
Heat Exchanger Laboratory Analysis



University of Wales Trinity Saint David

Thermofluid Mechanics

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Pedro do Carmo, p150667

BEng Automotive Engineering

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Introduction

In Engineering, it is very important that either machines are able to transfer heat out their system or into the system; this is possible by using Heat Exchanger systems that work by transferring heat from a fluid (either liquid or gas) to another. This system has three different ways to ensure the process of heat exchanging is successful, which are the following:

Counter Flow, which is a process that consists on having two fluids in opposite directions entering the system in opposite ends, which means that the cooler fluid will exit the system where the hot fluid enters reaching a temperature very similar to the hot fluid.

Cross Flow, represents a system that utilises two fluids perpendicular with each other that means that both fluids flow through their tubes and cross each other in a 90° angle. This is method is usually used in systems that one of the fluid changes state.

Parallel flow, this is the most important method within this experiment due to the fact that the machine used to develop this experiment uses the Parallel Flow method. This method is possible when both fluids flow in the same direction with both of the fluids entering the system on the same end, transferring heat from hotter to cooler allowing that the fluids reach similar temperatures.

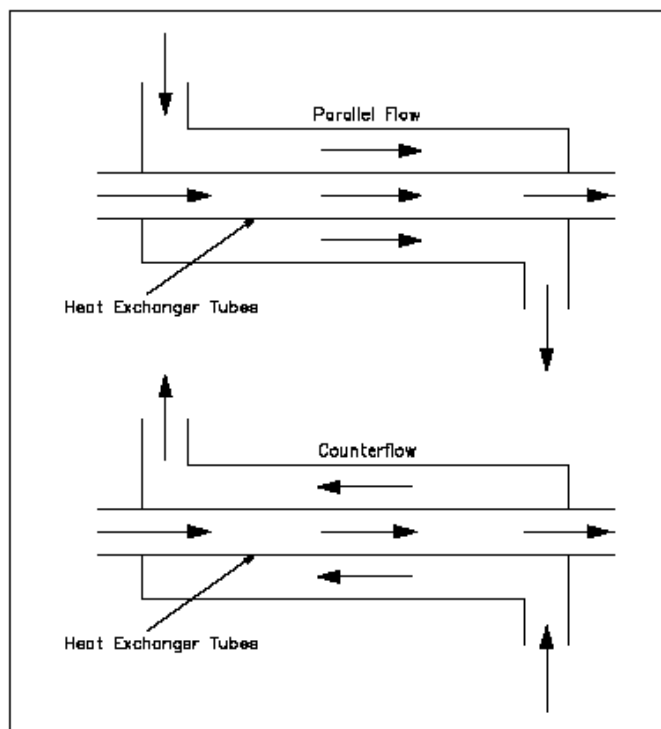


Figure 1: Parallel and Counter Flow

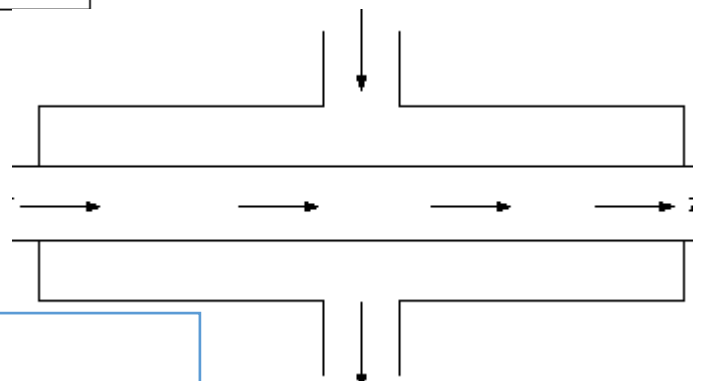


Figure 2: Cross Flow

Material

The machine used to conduct this experiment is the TD1007 Water to Air Heat Exchanger by TecQuipment equipped with the standard 32-tube heat exchanger, which is composed by two sets of 16 copper tubes, moreover this machine is equipped with mechanisms used to measure water and air characteristics such as water flow and air pressure. The machine also works with TecQuipment Versatile Data Acquisition System, which is a software, designed to record every experiment results, and therefore makes it easier to the user to obtain the results necessary to conduct the experiment.

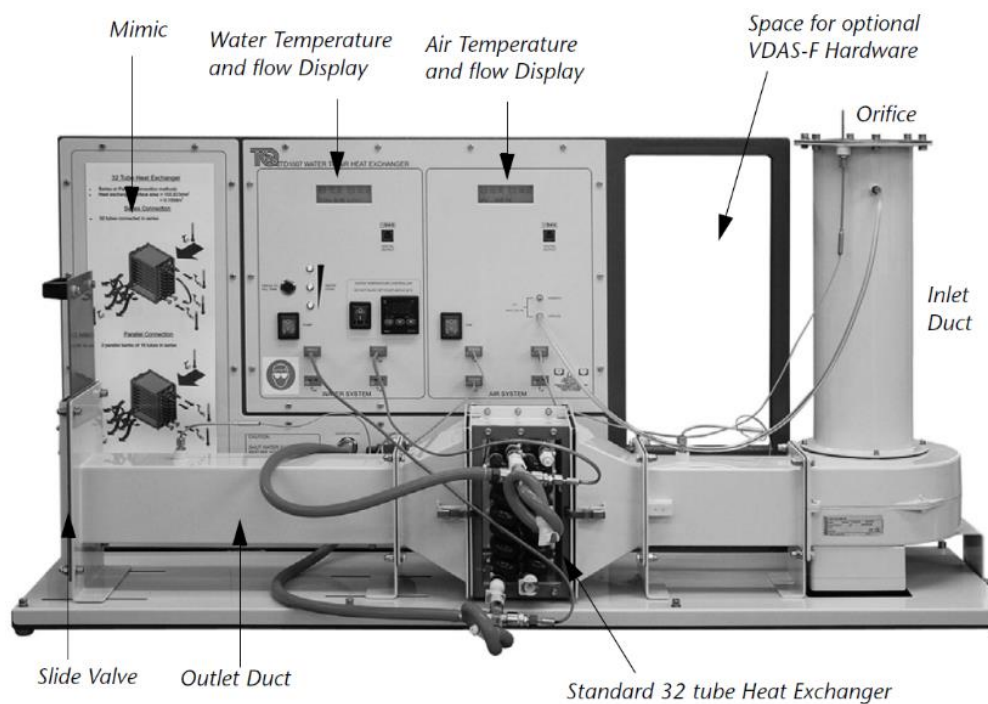


Figure 3: TD1007 Description

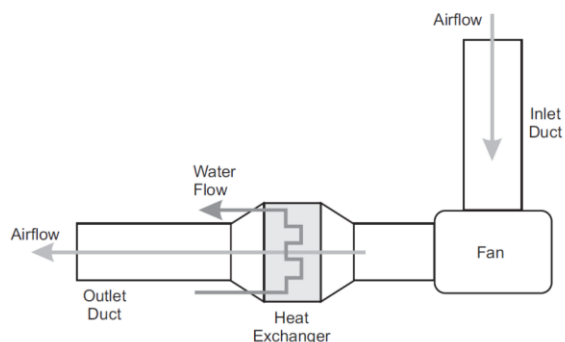


Figure 4: Flow paths

As shown in Figure 4, the air enters the system through the Inlet Duct and is conducted with the help of a fan through the section where the 32 standard tubes are, at this point the heat exchange takes place with the water flowing inside the tubes at certain temperature (on this experiment was at 60°C and 45°C) and a specific flow (L/min). Both of these characteristics and adding the different air pressures make it possible to heat exchange to take place, as proven in the experiment that is going to be described on this assignment.

Experiment 1

In order to prove that different water flow rates have a direct influence on the way that a heat exchanger performs a few steps need to be occur in order to have the machine ready to record the necessary results so that a successful laboratory can be written. The steps are the following:

1. Read and record the ambient pressure and temperature, in this case the ambient pressure was 1032 mBar and the ambient temperature 24°C.
2. Set the heater water tank to 60°C
3. Turn on the fan so that airflow pressure can be set to 250Pa
4. Switch on the water supply valve to 2.25 (L/min)
5. Wait 4 to 5 minutes so that the temperature can stabilize.
6. Record the temperatures needed.
7. Repeat steps 4 to 6 for water flow rates of 1.75, 1.25, 0.75, 0.25 (L/min)



Figure 5: TD1007 machine setup for conduct experiment 1

Experiment 2

In contrast to the previous experiment, this experiment uses different airflow rates instead of water flow rates to prove that the heat exchanger performs differently when used different airflow rates. Even using different values than the previous experiment, a few steps remain the same, while others change slightly in order to make the airflow the decisive aspect on this experiment, these steps are:

1. Keep the Water tank temperature at 60°C
2. Using the last measured water flow rate in experiment 1, which is 0.25 (L/min), record all the results using only this value.
3. Set up the airflow to give an orifice pressure drop of 250 Pa
4. Wait 4 to 5 minutes so that the temperature can stabilize
5. Record the temperatures needed
6. Using the slide valve repeat steps 3 to 5 for lower airflow rates of 200, 150, 100, 50, 25 pressure drop.



Figure 6: TD1007 machine setup for conduct experiment 2

Experiment 3

This last experiment of this laboratory experience is very similar to the one conducted previously on experiment 2 with the only difference being that instead of using a fixed temperature of 60°C, is used a temperature of 45°C. Therefore the steps required are:

1. Keep the Water tank temperature at 45°C
2. Using the last measured water flow rate in experiment 1, which is 0.25 (L/min), record all the results using only this value.
3. Set up the airflow to give an orifice pressure drop of 250 Pa
4. Wait 4 to 5 minutes so that the temperature can stabilize
5. Record the temperatures needed
6. Using the slide valve repeat steps 3 to 5 for lower airflow rates of 200, 150, 100, 50, 25 pressure drop.

Equations

After conducting all the steps described before the results should contemplate the following temperatures:

1. T_{w1} , T_{w2} , which are the inlet and outlet temperatures of the water flowing through the tubes at the heat exchanger.
2. T_{a1} , T_{a2} , which represent the inlet and outlet temperatures of the air flowing through the air duct at the heat exchanger.

After obtaining these values, several equations are required in order to find a new set of results these equations can be done by using the temperatures measured before. Below is the table used to find the new set of results required.

Symbol	Definition	Units
A	Heat Transfer Area	m^2
A_O	Orifice Area	m^2
C	Heat capacity	$J.K^{-1}$
C_d	Coefficient of discharge (orifice)	-
c_p and c_{pA} and c_{pW}	Specific Heat Capacity, of air and water at Constant Pressure (atmospheric pressure for air)	$J.kg^{-1}K^{-1}$
$LMTD$	Logarithmic Mean Temperature Difference	K or $^{\circ}C$ where shown
ρ and ρ_A and ρ_W	Density, of air and water	$kg.m^{-3}$
η_o	Overall Efficiency	%
C_{EB}	Energy Balance Coefficient	-
$\bar{\eta}_A$ and $\bar{\eta}_W$	Mean Temperature Efficiencies	%
Δp	Orifice pressure drop	Pa
Q	Heat energy transferred for a unit mass	$J.kg^{-1}$
$\dot{Q}$	Heat energy transferred for a unit time (heat transfer rate - or power)	W
$\dot{Q}_A$ and $\dot{Q}_W$	Heat energy (power) absorbed by the air and emitted by the water in a unit time	W
R	Specific gas constant for dry air	$287 J/kg.K$
T , T_W , T_A	Temperature, of water and air	K or $^{\circ}C$ where shown
ΔT	Change in Temperature	K or $^{\circ}C$ where shown
$\bar{T}$	Mean Temperature	K or $^{\circ}C$ where shown
U	Heat Transfer Coefficient	$W.m^{-2}K^{-1}$
$\dot{m}_W$ and $\dot{m}_A$	Mass Flow Rate (hot water circuit and air circuit)	$kg.s^{-1}$

After being acquainted with the names of the values that needed to be found, it is time to do the maths! So to do so the following equations were used:

For the Average Temperature:

$$\bar{T}_W = \frac{T_{W1} + T_{W2}}{2} \quad \bar{T}_A = \frac{T_{A1} + T_{A2}}{2}$$

For the Temperature Efficiency:

$$\eta_W = \frac{T_{W1} - T_{W2}}{T_{W1} - T_{A1}} \times 100 \quad \eta_A = \frac{T_{A2} - T_{A1}}{T_{W1} - T_{A1}} \times 100$$

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

For the Density:

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

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

For the Specific Heat Capacity:

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

CpA as fixed value of 1005 J/KgK

For the heat energy absorbed by the air and emitted by the water:

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

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

For the Energy Balance Coefficient:

$$C_{EB} = \frac{\dot{Q}_A}{\dot{Q}_W}$$

For the Logarithmic Mean Temperature Difference:

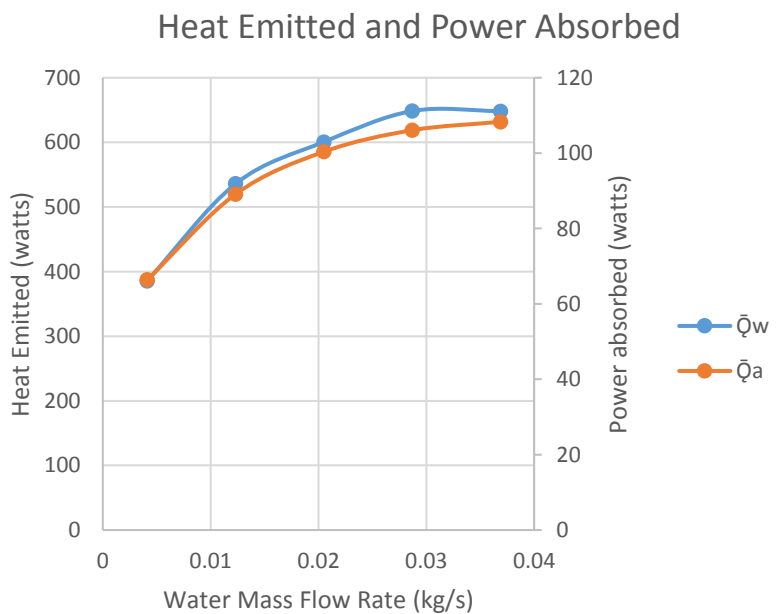
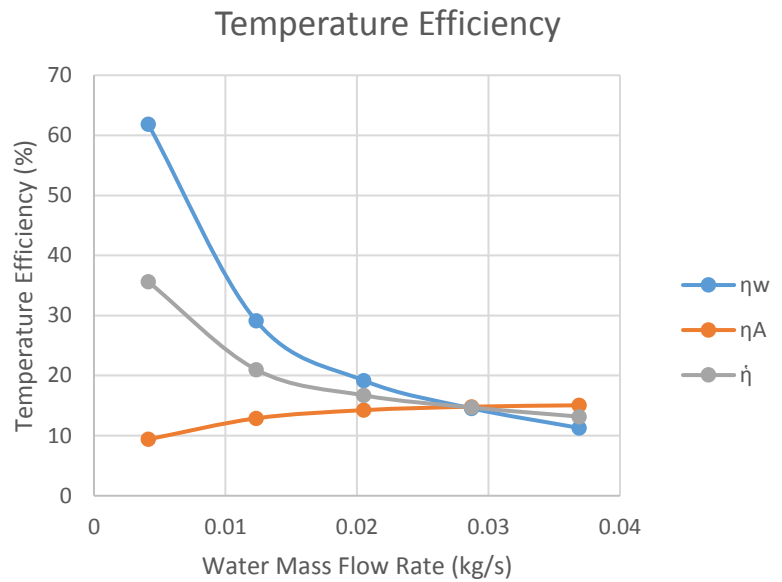
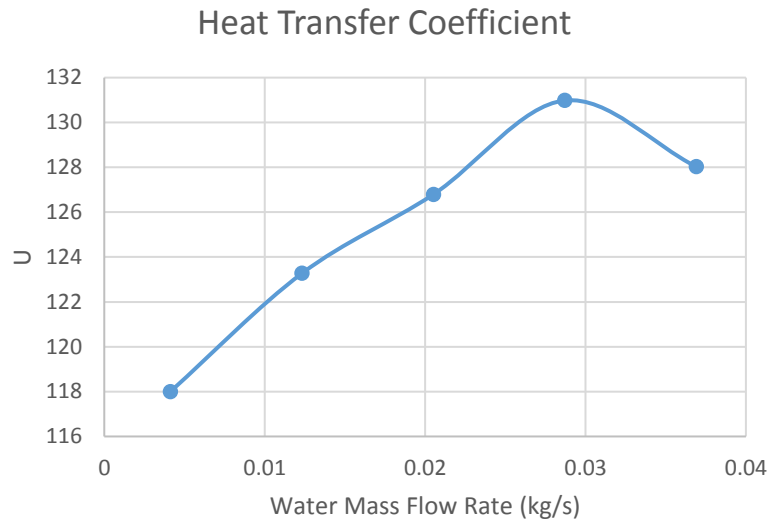
$$LMTD = \frac{(T_{W2} - T_{A2}) - (T_{W1} - T_{A1})}{\ln\left(\frac{T_{W2} - T_{A2}}{T_{W1} - T_{A1}}\right)}$$

Finally for the heat transfer coefficient:

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

Results – Experiment 1

Experiment 1		Heater Temperature = 60°												Heater Pressure = 250 Pa												Ambient Pressure = 1032 hPa												Orifice Diameter = 100.11 mm												Cd=0.6												Orifice Area = 0.007867 m²											
Hot Flow (L/min)	Tw1	Tw2	ΔTw	Average Tw			Tw3	TA1	TA2	ΔTA	Average TA			TA3	ηw	ηA	ρw	ρA	CpW	CpA	Q̇w	Q̇a	CEB	η	LMTD	U	ṁw	ṁA																																													
	2.25	60.6	56.4	4.2	58.5	30.6	23.4	29	5.6	26.2	23.2	11.29032	15.05376	983.9721	0.033247	4183.462	1005	648.3345974	108.3123	0.167062	13.17204	32.05068	128.028	0.036899	0.019245																																																
	1.75	60.7	55.3	5.4	58	31.7	23.6	29.1	5.5	26.35	23.3	14.55526	14.8248	984.2243	0.033058	4183.254	1005	648.4685049	106.075	0.163578	14.69003	31.33466	130.9805	0.028707	0.01919																																																
	1.25	60.2	53.2	7	56.7	32.5	23.7	28.9	5.2	26.3	23.4	19.17808	14.24658	984.8729	0.033121	4182.73	1005	600.7542447	100.3843	0.167097	16.71233	29.98752	126.7941	0.020518	0.019209																																																
	0.75	59.5	49.1	10.4	54.3	33.1	23.8	28.4	4.6	26.1	23.3	29.13165	12.88515	986.0432	0.033375	4181.828	1005	536.0501528	89.14112	0.166293	21.0084	27.52208	123.2728	0.012326	0.019282																																																
	0.25	60.2	37.8	22.4	49	33.4	24	27.4	3.4	25.7	23.8	61.87845	9.392265	988.4986	0.033894	4180.136	1005	385.6587863	66.39768	0.172167	35.63536	20.68545	117.9998	0.004119	0.019432																																																



Analysis – Experiment 1

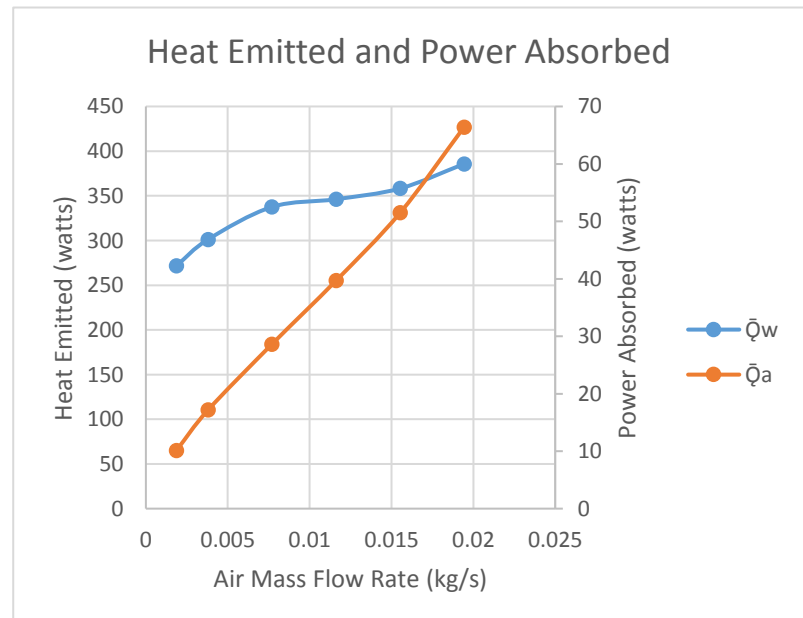
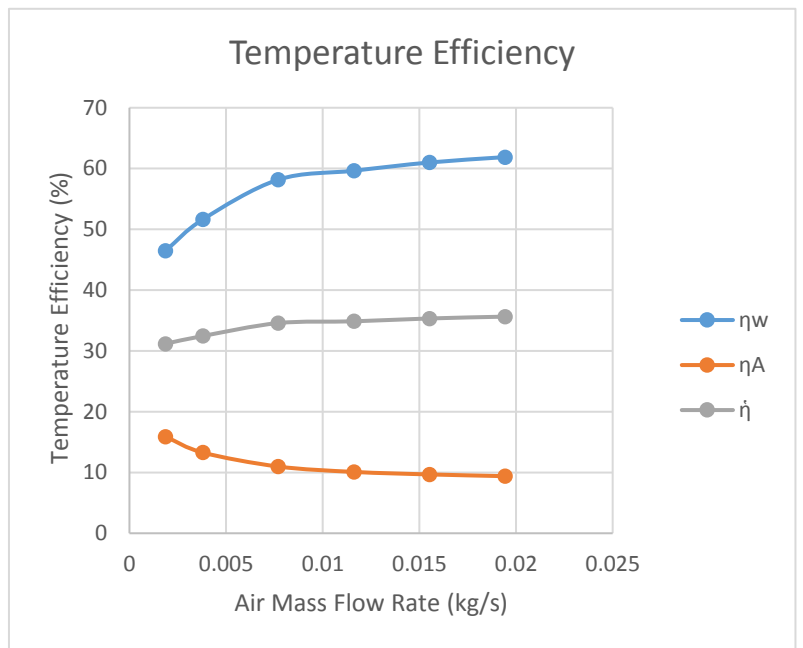
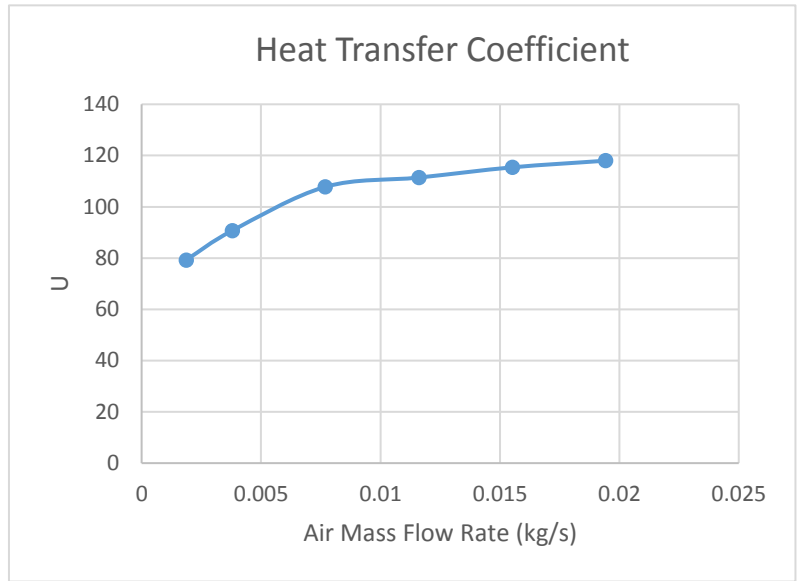
Analysing the graphs it is possible to analyse some aspects of the process of heat exchanging.

For instance in the first graph (Heat transfer Coefficient) it is possible to see that Heat Transfer Coefficient is directly influenced by the Water Mass Flow Rate especially because the temperature remains constant during the entire process of the experiment. Even though it is possible to see a slight irregularity on the graph (Predictably it would be a straight line) this can be concluded to be either a human error (Probably not waiting the amount of time required) or a technical problem with the machine (Not being hot enough at the beginning). That is shown because the Water Mass Flow Rate is being directly influenced by the Flow Rate, that the higher the Flow Rate is the higher the Heat Transfer Coefficient is.

On the other hand, it is possible to see that even though the Heat Emitted by the Water increases rapidly with the increase of the Water Mass Flow Rate, the Power absorbed by the Air increases much slower, a fact that is also possible to see when analysing the Temperature Efficiency graph. In this graph it is possible to see a drastic drop in the Water Temperature Efficiency that has Temperature Efficiency of 61.9% when the Flow Rate is at 0.25(L/min) and 11.3 when the Flow Rate is at its peak of 2.25 (L/min), this shows that even when considering that the Heat Emitted increases with higher Flow Rates, the Power Absorbed by the Air doesn't increase rapidly enough to keep a good Temperature Efficiency, concluding that the higher the flow rate the lower the Temperature Efficiency, due to the fact that the air just doesn't absorb heat as fast the water emits it.

Results – Experiment 2

Experiment 2		Heater Temperature = 60°										Water Flow = 0.25 (L/min)										Ambient Pressure = 1032 hPa										Orifice Diameter = 100.11 mm										Cd=0.6										Orifice Area = 0.007867 m ²																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
Air Pressure Δp (Pa)		Tw1	Tw2	ΔTw	Average Tw		Tw3	TA1	TA2	ΔTA	Average TA		TA3	ηw	ηA	ρW	ρA	CpW	CpA	Q̇w	Q̇a	C _{EB}	η	LMTD	U	ṁw																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											



Analysis – Experiment 2

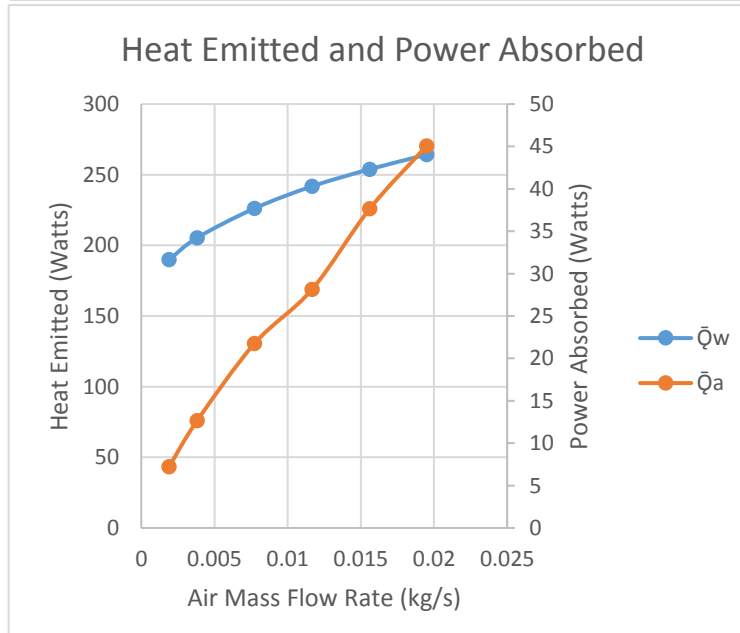
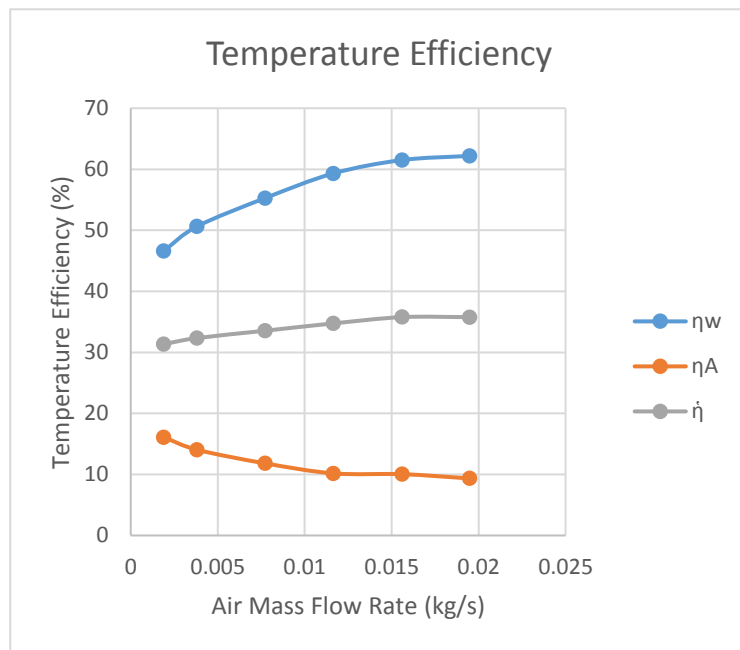
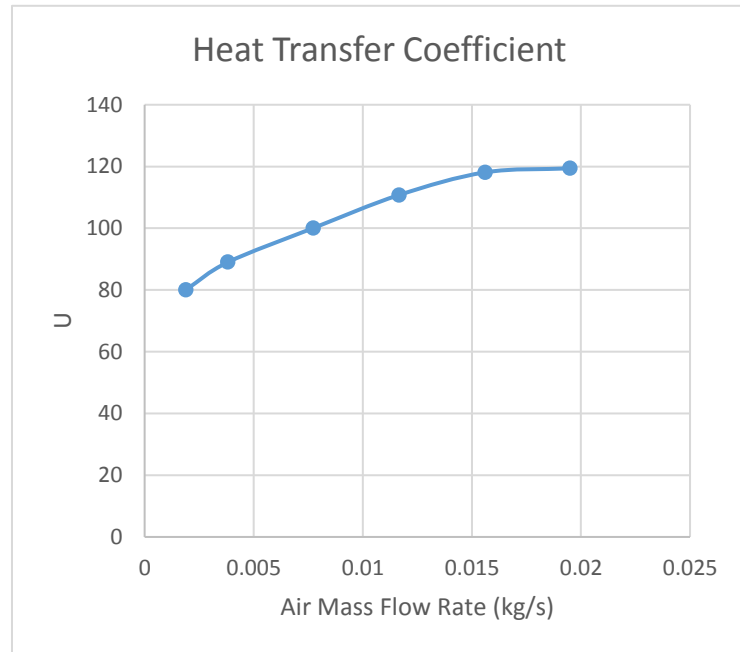
By analysing the graphs of the second experiment, it is possible to find that the results are different to experiment 1 where the Air Pressure was constant, revealing that the air pressure has an influence on the results such as:

Looking at the first graph it is possible to get a similar conclusion as the experiment 1, with the Heat Transfer Coefficient also increasing when the Air Mass Flow Rate increases, although in this case it is possible to see that the line in the graph is more stable than the one found in experiment 1 revealing that less mistakes were made in this part of the experiment.

Regarding the second graph (Temperature Efficiency), it is possible to see the opposite, as in experiment 1 with the Water Temperature Efficiency decreasing as the Air Mass Flow Rate decreases. It is also possible to see that with a lower Air Mass Flow Rate the Air Temperature Efficiency is higher, this is in fact visible when analysing the third graph (Heat Emitted and Power Absorbed), where the Power Absorbed decreases rapidly when the Air Pressure decreases, proving that with higher Air Pressure, the higher the Temperature Efficiency will be, which is due to the fact that when the Air Pressure is higher more Power is Absorbed by the Air.

Results – Experiment 3

Experiment 3										Heater Temperature = 45°										Water Flow = 0.25 (L/min), Ambient Pressure = 1032 hPa										Orifice Diameter = 100.11 mm										Cd=0.6										Orifice Area = 0.007867 m²									
Air Pressure Δp (Pa)		Tw1	Tw2	ΔTw	Average Tw			Tw3	TA1	TA2	ΔTA	Average TA			TA3	ηw	ηA	ρW	ρA	CpW	CpA	Q̇w	Q̇a	CεB	η̇	LMTD	U	ṁw	ṁA																														
250		49	33.7	15.3	41.35	33.7	24.4	26.7	2.3	25.55	23.9	62.19512	9.349593	991.7107	0.034093	4178.475	1005	264.1697115	45.04773	0.170526	35.77236	14.00341	119.3966	0.004132	0.019489																																		
200		48.2	33.5	14.7	40.85	33.5	24.3	26.7	2.4	25.5	23.9	61.50628	10.04184	991.9062	0.027328	4178.402	1005	253.8557177	37.64191	0.148281	35.77406	13.6043	118.1011	0.004133	0.015606																																		
150		48.1	34.1	14	41.1	33.4	24.5	26.9	2.4	25.7	23.8	59.32203	10.16949	991.8087	0.020337	4178.438	1005	241.7456555	28.12137	0.116326	34.74576	13.81442	110.7565	0.004133	0.011659																																		
100		48.3	35.2	13.1	41.75	33.2	24.6	27.4	2.8	26	23.7	55.27426	11.81435	991.553	0.013401	4178.537	1005	226.1518946	21.74562	0.096155	33.5443	14.30691	100.0455	0.004131	0.007728																																		
50		48.5	36.6	11.9	42.55	33.1	25	28.3	3.3	26.65	23.8	50.6383	14.04255	991.234	0.006537	4178.669	1005	205.3761188	12.65715	0.061629	32.34043	14.60492	89.00073	0.00413	0.003816																																		
25		48.9	37.9	11	43.4	33	25.3	29.1	3.8	27.2	23.8	46.61017	16.10169	990.8901	0.003203	4178.823	1005	189.7845663	7.213394	0.038008	31.35593	15.00261	80.06394	0.004129	0.001889																																		



Analysis – Experiment 3

The third part of this laboratory experience is very similar to the second with the only difference being the temperature, where on the second experiment the temperature was fixed at 60°C, on the third, the temperature was set at 45°C meaning that any difference in the results are all because of the temperature change.

On the first graph it is quite clear to determine that the temperature doesn't have such a vital importance, in comparison to the Air Pressure and Water Flow, due to the fact that the Heat Transfer Coefficient graph remained very similar than the one registered in the previous experiment.

Regarding the second graph it is also possible to determine that the graph didn't have any big changes, remaining very similar to the one obtained in experiment 2, proving that a temperature change doesn't have as much importance on the Temperature Efficiency as the Water Flow Rate and Air Pressure.

Finally, in the last graph it is possible to see a change when comparing the two experiments with the Heat Emitted and the Power Absorbed having lower values as the ones in experiment 2, proving that the temperature has a direct influence in the amount of Heat Emitted by the Water and the Power Absorbed by the Air.

Observations

While conducting the third experiment a problem was noticed, at the beginning of the experiment, the temperature floating between 44.7 °C and 46.3°C increasing and decreasing quite quickly. Eventually it ended to stabilize between 44.8°C and 45.5°C and even though that it kept on increasing and decreasing between the referred temperatures it did so in much steadily pace. Revealing that the machine needed more time to cool down, a possible way to fix this problem would be if the third experiment would be conducted in the first place due to clearly being easier to increase the temperature of the machine than decrease it.

Conclusion

This laboratory experience had the goal to show what changes in a heat exchanger when subjected to variables such as Air Pressure, Water Flow Rates and Temperature. By analysing, every part of this three part experiment is possible to see that when the Water Flow Rate and Air Pressure values change within the same experiment, it has a dramatic influence in values such as Heat Transfer Coefficient, Temperature Efficiency, Heat Emitted by the Water and Power Absorbed by the Air. While when just the temperature changes these values, do not change as much as on the other experiment, getting results quite close to the other experiment while using a different temperature.

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