ENGRD 2210 Portfolio Project: Heat Exchanger

Project Overview

In this project, I analyzed the performance of a small-scale liquid–liquid heat exchanger used in ENGRD 2210. The goal was to understand how heat exchanger performance depends on flow configuration (parallel flow versus counterflow) and operating conditions, specifically flow rate. I used temperature measurements collected during the experiment to evaluate heat transfer behavior and overall effectiveness.

Device Description and Real-World Context

Heat exchangers transfer thermal energy between two fluid streams without allowing them to mix. They can be used to either heat a colder fluid, such as warming water in a home heating system, or cool a hotter fluid, such as removing heat from an engine or power plant.

Heat exchangers are commonly used in automotive radiators, HVAC systems, power plants, and electronics cooling systems. Even though the heat exchanger used in this experiment was small and designed for lab use, it operates using the same basic thermodynamic principles as larger industrial heat exchangers.

Experimental Setup

The experimental setup consisted of a heat exchanger connected to two separate water loops. For the hot loop, water was heated using an immersion heater in a reservoir and circulated through the heat exchanger using a pump. For the cold loop, water was cooled using ice in an insulated reservoir and circulated using a second pump.

I tested the heat exchanger in both parallel flow and counterflow configurations. For each configuration, I ran the system at fast and slow pump speeds. After the system reached steady state, I recorded the inlet and outlet temperatures for both the hot and cold streams.

Modeling Assumptions

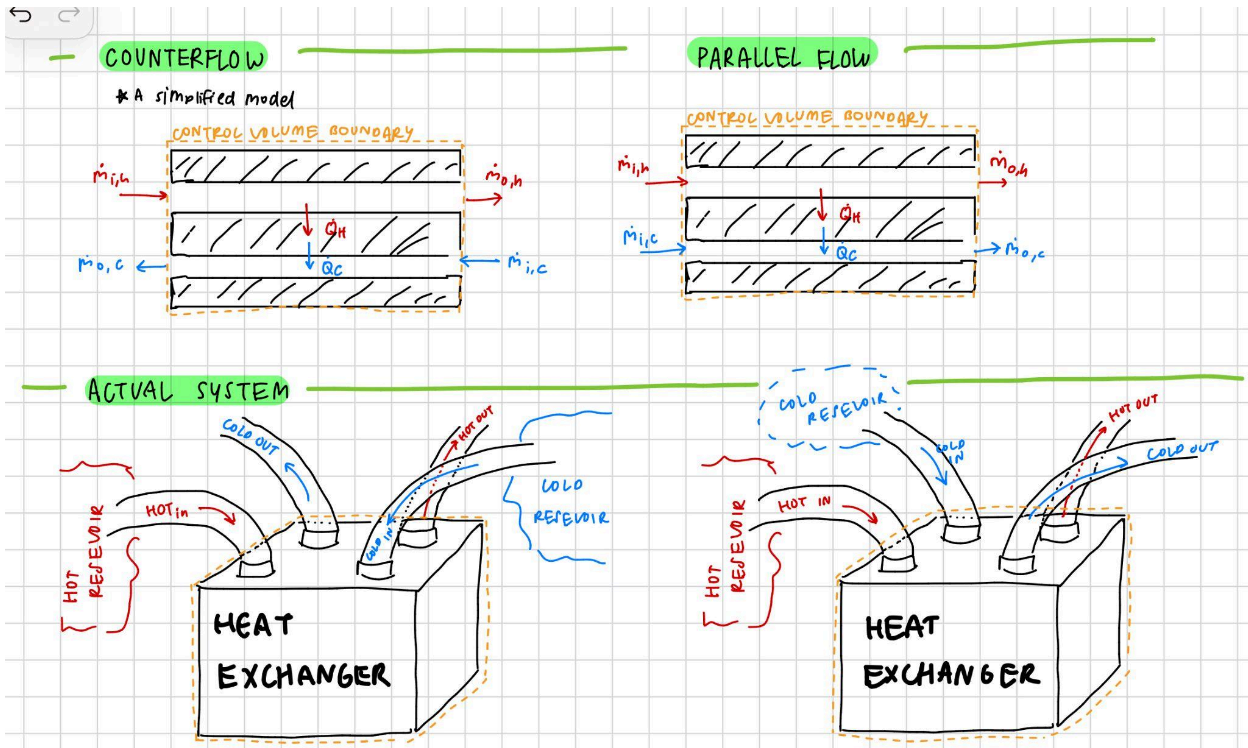
To simplify the analysis, I made the following assumptions:

- The system operates at steady state
- Mass flow rates are constant during each trial
- Water properties remain constant
- Kinetic and potential energy changes are negligible
- No shaft work is done
- Heat losses to the surroundings are small

System Model: Control Volume

I modeled the heat exchanger as a **steady-state control volume**. Mass enters and leaves the system through separate hot and cold flow paths, and heat is transferred internally between the two fluid streams. No work interactions were considered, and heat transfer with the surroundings was assumed to be small.

This control-volume approach is appropriate because the system involves continuous fluid flow and steady inlet and outlet conditions, rather than tracking a fixed amount of fluid over time.



Experimental Data

Table 1 – Measured Temperatures

Flow Type	Flow Rate	Hot Inlet (°C)	Hot Outlet (°C)	Cold Inlet (°C)	Cold Outlet (°C)
Parallel	Fast	43.0	31.8	17.5	29.3
Parallel	Slow	42.8	30.5	21.6	28.9

Counter	Fast	44.8	28.2	18.0	31.8
Counter	Slow	45.6	25.3	13.8	33.4

Table 2 – Temperature Changes

I calculated the temperature change for each stream as:

$$\Delta T_h = T_{h,i} - T_{h,o}, \qquad \Delta T_c = T_{c,o} - T_{c,i}$$

Flow Type	Flow Rate	Hot ΔT (°C)	Cold ΔT (°C)
Parallel	Fast	11.2	11.8
Parallel	Slow	12.3	7.3
Counter	Fast	16.6	13.8
Counter	Slow	20.3	19.6

Heat Exchanger Effectiveness

I estimated the effectiveness of the heat exchanger using:

$$\varepsilon = \frac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}}$$

This represents how much of the maximum possible temperature change of the hot fluid was actually achieved.

Table 3 – Effectiveness

Flow Type	Flow Rate	Effectiveness
Parallel	Fast	0.44
Parallel	Slow	0.58
Counter	Fast	0.62
Counter	Slow	0.64

Log Mean Temperature Difference (LMTD)

During heat exchange, the temperature difference between the hot and cold fluids changes along the length of the exchanger. To account for this, I used the **log mean temperature difference (LMTD)**, which provides an average temperature difference that better represents the actual heat transfer process.

For **parallel flow**, I calculated LMTD using:

$$\Delta T_{lm,p} = \frac{(T_{h,i} - T_{c,i}) - (T_{h,o} - T_{c,o})}{\ln\left(\frac{T_{h,i}-T_{c,i}}{T_{h,o}-T_{c,o}}\right)}$$

For **counterflow**, the equation becomes:

$$\Delta T_{lm,c} = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln\left(\frac{T_{h,i}-T_{c,o}}{T_{h,o}-T_{c,i}}\right)}$$

Table 4 – LMTD Results

Flow Type	Flow Rate	LMTD (°C)
Parallel	Fast	9.8
Parallel	Slow	7.4
Counter	Fast	11.5
Counter	Slow	11.8

The counterflow cases had higher LMTD values, which means the temperature difference driving heat transfer stayed more consistent throughout the exchanger.

Entropy Generation Analysis

Since water is flowing continuously, I modeled the heat exchanger as a control volume. For each trial, I calculated the entropy change of the hot and cold streams and used this to estimate entropy generation, which represents irreversibility in the heat exchanger.

The entropy change for a stream of water at constant c_p is:

$$\Delta S = mc_p \ln \frac{T_o}{T_i}$$

For steady-flow (mass flow rate $\dot{m}$), the entropy generation rate is:

$$\dot{S}_{gen} = \dot{m}_h c_p \ln \frac{T_{h,o}}{T_{h,i}} + \dot{m}_c c_p \ln \frac{T_{c,o}}{T_{c,i}}$$

I assumed $c_p = 4.18\ \mathrm{kJ/(kg \cdot K)}$ and $\dot{m}_h = \dot{m}_c = 0.01\ \mathrm{kg/s}$

The entropy generation rates ($\dot{S}_{gen}$) for each case, using the measured temperatures, are:

Flow Type	**Flow Rate**	$\dot{S}_{gen}\ [\mathrm{kW/K}]$
Parallel	Fast	0.000125
Parallel	Slow	0.000212
Counter	Fast	0.000243
Counter	Slow	0.000414

Discussion

I saw that counterflow gave bigger temperature changes and higher effectiveness than parallel flow because the hot fluid stays in contact with colder fluid along the whole exchanger. Slower flow rates increased heat transfer since the fluids spent more time in the exchanger.

When I looked at entropy generation ($\dot{S}_{gen}$), I noticed it was higher for slower flow rates and slightly higher for counterflow. This shows that more heat transfer also comes with more irreversibility, which makes sense because larger temperature differences increase entropy production.

These results connect to the real world because counterflow heat exchangers are widely used in things like car radiators, HVAC systems, and industrial process heaters, where maximizing heat transfer while controlling inefficiency is important. Understanding how flow rates affect both heat transfer and entropy generation helps engineers design systems that are effective but not unnecessarily wasteful.

Reflection

This project helped me understand energy balances, steady-state assumptions, and heat exchanger effectiveness in real systems. Calculating entropy generation showed how real systems are never perfectly efficient. Overall, the experiment explained why counterflow heat exchangers are common and how flow rates affect both performance and thermodynamic losses.