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Mechanical Engineering | 27/04/2020

Thermodynamics Lab Report

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1.0 Introduction

“Heat exchanger (HX) is a generic term applied to a wide range of mechanical systems, which are designed for the purpose of exchanging thermal energy between two streams of fluids separated by a solid surface. Some heat exchangers are used as heat sinks including automotive inter-coolers, containment air coolers, cooling towers, automotive radiators, and power plant condensers. Some other heat exchangers are used as a heat source including boilers, radiators for space heating, and steam generators.” (Massoud, 2005).

The aim of this lab report is to analysis a heat exchanger under pre-determined conditions and record results and compile data collected into graphs, give any suggestions to improve performance of a heat exchanger.

2.0 Objectives

- Show cognitive skills in the integration of the principles of heat transfer and fluid flow with thermodynamic theory / applications and the modelling of such problems.
- Demonstrate knowledge and critical understanding of the processes governing heat transfer in an experimental heat exchanger lab experiment and write up a details experimental report and analysis.

3.0 Theory/Background

There are many types of heat exchanger and each have their own application purposes. (Raju, 2011). These are listed below:

3.1 Shell and Tube Heat Exchanger

Shell and Tube (HX) is commonly used in the process industry, it exchanges heat between 2 fluids, each separated with no direct contact, one flows through the pipe side the other through the shell side. (Massoud, 2005).

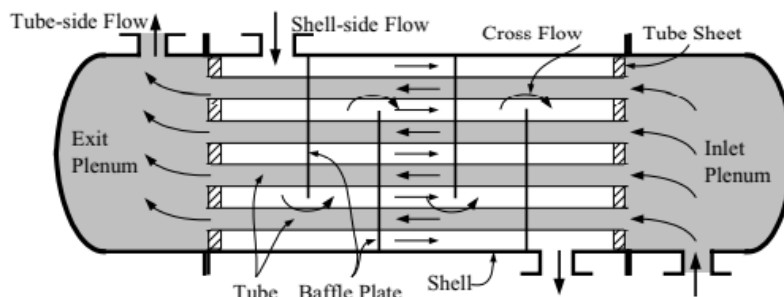


Figure (1): Shell and tube heat exchanger. (Raju, 2011).

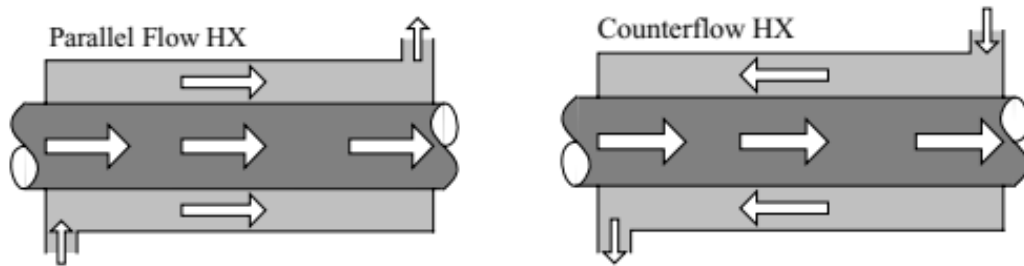


Figure (2): Shell and tube heat exchanger setups. (Massoud, 2005).

3.2 Air-Cooled Exchanger

“Has an integral electric motor or fluid-powered fan for the cooling or heat removal.” (Raju, 2011).

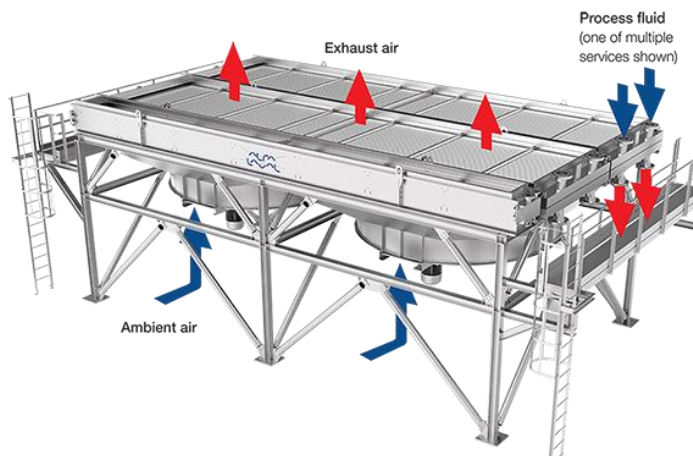


Figure (3): Shell and tube heat exchanger setups. (TUBETECH air cooled heat exchanger, 2020).

3.3 Plate Heat Exchanger

This type of heat exchanger is alternative to the tube and shell type, the shell and pipes are replaced by alternating channels of thin plate partitions for the flow of the fluids allow heat transfer between them, They are often used in low-viscosity applications. (Raju, 2011).

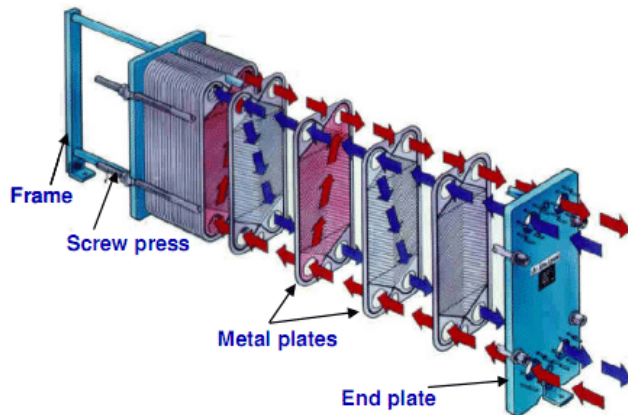


Figure (3): Plate heat exchanger setups. (Aqua Group 2020).

3.4 Crossflow Heat Exchanger

“Shell side flow in a heat exchanger is in the perpendicular direction instead of the customary counter or parallel flow, used in most exchangers.” (Massoud, 2005).

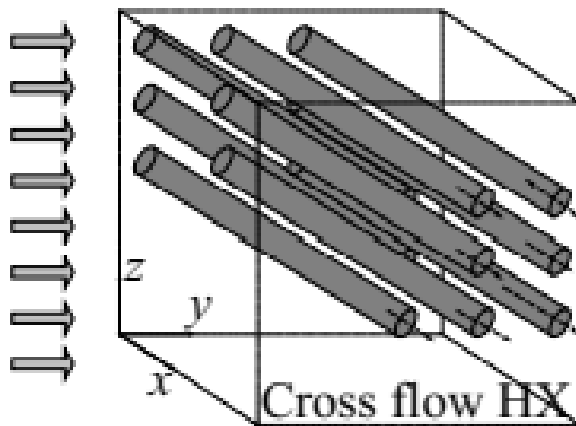


Figure (4): Plate heat exchanger setups. (Massoud, 2005).

3.5 Finned Tube/Extended Surface Heat Exchanger

This type of heat exchanger is used in applications where poor heat transfer where a larger given area is used. It is a class of compact exchanger, Heat transfer rate can be improved by adding fins, grooves, and threaded surfaces. The heat transfer rate is increased due to the increase in surface area see figure(4). (Massoud, 2005).



Figure (5): Finned Tube. (EXTENDED SURFACE HEAT TRANSFER, 2020).

3.6 Spiral Heat Exchanger

“Heat transfer surfaces are arranged in the form of a spiral to increase turbulence through increased shear by continuous direction change. Used in special applications justifying increased costs.”(Raju, 2011).

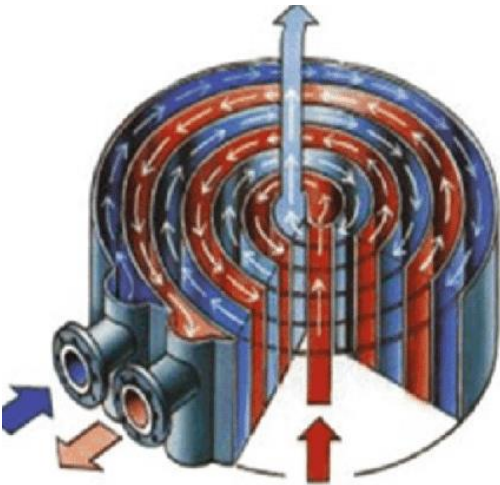


Figure (6): Spiral Heat Exchanger Diagram. (EXTENDED SURFACE HEAT TRANSFER, 2020).

3.7 Scraped Surface Heat Exchanger

Scraped surface heat exchanger uses highly viscous liquid which are subjected to mechanical scraping, the surfaces are constantly renewed to prevent products charring. It typically has a cylinder with rotating row of scrapers, normally utilized for freezing of ice cream or cooling fats during margarine manufacture. (Raju, 2011).

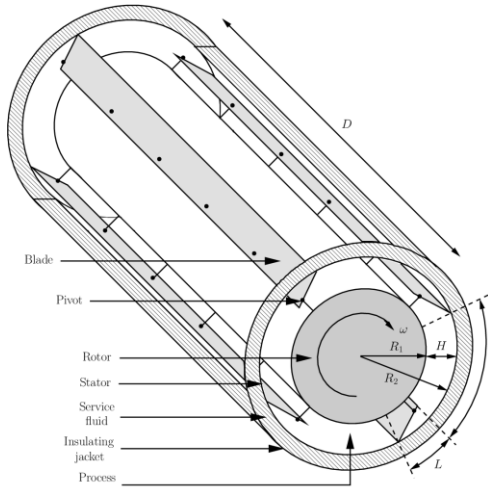


Figure (7): Scraped Surface Heat Exchanger. (Smith, Wilson, Duffy and Hall-Taylor, 2020)

4.0 Equipment

The Heat exchanger used for the experiment is a tube and shell type, which consists of 2 parallel back of 16 tubes in series which one liquid runs through, however the other liquid flows through a shell which houses the 32 tubes. The heat exchanger TD1007 is bench mounted water to air heat exchanger and consists of: (TecQuipment Ltd, 2014).

- Air temperature and flow display.
- Water temperature and flow display.
- Electric centrifugal fan.
- Orifice.
- Inlet duct.
- Standard 32 tube heat exchanger.
- Outlet duct.
- Slide valve.

5.0 Calculations

The following calculations were needed in-order to calculate values needed for this report.

Water Flow Rate

$$\text{Mass flow (kg. s}^{-1}\text{)} \dot{m}_w = \text{Volume flow} \frac{\text{L. min}^{-1}}{60000} * \text{Water density (kg. m}^{-3}\text{)}$$

Air Flow Rate

$$\dot{m}_A = C_d * A_o \sqrt{\Delta p * 2 * \rho_A}$$

Average Temperature Water

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

Average Temperature Air

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

Air Density

To find Air density to below graph was used, using temperature 60c.

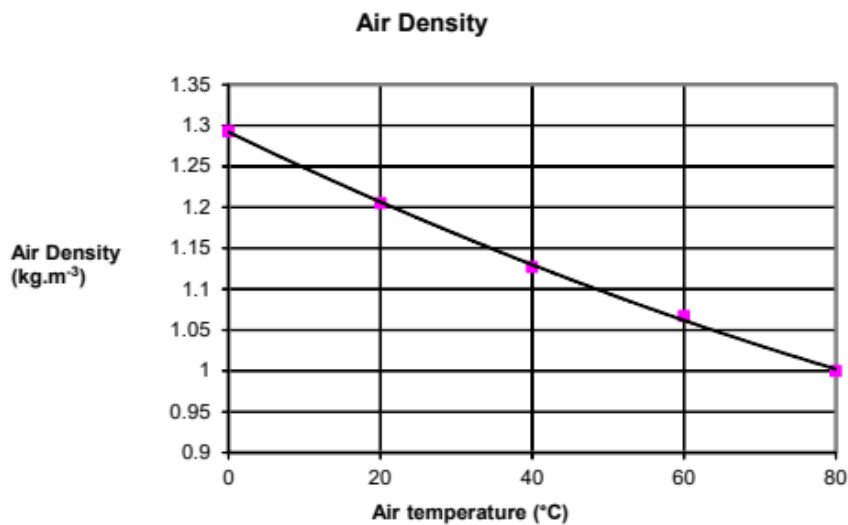


Fig (8) Air Density graph.

Water Density

To find Water density to below graph was used, using temperature 60c.

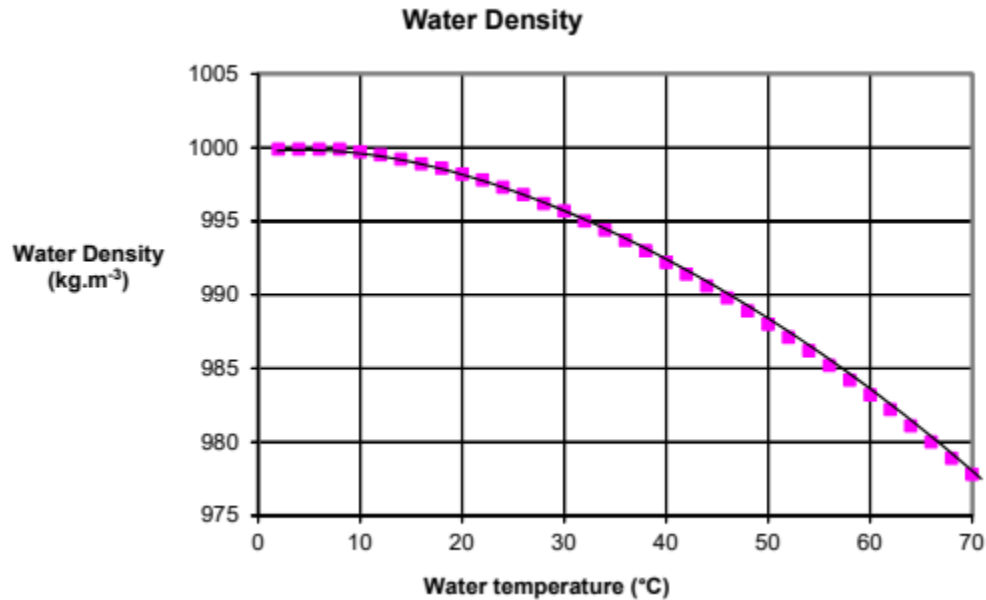


Fig (8) Water Density graph.

Specific Heat Capacity of Water

To find Specific heat capacity of water the below graph was used, using temperature 60c.

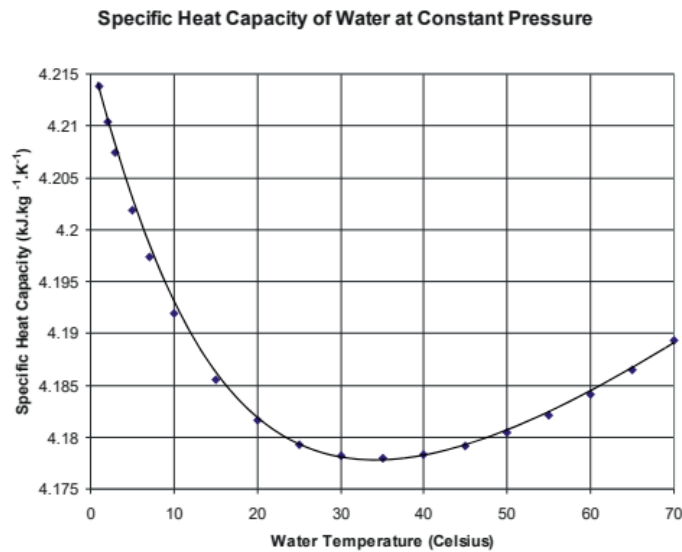


Fig (8) Water Density graph.

Energy Balance Coefficient

$$C_{EB} = \frac{Q_A}{Q_W}$$

Temperature Efficiency Water

$$\eta_W = \frac{T_{W1} - T_{W2}}{T_{W1} - T_{A1}} * 100$$

Temperature Efficiency Air

$$\eta_A = \frac{T_{A2} - T_{A1}}{T_{W1} - T_{A1}} * 100$$

Mean Temperature Efficiency

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

Logarithmic Temperature Difference (LMTD)

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

Heat Transfer Coefficient (U)

$$U = \frac{Q_W}{A * LMTD}$$

(TecQuipment Ltd, 2014).

6.0 Experiment (1) – The effect of varying water flow rate

6.1 Aim

Using different water flow rates to see how it affects the performance of heat exchanger, air flow & water temperature will remain constant throughout experiment 1.(Assignment handout, 2020).

6.2 Procedure:

- Connect and set up the standard 32 tube heat exchanger. Connect as for parallel flow and set a heater tank temperature of 60°C. Water enters the bottom of the heat exchanger and exits from the top.
- Note the ambient air pressure.
- Inspect the orifice and check its diameter - this is stamped on the surface of the orifice.
- Switch on the fan and use the slide valve to set the airflow to give an orifice pressure drop of 250 Pa (+/- 5 Pa tolerance).
- Switch on the pump and use the hand operated water supply valve to set the water flow to 2.25 L/minute (+/- 0.01 L/minute).
- Repeat the procedure for lower water flow rates of 1.75, 1.25, 0.75 and 0.25 L/min. (*Assignment handout, 2020*).

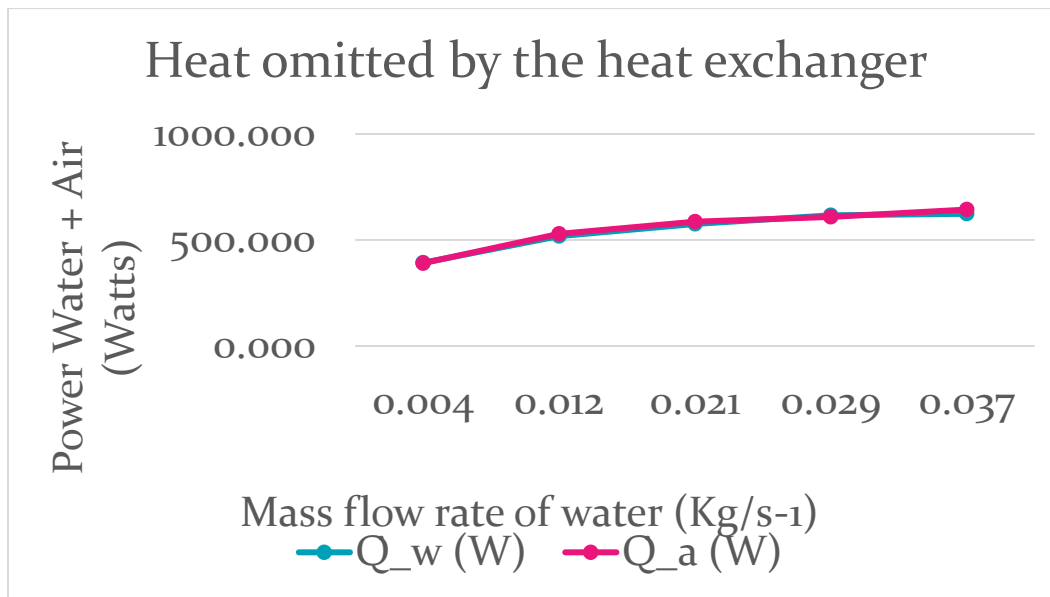
6.2.1 Important notes

- *Important note - Allow at least five minutes for the heat exchanger temperatures to stabilize, then record all readings.*
- *Your water and air flows may change slightly as you do the experiment, so regularly check and readjust them if necessary. (Assignment handout, 2020).*

6.3 Results

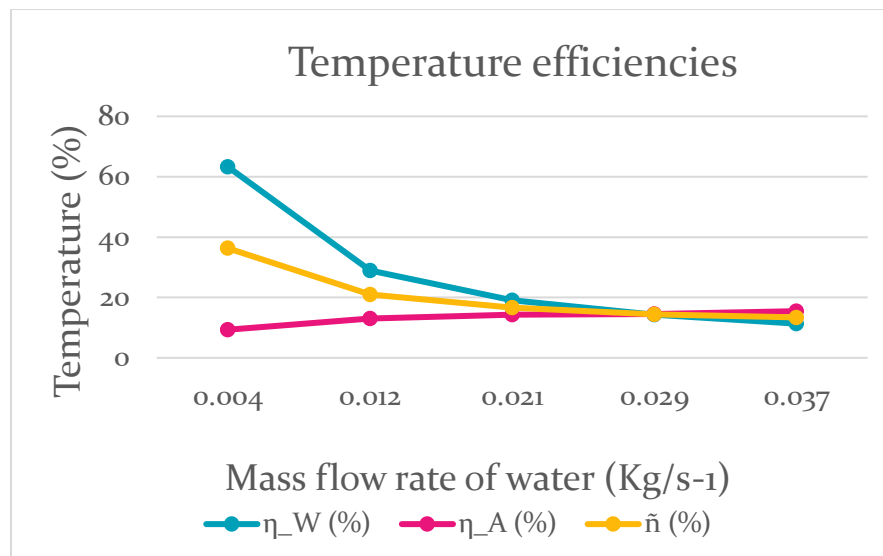
See Excel spreadsheet (Sheet 1) for results and calculations.

6.4 Graphs/Interpretation of data



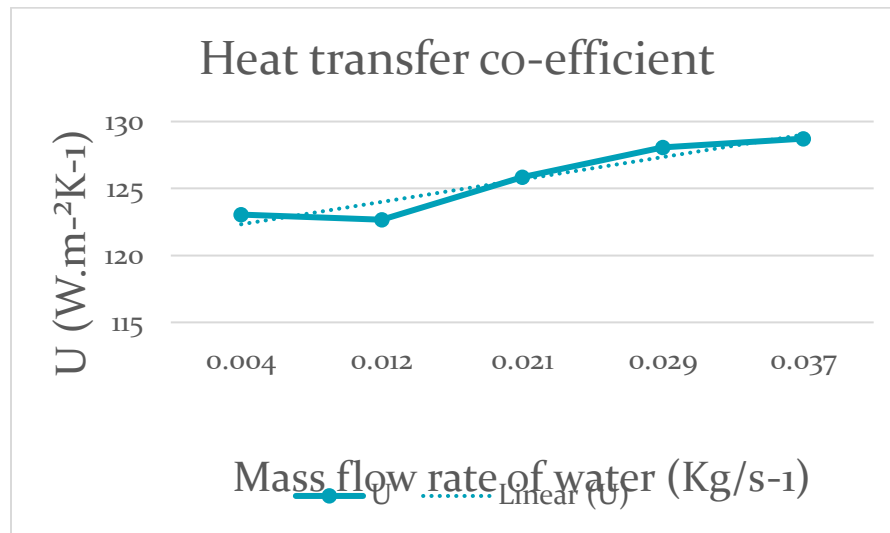
Graph 1: Heat omitted by the heat exchanger.(Excel).

The above graph(1) represents heat energy (power) it shows as water flow rate increases so does the performance. The max power transfer rate will be at around 0.04kg.s-1 as the slope is levelling off at around 0.037kg.s-1, this could be proved if the flow rate of water is increased. As the values of heat emitted from water and the air absorbs a similar value this would suggest that there is a good energy balance within the system. (TecQuipment Ltd, 2014).



Graph 2: Temperature efficiencies experiment(1).(Excel).

The above graph(2) Represents the efficiencies within experiment (1), the data shows water efficiency decreases with increased water, however the air efficiency increases. Thus, the change in water efficiency is larger than the change in air efficiency for changing mass flow rates. However, this was expected due to a higher temperature efficiency drop compared to water, also mean tempurate decreases with increase water mass flow rates. (*TecQuipment Ltd, 2014*).



Graph 3: Heat transfer co-efficient experiment(1).(Excel).

Graph (3) above represents Heat transfer co-efficient of heat exchanger, graphs data shows heat transfer co-effienct slightly increases intially, however it shows at $129 \text{ W.m}^{-2}\text{K}^{-1}$ it levels out suggesting this water flow rate is optimum at this value and no improvement will be made upon this. (*TecQuipment Ltd, 2014*).

7.0 Experiment (2) – The effect of varying air flow rate

7.1 Aim

To show how different air flow rates affect the performance of the heat exchanger for a given fixed water flow and temperature. (*Assignment handout, 2020*).

7.2 Procedure

- Check connections are set for parallel flow and set a heater tank temperature of 60°C. Water enters the bottom of the heat exchanger and exits from the top.
- Note the ambient air pressure. Inspect the orifice and check its diameter - this is stamped on the surface of the orifice.
- Switch on the fan and use the slide valve to set the airflow to give an orifice pressure drop of 250 Pa (+/- 5 Pa).
- Switch on the pump and use the hand operated water supply valve to set the flow to 0.25 L/minute (+/- 0.01 L/minute).
- Repeat the procedure for lower air flow rates of 200, 150, 100 and 50 Pa pressure drop. (*Assignment handout, 2020*).

7.2.1 Important notes

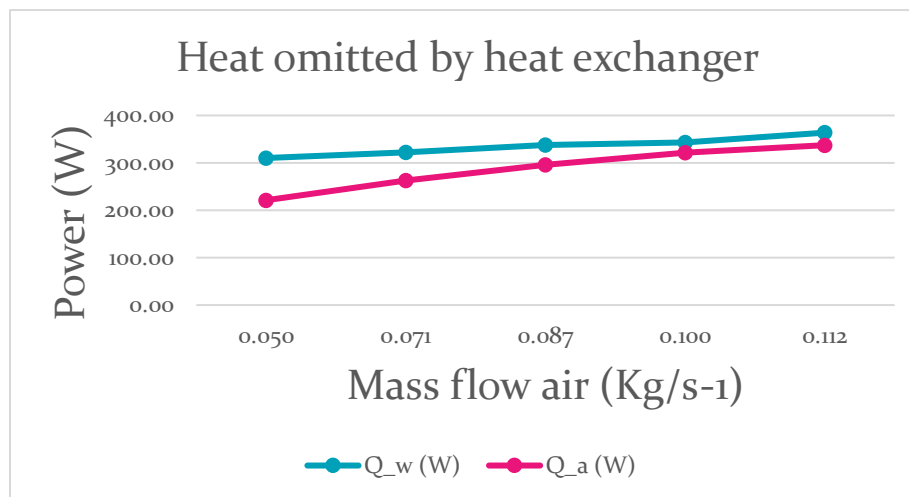
Allow at least five minutes for the heat exchanger temperatures to stabilize, then record all readings.

*Your water and air flows may change slightly as you do the experiment, so regularly check them, and adjust, as necessary. (*Assignment handout, 2020*).*

7.3 Results

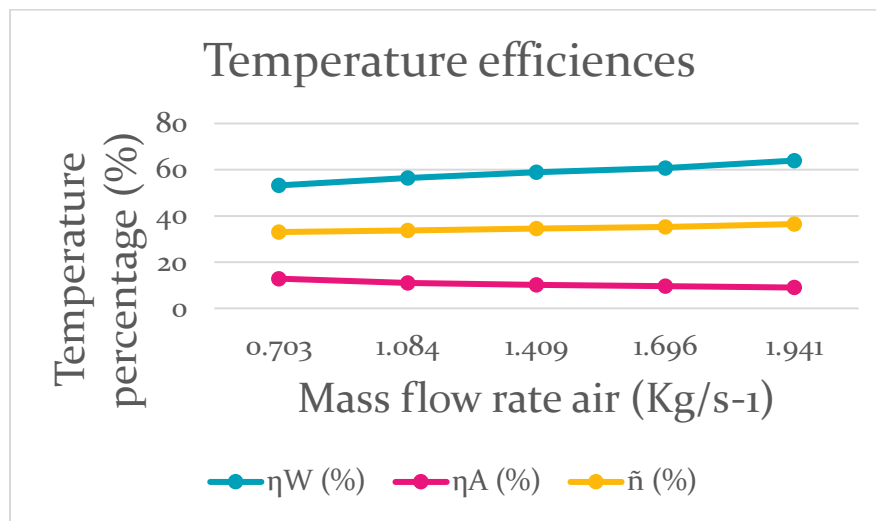
See Excel spreadsheet (Sheet 2) for results.

7.4 Graphs/Interpretation of data



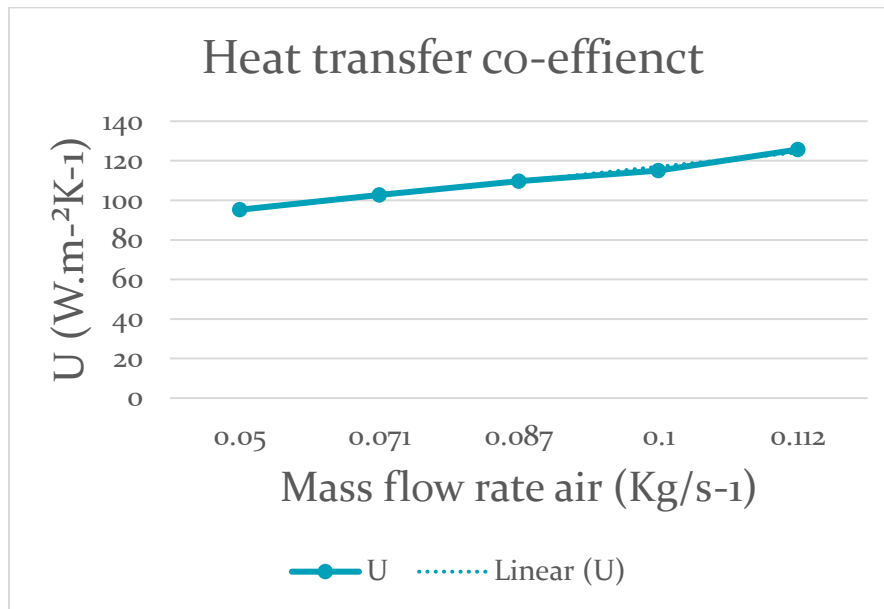
Graph 4: Heat omitted by the heat exchanger experiment(2).(Excel).

The above graph represents power transfer improves with the increased air flow rate; the gradients are fairly linear. At reduced airflows there are increased losses this could be due to the duct or body of the heat exchanger conducting some of the heat energy away. However, this has affected the energy balance co-efficient during this exercise. At 0.100 Kg/s^{-1} the two energies converge at the external losses become less dominate. As this experiment does not level off completely one can assume that increasing air flow rate could further improve heat transfer. (TecQuipment Ltd, 2014).



Graph 5: Temperature efficiencies experiment(2).(Excel).

The above graph shows that with increased air flow air efficiencies decrease while the water see a slight increase, however the range of efficiencies is similar over the given range ($0.703 > 1.941 \text{ Kg/s}^{-1}$). The mean efficiencies see a slight steady increase over increasing air flow. (TecQuipment Ltd, 2014).



Graph 6: Heat transfer co-efficient experiment(2).(Excel).

The above graph represents the heat transfer co-efficient the gradient is reasonably linear. From the data displayed one can assume that the increased air flow rate improves the performance of the heat exchanger. (*TecQuipment Ltd, 2014*).

8.0 Experiment (3) – The effect of varying temperature

8.1 Aim

To show how different hot water supply temperatures affect the performance of the heat exchanger for a given fixed water flow. (Assignment Handout, 2020)

8.2 Procedure

- Check connections are for parallel flow and set a heater tank temperature of 45°C . Water enters the bottom of the heat exchanger and exits from the top.
- Repeat Experiment 2 - The Effect of Varying Air Flow Rate. (*Assignment handout, 2020*).

8.2.1 Important notes

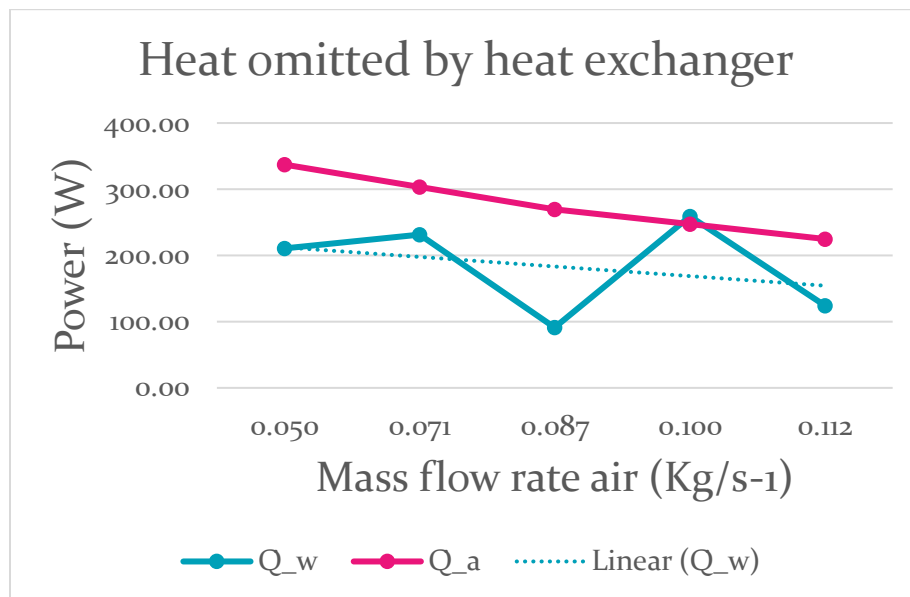
Allow at least five minutes for the heat exchanger temperatures to stabilize, then record all readings.

Your water and air flows may change slightly as you do the experiment, so regularly check them, and adjust, as necessary. (Assignment handout, 2020).

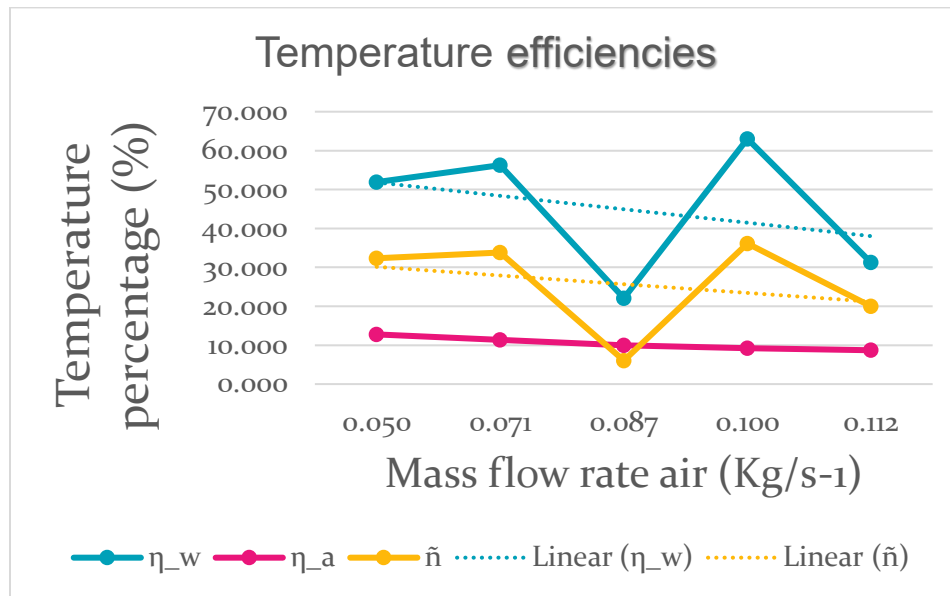
8.3 Results

See Excel spreadsheet (Sheet 3) for results.

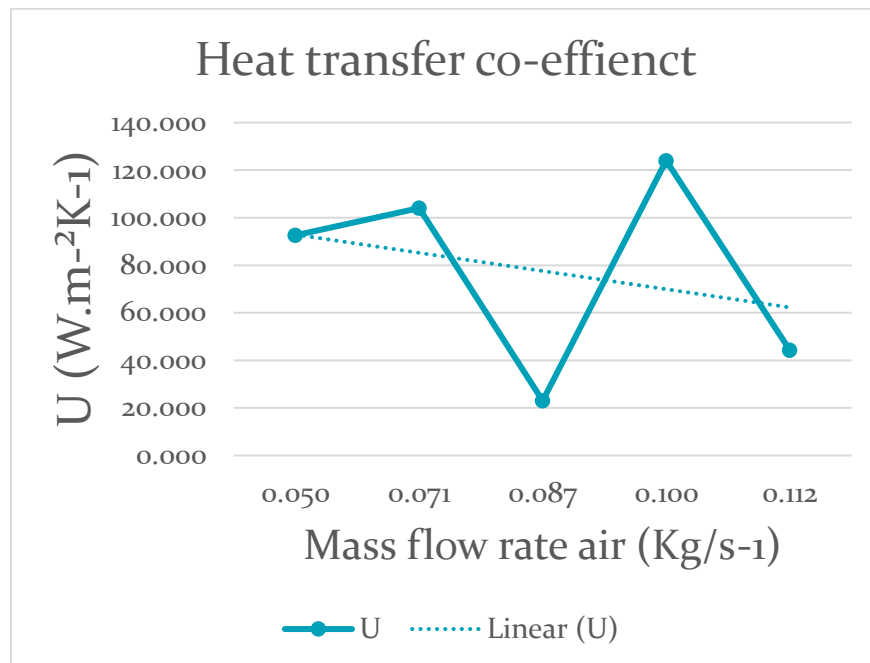
8.4 Graphs/Interpretation of data



Graph 7: Heat omitted by the heat exchanger experiment(3).(Excel).



Graph 8: Temperature efficiencies experiment(3).(Excel).



Graph 9: Heat transfer co-efficient experiment(3).(Excel).

Graphs 7-9 should have yielded similar results to experiment(2) however point 3 and 5 are in correct and do not support experiment (2) this is due to data being incorrectly recorded due to human error. One would assume that the gradient of all 3 graphs would correlate with experiment (2), but you would expect less power as there is less power being introduced into the system 25% less. All graphing data should be more linear than it currently is.

9.0 Improvement to improve performance

Heat exchanger enhancement can be achieved by the following passive techniques:

- Extended surfaces due to increased surface area. (fins)
- Inserts. Baffles.
- Coiled or twisted tubes, helical.
- Surface treatments and additives.

Heat exchanger enhancement can be achieved by the following active techniques:

- Surface vibration.
- Electrostatic fields.
- Injection.
- Suction.

Ultimately this improvement would have to be made and experiment completed again, only changing one variable at a time would be ideal to isolate what technique would make the biggest improvement.

9.0 Conclusion

If the experiment were to be completed again the following factors could be changed to gain more accurate results. Because of Covid-19, I did not personally carry out this lab session and can only make assumptions on the data provided, and research completed.

- Optimal heat exchanger is in experiment one at a mass flow rate of around 0.04 kg.s⁻¹.
- In-order to aid more accurate results each experiment should be completed 3 times and average readings taken.
- To eliminate human error, the VDAS system could be used in the future this would allow the experiment to be recorded with a push of a button rather than noting results on paper which evidently allows errors to occur. This would come at an extra cost for the system.

Hot Flow (L/Min)	T _{w1}	T _{w2}	ΔT_w	Average T_w
250	45.9	38.7	-7.2	42.3
200	47.1	32.1	-15	39.6
150	47.4	52.7	5.3	50.05
100	47.8	34.4	-13.4	41.1
50	48.1	35.9	-12.2	42

- Human error can be further proved because row 3 of the above table shows a temperature increase when you would expect a temperature decrease as the rest of the rows confirm.
- One can assume that allowing more than 5 minutes between each result allowing thermal equilibrium would aid better results..
- Cleaning out the machine and adding new water to the system could also aid in the performance and help with the fouling factor.

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