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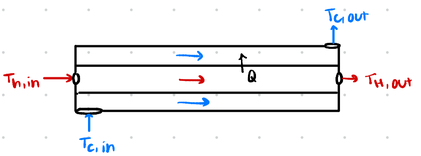
ENGRD 2210 Portfolio Assignment

Set-up: The device we studied was a water-to-water heat exchanger with 2 loops, one of which pulled water from a heated reservoir, and the other from a cooled reservoir. Instead of mixing the water, heat is exchanged through this device by both conduction, between inner metal separating the channels, and convection, between the fluid and metal. We tested many conditions, such as parallel flow, counter flow, and parallel with hot water inlet pinched, reducing flow. It was also assumed that this is an ideal heat exchanger, so there is no heat transfer to the surroundings.

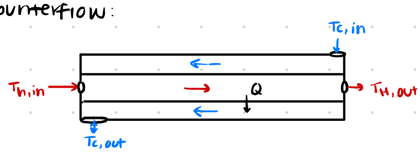
Diagram:

parallel:

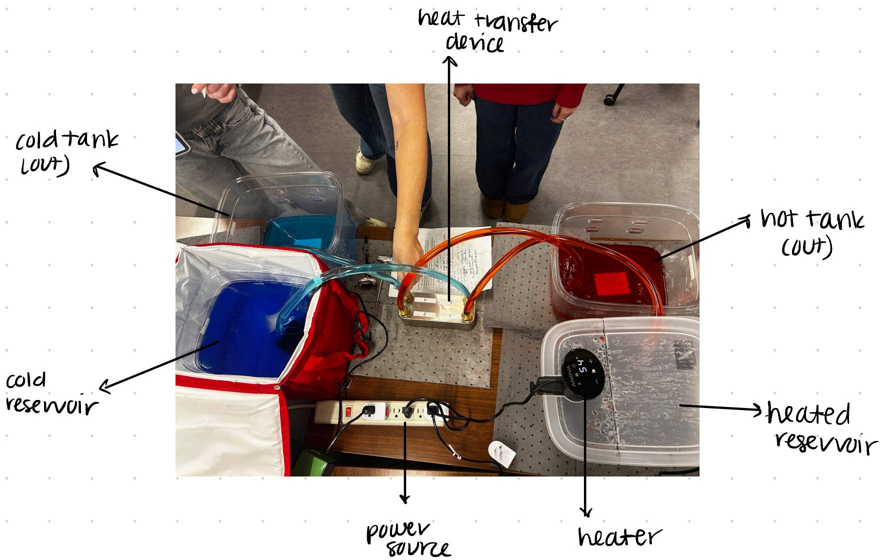


BOTH: $W=0$
All energy transfer is via heat
$Q_H < 0$
$Q_C > 0$

counterflow:

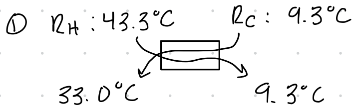


Photos:

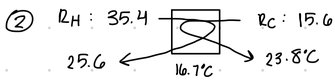


Data taken during experiment:

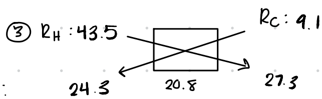
parallel:



counter:



pinched hot tube:



Mass balance: $\dot m_{h,in} = \dot m_{h,out} = \dot m_h$

$\dot m_{c,in} = \dot m_{c,in} = \dot m_c$

Energy balance: $\dot E = \dot Q - \cancel{\dot W}^{0} + \sum \dot m_{in}(h + \cancel{\frac{V^2}{2}}^{0} + \cancel{gz}^{0}) - \sum \dot m_{out}(h + \cancel{\frac{V^2}{2}} + \cancel{gz})$

$\Delta KE \approx \Delta PE = 0 \qquad W = 0$

$\dot Q + \dot m_h h_{h,in} + \dot m_c h_{c,in} = \dot m_h h_{h,out} + \dot m_c h_{c,out}$

$\dot m_h C_{p_h}(T_{h,in} - T_{h,out}) = \dot m_c C_{p_c}(T_{c,out} - T_{c,in}) + \dot Q$

$\dot m_h(T_{h,in} - T_{h,out}) = \dot m_c(T_{c,out} - T_{c,in})$

Entropy balance: $\sum \dot m s_{in} + \frac{\dot Q}{T_b} = \sum \dot m s_{out} + \dot\sigma \qquad \sigma \geq 0$

$\dot m_h C_{p_h} \ln\left(\frac{T_{h,out}}{T_{h,in}}\right) + \dot m_c C_{p_c} \ln\left(\frac{T_{c,out}}{T_{c,in}}\right) - \frac{\dot Q}{T_b} = \dot\sigma$

$T_{c,out} > T_{h,out}$

System change analysis: pinching hot tube → reducing hot mass flow rate

The pinched hot tube reduces $\dot m_h$ while keeping $\dot m_c$ constant. From our data, we saw that reducing $\dot m_h$ leads to a larger temperature drop in the hot water to supply the same heat to the cool stream. Since there is less water in the hot stream in the device than in the cold stream, the hot water leaves at a lower temperature. If $\dot m_h$ is too slow, the hot reservoir cools quickly and the device reaches a new steady-state.

Real - World Heat Exchanger Analysis

Device: GEA C2G Plate Heat Exchanger

Manfacturer: GEA Group

Application: HVAC, refrigeration, liquid-liquid heat transfer

Type: counterflow plate heat exchanger

Description: gasketed plate heat exchanger

- hot & cold fluids flow in alternating channels formed by stainless steel plates
- sealing gaskets direct fluid paths
- designed for high heat transfer efficiency in industrial cooling
- typically countercurrent flow

Assumptions:

- steady operation
- negligible heat loss to surroundings
- no shaft work
- only heat transfer occurs

GEA plate heat exchanger:

Real Operating Data: (from data sheets accessed online)

Parameter:	Hot fluid:	Cold fluid:
Inlet temp	$T_{h,in} = 70.0°C$	$T_{c,in} = 20.0°C$
outlet temp	$T_{h,out} = 40.0°C$	$T_{c,out} = 50.0°C$
mass flow rate	$\dot{m}_h = 0.8\ kg/s$	$\dot{m}_c = 0.9\ kg/s$
specific heat (water)	$c_p = 4180\ J/kgK$	same

Energy balance: $W = 0$

$$\dot{Q}_h = \dot{m}_h c_p (T_{h,out} - T_{h,in})$$
$$= (0.8)(4180)(40-70) = -100,320\,W$$

$$\dot{Q}_c = \dot{m}_c c_p (T_{c,out} - T_{c,in})$$
$$= (0.9)(4180)(50-20) = +112,860\,W$$

Entropy balance:

$$\dot{\sigma} = \Sigma \dot{m} s_{out} - \Sigma \dot{m} s_{in} - \cancel{\frac{\dot{Q}}{T_b}}^{\,0}$$

$$\dot{\sigma} = \dot{m}_h (s_{h,out} - s_{h,in}) + \dot{m}_c (s_{c,out} - s_{c,in})$$

$$\Delta s_h = c_p \ln\left(\frac{313}{343}\right) = -384\ J/kgK$$
$$\Delta s_c = c_p \ln\left(\frac{323}{293}\right) = 405\ J/kgK$$

$$\dot{S}_h = -307\ W/K$$
$$\dot{S}_c = 365\ W/K \Rightarrow \dot{\sigma} = (-307) + 365 = 58\ W/K$$

irreversible!

Comparison to Experimental Device:

- both devices obey the first law
- Lab results show that counter flow is more effective than parallel, which is why the GEA C2G exchanger is designed to operate in counterflow
- Heat transfer always occurs from the hot liquid to the cold fluid
- GEA C2G highlighted a real device, with measurement uncertainty, assumptions, and unavoidable losses
- GEA C2G allows direct evaluation of entropy generation, showing that heat transfer across finite temperature differences is irreversible

Design Change Analysis

Change: reduce hot-side mass flow rate

Effects:

- lowers hot stream's thermal capacity rate

$$C_h = \dot{m}_h C_p$$

- hot fluid undergoes a larger temperature drop

$$\dot{Q} = \dot{m}_h C_p (T_{h,out} - T_{h,in})$$

- cold outlet temperature may increase slightly due to better thermal matching
- less uniform temperature differences along the exchanger, reduces thermodynamic quality
- higher entropy generation

$$\dot{S}_{gen} \propto \int \frac{dQ}{T}$$

Analysis: In the lab, pinching the hot-water inlet increased the hot-side temperature drop, but did not improve overall effectiveness. In the real C2G exchanger, the same behavior occurs, but the effect is moderated by large surface area and counter-current flow. Both systems demonstrate that lower flow rate does not imply better thermodyamic performance, even if outlet temperatures appear favorable.