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Description: What is a Heat Exchanger: A heat exchanger is a device that transfers thermal energy between two fluids without allowing them to mix or come in direct contact. The way this works is that each fluid flows through its own passages that share a common wall made of thermally conductive material, in most cases, it's metal. For example, the hotter fluid flows on one side of this wall and the cooler fluid flows on the other side, ensuring that there isn't any mixing happening. Since heat naturally flows from high temperature to low temperature, energy leaves the hot fluid, passes by conduction through the wall, and then enters the cold fluid by convection. As a result, the hot stream is cooled and the cold stream is warmed. In our example, the passages can be defined in two ways: as a parallel flow both fluids move in the same direction, while in counterflow, they move in opposite directions. In the majority of cases, the counter-flow allows for more efficient heat transfer because the temperature difference between the streams stays larger along the length of the exchanger. In addition, some heat exchangers don't just have a flat wall between the liquids; there could be extra shapes on the surface. An example of these shapes is extra plates, fins, and corrugations; these shapes increase the amount of surface area where the hot and cold fluids touch the metal. This is important because the more surface area there is, the more room for heat to flow across, allowing for better heat transfer. Moreover, some applications of heat exchangers in the real world are automotive radiators, refrigerators, HVAC systems, and power plants. As all these systems are considered heat exchangers to help hit their ultimate goal of transferring thermal energy.

Supplies:

1. One heat exchanger
2. Two water pumps
3. Four water buckets
4. Ice
5. Water
6. Styrofoam (insulative material)
7. One thermocouple
8. Four thermometer
9. Food dye

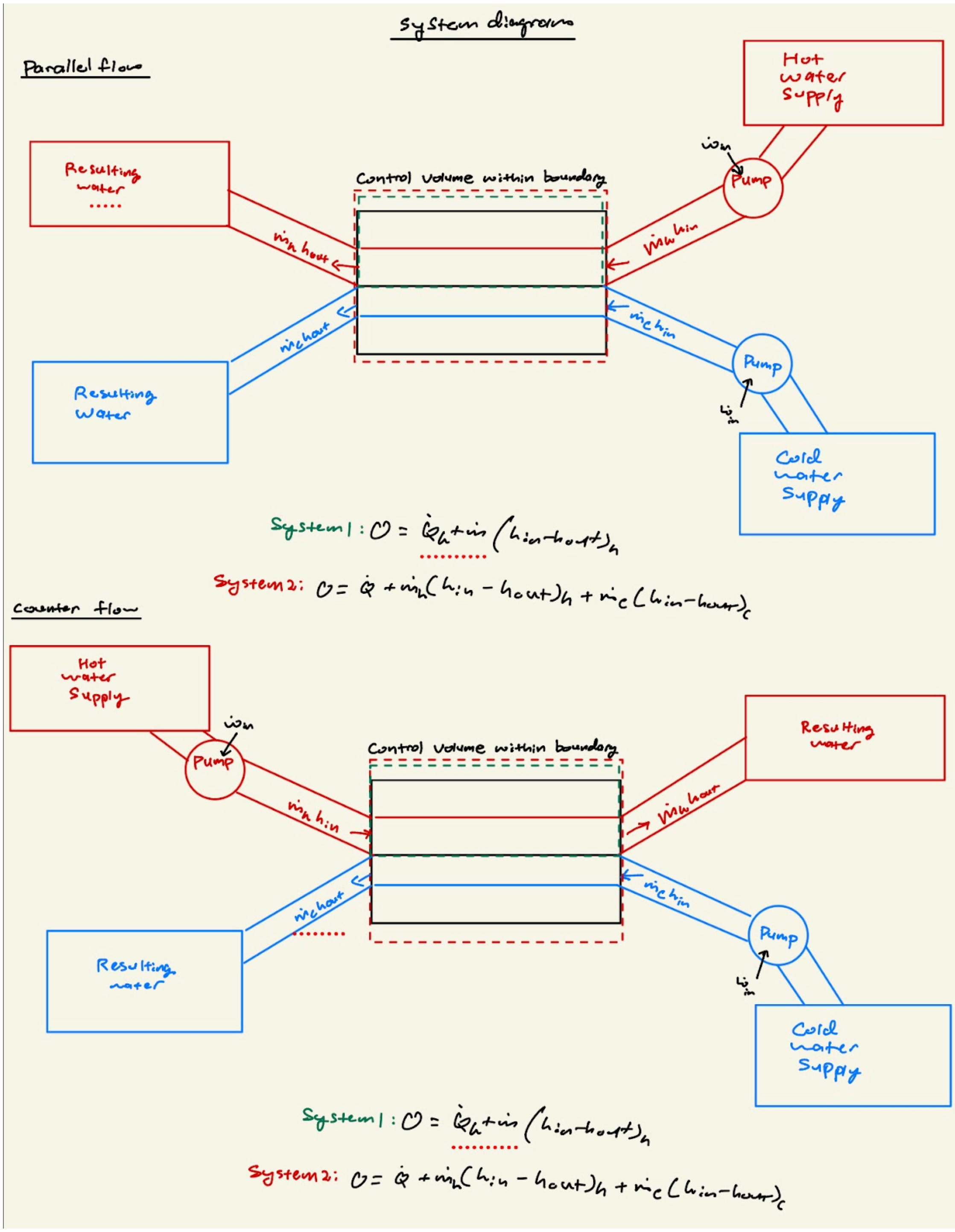
Discussion Prompt:

Please select a real-world instance of a device or system that we have learned about in this course, explain how it works in detail, and then discuss how its performance would change under a change in design or operating conditions. Your report should include:

• photos and schematics of the device or system
• a qualitative description of the device or system
• a system diagram of the device or system operating (either CV or CM), showing

work and heat transfer interactions as well as any relevant mass flows
• mass balance, energy balance, and entropy balance equations (as relevant) capturing the physics more central to the device or system operation

System diagram:



Data:

Initial temps:

*Both on High flow

Trial 1: 22.95 s * Parallel flow

Temp before

cold: 280°K

Hot: 40.9°C +273 K = 313.9 K

Temp after

cold: 294.0 K

Hot: 297.3 K

Trial 2: 22.18 s * Counter flow

Temp before:

cold: 283.0 K

Hot: 34°0C+273 = 307.0 K

Temp after:

cold: 295.1 K

Hot: 292.4 K

Hot High flow, cold low flow (Absolute flow rate change)

Trial 1: 22.51s * parallel flow

Temp before

cold: 282.6 K

Hot: 34.1 °C + 273 =

Temp after

cold: 294.2 K

Hot: 296.2 K

} considerably less cold volume outflow

Trial 2: 22.95 * Counter flow

Temp before:

cold: 282.5 K

Hot: 35 °C + 273 =

Temp after:

cold: 293.9 K

Hot: 290.5 K

- Hot tube seemed to be pinched due to tubing folding.

Results:

System: Control volume boundary around heat exchanger

Assumptions: adiabatic, steady state, water is an incompressible substance ($c_p = 4184\ \frac{J}{KgK}$), neglect change in kinetic and potential energies

Pump Model: Vivosun aquapump (210 gallons per hour)

$$210\ G/h \leftarrow \frac{\text{Volume}}{\text{time}} = \text{Area} \times \text{velocity}$$

$$Av = 2.20816 \times 10^{-4}\ \frac{m^3}{s}$$

$$\rho_{water} = 1000\ Kg/m^3$$

$$\dot{m} = \rho A v$$

$$= \left(1000\ \frac{Kg}{m^3}\right)\left(2.20816 \times 10^{-4}\ \frac{m^3}{s}\right)$$

$$\boxed{\dot{m} = 0.220816\ \frac{Kg}{s}}$$

Trial 1: (Parallel Flow) time = 22.95 s

	before	after
Hot	313.9K	294K
Cold	280K	297.3K

Mass balance: $\dot{m}_{cv} = 0$ because steady state, so $\dot{m}_{in} = \dot{m}_{out}$ for both hot and cold reservoirs since the compressors were at the same setting (maximum positive flow). $\dot{m}_c = \dot{m}_h$

Energy balance: $\cancel{\dot{E}}^{\,0} = \dot{Q} - \cancel{\dot{W}}^{\,0} + \Sigma \dot{m}_{in} h_{in} - \Sigma \dot{m}_{out} h_{out}$

$$0 = \dot{Q} + \dot{m}_h (h_{in\text{-}h} - h_{out\text{-}h}) + \dot{m}_c (h_{in\text{-}c} - h_{out\text{-}c})$$

$$\dot{Q} = \dot{m}(h_{out\text{-}h} - h_{in\text{-}h} + h_{out\text{-}c} - h_{in\text{-}c}) = \dot{m}\left(c_p(T_{out\text{-}h} - T_{in\text{-}h}) + c_p(T_{out\text{-}c} - T_{in\text{-}c})\right) = \dot{m} c_p (T_{out\text{-}h} - T_{in\text{-}h} + T_{out\text{-}c} - T_{in\text{-}c})$$

$$= \left(0.220816\ \frac{Kg}{s}\right)\left(4184\ \frac{J}{KgK}\right)(294K - 313.9K + 297.3K - 280K)$$

$$= -2402\ \frac{J}{s}$$

$$= -2.4\ KW$$

This value corresponds to the heat transfer of the heat exchanger.

Efficiency: $\varepsilon = \frac{|\dot{Q}_{transferred}|}{|\dot{Q}_{theoretical}|}$

$$\dot{Q}_{transferred} = \dot{m} c_p (T_{out\text{-}h} - T_{in\text{-}h}) = \left(0.220816\ \frac{Kg}{s}\right)\left(4184\ \frac{J}{KgK}\right)(313.9K - 294K)$$

$$= -18.385\ KW$$

$$\dot{Q}_{theoretical} = \dot{m} c_p (T_{in\text{-}h} - T_{in\text{-}c}) = \left(0.220816\ \frac{Kg}{s}\right)\left(4184\ \frac{J}{KgK}\right)(313.9K - 280K)$$

$$= -31.320\ KW$$

$$\varepsilon_{\parallel} = \frac{18.385\ KW}{31.320\ KW}$$

$$\boxed{\varepsilon_{\parallel} = 0.587 = 58.7\%}$$

Trial 2: (Counterflow) 22.18 s

	before	after
Hot	307K	292.2K
Cold	283K	295.1K

$$\dot{Q}_{transferred} = \dot{m} c_p (T_{out\text{-}h} - T_{in\text{-}h}) = \left(0.220816\ \frac{Kg}{s}\right)\left(4184\ \frac{J}{KgK}\right)(292.2K - 307K)$$

$$= -13.674\ KW$$

$$\dot{Q}_{theoretical} = \dot{m} c_p (T_{in\text{-}h} - T_{in\text{-}c}) = \left(0.220816\ \frac{Kg}{s}\right)\left(4184\ \frac{J}{KgK}\right)(307K - 283K)$$

$$= 22.173\ KW$$

$$\varepsilon_{counter} = \frac{13.674\ KW}{22.173\ KW}$$

$$\boxed{\varepsilon_{counter} = 0.6167 = 61.67\%}$$

From these trials, orienting the heat exchanger in counterflow is more efficient than parallel flow ($\varepsilon_{counter} > \varepsilon_{\parallel}$, 61.67% vs. 58.7%)

(Trial 1):
When running the experiment at the max flow rate of 0.220816 kg/s (210 GPH) in parallel flow, the initial temperature of the hot reservoir was 313.9K, and the initial temperature of the cold reservoirs of 280K. We found that the final temperature of the hot water reservoir was 297.3K, and the final temperature of the cold reservoir was 294.0K. These two temperatures are relatively similar and thus verify the function of the heat exchanger, where heat is transferred from the hot reservoir to the cold reservoir.

(Trial 2):
When running the experiment at the max flow rate of 0.220816 kg/s (210 GPH) in counter flow, the initial temperature of the hot reservoir was 307.0K, and the initial temperature of the cold reservoirs of 283.0K. We found that the final temperature of the hot water reservoir was 295.1K, and the final temperature of the cold reservoir was 292.4K. These two temperatures are relatively similar and thus verify the function of the heat exchanger, where heat is transferred from the hot reservoir to the cold reservoir.

(Trial 3):
When running the experiment at the different flow rates, max flow rate of 0.220816 kg/s (210 GPH) for hot water and lower flow rate of 0.136695 kg/s (130GPH) in parallel, the initial temperature of the hot reservoir was 307.1K, and the initial temperature of the cold reservoirs of 282.6K. We found that the final temperature of the hot water reservoir was 296.2K, and the final temperature of the cold reservoir was 294.2K. These two temperatures are relatively similar and thus verify the function of the heat exchanger, where heat is transferred from the hot reservoir to the cold reservoir.

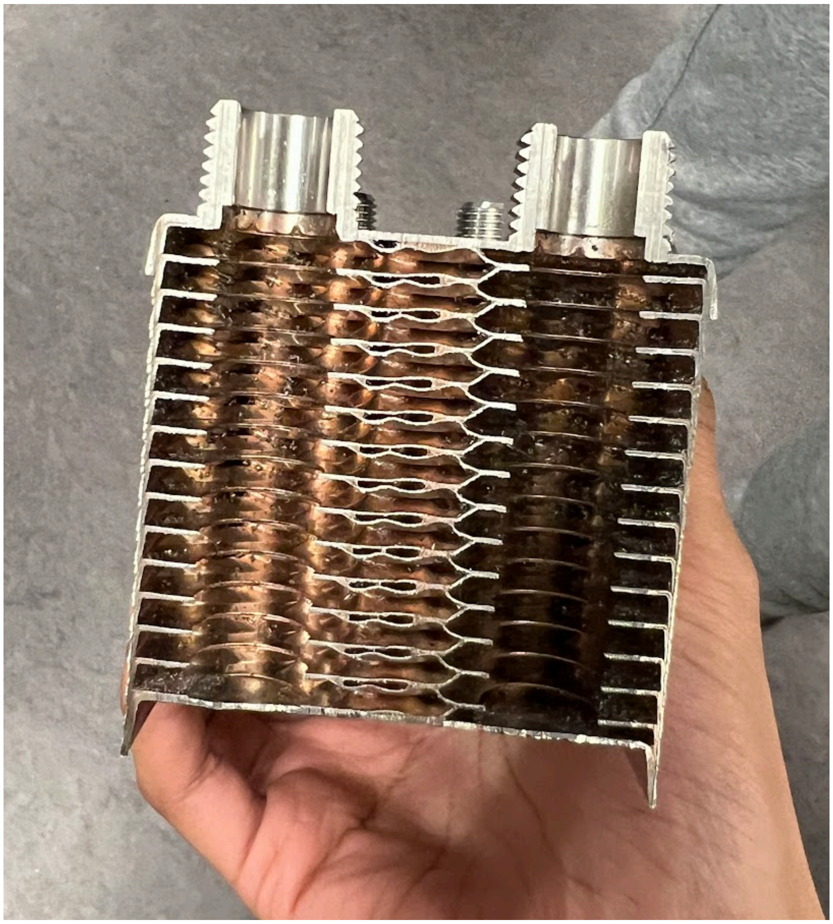
(Trial 4):
When running the experiment at the different flow rates, max flow rate of 0.220816 kg/s (210 GPH) for hot water and lower flow rate of 0.136695 kg/s (130GPH) in counterflow, the initial temperature of the hot reservoir was 308K, and the initial temperature of the cold reservoirs of 282.5K. We found that the final temperature of the hot water reservoir was 290.5K, and the final temperature of the cold reservoir was 293.9K. These two temperatures are relatively similar and thus verify the function of the heat exchanger, where heat is transferred from the hot reservoir to the cold reservoir.

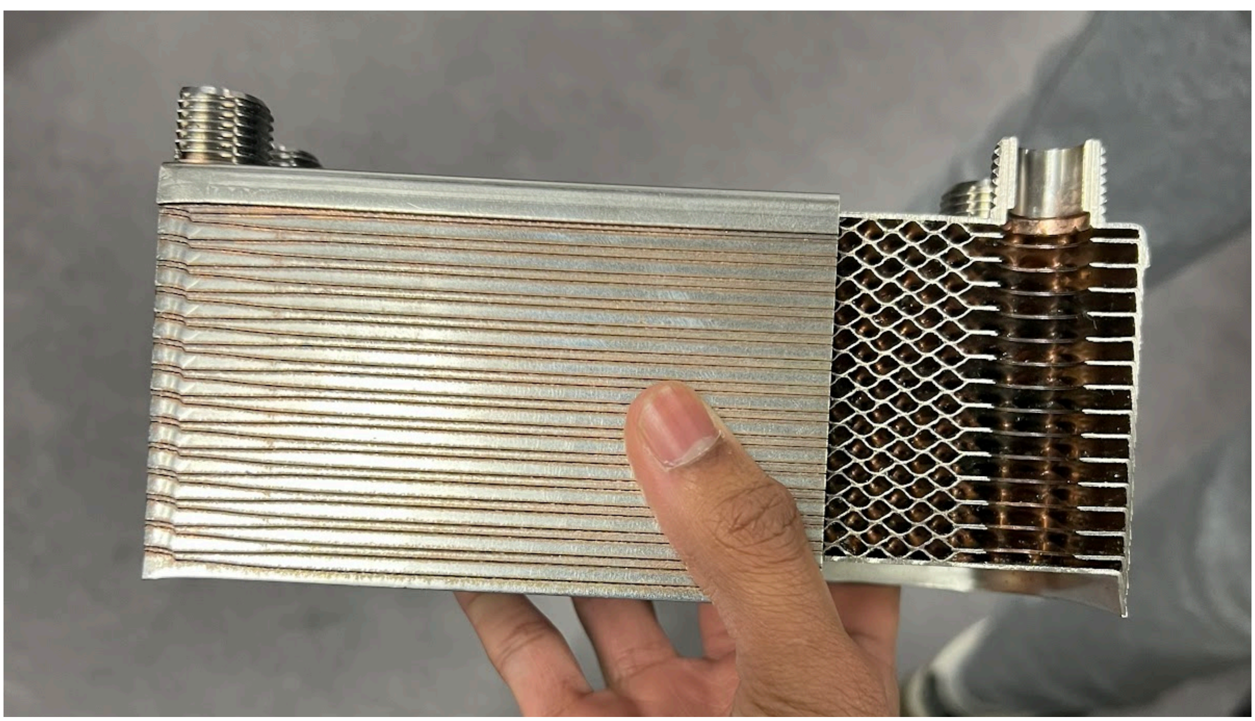
<u>Discussion</u>:
"Describe a change to device or system design or operating conditions and then how that change influences device performance"

Parallel vs Counterflow:
In a parallel flow system, hot and cold fluids enter the same end of the exchanger and move in the same direction. Because both fluids start at extreme temperatures in respect to one another, as they move together, the temperature difference between them decreases rapidly. Parallel flows, however, have very low effectiveness
In contrast, a counterflow heat exchanger system has the two fluids enter from opposite ends and flow in opposite directions. This arrangement maintains a higher and more uniform temperature difference across the entire length of the exchanger. The hottest portion of the hot liquid will always be in contact with the hottest portion of the colder liquid, which also makes this system more effective than parallel flow.
Counterflow is generally preferred over parallel flow in most use cases.

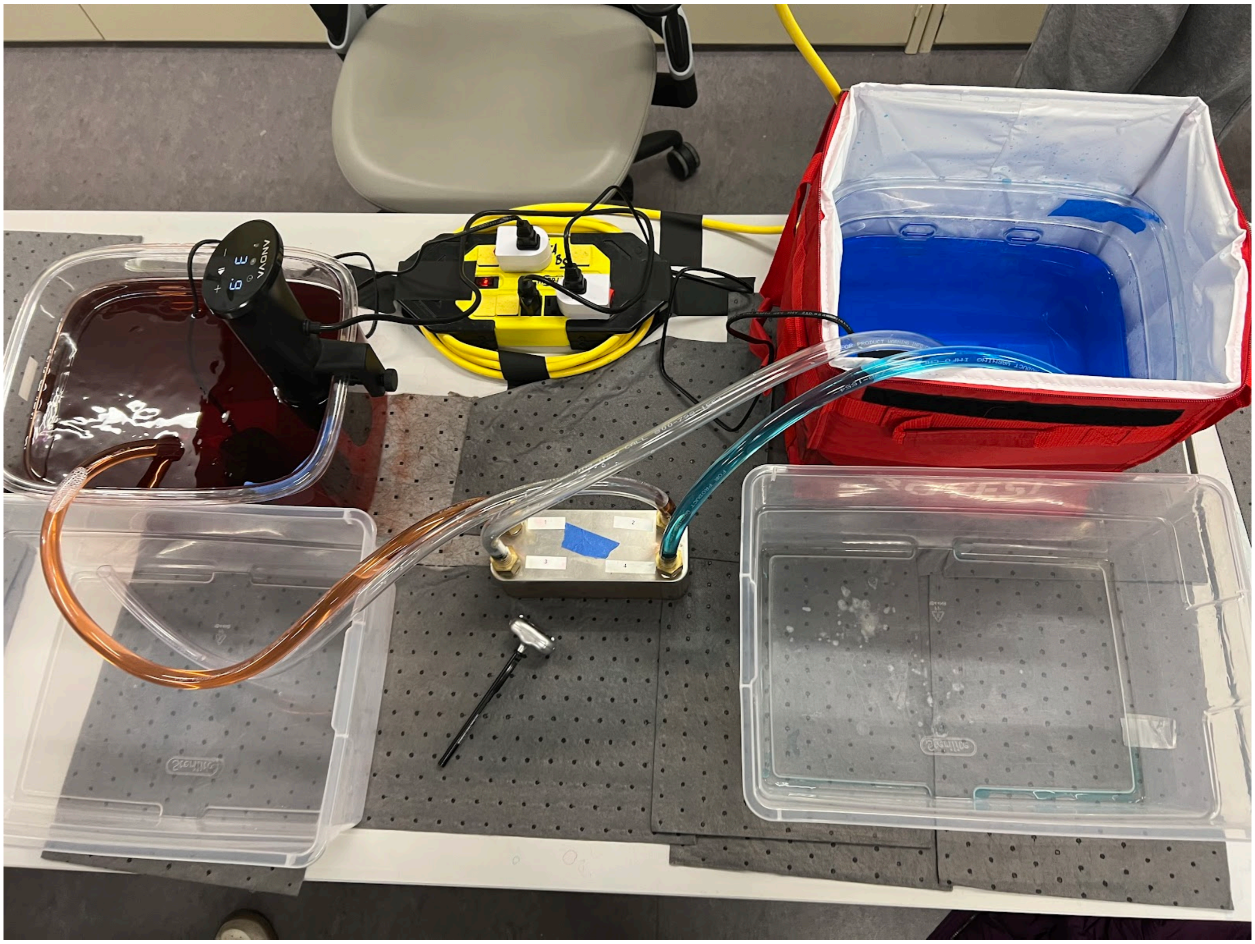
Hot Pump High Flow rate, Cold Pump Low Flow rate:
When a hot fluid is pumped at a high flow rate, it carries a large amount of thermal energy but does not cool down very much because its temperature change is spread across a large amount of mass. At the same time, the cold fluid moving at a low flow rate absorbs heat quickly relative to its small mass, so its temperature rises significantly. This imbalance means the cold fluid experiences a much larger temperature change than the hot fluid. This would sometimes allow the temperature of the cold stream to approach the temperature of the hot fluid's outlet, while the hot stream remains relatively close to its inlet temperature. This responds to
$Q = (m\_dot)(cp)(\Delta T)$, which dictates that a smaller mass flow must undergo a larger temperature change to account for the same heat transfer.

Cross-section of the heat exchanger:



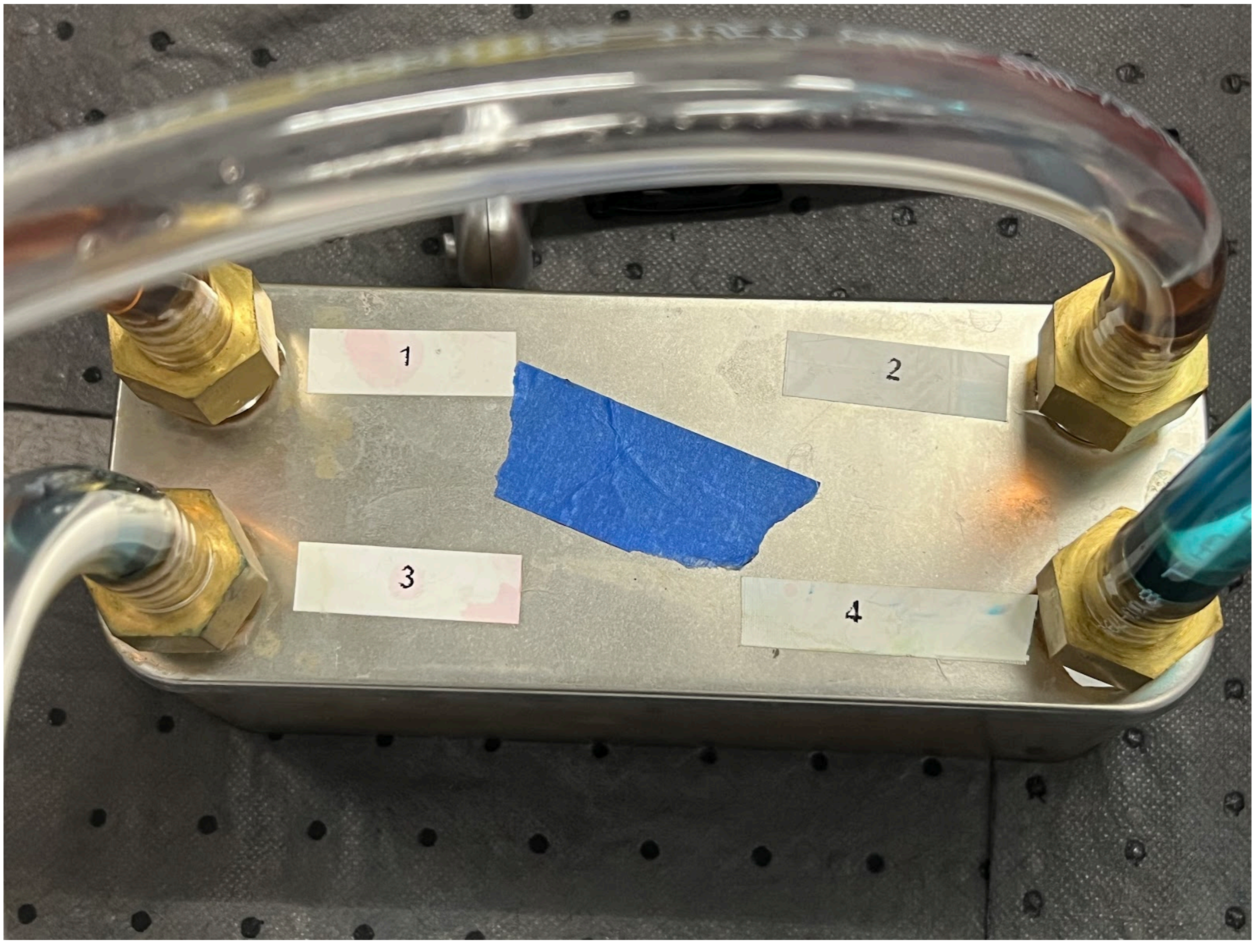


Lab setup:



Water Pump:

Heat exchanger (in counter flow: connected to 1 and 4):



Parallel flow setup (connected to 1 and 2):