

University of Wales Trinity Saint David
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Heat Exchanger Laboratory Analysis
Thermofluid Mechanics
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1 Introduction

This is a report that discuss the methodology and results of three experiments that were investigating the effect of varying the water flow rate, air flow rate and temperature in a heat exchanger. The heat exchanger used was a cross flow heat exchanger consisting of 32 tubes connected in parallel, where the water entered the bottom of it and exited out the top.

Heat exchangers are used in many applications to transfer heat from one place or fluid to another. This could be used for many different reasons such as to cool a hot fluid using a cold fluid or vice versa, as well as condense and boil fluids using cooler and hotter fluids.

There are different types of heat exchangers such as parallel flow, counter flow and cross flow. As it states in the name the differences between these heat exchangers are the way the two fluids flow pass one another. Parallel is where the two fluids flow in the same direction along the same path. Whereas counter flow is where the two fluids flow opposite to each other, where one fluid enters the other one exits. The final type of cross flow is where the fluids flow perpendicular, at 90° , to each other. This type is often used when one of the fluids will change state such as a steam condenser.

The most efficient heat exchanger is the counter flow however, all of them have their own advantages and disadvantages for different applications.

2 Methodology

To start the experiment, the standard 32 tube heat exchanger was connected in parallel. Next the heater tank temperature was set to 60°C, apart from in the third experiment where it was set to 45°C.

Once the set up was complete, the first things to note were the ambient air pressure and the orifice diameter. This was stamped on the surface of the orifice.

The orifice pressure drop was set to 250 Pascals. To do this, the fan was switched on and the air flow was adjusted via the valve. The value was set to within the tolerance of ± 5 Pascals. However, this value was only constant for experiment one as it became the variable for experiments two and three.

Next the rate of water supply was set. This was a value of 2.25 L/min for the start of experiment one, and 0.25 L/min for experiments two and three. This was done by switching on the pump and adjusting the water supply valve. This value was set within the tolerance of ± 0.01 L/min.

Between each reading for all three experiments the heat exchanger temperatures had stabilised. This mean after each change the heat exchanger was left for five minutes before the readings were recorded.

Finally, throughout all three experiments the water and air flow rates would fluctuate naturally. To ensure this did not happen these values needed to be observed regularly and readjusted when necessary.

2.1 Experiment One

Experiment one changed the water flow rates to 2.25, 1.75, 1.25, 0.75 and 0.25 L/min. The heater tank temperature was constants at 60°C and the pressure drop was also kept constant at 250 Pa.

2.2 Experiment Two

For experiment two, the Air Flow Rates were adjusted to the rates provided; 250, 200, 150, 100 and 50 Pa pressure drop. The heater tank temperature was constant at 60°C and the water supply was constant at 0.25 L/min.

2.3 Experiment Three

Experiment three followed the same Air Flow Rates as experiment two and the same water supply but the heater tank temperature was set to 45°C.

2.4 Calculations

The following values need to be calculated for each experiment in order to interpret the results. These were each inputted into the workbooks in the spreadsheet to produce the results seen in Tables 1, 2 and 3.

2.4.1 Thermal Efficiency

The thermal efficiency needs to be calculated for water and air and then the average using the following equations respectively.

$$\eta_w = \frac{T_{w1} - T_{w2}}{T_{w1} - T_{A1}} \times 100 \quad \eta_A = \frac{T_{A1} - T_{A2}}{T_{w1} - T_{A1}} \times 100 \quad \bar{\eta} = \frac{\eta_w + \eta_A}{2}$$

2.4.2 Density

This data allowed the mass flow rates for air and water to be calculated for each experiment. The water and air densities could be calculated at each temperature using the following equations (where T = the average temperature).

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

2.4.3 Specific Heat Capacity

To find the specific heat capacity for the water the equation below was used.

$$C_{pW} = (0.996185 + 0.0002874 \left(\frac{T + 100}{100} \right)^{5.26} + 0.011160 \times 10^{-0.036T}) \times 4185.5$$

This was carried out at each temperature. For the Specific heat capacity for air it was assumed to be constant at $1005 \text{ J kg}^{-1} \text{ K}^{-1}$ for normal atmospheric pressures.

2.4.4 Flow Rates

The air mass flow rate was calculated using the equation below.

$$\dot{m}_A = C_d \times A_0 \sqrt{\Delta P \times 2 \times \rho_A}$$

The water flow rate was then converted to mass flow rate. This is because the units that flow was recorded in are incorrect for the equations that use the flow rate. This was done through a simple calculation seen below.

$$\dot{m}_W = \frac{\text{Volume flow}}{60000} \times \rho_w$$

2.4.5 Heat Transfer Coefficient

To calculate the Heat Transfer Coefficient (U), the Logarithmic Mean Temperature Difference (LMTD) needs to be calculated. To start this off, the heat emitted, heat absorbed, and mean temperature efficiencies were calculated. The LMTD and Heat Transfer Coefficient were then calculated using the equations below.

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

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

2.4.6 Rate of Heat Transferred

To calculate the rate of heat transferred (power) the following equations were used.

$$\dot{Q}_W = \dot{m}_W \times c_{PW} \times \Delta T_W$$

$$\dot{Q}_A = \dot{m}_A \times c_{PA} \times \Delta T_A$$

3 Experiment One: The Effect of Varying Water Flow Rate

The first experiment is investigating the effects of changing the rate of water flow. The values that were investigated were 2.25, 1.75, 1.25, 0.75 and 0.25 L/min.

3.1 Data Collected

Table 1 displays the results from the spreadsheet.

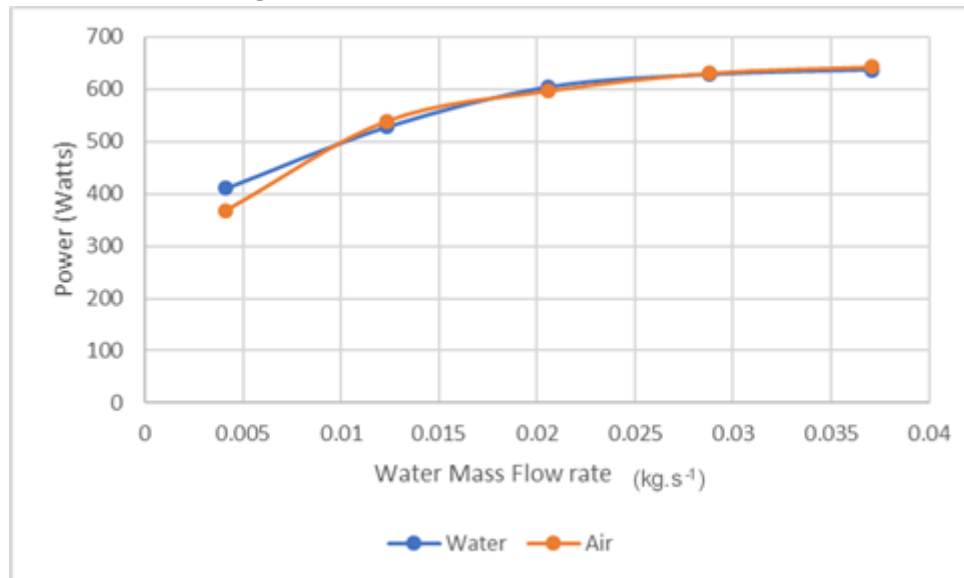
Experiment 1													
Heater Temperature: 60°C													
Orifice (Δp): 250 Pa													
Hot Flow (L/min)	T_{w1}	T_{w2}	ΔT_w	Average T_w	T_{w3}	T_{A1}	T_{A2}	ΔT_A	Average T_A	T_{A3}	η_w	η_A	ρ_w
2.25	60.1	56	-4.1	58.05	30	23	29	5.6	26.2	22.9	11.1717	15.2589	988.28
1.75	60.7	55.5	-5.2	58.1	31.5	24	29.3	5.5	26.55	23.4	14.0921	14.9051	988.27
1.25	60.7	53.7	-7	57.2	32.3	24	28.9	5.2	26.3	23.3	18.9189	14.0541	988.56
0.75	59.7	49.5	-10.2	54.6	32.8	24	28.5	4.7	26.15	23.3	28.4123	13.0919	989.4
0.25	61.1	37.3	-23.8	49.2	33.2	24	27.3	3.2	25.7	23.4	64.3243	8.64865	991.09

Cd: 0.6										
Ambient Pressure: 1003 mBar										
Orifice Diameter: 0.10011 m										
ρ_A	C_{pw}	C_{pA}	$\dot{m}_w$	$\dot{Q}_w$	$\dot{m}_A$	$\dot{Q}_A$	C_{EB}	$\bar{\eta}$	LMTD	U
1.16725	4183.27484	1005	0.03706	-635.643	0.11409	642.121	-0.98991	13	31.6023	-129.1004
1.16589	4183.29551	1005	0.02882	-627.023	0.11403	630.287	-0.99482	14	31.2452	-128.8048
1.16686	4182.92886	1005	0.0206	-603.032	0.11408	596.156	-1.01153	16	30.4943	-126.9269
1.16745	4181.93598	1005	0.01237	-527.543	0.1141	538.968	-0.9788	21	27.7874	-121.8549
1.1692	4180.19204	1005	0.00413	-410.842	0.11419	367.233	-1.11875	36	20.637	-127.7796

Table 1 –Experiment One: Varying Water Flow Rate Results

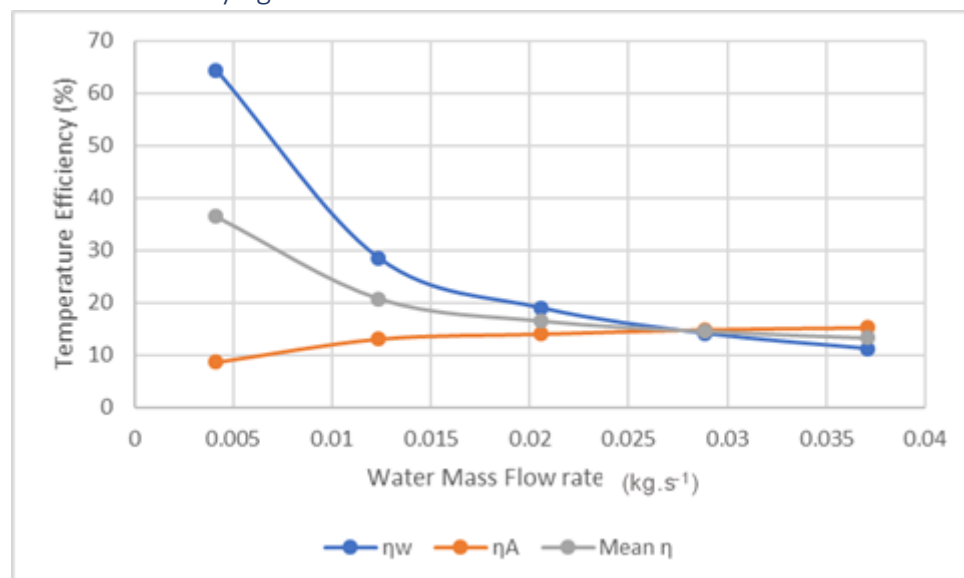
3.2 Results

3.2.1 Power Transferred against Rate of Mass Water Flow



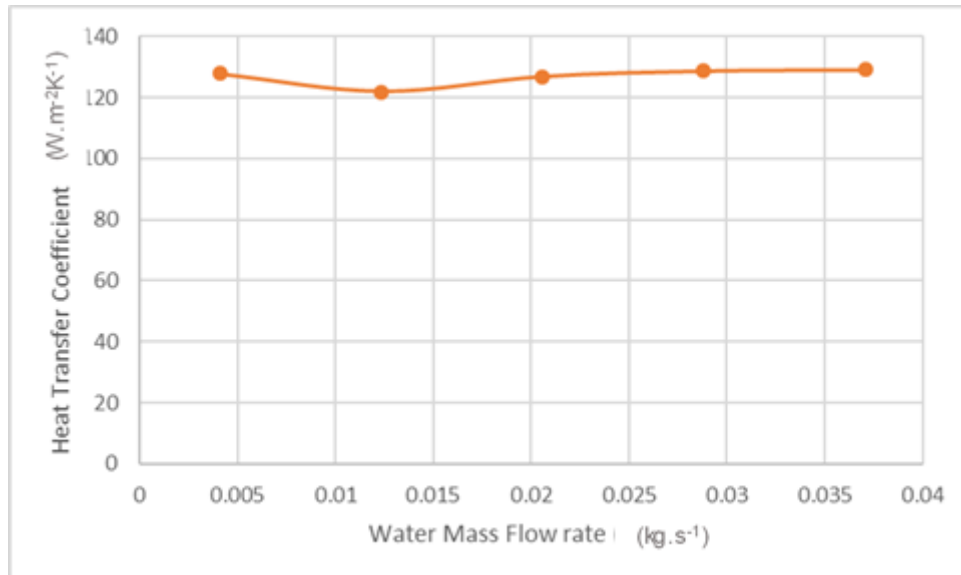
This graph shows that the power transfer increases as the rate of water flow increases. However, the gradient of the graph begins to decrease and level out. This indicates that it should reach a maximum power transfer. The power transferred from the water and to the air show very similar trends and values. This displays that this heat exchanger has a good energy balance coefficient.

3.2.2 Thermal Efficiency against Rate of Mass Water Flow



From the graph it can be observed that the efficiency of the air increases as the rate of water flow increases, whereas the water efficiency decreases with increase in rate of flow. The reason the change in efficiency is much higher for water is due to water having a much higher change in temperature. The average thermal efficiency gradually decreases as the rate of flow increases, this is due to the water efficiency being much larger than the air efficiency.

3.2.3 Heat Transfer Coefficient against Rate of Mass Water Flow



The graph shows that initially as flow increases the Heat Transfer Coefficient drops and then gradually increase. It then levels out suggesting that there is a maximum Heat Transfer Coefficient. This graph isn't as expected, the first value is recorded at a much larger value. It would be expected to be of a value of approximately $118\text{Wm}^{-2}\text{K}^{-1}$ for the Heat Transfer Coefficient.

4 Experiment Two: The Effect of Varying Air Flow Rate

This experiment looks at how the Air Flow Rates affects the performance of the heat exchanger. It investigates at the pressure drops provided; 250, 200, 150, 100 and 50 Pa.

4.1 Data Collected

Table 2 displays the results from the spreadsheet.

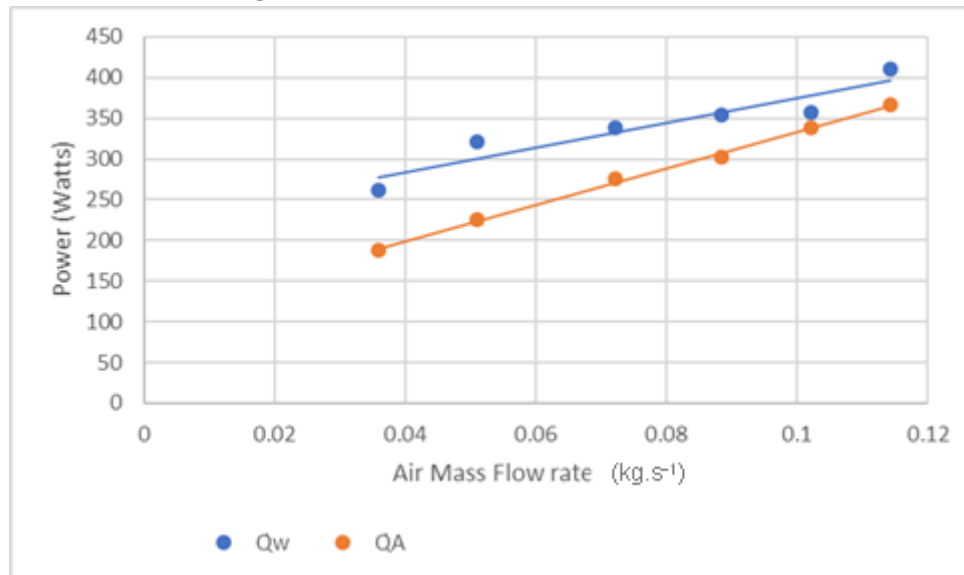
Experiment 2 Heat Exchanger Pipe Connection: Parallel Heater Temperature: 60°C Water Flow: 0.25 L/min												
Air Pressure Δp (Pa)	T_{w1}	T_{w2}	ΔT_w	Average T_w	T_{w3}	T_{A1}	T_{A2}	ΔT_A	Average T_A	T_{A3}	η_w	
250	61.1	37.3	-23.8	49.2	33.2	24.1	27.3	3.2	25.7	23.4	64.324	
200	58.3	37.6	-20.7	47.95	33.4	24.1	27.4	3.3	25.8	23.5	60.526	
150	58.3	37.8	-20.5	48.05	33.6	24.2	27.6	3.4	25.9	23.4	60.117	
100	58.6	39	-19.6	48.8	33.7	24.4	28.2	3.8	26.3	23.6	57.31	
50	58.9	40.3	-18.6	49.6	33.8	24.7	29.1	4.4	26.9	23.5	54.386	
25	58.6	43.4	-15.2	51	33.9	25.2	30.4	5.2	27.8	23.6	45.509	

Cd: 0.6 Ambient Pressure: 1003 mBar Orifice Diameter: 0.10011 m												
η_A	ρ_w	ρ_A	C_{pw}	C_{pA}	$\dot{m}_w$	$\dot{Q}_w$	$\dot{m}_A$	$\dot{Q}_A$	C_{EB}	$\bar{\eta}$	LMTD	U
8.6486	991.089	1.169	4180.19	1005	0.0041295	-410.8416	0.11419	367.2334	-1.1187	36.486	20.63695	-127.78
9.6491	991.47	1.169	4179.85	1005	0.0041311	-357.4371	0.10213	338.6997	-1.0553	35.088	19.83737	-115.65
9.9707	991.44	1.168	4179.88	1005	0.004131	-353.975	0.08842	302.1353	-1.1716	35.044	19.80264	-114.73
11.111	991.211	1.167	4180.08	1005	0.00413	-338.373	0.07215	275.5309	-1.2281	34.211	20.30053	-106.98
12.865	990.966	1.165	4180.31	1005	0.004129	-321.0468	0.05096	225.3667	-1.4246	33.626	20.60356	-100.01
15.569	990.532	1.161	4180.72	1006	0.0041272	-262.2723	0.03598	188.2378	-1.3933	30.539	21.61918	-77.866

Table 2 - Experiment Two: Varying Air Flow Rate Results at 60°C

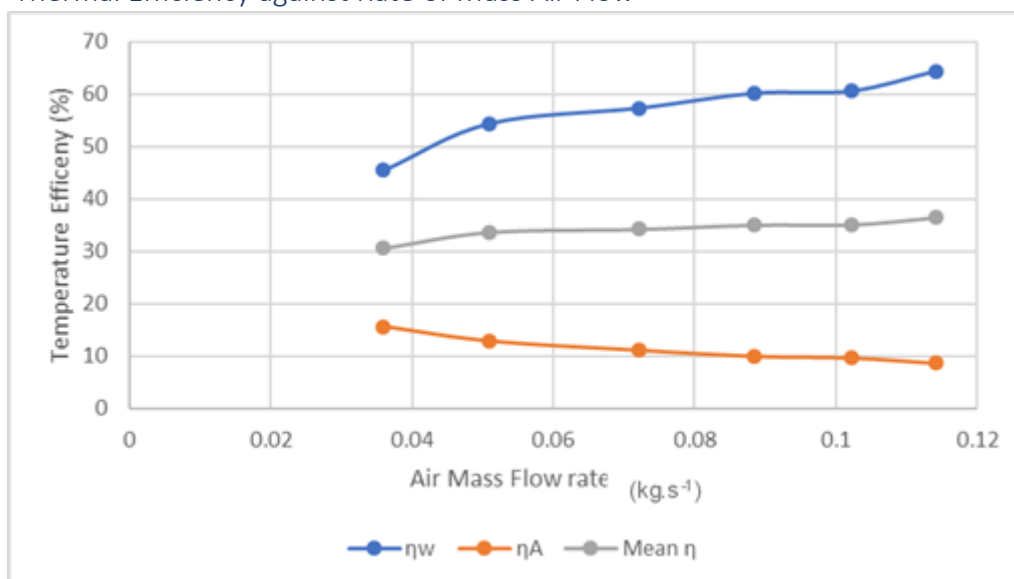
4.2 Results

4.2.1 Power Transferred against Rate of Mass Air Flow



The power transferred for both air and water show a linear trend which increases as the rate of flow of air increases. This experiment doesn't indicate that the line will level out which indicates at higher flow rates the power transfer will also be proportionally higher. The power transferred from the water is higher than the power absorbed by the air at lower rate of flow. This shows that at lower rates of flow the heat exchanger is less efficient and heat is most likely being transferred into the exchangers metal work or the air duct. However, as the rate of flow increases the value of power begin to converge which show that its more efficient.

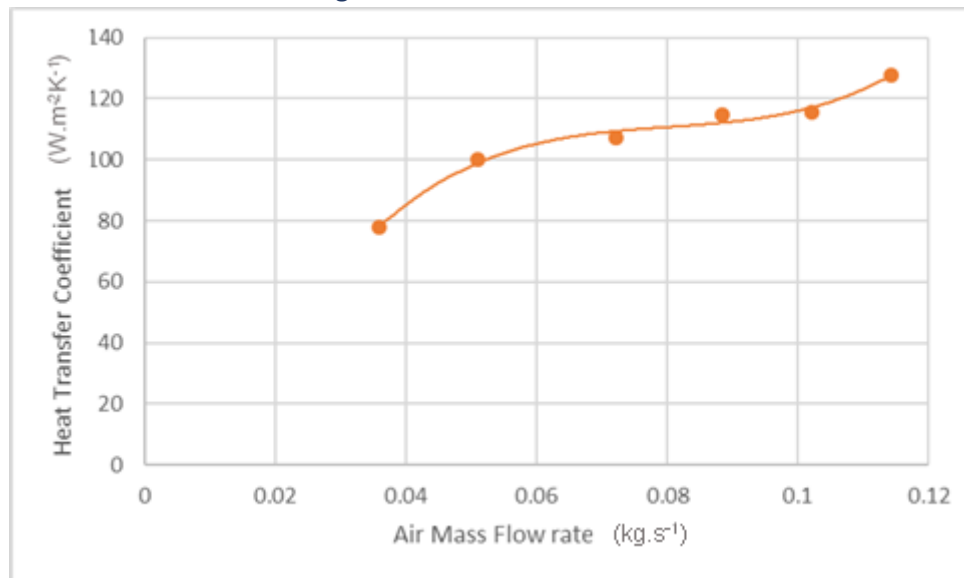
4.2.2 Thermal Efficiency against Rate of Mass Air Flow



The air efficiency gradually decreases as the rate of flow of air increases, whereas the efficiency of the water increases, slightly more than the decrease, as the rate of

flow increases. This means that the average efficiency very slightly increases with an increase in flow rate.

4.2.3 Heat Transfer Coefficient against Rate of Mass Air Flow



As the rate of flow of air increases so does the heat transfer coefficient, this means that at higher rates of flow of air the performance is better. The results were expected to be slightly more linear than they were however this error could be due to the external conditions on the day.

5 Experiment Three: Effect of Varying Temperature (Driving Force)

This final experiment follows experiment two in adjusting the air flow rates but at a different heater tank temperature. This enables analysis to be undertaken to see the effects of adjusting the heater tank temp when these results are compared to those of experiment two.

5.1 Data Collected

Table 3 displays the results from the spreadsheet.

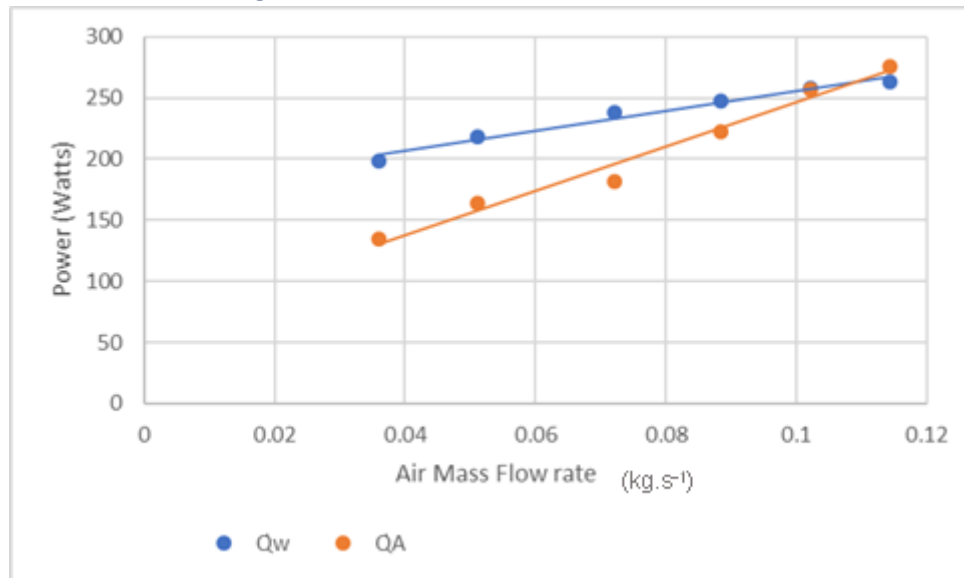
Experiment 3 Heat Exchanger Pipe Connection: Parallel Heater Temperature: 45°C Water Flow: 0.25 L/min												
Air Pressure Δp (Pa)	T_{w1}	T_{w2}	ΔT_w	Average T_w	T_{w3}	T_{A1}	T_{A2}	ΔT_A	Average T_A	T_{A3}	η_w	
250	48.8	33.6	-15.2	41.2	33.1	24.2	26.6	2.4	25.4	23.6	61.78862	
200	48.4	33.5	-14.9	41	33	24.1	26.6	2.5	25.4	23.5	61.31687	
150	48.3	34	-14.3	41.2	32.9	24.3	26.8	2.5	25.6	23.7	59.58333	
100	48.5	34.7	-13.8	41.6	32.8	24.6	27.1	2.5	25.9	23.5	57.74059	
50	48.7	36.1	-12.6	42.4	32.7	24.7	27.9	3.2	26.3	23.5	52.5	
25	49	37.5	-11.5	43.3	32.6	25.1	28.8	3.7	27	23.5	48.11715	

Cd: 0.6 Ambient Pressure: 1003 mBar Orifice Diameter: 0.10011 m												
η_A	ρ_w	ρ_A	C_{pw}	C_{pA}	$\dot{m}_w$	$\dot{Q}_w$	$\dot{m}_A$	$\dot{Q}_A$	C_{EB}	$\bar{\eta}$	LMTD	U
9.7561	993.46	1.1704	4178.45	1005	0.00414	-262.904	0.11425	275.56	-0.9541	35.7724	14.00341	-120.5022
10.288	993.53	1.1706	4178.42	1005	0.00414	-257.731	0.10219	256.76	-1.0038	35.8025	13.82099	-119.6905
10.417	993.47	1.1698	4178.45	1005	0.00414	-247.34	0.08847	222.29	-1.1127	35	13.9538	-113.7717
10.46	993.34	1.1686	4178.51	1005	0.00414	-238.665	0.0722	181.41	-1.3156	34.1004	14.22673	-107.6752
13.333	993.11	1.1669	4178.64	1005	0.00414	-217.868	0.05102	164.07	-1.3279	32.9167	14.71246	-95.04748
15.481	992.87	1.1643	4178.79	1006	0.00414	-198.806	0.03603	134.13	-1.4822	31.7992	15.04123	-84.83558

Table 3 - Experiment Three: Varying Air Flow Rate Results at 45°C

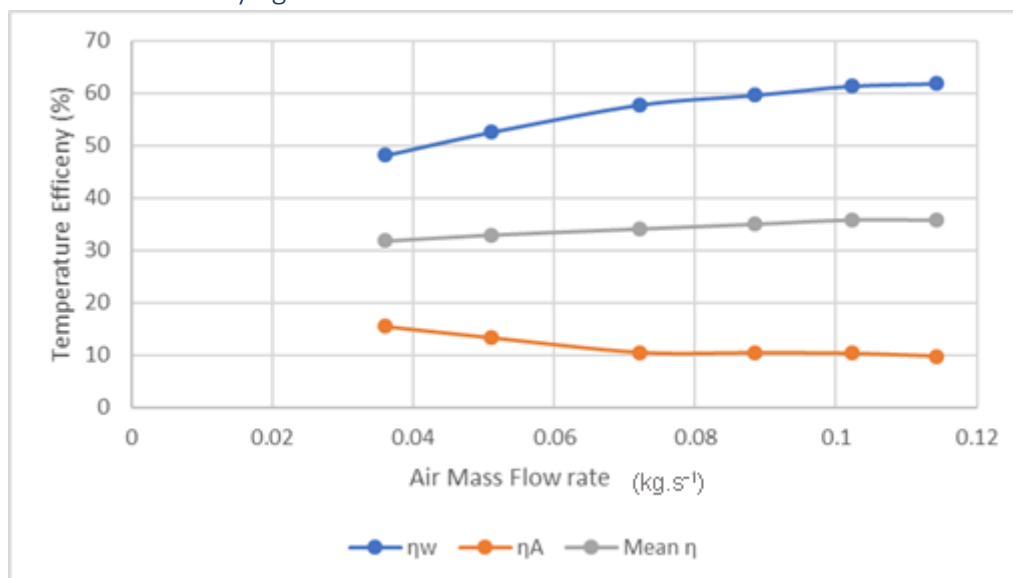
5.2 Results

5.2.1 Power Transferred against Rate of Mass Air Flow



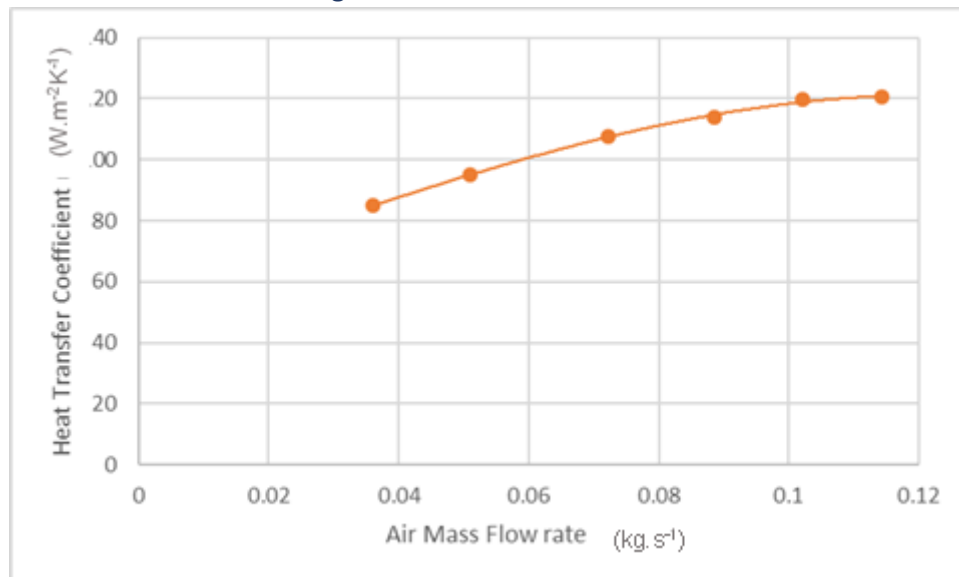
The power transferred begins to level as the rate of flow of air increases. This is different to the linear correlation in experiment two therefore, this suggests that at a lower temperature the heat transfer is tending towards its maximum value. However, the results weren't expected to converge like they have this could be due to errors in the surrounding conditions on the day.

5.2.2 Thermal Efficiency against Rate of Mass Air Flow



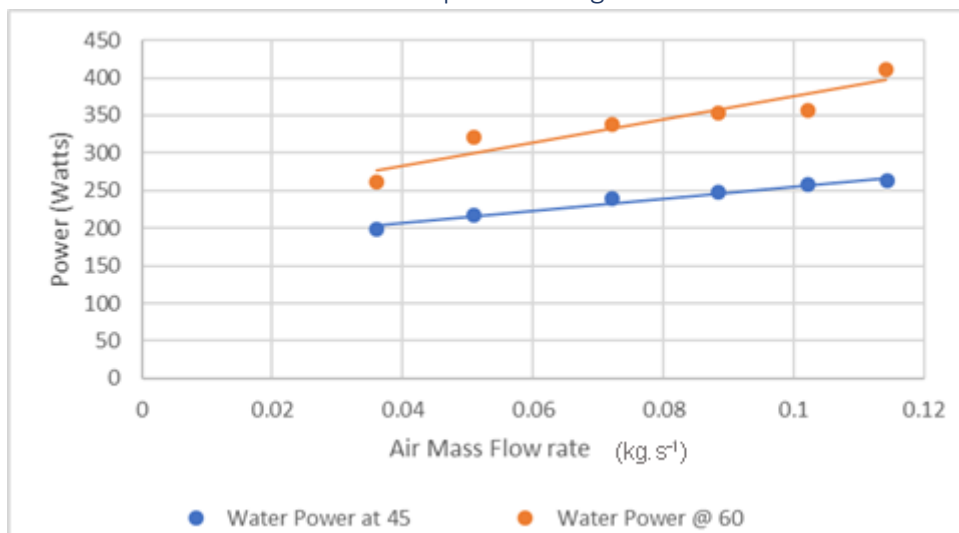
The thermal efficiency at 45°C shows very similar trends to that of experiment two. This suggest that the efficiency does not directly affect the efficiency of the heat exchanger.

5.2.3 Heat Transfer Coefficient against Rate of Mass Air Flow



The Heat transfer coefficient is affected very similarly to at both 45°C and 60°C. This is due to the formula used to calculate it taking in to account the different starting temperatures and different available power. This was carried out in the LMTD formula. This was considered because the available power is lower at lower temperatures. This means the performance of the heat exchanger is very similar for varying temperatures.

5.2.4 Power Transferred at different Temperatures against Rate of Mass Air Flow



As the rate of flow of air increases the difference between the water power increases. This suggests at higher temperatures the rate of flow has a larger effect on the power emitted from the water than it does at lower temperatures. This is due to the temperature being greater, meaning it can transfer more heat.

6 Conclusion

From these experiments the performance of the heat exchanger increases as both the air and water mass flow rates increase. However, the temperature of the water tank does not affect the performance of heat exchanger.

The variations and results that weren't expected could have been caused due to external room conditions effecting the effectiveness of the readings. Another cause for marginal errors could be due to the values set for the pressure drop and the water flow rate, this is because they only needed to be within a tolerance and this tolerance would affect the overall values. The day in which the experiments took place was quite a warm day this made it difficult to get the temperature of the water to drop and stabilise, so it was reading slightly higher than 45°C.

An assumption that was made for these experiments were that the heat exchanger was 'ideal'. Which means that there is no heat transfer across the system boundary. However, in reality some heat is transferred to the surrounding area through the duct work.

To improve the experiment next time, the experiment could have been conducted over a longer time to allow for the temperature to drop and reach 45°C. Also, more points could have been investigated to give a better display of trends. This would make it easier to spot and assess any anomalies.

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