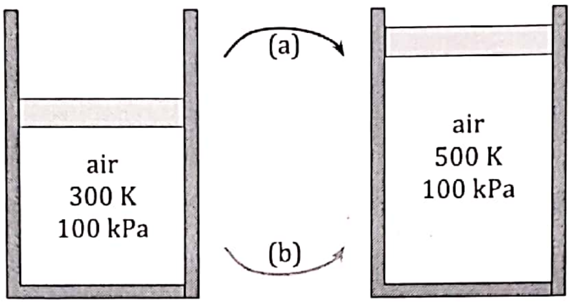
(1) Short Answers

i. A closed piston-cylinder system containing air could experience two different processes. In process (a), the system is insulated and stirred with a propeller. In process (b), heat is transferred to the system from a reservoir at 600 K. The final state of either isobaric process is air at 500 K.



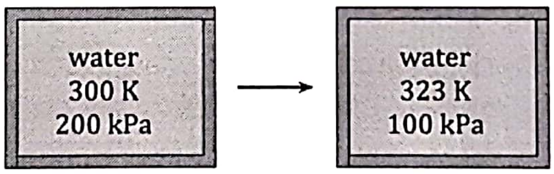
Which process has greater entropy generation? Why is that? You do NOT need to calculate S_{gen}.

a) $\underset{+}{S_2 - S_1} = \underset{\text{insulated}}{\cancel{Q_{in}}} / T_{body} + \underset{+}{S_{gen}}$

b) $\underset{+}{S_2 - S_1} = \underset{+\ /\ +}{Q_{in} / T_{body}} + \underset{+}{S_{gen}}$

ΔS is the same for both thus S_{gen} for a) must be greater

ii. Water undergoes an unknown process that changes its temperature and pressure from State 1 to 2.



SCL SCL

$P_{sat} = 4\,kPa$ $P_{sat} = 12\,kPa$

Determine its change in specific entropy, Δs. The specific heat of water is $c = 4.18$ kJ/kg·K.

$\Delta S = S_2 - S_1 = c \ln(T_2/T_1)$ for incompressible SCL

$\boxed{\Delta S = .309\ kJ/kgK}$

could also use tables...

$S_1 = S_f(T_1) = .393\ kJ/kgK$ (from interpolation)

$S_2 = S_f(T_2) = .702\ kJ/kgK$ (.7038 in Table)

$\Delta S = S_2 - S_1 = .309\ kJ/kgK$

iii. Argon is throttled from a higher pressure, P_1, to a lower pressure, P_2. If $T_1 = 350$ K, what is T_2?

Argon
350 K

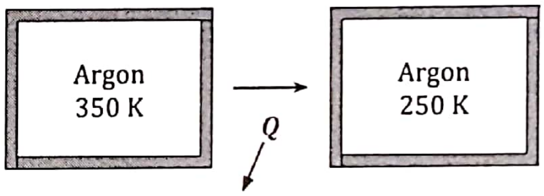
Is the specific entropy at the throttle exit, s_2, higher, lower, or the same as entropy at the inlet, s_1?

argon is an ideal gas $\therefore h = h(T)$

throttle $\rightarrow \Delta h = 0 \rightarrow$ $\boxed{T_2 = T_1 = 350K}$

$$s_2 - s_1 = \underbrace{c_p \ln(\underbrace{T_2/T_1}_{1})}_{0} \underbrace{- R \ln(\underbrace{P_2/P_1}_{-})}_{+} \rightarrow \boxed{\text{higher } s_2 > s_1}$$

iv. Instead of throttling, Argon is placed in a rigid tank. To cool it to $T_2 = 250$ K, heat is removed. Determine its change in specific enthalpy, Δh, for the process. How does this compare to part iii?



Is the final specific entropy of Argon, s_2, higher, lower, or the same as its initial entropy, s_1?

argon is an ideal gas $\therefore h = h(T)$

$\Delta h = c_p \Delta T = (.5203)(-100)$

$\boxed{\Delta h = -52.03 \text{ kJ/kg} \quad \text{less than iii}}$

$$s_2 - s_1 = \underbrace{c_v \ln(\underbrace{T_2/T_1}_{-})}_{-} + \underbrace{R \ln(\underbrace{v_2/v_1}_{1})}_{0} \rightarrow \boxed{\text{lower } s_2 < s_1}$$

(2) Steady-Flow Heat Exchanger

Steam enters one inlet port of a heat exchanger at 200 °C and 1 MPa and must be cooled to 90 °C by liquid water which enters another inlet port at 25 °C and 100 kPa. The cooling water can increase its temperature by no more than 15 °C, giving a maximum cooling water exit temperature of T_{max} = 40 °C.

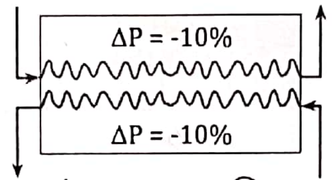
The heat exchanger is not ideal. Its piping pressure drop is 10 % in each stream. Additionally, the device is not well insulated and loses heat at a rate of 1500 kW through the heat exchanger walls, also at 25 °C.

h = 2828.3
s = 6.6956

① steam (SHV)
200 °C, 1 MPa

② water (SCL)
90 °C, 900kPa

h = h_f(T) = 377.04
s = s_f(T) = 1.1929



h = h_f(T) = 167.53
s = s_f(T) = .5724

④ water (SCL)
40°C, 90kPa

③ water (SCL)
25 °C, 100 kPa

h = h_f(T) = 104.83
s = s_f(T) = .3672

Assume changes in kinetic and potential energy are negligible and that the device operates at steady state. Also assume that the process is externally reversible, meaning no entropy is generated in the environment.

a) Using the 1st Law, if the mass flow rate of steam is 1 kg/s, what is the minimum mass flow rate of the cooling water? *Hint:* Apply a control volume around the entire device, including both streams.

$$\cancel{\frac{d}{dt}E_{cv}}^{S.S.} = \dot{Q}_{cv} - \cancel{\dot{W}_{cv}}^{0} + \dot{m}_{steam}(h_1 - h_2) + \dot{m}_{water}(h_3 - h_4)$$

$$0 = -1500 + 1\,(2828.3 - 377.04) + \dot{m}_w\,(104.83 - 167.53)$$

$$\rightarrow \boxed{\dot{m}_w = 15.17 \text{ kg/s}}$$

b) Using the 2nd Law, find $\dot{S}_{gen}$ in the heat exchanger. Regardless of your result in part a), assume the mass flow rate of cooling water to be 20 kg/s with the same inlet and exit conditions as above.

$$\cancel{\frac{d}{dt}S_{cv}}^{S.S.} = \dot{Q}_{cv}/T + \dot{m}_{steam}(s_1 - s_2) + \dot{m}_{water}(s_3 - s_4) + \dot{S}_{gen}$$

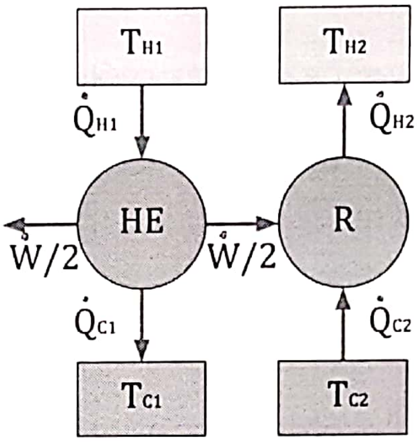
$$\underbrace{-\dot{S}_{gen}}_{-} = \underbrace{-1500/298}_{-} + 1\,\underbrace{(6.6956 - 1.1929)}_{+} + 20\,\underbrace{(.3672 - .5724)}_{-}$$

$$\rightarrow \boxed{\dot{S}_{gen} = 3.63 \text{ kW/K}}$$

technically the exit temp would be less than 40°C if flow rate were 20 kg/s ∴ s_4 would be smaller leading to less $\dot{S}_{gen}$ than this result predicts

(3) Dual Heat Engine / Refrigerator

A heat engine operates between two reservoirs at $T_{H1} = 800$ °C and $T_{C1} = 20$ °C. What is the maximum net power, $\dot{W}_{max}$, that such a heat engine could produce by extracting $\dot{Q}_{H1} = 1.75$ kW from the hot reservoir? If the actual heat engine produces $\dot{W} = 1$ kW, at what rate is entropy generated?



One-half of the power output of this heat engine is used to drive a refrigerator that removes heat from the cold freezer cabinet at $T_{C2} = -5$ °C and transfers it to a kitchen at $T_{H2} = 22$ °C. The inventor tells you that the heat engine / refrigerator system design is capable of removing heat at a rate of $\dot{Q}_{C2} = 6.25$ kW.

If irreversibilities in the heat engine / refrigerator system are reduced, is this theoretically possible? As an engineer with a strong Thermodynamics background, would you invest in the product? Why or why not?

Heat Engine

$\eta_{carnot} = 1 - \frac{T_{C1}}{T_{H1}} = \frac{\dot{W}_{max}}{\dot{Q}_{H1}}$

→ $\boxed{\dot{W}_{max} = 1.27\ kW}$

$\Delta U = Q_{in} - W_{out}$

$\dot{W} = \dot{Q}_H - \dot{Q}_C$

→ $\dot{Q}_C = .75\ kW$

$\frac{d}{dt}S = \dot{Q}_{in}/T + \dot{S}_{gen}$

$-\dot{S}_{gen} = 1.75/1073 - .75/293$

→ $\boxed{\dot{S}_{gen} = .93\ W/K}$

(for case of $\dot{W} = \dot{W}_{max}$

→ $\boxed{\dot{S}_{gen} = 0\ W/K}$)

Refrigerator

$COP_{R,carnot} = \frac{1}{(T_{H2}/T_{C2}) - 1} = \frac{\dot{Q}_{C2,max}}{\dot{W}}$

T_{H2}: 295, T_{C2}: 268

two possibilities...

$\frac{\dot{W}}{2} = \frac{1\ kW}{2}$ ↓ $\dot{Q}_{C2,max} = 4.96\ kW$

$\frac{\dot{W}}{2} = \frac{\dot{W}_{max}}{2} = \frac{1.27\ kW}{2}$ ↓ $\dot{Q}_{C2,max} = 6.30\ kW$

we've told $\dot{Q}_{C2,actual} = 6.25\ kW$

This is impossible! ↓ definitely won't invest in this

theoretically possible but highly unlikely ↓ I might invest but probably wouldn't unless inventor convinced me

reducing irreversibilities in HE