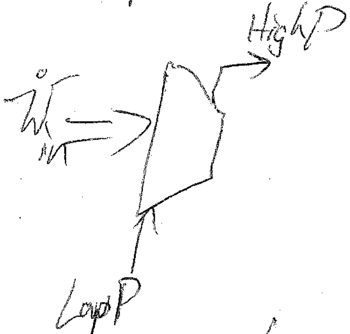
Efficiencies of Engineering Components II

Compressors: Consume power to increase the pressure of a gas
- Reverse of a Turbine



Will an ideal compressor consume more power than a real compressor to achieve the same result? → No!,
→ The ideal does more with less

Logical definition of compressor efficiency: $\eta_{comp} = \frac{\dot{W}_{ideal}}{\dot{W}_{actual}}$ (Power consumed by reversible comp to do the same job / actual power consumed by compressor)

→ Same job? 1) Same fluid/inlet conditions, 2) Same exit pressure

→ To have η_{comp} be a true efficiency ≤ 1 this is the inverse of a turbine

$$\eta_{comp} = \frac{\dot{W}_{ideal}}{\dot{W}_{actual}} = \frac{h_{2s} - h_1}{h_2 - h_1}$$ ← for comp that is 1) adiabatic, 2) ΔPE & ΔKE = 0, 3) 1 inlet, 1 exit 4) steady state

→ from here it's the same game as the turbine

Pumps: Similar to compressors, usually run on liquid, so its usually/sometimes acceptable to assume incompressible substance. If not incompressible (real fluid) then analysis is same as compressor

$$\eta_{pump} = \frac{\dot{W}_{ideal}}{\dot{W}_{actual}}$$ ← for an incompressible substance there is a more common relationship

IC rules: 1) v = constant 2) $u = f(T) \Rightarrow u_2 - u_1 = C(T_2 - T_1)$,
3) $h \neq f(T) \Rightarrow h_2 - h_1 = C(T_2 - T_1) + v(P_2 - P_1)$, 4) $s_2 - s_1 = C\ln\left(\frac{T_2}{T_1}\right)$ if $s_2 = s_1$ then $T_2 = T_1$

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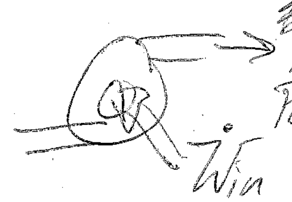
Let's find the pump efficiency for an incompressible substance



Entropy Balance on Reversible pump: $\dot{S}_{in} + \dot{S}_{gen} = \dot{S}_{out} + \frac{dS_{stored}}{dt}$ ($\dot{S}_{gen} = 0$, $\frac{dS_{stored}}{dt} = 0$)

$\dot{m}_{in} s_{in} = \dot{m}_{out} s_{out}$ $\quad s_{in} = s_{out}$ $\quad T_{2s} = T_1$, & $v_{2s} = v_1$

Energy Balance on Reversible Pump: $\dot{E}_{in} = \dot{E}_{out} + \frac{dE_{stored}}{dt}$ ($\frac{dE_{stored}}{dt} = 0$)

$$\dot{W}_{in,ideal} + \dot{m} h_1 = \dot{m} h_{2s} \Rightarrow \dot{W}_{in,ideal} = \dot{m}(h_{2s} - h_1) \Rightarrow$$

$$\Rightarrow \dot{W}_{in,ideal} = \dot{m}\left[c(T_2 - T_1) + v(P_2 - P_1)\right] \Rightarrow \dot{W}_{in,ideal} = \dot{m} v (P_2 - P_1)$$

~~Actual~~ Energy Balance on Actual Pump: $\dot{E}_{in} = \dot{E}_{out} + \frac{dE_{stored}}{dt}$ ($= 0$)

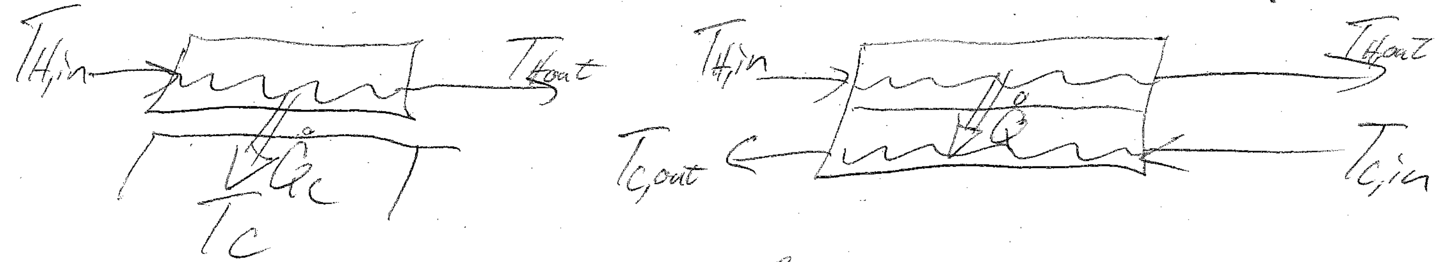
$$\dot{W}_{in,actual} + \dot{m} h_1 = \dot{m} h_2 \Rightarrow \dot{W}_{in,actual} = \dot{m}(h_2 - h_1) \qquad \dot{m} v = \dot{V}$$

$$\eta_{pump} = \frac{\dot{W}_{ideal}}{\dot{W}_{actual}} \Rightarrow \dot{W}_{actual} = \frac{\dot{W}_{ideal}}{\eta_{pump}} \Rightarrow \dot{W}_{actual} = \frac{\dot{V} \Delta P}{\eta_{pump}}$$

This form is a handy result that comes up a lot (fluid mechanics)
it is handy for pumps, fans, blowers, anything with constant v
Also handy for using pump curves. I won't make you do this.

Heat exchangers: Last component we need to talk about.

→ Transfer heat from a fluid to a thermal temperature reservoir or more often from 1 fluid to another.



Heat exchanger efficiency is called effectiveness: ε

ε is defined a little differently than other component efficiencies. It's not defined relative to a reversible heat exchanger.

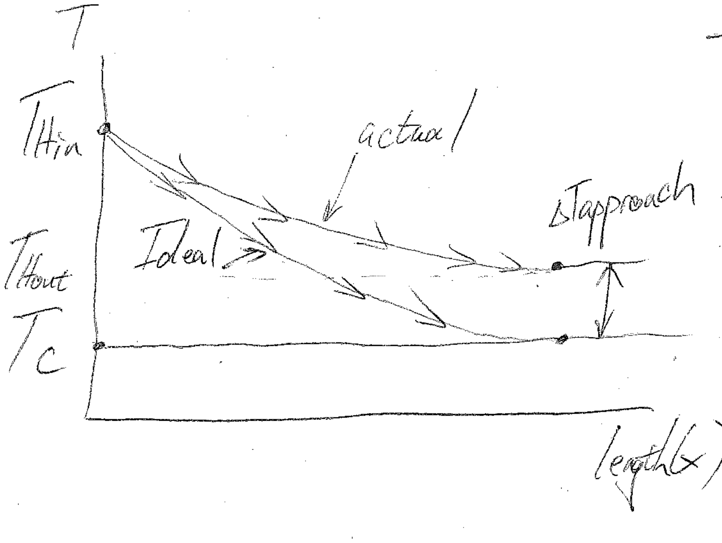
Why? → because reversible heat exchangers are not possible

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{Max}}$$

$\dot{Q}$ ← actual heat exchange rate in HEX

$\dot{Q}_{Max}$ ← Maximum possible heat exchange rate in ideal heat exchanger, not a reversible heat exchanger

For a Cold Thermal Reservoir: Best Possible HEX brings $T_{H,out}$ down to T_C



- This defines ideal limit, $\dot{Q}_{Max}$: occurs when temperatures are the same (called the pinch point)
- The ΔT between the actual stream & the pinch point / ideal is called the approach temperature differential
- The ideal HEX has a $\Delta T_{approach} = 0$

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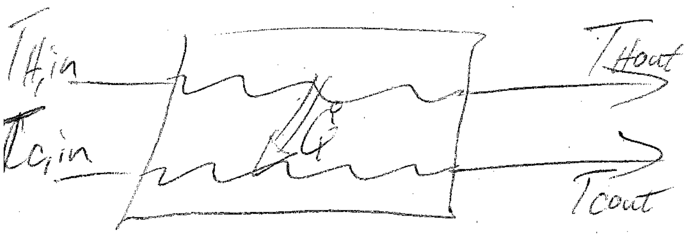
If I told you this heat exchanger had a $\Delta T_{approach} = 4K$ & $T_C = 300K$, what would be the outlet T, $T_{H,out} = ? = 304K$

$T_{H,out,ideal} = ? = 300K = T_C$

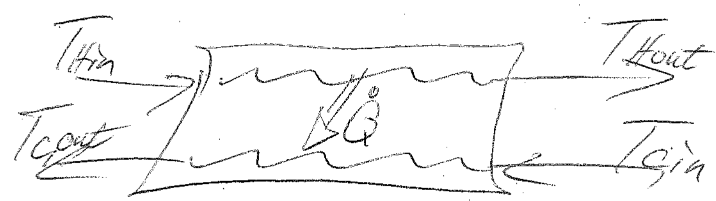
$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{Max}} = \frac{\dot{M}(h_{in} - h_{out})}{\dot{M}(h_{in} - h_{out,ideal})} \Leftarrow \text{for cooling stream}$$

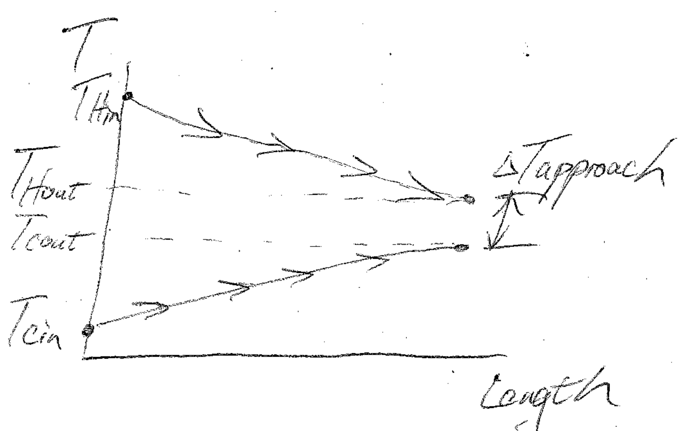
Dual fluid HEX's are a little more difficult

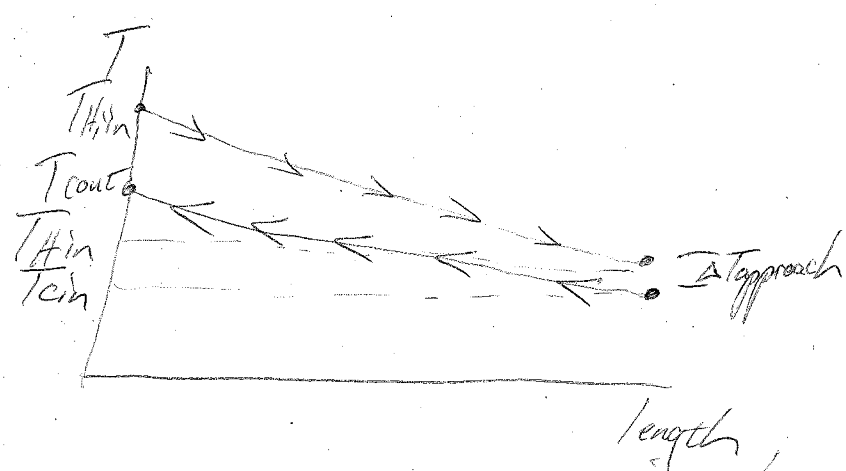
Parallel flow



Counter flow







These get tough! In heat transfer you will do a lot of these & learn how to determine the location of a pinch point. In this class you will be given the location of the pinch point & either the ΔT of approach or ε.