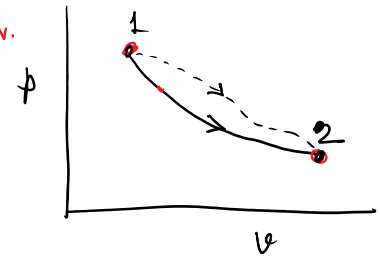
Entropy Equation / Second Law for a closed System

$$\oint \left(\frac{\delta Q}{T_b}\right) < 0$$

$$\Rightarrow \quad \underbrace{S_2 - S_1}_{\text{Change of entropy}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T_b}\right)_{Rev}}_{\text{Entropy supplied with heat}} + \underbrace{S_{gen}}_{\text{Entropy generated due to irrev.}}$$

$S_{gen} \to 0$ for Rev.



$$\int_1^2 \left(\frac{\delta Q}{T_b}\right)_{Rev} = S_2 - S_1$$

$$\int_1^2 \left(\frac{\delta Q}{T_b}\right)_{Irrev} = (S_2 - S_1) - S_{gen}$$

1st Law for a Non-flow system

$$E_2 - E_1 = \int_1^2 \delta Q - \int_1^2 \delta W$$

(Change of stored energy) — Energy in due to heat — Energy out due to work

2nd Law for a non-flow system

↳ Closed

$$\boxed{S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T_b}\right) + S_{gen}}$$

Work transfer is entropy-free

Adiabatic process 1 − 2

$$S_2 - S_1 = \Delta S = \int_1^2 C_p \frac{dT}{T} - R \ln p_2/p_1$$

$$= C_p \ln \frac{T_2}{T_1} - R \ln p_2/p_1$$

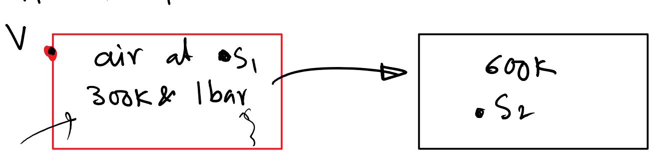
$$= C_p\left(\frac{\gamma-1}{\gamma}\right) \ln p_2/p_1 - R \ln \frac{p_2}{p_1} = R \ln \frac{p_2}{p_1} - R \ln p_2/p_1 = \underline{0}$$

$C_p\left(\frac{\gamma-1}{\gamma}\right) = R$

$$p_1 v_1^\gamma = p_2 v_2^\gamma \Rightarrow \boxed{\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{v_1}{v}\right)^{\gamma-1}}$$

$$C_p \times \frac{\gamma-1}{\gamma} = \gamma \frac{R}{\gamma-1} \cdot \frac{\gamma-1}{\gamma} = R$$

$p_1 = 1$ bar, $T_1 = 300$K



Rigid Container

Heating is done

a) By placing the container on a 700 K Hot Plate (the wall in contact with the hot plate is at 700 K)

b) By adiabatic stirring with a paddle wheel.

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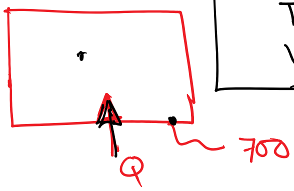
Find for each case, the ΔS of the system & S_{gen}

$C_p = 1.04$ kJ/kg K

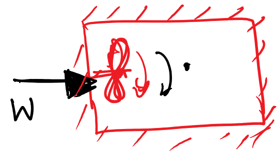
(a)



1: $P_1 = 1$ bar	$\longleftrightarrow$	$P_2 = 2$ bar
$T_1 = 300$	$\longleftrightarrow$	$T_2 = 600$ K
$V_1 = V$	$\longleftrightarrow$	$V_2 = V$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

(b)



$S_2 - S_1 =$

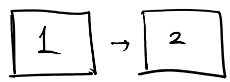
$$s_2 - s_1 = C_p \ln T_2/T_1 - R \ln P_2/P_1$$

$$= \ln 2 - 0.287 \ln 2 = (1 - 0.287)\ln 2 = 0.494 \ \frac{kJ}{kg\,K}$$

$s_2 - s_1$ will be the same for both (a) & (b)

a)

$$s_2 - s_1 = \int \delta Q/T_b + s_{gen}$$



1st Law $\quad q - \cancel{w}^{\,0} = \Delta u$

$q = \Delta u = C_v \Delta T$

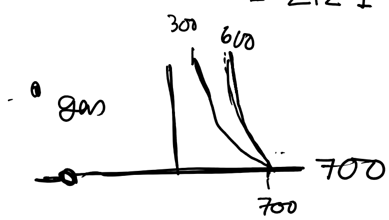
$\Rightarrow q = 0.707 \times 300$

$= 212.1$ kJ

$$s_2 - s_1 = \frac{q}{700} + s_{gen}$$

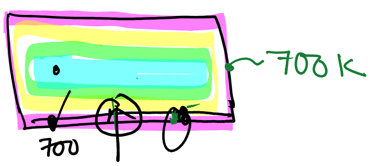
$$0.494 = \frac{212.1}{700} + s_{gen}$$

$$\Rightarrow \boxed{S_{gen} = 0.494 - 0.303 = 0.191 \ \frac{kJ}{kg\,K}}$$

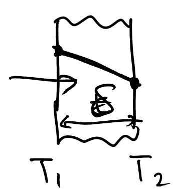


$\Delta S = S_Q + S_I$

$$\boxed{0.494 = \underbrace{0.303}_{S_Q} + \underbrace{0.191}_{S_I}}$$

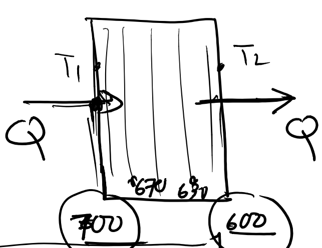


Steady Heat Transfer across a slab



$$\dot{Q} = kA\left(\frac{T_1 - T_2}{\delta}\right)$$

$$\boxed{\Delta S} = \int \frac{\delta Q}{T_b} + S_{gen}$$



$$\cancel{\Delta S}^{\,0} = \frac{+Q}{T_1} + \frac{-Q}{T_2} + S_{gen}$$

$$0 = Q\left(\frac{1}{T_1} - \frac{1}{T_2}\right) + S_{gen} \Rightarrow \boxed{S_{gen} = Q\underbrace{\left(\frac{1}{T_2} - \frac{1}{T_1}\right)}_{+ve}}$$

$T_1 > T_2$

(b) Adiabatic Stirring

$$\Delta S = 0.494 \text{ kJ/kg K}$$

$$\Delta S = \int \cancel{\delta Q}^{\,0}/T_b + S_{gen}$$

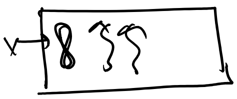
(b) Adiabatic stirring

$\Delta S = 0.494 \ kJ/kg\,K$

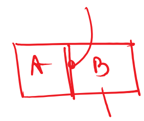
$S_q = 0$ (adiabatic)

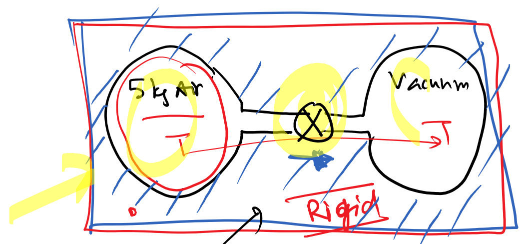
$S_{gen} = 0.494$

$\Delta S = \int \cancel{\delta Q / T_b} + S_{gen}$



24. Two identical, rigid vessels are connected by a short pipeline with a valve, and the entire system is thermally insulated. One vessel contains 5 kg of air and the other is completely evacuated. The valve is suddenly opened when air is allowed to fill the empty vessel until the pressure in both vessels becomes equal. Find the total entropy generated. Assume $C_p = 1.004$ kJ/kg.K and $\gamma = 1.4$.





1st Law $\cancel{Q}^{0} - \cancel{W}^{0} = \Delta U = 0$

$\Delta T = 0$

$P_1 \rightarrow P_2 \Rightarrow \boxed{P_2/P_1 = 1/2}$

2nd Law

$S_2 - S_1 = \int_1^2 \cancel{\delta Q / T_b}^{0} + S_{gen}$

$$\boxed{S_2 - S_1 = S_{gen}}$$

$S_2 - S_1 = m\left[s_2 - s_1\right]$

$= m\left[C_p \ln \cancel{\frac{T_2}{T_1}} - R \ln P_2/P_1\right]$

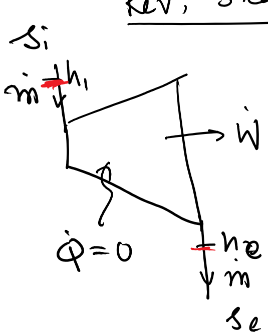
$= -mR \ln 0.5 = -5 \times 0.287 \times \ln 0.5 = +1 \ kJ/K$

$S_{gen} = 1 \ kJ/K$

Expansion in the turbine

Rev, Steady

Irrev.



$\dot W = \dot m (h_1 - h_2)$

2nd Law

$$\cancel{\frac{dS}{dt}}^{0} = \cancel{\frac{\dot Q}{T_b}}^{0 \text{ adiabatic}} + \cancel{\dot S_{gen}}^{0 \text{ Rev.}} + \dot m \cdot s_i - \dot m s_e$$

steady

$\Rightarrow \dot S_{gen} = \dot m (s_e - s_i)$

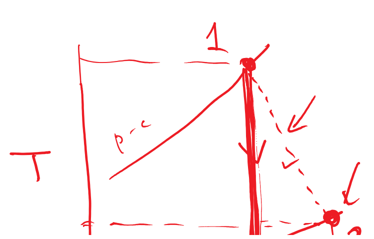
$0 = \dot m (s_e - s_i)$

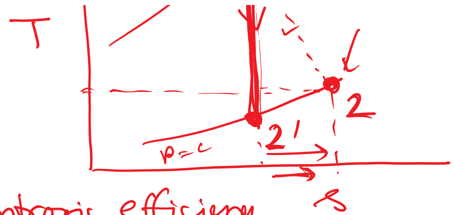
$(s_e = s_i)$

$\dot S_{gen} = \dot m (s_e - s_i)$

$s_e - s_i = \frac{\dot S_{gen}}{\dot m}$

$s_e > s_i$





Isentropic efficiency

$$\boxed{\eta = \frac{h_1 - h_2}{h_1 - h_{2'}}}$$

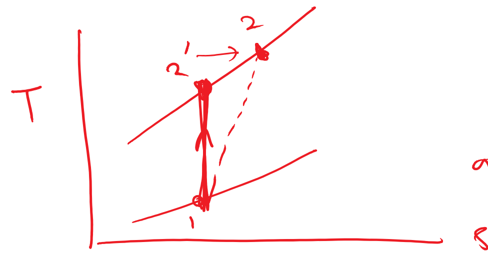
$$\dot{W}_{Rev} = \dot{m}(h_1 - h_{2'}) = \dot{m}C_p(T_1 - T_{2'})$$

$$\dot{W}_{act} = \dot{m}(h_1 - h_2) = \dot{m}C_p(T_1 - T_2)$$

$$T_2 > T_{2'} \Rightarrow (T_1 - T_{2'}) > (T_1 - T_2)$$

$$\dot{W}_{rev} > \dot{W}_{actual}.$$

Adiabatic Compressor



$s_e \quad s_i$

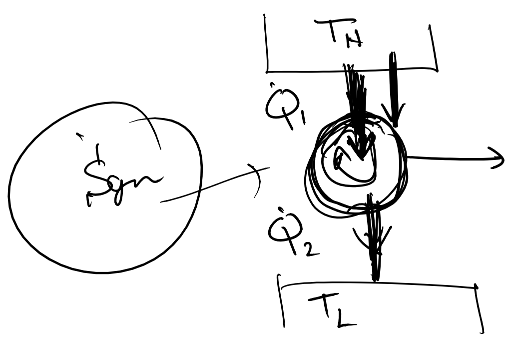
or $s_2 > s_1$

$p_1 > p_2$

$s_2 > s_i$

$$\eta_{isen} = \frac{\text{isentropic work}}{\text{Actual work}} = \frac{h_{2'} - h_1}{h_2 - h_1}$$

Find out the $\dot{S}_{gen}$ in a Carnot Engine



$\dot{S}$

$$\cancel{\frac{dS}{dt}}^{\,0} = \frac{+\dot{Q}_1}{T_H} + \frac{-\dot{Q}_2}{T_L} + \dot{S}_{gen}$$

$$-\frac{\dot{Q}_1}{T_H} + \frac{\dot{Q}_2}{T_L} = \dot{S}_{gen}$$

0