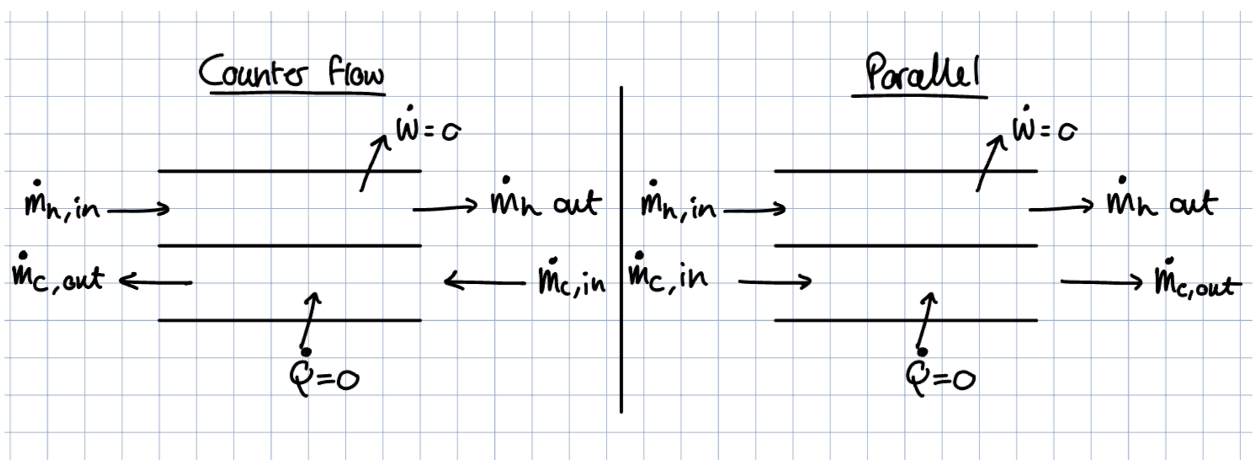
Counter flow vs. Parallel flow Heat Exchangers

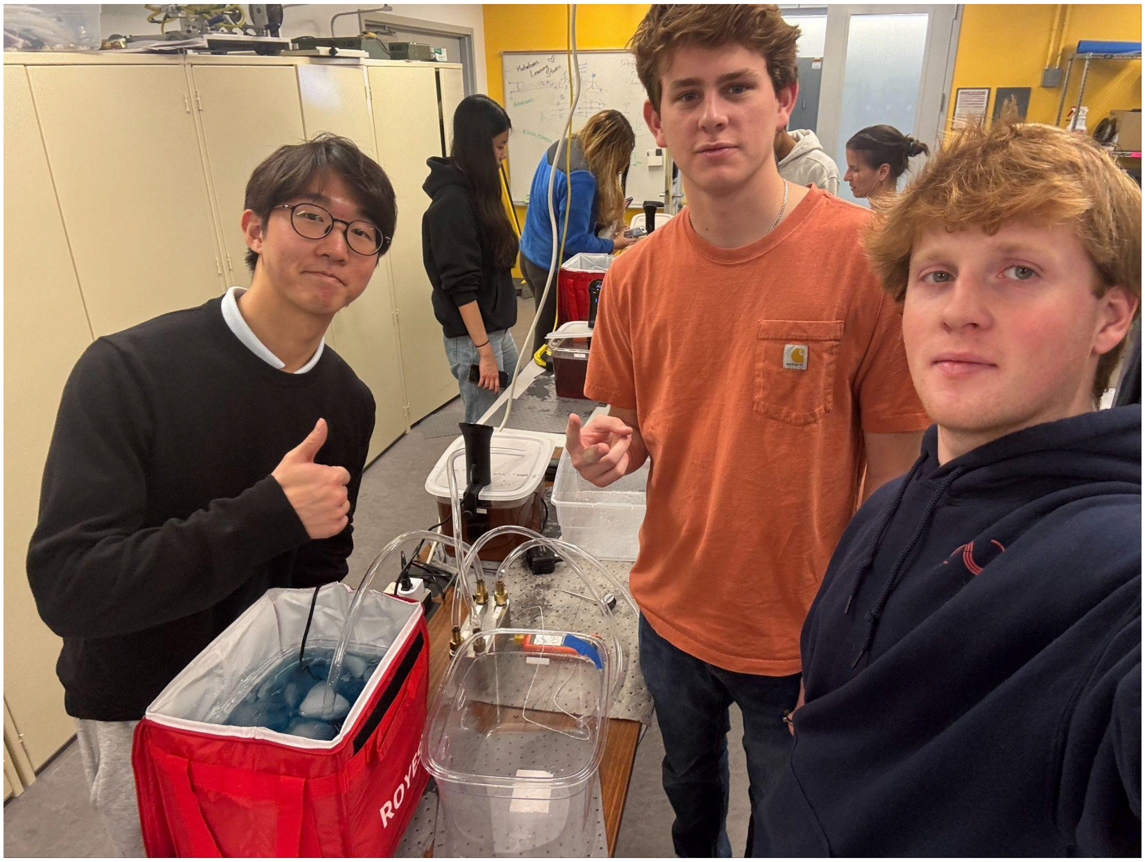
A heat exchanger is a device that allows thermal energy to be transferred between two fluids without letting them mix. One fluid is warmer and releases heat, while the other is cooler and absorbs that heat. The two fluids typically flow through separate channels—such as tubes, plates, or passages—separated by a solid wall that conducts heat but prevents direct contact. As they move through the exchanger, the temperature difference between them drives heat from the hot side to the cold side.

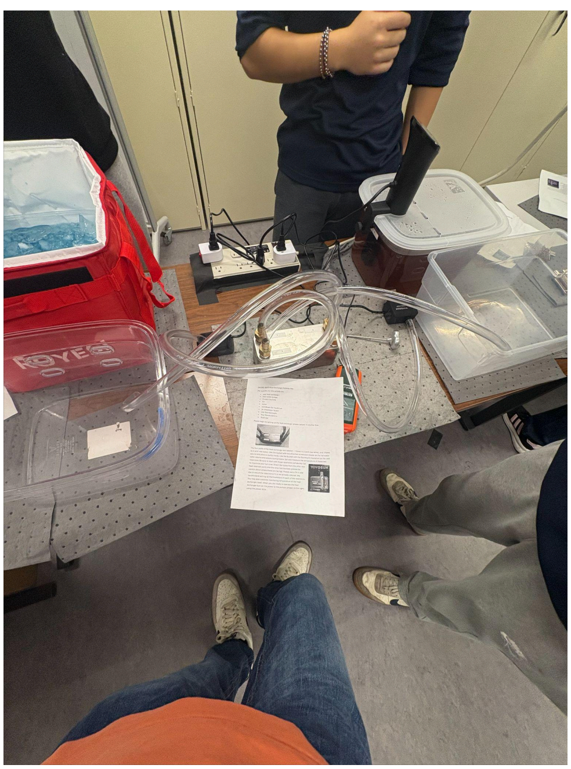
Depending on how the fluids move relative to one another, the exchanger can operate in different configurations. In parallel flow, both fluids enter from the same end and move in the same direction, causing the temperature difference to be largest at the inlet and decrease rapidly along the exchanger. In counter-flow, the fluids move in opposite directions, maintaining a more uniform temperature difference and enabling more effective heat transfer.

Overall, a heat exchanger's purpose is to efficiently transfer thermal energy between fluids for heating, cooling, or energy recovery in systems such as power plants, refrigeration units, car radiators, and industrial processes.



Photos:





Data:

Counter Flow

Run	State	T_C (°C)	T_H (°C)	T_{HE} (°C)
1	Initial	2.1	28.0	22.0
	Final	11.3	10	23.1
2	Initial	7.0	21.0	21.5
	Final	13.2	11.5	19.0

Parallel Flow

Run	State	T_C (°C)	T_H (°C)	T_{HE} (°C)
1	Initial	7.3	23.0	23.0
	Final	12.0	13.9	20.0
2	Initial	8.5	21.1	22.5
	Final	12.2	13.6	20.1

Analysis:

In the counter-flow configuration, the cold fluid experienced a substantial temperature rise for both runs, while the hot fluid cooled significantly, showing there was efficient energy exchange. Notably, the cold outlet temperature became higher than the hot outlet temperature—an outcome which I initially believed to break the 2nd law of thermodynamics. However, upon further research discovered this is actually possible only for counter flow systems. Since the two streams move in opposite directions, the cold fluid is always encountering hotter fluid upstream, allowing it to reach temperatures close to the hot stream's inlet temperature. This explains the reason for the effectiveness values to be high relative to that of the parallel flow values (35% to 45% compared with 29%)

In the parallel-flow configuration, both the cold and hot fluids experienced smaller temperature changes compared to the counter-flow runs. The hot outlet temperature always remained higher than the cold outlet temperature, and the temperature differences between the streams decreased quickly along the exchanger, producing noticeably weaker heat-transfer performance. These observations reflect the fundamental limitation of parallel flow: both fluids enter at their largest temperature difference, but that difference rapidly collapses as they move together in the same direction. Once the temperatures begin converging, the driving force for heat transfer diminishes, resulting in lower effectiveness and less pronounced heating and cooling of the fluids.

Across all tests, counter-flow consistently produced larger temperature changes and higher cold outlet temperatures, while parallel flow produced smaller changes with no temperature crossing. These observed differences reflect the underlying thermal behavior of each configuration. Counter-flow maintains a strong temperature difference throughout the exchanger, allowing more complete heat transfer and enabling the cold fluid to approach or exceed the hot outlet temperature. Parallel flow, on the other hand, loses its temperature gradient quickly, limiting the achievable heat transfer. Despite these differences, both configurations behaved in ways that are consistent with theory, confirming that the experiments correctly demonstrated the contrasting performance of counter-flow versus parallel-flow heat exchangers.

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