

# HEAT EXCHANGER LABORATORY ANALYSIS

**THERMOFLUIDS MECHANICS**

MEng Motorcycle Engineering

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**SUPERVISION**

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# 1 Introduction

This assignment was developed for the 2<sup>nd</sup> semester assessment of the module of Thermofluid Mechanics. It was intended to consolidate the knowledge about heat transfer and fluid flow throughout an experimental heat exchanger lab experiment and performing a report and analysis.

For a better understanding of the experiment, the fundamentals of a heat exchanger needed to be comprehended as well as some thermodynamic theory.

A heat exchanger is an element that enables the transfer of heat from one fluid to another fluid – the fluid may be liquid or gas. In the study case, being a non-regenerative heat exchanger, the heat is transfer between fluids trough a dividing wall which can also be referred as interface between the fluid streams.

A heat exchanger can be used in distinct scenarios, being necessary different temperatures and thermal contact between the fluids to heat transfer occur. Important to note as well, that heat flows from hotter to cooler fluid and that is no mass transfer between them.

To gain further knowledge upon the subject, three different experiments were conducted with the aim of analysing the performance of the heat exchanger when changing different parameters (water flows rates, air flow rates and hot water supply temperatures).

## 2 Description

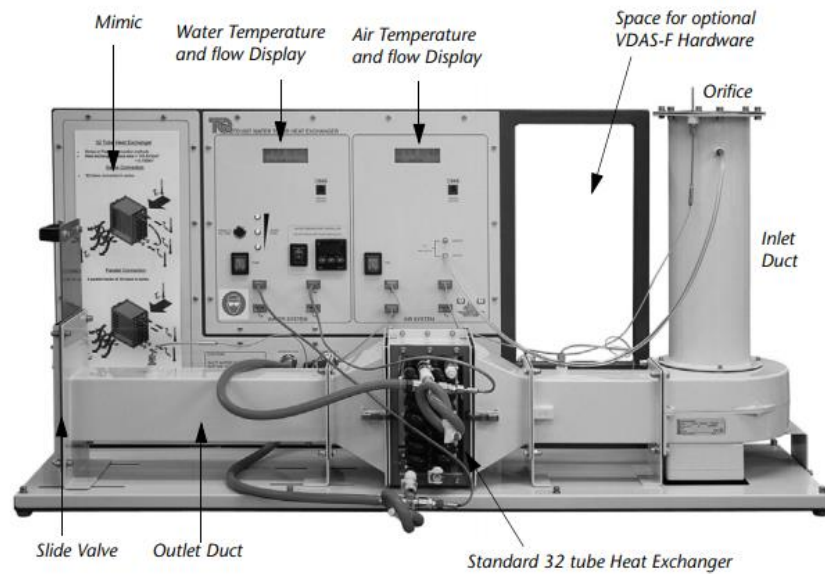


Figure 1 – Water to Air Heat Exchanger TD1007

The experiments conducted were performed in the Water to Air Heat Exchanger TD1007, connected as for cross flow and setting the water temperature to 60 °C. In the *Heat Exchanger*, the water circulates from the bottom (Tw1) to the top (Tw2). Right after the *Inlet Duct*, a fan accelerates the air forcing it to go through the horizontal rectangular duct, passing through the Heat Exchanger and leaving through the Slide Valve.

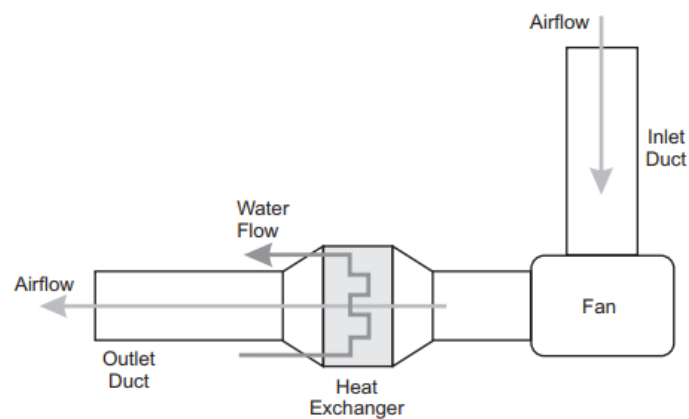


Figure 2 – Flow circuit

The Slide Valve due to its adjustable character allows the user to tune/adjust the airflow rate going through the duct in order to perform the changes needed to conduct the experiments

that will be further discuss. The *Orifice* at the top of the inlet duct was inspected and it had a diameter of 0.10011m.

During the experiments, it was assumed that the ambient pressure was constant and equal to 102900 Pa.

In order to minimize the errors occurring during the experiment certain procedures were used, as for example, record each reading with an interval of 5min to allow the Heat Exchanger temperatures to stabilize and define tolerances when setting the airflow/orifice pressure drop ( $\pm 5$  Pa) and water flow ( $\pm 0.001$  L/minute) to assure the accuracy of the results.

To be able to analyse and obtain results from all the data collected from the three experiments, described in the following chapters, a certain number of thermodynamic equations were used. All these equations are present in the appendixes section in the order that they were used to perform all the calculations needed.

## 3 Experiment 1

### 3.1 Objectives

In the Experiment 1 it was intended to study how changing the water flow (L/min) could affect the heat exchanger performance, by analysing certain thermodynamic values calculated from the results of the experiment.

To perform this experiment the heater temperature and the orifice pressure drop were set as constant, 60 °C and 250Pa respectively, and the water flow was set by a hand operated water supply valve. The experiment was carried out for a water flow of 2.25 L/minute and repeated in steps of minus 0.5L/min until a water flow of 0.25L/minute.

### 3.2 Measured Values

| CONSTANTS AND LEGEND        |              |                |
|-----------------------------|--------------|----------------|
| Tw1 =                       | Hot water    | °C             |
| Tw2 =                       | Cold water   | °C             |
| Ta1 =                       | Inlet duct   | °C             |
| Ta2 =                       | Outlet duct  | °C             |
| Ta3 =                       | Ambient temp | °C             |
| Heater Temperature          | 60           | °C             |
| Orifice dP                  | 250          |                |
| Ambient Pressure            | 102900       | Pa             |
| Orifice Diameter            | 0.10011      | m              |
| Gas Constant of Air / R     | 287.05       | J/Kg K         |
| Cd                          | 0.6          |                |
| Heat exchanger surface area | 0.1558       | m <sup>2</sup> |
| In Tolerance                |              |                |
| Out of Tolerance            |              |                |

| EXPERIMENT 1 - MEASURED VALUES |                             |               |                            |      |      |     |      |      |      |
|--------------------------------|-----------------------------|---------------|----------------------------|------|------|-----|------|------|------|
| Hot Flow (L/min)               | Hot Flow Experiment (L/min) | dP Experiment | Water temp Experiment (°C) | Tw1  | Tw2  | Tw3 | Ta1  | Ta2  | Ta3  |
| 2.25                           | 2.26                        | 249.0         | 60.0                       | 60.9 | 57.0 | 0.0 | 25.2 | 30.7 | 24.8 |
| 1.75                           | 1.76                        | 249.0         | 60.0                       | 60.9 | 55.9 | 0.0 | 25.2 | 30.5 | 24.9 |
| 1.25                           | 1.26                        | 250.0         | 60.1                       | 60.5 | 53.8 | 0.0 | 25.3 | 30.4 | 25.0 |
| 0.75                           | 0.76                        | 248           | 59.8                       | 59.9 | 50.0 | 0.0 | 25.2 | 29.8 | 24.8 |
| 0.25                           | 0.25                        | 250.0         | 60.1                       | 60.2 | 38.7 | 0.0 | 25.3 | 28.6 | 25.2 |

Figure 3 – Table with measured values from Experiment 1

### 3.3 Results and Analysis

| EXPERIMENT 1 - RESULTS |                  |                      |       |            |     |            |          |          |                         |                         |             |             |        |        |       |        |      |                        |
|------------------------|------------------|----------------------|-------|------------|-----|------------|----------|----------|-------------------------|-------------------------|-------------|-------------|--------|--------|-------|--------|------|------------------------|
| Hot Flow (L/min)       | Mass Flow (Kg/s) | Air flow rate (Kg/s) | dTw   | Average Tw | dTa | Average Ta | $\eta_w$ | $\eta_a$ | Pw (Kg/m <sup>3</sup> ) | Pa (Kg/m <sup>3</sup> ) | Cpw (J/KgK) | Cpa (J/KgK) | Qe (W) | Qa (W) | C eb  | $\eta$ | LMTD | U (W/m <sup>2</sup> K) |
| 2.25                   | 0.03705          | 0.1156               | -3.9  | 59.0       | 5.5 | 28.0       | 10.9     | 15.4     | 983.7                   | 1.2                     | 4183.7      | 1005        | -604.6 | 639.2  | -1.06 | 13.2   | 30.8 | -126.1                 |
| 1.75                   | 0.02886          | 0.1156               | -5.0  | 58.4       | 5.3 | 27.9       | 14.0     | 14.8     | 984.0                   | 1.2                     | 4183.4      | 1005        | -603.7 | 615.9  | -1.02 | 14.4   | 30.3 | -128.1                 |
| 1.25                   | 0.02068          | 0.1159               | -6.7  | 57.2       | 5.1 | 27.9       | 19.0     | 14.5     | 984.6                   | 1.2                     | 4182.9      | 1005        | -579.5 | 593.9  | -1.02 | 16.8   | 28.9 | -128.7                 |
| 0.75                   | 0.01249          | 0.1154               | -9.9  | 55.0       | 4.6 | 27.5       | 28.5     | 13.3     | 985.7                   | 1.2                     | 4182.1      | 1005        | -516.9 | 533.5  | -1.03 | 20.9   | 26.8 | -123.8                 |
| 0.25                   | 0.00412          | 0.1159               | -21.5 | 49.5       | 3.3 | 27.0       | 61.6     | 9.5      | 988.3                   | 1.2                     | 4180.3      | 1005        | -370.1 | 384.3  | -1.04 | 35.5   | 20.0 | -118.8                 |

Figure 4 – Table with calculated results from Experiment 1

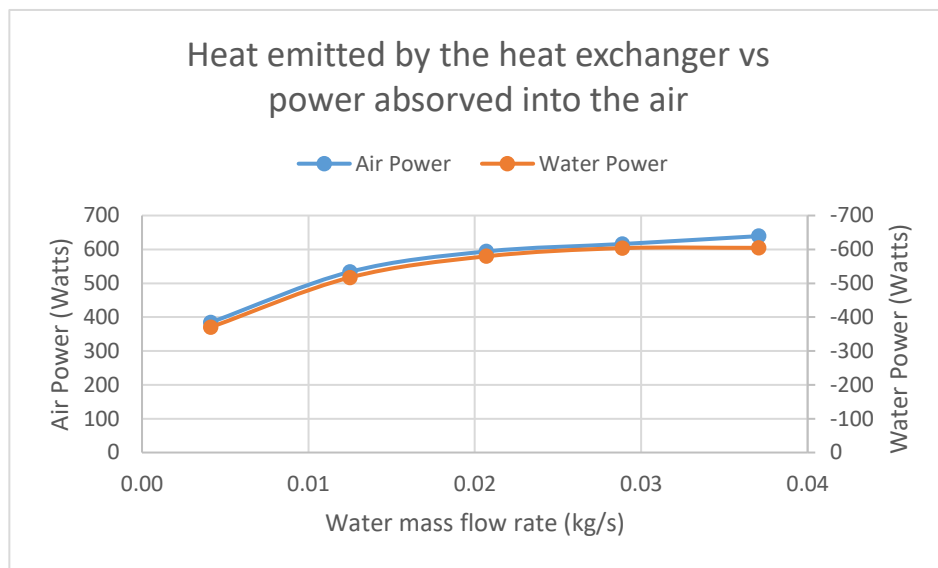


Figure 5 – Chart 1 from Experiment 1

In the figure above, it can be observed that the heat emitted by the heat exchanger and the power absorbed into the air increases with the water mass flow rate. The gradient is reducing, which reveals the non-linear characteristics of the results, until it gets close to zero near 0.037 kg/s. These results indicate that there is a limit/maximum in the heat energy transfer after a certain mass flow value.

The values from heat emitted by the water and absorbed into the air are similar, this relation represents an energy balance coefficient close to 1 (from -1.02 to -1.06). Due to being greater than 1, it allows the conclusion that the heat exchanger is absorbing energy from the surroundings, as it is here represented:

$$Q_e = Q_a \pm \text{Losses or gains from surroundings}$$

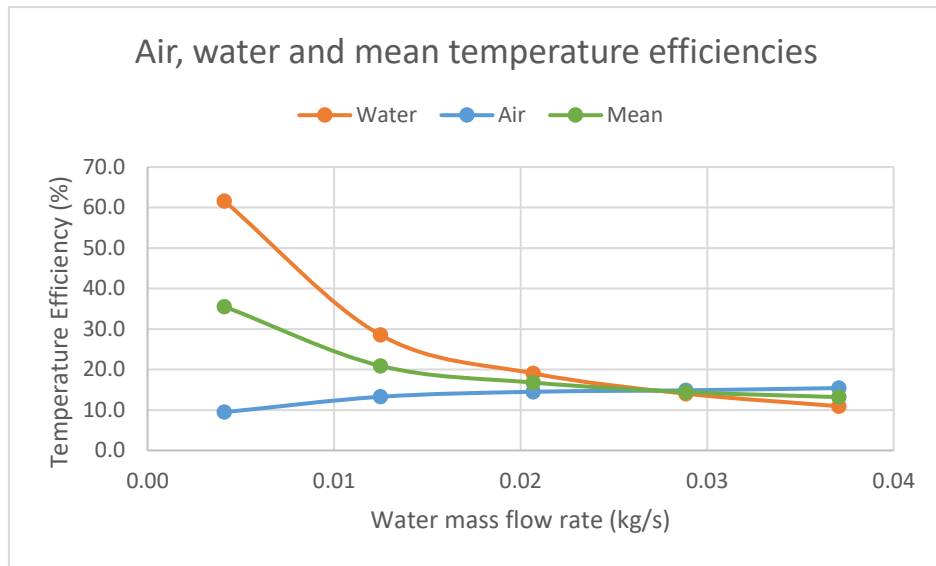


Figure 6 – Chart 2 from Experiment 1

In the figure above it is represented the air, water and mean temperature efficiencies for the heat exchanger. As it can be observed, the water efficiency is decreasing and the air efficiency is increasing while the water mass flow rate gets bigger. The rate of change of the efficiencies is related to the temperatures changes ( $dT_w$  and  $dT_a$ ) calculated and present in figure 4. Reason why the changes in water efficiency are bigger than the ones noticed in the air efficiency.

Comparing the mean temperature efficiency from figure 6 with the heat transfer from figure 5 above, it can be judge that with lower water mass flow rates the efficiency of the system is higher, but the heat transfer is lower and while the flows increase the inverse happens. These gradient changes in the values occur until a certain water mass flow rate value is achieved, where the heat transfer starts to be constant and consequently happening the same to the mean temperature efficiency.

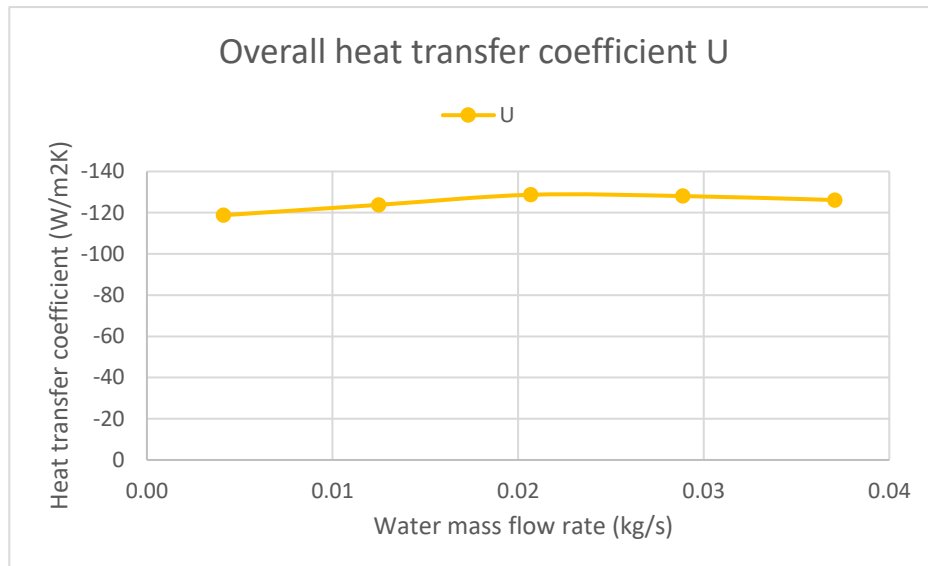


Figure 7 – Chart 3 from Experiment 1

The overall heat transfer coefficient  $U$  is a measure of how well the heat exchanger works. Following this reasoning and analysing the figure above, it can be said that the heat exchanger from the experiment performs the best within a certain water mass flow rate range of values. In the figure it can be observed that the heat transfer coefficient increases until a certain optimal water flow and after that point there is now improvement in performance.

## 4 Experiment 2

### 4.1 Objectives

In the Experiment 2 it was intended to study how changing the air flow rates (Kg/s) could affect the heat exchanger performance, for a fixed value of water mass flow rate and temperature.

To perform this experiment the heater temperature and water mass flow rate were set as constant, 60 °C and 0.25 L/min respectively, and the air mass flow rate (kg/s) was set by adjusting the *Slide Valve*. The experiment will be carried out for air flow rates of 250, 200, 150, 100, 50 and 25 Pa pressure drop.

### 4.2 Measured Values

| CONSTANTS AND LEGEND        |              |        |
|-----------------------------|--------------|--------|
| Tw1 =                       | Hot water    | °C     |
| Tw2 =                       | Cold water   | °C     |
| Ta1 =                       | Inlet duct   | °C     |
| Ta2 =                       | Outlet duct  | °C     |
| Ta3 =                       | Ambient temp | °C     |
| Heater Temperature          | 60           | °C     |
| Water flow                  | 0.25         | L/min  |
| Ambient Pressure            | 102900       | Pa     |
| Orifice Diameter            | 0.10011      | m      |
| Gas Constant of Air / R     | 287.05       | J/Kg K |
| Cd                          | 0.6          |        |
| Heat exchanger surface area | 0.1558       | m2     |
| In Tolerance                |              |        |
| Out of Tolerance            |              |        |

| EXPERIMENT 2 - MEASURED VALUES |                     |               |                       |      |      |     |      |      |      |
|--------------------------------|---------------------|---------------|-----------------------|------|------|-----|------|------|------|
| Air pressure dP (Pa)           | Hot Flow Experiment | dP Experiment | Water temp Experiment | Tw1  | Tw2  | Tw3 | Ta1  | Ta2  | Ta3  |
| 250                            | 0.25                | 250.0         | 60.1                  | 60.2 | 38.7 | 0.0 | 25.3 | 28.6 | 25.2 |
| 200                            | 0.24                | 200.0         | 59.9                  | 58.7 | 38.4 | 0.0 | 25.4 | 28.7 | 24.9 |
| 150                            | 0.24                | 149.0         | 60.1                  | 58.5 | 39.0 | 0.0 | 25.6 | 28.9 | 25.1 |
| 100                            | 0.24                | 99            | 60.1                  | 58.8 | 40.0 | 0.0 | 25.7 | 29.4 | 24.9 |
| 50                             | 0.24                | 50.0          | 60.0                  | 59.1 | 42.0 | 0.0 | 25.9 | 30.4 | 24.7 |
| 25                             | 0.24                | 25.0          | 60.1                  | 59.6 | 44.0 | 0.0 | 26.4 | 31.6 | 25.0 |

Figure 8 - Table with measured values from Experiment 2

### 4.3 Results and Analysis

| EXPERIMENT 2 - RESULTS |                  |                      |       |            |     |            |      |          |          |            |            |             |             |        |        |       |        |
|------------------------|------------------|----------------------|-------|------------|-----|------------|------|----------|----------|------------|------------|-------------|-------------|--------|--------|-------|--------|
| Air pressure dP (Pa)   | Mass Flow (Kg/s) | Air flow rate (Kg/s) | dTw   | Average Tw | dTa | Average Ta | Ta3  | $\eta_w$ | $\eta_a$ | Pw (Kg/m3) | Pa (Kg/m3) | Cpw (J/KgK) | Cpa (J/KgK) | Qe (W) | Qa (W) | C eb  | $\eta$ |
| 250                    | 0.00412          | 0.1158               | -21.5 | 49.5       | 3.3 | 27.0       | 25.2 | 61.6     | 9.5      | 988.3      | 1.2        | 4180.3      | 1005        | -370.1 | 384.0  | -1.04 | 35.5   |
| 200                    | 0.00395          | 0.1036               | -20.3 | 48.6       | 3.3 | 27.1       | 24.9 | 61.0     | 9.9      | 988.7      | 1.2        | 4180.0      | 1005        | -335.6 | 343.5  | -1.02 | 35.4   |
| 150                    | 0.00395          | 0.0894               | -19.5 | 48.8       | 3.3 | 27.3       | 25.1 | 59.3     | 10.0     | 988.6      | 1.2        | 4180.1      | 1005        | -322.3 | 296.5  | -0.92 | 34.7   |
| 100                    | 0.00395          | 0.0729               | -18.8 | 49.4       | 3.7 | 27.6       | 24.9 | 56.8     | 11.2     | 988.3      | 1.2        | 4180.2      | 1005        | -310.7 | 270.9  | -0.87 | 34.0   |
| 50                     | 0.00395          | 0.0518               | -17.1 | 50.6       | 4.5 | 28.2       | 24.7 | 51.5     | 13.6     | 987.8      | 1.2        | 4180.6      | 1005        | -282.5 | 234.2  | -0.83 | 32.5   |
| 25                     | 0.00395          | 0.0366               | -15.6 | 51.8       | 5.2 | 29.0       | 25.0 | 47.0     | 15.7     | 987.2      | 1.2        | 4181.0      | 1006        | -257.6 | 191.5  | -0.74 | 31.3   |

Figure 9 - Table with calculated results from Experiment 2

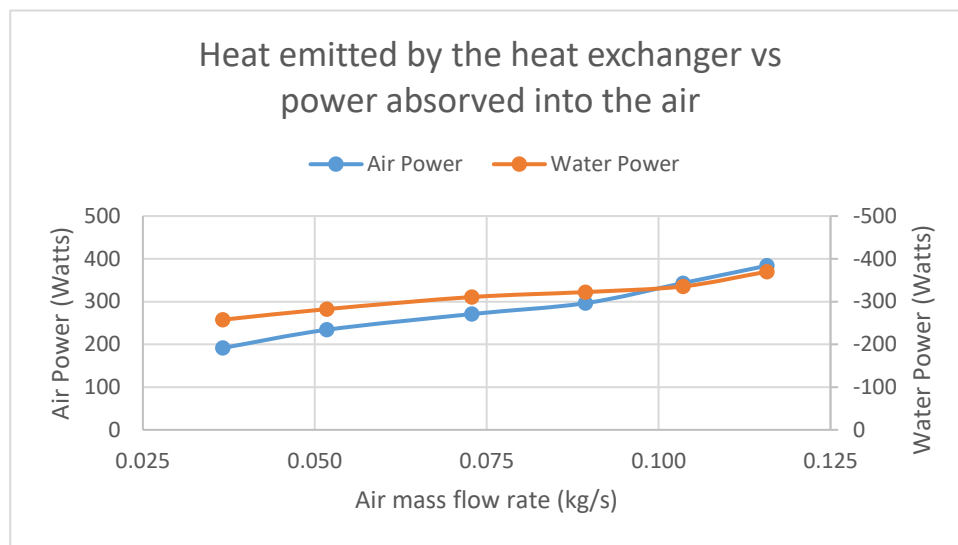


Figure 10 – Chart 1 from Experiment 2

In the figure above, it can be observed that the heat emitted by the heat exchanger and the power absorbed into the air increases, with a linear behaviour, with the air mass flow rate. The heat emitted by the water is bigger than the heat absorbed by the air for lower air mass flow rate values, which indicates that there might have been losses from the heat exchanger that transfer some heat energy away through, for example, the outlet duct walls.

Analysing the energy balance coefficient values from figure 9, it can be observed that the performance of the heat exchanger is increasing with the air mass flow rate (from -0.74 to -1.04). This growth suggests that after a certain air flow the losses from the surroundings became less significant.

$$Q_e = Q_a \pm \text{Losses or gains from surroundings}$$

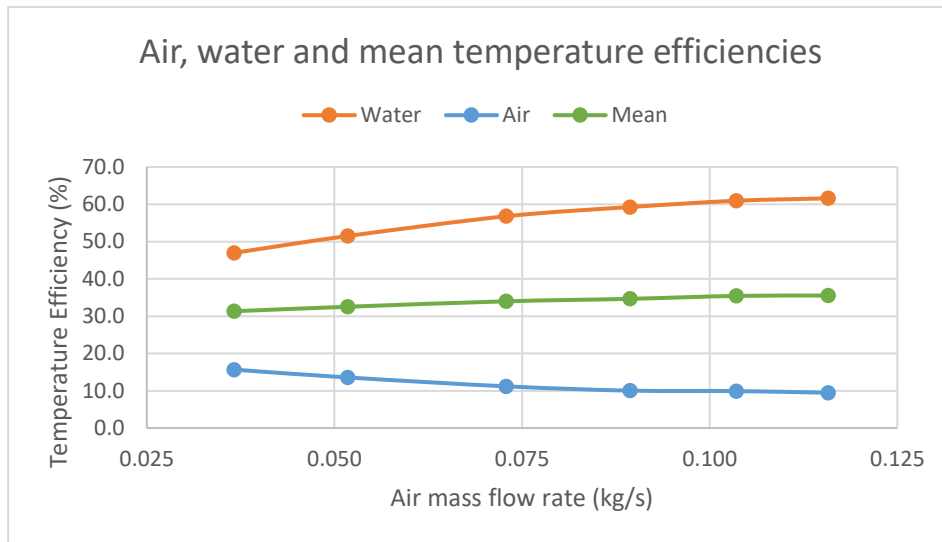


Figure 11 – Chart 2 from Experiment 2

In the figure above it is represented the air, water and mean temperature efficiencies for the heat exchanger. As it can be observed, the water efficiency is increasing and the air efficiency is decreasing while the air mass flow rate gets bigger. The rate of change of the efficiencies is quite similar and is related to the temperatures changes ( $dT_w$  and  $dT_a$ ) calculated and present in figure 9.

Analysing the mean temperature efficiency from figure 11, it can be judge that with the mean temperature efficiency increases moderately with the increase in air mass flow.

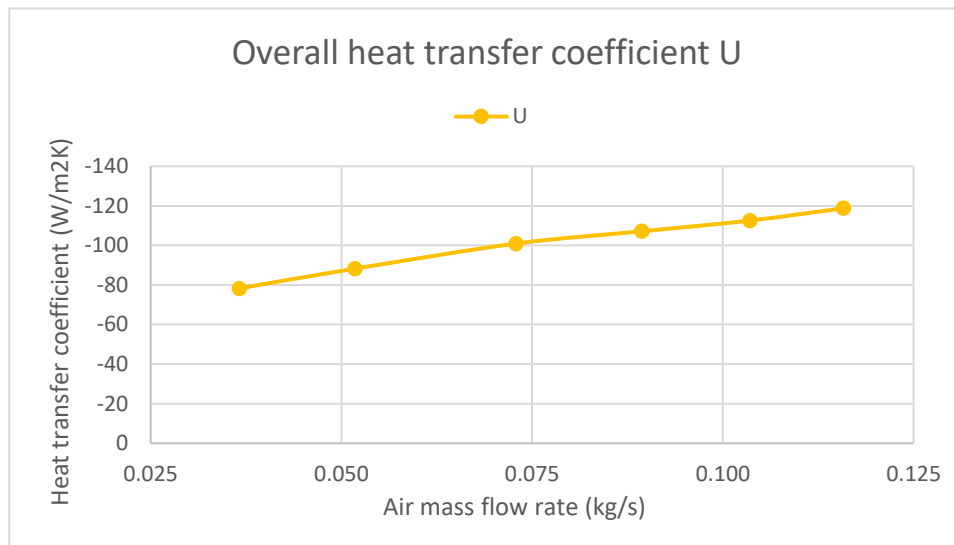


Figure 12 – Chart 3 from Experiment 2

As mentioned before the overall heat transfer coefficient  $U$  is a measure of how well the heat exchanger works. The results show that increasing the air mass flow rate will affect the overall heat transfer coefficient in the same way. This conclusion reinforces, what have been said over experiment 2, that increasing air flow increases the performance of the heat exchanger and allows for more heat to be transfer.

## 5 Experiment 3

### 5.1 Objectives

In the Experiment 3 it was intended to study how changing the hot water supply temperatures would affect the heat exchanger performance, for a fixed value of water mass flow rate.

The procedure of this experiment was similar to the previous one, with the exception of setting the heater tank temperature to 45 °C instead of 60 °C. The water mass flow rate was at 0.25 L/min and the air mass flow rate (kg/s) was set by adjusting the *Slide Valve*. The experiment was carried out for air flow rates of 250, 200, 150, 100, 50 and 25 Pa pressure drop.

### 5.2 Measured Values

| CONSTANTS AND LEGEND        |              |                |
|-----------------------------|--------------|----------------|
| Tw1 =                       | Hot water    | °C             |
| Tw2 =                       | Cold water   | °C             |
| Ta1 =                       | Inlet duct   | °C             |
| Ta2 =                       | Outlet duct  | °C             |
| Ta3 =                       | Ambient temp | °C             |
| Heater Temperature          | 45           | °C             |
| Water flow                  | 0.25         | L/min          |
| Ambient Pressure            | 102900       | Pa             |
| Orifice Diameter            | 0.10011      | m              |
| Gas Constant of Air / R     | 287.05       | J/Kg K         |
| Cd                          | 0.6          |                |
| Heat exchanger surface area | 0.1558       | m <sup>2</sup> |
| In Tolerance                |              |                |
| Out of Tolerance            |              |                |

| EXPERIMENT 3 - MEASURED VALUES |                     |               |                       |      |      |     |      |      |      |
|--------------------------------|---------------------|---------------|-----------------------|------|------|-----|------|------|------|
| Air pressure dP (Pa)           | Hot Flow Experiment | dP Experiment | Water temp Experiment | Tw1  | Tw2  | Tw3 | Ta1  | Ta2  | Ta3  |
| 250                            | 0.24                | 250           | 45.0                  | 48.8 | 34.0 | 0.0 | 25.3 | 27.5 | 24.7 |
| 200                            | 0.24                | 200           | 45.8                  | 48.5 | 34.4 | 0.0 | 25.4 | 27.7 | 25.3 |
| 150                            | 0.24                | 149           | 45.0                  | 48.5 | 34.9 | 0.0 | 25.5 | 27.9 | 24.8 |
| 100                            | 0.24                | 103           | 44.9                  | 48.7 | 35.6 | 0.0 | 25.6 | 28.2 | 24.7 |
| 50                             | 0.24                | 50            | 45.7                  | 48.9 | 37.0 | 0.0 | 25.8 | 29.0 | 24.7 |
| 25                             | 0.24                | 26            | 45.6                  | 49.1 | 38.3 | 0.0 | 26.2 | 29.7 | 24.7 |

Figure 13 – Table with measured values from Experiment 3

### 5.3 Results and Analysis

| EXPERIMENT 3 - RESULTS  |                     |                         |       |            |            |      |      |               |               |                |                |           |           |       |      |      |              |
|-------------------------|---------------------|-------------------------|-------|------------|------------|------|------|---------------|---------------|----------------|----------------|-----------|-----------|-------|------|------|--------------|
| Air pressure dP<br>(Pa) | Mass Flow<br>(Kg/s) | Air flow rate<br>(Kg/s) | dTw   | Average Tw | Average Ta | ηw   | ηa   | Pw<br>(Kg/m3) | Pa<br>(Kg/m3) | Cpw<br>(J/KgK) | Cpa<br>(J/KgK) | Qe<br>(W) | Qa<br>(W) | C eb  | η    | LMTD | U<br>(W/m2K) |
| 250                     | 0.00397             | 0.1159                  | -14.8 | 41.4       | 26.4       | 63.0 | 9.4  | 991.7         | 1.2           | 4178.5         | 1005           | -245.3    | 256.2     | -1.04 | 36.2 | 13.2 | -119.0       |
| 200                     | 0.00397             | 0.1036                  | -14.1 | 41.5       | 26.6       | 61.0 | 10.0 | 991.6         | 1.2           | 4178.5         | 1005           | -233.7    | 239.6     | -1.03 | 35.5 | 13.3 | -113.2       |
| 150                     | 0.00397             | 0.0895                  | -13.6 | 41.7       | 26.7       | 59.1 | 10.4 | 991.5         | 1.2           | 4178.5         | 1005           | -225.4    | 215.8     | -0.96 | 34.8 | 13.5 | -107.6       |
| 100                     | 0.00397             | 0.0744                  | -13.1 | 42.2       | 26.9       | 56.7 | 11.3 | 991.4         | 1.2           | 4178.6         | 1005           | -217.1    | 194.4     | -0.90 | 34.0 | 13.8 | -101.0       |
| 50                      | 0.00396             | 0.0518                  | -11.9 | 43.0       | 27.4       | 51.5 | 13.9 | 991.0         | 1.2           | 4178.7         | 1005           | -197.1    | 166.7     | -0.85 | 32.7 | 14.2 | -88.9        |
| 25                      | 0.00396             | 0.0374                  | -10.8 | 43.7       | 28.0       | 47.2 | 15.3 | 990.7         | 1.2           | 4178.9         | 1006           | -178.9    | 131.6     | -0.74 | 31.2 | 14.6 | -78.6        |

Figure 14 – Table with calculated results from Experiment 3

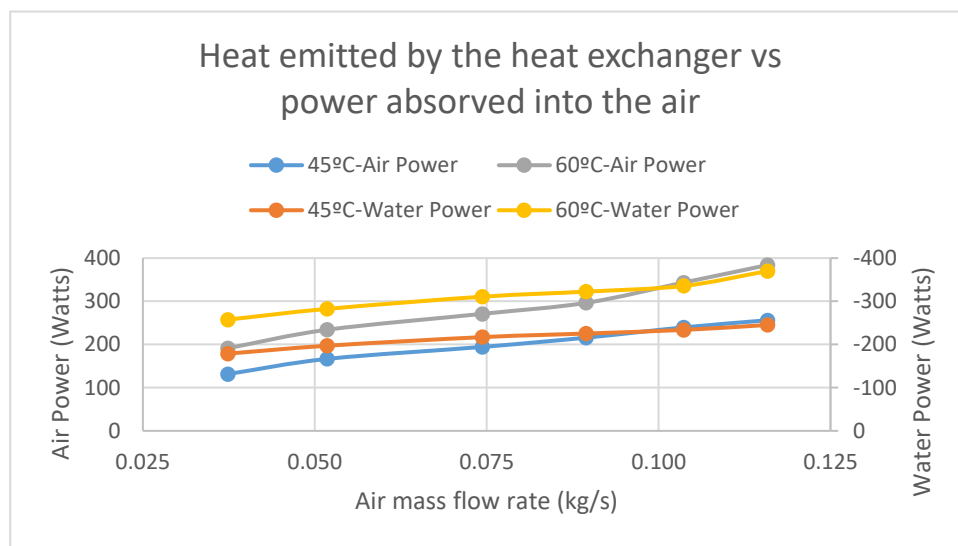


Figure 15 – Chart 1 from Experiment 3

In the figure above, it can be observed that the heat emitted by the heat exchanger and the power absorbed into the air at 45 °C follows that same behaviour as at 60 °C. This means that the heat transfer increases with the air mass flow rate.

The overall heat transfer at 45 °C is inferior than at 60 °C due to the inferior difference of temperature between the air and water. As it was explained in the Experiment 2, for lower air mass flow rate values there might have been losses from the heat exchanger that transfer some heat energy away through, for example, the outlet duct walls.

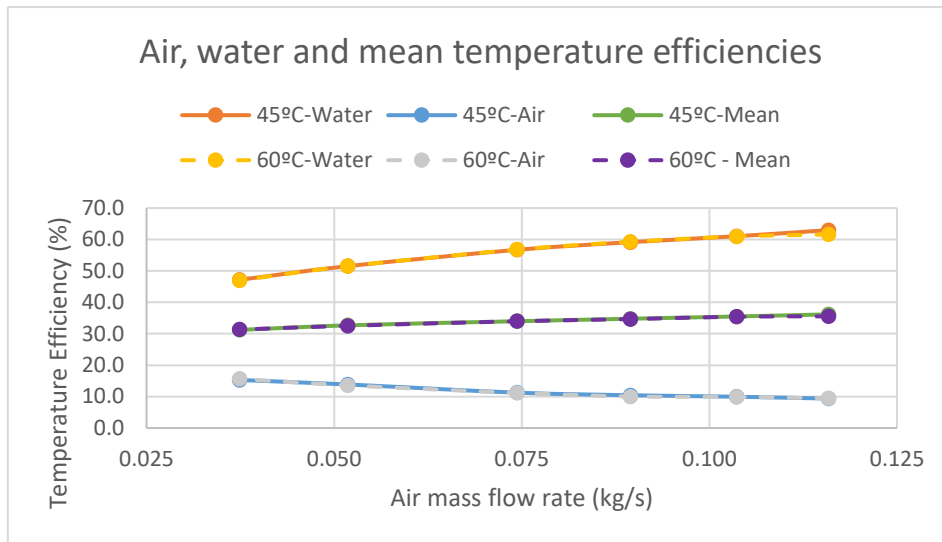


Figure 17 - Chart 2 from Experiment 3

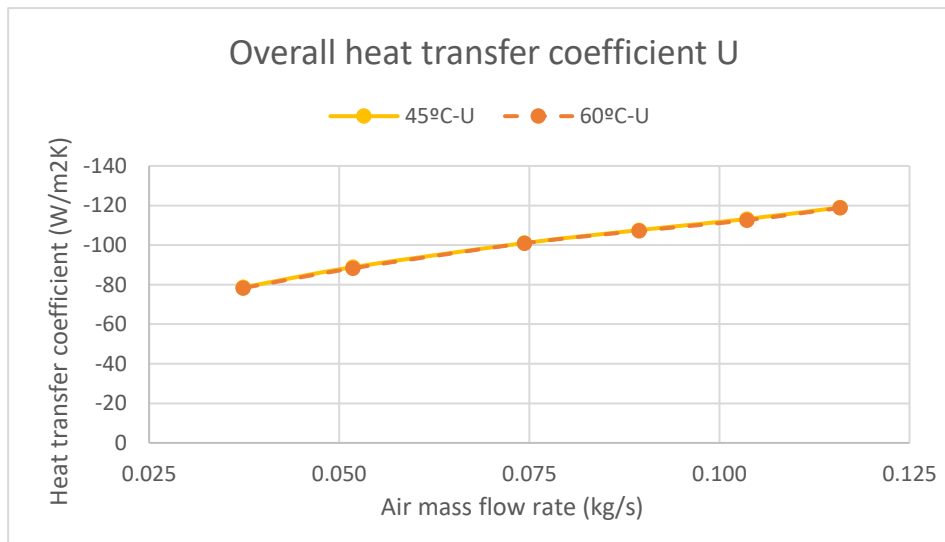


Figure 16 – Chart 3 from Experiment 3

The two figures above (Figure 16 and 17) show similar results at 45 °C and 60 °C for the air, water and mean temperature efficiencies and overall heat transfer coefficient of the heat exchanger.

It can be concluded that by lowering the heater temperature (driving force) the efficiency and performance of the heat exchanger present the same results. The overall heat transfer coefficient (performance of the heat exchanger) remains the same but the available power is reduced by the lower heater temperature. The available power could be analysed by comparing the LMTD column of figure 9 for 60 °C and figure 14 for 45 °C, that represents a measure of the heat driving force that creates the heat transfer.

## 6 Conclusion and further improvements

The theoretical information of heat exchanger learned in class allied with the data collected and the analysis conducted over the three experiments that were performed, allowed the author to reach the further conclusions about the heat exchanger performance:

- The thermal efficiency of the heat exchanger increases with lower the mass flow;
- After a certain value of mass flow the heat transfer reaches a maximum;
- Increasing the air flow also increases the heat transfer and efficiency of the system;
- With lower hot water supply temperatures (driving force) less heat is transfer;
- With lower hot water supply temperatures (driving force) the efficiency and performance remain with similar results but less power to create heat transfer.

Some errors that could have affected the results of the experiments were coming from the assumption made of having constant air pressure in the laboratory during the period that experiments were being performed.

To improve the performance of the heat exchanger some changes could be done to the inlet and outlet duct, changing the material of the walls for a material with less thermal conductivity in order to minimize losses from the surroundings.

## 7 Bibliography

- Heat Exchanger Lab documents & Assignment – Rob Goodson
  - TD1007 equipment guidelines
  - Heat Exchanger summary document
  - Fundamentals of Heat Exchangers
- Thermofluid Mechanics 2<sup>nd</sup> Term lectures;

## 8 Appendixes

In this chapter it will be presented the following content:

- Data collection – Some pictures to represent how the data was collected during the three experiments;
- Theory and Equations – Equations used for all calculations required to obtain the results;
- Excel sheets – Excel sheets used to perform the calculations and plot the graphics present in this report;

### 8.1 Data collection



Figure 18 – Experiment 1 data collection

## 8.2 Theory and Equations

In order to analyse and obtain results from all the data collected from the three experiments a certain number of thermodynamic equations were used. The equations will be presented in this section in the order that they were calculated.

Data collected:

| CONSTANTS AND LEGEND        |              |                |
|-----------------------------|--------------|----------------|
| Tw1 =                       | Hot water    | °C             |
| Tw2 =                       | Cold water   | °C             |
| Ta1 =                       | Inlet duct   | °C             |
| Ta2 =                       | Outlet duct  | °C             |
| Ta3 =                       | Ambient temp | °C             |
| Heater Temperature          | 45           | °C             |
| Water flow                  | 0.25         | L/min          |
| Ambient Pressure            | 102900       | Pa             |
| Orifice Diameter            | 0.10011      | m              |
| Gas Constant of Air / R     | 287.05       | J/Kg K         |
| Cd                          | 0.6          |                |
| Heat exchanger surface area | 0.1558       | m <sup>2</sup> |

Equations:

- Air flow and Water flow conversion

$$\dot{M}_W = \frac{\text{Hot Flow}}{6000 \times \rho_W}$$

$$\dot{M}_A = C_d \times A_{\text{orifice}} \sqrt{\Delta p \times 2 \times \rho_A}$$

- Average Temperatures in Heat Exchangers

$$\text{Average } T_W = \frac{T_{W1} + T_{W2}}{2}$$

$$\text{Average } T_A = \frac{T_{A1} + T_{A2}}{2}$$

- Specific Heat Capacity

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

$$C_{pA} = 1005$$

- Density

$$\rho_A = \frac{(p \times 10^5) - \Delta p}{287.058 \times (T_{A3} + 273)}$$

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

- Heat Energy Transfer, Energy Balance and Efficiencies

$$\dot{Q}_W = \dot{M}_W \times C_{pW} \times \Delta T_W$$

$$\dot{Q}_A = \dot{M}_A \times C_{pA} \times \Delta T_A$$

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

$$\eta_W = \frac{T_{w1} - T_{w2}}{T_{w1} - T_{A1}} \times 100$$

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

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

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

$$U = \frac{\dot{Q}_W}{A_{heat transfer} \times LMTD}$$

### 8.3 Excel sheets

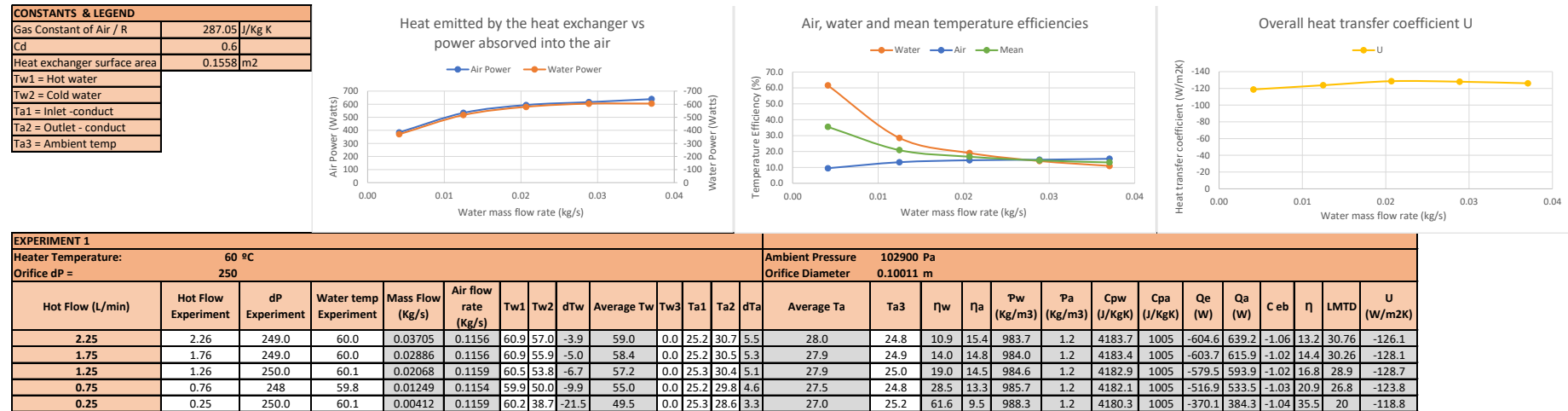


Figure 19 – Excel sheet from Experiment 1

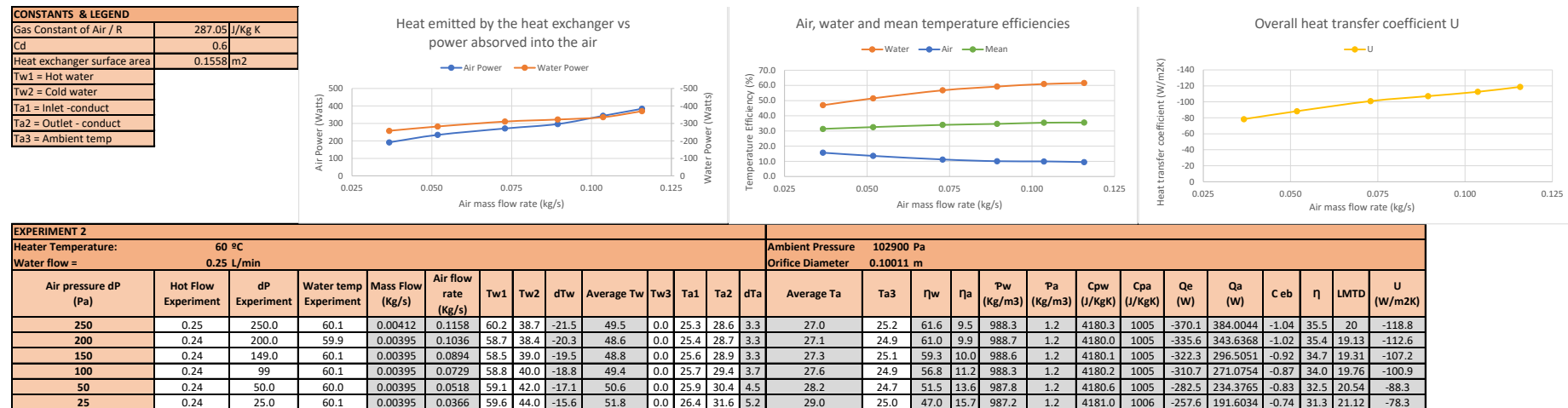
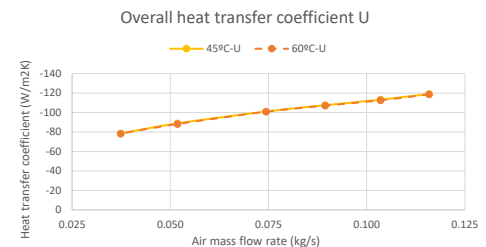
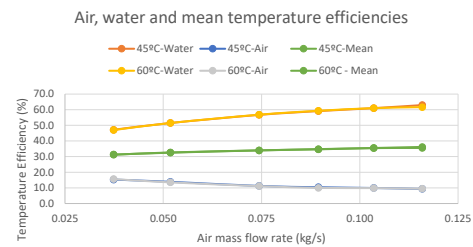
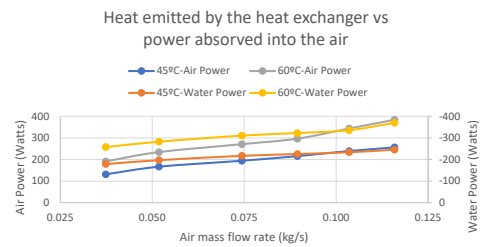


Figure 20 – Excel sheet from Experiment 2

| CONSTANTS & LEGEND          |                       |
|-----------------------------|-----------------------|
| Gas Constant of Air / R     | 287.05 J/Kg K         |
| Cd                          | 0.6                   |
| Heat exchanger surface area | 0.1558 m <sup>2</sup> |
| Tw1 = Hot water             |                       |
| Tw2 = Cold water            |                       |
| Ta1 = Inlet - conduct       |                       |
| Ta2 = Outlet - conduct      |                       |
| Ta3 = Ambient temp          |                       |



| EXPERIMENT 3              |                     |               |                       |                  |                      |      |      |       |            |     |      |      |     | Ambient Pressure 102900 Pa |      |      |      |            |            |             |             |        |        |       |      |       |           |
|---------------------------|---------------------|---------------|-----------------------|------------------|----------------------|------|------|-------|------------|-----|------|------|-----|----------------------------|------|------|------|------------|------------|-------------|-------------|--------|--------|-------|------|-------|-----------|
| Heater Temperature: 45 °C |                     |               |                       |                  |                      |      |      |       |            |     |      |      |     | Orifice Diameter 0.10011 m |      |      |      |            |            |             |             |        |        |       |      |       |           |
| Water flow = 0.25         |                     |               |                       |                  |                      |      |      |       |            |     |      |      |     |                            |      |      |      |            |            |             |             |        |        |       |      |       |           |
| Air pressure dP (Pa)      | Hot Flow Experiment | dP Experiment | Water temp Experiment | Mass Flow (Kg/s) | Air flow rate (Kg/s) | Tw1  | Tw2  | dTw   | Average Tw | Tw3 | Ta1  | Ta2  | dTa | Average Ta                 | Ta3  | ηw   | ηa   | ρw (Kg/m3) | ρa (Kg/m3) | Cpw (J/KgK) | Cpa (J/KgK) | Qe (W) | Qa (W) | Ceb   | η    | LMTD  | U (W/m2K) |
| 250                       | 0.24                | 250           | 45.0                  | 0.00397          | 0.1159               | 48.8 | 34.0 | -14.8 | 41.4       | 0.0 | 25.3 | 27.5 | 2.2 | 26.4                       | 24.7 | 63.0 | 9.4  | 991.7      | 1.2        | 4178.5      | 1005        | -245.3 | 256.2  | -1.04 | 36.2 | 13.23 | -119.0    |
| 200                       | 0.24                | 200           | 45.8                  | 0.00397          | 0.1035               | 48.5 | 34.4 | -14.1 | 41.5       | 0.0 | 25.4 | 27.7 | 2.3 | 26.6                       | 25.3 | 61.0 | 10.0 | 991.6      | 1.2        | 4178.5      | 1005        | -233.7 | 239.3  | -1.02 | 35.5 | 13.25 | -113.2    |
| 150                       | 0.24                | 149           | 45.0                  | 0.00397          | 0.0894               | 48.5 | 34.9 | -13.6 | 41.7       | 0.0 | 25.5 | 27.9 | 2.4 | 26.7                       | 24.8 | 59.1 | 10.4 | 991.5      | 1.2        | 4178.5      | 1005        | -225.4 | 215.7  | -0.96 | 34.8 | 13.45 | -107.6    |
| 100                       | 0.24                | 103           | 44.9                  | 0.00397          | 0.0744               | 48.7 | 35.6 | -13.1 | 42.2       | 0.0 | 25.6 | 28.2 | 2.6 | 26.9                       | 24.7 | 56.7 | 11.3 | 991.4      | 1.2        | 4178.6      | 1005        | -217.1 | 194.4  | -0.90 | 34.0 | 13.79 | -101.0    |
| 50                        | 0.24                | 50            | 45.7                  | 0.00396          | 0.0518               | 48.9 | 37.0 | -11.9 | 43.0       | 0.0 | 25.8 | 29.0 | 3.2 | 27.4                       | 24.7 | 51.5 | 13.9 | 991.0      | 1.2        | 4178.7      | 1005        | -197.1 | 166.7  | -0.85 | 32.7 | 14.24 | -88.9     |
| 25                        | 0.24                | 26            | 45.6                  | 0.00396          | 0.0374               | 49.1 | 38.3 | -10.8 | 43.7       | 0.0 | 26.2 | 29.7 | 3.5 | 28.0                       | 24.7 | 47.2 | 15.3 | 990.7      | 1.2        | 4178.9      | 1006        | -178.9 | 131.6  | -0.74 | 31.2 | 14.6  | -78.6     |

Figure 21 – Excel sheet from Experiment 3