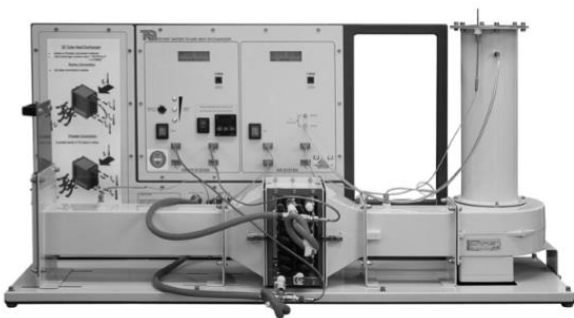




PRIFYSGOL CYMRU
Y Drindod Dewi Sant
UNIVERSITY OF WALES
Trinity Saint David
SWANSEA - ABERTAWE

SCHOOL OF ENGINEERING



Thermofluid Mechanical

MODULE CODE: M5X00406

STUDENT NAME: ZHANGWEI GUO

STUDENT NUMBER: 1805078

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Abstract.

Heat can be transferred from one fluid to another in almost any system and the heat exchangers are exclusively used to implement this processes. It is important to have a deep understand of the basic components of a heat exchanger to make sense how they function and operate.

In order to better use the knowledge learned in the lecture and test the students' actual experimental operation, this experiment uses air and water heat exchangers to design three sets of control variable experiments to explore the effect of different water flow velocities, different air flow velocities and different water temperature on the process of heat exchange between water and air. Through the processing of the experimental results, the corresponding curves are obtained, thereby verifying the correctness of the experimental process and the applicability of the experimental principle.

Special Equipment.

A heat exchanger is a component which permits the heat transferred from one fluid to another. The short experiment course concentrates on one particular type which is recuperative heat exchangers. In this exchanger, heat is allowed to transfer from one fluid to another through a dividing wall which is typically named as the interface. Some reasons for heat transfer are as follows:

1. To heat a cooler fluid by means of a hotter fluid
2. To reduce the temperature of a hot fluid by means of a cooler fluid
3. To boil a liquid by means of a hotter fluid
4. To condense a gaseous fluid by means of a cooler fluid
5. To boil a liquid while condensing a hotter gaseous fluid

During the experiment, the first one has been used.

In the heat exchanger, the fluids must be at different temperatures and come into thermal contact but no mass transfer between each other in order to transfer heat and it can be transferred only from the hotter to the cooler.

Most heat exchangers can be divided into two categories by construction which are tube (Figure 1) and plate (Figure 2) even if they are quite different in shapes and sizes and each type has its advantages and disadvantages.

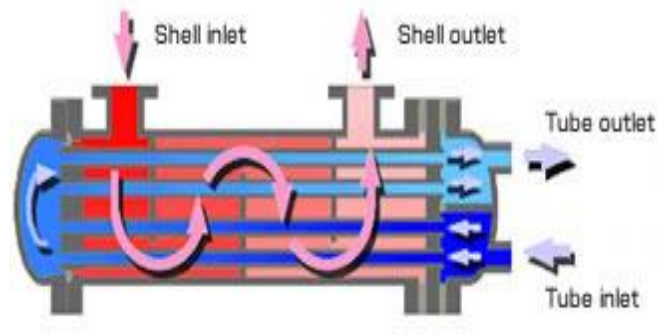


Figure 1. Construction of a tube type heat exchange

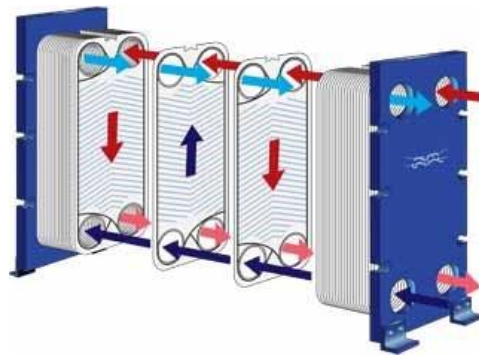


Figure 2. Construction of a plate type heat exchanger

After that, they can also be categorized on account of common characteristics and one of them is the direction of flow which means the relative between two fluids. They are parallel flow, counter flow and cross flow.

Parallel flow (Figure 3) means both the tube side and the shell side fluids flow in the same direction which indicates that both of them enter the heat exchanger from the same side with a big temperature difference and heat will be transferred from hotter to cooler but the temperature of cold fluid is always lower than the hot one during whole exchange process.

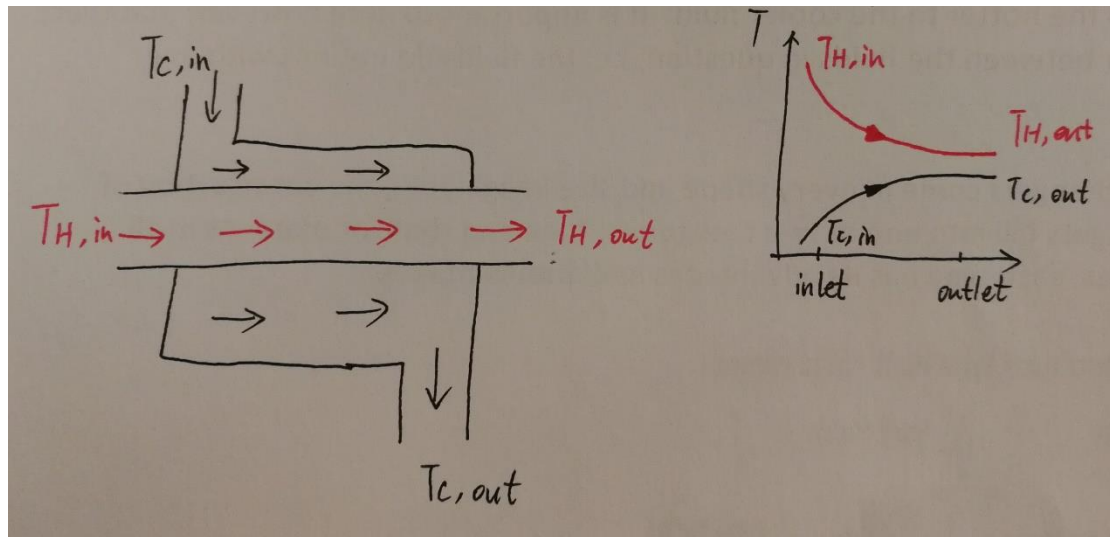


Figure 3. Parallel flow

Counter flow (Figure 4) exactly the opposite to the parallel flow in which two fluids flow in opposite directions. On account of the cooler fluid exits the exchanger where the hot fluid enters, the cooler fluid will nearly approach the inlet temperature of the hot fluid. Counter flow heat exchanger is the most efficient of the three types heat exchangers due to the hottest temperature of cold-fluid can be higher than the coldest temperature of hot-fluid when it comes to the comparison with the parallel flow heat exchanger.

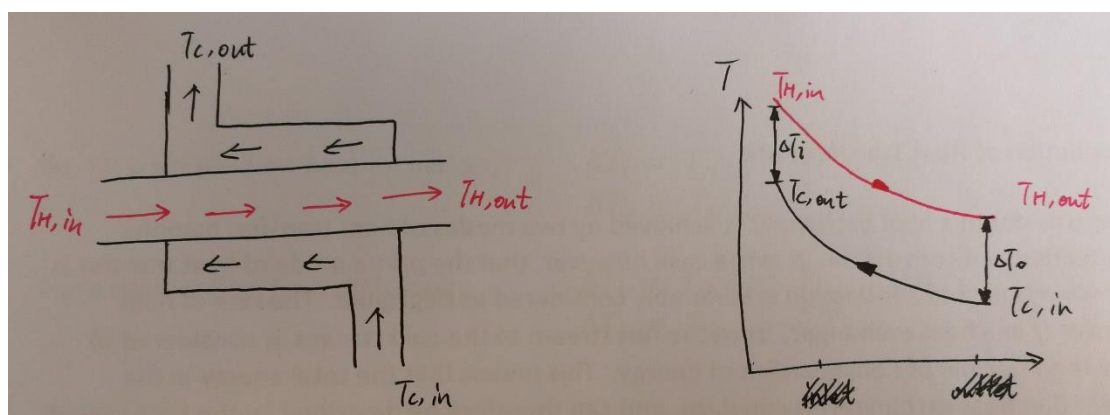


Figure 4. Counter flow

Cross flow (Figure 5) means one fluid flows perpendicular to the

second fluid. For example, one fluid flows through tubes and the second passes around the tubes at 90° angle.

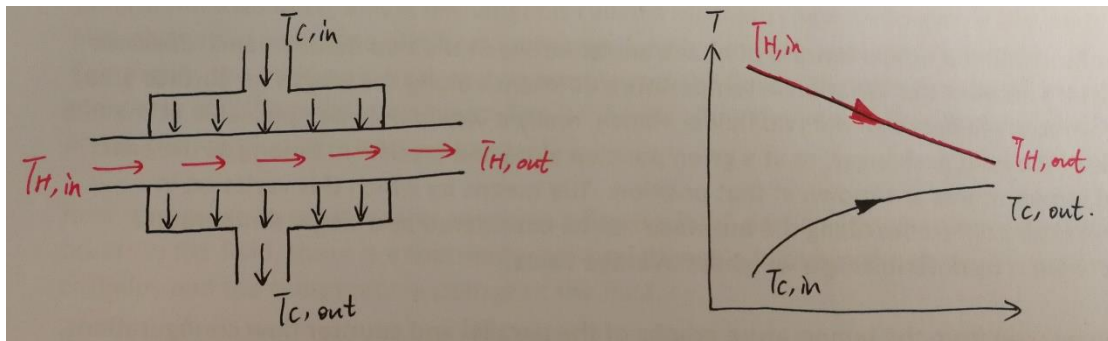


Figure 5. Cross flow

Each type of these three heat exchangers above has both advantages and disadvantages. But the counter flow heat exchanger is the most efficient one.

Principles of Researches.

$$\text{Mass flow (kg.s}^{-1}\text{)} \dot{m}_W = \text{Volume flow (L.min}^{-1}\text{)}/60000 \times \text{Water density (kg.m}^{-3}\text{)} \quad (1)$$

The heat exchanger measures water flow in liters per minute, but the calculations need mass flow in kilograms per second. Formula (1) can finish that conversion.

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

The equipment measures the pressure drop across the inlet orifice. The air flow through the duct can be achieved through formula (2) with the pressure drop with the orifice discharge coefficient (Cd), its area and local air conditions.

For average temperatures in heat exchangers, the calculated value of the temperature at a mid-point between the inlet and outlet of the circuit can be found through formula (3) and (4).

The average temperature of the water circuit:

$$\bar{T}_W = \frac{T_{W1} + T_{W2}}{2} \quad (3)$$

The average temperature of the air circuit:

$$\bar{T}_A = \frac{T_{A1} + T_{A2}}{2} \quad (4)$$

Heat capacity is a measure of the heat needed to increase the temperature of a given mass of material by 1 degree (Kelvin or Celsius).

$$C = m \times c \quad (5)$$

As can be seen from formula (5), it is a product of the mass of a material (m) and its specific heat capacity (c). But specific heat capacity is the amount of heat energy needed to raise the temperature of exactly 1 kg of material by 1 degree (Celsius). It is a ratio of the change in heat energy and the change in temperature as showed in formula (6).

$$c = \frac{\Delta Q}{\Delta T} \quad (6)$$

Specific heat capacity can be affected by pressure and temperature, so equation (7) assumes constant pressure over a known range of temperature. It is called ‘isobaric’ (equal pressure) specific heat capacity.

$$c_P = \frac{Q}{\Delta T} \quad (7)$$

The specific heat capacity for air is constant around 1005 J.kg-1.K-1 with normal pressure and the temperature.

An accurate specific heat capacity for water can be obtained through equation (8).

$$\frac{c_{pW}(\text{at } T^{\circ}\text{C})}{c_{pW}(\text{at } 15^{\circ}\text{C})} = 0.996185 + 0.0002874 \left(\frac{T+100}{100} \right)^{5.26} + 0.011160 \times 10^{-0.036T} \quad (8)$$

The specific heat capacity of water at 15°C is 4185.5 J.kg-1.K-1 from tests.

On account of local air pressure has effects on air density, for more accuracy, equation (9) can finish the calculation of the air density at a given

pressure and temperature.

$$\rho_A = \frac{p}{RT} \quad (9)$$

The same as air density, for more accuracy, the water density can be obtained through equation (9).

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

Where T is your average water temperature in degrees centigrade.

Power is the rate of heat energy transferred per unit time from the hotter to the cooler circuit in heat exchangers. Because the calculation is based on a mass flow rate, the heat transfer is also a rate as shown in formula (10).

$$\dot{Q} = \dot{m} \times c_p \times \Delta T \quad (10)$$

So the heat emitted from the water is:

$$\dot{Q}_W = \dot{m}_W \times c_{pW} \times \Delta T_W \quad (11)$$

And the heat absorbed in the air is:

$$\dot{Q}_A = \dot{m}_A \times c_{pA} \times \Delta T_A \quad (12)$$

The heat the cooler absorbs and the hotter emitted should be equal in an ideal heat exchanger in which no heat lose or absorb from its surroundings.

$$\dot{Q} = \dot{Q}_W = \dot{Q}_A = \dot{m}_W \times c_{pW} \times \Delta T_W = \dot{m}_A \times c_{pA} \times \Delta T_A \quad (13)$$

As shown in formula (14), the energy balance coefficient indicates the

relationship between the energy absorbed and emitted.

$$C_{EB} = \frac{\dot{Q}_A}{\dot{Q}_W} \quad (14)$$

More useful results can be obtained through comparison of mean temperature efficiency and heat transfer coefficient between heat exchangers.

The temperature efficiency of the hot water is the ratio of the temperature change in hot water divided by the difference between the maximum and minimum temperatures of the hot and cold circuits as follows:

$$\eta_W = \frac{T_{W1} - T_{W2}}{T_{W1} - T_{A1}} \times 100 \quad (15)$$

Similar to the above, the temperature efficiency of the air can be achieved through formula (16).

$$\eta_A = \frac{T_{A2} - T_{A1}}{T_{W1} - T_{A1}} \times 100 \quad (16)$$

For the mean temperature efficiency, it is the average efficiency of both the temperature efficiencies of the water and the air.

$$\bar{\eta} = \frac{\eta_W + \eta_A}{2} \quad (17)$$

The logarithmic mean temperature difference is a logarithmic average of the temperature difference which is the driving force that creates the heat transfer between the hot and cold circuits at each end of the heat exchanger.

$$LMTD = \frac{(T_{W2} - T_{A2}) - (T_{W1} - T_{A1})}{\ln\left(\frac{T_{W2} - T_{A2}}{T_{W1} - T_{A1}}\right)} \quad (18)$$

Heat transfer coefficient is a measure of how well the heat exchanger works from evaluate how well the wall and boundary layers work. A high coefficient can be found on a good heat exchanger.

$$U = \frac{\dot{Q}_W}{A \times LMTD} \quad (19)$$

Process of Researches.

Experiment 1 expected to show the effect of different water flow rate on the performance of heat exchanger on a fixed air flow and water temperature.

First of all, connect and set up the standard 32 tube heat exchanger as for *parallel* flow and set tank temperature to 60°C. Let water enters the bottom of the heat exchanger and exits from the top.

After that, record the ambient air pressure and diameter of the orifice which is stamped on the surface of the orifice.

And then, switch on the fan and set an orifice pressure drop of 250 Pa (+/- 5 Pa tolerance) through the slide valve. On the meanwhile, switch on the pump and set the water flow to 2.25 L/minute (+/- 0.01 L/minute) using the hand operated water supply valve.

After all sets done, record all readings at least five minutes later for the heat exchanger temperatures to stabilize and repeat the procedure for lower water flow rates of 1.75, 1.25, 0.75 and 0.25 L/min.

Experiment 2 expected to show the effect of different air flow rates on the performance of heat exchanger on a fixed water flow and temperature.

All sets are same with the experiment 1 except for switching on the

pump and set the flow to 0.25 L/minute (+/- 0.01 L/minute) through the hand operated water supply valve and repeat the procedure for lower air flow rates of 200, 150, 100 and 50 Pa pressure drop.

Experiment 3 expected to show the effect of different hot water supply temperatures on the performance of heat exchanger on a fixed water flow.

Set the tank temperature of 45°C and repeat experiment 2 with other sets all the same with experiment 2.

Results and Analysis.

For the processing of the experimental results, the data record table in the guidance is first established in excel, and the recorded experimental results are filled in the table, as shown in the following figure:

Experiment 1 Heater Temperature: 60°C Orifice dp=250Pa																											Experiment 2 Heat exchanger: Pipe Connection: Heater temperature: 60°C Water flow:25l/min																											Experiment 3 Heat exchanger: Pipe Connection: Heater Temperature: 45°C Water flow:25l/min																											Experiment 4 Heat exchanger: Pipe Connection: Heater Temperature: 45°C Water flow:25l/min																																																														
Hot flow(L/min)										Cold flow(L/min)										Hot flow(L/min)										Cold flow(L/min)										Hot flow(L/min)										Cold flow(L/min)										Hot flow(L/min)										Cold flow(L/min)																																																																									
Tw1	Tw2	dtw	Average Tw	Ta1	Ta2	dTa	Average Ta	Ta3	nw	na	pw	pa	mfw	mfa	Cpw	Cpa	Qw	Qa	Ceb	η	LMTD	U	Tw1	Tw2	dtw	Average Tw	Ta1	Ta2	dTa	Average Ta	Ta3	nw	na	pw	pa	mfw	mfa	Cpw	Cpa	Qw	Qa	Ceb	η	LMTD	U	Tw1	Tw2	dtw	Average Tw	Ta1	Ta2	dTa	Average Ta	Ta3	nw	na	pw	pa	mfw	mfa	Cpw	Cpa	Qw	Qa	Ceb	η	LMTD	U	Tw1	Tw2	dtw	Average Tw	Ta1	Ta2	dTa	Average Ta	Ta3	nw	na	pw	pa	mfw	mfa	Cpw	Cpa	Qw	Qa	Ceb	η	LMTD	U																																																				
2.25	61.1	56.6	-4.5	58.85	23.5	29.3	5.8	26.40	23.3	11.9681	15.4255	983.7691	1.1842	0.03689	0.11492	4183.61	1005	-694.525	669.877	0.96451	13.69681	32.17570	-138.546	1.75	60.8	55.5	-5.3	58.15	23.6	29.2	5.6	26.40	23.2	14.2973	15.0538	994.1231	1.1842	0.02870	0.11492	4183.32	1005	-656.404	646.778	1.01630	14.65054	31.43667	-129.940	0.75	59.7	49.3	-10.4	54.50	23.7	28.4	4.7	26.05	23.3	28.8899	13.0556	985.9205	1.1866	0.01232	0.11499	4181.90	1005	-535.993	543.149	1.01335	20.9722	27.76910	-123.888	0.25	60.5	38.2	-22.3	49.35	23.8	27.3	3.5	25.55	23.5	60.7629	9.5368	988.3142	1.1876	0.00412	0.11508	4180.23	1005	-388.875	404.811	1.05454	35.14966	21.25181	-115.938																																																
250	48.6	33.6	-15.0	41.10	23.6	26.1	2.5	24.85	23.1	60.0000	10.0000	991.7786	1.1904	0.00412	0.11522	4178.44	1005	-236.227	289.490	1.12107	35.00000	14.53521	-114.029	200	48.1	33.8	-14.3	40.95	24.0	26.4	2.4	25.20	23.4	59.3361	9.9585	991.8371	1.1890	0.00412	0.10300	4178.42	1005	-246.176	248.425	1.00914	34.64730	14.14377	-111.715	150	48.1	34.2	-13.9	41.15	23.9	26.5	2.6	25.20	23.2	57.4380	10.7438	991.7599	1.1890	0.00412	0.08920	4178.45	1005	-239.291	233.071	0.97400	34.99091	14.48882	-106.594	100	48.2	34.9	-13.3	41.55	23.9	26.8	2.9	25.35	23.1	54.7325	11.9342	991.6020	1.1884	0.00412	0.07381	4178.51	1005	-228.965	212.206	0.92680	33.33333	14.74588	-99.663	50	48.3	36.4	-11.9	42.35	24.3	26.7	2.4	25.50	23.2	49.5833	10.0000	991.2845	1.1878	0.00412	0.05147	4178.64	1005	-204.870	124.150	0.60589	29.79167	15.78492	-83.305	25	48.3	37.6	-10.7	42.95	24.7	26.5	3.8	26.60	23.2	45.3390	16.1017	991.0433	1.1834	0.00412	0.03633	4178.74	1005	-184.216	138.741	0.75315	30.72034	15.21555	-77.709

Figure 6.

Experiment 1

For the data processing of Experiment 1, under the premise that all the key requirements are met, the required parameters are calculated, and the following three graphs are drawn:

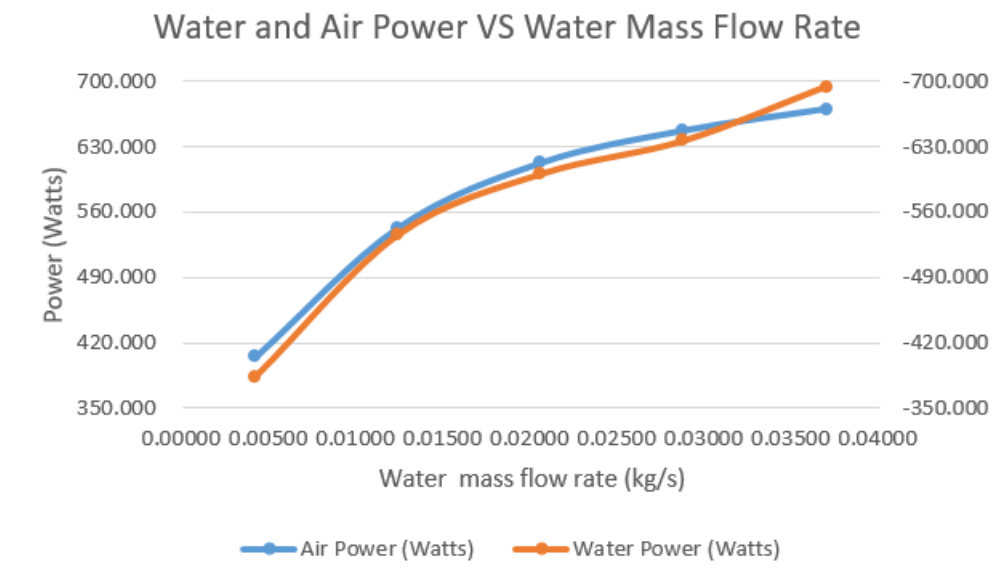


Figure 7.

Figure 7 shows the relationship between the power emitted by the water and the power absorbed into the air. The first axis on the left is for the air and the second on the right is for the water.

As shown on the graph, the two fit curves almost coincide, but produce a large difference at the last data point. It can be approximated that the heat generated by the water flow in the whole process is slightly smaller than the heat absorbed by the air. The reason is that the air has a part of kinetic energy through the acceleration itself, and not only the friction with the channel can make its temperature rise slightly, and the contact portion with the channel also allows it to receive heat from a portion of the channel.

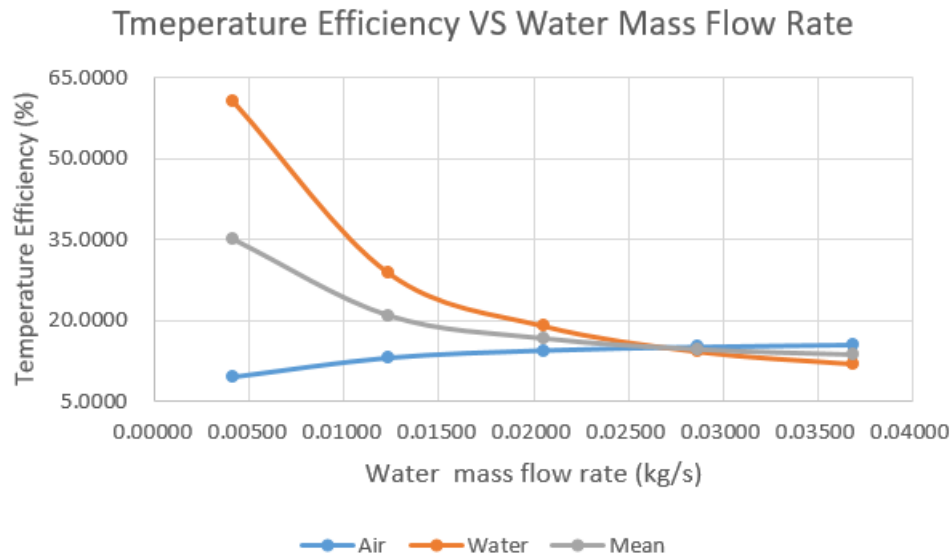


Figure 8.

For the temperature efficiency, as we can see from this figure, the value for water drops and air increases as the water mass flow rate increases. For the reasons of this phenomenon, the dT_w decreases quickly as the water flow rate increases while the dT_a increases slowly. It will be better for the performance of mean temperature efficiency when it comes with a lower water flow mass rate.

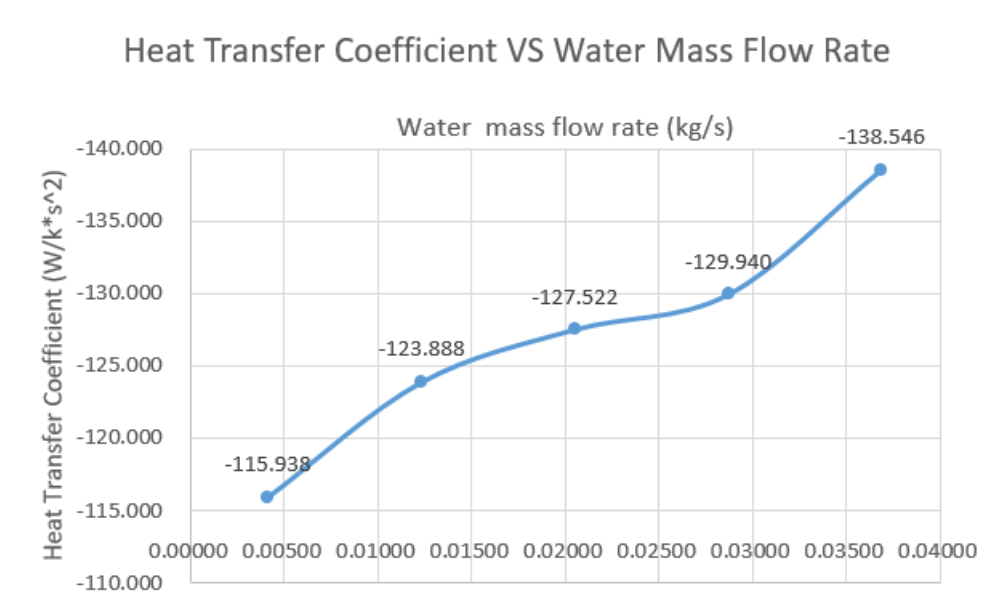


Figure 9.

As for the heat transfer coefficient, as we can see from the figure, it decreases with the water flow mass rate increases. It means the heat transfer will be much more efficient with a bigger water mass flow rate when it comes to a comparison with a small water mass flow rate.

With all these three charts, the power emitted by the water, the power absorbed into the air, mean temperature efficiency and the heat transfer coefficient all increases whatever quickly or slowly with the water mass flow rate increases. That means the performance of the heat exchanger is better with a higher water mass flow rate.

Experiment 2.

For the data processing of Experiment 2, under the premise that all the key requirements are met, the required parameters are calculated, and the following three graphs are drawn:

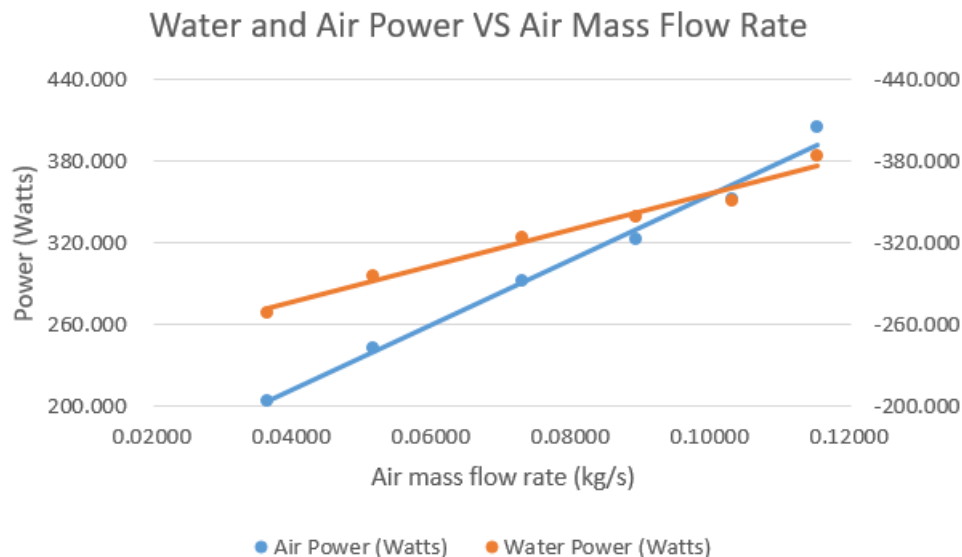


Figure 10.

From this chart, the power of both water and air have a nearly linear increase with the air mass flow rate added. The power emitted by the water is bigger than the power absorbed into the air when the air mass flow on a low condition. But as the air mass flow increases, the power absorbed into the air increases much quicker than the power emitted by the water and finally over it on account of the equipment became hotter and gave much more heat to the air.

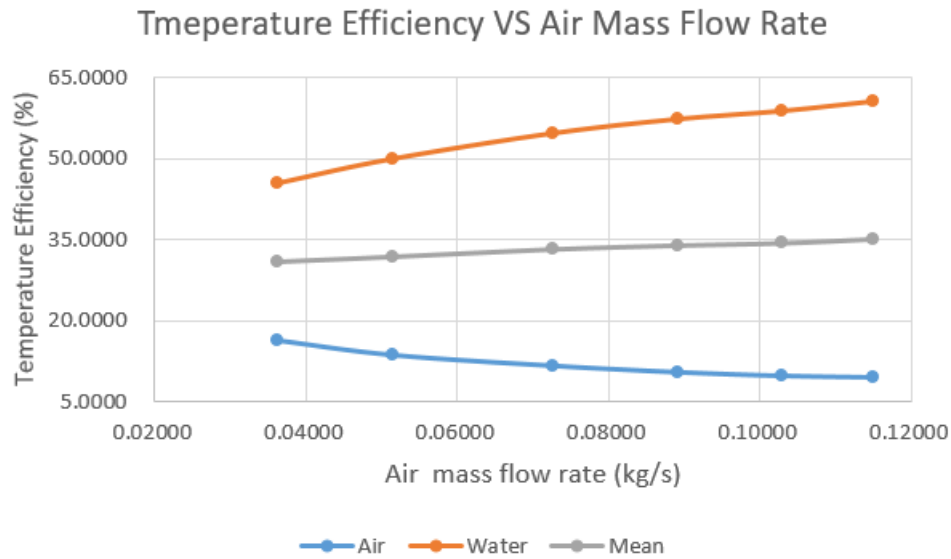


Figure 11.

As we can see from the chart, the temperature efficiency of water increases with air mass flow rate increased and fixed water flow rate and temperature.

But the temperature efficiency for air drops with the flow rate increases but less than the water increases. It will be better with a high air mass flow rate on account of the mean temperature efficiency increases with the air mass flow rate increases.

Heat Transfer Coefficient VS Air Mass Flow Rate

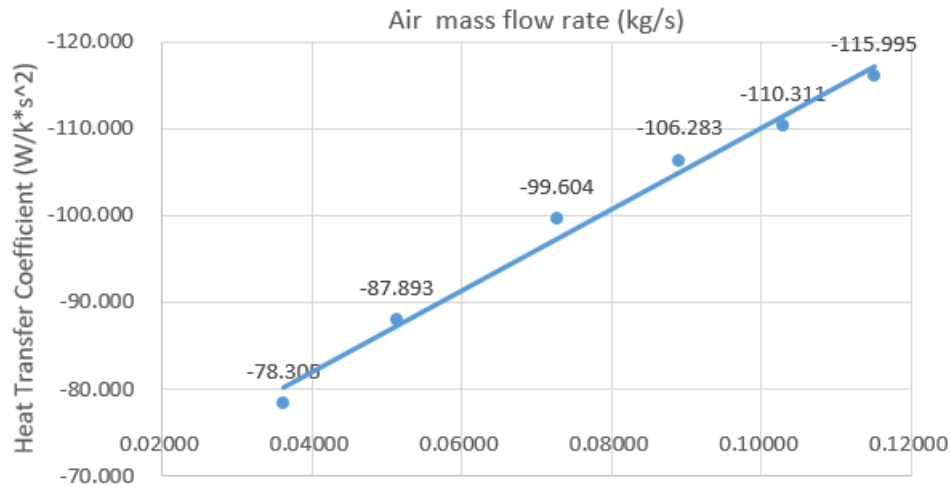


Figure 12.

For the heat transfer coefficient, as we can see from chart, it has a linear increase with the air flow mass rate increases. It means the heat transfer will have a higher efficiency with a bigger air mass flow rate.

From all these three charts above, the performance of the heat exchanger is better with a higher air mass flow rate on account of the power emitted by the water, the power absorbed into the air, mean temperature efficiency and the heat transfer coefficient all increases whatever quickly or slowly with the air mass flow rate increases.

Experiment 3.

For the data processing of Experiment 3, it is all the same with the experiment 2 and the following three graphs are drawn:

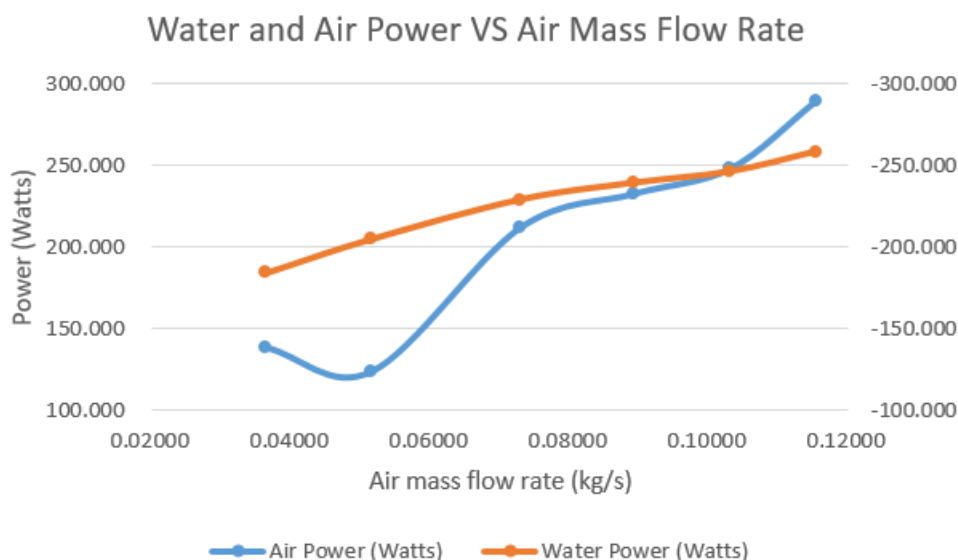


Figure 13.

As we can see from this chart, the power emitted by the water is bigger than the power absorbed into the air and both of them increases with the air mass flow rate increases on the common condition. But it seems has some problems with the power absorbed into the air on the air mass flow rate of 0.04kg/s which is much lower than expected. We have to wait at least five minutes for the readings become stable before making the record. For the last point of air mass flow rate of 0.12kg/s, the power absorbed into the air is bigger than the power admitted by the water which is not reasonable.

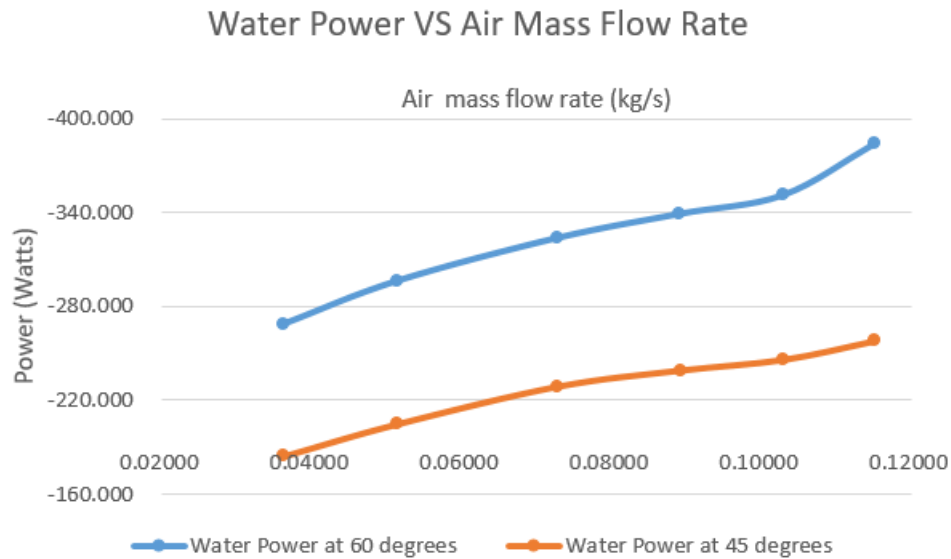


Figure 14.

When it comes to the comparison with the experiment 2, both the power of water and air are much smaller on the same setups except with the temperature of 45°C and they all increases with the air mass flow rate increases which indicates that higher water temperature is a better choice for the heat exchanger experiment.

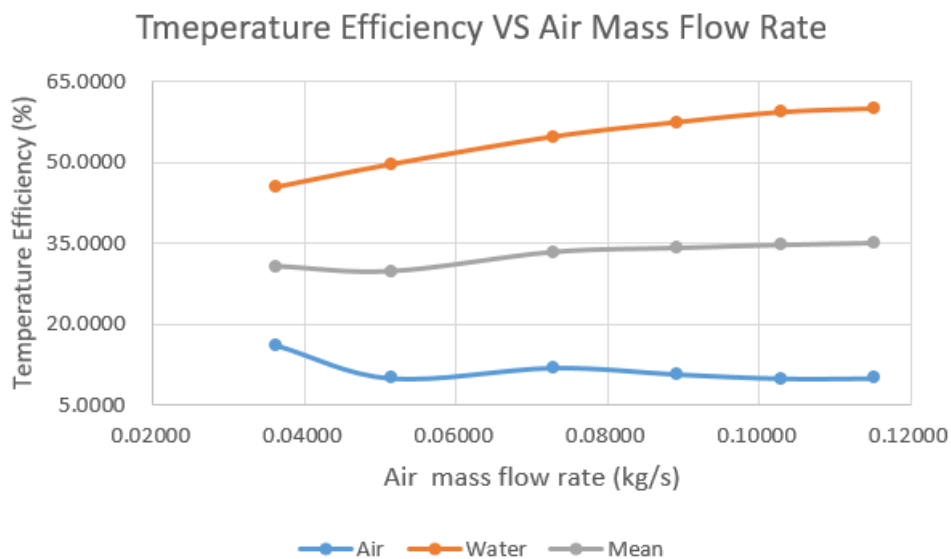


Figure 15.

The same with the experiment 2, the temperature efficiency of water and the mean temperature efficiency increase with air mass flow rate increased.

But the temperature efficiency for air drops with the flow rate increases but less than the water increases.

But there have no huge difference between two mean temperature efficiency of 60°C and 45°C which means the temperature of water inlet has no effect on the mean temperature efficiency.

(2014, 2019) (Maintenance, 2019) (Thermofluid Mechnics, 2019)

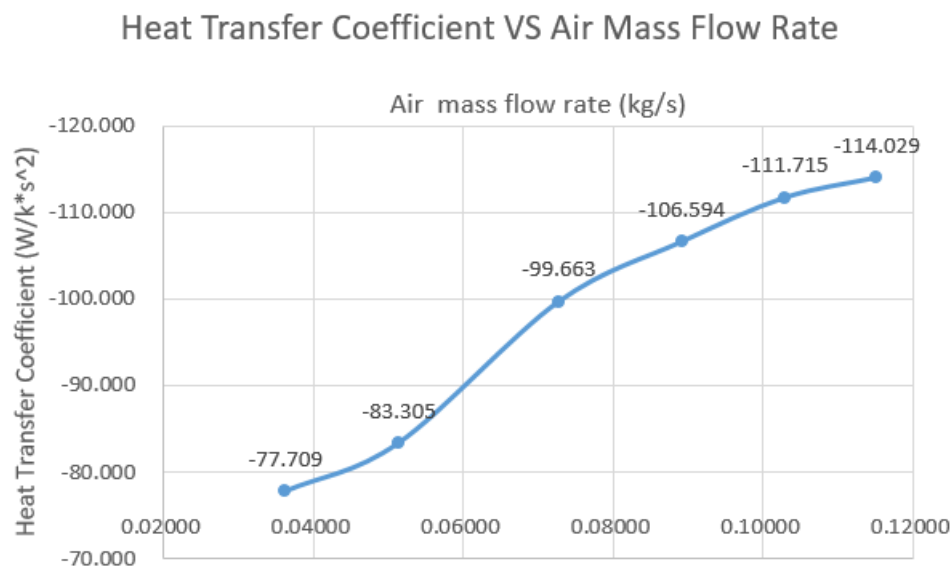


Figure 16.

As we can see from chart, the heat transfer coefficient has a nearly linear increase which is similar to the curve obtained in the experiment 2 with the air flow mass rate increases.

Over analysis these four charts, only the power emitted by the water and the power absorbed into the air decrease on the condition of a lower

water inlet temperature. There is no difference of the mean temperature efficiency and the heat transfer coefficient between 45°C and 60°C.

Conclusion.

In the above three experiments, the heat emitted by the water circuit and the heat absorbed by the air circuit will increase with the mass flow rate of the water or the mass flow rate of the air. In most cases, the heat absorbed by the air circuit will be slightly larger than the heat released by the water circuit. After that, the higher the temperature of the inlet, the higher the two powers will be.

For the temperature transfer efficiency, when only the water flow mass flow rate is changed: as the flow rate increases, the water temperature transfer efficiency decreases sharply, and the air transfer efficiency increases, but the integrated temperature transfer efficiency still shows a downward trend; In the case of only the air quality is changed: as the air mass flow rate increases, the water and integrated temperature transfer efficiency increase slowly, while the air temperature transfer efficiency decreases. In addition, changing the inlet water temperature of the inlet has a negligible effect on the temperature transfer efficiency.

For heat transfer efficiency, whether changing the water flow mass flow rate or the air mass flow rate, it will increase almost linearly with the increase of the change amount. Only changing the inlet water inlet temperature has little effect on the overall heat transfer efficiency.

For the whole experiment, the experimental results are basically in line with expectations, verifying the correctness and applicability of each experimental principle. A deeper understanding of the experimental process and experimental research methods can be obtained while applying the knowledge acquired in the course.

Areas of concern.

During the experiment, some of the collected experimental data have obvious errors. Considering the reason for their occurrence may be that the waiting time is not long enough for the reading to be stable or the experimental results have accidental errors. If there is a next chance to experiment, change the experimental control variables of the third experiment to explore the effect of air inlet temperature on each of the resulting parameters, because the specific heat capacity of the air is small all fluid and the temperature is more likely to change.

In the processing of the experimental results, for the calculation of the air mass density, the calculation formula in the guidebook misses the molar mass of the air, so it is necessary to multiply by 29 in the actual calculation process.

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