1st Law

Closed	Open
$\frac{dE}{dt} = \dot{Q} - \dot{W}$	$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_i (h_i + c_i^2/2 + gz_i) - \sum \dot{m}_e (h_e + \frac{c_e^2}{2} + gz_e)$
2nd Law	
$\frac{dS}{dt} = \sum \dot{Q}/T_b + \dot{S}_{gen}$	$\frac{dS}{dt} = \sum \frac{\dot{Q}}{T_b} + \dot{S}_{gen} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e$

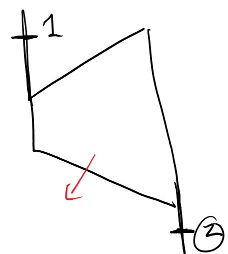
$\boxed{\dot{S}_{gen}} \rightarrow$ $\dot{S}_{gen} \rightarrow$ entropy generation rate

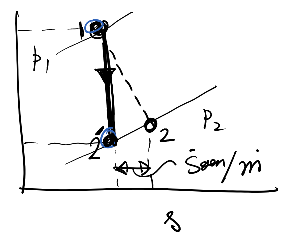
↳ an indicator of Irrev.

$\Delta S \rightarrow$ increase / decrease of entropy of a system

$\dot{S}_{gen} \neq$

$\dot{S}_{gen} \equiv$ Indicator of irreversibility





1st Law $\quad \dot{W} = \dot{m}(h_1 - h_2)$

2nd Law $\quad \cancel{\frac{dS}{dt}}^{0} = \cancel{\dot{Q}}^{0}/T_b + \dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{S}_{gen}$

$$\boxed{s_2 = s_1 + \dot{S}_{gen}/\dot{m}}$$

$1 \rightarrow 2$

$$\frac{T_{2'}}{T_1} = \left(\frac{p_{2'}}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \leftarrow$$

$$\boxed{s_{2'} - s_1} = C_p \ln \frac{T_2'}{T_1} - R \ln \frac{p_2'}{p_1}$$

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

$$= R \ln p_2'/p_1 - R \ln p_2'/p_1 = \text{☺}$$

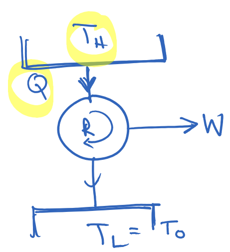
$C_v = \frac{R}{\gamma - 1}$

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

Guoy Stodola Theorem

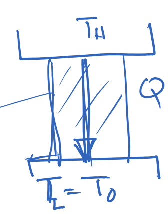
$\dot{S}_{gen} \Rightarrow \boxed{\text{Lost Work} = T_0 \dot{S}_{gen}}$

↳ Lost work potential



$W = Q\left(1 - \frac{T_0}{T_H}\right)$

maximum work one can get from Q that is available at T_H



$\boxed{\dot{W} = 0}$

$\dot{W}_{lost} = Q\left(1 - \frac{T_0}{T_H}\right)$

is available at T_H

$W_{lost} = Q\left(1 - \frac{T_0}{T_H}\right)$

$\boxed{\dot{W}_{lost} = T_0\left[\dot{Q}\left(\frac{1}{T_0} - \frac{1}{T_H}\right)\right]}$

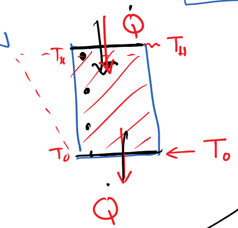
$\dot{S}_{gen}$

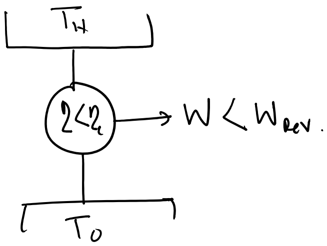
$\boxed{\dot{W}_{lost} = T_0\,\dot{S}_{gen}}$

$\frac{dS}{dt} = \sum \dot{Q}/T_b + \dot{S}_{gen}$

$\Rightarrow \quad 0 = \frac{+\dot{Q}}{T_H} + \frac{-\dot{Q}}{T_0} + \dot{S}_{gen}$

or $\dot{S}_{gen} = \dot{Q}\left[\frac{1}{T_0} - \frac{1}{T_H}\right]$





$\boxed{W_{actual} + T_0\,S_{gen} = W_{Rev}}$

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12. A 0.8-m³ rigid tank contains carbon dioxide (CO2) gas at 250 K and 100 kPa. A 500-W electric resistance heater placed in the tank is now turned on and kept on for 40 min after which the pressure of CO2 is measured to be 175 kPa. Assuming the surroundings to be at 300 K and using constant specific heats, determine (*a*) the final temperature of CO2, (*b*) the net amount of heat transfer from the tank, and (*c*) the entropy generation during this process.

$T_2 = \checkmark$

$Q = ?$

$S_{gen} = ?$

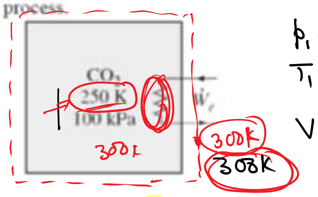
$\gamma_{CO_2} =$

M: 1.67
D: 1.4
Tr: 1.28

$\gamma = 5/3$ M $C_v = 3/2 R, C_p = 5/2 R$

$\gamma = 7/5$ D $C_v = 5/2 R, C_p = 7/2 R$

$\gamma = 9/7$ T $C_v = 7/2 R, C_p = 9/2 R$



$t = 2400\,s$

$p_1 = 100\,kPa$ $\quad p_2 = 175\,kPa$

$T_1 = 250\,K$ $\quad T_2 = 437.5\,K$

$V_1 = 0.8\,m^3 = V_2$

$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$

$T_2 = \frac{175}{100} \times 250$

1st Law : $Q - W = \Delta U$

$\boxed{\Delta U = m\,C_v\,\Delta T = 1.7 \times 0.675 \times 187.5 = 215.15}$

$W = -\frac{500}{1000} \times 2400\ kJ = -1200\ kJ$

$C_{v_{CO_2}} = \frac{R_{CO_2}}{\gamma - 1} = \frac{8.315}{44} \times \frac{1}{0.28} = 0.675\ kJ/kg\,K$

$m = \frac{p_1 V_1}{R T_1} = \frac{100 \times 0.8 \times 44}{8.315 \times 250} = 1.7\ kg$

$Q = W + \Delta U = -1200 + 215.15 = -984.85\ kJ$

$0.8\,m^3 \rightarrow 0.8\,m^3$

$100\,kPa \rightarrow 175\,kPa$

$250\,K \rightarrow 437.5\,K$

2nd Law $\quad \Delta S = Q/T_b + S_{gen}$

$\Delta S = m\left[C_p \ln T_2/T_1 - R \ln p_2/p_1\right]$

$= m\left[C_v \ln \frac{T_2}{T_1} + R \ln V_2/V_1\right]$

$= 1.7 \times 0.675 \ln \frac{437.5}{...} = 0.642\ kJ/K$

$S_{gen} = \Delta S - Q/T_b$

$= 0.642 - (-3.28)$

$= 3.924\ kJ/K$

$= m\left[C_v \ln \frac{T_2}{T_1} + R \ln v_2/v_1\right]$

$= 1.7 \times 0.675 \ln \frac{437.5}{250} = 0.642$ kJ/K

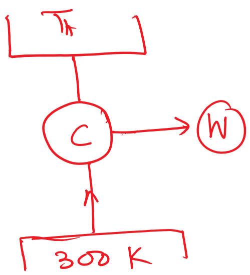
$S_{gen} = 0.642 - (-3.28)$

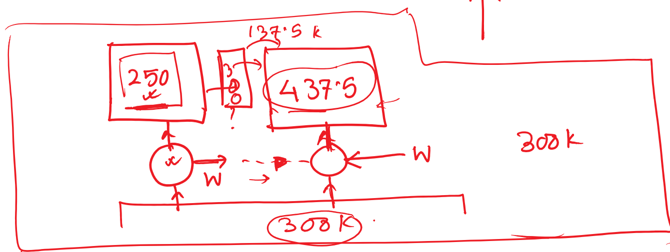
$= 3.924$ kJ/K

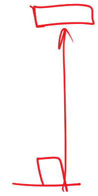
$Q/T_b = \frac{-984.85}{300} = -3.28$ kJ/K

$\boxed{W_{lost} = T_0 \times S_{gen} = 1177.45}$

$1200 - 1177.45$ ( )







Find the net Work required to heat the CO_2 from T_1 to T_2 by using a combination 1 Reversible Heat engine (betn 300 K & the CO_2 gas for $T \leq 300$ K) & then a heat pump (for $T \geq 300$ K). The net consumption by the Carnot Heat pump will be $(1200 - 1177.45)$ kJ (verify)

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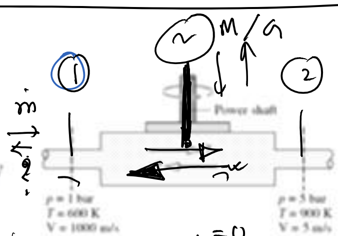
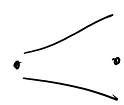
2. The figure on right shows steady-state operating data for a well-insulated device with air entering at one location and exiting at another with a mass flow rate of 10 kg/s. Assuming ideal gas behavior and negligible potential energy effects, determine the direction of flow and the power, in kW.





$\dot{m} = 10$ kg/s

1st Law

$0 = \cancel{\dot{Q}}^{0} - \dot{W} + \dot{m}\left[h_i - h_e\right] + \frac{\dot{m}}{2}\left[C_i^2 - C_e^2\right]$

$\dot{W} = \dot{m}\left[h_i - h_e\right] + \frac{\dot{m}}{2}\left[C_i^2 - C_e^2\right]$

$1 = 0$

$P_1 = 1$ bar	$P_2 = 5$ bar
$T_1 = 600$ K	$T_2 = 900$ K
$C_1 = 1000$ m/s	$C_2 = 5$ m/s
$h_1 = 607.02$	$h_2 = 932.93$ kJ/kg
$s^\circ(600) = 2.40902$	$s^\circ(900) = 2.849$ kJ/kgK
$s(600, 1) = s^\circ(600) - R \ln (P/P_0)$	$s_2(900, 5) = s^\circ(900) - R \ln \frac{5}{1}$
$s_1(600, 1) = 2.40902$ kJ/kgK	$= 2.849 - 0.287 \ln 5 = 2.387$

2nd Law $\frac{dS}{dt}^{0} = \sum \cancel{\dot{Q}/T_b}^{0} + \dot{m}(s_i - s_e) + \dot{S}_{gen}$

$\boxed{s_e - s_i = \left(\dot{S}_{gen}/\dot{m}\right)}$

$s_e > s_i \Rightarrow \boxed{i = 2}$ inlet

$e = 1$

$W = \dot{m}\left[h_2 - h_1\right] + \dot{m}\left[C_2^2/2 - C_1^2/2\right]$

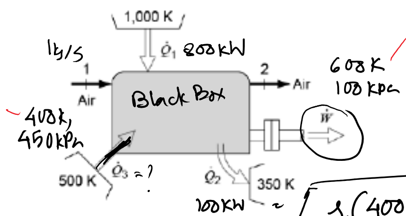
$$e = 1$$

$$W = \dot{m}\left[h_2 - h_1\right] + \dot{m}\left[\frac{C_2^2}{2} - \frac{C_1^2}{2}\right]$$

$$= 10\left[(932.93 - 607.02) + \frac{5^2 - 1000^2}{2000}\right]$$

$$=$$

12. A reversible steady-state device receives a flow of 1 kg/s air at 400 K, 450 kPa, and the air leaves at 600 K, 100 kPa. Heat transfer of 800 kW is added from a 1000 K reservoir, 100 kW is rejected at 350 K, and some heat transfer takes place at 500 K. Find the heat transferred at 500 K and the rate of work produced.



1st Law

$$\dot{Q}_1 - \dot{Q}_2 \pm \dot{Q}_3 - \dot{W} + \dot{m}(h_1 - h_2) = 0$$

$s_1(400\,K, 450\,kPa)$
$= s^\circ(400) - R\ln\frac{450}{100}$
$= 1.99194 - .287\ln 4.5$
$= 1.56$ kJ/kg K

2nd Law

$$\frac{dS}{dt} = \frac{\dot{Q}_1}{T_1} + \frac{-\dot{Q}_2}{T_2} + \frac{\pm\dot{Q}_3}{T_3} + \dot{S}_{gen} + \dot{m}(s_1 - s_2)$$

$s_2(600, 100\,kPa)$
$= s^\circ(600) - R\ln\frac{100}{100}$
$= 2.40902$ kJ/kg K

$$0 = \frac{800}{1000} + \frac{-100}{350} + \frac{\dot{Q}_3}{T_3} + \dot{S}_{gen} + 1(1.56 - 2.409)$$

$$\frac{Q_3}{T_3} = -0.8 + 0.2857 + 0.849$$

$$= 0.3347$$

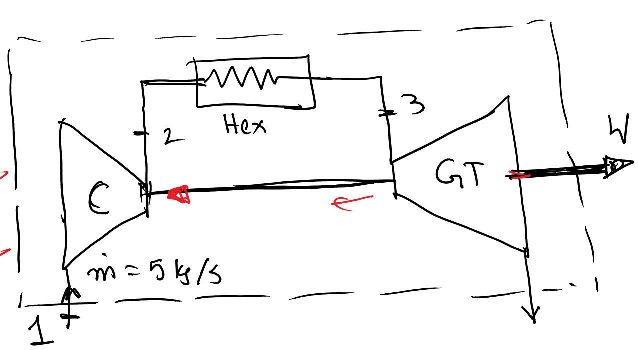
$$Q_3 = 500 \times .3347 =$$

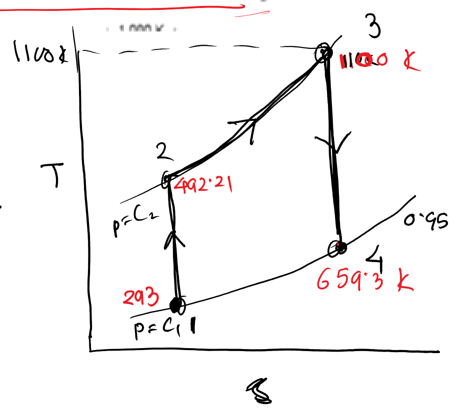
$h_1 = 400.98$ kJ/kg

$h_2 = 607.02$ kJ/kg

11. In a gas turbine operating at steady state, air enters the compressor with a mass flow rate of 5 kg/s at 0.95 bar and 22 °C and exits at 5.7 bar. The air then passes through a heat exchanger before entering the turbine at 1100 K, 5.7 bar. Air exits the turbine at 0.95 bar. The compressor and turbine operate adiabatically and kinetic and potential energy effects can be ignored. Determine the *net* power developed by the plant, in kW, if (a) the compressor and turbine operate without internal irreversibilities, and (b) the compressor and turbine isentropic efficiencies are 82 and 85%, respectively.

Gas Turbine Cycle





$$\delta q = Tds$$

$$Tds = du + pdv$$

1 = 0.95 bar, 295 K

$\delta q = T ds$

$T ds = du + p dv$

$= du + p dv + v dp - v dp$

$T ds = dh - v dp$

for $p = \text{Const}$ $\quad T ds = dh$

$T ds = C_p dT \Rightarrow \boxed{\dfrac{dT}{ds} = \dfrac{T}{C_p}}$

1 = 0·95 bar, 295 K

2 ⇒ 5·7 bar, $T_2 =$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{5.7}{0.95}\right)^{0.4/1.4} = 1.6685 \Rightarrow T_2 = 492.21\ K$$

$$\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{5.7}{0.95}\right)^{0.4/1.4} = 1.6685 \Rightarrow T_4 = 659.3$$

$W_{net} = \dot{m}\left[w_T - w_C\right]$

$= ✓$

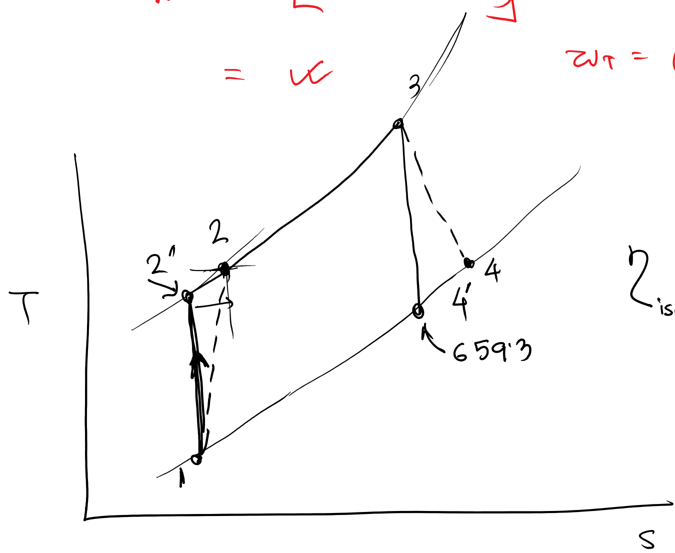
$w_C = (h_2 - h_1) = C_p(T_2 - T_1)$

$= 1.004 \times 197.21$

$w_T = (h_3 - h_4) = C_p(T_3 - T_4)$

$= 1.004 \times (1100 - 659.3)$

kJ/kg



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

$$= 0.82 = \frac{\cancel{C_p}(T_{2'} - T_1)}{\cancel{C_p}(T_2 - T_1)}$$

$$\Rightarrow \frac{T_{2'} - T_1}{T_2 - T_1}$$

$T_2' = 492.21\ K$

$$\frac{T_2' - T_1}{0.82} = T_2 - T_1$$

$$\Rightarrow T_2 = \frac{(492.21 - 295)}{0.82} + 295$$

$= ✓$

For turbine $\quad \eta_{isen} = \dfrac{h_1 - h_4}{h_1 - h_{4'}}$

$$\frac{T_1 - T_4}{T_1 - T_4'} = 0.85$$

$\Rightarrow T_4 = ✓$

$w_c = (h_2 - h_1) = ✓$ ↑

$w = (h_3 - h_4) = ✓$ ↓

$\boxed{\text{Google Form}}$

→ CO1

→ CO1

→ CO2

→ CO3

→ CO4