



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

UNIVERSITY OF WALES TRINITY SAINT
DAVID

SCHOOL OF ENGINEERING

Heat exchanger laboratory analysis

By

Milena Tomaszewska (1902366)

BEng Energy and Environmental Engineering

Plant and Asset Engineering (ACMA6007)

Contents

Contents.....	2
1. Introduction	1
2. Methodology.....	2
3. Results.....	6
3.1 Experiment 1 - Fluid	6
3.1.1 VDAS Results	6
3.1.2 VDAS Results Tables.....	8
3.2 Experiment 2 - Pressure.....	10
3.2.1 VDAS results.....	10
3.2.2 VDAS Results Tables.....	12
4. Analysis	15
4.1 Change in temperature for each circuit.	15
4.1.1 Experiment 1	15
4.1.2 Experiment 2	16
4.2 Water and air densities at each temperature.	16
4.2.1 Experiment 1	16
4.2.2 Experiment 2	17
4.2 Air mass flow rate.	18
4.2.1 Experiment 1	18
4.2.2 Experiment 2	18
4.3 Water flow to mass flow conversion.	19
4.3.1 Experiment 1	19
4.3.2 Experiment 2	19
4.4 Specific heat capacity at each flow rate.	19
4.4.1 Experiment 1	20
4.4.2 Experiment 2	20

4.5 Heat emitted from the water.	20
4.5.1 Experiment 1.....	21
4.5.2 Experiment 2.....	22
4.6 Heat absorbed by the air.	22
4.6.1 Experiment 1.....	23
4.6.2 Experiment 2.....	23
4.7 Mean temperature efficiencies.	23
4.7.1 Water efficiencies.	23
4.7.1.1 Experiment 1.....	24
4.7.1.2 Experiment 2.....	24
4.7.2 Air efficiencies.....	24
4.7.2.1 Experiment 1.....	24
4.7.2.2 Experiment 2.....	25
4.7.2 Mean Temperature Efficiency	25
4.7.2.1 Experiment 1.....	25
4.7.2.2 Experiment 2.....	25
4.8 LMTD.....	26
4.8.1 Experiment 1.....	26
4.8.2 Experiment 2.....	26
4.9 Overall heat transfer (U) for each flow.....	26
4.9.1 Experiment 1.....	27
4.9.2 Experiment 2.....	27
4.10 Chart 1 – Heat emitted by the heat exchanger vs power absorbed into the air.	28
4.10.1 Experiment 1.....	28
4.10.2 Experiment 2.....	29
4.11 Chart 2 – Air, water, and mean temperature efficiencies.....	29
4.11.1 Experiment 1.....	30
4.11.2 Experiment 2.....	30

4.12 Chart 3 – Overall heat transfer coefficient U.....	31
4.12.1 Experiment 1.....	32
4.12.2 Experiment 2.....	32
5. Discussion	34
6. Conclusion.....	34

1. Introduction

Heat exchangers are widely used in various industrial and commercial applications to transfer heat from one fluid to another e.g., crude oil manufacturing. They are essential for efficient energy management, allowing thermal energy to pass between fluids without mixing them. The performance of a heat exchanger depends on several factors, including the heat transfer coefficient, mean temperature efficiency, hot water and cool air efficiency, heat emitted, heat absorbed, pressure drop, heat capacity rate, flow rate, and temperature difference. The air flow rate is a crucial factor that affects the heat transfer rate and, consequently, the overall performance of the heat exchanger. This report will discuss how the air flow rate affects the performance of the heat exchanger and the key features and properties of heat exchanger performance. In addition, there are suggestions for improving heat exchanger performance.

2. Methodology

A) Firstly, prepare the heat exchanger (for the purpose of this experiment the TD1007 Tube Heat Exchanger was used) to ensure the experiment findings are accurate. The tank must be set up for parallel flow as shown in Figure 1&2 so ensure the tubes are set up correctly. The water will enter through the bottom of the tank (T_{w1}) and exit through the top (T_{w2})

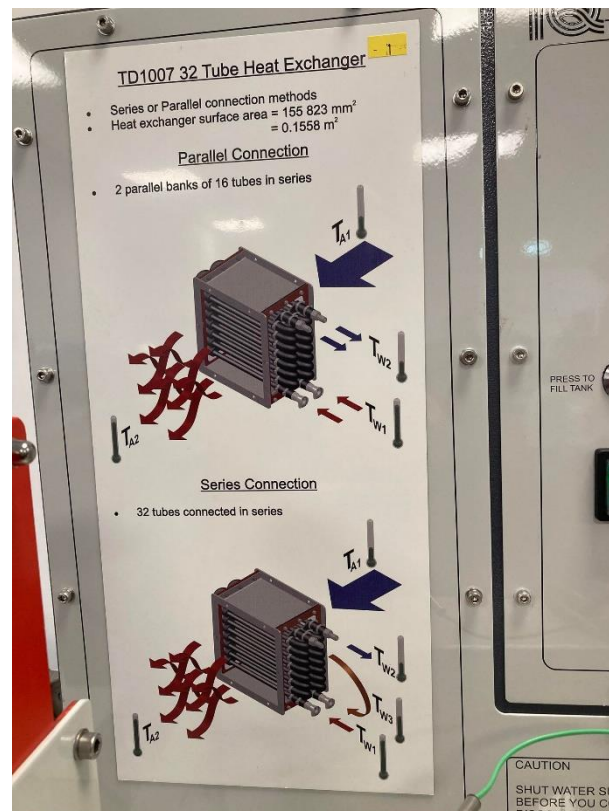


Figure 1. Parallel and Series connections of the heat exchanger represented visually.

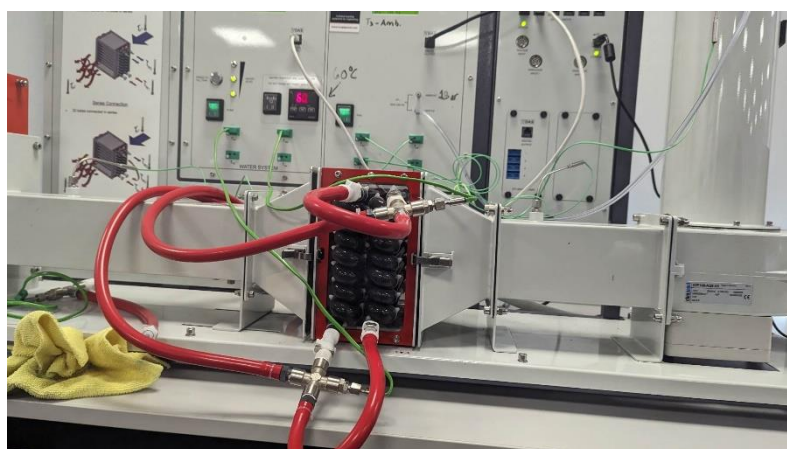


Figure 2. Parallel set up on the heat exchanger,

B) Next, an appropriate temperature of the heater tank must get chosen. For this experiment 60 degree Celsius was used. It is a safe temperature to be used for this type of experiment to avoid injuries such as burns, while still providing a constant temperature for viable results.

The ambient air pressure is 1Bar as shown in Figure 3.

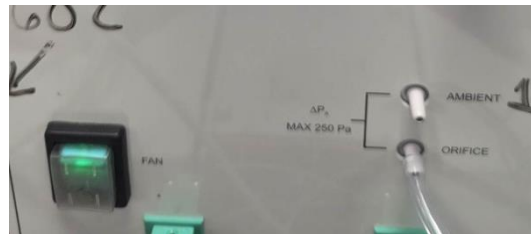


Figure 3. Ambient air pressure valve.

The diameter of the orifice is $A_o = 100.11\text{mm}^2$.

C) Next, switch on the fan and using the valve shown in Figure 4, set the airflow so that the orifice pressure is 250Pa (+/-5 Pa) by gently sliding it up and down until the value is reached. You can see how the pressure is changing on a digital screen as shown in Figure 5.

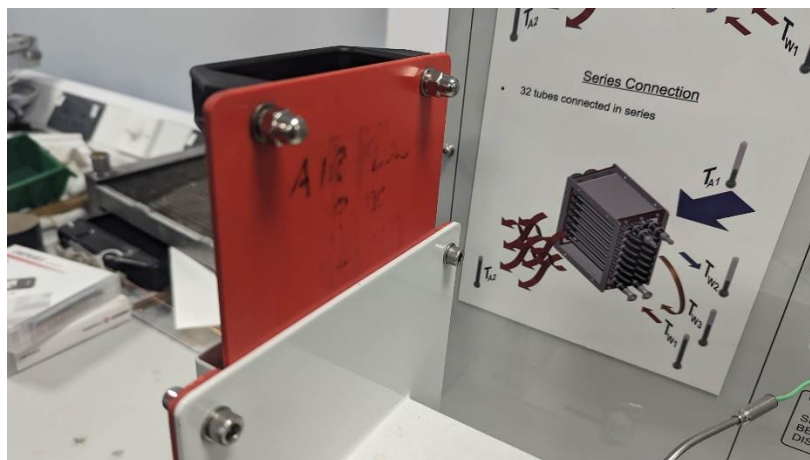


Figure 4. Orifice Pressure control valve.

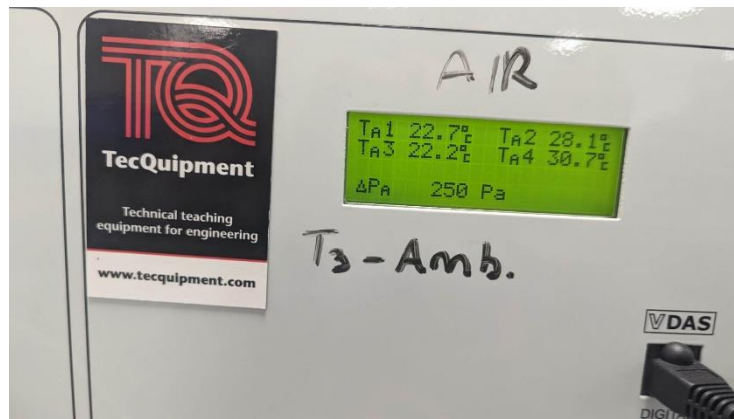


Figure 5. Digital screen showing the orifice pressure (Pa).

The last step will differ for Experiment 1 and Experiment 2 and is described in paragraph E and F below.

Experiment 1 - Fluid

E) Switch on the pump and use the hand operated water supply valve (spin it either left or right) to set the water flow to 1.55 L/minute (+/- 0.01 L/minute). The temperatures will take at least 5 minutes to stabilise so do not take any readings until then. Ensure the water flow stays constant and re-adjust it if needed. Repeat the process for lower water flow rates of 1.25, 1.00, 0.75, 0.50 L/min and take readings, using the VDAS software. For the analysis, the readings taken every two minutes will be used for calculations. Take a reading every 2 seconds, for 4 minutes and then work out the average Temperatures 1&2&3&4 for water & air for that duration using the following equation:

$$\text{Water: } \overline{T}_W = \frac{T_{W1} + T_{W2}}{2} \quad [\text{Equation. 1}]$$

$$\text{Air: } \overline{T}_A = \frac{T_{A1} + T_{A2}}{2} \quad [\text{Equation. 2}]$$

In Excel:

=AVERAGE(All values for (e.g., Temperature 1) between 0-240s)

e.g., =AVERAGE(B5:B125) (This function will take an average of all cells between B5 and B125).

Experiment 2 - Pressure

F) Switch on the pump and use the hand-operated water supply valve (spin it either left or right) to set the water flow to 0.25 L/minute (+/- 0.01 L/minute). The temperatures will take at least 5 minutes to stabilise so do not take any readings until then. Ensure the water flow stays constant and re-adjust it if

needed. Repeat the process for lower pressures of 200, 150, 100 and 50 Pa and take readings, using the VDAS software. Take a reading every 2 seconds, for 4 minutes and then work out the average using the same equations as for Experiment 1.

To take readings set up the screen using the software the heat exchanges come with (VDAS) and test run it to ensure it works correctly. As shown in Figures 6&7.

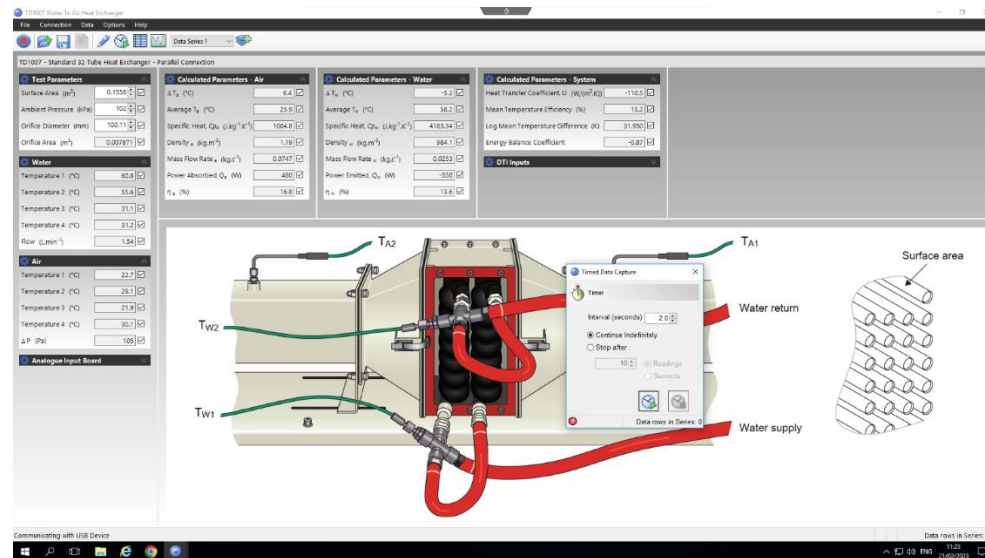


Figure 6. VDAS screen set-up. Showing: test parameters, temperatures and parameters of water and air.

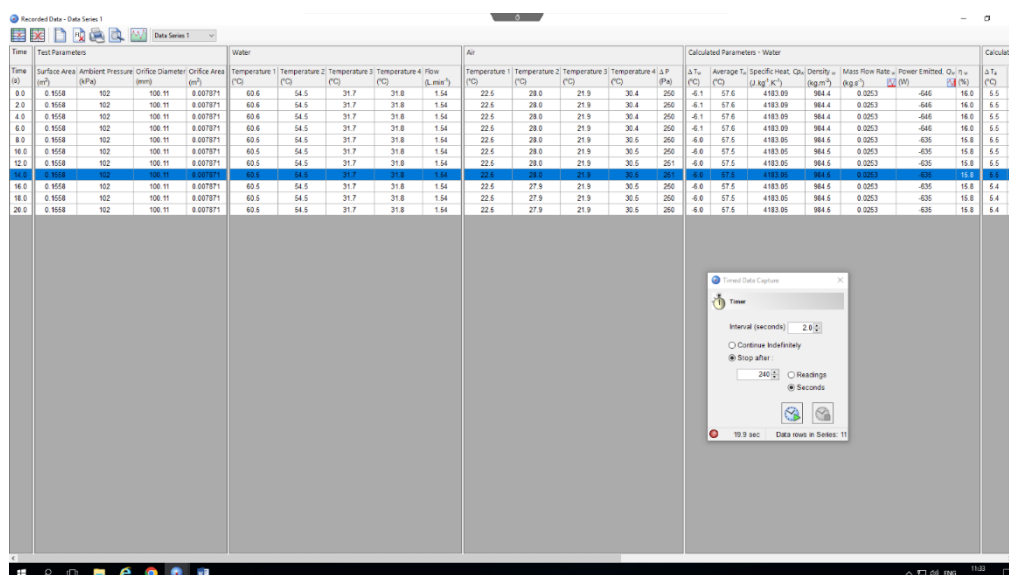


Figure 7. VDAS test run showing the time, test parameters, temperatures and parameters of water and air.

3. Results

3.1 Experiment 1 - Fluid

3.1.1 VDAS Results

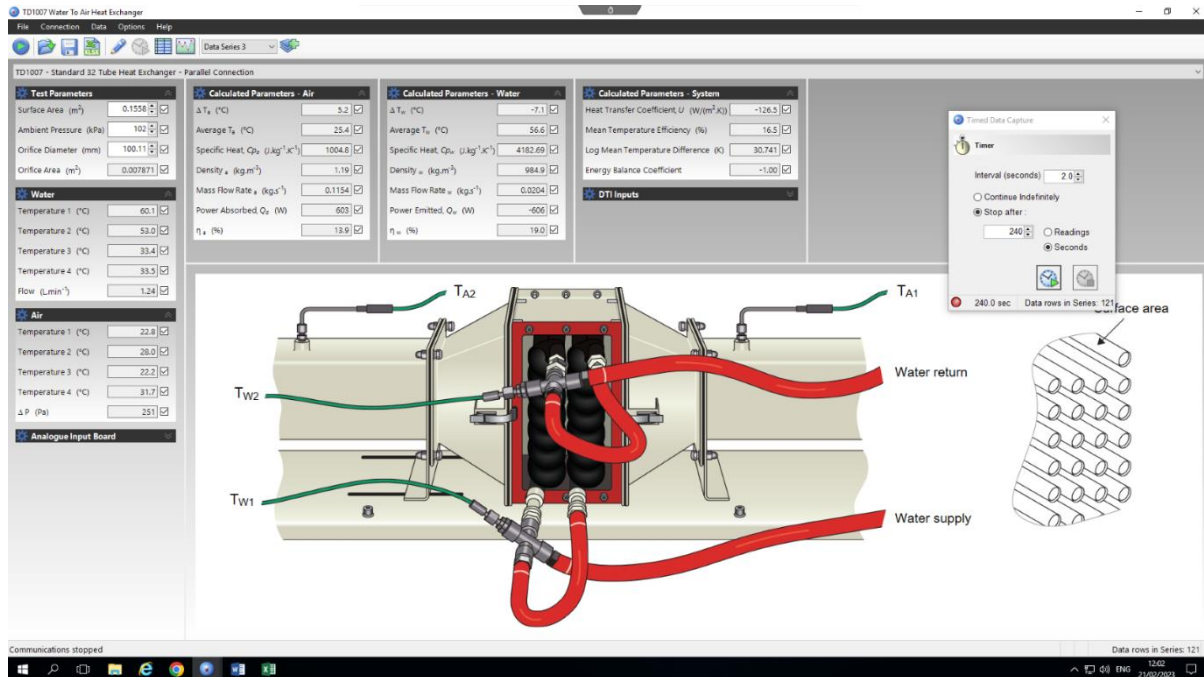


Figure 8. VDAS results for water flow rate of 1.25L/min.

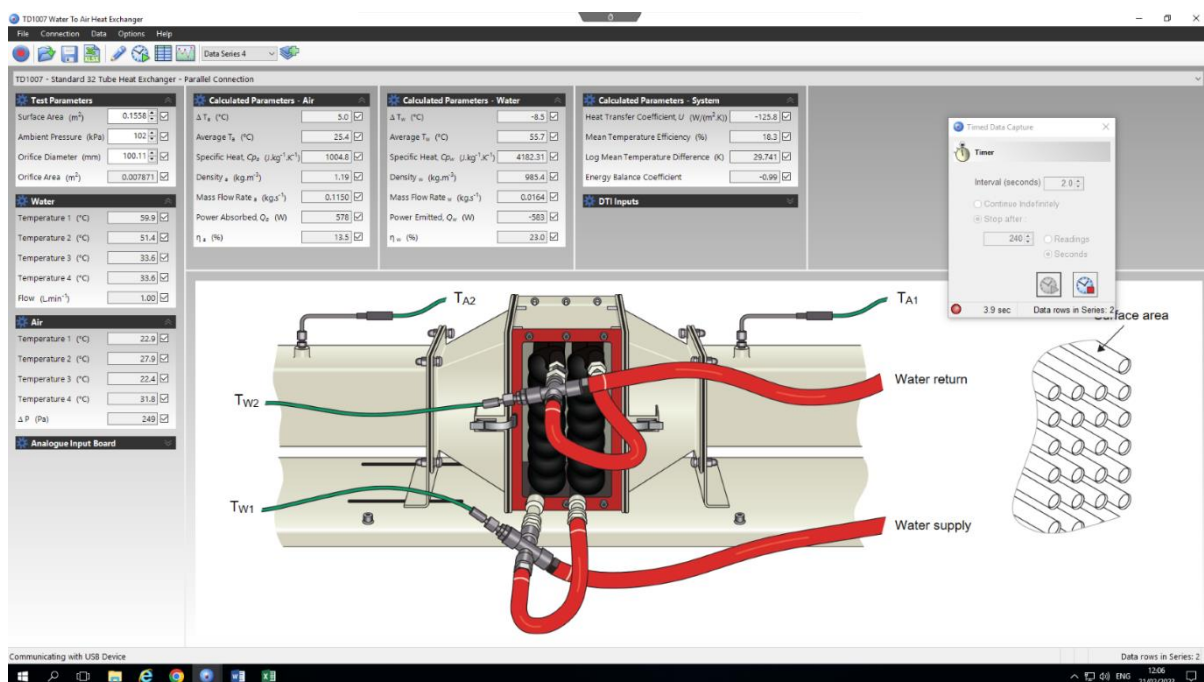


Figure 9. VDAS results for water flow rate of 1.00L/min.

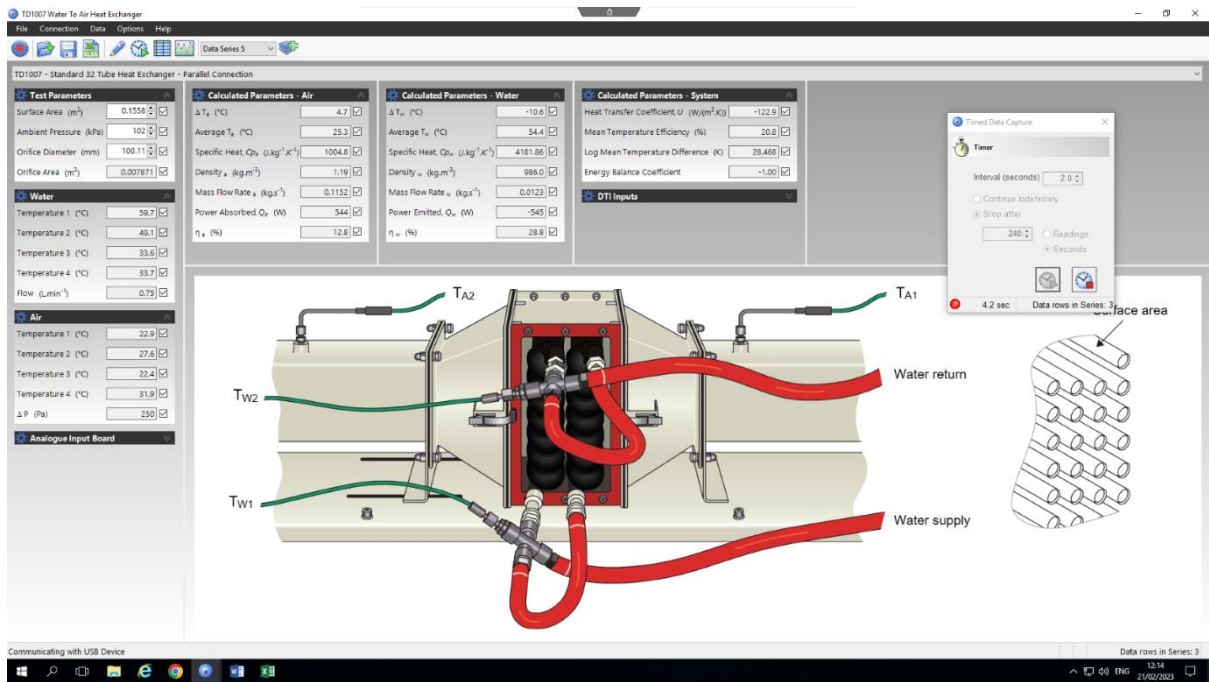


Figure 10. VDAS results for water flow rate of 0.75L/min.

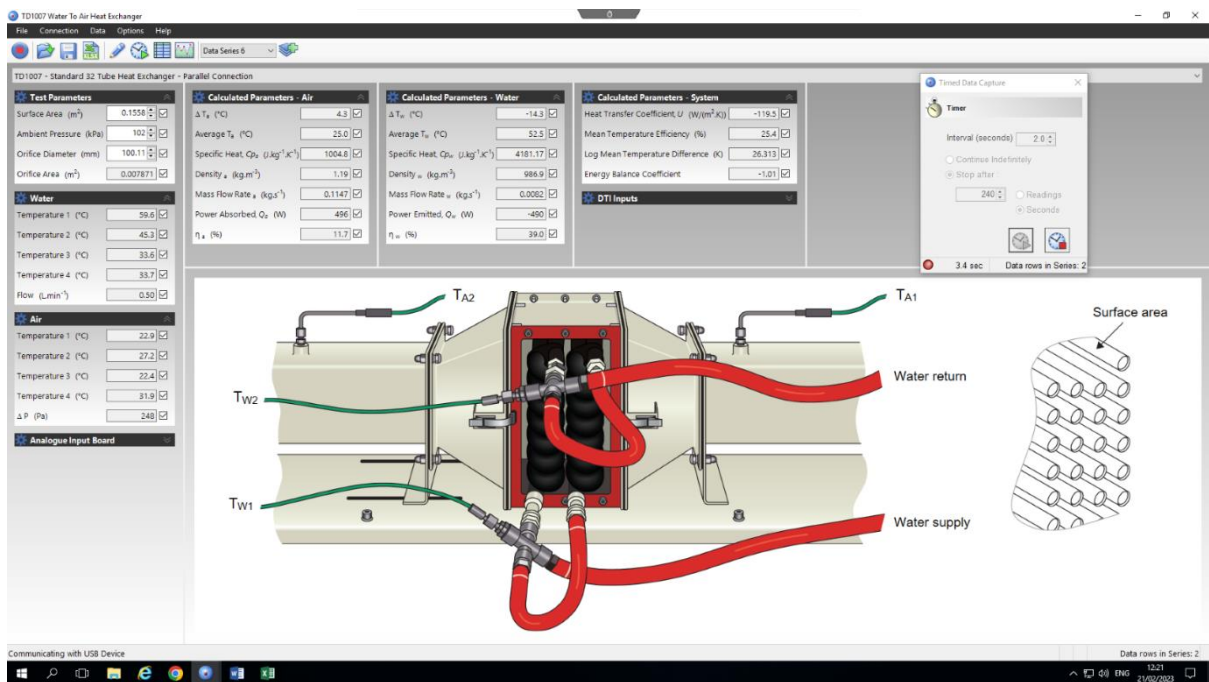


Figure 11. VDAS results for water flow rate of 0.50L/min.

3.1.2 VDAS Results Tables

Table 1. Test Parameters.

Test Parameters				
Flow	Surface Area	Ambient Pressure	Orifice Diameter	Orifice Area
(L/min)	(m ²)	(kPa)	(mm)	(m ²)
1.5	0.1558	102	100.11	0.007871
1.25	0.1558	102	100.11	0.007871
1	0.1558	102	100.11	0.007871
0.75	0.1558	102	100.11	0.007871
0.5	0.1558	102	100.11	0.007871

Table 2. Water temperature results depending on flow.

Water				
Flow	Temperature 1	Temperature 2	Temperature 3	Temperature 4
(L/min)	(°C)	(°C)	(°C)	(°C)
1.5	60.59	54.31	32.72	32.8
1.25	60.25	53.10	33.39	33.48
1	59.87	51.34	33.58	33.64
0.75	59.58	48.99	33.60	33.70
0.5	59.2	45	33.6	33.7

Table 3. Air temperature results depending on flow.

Air					
Flow	Temperature 1	Temperature 2	Temperature 3	Temperature 4	D P
(L/min)	(°C)	(°C)	(°C)	(°C)	(Pa)
1.5	22.73	28.13	22.13	31.13	249.42
1.25	22.77	28.01	22.20	31.67	249.90
1	22.87	27.84	22.28	31.84	249.92
0.75	22.88	27.53	22.31	31.90	250.32
0.5	22.9	27.1	22.3	31.9	249.75

Table 4. Water – calculated parameters results.

Water - Calculated Parameters							
Flow	D Tw	Average Tw	Specific Heat, Cp _w	Density w	Mass Flow Rate w	Power Emitted, Q _w	η w
(L/min)	(°C)	(°C)	(J.kg-1.K-1)	(kg.m-3)	(kg.s-1)	(W)	(%)
1.5	-6.28	57.47	4183.03	984.5	0.0243	-637.83	16.58
1.25	-7.16	56.70	4182.72	984.88	0.0205	-612.56	19.09
1	-8.53	55.63	4182.31	985.40	0.0164	-585.97	23.05
0.75	-10.59	54.29	4181.82	986.05	0.0123	-546.01	28.88
0.5	-14.23	52.14	4181.08	987.07	0.0080	-477.03	39.16

Table 5. Air – calculated parameters results.

Air - Calculated Parameters							
Flow	D Ta	Average Ta	Specific Heat, Cp _a	Density a	Mass Flow Rate a	Power Absorbed, Q _a	η a
(L/min)	(°C)	(°C)	(J.kg-1.K-1)	(kg.m-3)	(kg.s-1)	(W)	(%)
1.5	5.4	25.44	1004.8	1.19	0.1151	624.94	14.27
1.25	5.24	25.40	1004.80	1.19	0.1152	606.32	13.98
1	4.97	25.37	1004.80	1.19	0.1152	575.29	13.44
0.75	4.66	25.23	1004.80	1.19	0.1153	539.23	12.70
0.5	4.21	25.01	1004.80	1.19	0.1151	487.10	11.58

Table 6. System – calculated parameters results.

System - Calculated parameters				
Flow	Heat Transfer Coefficient, U	Mean Temperature Efficiency	Log Mean Temperature Difference	Energy Balance Coefficient
(L/min)	(W/(m ² .K))	(%)	(K)	
1.5	-129.3	15.45	31.66	-0.98
1.25	-127.34	16.57	30.87	-0.99
1	-126.47	18.27	29.74	-0.98
0.75	-123.42	20.80	28.40	-0.99
0.5	-117.61	25.40	26.03	-1.02

SEP

3.2 Experiment 2 - Pressure

3.2.1 VDAS results

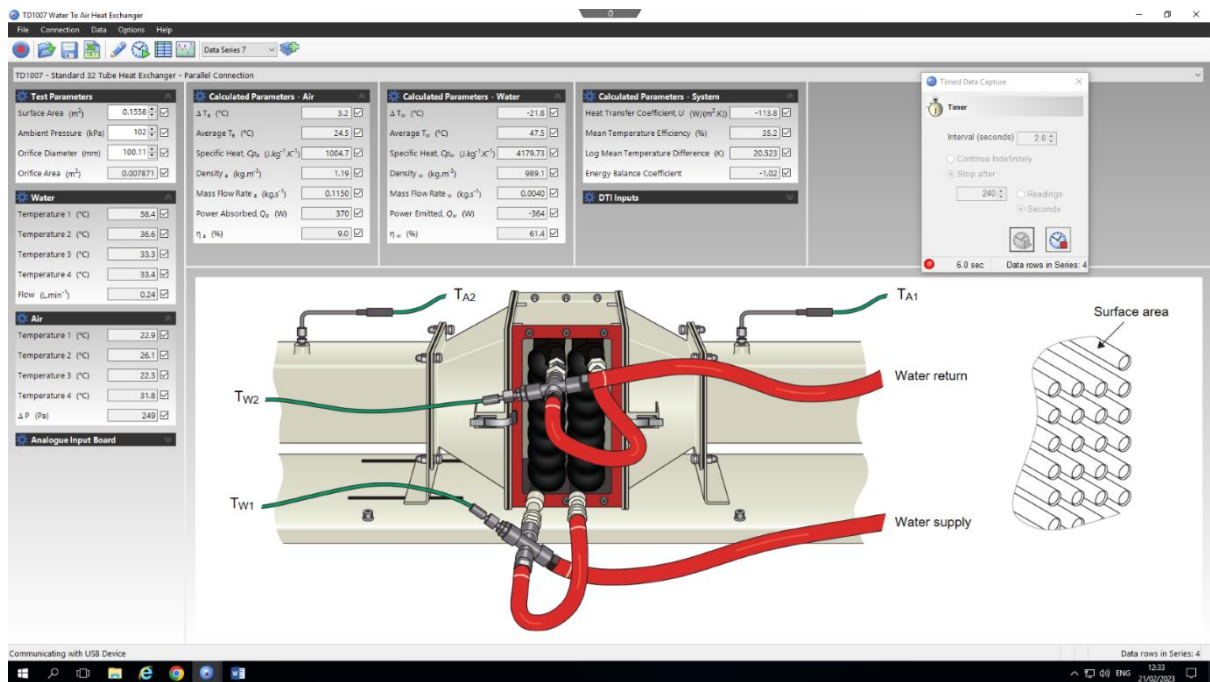


Figure 12. VDAS results for pressure at 250Pa.

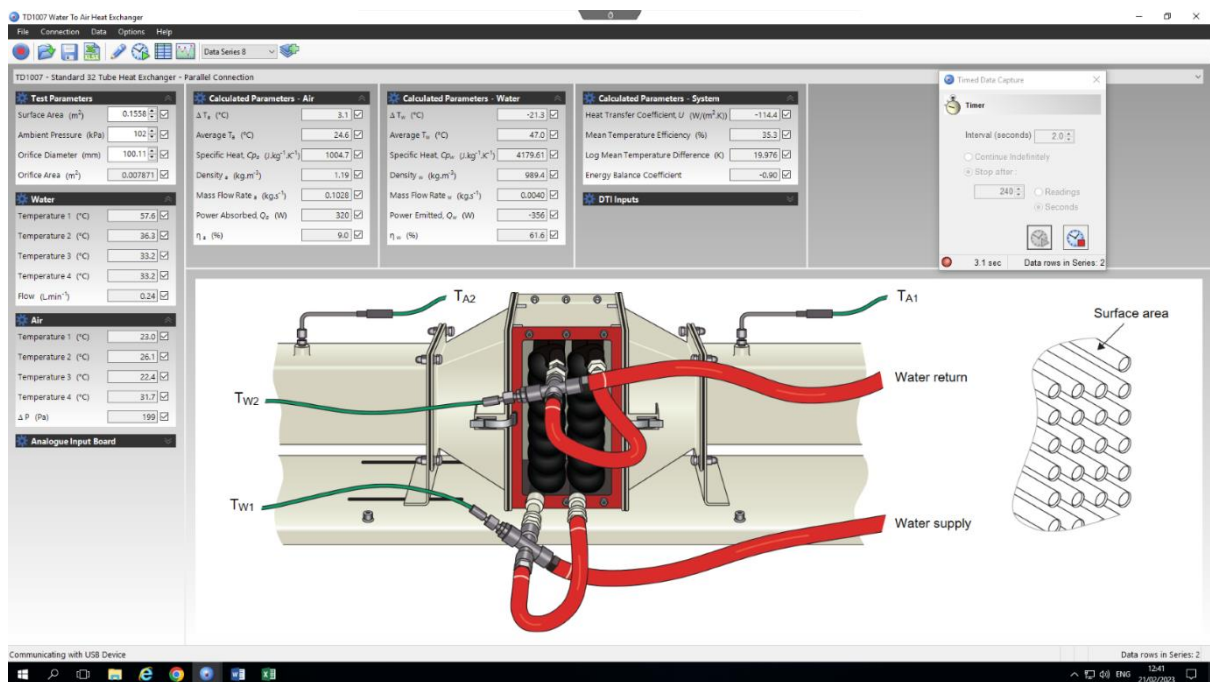


Figure 13. VDAS results for pressure at 200Pa.

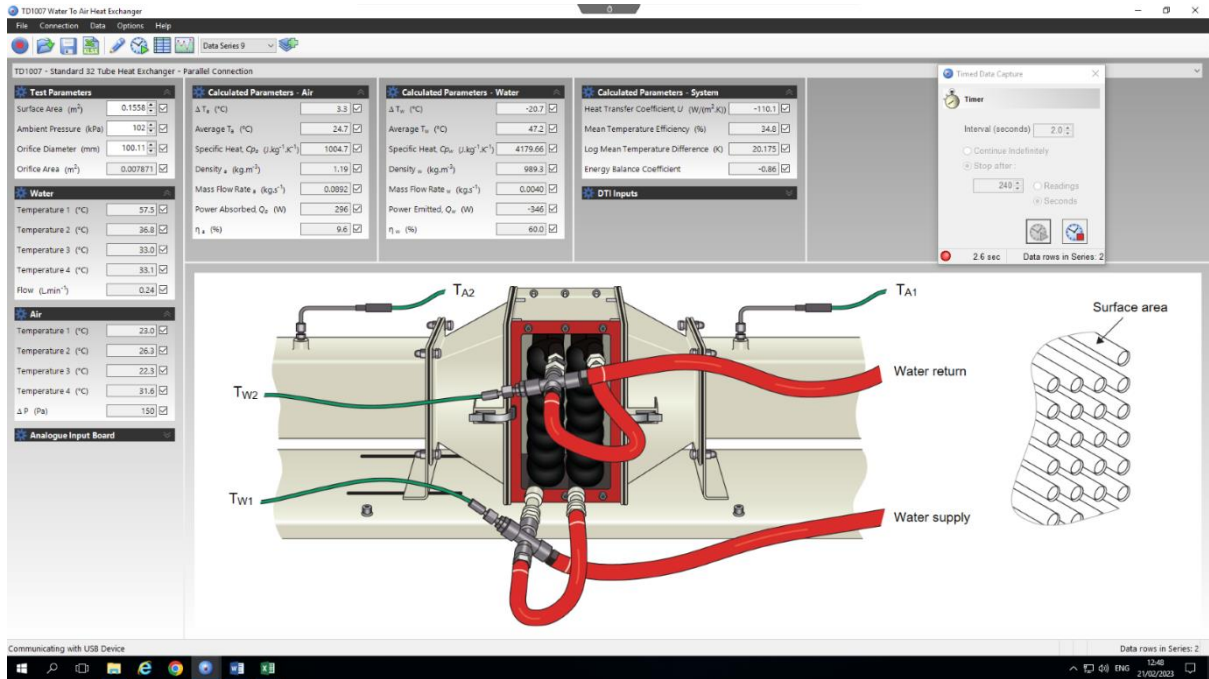


Figure 14. VADAS results for pressure at 150Pa.

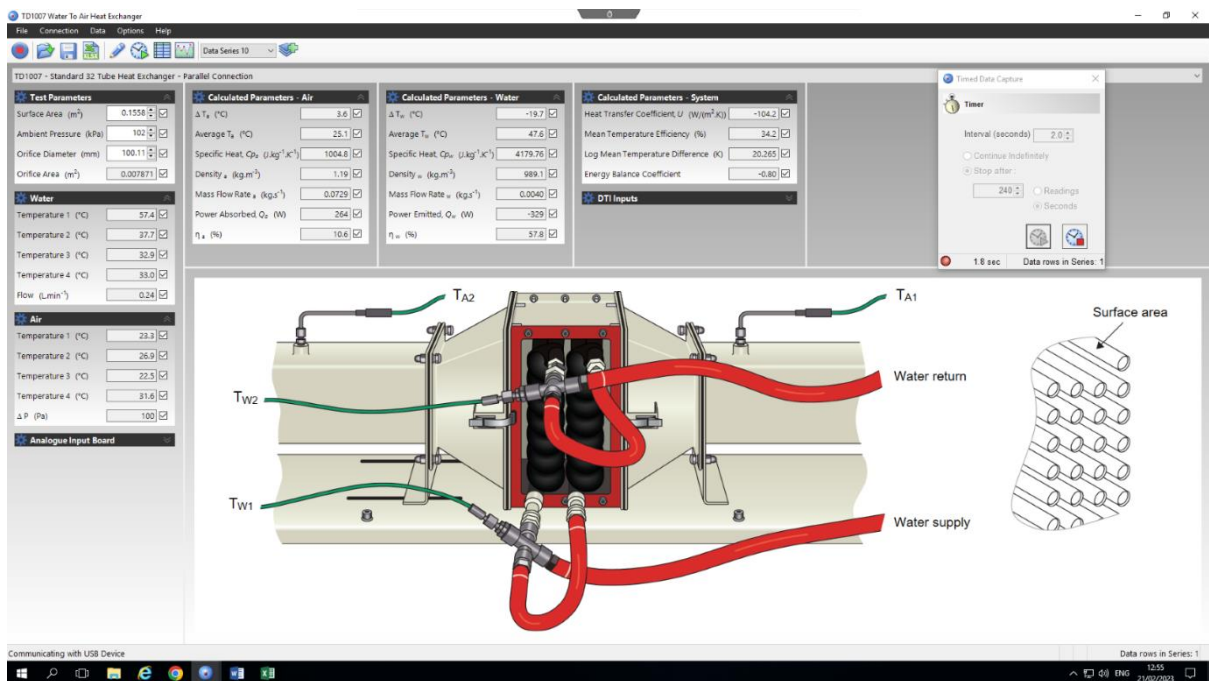


Figure 15. VADAS results for pressure at 100Pa.

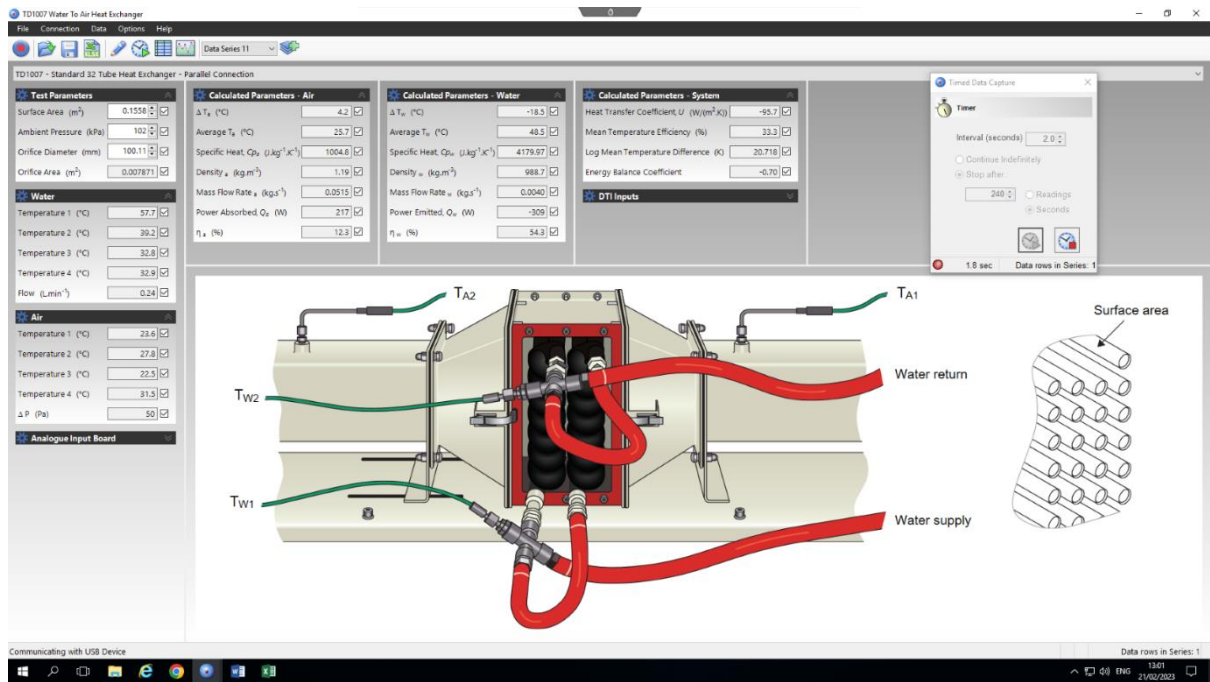


Figure 16. VDAS results for pressure at 50Pa.

3.2.2 VDAS Results Tables

Table 7. Test Parameters.

Test Parameters				
Pressure	Surface Area	Ambient Pressure	Orifice Diameter	Orifice Area
Pa	(m2)	(kPa)	(mm)	(m2)
250	0.1558	102	100.11	0.007871
200	0.1558	102	100.11	0.007871
150	0.1558	102	100.11	0.007871
100	0.1558	102	100.11	0.007871
50	0.1558	102	100.11	0.007871

Table 8. Water temperature results depending on flow.

Water					
Pressure	Temperature 1	Temperature 2	Temperature 3	Temperature 4	Flow
Pa	(°C)	(°C)	(°C)	(°C)	(L.min-1)
250	58.01570248	36.35041322	33.2892562	33.37355372	0.242809917
200	57.56	36.29	33.10	33.19	0.24
150	57.58	36.80	32.96	33.05	0.24
100	57.56	37.79	32.88	32.97	0.24
50	57.76	39.62	32.80	32.90	0.23

Table 9. Air temperature results depending on flow.

Air					
Pressure	Temperature 1	Temperature 2	Temperature 3	Temperature 4	D P
Pa	(°C)	(°C)	(°C)	(°C)	(Pa)
250	22.89	26.06	22.34	31.80	249.75
200	23.00	26.18	22.36	31.70	199.93
150	23.05	26.35	22.36	31.60	150.73
100	23.21	26.86	22.36	31.59	100.78
50	23.53	27.86	22.50	31.51	50.21

Table 10. Water – calculated parameters results.

Water - Calculated Parameters							
Pressure	D Tw	Average Tw	Specific Heat, Cp _w	Density w	Mass Flow Rate w	Power Emitted, Q _w	η w
Pa	(°C)	(°C)	(J.kg-1.K-1)	(kg.m-3)	(kg.s-1)	(W)	(%)
250	-21.67	47.21	4179.66	989.29	0.0040	-364.88	61.68
200	-21.27	46.95	4179.60	989.40	0.0040	-356.74	61.54
150	-20.79	47.20	4179.66	989.30	0.0040	-347.69	60.20
100	-19.77	47.69	4179.78	989.09	0.0040	-330.23	57.58
50	-18.14	48.71	4180.06	988.62	0.0039	-292.95	53.00

Table 11. Air – calculated parameters results.

Air - Calculated Parameters							
Pressure	D Ta	Average Ta	Specific Heat, Cp _a	Density a	Mass Flow Rate a	Power Absorbed, Q _a	η a
Pa	(°C)	(°C)	(J.kg-1.K-1)	(kg.m-3)	(kg.s-1)	(W)	(%)
250	3.17	24.49	1004.70	1.19	0.1152	367.02	9.02
200	3.18	24.60	1004.70	1.19	0.1030	329.33	9.19
150	3.29	24.75	1004.70	1.19	0.0894	296.15	9.55
100	3.65	25.02	1004.80	1.19	0.0731	268.26	10.65
50	4.32	25.72	1004.80	1.19	0.0516	224.29	12.63

Table 12. System – calculated parameters results.

System - Calculated parameters				
Pressure	Heat Transfer Coefficient, U	Mean Temperature Efficiency	Log Mean Temperature Difference	Energy Balance. Coefficient
Pa	(W/(m ² .K))	(%)	(K)	
250	-115.80	35.36	20.22	-1.01
200	-115.07	35.38	19.90	-0.92
150	-110.76	34.86	20.14	-0.85
100	-103.68	34.14	20.45	-0.81
50	-89.40	32.84	21.04	-0.77

4. Analysis

4.1 Change in temperature for each circuit.

The change in temperature is calculated by:

$$\text{Water: } \Delta T_W = T_{W1} - T_{W2} \quad [\text{Equation. 3}]$$

$$\text{Air: } \Delta T_A = T_{A1} - T_{A2} \quad [\text{Equation 4}]$$

4.1.1 Experiment 1

Table 13. Difference between Temperature 1&2 – Water.

Water	
Flow	Difference between temperature 1&2
(L/min)	(°C)
	-6.28
	-7.156198347
	-8.528099174
	-10.59173554
	-14.2

Table 14. Difference between Temperature 1&2 – Air.

Air	
Flow	Difference between temperature 1&2
(L/min)	(°C)
1.5	-5.40
1.25	-5.239669421
1	-4.970247934
0.75	-4.657024793
0.5	-4.2

4.1.2 Experiment 2

Table 15. Difference between Temperature 1&2 – Water.

Water	
Pressure	Difference between temperature 1&2
Pa	(°C)
250	-21.66528926
200	-21.27107438
150	-20.78595041
100	-19.76694215
50	-18.13966942

Table 16. Difference between Temperature 1&2 – Air.

Air	
Pressure	Difference between temperature 1&2
Pa	(°C)
250	3.17
200	3.18
150	3.29
100	3.65
50	4.32

4.2 Water and air densities at each temperature.

4.2.1 Experiment 1

Table 16. Water density.

Water Density (kg.m-3) at each temperature				
Flow	Temperature 1	Temperature 2	Temperature 3	Temperature 4
(L/min)				
1.5	983.5	986	995	995
1.25	983.5	987.00	995	995
1	983.5	987.50	995	995
0.75	983.5	989.00	995	995
0.5	983.5	990	995	995

Table 17. Air density.

Air Density (kg.m-3) at each temperature					
Flow					D P
(L/min)	Temperature 1	Temperature 2	Temperature 3	Temperature 4	(Pa)
1.5	1.2	1.155	1.158	1.155	249.42
1.25	1.2	1.155	1.158	1.155	249.90
1	1.2	1.155	1.158	1.155	249.92
0.75	1.2	1.155	1.158	1.155	250.32
0.5	1.2	1.155	1.158	1.155	249.75

4.2.2 Experiment 2

Table 18. Water density.

Water Density (kg.m-3) at each temperature				
Flow				
(L/min)	Temperature 1	Temperature 2	Temperature 3	Temperature 4
1.5	984	993	994	994
1.25	984.00	993.00	994.00	994.00
1	984.00	993.00	994.00	994.00
0.75	984.00	993.00	994.00	994.00
0.5	984	992.5	994	994

Table 19. Air density.

Air Density (kg.m-3) at each temperature					
Flow					D P
(L/min)	Temperature 1	Temperature 2	Temperature 3	Temperature 4	(Pa)
1.5	1.2	1.152	1.2	1.155	249.42
1.25	1.20	1.152	1.2	1.155	249.90
1	1.20	1.152	1.2	1.155	249.92
0.75	1.20	1.152	1.2	1.155	250.32
0.5	1.2	1.152	1.2	1.155	249.75

4.2 Air mass flow rate.

Airflow

$$m_A = C_d \times A_o \sqrt{\Delta p \times 2 \times \rho_A} \text{ [Equation. 5]}$$

Orifice diameter = 100.15mm = 0.1m

$$\text{Orifice area} = A = \pi r^2 \quad \text{[Equation 6.]}$$

$$\text{Orifice area} = \pi \times \left(\frac{0.1}{2}\right)^2 = 0.008\text{m}^2$$

4.2.1 Experiment 1

Using Excel work out the mass air flow by using the following function=

=SUM(Orifice discharge coefficient*Orifice area*SQRT(D P*2*TA3 Density))

Table 20. Mass air flow.

Air					
Flow	TA3 Density	Orifice Area	D P	Orifice discharge coefficient	Mass air flow
(L/min)	(kg.m-3)	(m2)	(Pa)		(kg.s-1)
1.5	1.158	0.008	249.42	0.6	0.115365553
1.25	1.158	0.008	249.90	0.6	0.115476699
1	1.158	0.008	249.92	0.6	0.115480518
0.75	1.158	0.008	250.32	0.6	0.115574041
0.5	1.158	0.008	249.75	0.6	0.115441846

4.2.2 Experiment 2

Table 21. Mass air flow.

Air					
Flow	TA3 Density	Orifice Area	D P	Orifice discharge coefficient	Mass air flow
(L/min)	(kg.m-3)	(m2)	(Pa)		(kg.s-1)
1.5	1.2	0.008	249.75	0.6	0.117517191
1.25	1.2	0.008	199.93	0.6	0.105145347
1	1.2	0.008	150.73	0.6	0.091294114
0.75	1.2	0.008	100.78	0.6	0.074649563
0.5	1.2	0.008	50.21	0.6	0.052689893

4.3 Water flow to mass flow conversion.

Water Flow Conversion

To convert the volumetric water flow from L.min^{-1} to kg.s^{-1} use the following equation:

$$\text{Mass flow (kg.s}^{-1}\text{)} m_W = \frac{\text{Volume flow (L.min}^{-1}\text{)}}{60000 \times \text{Water density (kg.m}^{-3}\text{)}} \quad [\text{Equation. 7}]$$

Use the following function in Excel:

=SUM(Flow(L/min)/60000*Temperature)

4.3.1 Experiment 1

Table 22. Mass flow.

Water			
Mass flow (kg.s-1)			
Temperature 1	Temperature 2	Temperature 3	Temperature 4
0.0245875	0.02465	0.024875	0.024875
0.020489583	0.0205625	0.020729167	0.020729167
0.016391667	0.016458333	0.016583333	0.016583333
0.01229375	0.0123625	0.0124375	0.0124375
0.008195833	0.00825	0.008291667	0.008291667

4.3.2 Experiment 2

Table 23. Mass flow.

Water			
Mass flow (kg.s-1)			
Temperature 1	Temperature 2	Temperature 3	Temperature 4
0.0246	0.024825	0.02485	0.02485
0.0205	0.0206875	0.020708333	0.020708333
0.0164	0.01655	0.016566667	0.016566667
0.0123	0.0124125	0.012425	0.012425
0.0082	0.008270833	0.008283333	0.008283333

4.4 Specific heat capacity at each flow rate.

Specific Heat Capacity

$$c = \frac{\Delta Q}{\Delta T} \quad [\text{Equation. 8}]$$

Using the ‘Specific Heat Capacity of Water at Constant Pressure’ chart from the Guidance notes, the specific heat capacity for the water at each flow rate was sourced.

4.4.1 Experiment 1

Table 24. Specific Heat Capacity.

Water					
Specific Heat Capacity (kJ.kg-1.K-1)					
Pressure					Flow
Pa	Temperature 1	Temperature 2	Temperature 3	Temperature 4	(L.min-1)
250	4.185	4.183	4.178	4.178	0.242809917
200	4.185	4.183	4.178	4.178	0.24
150	4.185	4.183	4.178	4.178	0.24
100	4.185	4.183	4.178	4.178	0.24
50	4.185	4.183	4.178	4.178	0.23

4.4.2 Experiment 2

Table 25. Specific Heat Capacity.

Water					
Specific Heat Capacity (kJ.kg-1.K-1)					
Pressure					Flow
Pa	Temperature 1	Temperature 2	Temperature 3	Temperature 4	(L.min-1)
250	4.184	4.178	4.178	4.178	0.242809917
200	4.184	4.178	4.178	4.178	0.24
150	4.184	4.178	4.178	4.178	0.24
100	4.184	4.178	4.178	4.178	0.24
50	4.184	4.178	4.178	4.178	0.23

4.5 Heat emitted from the water.

c_{pW} is calculated by multiplying Specific Heat Capacity by 1000.

To calculate water power the following equation was used:

$$\dot{Q}_W = \dot{m}_W \times c_{pW} \times \Delta T_W \text{ [Equation. 9]}$$

4.5.1 Experiment 1

Table 26. *cpW*.

Water					
Heat emitted (Watts)					
cpW					
J.kg-1.K-1					
Pressure	Temperature 1	Temperature 2	Temperature 3	Temperature 4	Flow
Pa					(L.min-1)
250	4185	4183	4178	4178	0.242809917
200	4185	4183	4178	4178	0.24
150	4185	4183	4178	4178	0.24
100	4185	4183	4178	4178	0.24
50	4185	4183	4178	4178	0.23

Table 27. *Water power*.

Water					
Heat emitted (Watts)					
Pressure	Temperature 1	Temperature 2	Temperature 3	Temperature 4	Flow
Pa					(L.min-1)
250	-646.2037575	-647.536766	-652.66627	-652.66627	0.242809917
200	-613.6361812	-615.5256412	-619.772994	-619.772994	0.24
150	-585.0201412	-587.1187643	-590.8707726	-590.8707726	0.24
100	-544.9378426	-547.7234028	-550.3876215	-550.3876215	0.24
50	-487.0537875	-490.03845	-491.9246833	-491.9246833	0.23

4.5.2 Experiment 2

Table 28. *cpW*.

Water					
Heat emitted (Watts)					
cpW					
J.kg-1.K-1					
Pressure	Temperature 1	Temperature 2	Temperature 3	Temperature 4	Flow
Pa					(L.min-1)
250	4185	4183	4178	4178	0.242809917
200	4185	4183	4178	4178	0.24
150	4185	4183	4178	4178	0.24
100	4185	4183	4178	4178	0.24
50	4185	4183	4178	4178	0.23

Table 29. *Water power*.

Water					
Heat emitted (Watts)					
Pressure	Temperature 1	Temperature 2	Temperature 3	Temperature 4	Flow
Pa					(L.min-1)
250	-2229.930228	-2247.098887	-2249.361826	-2249.361826	0.242809917
200	-1824.462592	830586400	-1840.360947	-1840.360947	0.24
150	-1426.282031	622939800	-1438.710644	-1438.710644	0.24
100	-1017.270097	415293200	-1026.134582	-1026.134582	0.24
50	-622.3502902	207646600	-627.7734467	-627.7734467	0.23

4.6 Heat absorbed by the air.

cpA is calculated by multiplying Specific Heat Capacity by 1000.

To calculate water power the following equation was used:

$$\dot{Q}_A = \dot{m}_A \times c_{pA} \times \Delta T_A \quad [\text{Equation. 10}]$$

4.6.1 Experiment 1

Table 30. Air power.

Air					
Heat absorbed (Watts)					
Flow					D P
(L/min)	Temperature 1	Temperature 2	Temperature 3	Temperature 4	(Pa)
1.5	626.0888564	626.0888564	626.0888564	626.0888564	249.42
1.25	608.0850278	608.0850278	608.0850278	608.0850278	249.90
1	576.8366399	576.8366399	576.8366399	576.8366399	249.92
0.75	540.9223289	540.9223289	540.9223289	540.9223289	250.32
0.5	487.2800326	487.2800326	487.2800326	487.2800326	249.75

4.6.2 Experiment 2

Table 31. Air power.

Air					
Heat absorbed (Watts)					
Flow					D P
(L/min)	Temperature 1	Temperature 2	Temperature 3	Temperature 4	(Pa)
1.5	374.8118551	374.8118551	374.8118551	374.8118551	249.42
1.25	336.1388133	336.1388133	336.1388133	336.1388133	249.90
1	302.246141	302.246141	302.246141	302.246141	249.92
0.75	273.8022575	273.8022575	273.8022575	273.8022575	250.32
0.5	228.9247379	228.9247379	228.9247379	228.9247379	249.75

4.7 Mean temperature efficiencies.

4.7.1 Water efficiencies.

To calculate the temperature efficiency of the hot water the following equation was used:

$$\eta = \frac{T_{W1} - T_{W2}}{T_{W1} - T_{A1}} \times 100 \quad [\text{Equation. 11}]$$

4.7.1.1 Experiment 1

Table 32. Water efficiency.

Hot Water Efficiency	
Pressure	
Pa	
250	16.58742736
200	19.0903479
150	23.05149112
100	28.85901506
50	39.1184573

4.7.1.2 Experiment 2

Table 33. Water efficiency.

Hot Water Efficiency	
Pressure	
Pa	
250	61.67509705
200	61.53882938
150	60.20010053
100	57.56022429
50	52.9938674

4.7.2 Air efficiencies

To calculate the temperature efficiency of the hot water the following equation was used:

$$\eta_A = \frac{T_{A2} - T_{A1}}{T_{W1} - T_{A1}} \times 100 \quad [\text{Equation. 12}]$$

4.7.2.1 Experiment 1

Table 34. Air efficiency.

Cool Air Efficiency	
Flow	
(L/min)	
1.5	14.26307448
1.25	13.97768861
1	13.43460293
0.75	12.68886937
0.5	11.57024793

4.7.2.2 Experiment 2

Table 35. Air efficiency.

Cool Air Efficiency	
Flow (L/min)	
1.5	9.034231267
1.25	9.202850038
1	9.540678331
0.75	10.62739152
0.5	12.62977449

4.7.2 Mean Temperature Efficiency

The mean temperature efficiency is calculated using the following equation:

$$\bar{\eta} = \frac{\eta_W + \eta_A}{2} \quad [\text{Equation. 13}]$$

4.7.2.1 Experiment 1

Table 36. Mean temperature efficiency.

Mean temperature efficiency
%
15.42525092
16.53401825
18.24304702
20.77394222
25.34435262

4.7.2.2 Experiment 2

Table 37. Mean temperature efficiency.

Mean temperature efficiency
%
35.35466416
35.37083971
34.87038943
34.09380791
32.81182095

4.8 LMTD.

To calculate LMTD the following equation was used:

$$LMTD = \frac{(T_{W2}-T_{A2})-(T_{W1}-T_{A1})}{\ln\left(\frac{T_{W2}-T_{A2}}{T_{W1}-T_{A1}}\right)} \quad [\text{Equation. 14}]$$

4.8.1 Experiment 1

Table 38. LMTD.

Flow	
(L/min)	LMTD
1.5	31.6617497
1.25	30.8743881
1	29.73785127
0.75	28.39819519
0.5	26.02483287

4.8.2 Experiment 2

Table 39. LMTD.

Flow	
(L/min)	LMTD
1.5	20.22870011
1.25	19.8958039
1	20.14454191
0.75	20.44550057
0.5	21.03651087

4.9 Overall heat transfer (U) for each flow.

To calculate the heat transfer coefficient the following equation was used:

$$U = \frac{\dot{Q}_w}{A \times LMTD} \quad [\text{Equation. 15}]$$

4.9.1 Experiment 1

Table 40. Heat transfer coefficient.

Flow (L/min)	Heat Transfer Coefficient, U W.m-2K-1
1.5	-131.7213377
1.25	-128.3050905
1	-127.0127655
0.75	-123.9386836
0.5	-120.9063935

4.9.2 Experiment 2

Table 41. Heat transfer coefficient.

Flow (L/min)	Heat Transfer Coefficient, U W.m-2K-1
1.5	-711.992569
1.25	66987381.35
1	49620168.88
0.75	32593156.16
0.5	15838707.66

4.10 Chart 1 – Heat emitted by the heat exchanger vs power absorbed into the air.

4.10.1 Experiment 1

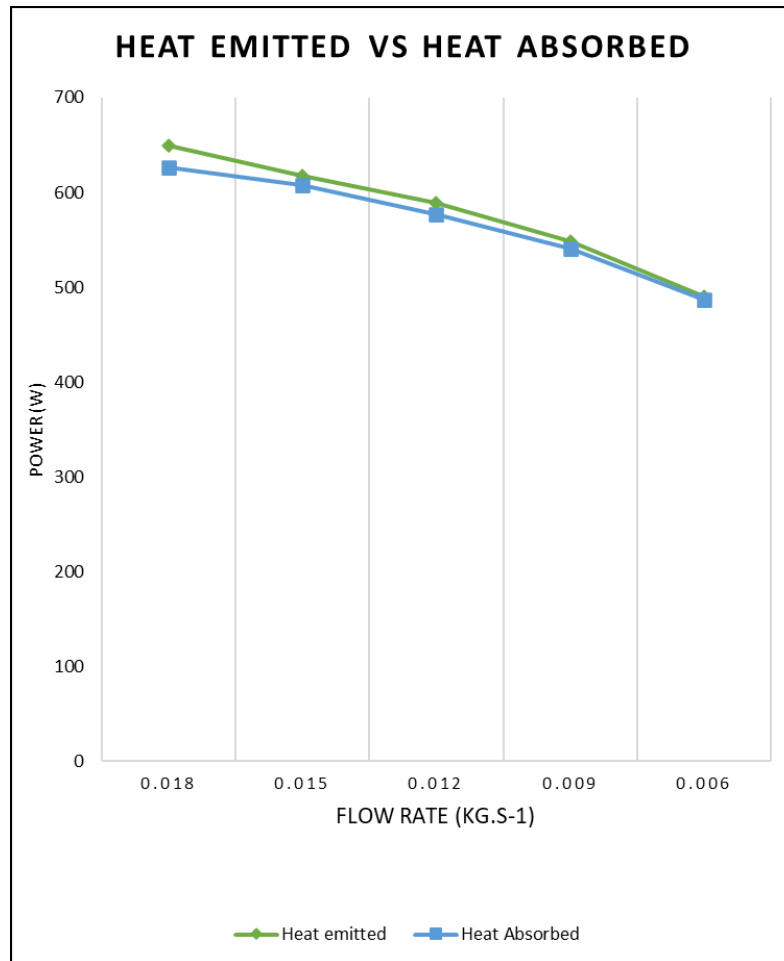


Figure 17. Heat Emitted vs Heat absorbed chart Experiment 1.

4.10.2 Experiment 2

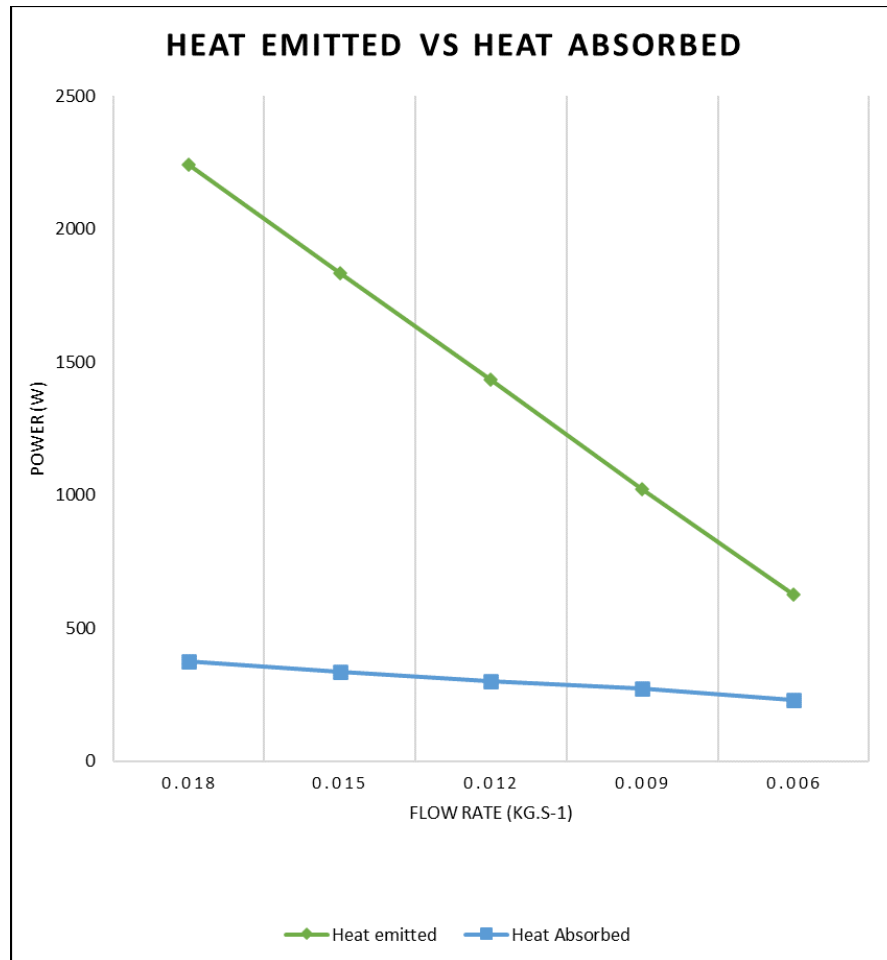


Figure 18. Heat Emitted vs Heat absorbed chart Experiment 2.

4.11 Chart 2 – Air, water, and mean temperature efficiencies.

4.11.1 Experiment 1

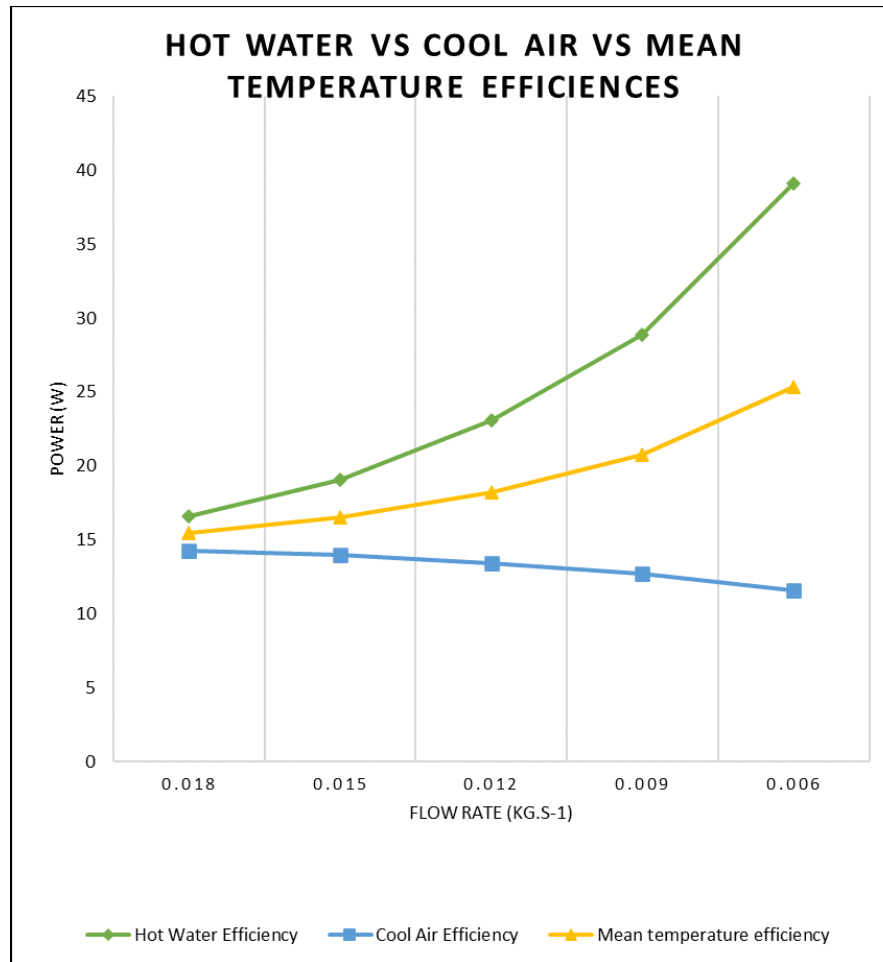


Figure 19. Hot water vs Cool air vs Mean temperature, efficiencies.

4.11.2 Experiment 2

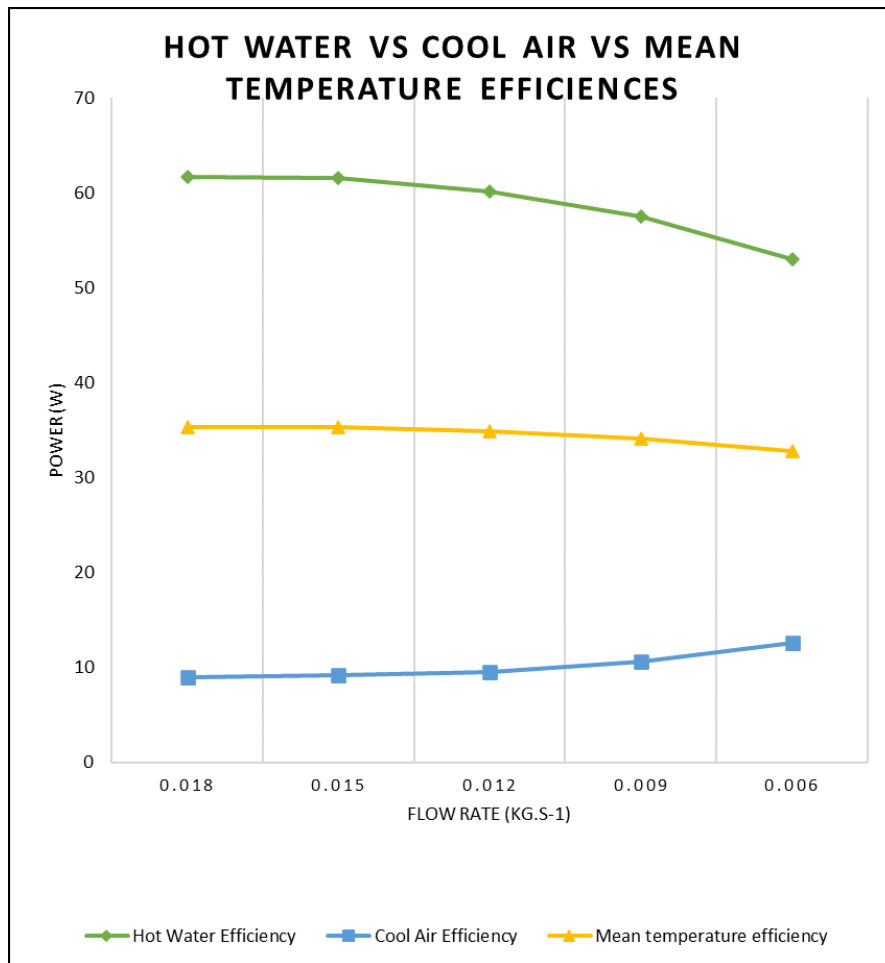


Figure 20. Hot water vs Cool air vs Mean temperature, efficiencies.

4.12 Chart 3 – Overall heat transfer coefficient U.

4.12.1 Experiment 1

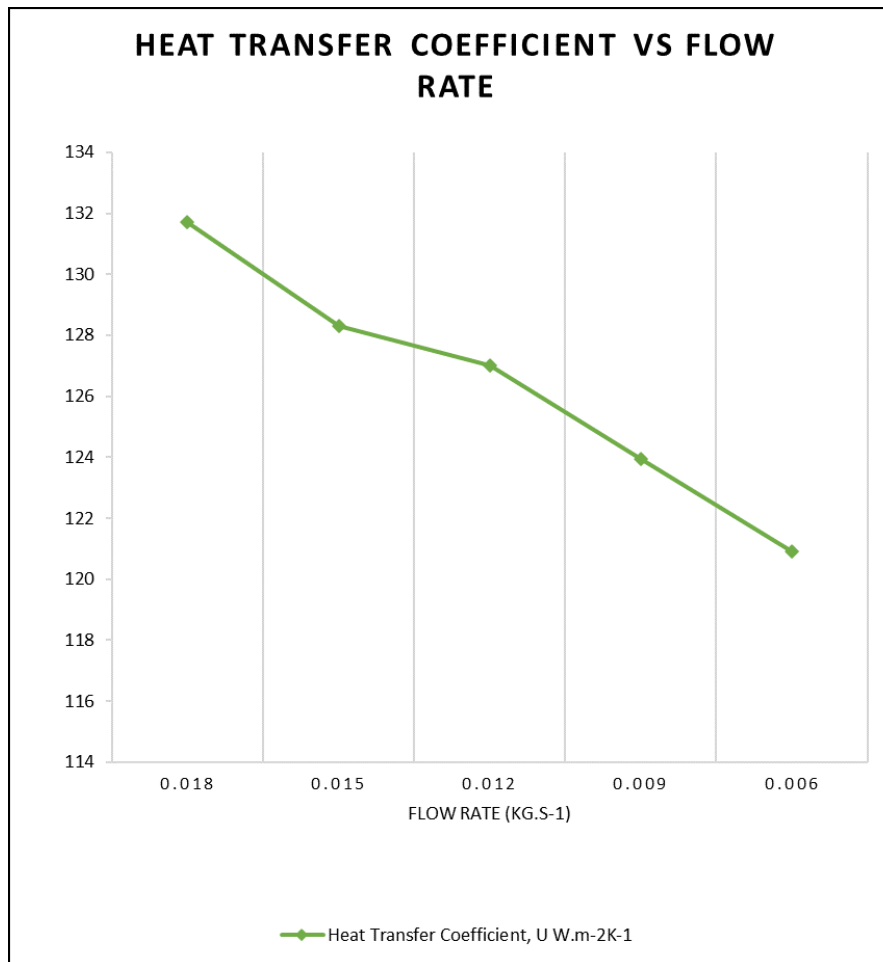


Figure 21. Heat transfer coefficient vs Flow rate

4.12.2 Experiment 2

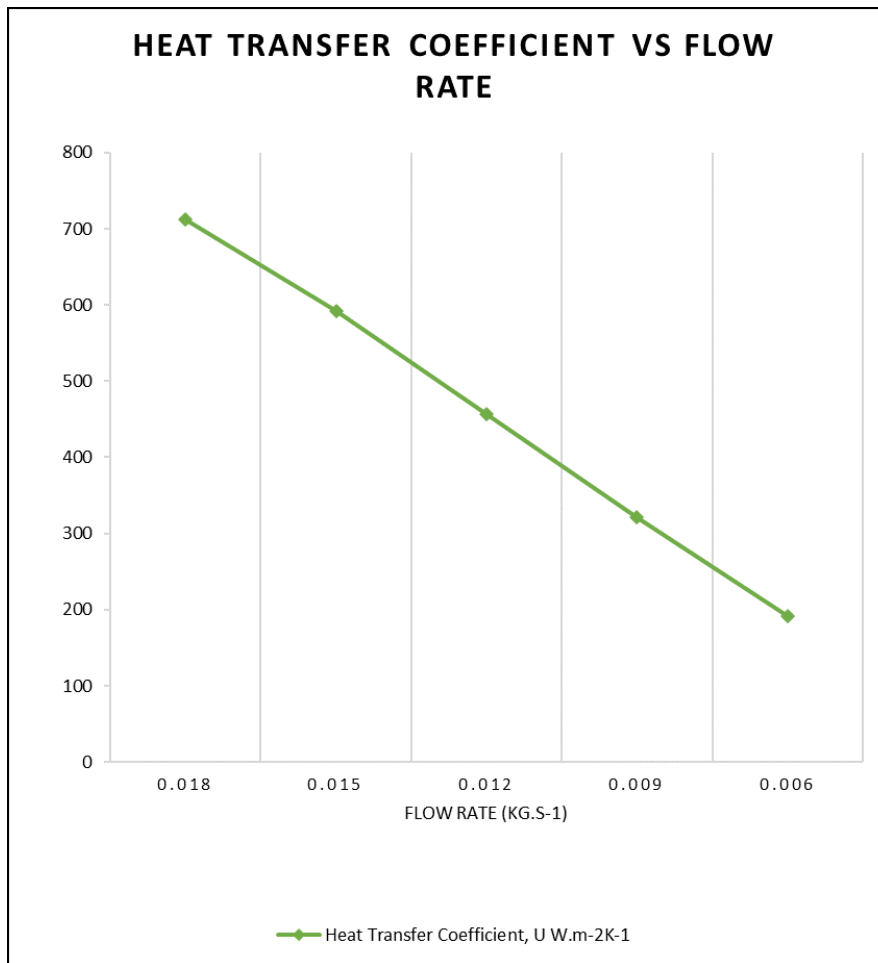


Figure 22. Heat transfer coefficient vs Flow rate

5. Discussion

In Experiment 1, the 'heat emitted' and 'heat absorbed' are remarkably similar, as shown in Figure 17. There are no significant losses or gains in heat energy to the environment because the heat exchanger operates in a balanced state of heat transfer between the two fluids. However, Figure 18 shows that in Experiment 2, the heat emitted increases much faster than the heat absorbed. It may be because Experiment 2's air density was slightly higher. Higher-density air has a higher thermal conductivity easing the heat from the hot fluid to the cooler air.

The temperature efficiencies vary a lot between Experiment 1 and 2 (Figures 19&20). This is due to the big temperature difference between Temperature 1 and Temperature 2 of fluids. Comparing Table 13 and Table 15, the Experiment 1 had a very low fluid temperature difference compared to all the other temperature differences. It is uncertain why that has happened and more testing is recommended.

The performance of a heat exchanger is significantly impacted by the air flow rate. The air flow rate affects the heat transfer rate and, consequently, the overall performance.

Here are some ways in which air flow rate affects the performance of a heat exchanger:

- The air flow rate and the rate of heat transfer are directly proportional. Figures 21 and 22 show that when the air flow rate rises, so do the heat transfer coefficient. This is because a larger air flow rate allows for a greater exchange of heat between the two fluids. When the flow rate is highest, the heat transfer coefficient is also highest. The hot stream exponentially cools down and the cold stream exponentially heats up. Figure 21 also shows some possible slight errors because the line trend is not as clean as the one on Figure 22.

6. Conclusion

The key properties of a heat exchanger are:

- Heat transfer coefficient - The heat transfer coefficient measures the efficiency of the heat transfer process. It describes how well the heat exchanger transfers heat between the two fluids. The higher the heat transfer coefficient, the better the heat exchanger transfers heat.
- Mean temperature efficiency - ratio of the actual heat transfer rate to the maximum possible heat transfer rate between the two fluids.
- Hot water and cool air efficiency - measures how effectively the heat exchanger transfers heat from the hot water to the cold air stream
- Heat emitted - the heat released from the heat exchanger to the environment.
- Heat absorbed - the heat absorbed by the heat exchanger from the environment.
- Pressure drop - difference in pressure between the inlet and outlet of the heat exchanger.
- Heat capacity rate - heat transferred between the two fluids per unit time.

- Flow rate - the rate at which the fluid flows through the heat exchanger.
- Temperature difference between the hot and cold streams.

The key features of a heat exchanger are:

- The operating conditions, such as temperature, pressure, and flow rate of the two fluids.
- The flow configuration of the two fluids (parallel flow- streams flow in the same direction, counterflow – streams flow in opposite directions, crossflow) is an important feature that determines the direction and rate of heat transfer between the fluids.

The performance of the heat exchanger could get improved by optimising the temperature difference. The temperature difference between the hot and cold fluids can impact the performance of the heat exchanger. A high-temperature difference can increase the heat transfer rate but also increase energy consumption. Finding the optimal temperature difference can help to maximise the heat transfer rate while minimising energy consumption.