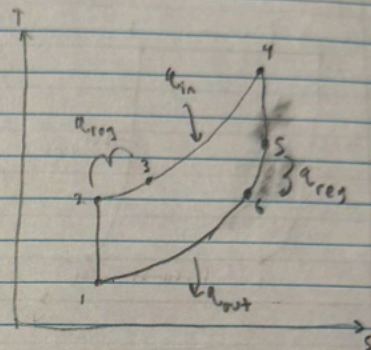
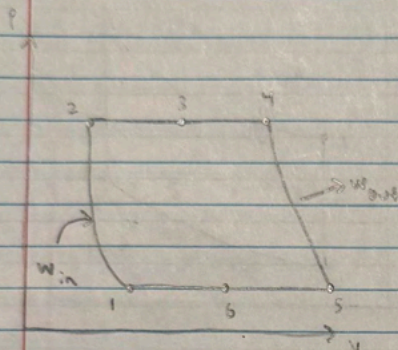


constant c_p, c_v

1. Brayton cycle $T_1 = 303.15 \text{ K}$ $P_1 = 100 \text{ kPa}$ $r_p = 10$ $T_4 = 1073.15 \text{ K}$
 Brayton cycle with regeneration $k = 1.4$ $c_p = 1.005 \text{ kJ/kg} \cdot \text{K}$



1 $\xrightarrow{\text{Isentropic}}$ 2 $\xrightarrow{P=\text{const}}$ 3 $\xrightarrow{P=\text{const}}$ 4 $\xrightarrow{\text{Isentropic}}$ 5

$P_1 = 100 \text{ kPa}$ $P_2 = 10 P_1 = 1000 \text{ kPa}$ $P_3 = P_2 = 1000 \text{ kPa}$ $P_4 = P_3 = 1000 \text{ kPa}$
 $T_1 = 303.15 \text{ K}$ $T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} = 585.29 \text{ K}$ $T_3 = T_5 = 10$ $T_4 = 1073.15 \text{ K}$
 $V_1 = \frac{R T_1}{P_1} = \frac{0.287 (303.15)}{100 \text{ kPa}} = 0.87 \text{ m}^3/\text{kg}$ $T_5 = 555.835 \text{ K}$ $T_6 = 512.375 \text{ K}$

5 $\xrightarrow{\text{Isentropic}}$ 6 $\xrightarrow{P=\text{const}}$ 1 $\xrightarrow{P=\text{const}}$ 2

$P_5 = 100 \text{ kPa}$ $P_6 = 100 \text{ kPa}$ $P_1 = 100 \text{ kPa}$
 $T_5 = T_4 \left(\frac{P_5}{P_4} \right)^{\frac{k-1}{k}} = 555.835 \text{ K}$ $T_6 = T_5 - (T_3 - T_2) = 512.375 \text{ K}$
 $\eta_{th} = 1 - \frac{q_c}{q_h} \rightarrow 1 - \frac{c_p(T_6 - T_1)}{c_p(T_4 - T_3)} = 1 - \frac{T_6 - T_1}{T_4 - T_3} = 1 - \frac{512.375 - 303.15}{1073.15 - 585.835} = 0.60318$

$q_{out} = (P(T_6 - T_1)) \rightarrow 1.005 (512.375 - 303.15) = 210.29 \text{ kJ}$

$q_{in} = (P(T_4 - T_3)) \rightarrow 1.005 (1073.15 - 585.835) = 529.95 \text{ kJ}$

$w_{net} = w_{out} - w_{in} \rightarrow c_p(T_4 - T_5) - (c_p(T_2 - T_1))$

$w_{net} = 1.005 (1073.15 - 555.835) - 1.005 (585.29 - 303.15)$

$w_{net} = 234.33$

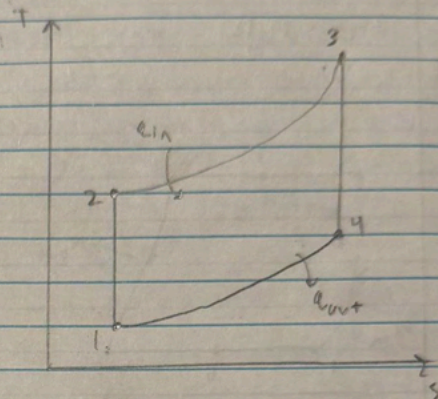
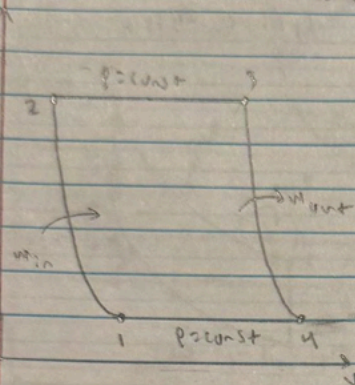
$\epsilon = \frac{h_5 - h_2}{h_4 - h_2} = \frac{1(c_p(T_5 - T_2))}{1(c_p(T_4 - T_2))} = \frac{1.005 (555.835 - 585.29)}{1.005 (1073.15 - 585.29)}$

$\epsilon = 0.0603$

$$T_1 = 303.13 \text{ K} \quad r_p = 10$$

$$P_1 = 100 \text{ kPa} \quad T_3 = 1073.15 \text{ K}$$

1b. Brayton without regens



$$1 \xrightarrow{\text{Isentrop}} 2 \xrightarrow{p=\text{const}} 3 \xrightarrow{\text{Isentrop}} 4$$

$$P_1 = 100 \text{ kPa} \quad P_2 = 10 P_1 = 1000 \text{ kPa} \quad P_3 = 1000 \text{ kPa} \quad P_4 = 100 \text{ kPa}$$

$$T_1 = 303.13 \text{ K} \quad T_2 = T_1 (10)^{\frac{1}{1.4}} = 585.252 \text{ K} \quad T_3 = 1073.15 \text{ K} \quad T_4 = T_3 \left(\frac{1}{10}\right)^{\frac{1}{1.4}} = 555.835 \text{ K}$$

$$W_{\text{net}} = W_{\text{out}} - W_{\text{in}}$$

$$W_{\text{in } 1-2} = (p(T_2 - T_1)) = 283.53$$

$$W_{\text{out } 3-4} = (p(T_3 - T_4)) = 519.901$$

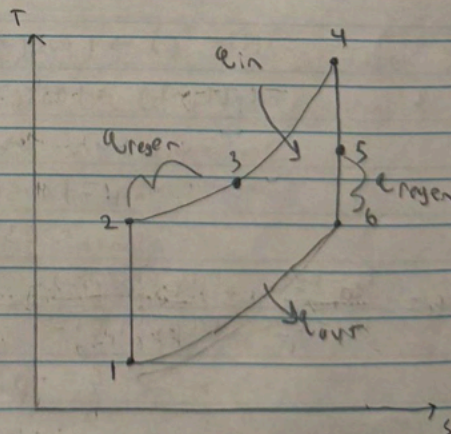
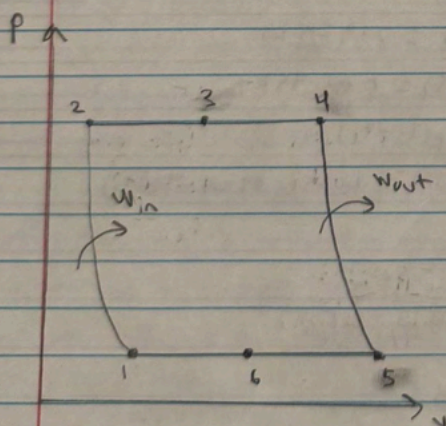
$$W_{\text{net}} = 236.37$$

$$q_{\text{in } 2-3} = h_3 - h_2 = (p(T_3 - T_2)) = 1.005(1073.15 \text{ K} - 585.252 \text{ K}) = 490.337$$

$$q_{\text{out } 4-1} = h_4 - h_1 = (p(T_4 - T_1)) = 1.005(555.835 - 303.13) = 253.96$$

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{q_{\text{in}}} = \frac{236.37}{490.337} = 0.482$$

1c. OG Design w regen but $r_p = 8.58$



1	Isentrop	2	$p = \text{const}$	3	$p = \text{const}$	4
$P_1 = 100 \text{ kPa}$		$P_2 = 100 \text{ kPa}$		$P_3 = P_2 = 850 \text{ kPa}$		$P_4 = P_3 = 850 \text{ kPa}$
$T_1 = 303.13 \text{ K}$		$T_2 = T_1 (2.08)^{\frac{0.4}{1.4}}$		$T_3 = T_2 - 10$		$T_4 = 1073.15 \text{ K}$
		$T_2 = 560.195 \text{ K}$		$T_3 = 570.697$		

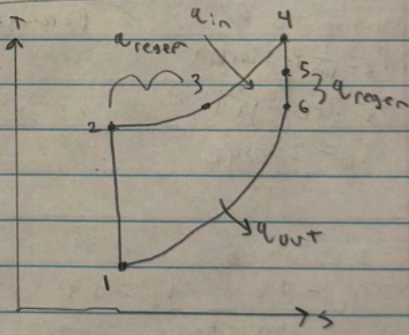
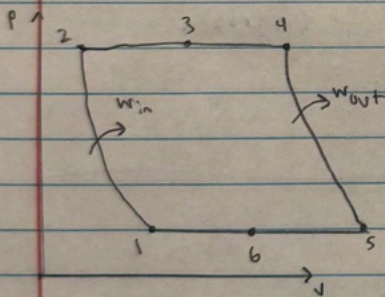
5	Isentrop	6	$p = \text{const}$	1
$P_5 = 100 \text{ kPa}$		$P_6 = 100 \text{ kPa}$		
$T_5 = T_4 \left(\frac{1}{2.08} \right)^{\frac{0.4}{1.4}}$		$T_6 = T_5 - (T_3 - T_2)$		$\eta = \frac{h_5 - h_2}{h_4 - h_2}$
$T_5 = 580.697$		$T_6 = 570.195$		$\eta = 0.034997$
$W_{\text{out } 4-5} = (p(T_4 - T_5))$		$W_{\text{in } 1-2} = (p(T_2 - T_1))$		
$1.005(1073.15 - 580.697) = 494.915$		$1.005(570.195 - 303.13) = 258.35$		

$$Q_{\text{in}} = (p(T_4 - T_3)) = 1.005(1073.15 - 570.697) = 504.965$$

$$Q_{\text{out}} = (p(T_6 - T_1)) = 1.005(570.195 - 303.13) = 268.40$$

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{Q_{\text{in}}} = \frac{236.565}{504.965} = 0.468$$

06 Design w temp max = 895.48°C



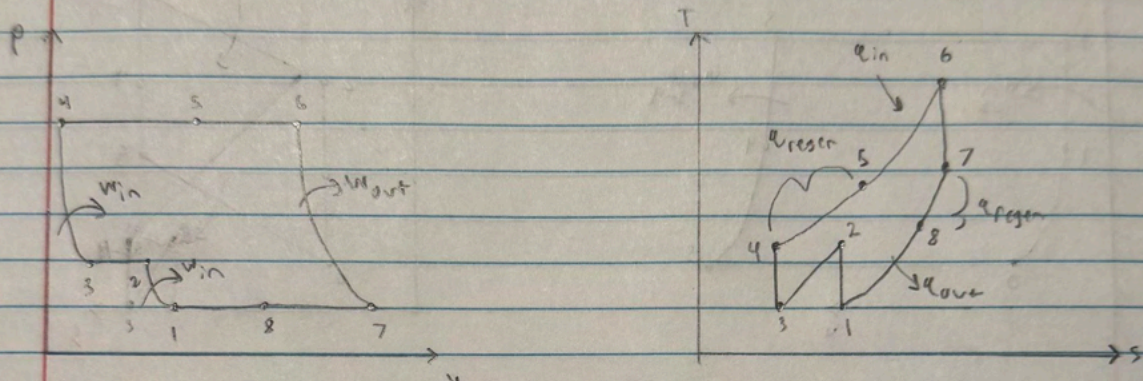
1	Isentrop	2	$p = \text{const}$	3	$p = \text{const}$	4	Isentrop	5	$p = \text{const}$	6
$P_1 = 100 \text{ kPa}$		$P_2 = 10 P_1 = 1000 \text{ kPa}$		$P_3 = P_2 = 1000 \text{ kPa}$		$P_4 = 100 \text{ kPa}$		$P_5 = 100 \text{ kPa}$		$P_6 = 100 \text{ kPa}$
$T_1 = 303.13 \text{ K}$		$T_2 = T_1 (10)^{\frac{0.4}{1.4}}$		$T_3 = T_2 - 10$		$T_4 = 1168.63 \text{ K}$		$T_5 = T_4 \left(\frac{1}{10} \right)^{\frac{0.4}{1.4}}$		$T_6 = T_5 - (T_3 - T_2)$
		$T_2 = 585.29 \text{ K}$		$T_3 = 595.29 \text{ K}$				$T_5 = 605.288$		$T_6 = 595.29$

$$W_{\text{net}} = W_{\text{out}} - W_{\text{in}} \rightarrow (p(T_4 - T_5)) - (p(T_2 - T_1)) = 282.28$$

$$Q_{\text{in}} = (p(T_4 - T_3)) = 576.4077 \quad Q_{\text{out}} = (p(T_6 - T_1)) = 293.6288$$

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{Q_{\text{in}}} = 0.4905 \quad \epsilon = \frac{h_5 - h_2}{h_4 - h_2} = 0.03428$$

06 Design with 2 stage w inter cooling



1	$\xrightarrow{p=\text{const}}$	2	$\xrightarrow{p=\text{const}}$	3	$\xrightarrow{p=\text{const}}$	4
$P_1 = 190 \text{ kPa}$		$P_2 = 1000 \text{ kPa}$		$P_3 = 1000 \text{ kPa}$		$P_4 = 1000 \text{ kPa}$
$T_1 = 303.15 \text{ K}$		$T_2 = T_1 (10)^{\frac{1.4}{1}}$		$T_3 = 303.15 \text{ K}$		$T_4 = T_3 (10)^{\frac{1.4}{1}}$
		$T_2 = 585.29 \text{ K}$				$T_4 = 585.29 \text{ K}$

$\xrightarrow{p=\text{const}}$	5	$\xrightarrow{p=\text{const}}$	6	$\xrightarrow{p=\text{const}}$	7	$\xrightarrow{p=\text{const}}$	8	$\xrightarrow{p=\text{const}}$	1
	$P_5 = 10000 \text{ kPa}$		$T_6 = 1072.15 \text{ K}$		$P_7 = 100 \text{ kPa}$		$P_8 = 100 \text{ kPa}$		
	$T_5 = T_2 - 10$		$P_6 = 10000 \text{ kPa}$		$T_7 = 1072.15 (100)^{\frac{1.4}{1}}$		$T_8 = T_7 + \frac{q_{in}}{c_p}$		
	$T_5 = 277.89 \text{ K}$				$T_7 = 2287.89$		$T_8 = 1083.14$		

$$W_{net} = W_{out} - W_{in} \rightarrow c_p (T_6 - T_7) - (c_p (T_2 - T_1) + (c_p (T_4 - T_3)))$$

$$W_{net} = 222.04$$

$$q_{in} = c_p (T_6 - T_5) = 794.2363 \quad q_{out} = c_p (T_8 - T_1) = 1783.88$$

$$\eta_{th} = \frac{W_{net}}{q_{in}} = 0.2778 \quad \epsilon = \frac{h_5 - h_2}{h_4 - h_2} = \frac{h_7 - h_4}{h_6 - h_4} = 0.6046$$

Variable c_p

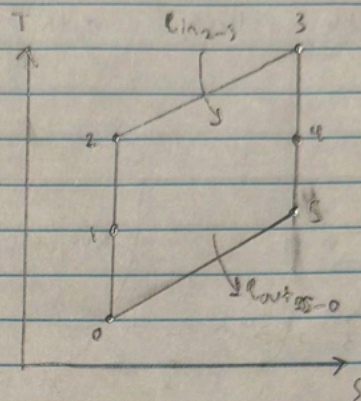
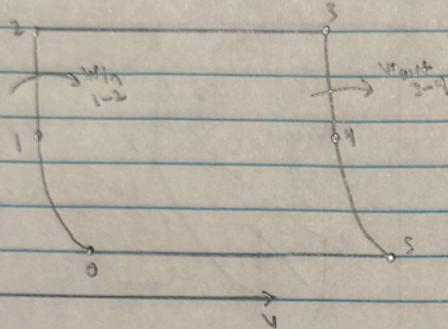
$$V_0 = 250 \text{ m/s}$$

$$W_0 = W_0 = 500 \text{ kJ/kg}$$

$$\eta_c = 0.8$$

$$\eta_t = 0.9$$

P



0 $\xrightarrow{\text{Isentrop}}$ 1

$$T_0 = 238.15 \text{ K}$$

$$P_0 = 40 \text{ kPa}$$

$$P_{r0} = 0.6192$$

$$h_0 = 238.17$$

1 $\xrightarrow{\text{Isentrop}}$ 2

$$h_1 = h_0 + \frac{V_0^2}{2000}$$

$$h_1 = 269.42$$

$$T_1 = 269.311$$

$$P_{r1} = 0.9508$$

$$P_1 = P_0 \left(\frac{P_{r1}}{P_{r0}} \right) = 61.41 \text{ kPa}$$

2 $\xrightarrow{\text{Isentrop}}$ 3

$$W_{in,1-2} = h_2 - h_1$$

$$h_2 = W_{in,1-2} + h_1 = 769.425$$

$$T_2 = 751.48 \text{ K}$$

$$\eta_c = \frac{h_2 - h_1}{h_{2s} - h_1}$$

$$h_{2s} = h_1 + \eta_c (h_2 - h_1)$$

$$h_{2s} = 669.311$$

$$P_2 = P_1 \left(\frac{P_{r2}}{P_{r1}} \right) = 1484.23$$

$$T_3 = 1223.15 \text{ K}$$

$$P_2 = P_3 = 1484.21 \text{ kPa}$$

$$h_3 = 1305.03$$

$$P_{r3} = 257.44$$

3 $\xrightarrow{\text{Isentrop}}$ 4

$$W_{out,3-4} = h_3 - h_4$$

$$h_4 = h_3 - W_{out,3-4}$$

$$h_4 = 801.8 \text{ kJ/kg}$$

$$T_4 = 791.183$$

$$P_{r4} = 43.61$$

$$P_4 = P_3 \left(\frac{P_{r4}}{P_{r3}} \right)$$

$$P_4 = 251.423 \text{ kPa}$$

4 $\xrightarrow{\text{Isentrop}}$ 5

$$P_5 = 40 \text{ kPa}$$

$$P_{r5} = P_{r4} \left(\frac{P_5}{P_4} \right)$$

$$P_{r5} = 6.938$$

$$h_5 = 476.29$$

$$T_5 = 473.226$$

5 $\xrightarrow{\text{Isentrop}}$ 0

$$P_5 = 40 \text{ kPa}$$

$$P_0 = 40$$

Exit Turbine Pressure: 251.423 kPa

Nozzle exit velocity: $V_5 = \sqrt{2(h_4 - h_5)} = 1000$

$$V_5 = 806.858 \text{ m/s}$$

Find Thrust: $F = \dot{m}(V_5 - V_0)$

$$\dot{m} = \rho_0 A V_0$$

$$\rho_0 = \frac{P_0}{R T_0} = \frac{40 \text{ kPa}}{0.287(238.15)}$$

$$\rho_0 = 0.585 \text{ kg/m}^3$$

$$\dot{m} = 0.585 \left(\frac{\pi \cdot 1.6^2}{4} \right) (250) = 294.1 \text{ kg/s}$$

$$F = 294.1 \text{ kg/s} (806.858 - 250)$$

$$F = 163771.94 \text{ N} / 163.771 \text{ kN}$$