25	41.5	991.64136	0.004131839
0.25	41.7	991.54282	0.004131428
0.25	42.2	991.36429	0.004130685
0.25	43.0	991.04329	0.004129347
0.25	43.7	990.73819	0.004128076

Table 7

Power Heat Absorbed (air)	Power Heat Emitted (water)	Temperature efficiency Air	Temperature Efficiency Water	Mean Temperature Efficiency	LMTD	Heat Transfer Coefficient
255.511611	255.9666434	9.361702128	62.9787234	36.17021277	13.22753	124.2044403
238.8647284	243.8983648	9.956709957	61.03896104	35.4978355	13.25012	118.1467507
215.0823919	235.2575311	10.43478261	59.13043478	34.7826087	13.45008	112.2667725
189.8657222	226.5992798	11.25541126	56.70995671	33.98268398	13.79186	105.4552559
165.9315116	205.8503243	13.85281385	51.51515152	32.68398268	14.24003	92.78402724
128.213787	186.8338617	15.28384279	47.16157205	31.22270742	14.60115	82.12984132

Table 8

Analysis

In order to determine the effect, changing hot water temperature would have on the heat exchanger, it is important to compare the results like for like. No change in process to place between recording data for experiment 2 and 3, so that the only change effecting the results, would be the temperature change of the hot water supply from 60°C in experiment 2, to 45°C in experiment 3.

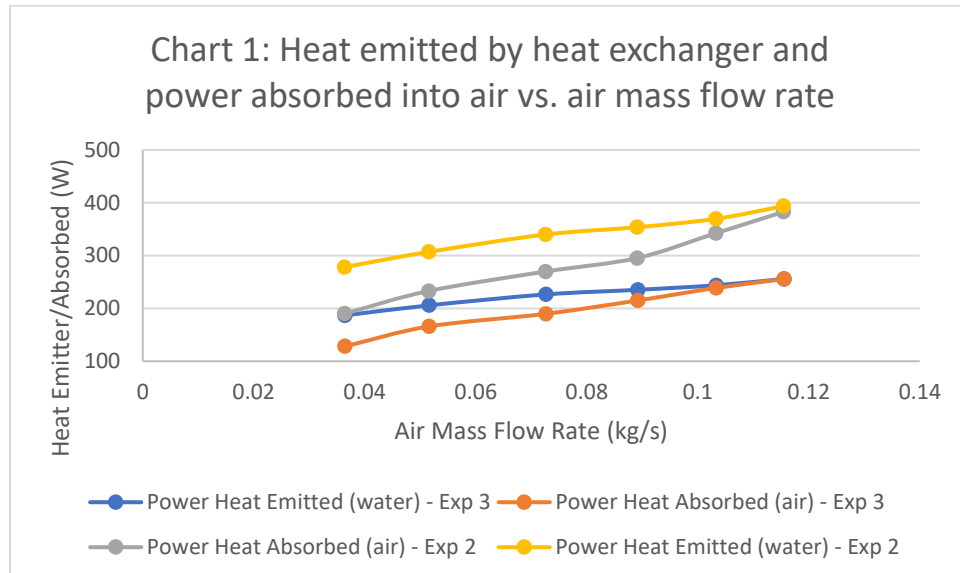


Figure 10 - Heat Transfer vs. Air Mass Flow Rate

Figure 10, as expected (Physicsclassroom.com, 2019), shows that the greater temperature produces the greatest heat transfer. This is due to the greater temperature difference between the water and the air. It also shows that there is no change in trend between the absorbed or emitted lines, between experiment 2 and 3.

The common trends, combined with the data in figure 11, shows that whilst there is a greater rate of heat transfer, the efficiency almost remains constant. It is unclear why towards the higher air flow rate, the efficiency of water seems to deviate, however it is possible that this is due to an anomaly in the readings, either during experiment 2 or 3. In order to rule this out, further readings at higher air flow rates would be required, and repeated readings would also support in evaluation.

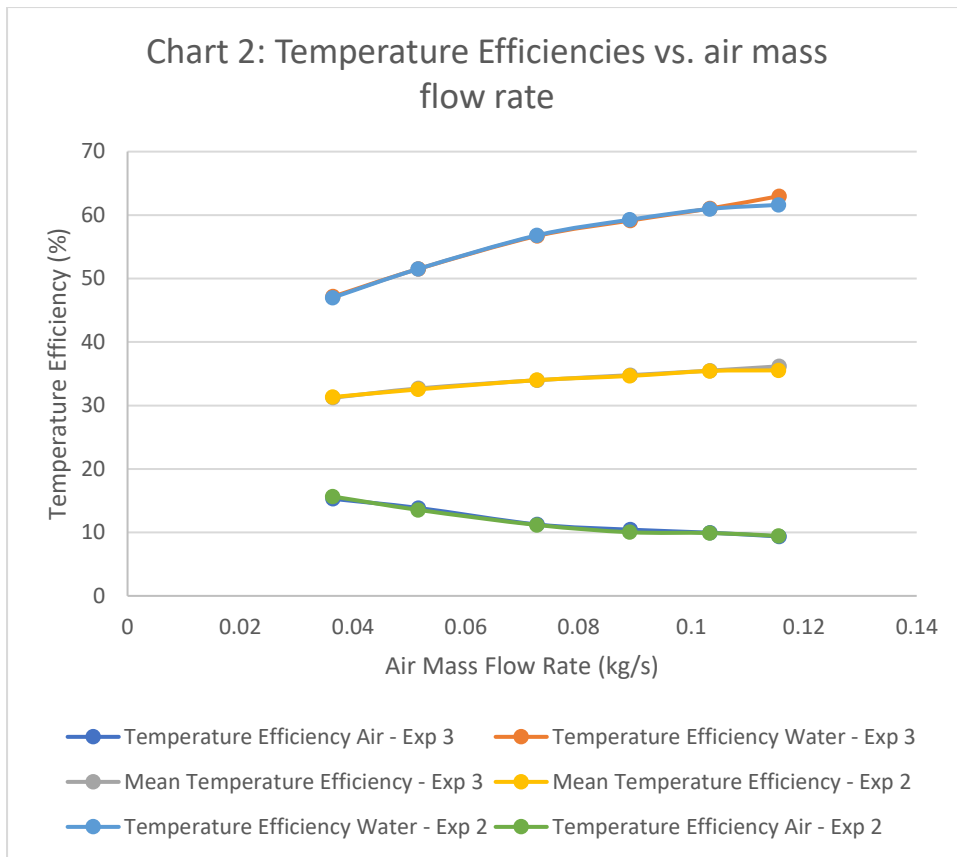


Figure 11 - Temperature Efficiency vs. Air Mass Flow Rate

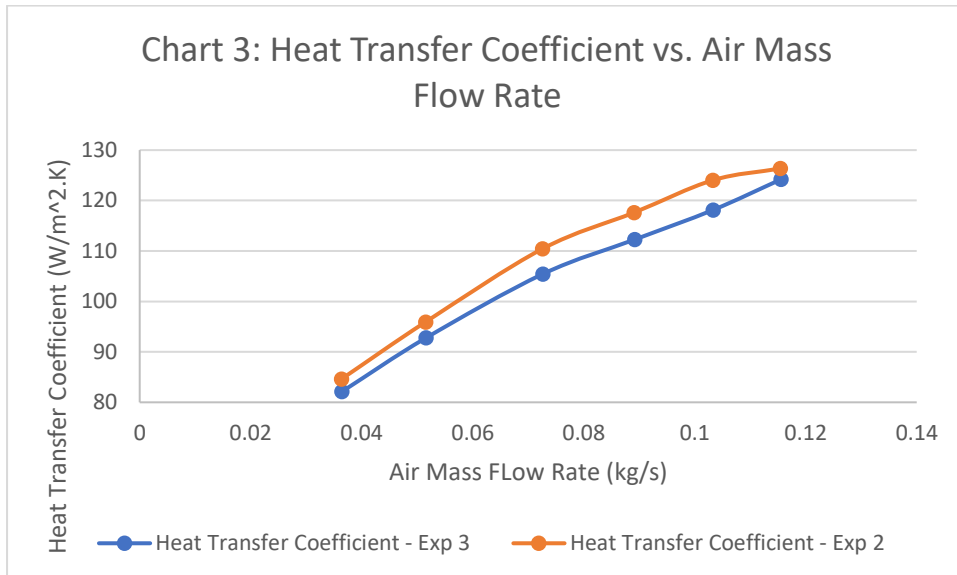


Figure 12 - Heat Transfer Coefficient vs. Air Mass Flow Rate

Figure 12 shows that the heat transfer coefficient in experiment 2 was higher than that in experiment 3. This would suggest that for transferring heat, the higher temperature seen during experiment 2 is more effective. This would support the conclusions drawn from figure 10.

Conclusion

The experiments and results outlined above, have allowed the evaluation of a heat exchanger based on 3 different key characteristics. The effects of changing air flow rate, water flow rate and the temperature of the inlet water were investigated and evaluated.

The results showed that changing water flow rate would have a significant effect on both the rate of heat transfer, and its efficiency. However, this was shown to only be true to a point, where efficiency seemed to decrease, and the rate of heat transfer no longer increased, but remained constant.

It was also shown that changing the air mass flow rate would affect the efficiency and rate of heat transfer. The results showed that the effect of changing this was more significant than the effect of changing the water flow rate. It was also not clear if, and when, the increase in efficiency would stop, and the same was true for the rate of heat transfer.

Finally, the temperature of the inlet water, was seen to affect the both the rate of heat transfer and its efficiency. The efficiency seemed to only be affected slightly when compared to the effect changing air, and water mass flow rate had on the heat transfer coefficient.

Moving forward, further investigation through testing would be required on the heat exchanger. It is necessary to investigate at what point increasing air flow rate stops effecting efficiency and rate of heat transfer, and there were a few anomalies in the data that could be disregarded, with further data.

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