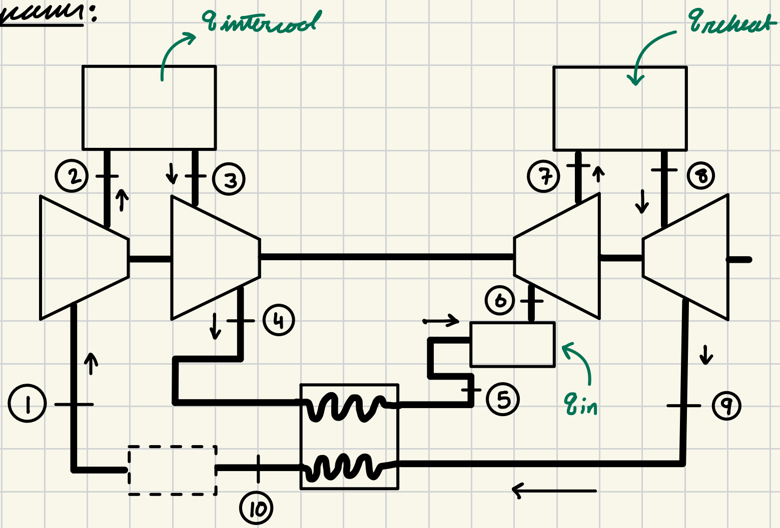
Thermal Application Exam 1

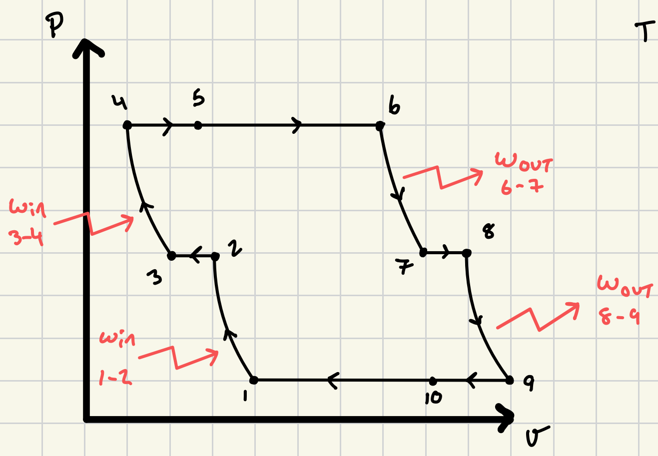
GRANT BIDDLECOMB

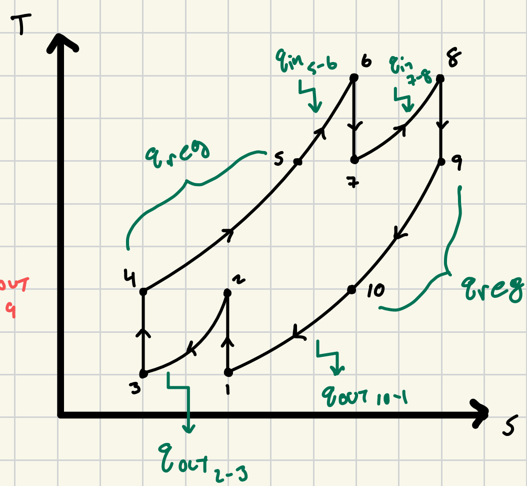
Problem #1

→ **Purpose:** The purpose of this problem is to first calculate the effectiveness of the regeneration heat exchanger & compare it to typical values of effectiveness, and then to find the produced power if the reheater is turned off, and determine whether or not η_{TH} will change.

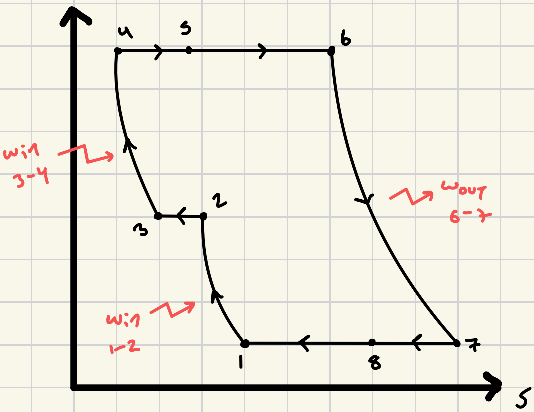
→ **Diagram:**

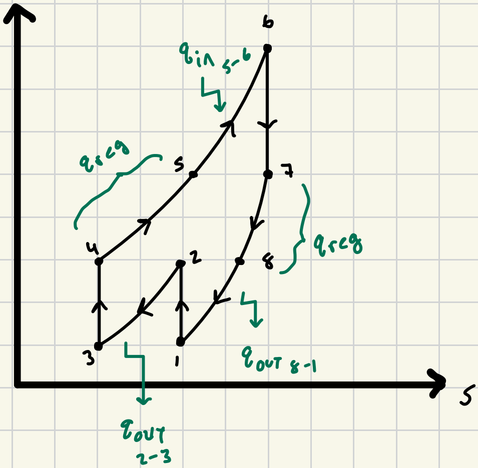






(after reheater is turned off)





→ **Source:** Cengel & Boles. Thermodynamics - an Engineering approach. 8th edition McGraw Hill. 2015

→ **Design Considerations:** The following is assumed:

- air behaves as ideal gas,
- c_p & c_v are constant & evaluated at room temperature (25°C or 298K)
- compression & expansion are isentropic
- no heat loss in connecting pipes or fluid flow friction

→ **Data & Variables:**

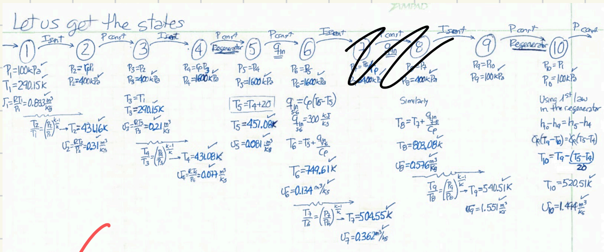
$q_{in} = 300\ kJ/kg$ $\qquad r_p = 4$

$P_1 = 100\ kPa$ $\qquad T_5 = T_4 + 20$

$T_1 = 17°C$ $\qquad \dot{w}_{net} = 90\ kW$ (Part B)

→ **Materials:** air as ideal gas

→ **Procedure & Calculation:** The in class discussion and calculations of problem 9-133 will be referenced to extract sufficient information to calculate the efficiency of the HX.


Let us get the states

1 → (Isent) → 2 → (P const) → 3 → (Isent) → 4 → (P const, Regenerator) → 5 → (P const, q_{in}) → 6 → (Isent) → 7 → (P const, q_{in}) → 8 → (Isent) → 9 → (P const, Regenerator) → 10 → (P const)

State 1: $P_1 = 100\,kPa$, $T_1 = 290.15\,K$, $v_1 = \frac{RT_1}{P_1} = 0.833\,\frac{m^3}{kg}$

$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \rightarrow T_2 = 431.16\,K$, $v_2 = \frac{RT_2}{P_2} = 0.31\,\frac{m^3}{kg}$

State 2: $P_2 = r_p P_1$, $P_2 = 400\,kPa$

State 3: $P_3 = P_2$, $P_3 = 400\,kPa$, $T_3 = T_1$, $T_3 = 290.15\,K$, $v_3 = \frac{RT_3}{P_3} = 0.21\,\frac{m^3}{kg}$

$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}} \rightarrow T_4 = 431.08\,K$, $v_4 = \frac{RT_4}{P_4} = 0.077\,\frac{m^3}{kg}$

State 4: $P_4 = r_p P_3$, $P_4 = 1600\,kPa$

State 5: $P_5 = P_4$, $P_5 = 1600\,kPa$, $T_5 = T_4 + 20$, $T_5 = 451.08\,K$, $v_5 = 0.081\,\frac{m^3}{kg}$

State 6: $P_6 = P_5$, $P_6 = 1600\,kPa$, $q_{in,5\text{-}6} = c_p(T_6 - T_5)$, $q_{in,5\text{-}6} = 300\,\frac{kJ}{kg}$, $T_6 = T_5 + \frac{q_{in,5\text{-}6}}{c_p}$, $T_6 = 749.61\,K$, $v_6 = 0.134\,m^3/kg$

$\frac{T_7}{T_6} = \left(\frac{P_7}{P_6}\right)^{\frac{k-1}{k}} \rightarrow T_7 = 504.55\,K$, $v_7 = 0.362\,m^3/kg$

State 8: $P_8 = P_7$, $P_8 = 400\,kPa$

Similarly $T_8 = T_7 + \frac{q_{in,7\text{-}8}}{c_p}$, $T_8 = 803.08\,K$, $v_8 = 0.576\,\frac{m^3}{kg}$

$\frac{T_9}{T_8} = \left(\frac{P_9}{P_8}\right)^{\frac{k-1}{k}} \rightarrow T_9 = 540.51\,K$, $v_9 = 1.551\,\frac{m^3}{kg}$

State 9: $P_9 = P_{10}$, $P_9 = 100\,kPa$

State 10: $P_{10} = P_1$, $P_{10} = 100\,kPa$

Using 1st law in the regenerator: $h_{10} - h_9 = h_5 - h_4$, $c_p(T_9 - T_{10}) = c_p(T_5 - T_4)$, $T_{10} = T_9 - (T_5 - T_4)$, $T_{10} = 520.51\,K$, $v_{10} = 1.494\,\frac{m^3}{kg}$

↳ write by hand if time

effectiveness of a heat exchanger is:

$$\epsilon = \frac{(T_{hi} - T_{ho})}{(T_{hi} - T_{ci})} \quad \text{or} \quad \frac{T_5 - T_4}{T_9 - T_4}$$

$$\rightarrow \frac{451.08 - 431.08}{540.51 - 431.08} \Rightarrow \boxed{\epsilon = .1828 \text{ or } 18.3\%}$$

Now for the second part, the states may be recomputed while omitting the previous process from 7-8

1 —ISENT→ 2 —P CONST→ 3 —ISENT→ 4 —P CONST→ 5 —P CONST→ 6 —ISENT→ 7 —P CONST→ 8 —P CONST

1	2	3	4	5	6	7	8
$P_1 = 100kPa$	$P_2 = 400kPa$	$P_3 = 400kPa$	$P_4 = 1600kPa$	$P_5 = 1600kPa$	$P_6 = 1600kPa$	$P_7 = 100kPa$	$P_8 = 100kPa$
$T_1 = 290.15K$	$T_2 = 436.16K$	$T_3 = 290.15K$	$T_4 = 431.08K$	$T_5 = 418.36K$	$T_6 = 716.87K$	$T_7 = 324.25K$	$T_8 =$
$v_1 = .833\ m^3/kg$	$v_2 = .31\ m^3/kg$	$v_3 = .21\ m^3/kg$	$v_4 = .077\ m^3/kg$				

$\left(\frac{100}{1600}\right)^{.4/1.4} = \frac{T_7}{716}$

$T_6 - \frac{300}{1.005} = T_5$ $\qquad$ $T_6 = T_5 + \frac{300}{1.005}$

$Q_{in} = \frac{\dot{w}_{net}}{\eta_{TH}} =$

$\dot{w}_{net} = 800kW$

$w_{net} = 226.801 \times$ old system

$w_{net} = w_T - w_c$

$\eta_{TH} = P/Q_{in}$

$\frac{T_6}{T_5} = 1^{.4/1.4}$ $\Rightarrow$ $T_6 = T_5(1^{.4/1.4})$ → $P_5/P_4{}^{.4/1.4}$ didn't work b/c in itself 1

$\rightarrow (1^{.4/1.4}) T_5 = T_5 + \frac{300}{1.005}$

$\text{Power} = \dot{m}(w_{TURB} - w_{comp})$

$Q_{in} = \dot{m} c_p (T_6 - T_5)$

$\dot{m} = \frac{\dot{w}_{net}}{w_{net}} = \frac{800kW}{106.21}$

$\Rightarrow \dot{m} = 7.53\ kg/s$

$300\ kJ/kg = h_6 - h_4 = h_6 - 431.45$

from hw 1.4 sol. → so $h_6 = 731.45$

$\text{Power} = 7.53[106.21] \Rightarrow$ **Power = 800kW**

$w_{net} = w_{OUT\,6\text{-}7} - w_{in\,1\text{-}2} - w_{in\,3\text{-}4} \Rightarrow 106.21\ kJ/kg$

$w_{OUT\,6\text{-}7} = 1.005(716.87 - 324.25) = 394.58$

$w_{in\,1\text{-}2} = 1.005(436.16 - 290.15) = 146.74$

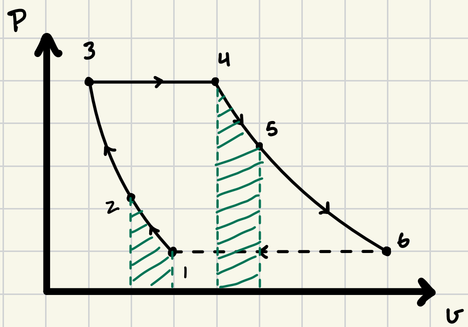
$w_{in\,3\text{-}4} = 1.005(431.08 - 290.15) = 141.63$

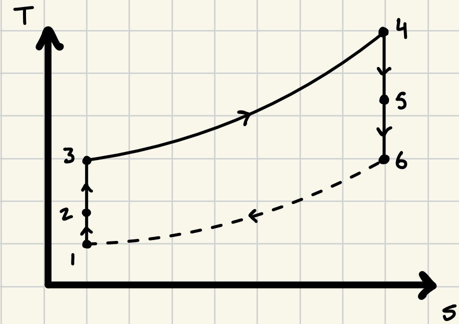
→ **Analysis:** The produced power if the reheater is turned off is 800kW. Because this is the same as the problem statement, it is safe to assume the thermal efficiency does not change. Like the problem states, efficiency of any one particular part will not change; instead the rate of flow or amount of Q_{in} will change throughout to balance assumptions.

Problem #2

→ **Purpose:** The purpose of this problem is to compare the propulsive efficiency of jet propulsion cycles with different compressor & turbine efficiencies.

→ **Diagrams:**





→ **Source:** Cengel & Boles. Thermodynamics — An Engineering Approach. 8th edition. McGraw Hill. 2015

→ **Design Considerations:** To solve the problem the following will be assumed

- variable c_p, c_v
- air behaves as an ideal gas
- turbine $work_{in}$ & $work_{out}$ are equal
- isentropic expansion & compression processes
- ideal operation of all components

→ **Data & Variables:**

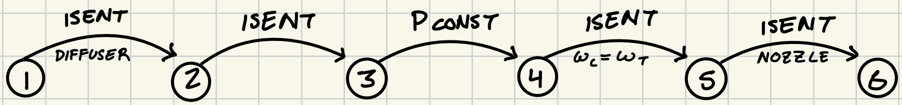
$V_{aircraft} = 240\ m/s$ $\quad$ $D_{engine\ inlet} = 16m$

$P_1 = 45\ kPa$ $\quad$ $r_p = 13$ (compressor)

$T_1 = -13°C$ $\quad$ $T_{inlet\ turb} = 557°C$

→ Materials: Air as ideal gas

→ Procedure & Calculations: The first goal is to obtain the states with the new efficiencies given to us



①	②	③	④	⑤	⑥
$P_1 = 45\text{kPa}$	$V_2 = 0 \text{ m/s}$	$V_3 = 0 \text{ m/s}$	$V_4 = 0 \text{ m/s}$	$V_5 = 0 \text{ m/s}$	$P_6 = 45\text{kPa}$
$T_1 = 260\text{K}$	$T_2 = 288.71\text{K}$	$P_3 = 18\text{MPa}$	$P_4 = 18\text{MPa}$	$T_5 = 680\text{K}$	$T_6 = 168\text{K}$
$V_1 = 240 \text{ m/s}$	$P_2 = 64.89\text{kPa}$	$T_3 = 1304.91\text{K}$	$T_4 = 830.15$	$P_5 = 9.43\text{MPa}$	

↑ $T_2 = T_1 + \frac{V_1^2}{2c_p}$

$\frac{P_2}{45} = \frac{1.212}{.8405}$ →

$\frac{18E3}{64.89} = \frac{P_{r_3}}{1.212}$

↑ from statement

↑ $T_5 = T_4 - (T_2 - T_3)$

had to rev. for (+) value

$\frac{45}{9.4E3} = \frac{P_{r_6}}{28.85}$

$\frac{P_{r_5}}{P_{r_4}} = \frac{28.85}{55.09}$

$\eta_c \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$ or $1 - \frac{1}{r_p^{\frac{k-1}{k}}} = .8 \rightarrow \frac{P_3}{P_2} = 27951$ *

pressure ratios may be too high?

$\eta_T \cong \frac{h_3 - h_{4a}}{h_3 - h_{4s}} = .85$ or $1 - \frac{1}{r_p^{\frac{k-1}{k}}} = .85 \rightarrow \frac{P_5}{P_4} = 759.97$ *

↳ did not make sense to me for P_5

$.85 = \frac{1395.97 -}{1395.97 -}$

c_p of air at 260K $= 1003.0 \text{ J/kg·K}$

$V_{EX} \rightarrow 260 = 168 + \frac{V_6^2}{2(1003.58)}$

$\rightarrow V_6 = 429.78$

$\eta_p = \frac{(429 - 240)\, 240}{c_p(1304.91 - 830.15)} \Rightarrow$ **$\eta_p = .095$ or 9.5%**

The next step is to calculate efficiency of the cycle as it was given in the original cycle (should've been first step but I did not realize we didn't already calculate it).

$$\eta_p = \frac{(V_6 - V_1)\ V_1}{c_p(T_4 - T_3)} = \frac{(564.52-240)\,240}{1004(830.15-600.99)} \Rightarrow \eta_p = .339 \text{ or } 33.9\%$$

→ <u>Analysis:</u>

After setting the compressor & turbine efficiencies to 80% & 85% respectively, the propulsive efficiency dropped from roughly 34% to 9.5%. The efficiency did in fact change because the supposed change in efficiencies affected the subsequent calculations for temperature & pressure. That makes sense because of the fact that the values that changed most are prevalent in the major calculations done, i.e the final velocity dropping while the inlet stayed the same and the heat going into the system increasing.