Lab Experiment 2: Heat Exchangers

Section 23L

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Adam VanBuskirk: Equipment Operation, Data Uncertainty Analysis
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Jacob Klofta: Data and Uncertainty Analysis, , Discussion, Design Objective
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Experiment Performed: March 6, 2019
Report Submitted: March 20, 2019

Objectives:
A1 & AA1:

- To observe and measure the heat transfer processes in a basic heat exchanger.
- To observe and use the basic relation between thermal power, fluid flow, and temperature change in a fluid heating process.

Summary:

Supermini Gaming Computers, Inc
30th Floor Room X
BeatOurComputer Casino
Las Vegas, Nevada

Given the restraints governing the project, we have determined that this heat exchanger is an adequate cooling solution for your circuit board. According to our tests, the flow rate of the cooling water is the limiting factor in providing the necessary cooling, which can be seen in our analysis attached below. The board requires 5000 W to be able to be absorbed by the exchanger, which can be done through the tube walls which alone can handle up to 5590 W. These calculations were completed using the upper limits of the provided constraints to ensure that there will be no issues within the normal operating

We are available to continue offering our consultation services should you choose to do so. Thank you for requesting our consultation.

Sincerely,
MEEG346-010 Team A1
Mechanical Engineering Dept.

Theoretical Background:
A1:

Two fluid heat exchangers are used extensively throughout the world, across many different types of applications. They are present in automobiles, air conditioning units, and even biologically (lungs and artery systems). In this experiment the exchanger was operating in countercurrent mode. The biggest difference in using this type of flow is that the difference in the exit temperatures is greater than the difference in entrance temperatures. The formula describing these temperatures and their respective flow rate is as follows:

$$Q = m_h C_{ph}(T_{h,i} - T_{h,o}) = m_c C_{pc}(T_{c,i} - T_{c,o})$$

Equation 1: Equation relating flow rate with mass, specific heat, and temperature change.

The heat transfer through tube walls is also very important. This is dependent on both the material conductivity and convection heat transfer coefficients. Since the temperature change varies along the tube's length, temperature change can be expressed as the log mean temperature difference (LMTD):

$$Q = UA\Delta T_{lm} \qquad \Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{ln(\Delta T_2/\Delta T_1)}$$

Equations 2 & 3: Flow rate equation from heat transfer coefficient, surface area, and LMTD (Left). The log mean temperature difference formula (LMTD) which expresses the temperature difference logarithmically.

AA1

The theory for the second experiment is identical to the first, except that for in this experiment, a parallel heat exchanger setup is used. The biggest difference in using this type of flow is that the difference in the entrance temperatures is now greater than the difference in exit temperatures. The formula describing these temperatures and their respective flow rate is as follows:

$$Q = m_h C_{ph}(T_{h,i} - T_{h,o}) = m_c C_{pc}(T_{c,i} - T_{c,o})$$

Equation 1: Equation relating flow rate with mass, specific heat, and temperature change.

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Equations 2 & 3: Flow rate equation from heat transfer coefficient, surface area, and LMTD (Left). The log mean temperature difference formula (LMTD) which expresses the temperature difference logarithmically.

Equipment:

Both experiments in this lab use the same simple shell-and-tube heat exchanger. The hot water travels through the tubes, and the cold water flows around it inside the shell. The cold water comes from the sink and is not recirculated. The heater element heats the hot flow in the tall vertical cylinder and pumps it through the silver exchanger pipes. The countercurrent flow experiment has the hot and cold water flowing against each other, while the parallel experiment has the different temperatures flowing in the same direction.

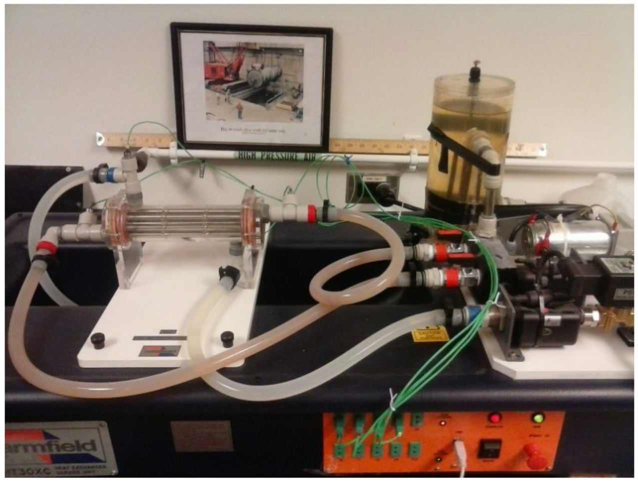

Figure 1: Simple open-loop shell-and-tube heat exchanger used in both A1 and AA1.

Procedure:

A1

Operates experiment in countercurrent flow configuration

AA1

Operates experiment in parallel flow configuration

Both

1. Examine the equipment, identifying cold and hot fluid inlets and outlets. Cold fluid is taken from sink and discharged to sink drain. Hot water recirculates and a thermostat controls the heater element to set point temperature.
2. Examine the control computer monitor screen, and find where data is displayed, and how you can change temperature set point and fluid flow rates.
3. Note the direction of flow, T1→T2 is hot water. T3 and T4 is cold water and the direction depends on whether it is counterflow or parallel flow.
4. Adjust the hot flow rate to 3 L/min and the cold flow rate to 1 L/min.
5. When flows and temperatures are reasonably steady, record them.
6. Maintain inlet hot water temperature at 60°C and change the cold flow rate to match 3 L/min.
7. At steady state, record all temperatures and flows.
8. Stop the system flows, turn off the water heater and sink.

Results:

Parallel-Flow	**Temperatures (°C)**
Hot Inlet	62
Hot Outlet	58

Cold Inlet	20.8
Cold Outlet	33.0

Table 1: Temperature readings for parallel flow tests. Per instruction, only one trial was conducted in parallel flow, with a cold flow rate of 1 L/min.

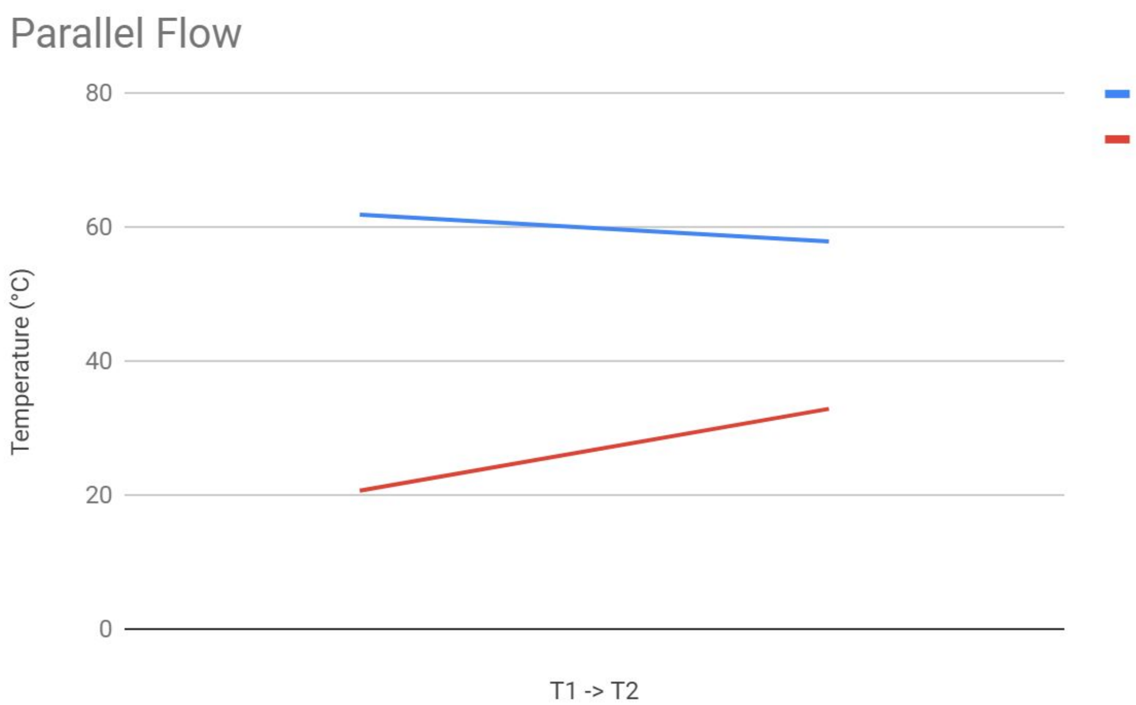

Chart 1: Plot of inlet and outlet temperatures of Hot water (blue line) and Cold water (red line) for parallel flow where the cold water flow rate is 1 L/min and the hot water flow rate is 3 L/min.

Counter-Flow	**Temp 1 (°C)**	**Temp 2 (°C)**
Hot Inlet	63.2	58.5
Hot Outlet	59	52.4
Cold Inlet	20.8	19.3
Cold Outlet	33	24.8

Table 2: Temperature readings for counter-flow tests. Temp 1 refers to cold flow of 1 L/min, Temp 2 refers to cold flow of 3 L/min.

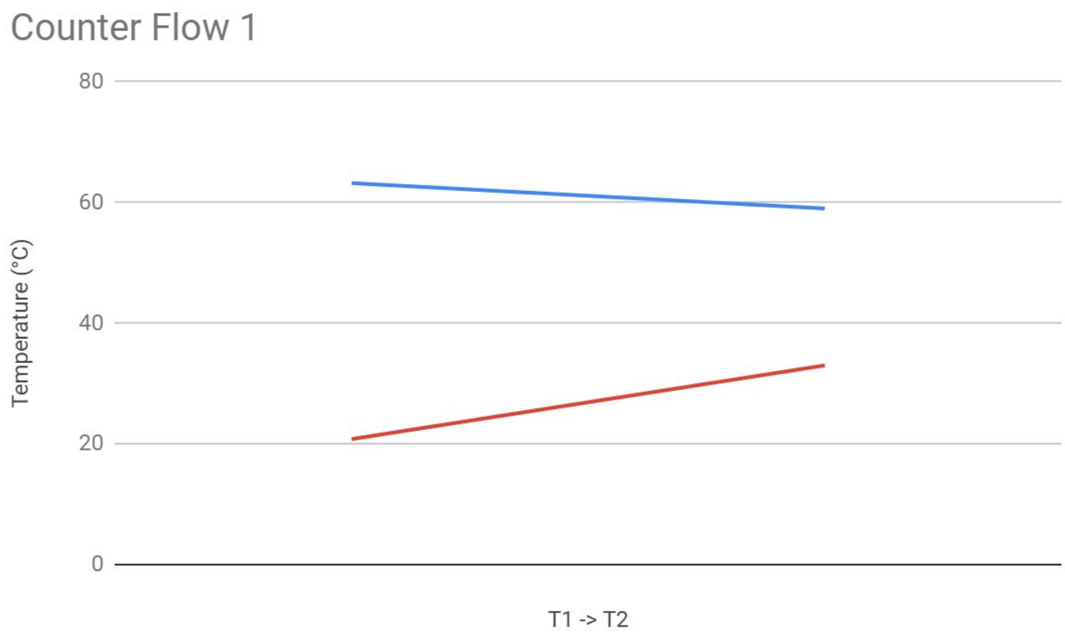

Chart 2: Plot of inlet and outlet temperatures of Hot water (blue line) and Cold water (red line) for parallel flow where the cold water flow rate is 1 L/min and the hot water flow rate is 1 L/min.

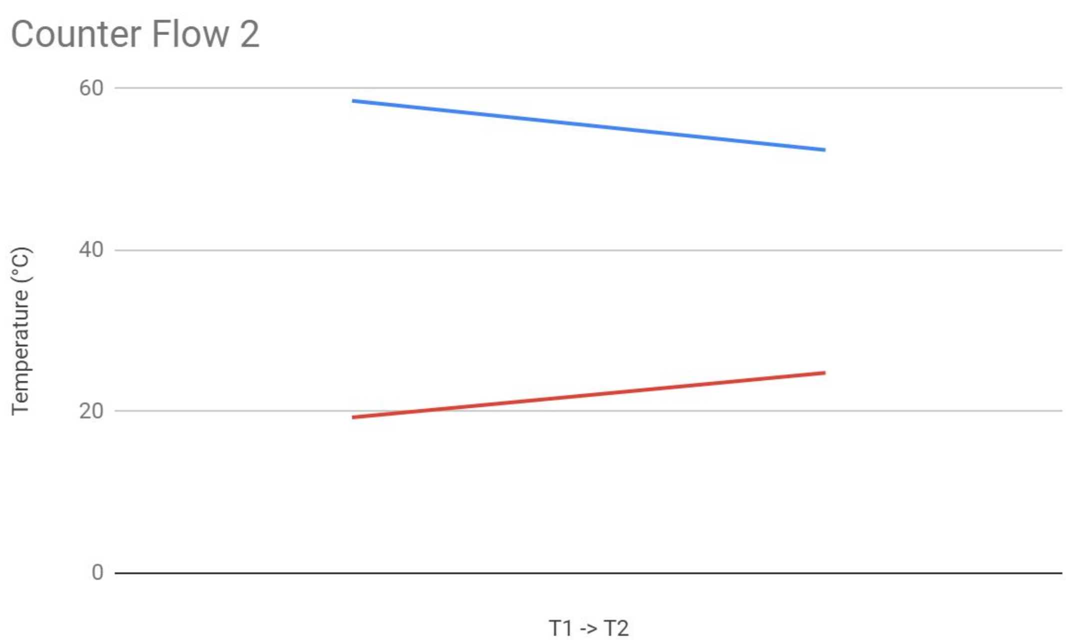

Chart 2: Plot of inlet and outlet temperatures of Hot water (blue line) and Cold water (red line) for parallel flow where the cold water flow rate is 3 L/min and the hot water flow rate is 3 L/min.

Parallel Flow	1	
Delta T_h	4 K	
Delta T_c	12.2 K	
Q_h	857 W	
Q_c	871 W	
Efficiency	.9801	
Delta T_lm	32.93 K	
A	.01821 m^2	
U	1429.2 J/m^2Ks	
Counter-Flow	**1**	**2**
Delta T_h	4.2 C	6.1 C
Delta T_c	12.2 C	5.5 C
Q_h	900 W	1307 W
Q_c	871 W	1178 W
Efficiency	0.9677	0.9013
Delta T_lm	34.04 C	33.4 C
A	.01821 m^2	.01821 m^2
U	1405.1 J/m^2Ks	1936.21 J/m^2Ks

Table 3: Values for all calculated variables using equations 2 and 3 specifically to find U. All calculations can be found in Appendix C.

Uncertainty Analysis:

$$\Delta Q = c_p\sqrt{((T_i - T_o)\Delta m)^2 + (m\Delta T_i)^2 + (m\Delta T_o)^2}$$

$$\Delta T_i = \Delta T_o = 0.1C$$

$$\Delta m = 0.1\ L/min = 0.00167\ kg/s$$

Trial 1: $\Delta Q = 41.3\ W$, 4.7%

Trial 2: $\Delta Q = 33.5\ W$, 3.8%

Trial 3: $\Delta Q = 52.4\ W$, 4.5%

The uncertainty values for the mass flow rate and temperatures are dictated by the accuracy of the reporting software. The value of c_p is assumed constant for this experiment and therefore there is no uncertainty involved. Additional uncertainty could have developed from taking readings before reaching steady state, or a fluctuating mass flow rate, as the control was very responsive to even the slightest adjustment. Sample calculations for how these values were obtained can be found in Appendix D.

Discussion & Conclusion:

The experimental data shows that one specific configuration yielded the most efficient cooling solution: when the hot and cold flow rates were equal and in counter-current flow. This orientation provided the lowest outlet temperatures for both hot and cold flows, so this solution was chosen to model the most efficient exchanger for the circuit board. It has been observed that while the heat transfer coefficient for this test is the highest, the efficiency is lowest. We are unsure how to account for this difference, but we believe this to be a factor of the flow rate, as the flow direction did not affect the efficiency at a lower mass flow rate. However, even the lowest efficiency of 0.90 shows that this type of heat exchanger is generally very efficient, even when not tailored for optimum performance.

Design Objective Analysis:
Refer to Appendix E for all mentioned calculations and values.

The heat exchanger with the given flow rate will be capable of removing the higher heat load required. The numerical value of the minimum heat that the tubes must be input and output was calculated to be 5 kW. Based on the given maximum limits the cold tube shell can absorb 5.59 kW of heat. The handwritten calculations done conclude that the hot tubes can transmit the same amount of heat as well. However, we believe the hot tubes are capable of outputting larger amounts of heat if needed and that this is not a limiting factor based on the overall heat transfer coefficient. In addition, the amount of heat that can be transmitted by the tubes can be increased by minimizing the value of Tho which has no set limit from the given parameters. A value of 55C was chosen for this variable to most closely resemble the relationship between hot and cold flows seen in our experiment. The U value of 1.405 kJ/(K*s*m^2) was the minimum value calculated for counterflow in our experiment. This value was used for calculations as the higher U value may not be valid for the reduced flow rate. The amount of heat that can be conducted through the tube walls was calculated to be 18.12 kW. Therefore, among all the cooling elements in the heat exchanger, the required 5000 W can easily be cooled by this solution.

Appendix A: Lab Roles

Lab Section 23 Experiment # 2 Date 3/6

Note: Roles must be agreed on before work starts. Every team member must be represented. It is a commitment. The roles should be rotated for each experiment. Each role in principle has a specific contribution (page or paragraph) to create for the report.

	Name
Team Leader/ Coordinator	BG
Theoretical and Procedure write up	JDS
Equipment operation (1 or more)	AV
Data recorder	JDS
Equipment diagram (sketch or photo. Include instrumentation)	AV
Graphs, data tables for report (2 people)	BG/JDS
Data & Uncertainty analysis for report (2 people)	AV/JK
Discussion and Conclusion	JK
Summary Letter	BG
Report typing and compilation	KR
Design Objective Analysis (2 people)	JK KR

TA initial CK

Appendix B: Data Sheets

parallel flow

	COLD FLOW = 1 L/min HOT FLOW = 3 L/min	~~COLD FLOW MAX = 4 L/min~~ ~~HOT FLOW = 4 L/min~~
T_1 - hot ~~inlet~~ outlet	58C ~~62C~~	
T_2 - hot ~~outlet~~ inlet	62C	
T_3 - cold inlet	20.8C	
T_4 - cold outlet	33.0C	

Counter current		COLD FLOW = 3 L/min HOT FLOW = 3 L/min
T_1 - hot inlet	63.2 C	58.5C
T_2 - hot outlet	59 C	52.4 C
T_3 - cold inlet	20.8 C	19.3 C
T_4 - cold outlet	33 C	24.8 C

CK

Appendix C: Analysis Calculations

$T_{h,i} = 58.5°C$

$T_{h,o} = 52.4°C$ $\Big\rangle\, \Delta T_H = 6.1\ C\ (K)$

$T_{c,i} = 19.3°C$

$T_{c,o} = 24.8°C$ $\Big\rangle\, \Delta T_c = 5.5C\ (K)$

$$Q_h = \left(3\frac{L}{min}\right)\left(\frac{min}{60s}\right)\left(\frac{1kg}{L}\right) \cdot 4.2\frac{kJ}{kg \cdot K} \cdot 6.1\ K = 1.307\ kW$$

$$Q_c = \left(3\frac{L}{min}\right)\left(\frac{Min}{60s}\right)\left(\frac{1kg}{L}\right) \cdot 4.2\frac{kJ}{kg \cdot K} \cdot 5.5K = 1.178\ kW$$

$$\text{efficiency} = \frac{Q_{min}}{Q_{max}} = \frac{Q_c}{Q_h} = \frac{1.178\ kW}{1.307\ kW} = 0.9013$$

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

$$\Delta T_1 = T_{h,i} - T_{c,o} = 58.5 - 24.8 = 33.7\ K$$

$$\Delta T_2 = T_{h,o} - T_{c,i} = 52.4 - 19.3 = 33.1\ K$$

$$\Delta T_{lm} = \frac{33.1 - 33.7}{\ln\left(\frac{33.1}{33.7}\right)} = 33.4\ K$$

$$A = 7\pi\left(\frac{d_i + d_o}{2}\right)L = 7\pi\left(\frac{0.00515m + 0.00635m}{2}\right)(0.144m)$$

$$A = 0.01821 m^2$$

$$U = \frac{Q_{min}}{A \Delta T_{lm}} = \frac{1178W}{(.01821m^2)(33.4K} = 1936.2\ \frac{J}{m^2 \cdot K \cdot S}$$

Appendix D: Uncertainty Calculations

$$\Delta Q = C_p \sqrt{\left((T_i - T_o)\Delta m\right)^2 + (m \Delta T_i)^2 + (-m \Delta T_o)^2}$$

$$\Delta Q = \left(4.2 \frac{kJ}{kg\,K}\right) \sqrt{\left((62-58)(.00167 \tfrac{kg}{s})\right)^2 + \left((.051 \tfrac{kg}{s})(0.1)\right)^2 + \left(-0.51 \tfrac{kg}{s} \cdot 0.1\right)^2}$$

$$\Delta Q_1 = 0.0413\ kW = 41.3\ W$$

$$\frac{\Delta Q_1}{Q} = \frac{41.3W}{871W} = 4.74\%$$

$$\Delta Q_2 = 33.5W$$

$$\frac{\Delta Q_2}{Q} = \frac{33.5W}{871W} = 3.8\%$$

$$\Delta Q_3 = 52.4W$$

$$\frac{\Delta Q_3}{\Delta Q} = \frac{52.4W}{1178W} = 4.48\%$$

Appendix E: Design Objective Calculations

Design objective analysis calculations

$0.5\,m^2\left(\frac{100\,cm}{m}\right)^2 = 5000\,cm\left(\frac{1\,Watt}{cm^2}\right) = 5\,kW$

$Q_{actual} = 5\,kW$

Cold side

$Q_C = 2\,\frac{L}{Min} \times \frac{1\,kg}{L} \cdot \frac{1\,min}{60\,s} \times 4.19\,\frac{kJ}{kg \cdot K} \cdot (60\,K - 20\,K) = 5.59\,kW$

Hot side

$Q_H = 2\,\frac{L}{min} \times \frac{1\,kg}{L} \times \frac{1\,min}{60\,s} \times 4.19\,\frac{kJ}{kg \cdot K}(95\,K - 55\,K) = 5.59\,kW$

Conduction through tube walls

$U = 1.405\,\frac{kJ}{m^2 K s}$ ← lowest for counterflow

$A = 0.5\,m^2$

$\Delta T_m = (\Delta T_2 - \Delta T_1) / \ln(\Delta T_2 - \Delta T_1) = (75 - 5)/\ln(75/5)$

$\Delta T_m = 25.8\,K$

$Q = UA\Delta T_m = \left(1.405\,\frac{kJ}{m^2 K s}\right)(0.5\,m^2)(25.8\,K)$

$Q = 18.12\,kW$