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Alexandria University – FOE

ALEXANDRIA UNIVERSITY


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# MEC212 Thermodynamics II

**(2)** A gas turbine power plant operates on a simple gas turbine cycle with air as the working fluid. The air enters the compressor at 95 kPa and 310 K and the turbine at 1300 K. The isentropic efficiency is 80% for the compression and 85% for the expansion. Accounting for the variation of specific heats with temperature. **(Hint: Vary the pressure ratio from 2 to 20)** **Using EES:**

**A-** Find the optimum pressure ratio for maximizing net work output of the cycle and plot the $r_p$-$w_{net}$ relation.

**B-** Plot the relation between the pressure ratio and the thermal efficiency then compare it with the simple ideal cycle.

**C-** Use an ideal regenerator and plot the relation between the pressure ratio and the thermal efficiency to compare it with the simple ones and find out the maximum pressure ratio can be used with the regenerative cycle.

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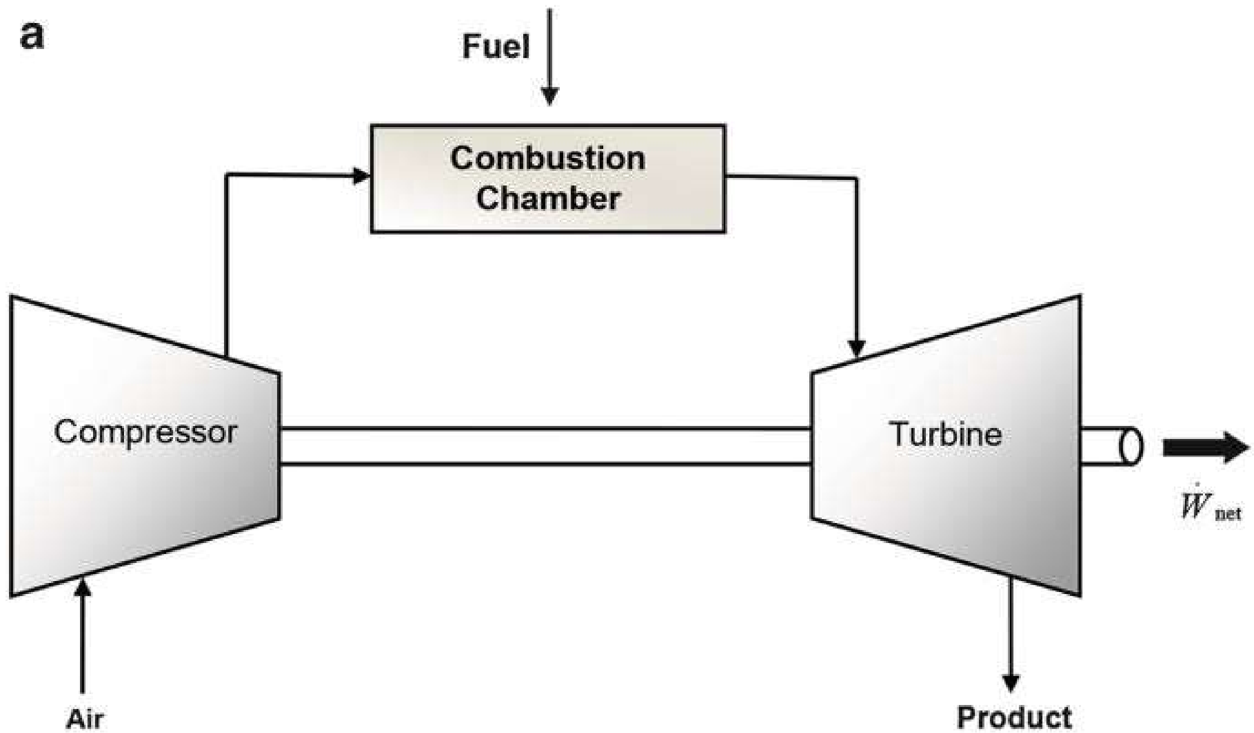
## Instructions:

1. The project is performed in groups of 8 to 10 members.
2. Discussions' date will be determined and announced (around 3 weeks).
3. A detailed report must be submitted containing the required results and graphs in addition to a lap-top to check the computational codes.
4. The ESS manual should be consulted whenever is needed.




**Flow Diagram**

Givens:

$$P_{Min} = .95\ bar\ , P_{Max} = (r\_p * p\_\mathrm{min}\ )bar\ ,$$

$$T_{Max} = 1300°\mathrm{C}\ , T_{Min} = 310°\mathrm{C}\ \ , \eta_T = 0.85\ \ ,$$
$$\eta_C = 0.80\ \ , r_p = \ 2 \rightarrow 20$$

$$\rightarrow h_1 \rightarrow (from\ Air\ Table)\ @\ T = T_{Min}\ \&\ P = P_{Min}$$

$$\rightarrow h_1 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_1$$

$$\rightarrow r_p = \frac{P_2}{P_1} = \frac{P_{r_{2_s}}}{P_{r_1}}\ \rightarrow P_{r_{2_s}}$$

$$\rightarrow h_{2s} \rightarrow (From\ Air\ \ Table)\ @\ P_{r_{2_s}}$$

$$\rightarrow\ \ \eta_C = \frac{h_{2s} - \ h_1}{h_2 - \ h_1} \rightarrow\ h_2 = \frac{h_{2s} - \ h_1}{\eta_p} + h_1$$

$$\rightarrow h_2 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_2$$

$$\rightarrow h_3 \rightarrow (from\ Air\ Table)\ @\ T = T_{Max}\ \&\ P = P_{Max}$$

$$\rightarrow h_3 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_3$$

$$\rightarrow\ \frac{1}{r_P} = \frac{P_4}{P_3} = \frac{P_{r_{4_s}}}{P_{r_3}}\ \rightarrow P_{r_{4_s}}$$

$$\rightarrow h_{4s} \rightarrow (From\ Air\ \ Table)\ @\ P_{r_{4_s}}$$

$$\rightarrow\ \ \eta_T = \frac{h_3 - \ h_4}{h_3 - \ h_{4s}} \rightarrow\ h_4 = h_3 - \left(\eta_T \times (h_3 - \ h_{4s})\right)$$

$$\rightarrow h_4 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_4$$

## Requirements

$\rightarrow W_{Turbine} = (h_3 - h_4)$

$\rightarrow W_{Compressor} = (h_2 - h_1)$

$\rightarrow W_{Net} = W_{Turbine} - W_{Compressor}$

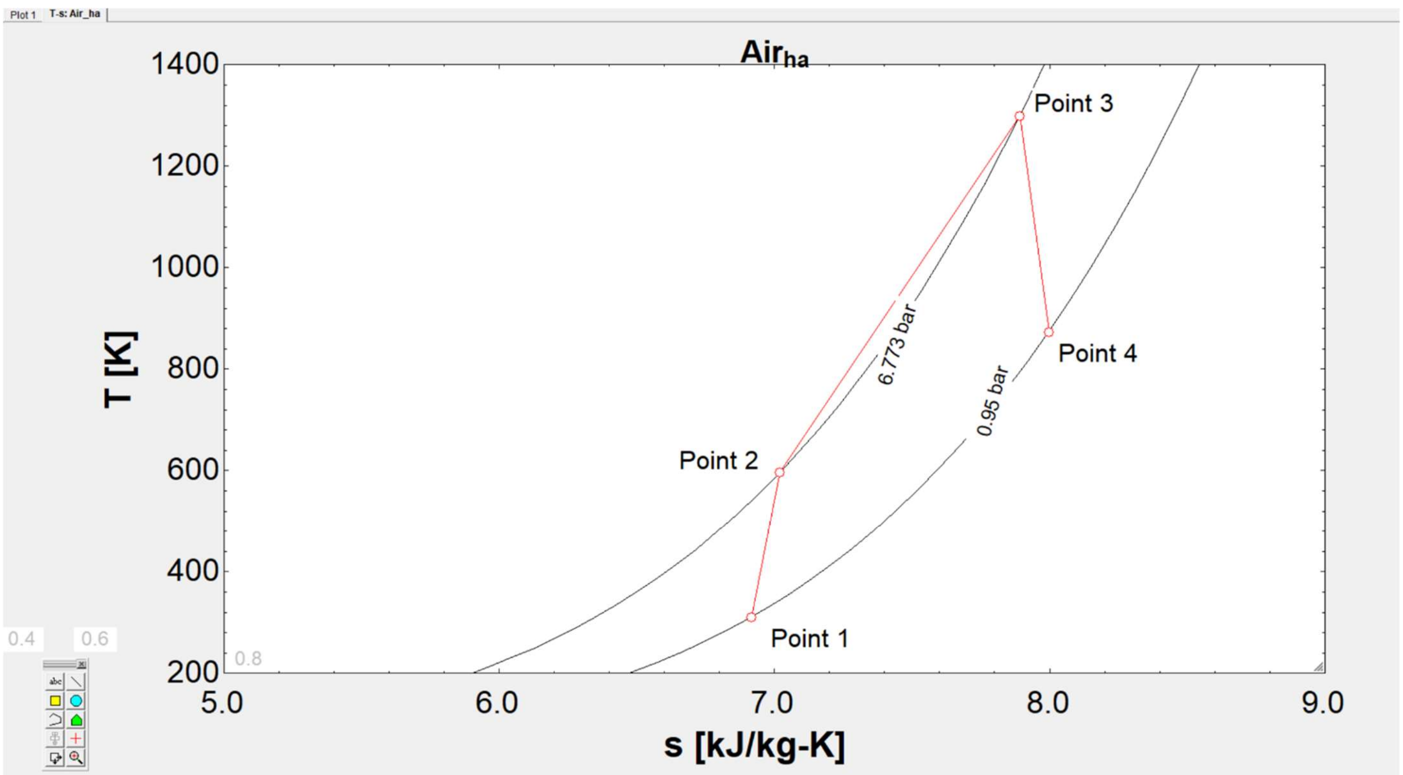
$\rightarrow Q_{Add} = (h_3 - h_2)$

$$\eta_{th} = \frac{W_{Net}}{Q_{Add}}$$

## Requirement (A)

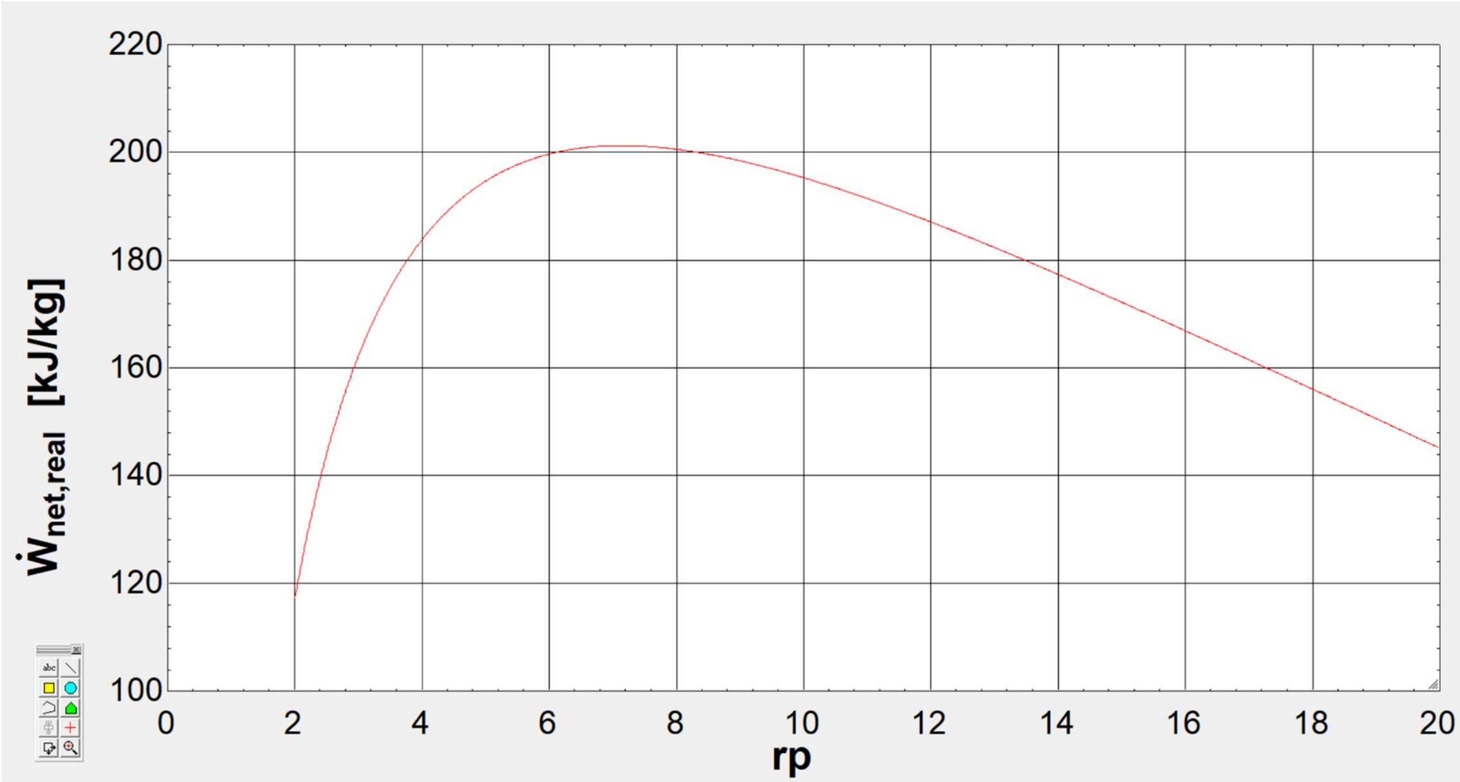
Maximization of W_dot_net_real(rp) = 201.2    20 iterations: Golden Section method

| | | | |
|---|---|---|---|
| $\eta_p = 0.8$ | $\eta_t = 0.85$ | $\eta_{th,ideal} = 0.407$ | $\eta_{th,real} = 0.2535$ |
| $\eta_{th,regenerative} = 0.4073$ | $h_1 = 310.3$ [kJ/kg] | $h_2 = 603$ [kJ/kg] | $h_{2s} = 544.5$ [kJ/kg] |
| $h_3 = 1397$ [kJ/kg] | $h_4 = 902.8$ [kJ/kg] | $h_{4s} = 815.7$ [kJ/kg] | $h_a = 902.8$ [kJ/kg] |
| $h_b = 603$ [kJ/kg] | $p_{max} = 6.773$ [bar] | $p_{min} = 0.95$ [bar] | $\dot{Q}_{add,ideal} = 852.2$ [kJ/kg] |
| $\dot{Q}_{add,real} = 793.7$ [kJ/kg] | $\dot{Q}_{add,regenerative} = 493.9$ [kJ/kg] | $\dot{Q}_{rej,ideal} = 505.4$ [kJ/kg] | $\dot{Q}_{rej,real} = 592.5$ [kJ/kg] |
| $\dot{Q}_{rej,regenerative} = 292.7$ [kJ/kg] | $rp = 7.129$ | $s_1 = 6.916$ [kJ/kg-K] | $s_2 = 7.02$ |
| $s_3 = 7.892$ [kJ/kg-K] | $s_4 = 7.996$ | $s_a = 7.432$ | $s_b = 7.584$ [kJ/kg-K] |
| $T_1 = 310$ [F] | $T_2 = 596$ | $T_3 = 1300$ | $T_4 = 872.7$ [F] |
| $T_a = 872.5$ | $T_b = 595.9$ | $T_{max} = 1300$ [k] | $T_{min} = 310$ [k] |
| $\dot{W}_{net,ideal} = 346.9$ [kJ/kg] | $\dot{W}_{net,real} = 201.2$ [kJ/kg] | $\dot{W}_{net,regenerative} = 201.2$ [kJ/kg] | |



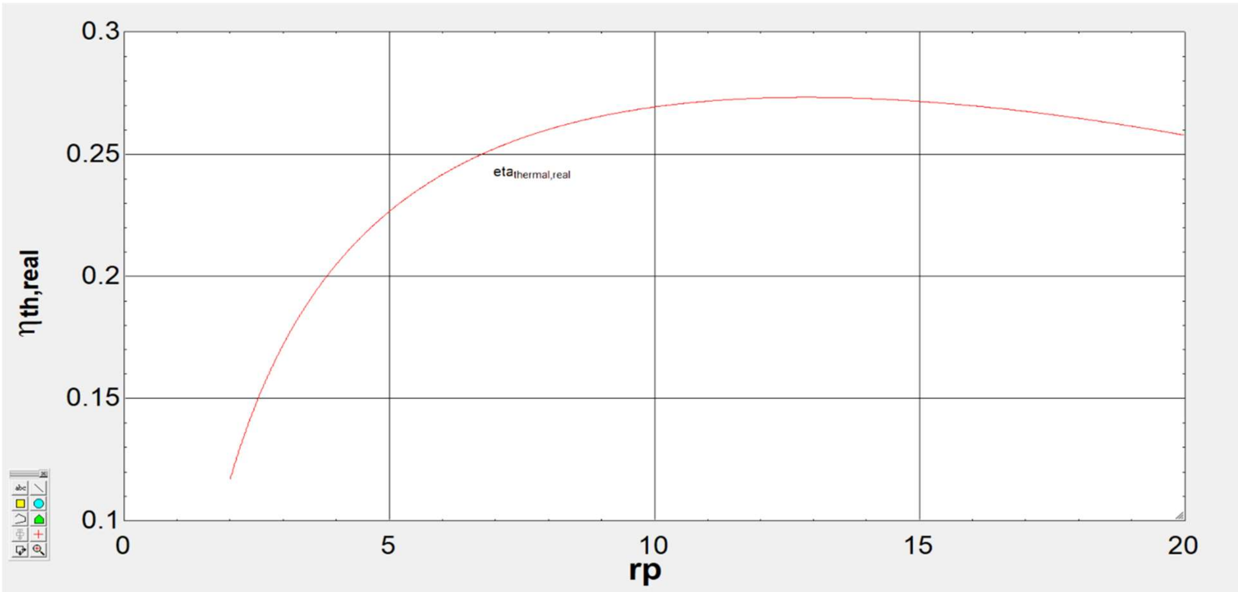

**The optimum $r_P = 7.129$**

**(for maximum $W_{Net}$ )**

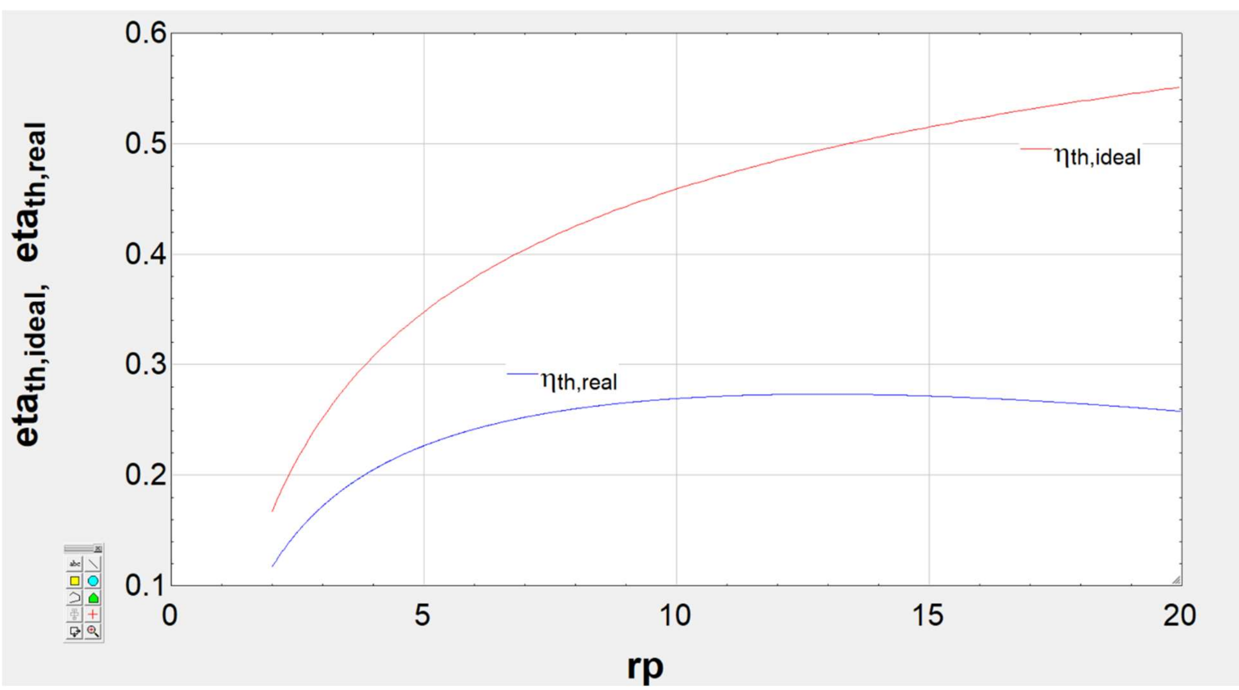



**The relation between $W_{Net}$ & $r_P$**

## Requirement (B)

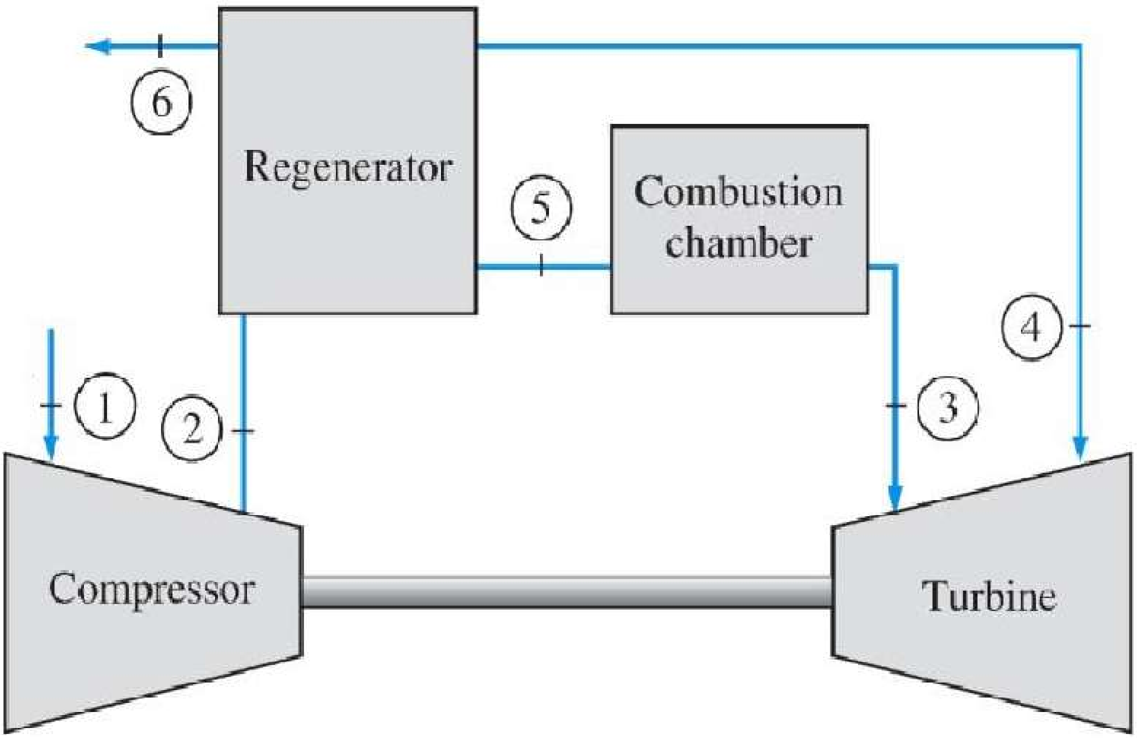



**The relation between the Efficiency & $r_P$**




**The relation between the Efficiency & ideal Efficiency & $r_P$**

**Requirement (C)**




## Flow Diagram

Givens:

$$P_{Min} = .95\ bar\ , P_{Max} = (r\_p * p\_\min\ )bar\ ,$$

$$T_{Max} = 1300°\text{C}\ , T_{Min} = 310°\text{C}\ \ , \eta_T = 0.85\ \ ,$$
$$\eta_C = 0.80\ \ , r_p = \ 2 \rightarrow 20\ , \varepsilon_{\text{regen}} = 1$$

$$\rightarrow h_1 \rightarrow (from\ Air\ Table)\ @\ T = T_{Min}\ \&\ P = P_{Min}$$

$$\rightarrow h_1 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_1$$

$$\rightarrow r_p = \frac{P_2}{P_1} = \frac{P_{r_{2s}}}{P_{r_1}}\ \rightarrow P_{r_{2s}}$$

$$\rightarrow h_{2s} \rightarrow (From\ Air\ \ Table)\ @\ P_{r_{2s}}$$

$$\rightarrow\ \ \eta_C = \frac{h_{2s} -\ h_1}{h_2 -\ h_1}\ \rightarrow\ h_2 = \frac{h_{2s} -\ h_1}{\eta_p} + h_1$$

$$\rightarrow h_2 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_2$$

$$\rightarrow h_3 \rightarrow (from\ Air\ Table)\ @\ T = T_{Max}\ \&\ P = P_{Max}$$

$$\rightarrow h_3 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_3$$

$$\rightarrow\ \frac{1}{r_P} = \frac{P_4}{P_3} = \frac{P_{r_{4s}}}{P_{r_3}}\ \rightarrow P_{r_{4s}}$$

$$\rightarrow h_{4s} \rightarrow (From\ Air\ \ Table)\ @\ P_{r_{4s}}$$

$$\rightarrow\ \ \eta_T = \frac{h_3 -\ h_4}{h_3 -\ h_{4s}}\ \rightarrow\ h_4 = h_3 - \left(\eta_T \times (h_3 -\ h_{4s})\right)$$

$$\rightarrow h_4 \rightarrow (From\ Air\ \ Table)\ \rightarrow T_4$$

$$\rightarrow \varepsilon_{regen} = 1\ \rightarrow \mathrm{h_a} =\ \mathrm{h_4}\ \&\ \mathrm{h_b} =\ \mathrm{h_2}$$

## Requirements

$\rightarrow W_{Turbine} = (h_3 - h_4)$

$\rightarrow W_{Compressor} = (h_2 - h_1)$

$\rightarrow W_{Net} = W_{Turbine} - W_{Compressor}$

$\rightarrow Q_{Add} = (h_3 - h_2)$

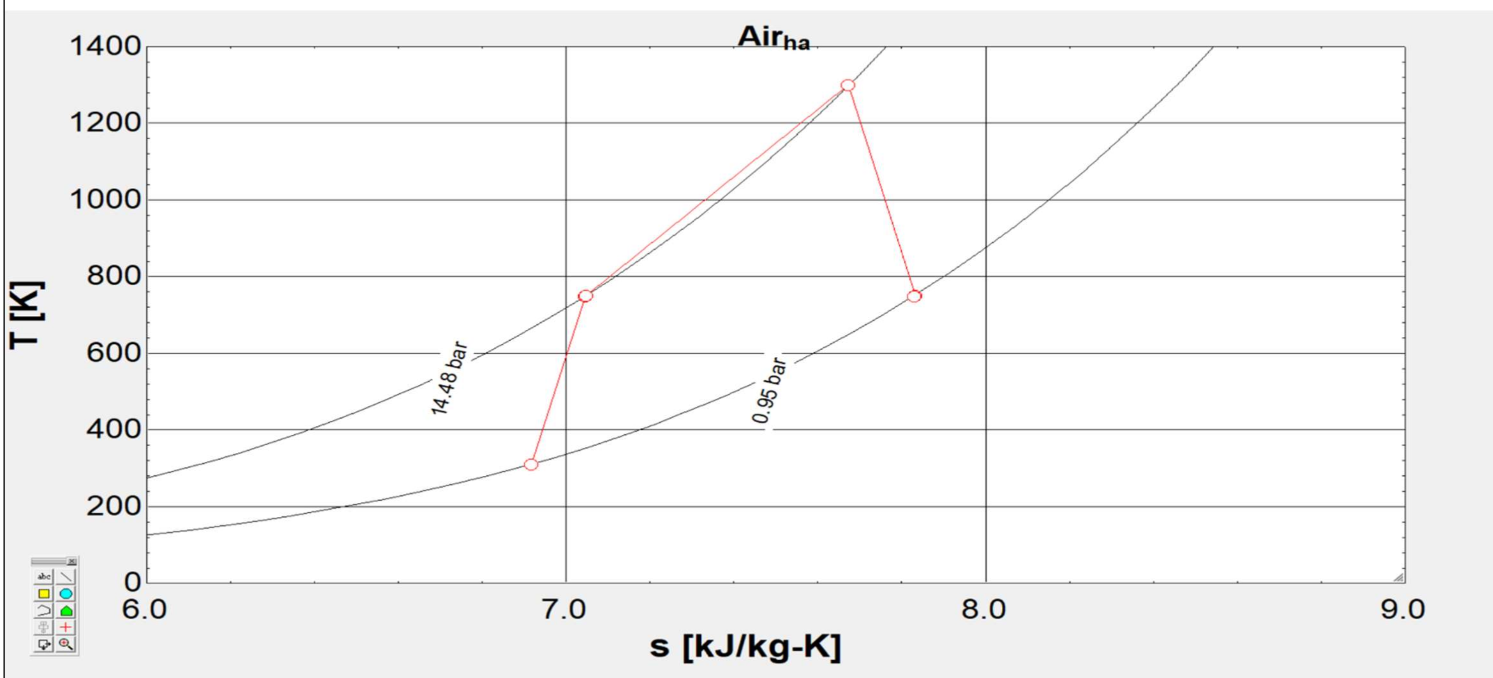
$\rightarrow Q_{Add\_regen} = (h_3 - h_a)$

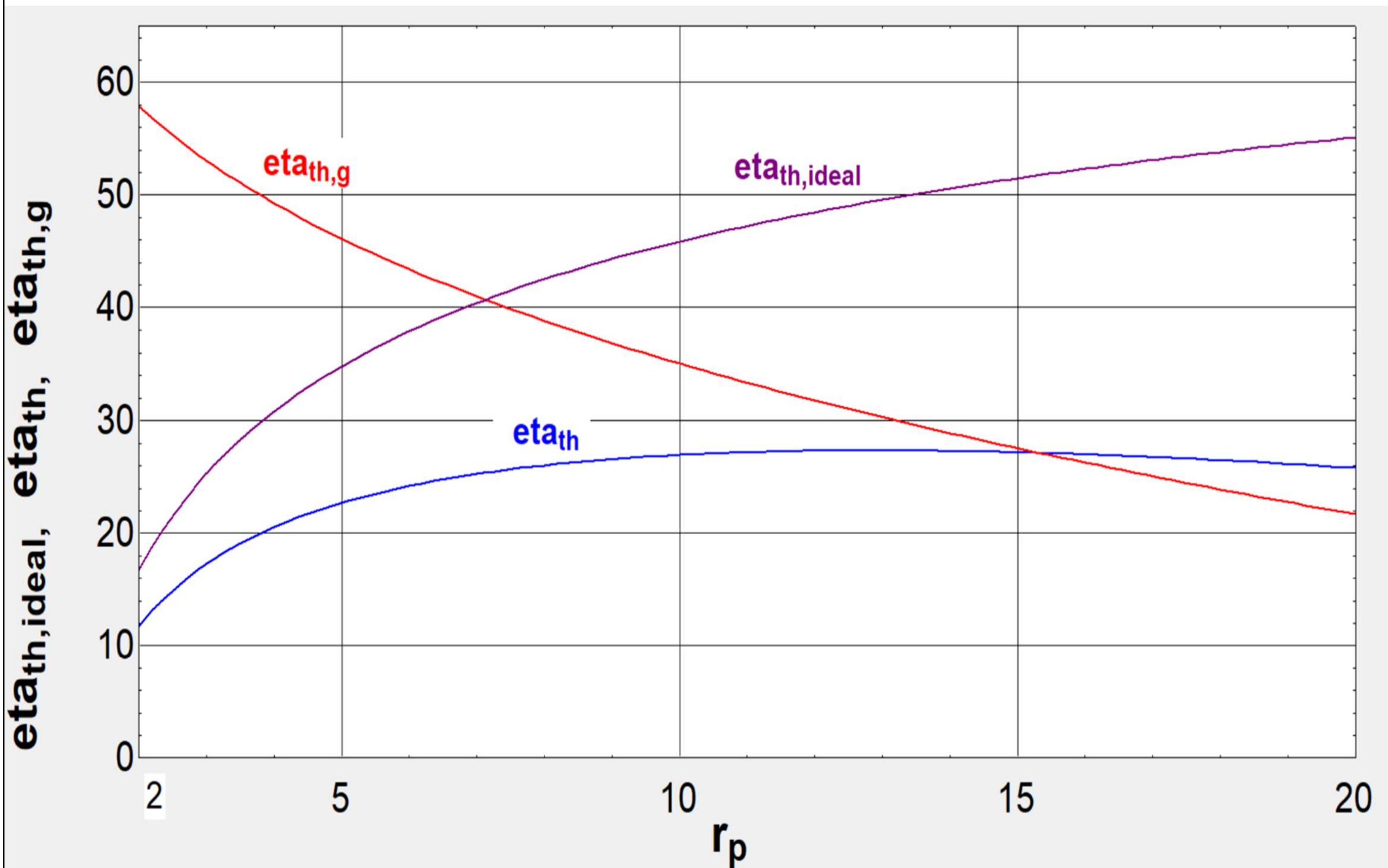
$$\eta_{th} = \frac{W_{Net}}{Q_{Add}}$$

$$\eta_{th\_regen} = \frac{W_{Net}}{Q_{Add\_regen}}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| $\eta_C$ = 0.8 | $\eta_T$ = 0.85 | $\eta_{th}$ = 27.1 | $\eta_{th,g}$ = 27.19 | $\eta_{th,ideal}$ = 51.71 | $p_1$ = 95 [kpa] | $Q_{add}$ = 629.9 |
| $Q_{add,g}$ = 627.9 | $Q_{add,ideal}$ = 721.3 | $r_p$ = 15.247 | $T_1$ = 310 [k] | $T_{max}$ = 1300 [k] | $W_C$ = 457.1 | $W_{C,g}$ = 457.1 |
| $W_{C,ideal}$ = 365.7 | $W_{net}$ = 170.7 | $W_{net,g}$ = 170.7 | $W_{net,ideal}$ = 373 | $W_T$ = 627.9 | $W_{T,g}$ = 627.9 | $W_{T,ideal}$ = 738.7 |

Click on this line to see the array variables in the Arrays Table window






| rp | $\eta_{th,ideal}$ | $\dot{W}_{net,ideal}$ [kJ/kg] | $\eta_{th,real}$ | $\dot{W}_{net,real}$ [kJ/kg] | $\eta_{th,regenerative}$ | $\dot{W}_{net,regenerative}$ [kJ/kg] |
|---|---|---|---|---|---|---|
| 15.3 | 0.5175 | 373.1 | 0.271 | 170.6 | 0.2713 | 170.6 |
| 15.31 | 0.5176 | 373.1 | 0.271 | 170.5 | 0.2712 | 170.5 |
| 15.32 | 0.5177 | 373.1 | 0.271 | 170.5 | 0.2711 | 170.5 |
| 15.33 | 0.5178 | 373.1 | 0.271 | 170.4 | 0.271 | 170.4 |

**The Maximum $r_P = 15.33$**

**(with respect to Efficiency)**