

University of Wales Trinity Saint David School of Engineering

Heat Exchanger Laboratory Analysis
Thermofluid Mechanics M5X00406

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1 Introduction

The objectives of experiment one is to investigate how different water flow rates affect the performance of a heat exchanger with a fixed air flow and water temperature. We will also investigate the air flow over a heat exchanger affects its performance with a fixed water flow and temperature in experiments two and three. After this we will study performance of a heat exchanger when the temperature of the hot water supply is varied with a fixed water supply. From the variables we will get values for change in temperature and flow rate.

1.1 Materials

- 32 Tube Heat exchanger
- Heater tank
- Fan with variable air flow
- Pressure and temperature reader
- Water supply

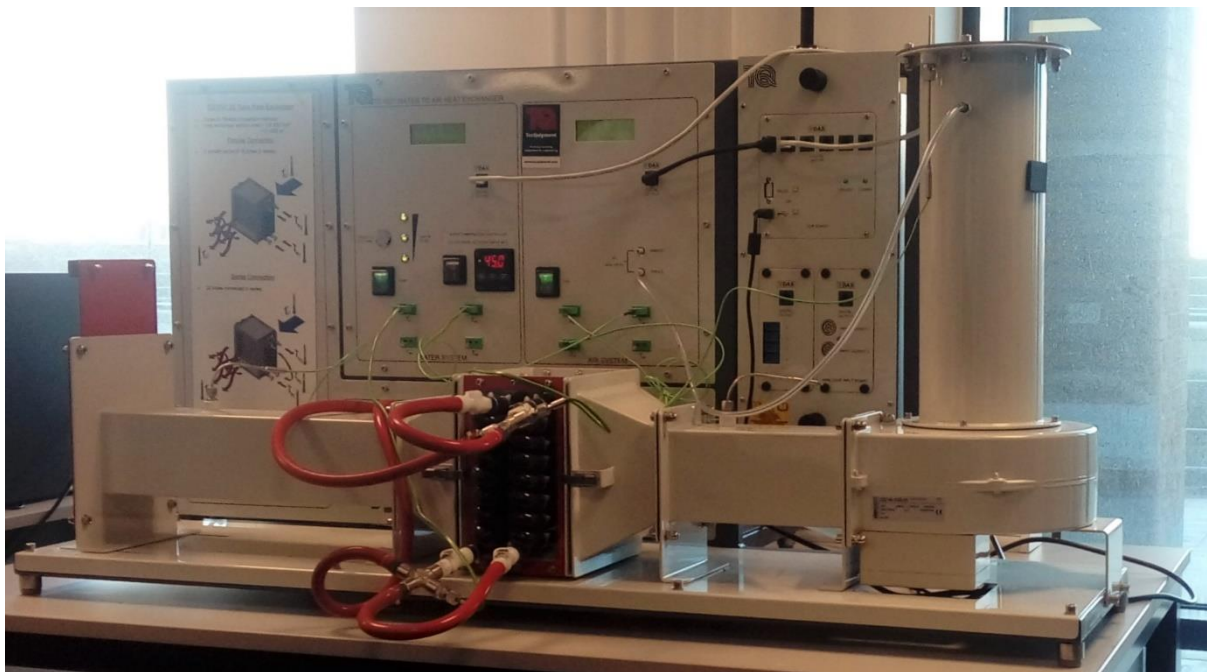


Figure 1-1 Heat Exchanger

1.2 Equations

Conversion from L/min-Kg/s

$$\frac{Kg}{s} = \frac{L/min \times 60}{1000} \times \rho_w$$

Air flow Rate

$$\text{Air flow rate} = 0.6 \times \phi \text{Orifice} \times \sqrt{\Delta P \times 2 \times \rho_A}$$

Mean Temperature Efficiency

$$\eta_w = \frac{T_{w1} - T_{w2}}{T_{w1} - T_{a1}} \times 100$$

$$\eta_A = \frac{T_{A2} - T_{A1}}{T_{w1} - T_{A1}} \times 100$$

Density

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

$$\rho_A = \frac{\Delta P}{RT}$$

Power

$$\dot{Q}_w = \dot{m}_w \times C_{pw} \times \Delta T_A$$

$$\dot{Q}_A = C_d \times A_0 \sqrt{\Delta P \times 2 \times \rho_A} \times C_{pA} \times \Delta T_A$$

Coefficient Energy Balance

$$CEB = \frac{\dot{Q}_A}{\dot{Q}_w}$$

Mean Efficiency

$$\bar{\eta} = \frac{\eta_w + \eta_A}{2}$$

Log Mean Temperature Difference

$$LMTD = \frac{(T_{w2} - T_{A2}) - (T_{w1} - T_{A1})}{\ln \left(\frac{T_{w2} - T_{A2}}{T_{w1} - T_{A1}} \right)}$$

2 Background Information

The heat exchanger used in this experiment is a parallel flow heat exchanger. These have many uses in the world such as air conditioning, refrigeration and power plants (Mehrabian & Samadi, 2010). A parallel heat exchanger is an effective method of removing heat from a flowing liquid in a simple manner. However, a slightly more complicated method of heat exchanger is available in the form of cross-flow heat exchanger. This is because cross flow causes fewer thermal stresses on the dividing material as there is a more uniform temperature difference between the two fluids. To add to that, because of the smaller difference there can be a more even rate of heat transfer throughout the heat exchanger (Engineers Edge, LLC, 2019). However, the parallel flow heat exchanger has its benefits as it is a much simpler design.

3 Experiment 1- The effect of Varying Water Flow Rate

3.1 Procedure

1. Connect heat exchanger in parallel flow and set heater to 60°C.
2. Note the ambient temperature
3. Check the orifice diameter which is stamped on top
4. Switch on the fan and use the slide to regulate the airflow to give an air pressure drop of 250 Pa (± 5 Pa).
5. Switch on the water pump and adjust the valve to set the water flow to 2.25 L/minute (± 0.01 L/Minute).
6. Allow at least 4 minutes for the heat exchanger to reach thermal equilibrium and the temperatures to settle.
7. Repeat the procedure for all of the other water flow rates.

3.2 Results Analysis – Experiment 1

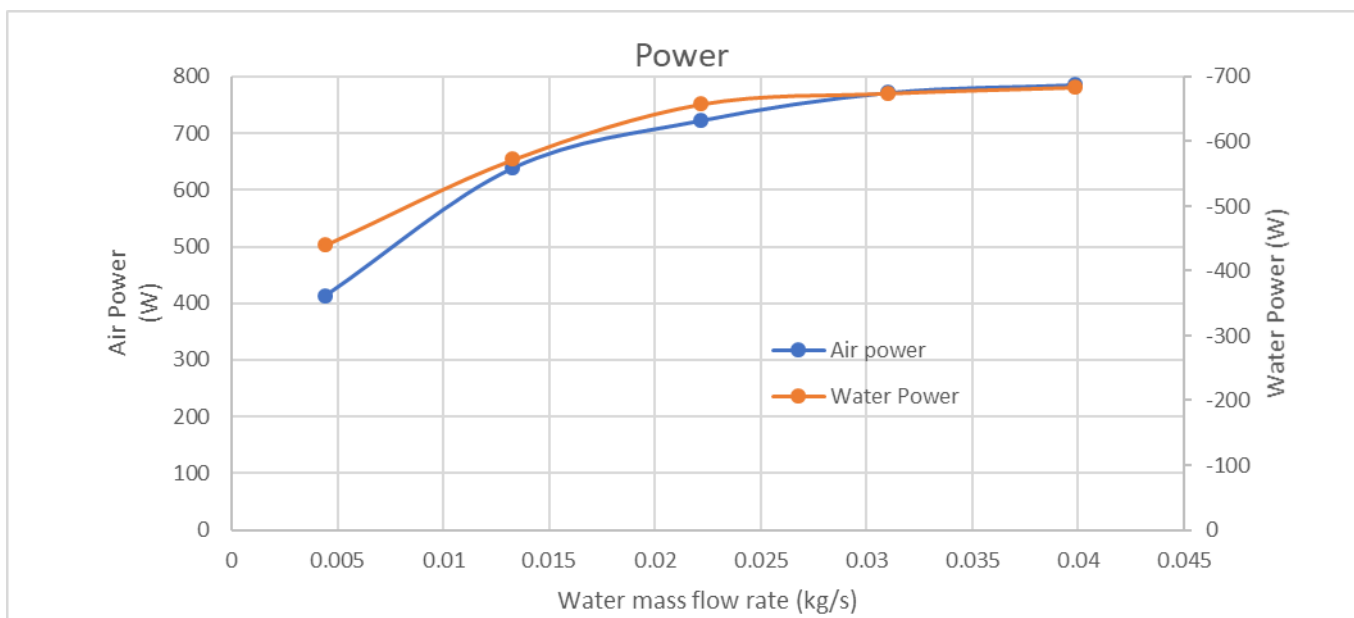


Figure 3-1 Graph of power against Water mass flow rate

As can be seen in figure 3-1 as the water flow increases so does the power transfer rate. This is as expected as this means the quicker the water comes in the quicker it can take it away which makes logical sense as power is the transference of energy. As the graph is curving though this suggests that there is a maximum water flow rate where the power transfer is most efficient and then the author assumes it will flatten out and the water cannot transfer energy any quicker than it already is. From the data also shows that the water is work in as the power is negative and the air power is work out as it is positive. This supports the sign convention from the first law of thermodynamics. There is also a slight difference in the two powers more pronounced at the start. This could be cause from loses in the system such as the pipes not being fully insulated or an air leak somewhere along the system.

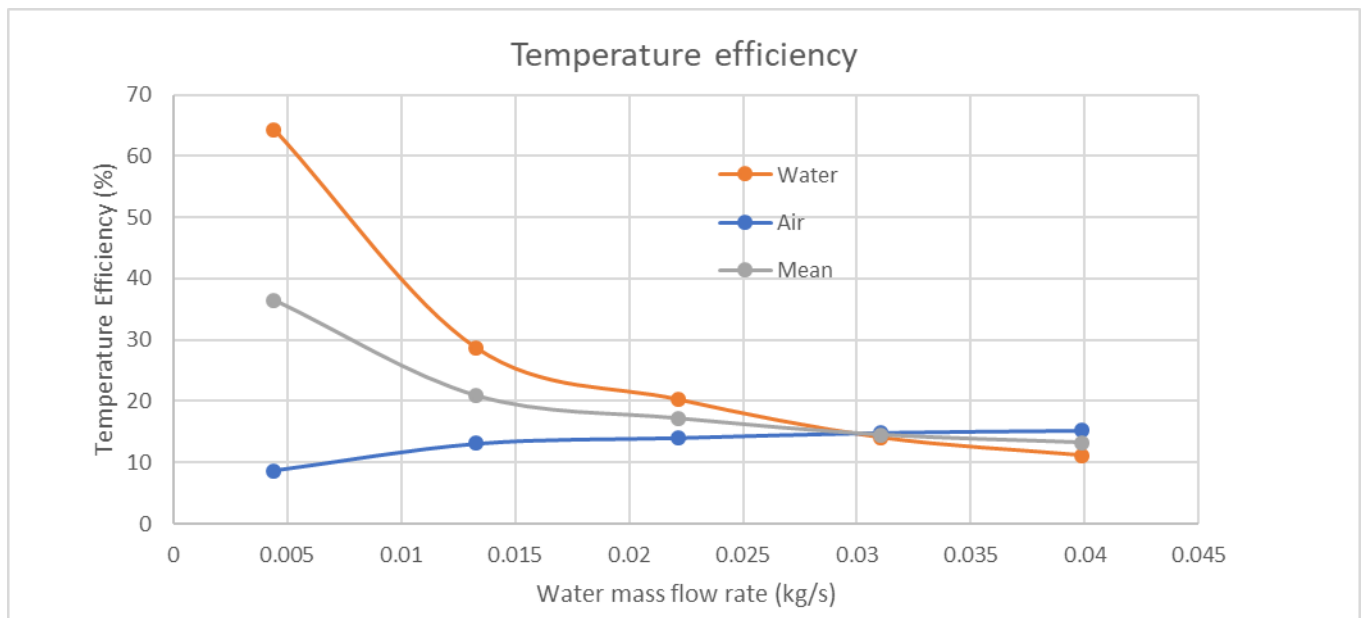


Figure 3-2 Graph of Temperature Efficiency against water mass flow rate

As can be seen as the flow gets greater the water efficiency decreases and the air efficiency increases. However, the water efficiency changes more than the air as the water flow increases. This is expected as there is a slightly larger change in water temperature than change in air temperature. But both efficiencies flatten off suggesting that there is a spot where there is the best efficiency for both variables which is around 0.032kg/s. This suggest that the water flow rate increases the air efficiency and decreases the water efficiency.

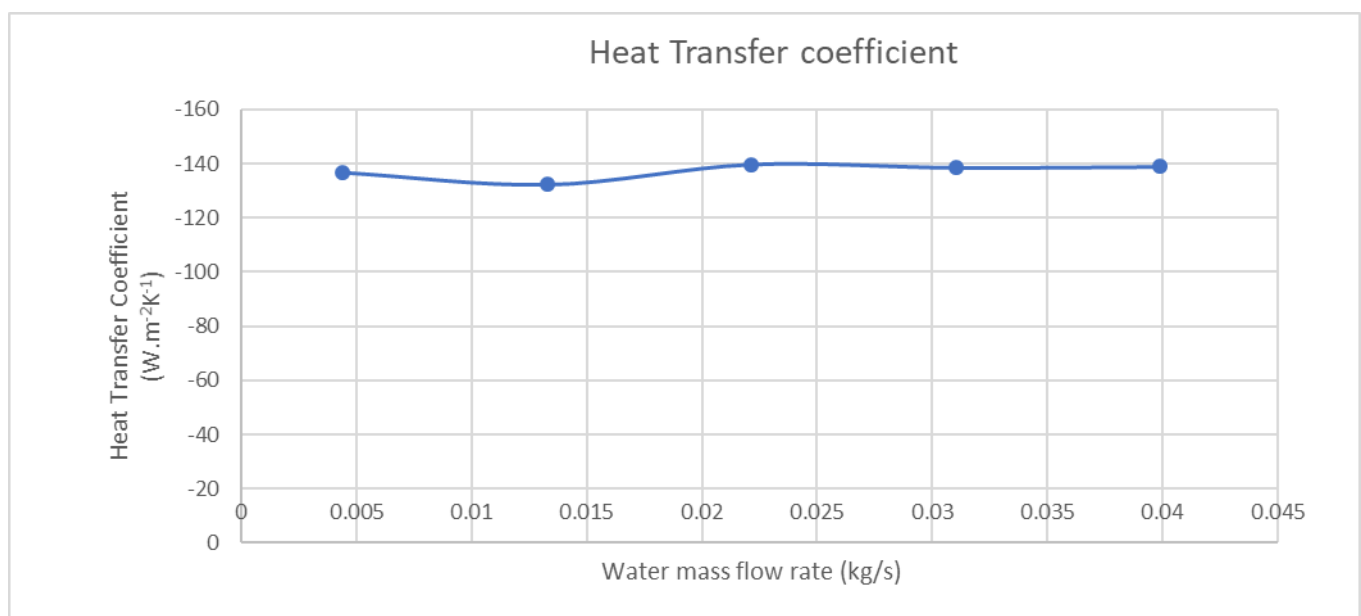


Figure 3-3 Graph of heat transfer coefficient against water mass flow rate

From the graph the heat transfer coefficient generally stays at a similar level which is unexpected. This is because it would have been thought that as the power output increases so does the heat transfer. But in general, it does go up by a very small amount. This suggests that the water flow rate has a very small effect on the heat transfer coefficient but still does have an effect.

4 Experiment 2- The Effect of Varying Air flow Rate

4.1 Procedure

1. Set up heat exchanger in parallel flow and set the water heater to 60°C
2. Note ambient air pressure
3. Note size of orifice (diameter stamped on surface of plate)
4. Switch on fan and move slide to set the air flow to have a pressure drop of 250Pa (± 5 Pa) across the orifice
5. Switch on water pump and set flow (located in between control panel and heat exchanger) to 0.25L/minute (± 0.01 L/minute)
6. Allow at least 4 minutes for the temperatures to settle and the system to reach thermal equilibrium
7. Repeat the process for the lower air flow rate by adjusting the slide valve.

4.2 Results Analysis – Experiment 2

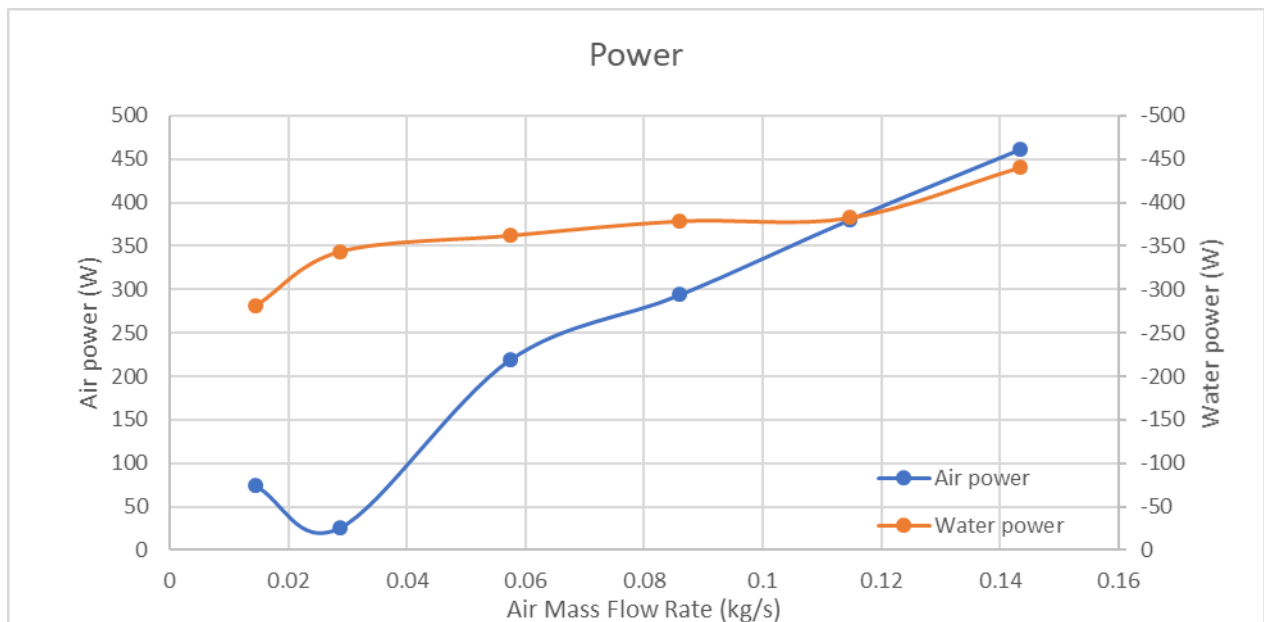


Figure 4-1 Graph of power against Air mass flow rate at 60°C

The graph shows that as the air mass flow rate increases so does the power transferred at an overall linear rate. However, there are large errors in the data that bucks this trend significantly. Compared to experiment 1 the increase does not flatten out as higher mass flow rates. This gives the impression that there is not a flow rate that is at optimum power transfer as it is with water mass flow rate. At lower values there is a greater water power than air power (difference of 901.2934W) and as the air mass flow rate increases this gap reduces (difference of 356.17423W). This implies that there are larger heat losses at lower air flow rates. This could potentially be down to parts of the heat exchanger such as pipes and metal work conducting more heat energy away at lower air flow rates.

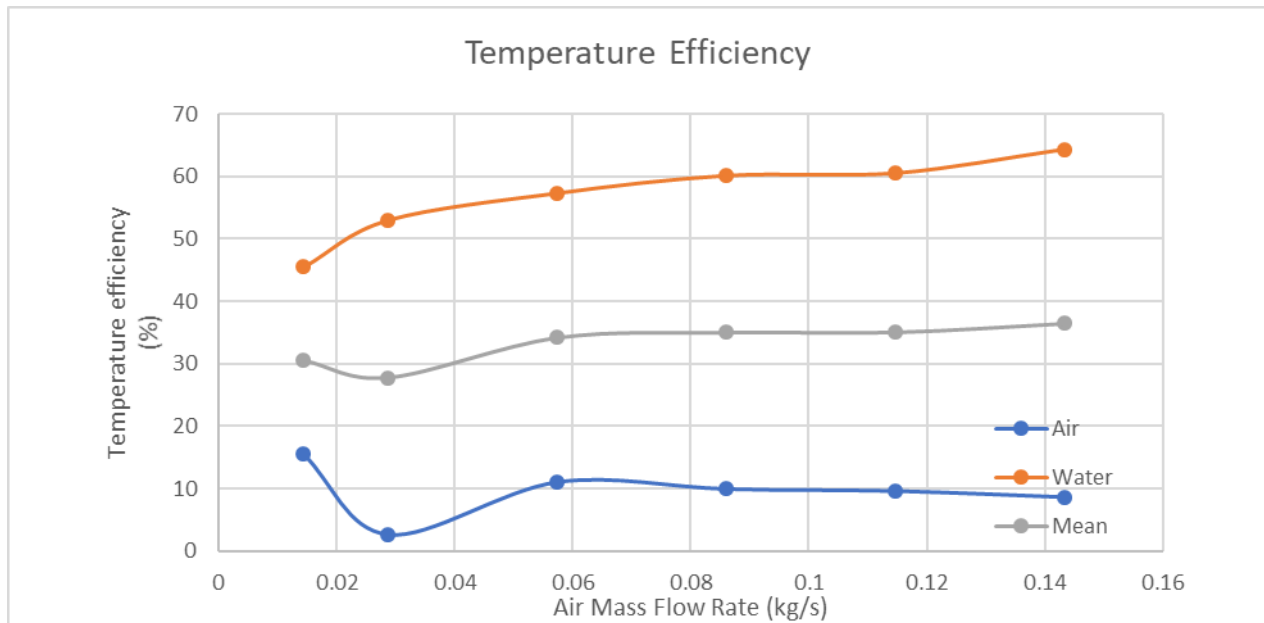


Figure 4-2 Graph of Temperature efficiency against air mass flow rate at 60°C

The temperature efficiencies with change of air mass flow rate do not significantly change when compared to change in water mass flow rate. However, when the air flow rate increases the air efficiency decreases and the water efficiency increases. Overall the mean efficiency increases as the water increases more than the air decreases. However, there is again a large dip in the results at 0.114726723kg/s. This could be down to the fact that on the day of the experiment there was quite a few people walking in and out of the room sometimes leaving the door open for extended periods of time. This changes the atmospheric pressure and temperature within the room which may have large effects on the data. To get around this issue the atmospheric pressure and temperature could be taken at the same times as the reading and the changes could be accounted to help remove errors in the data.

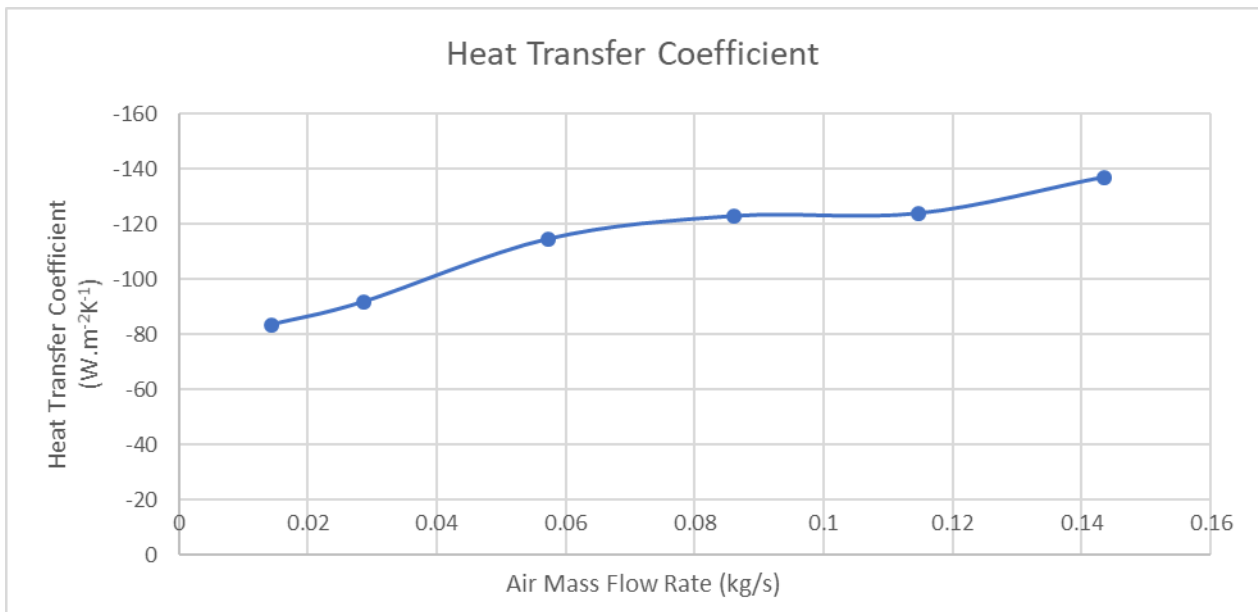


Figure 4-3 Graph of Heat Transfer Coefficient against Air mass flow rate at 60°C

Overall, the heat transfer coefficient increases linearly as the air flow rate increases. This again gives the idea that the heat transfer increases as the air mass flow rate increases. This all makes sense as the quicker the air can go through the more heat it can carry away from the heat exchanger. What is interesting though is that it does not flatten out like the change in water flow rate but appears to just keep increasing. To get a fuller picture a broader range of results would need to be taken.

5 Experiment 3- Effect of Varying Temperature (Driving Force)

5.1 Procedure

1. After completion of experiment 2 close the slide valve so there is around a 1 ½ inch gap and increase water flow to 1.5L/minute (helps to cool the heater quicker). Change heater temperature to 45°C. Allow the heater to drop down to temperature.
2. Change the slide valve to create a pressure drop of 250Pa (± 5 Pa) across the orifice.
3. Adjust the water pump to have a flow of 0.25L/minute (± 0.01 L/minute)
4. Allow at least 4 minutes for the temperatures to settle and the system to reach thermal equilibrium
5. Repeat the process for the lower air flow rate by adjusting the slide valve.

5.2 Results Analysis – Experiment 3

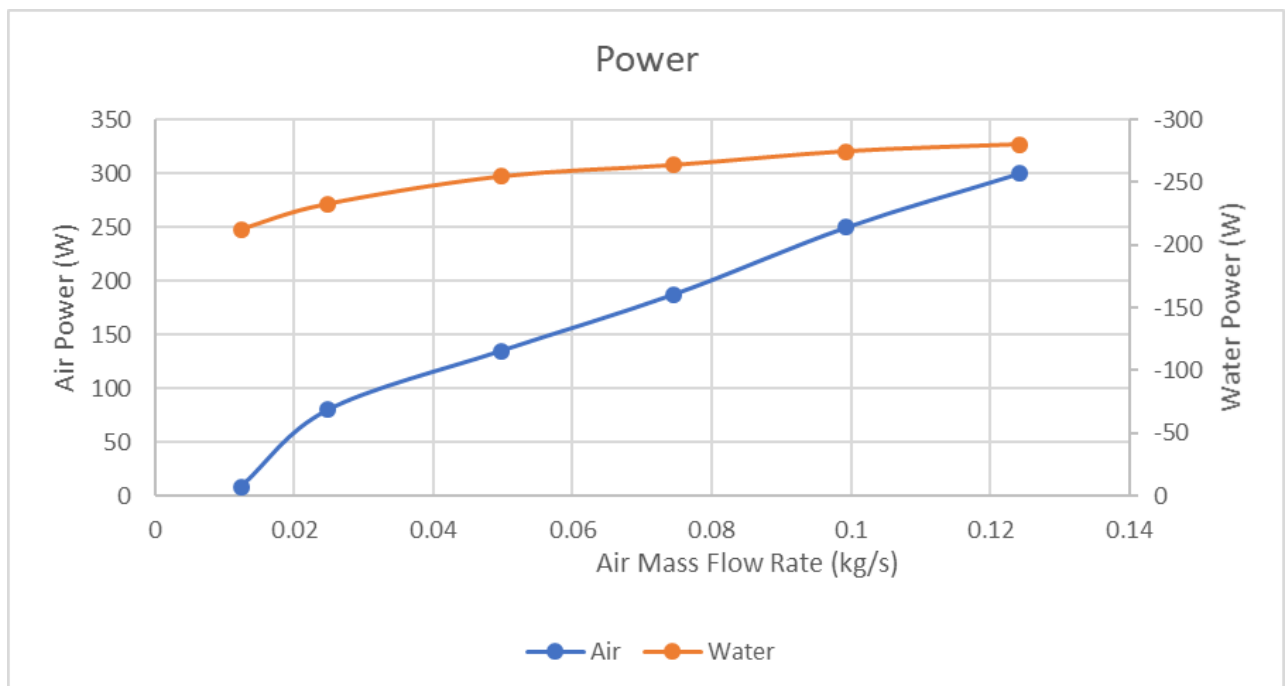


Figure 5-1 Graph of Power against air mass flow rate at 45°C

As can be seen at 45°C it is the same as 60°C. The power increases as the air mass flow rate increases. With the water power increasing at a much slower rate than the air power. At the beginning there is a much larger difference than at the end of the results which conveys the idea that there are larger heat losses at lower air mass flow rates. This could be down to the metal absorbing some of the heat or an air leak along the system somewhere. There is a slight error within the trend of the first reading as it dips a little more than the rest of the values.

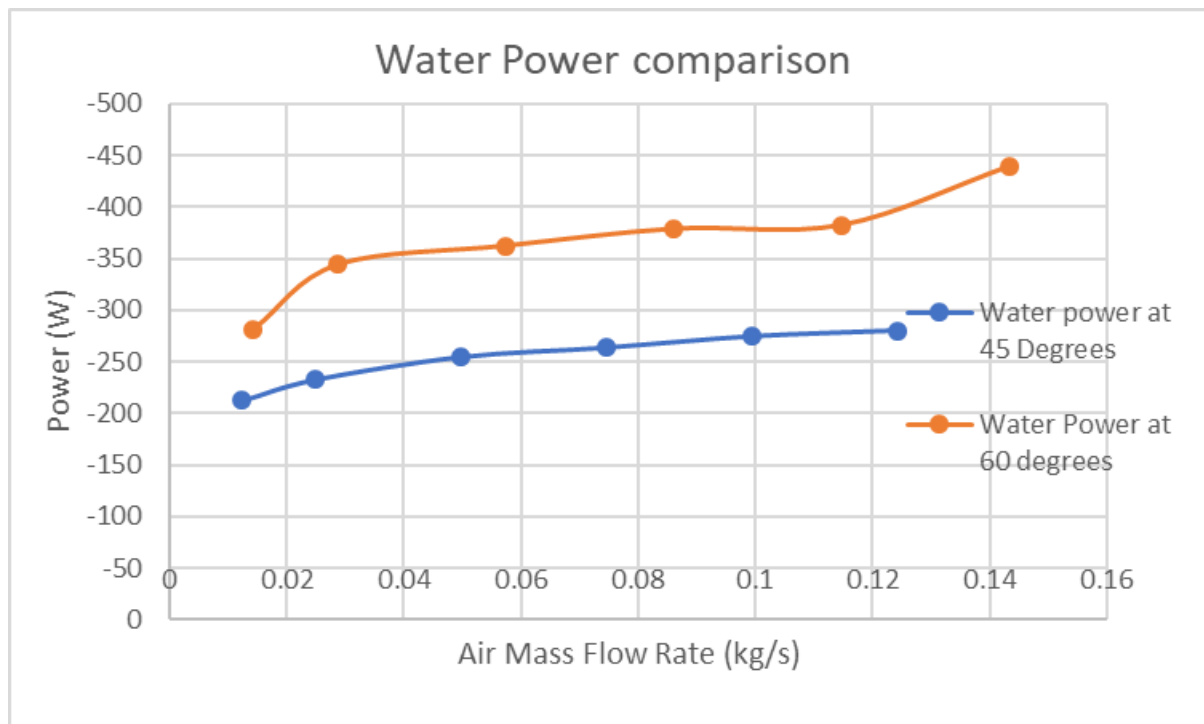


Figure 5-2 Graph of water power comparison against air mass flow rate

As expected, the power given off at 60°C is higher than at 45°C. This is because the water has more heat in it to start with, so it is able to transfer more which gives more power. Interestingly though the water power at 60°C increases at a higher rate than at 45°C. This could be down to there being less energy being absorbed and lost through the system at 45°C. Another interesting point is when at 60° the data was more prone to errors as can be seen from spikes at the beginning and end values.

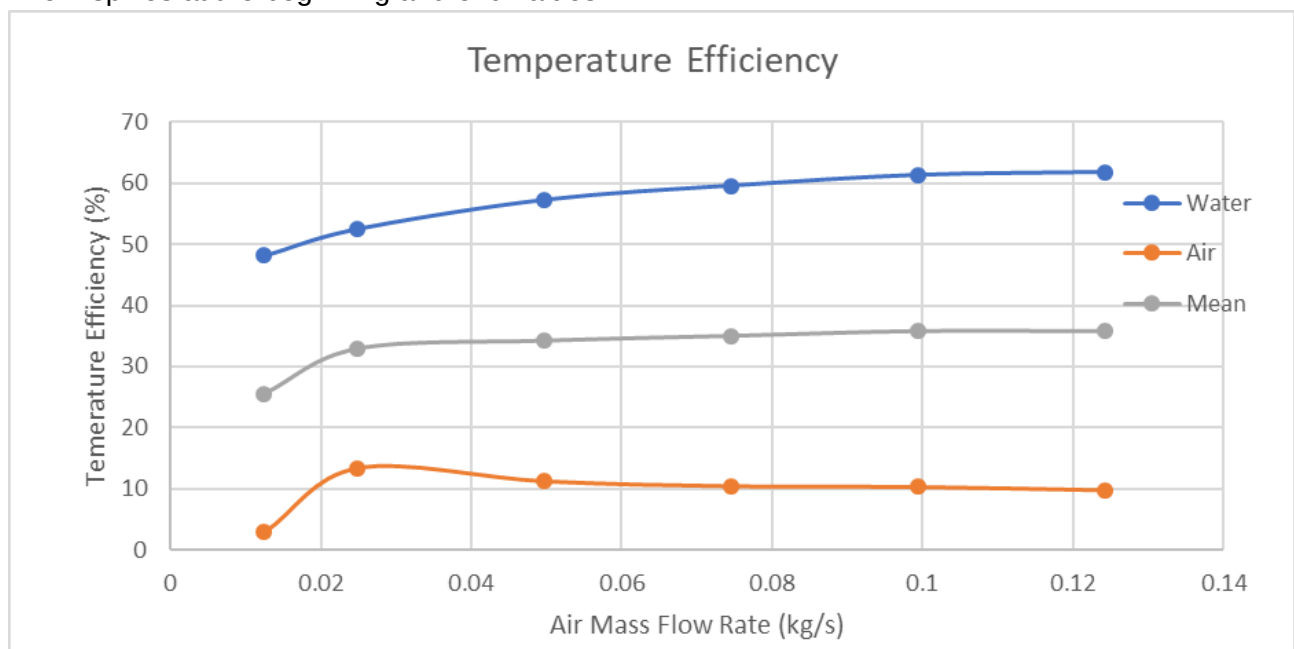


Figure 5-3 Graph of Temperature efficiency against air mass flow rate at 45°C

Similar to what happened at 60°C the water efficiency increases, and the air efficiency decreases as the air mass flow rate increases. As the water is increasing more than the air the mean

slightly increases as the flow rate increases. There is however an error at the beginning which is consistent with the rest of the graphs which could be down to similar reasons previously stated such as leaks or absorption.

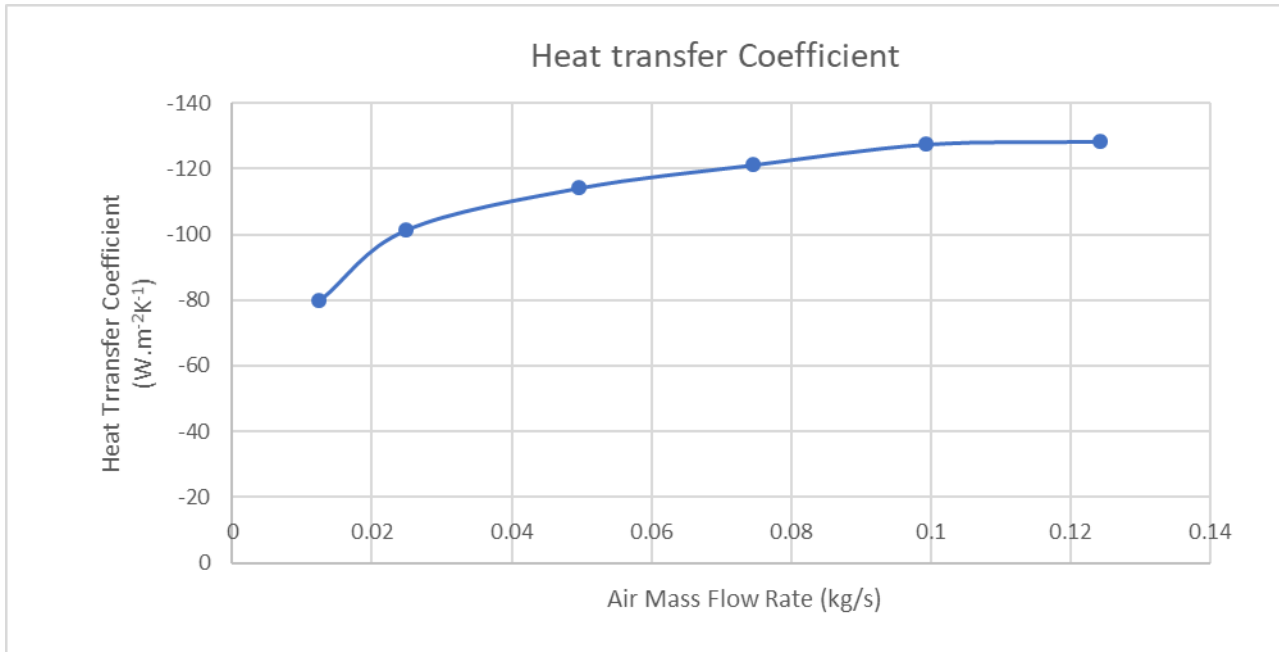


Figure 5-4 Graph of Heat Transfer Coefficient against air mass flow rate at 45°C

As can be seen again the heat transfer coefficient increases with the air mass flow. What is interesting is that it appears to be flattening out similar to experiment 1. This is in contrast to 60°C as that linearly increase without any sign of flattening out. This is very odd so to get a better understanding the experiment would have to be repeated to see if the same results appear.

6 Errors

A number of errors within the experiment could occur. One of which is heat loss through parts of the system such as pipes and the metal walls of the air flow. This could be minimised by insulating each part with a reflective substance or foam to minimize the heat loss of the system. Another error that may be cause is through air leaks through parts such as on the joins between the parts of the inlet/outlet duct and the heat exchanger itself. This may mean that there is not a steady flow of air which could then affect the power of the air and the rest of results. Another error introduced was the fact that people were walking in and out of the room. This meant that the temperature and air pressure of the room kept on changing which may affect the results. Also, there was another experiment happening next to this one so there were people walking past the orifice which may affect the results. This will also affect the way the air flow through the heat exchanger. To get around this people should not be able to come in and out of the room as the experiment is going in and should keep away from the orifice. Also, the atmospheric temperature and pressure should be taken at each reading so that any changes can be taken into considerations when calculating results. To get a truer understanding of the results the experiments should be repeated a minimum of three times. This will make sure that the results are true and are repeatable. To add to that the system should be left for more than four minutes before taking a reading. This will ensure that the system can get to thermal equilibrium which will make sure that the data is at the correct temperature.

7 Conclusions

In conclusion as the water mass flow rate increases so does the power transferred through the heat exchanger to a point. This means that there is a peak at which the system is most efficient which is at 0.033kg/s where there is the best of all of the different efficiencies. Also, the as the air mass flow rate increases so does the power transferred. This is different from the water as the data suggest that there is no peak, so the more air flow the further the power transfer will increase. However, there is less heat losses at higher flow rates than there are at lower flow rates. To add to that the efficiency does not change that much though the different mass air flow rates but does overall slightly increase.

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9 References

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[Accessed 4 April 2019].

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10 Appendices

Experiment 1																							
Heater Temperature:				60						Ambient Pressure		1003	mBar										
Orifice Δp=				250						Orifice Diameter		100.11	mm									0.007871	m^2
Hot flow (L/min)	Hot flow (kg/s)	Air flow rate (kg/s)	T _{w1}	T _{w2}	ΔT _w	Average T _w	T _{A1}	T _{A2}	ΔT _A	Average T _A	η _w	η _A	ρ _w	ρ _A	CP _w	CP _A (J.kg-1.K-1)	Q̇ _w	Q̇ _a	CEB	η̄	LMTD	U	
2.25	0.03987	0.13952	60.1	56.0	-4.1	58.05	23.4	29.0	5.6	26.2	11.17166	15.25886	1.063321	1.74555	4183	1005	-683.86	785.2379	-1.14824	13.21526	31.60228	-138.893	
1.75	0.03101	0.13958	60.7	55.5	-5.2	58.1	23.8	29.3	5.5	26.55	14.09214	14.90515	1.06333	1.747053	4183	1005	-674.6	771.5479	-1.14371	14.49864	31.24524	-138.578	
1.25	0.02215	0.1382	60.7	53.2	-7.1	56.95	23.7	28.9	5.2	26.3	20.27027	14.05405	1.063106	1.712473	4183	1005	-657.781	722.208	-1.09795	17.16216	30.20634	-139.771	
0.75	0.01328	0.13525	59.7	49.4	-10.3	54.55	23.8	28.5	4.7	26.15	28.69081	13.09192	1.06256	1.640306	4183	1005	-572.254	638.8624	-1.1164	20.89136	27.72704	-132.47	
0.25	0.00442	0.12845	61.1	37.3	-23.8	49.2	24.1	27.3	3.2	25.7	64.32432	8.648649	1.060938	1.479432	4183	1005	-440.092	413.09	-0.93864	36.48649	20.63695	-136.877	
Experiment 2																							
Heat Exchanger:				Tube								Ambient Pressure:		1003	mBar <th colspan="8" rowspan="3"></th>								
Pipe Connection:				Parallel								Orifice Diameter:		100.11	mm								
Heater Temperature:				60								Orifice Area:		0.007871	m^2								
Water Flow:				0.25																			
Air Pressure Δp (Pa)	Water flow rate (kg/s)	Air Flow rate	T _{w1}	T _{w2}	ΔT _w	Average T _w	T _{A1}	T _{A2}	ΔT _A	Average T _A	η _w	η _A	ρ _w	ρ _A	CP _w	CP _A	Q̇ _w	Q̇ _a	CEB	η̄	LMTD	U	
250	0.004421	0.143408	61.1	37.3	-23.8	49.2	24.1	27.3	3.2	25.7	64.32432	8.648649	1060.938	1.844111	4183	1005	-440.092	461.2014	-1.04797	36.48649	20.63695	-136.877	
200	0.004419	0.114727	58.3	37.6	-20.7	47.95	24.1	27.4	3.3	25.75	60.52632	9.649123	1060.473	1.475289	4183	1005	-382.602	380.4912	-0.99448	35.08772	19.83737	-123.793	
150	0.004419	0.086045	58.3	37.8	-20.5	48.05	24.2	27.6	3.4	25.9	60.1173	9.970674	1060.512	1.106467	4183	1005	-378.919	294.0159	-0.77593	35.04399	19.80264	-122.816	
100	0.00442	0.057363	58.6	39	-19.6	48.8	24.4	28.2	3.8	26.3	57.30994	11.11111	1060.793	0.737644	4183	1005	-362.379	219.0707	-0.60453	34.21053	20.30053	-114.575	
50	0.004421	0.028682	58.9	40.3	-18.6	49.6	23.8	24.7	0.9	24.25	52.99145	2.564103	1061.08	0.368822	4183	1005	-343.984	25.94258	-0.07542	27.77778	24.04646	-91.8161	
25	0.004423	0.014341	58.6	43.4	-15.2	51	25.2	30.4	5.2	27.8	45.50898	15.56886	1061.549	0.184411	4183	1005	-281.229	74.94523	-0.26649	30.53892	21.61918	-83.4937	
Experiment 3																							
Heat Exchanger:				Tube								Ambient Pressure:		1003	mBar <th colspan="8" rowspan="3"></th>								
Pipe Connection:				parallel								Orifice Diameter:		100.11	mm								
Heater Temperature:				45								Orifice Area:		0.007871	m^2								
Water Flow:				0.25		0.015																	
Air Pressure Δp (Pa)	Mass Flow rate (kg/s)	Air Flow rate (kg/s)	T _{w1}	T _{w2}	ΔT _w	Average T _w	T _{A1}	T _{A2}	ΔT _A	Average T _A	η _w	η _A	ρ _w	ρ _A	CP _w	CP _A	Q̇ _w	Q̇ _a	CEB	η̄	LMTD	U	
250	0.004406	0.124195	48.8	33.6	-15.2	41.2	24.2	26.6	2.4	25.4	61.78862	9.756098	1057.339	1.383083	4183	1005	-280.114	299.5591	-1.06942	35.77236	14.00341	-128.391	
200	0.004405	0.099356	48.4	33.5	-14.9	40.95	24.1	26.6	2.5	25.35	61.31687	10.28807	1057.201	1.106467	4183	1005	-274.549	249.6326	-0.90924	35.80247	13.82099	-127.501	
150	0.004405	0.074517	48.3	34	-14.3	41.15	24.3	26.8	2.5	25.55	59.58333	10.41667	1057.312	0.82985	4183	1005	-263.521	187.2244	-0.71047	35	13.9538	-121.215	
100	0.004406	0.049678	48.5	34.7	-13.8	41.6	24.4	27.1	2.7	25.75	57.26141	11.20332	1057.556	0.553233	4183	1005	-254.366	134.8016	-0.52995	34.23237	14.29731	-114.192	
50	0.004408	0.024839	48.7	36.1	-12.6	42.4	24.7	27.9	3.2	26.3	52.5	13.33333	1057.977	0.276617	4183	1005	-232.34	79.88243	-0.34382	32.91667	14.71246	-101.361	
25	0.00441	0.01242	49	37.5	-11.5	43.25	25.1	25.8	0.7	25.45	48.11715	2.92887	1058.408	0.138308	4183	1005	-212.142	8.737141	-0.04119	25.52301	17.07991	-79.7213	