MAK 212 - TERMODİNAMİK
CRN: 21688, 21689, 21690, 21691, 21692
2010-2011 BAHAR

ÖDEV 8-ÇÖZÜMLER

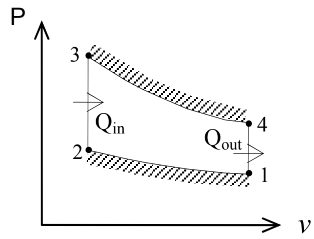
1 (a) We treat air as an ideal gas with constant specific heats.

Process 1-2: isentropic compression.

$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = (290K)(9.5)^{0.4} = 713.7K$$

$$\frac{P_2 v_2}{T_2} = \frac{P_1 v_1}{T_1} \longrightarrow P_2 = \frac{v_1}{v_2}\frac{T_2}{T_1}P_1 = (9.5)\left(\frac{713.7K}{290K}\right)(100kPa) = 2338kPa$$

Process 3-4: isentropic expansion.



$$T_3 = T_4\left(\frac{v_4}{v_3}\right)^{k-1} = (800K)(9.5)^{0.4} = \mathbf{1969K}$$

Process 2-3: v = constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow P_3 = \frac{T_3}{T_2}P_2 = \left(\frac{1969K}{713.7K}\right)(2338kPa) = \mathbf{6449kPa}$$

(b) $$m = \frac{P_1 V_1}{RT_1} = \frac{(100kPa)(0.0006m^3)}{(0.287kPa\cdot m^3/kg\cdot K)(290K)} = 7.21\times10^{-4}kg$$

$$Q_{23} - W_{23}^{\nearrow 0} = m(u_3 - u_2) \longrightarrow Q_{in} = Q_{23} = m(u_3 - u_2) = mC_v(T_3 - T_2)$$

or,

$$Q_{in} = (7.21\times10^{-4}kg)(0.718kJ/kg\cdot K)(1969 - 713.7)K = \mathbf{0.650kJ}$$

(c) Process 4-1: v = constant heat rejection.

$$Q_{41} - W_{41}^{\nearrow 0} = m(u_1 - u_4) \longrightarrow Q_{23} = m(u_1 - u_4) = mC_v(T_1 - T_4)$$

or,

$$Q_{out} = -Q_{41} = -(7.21\times10^{-4}kg)(0.718kJ/kg\cdot K)(290 - 800)K = \mathbf{0.264kJ}$$

$$W_{net} = Q_{in} - Q_{out} = 0.650 - 0.264 = 0.386\ kJ$$

$$\eta_{th} = \frac{W_{net}}{Q_{in}} = \frac{0.386\ kJ}{0.650\ kJ} = \mathbf{59.4\%}$$

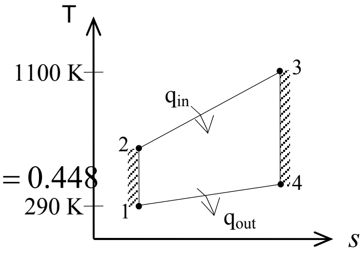
(d) $$V_{min} = V_2 = \frac{V_{max}}{r}$$

$$MEP = \frac{W_{net}}{V_1 - V_2} = \frac{W_{net}}{V_1(1-1/r)} = \frac{0.386kJ}{(0.0006m^3)(1-1/9.5)}\left(\frac{kPa\cdot m^3}{kJ}\right) = \mathbf{719kPa}$$

2 (a) Air at specified conditions can be treated as an ideal gas. Assuming constant specific heats,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (290K)(8)^{0.4/1.4} = 525.3K$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (1100K)\left(\frac{1}{8}\right)^{0.4/1.4} = 607.2K$$



$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{C_p(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{607.2 - 290}{1100 - 525.3} = 0.448$$

$$\dot{W}_{net} = \eta_T \dot{Q}_{in} = (0.448)(50{,}000kW) = \mathbf{22{,}400kW}$$

(b) Assuming variable specific heats,

$$T_1 = 290K \longrightarrow \begin{array}{l} h_1 = 290.16kJ/kg \\ P_{r_1} = 1.2311 \end{array}$$

$$P_{r_2} = \frac{P_2}{P_1}P_{r_1} = (8)(1.2311) = 9.8488 \longrightarrow h_2 = 526.11kJ/kg$$

$$T_3 = 1100K \longrightarrow \begin{array}{l} h_3 = 1161.07kJ/kg \\ P_{r_3} = 167.1 \end{array}$$

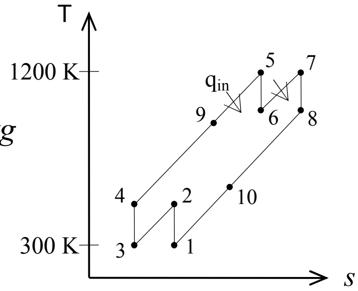
$$P_{r_4} = \frac{P_4}{P_3}P_{r_3} = \left(\frac{1}{8}\right)(167.1) = 20.89 \longrightarrow h_4 = 651.37kJ/kg$$

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} == 1 - \frac{h_4 - h_1}{h_3 - h_2} = 1 - \frac{651.37 - 290.16}{1161.07 - 526.11} = 0.431$$

$$\dot{W}_{net} = \eta_T \dot{Q}_{in} = (0.431)(50{,}000kW) = \mathbf{22{,}550kW}$$

3 (a) Air at specified conditions can be treated as an ideal gas with variable specific heats. The work inputs to each stage of compressor are identical, so are the work outputs of each stage of the turbine.

$$T_1 = 300K \longrightarrow \begin{array}{l} h_1 = 300.19kJ/kg \\ P_{r_1} = 1.386 \end{array}$$



$$P_{r_2} = \frac{P_2}{P_1}P_{r_1} = (3)(1.386) = 4.158 \longrightarrow h_2 = h_4 = 411.26kJ/kg$$

$$T_5 = 1200K \longrightarrow \begin{array}{l} h_5 = h_7 = 1277.79kJ/kg \\ P_{r_5} = 238 \end{array}$$

$$P_{r_6} = \frac{P_6}{P_5}P_{r_5} = \left(\frac{1}{3}\right)(238) = 79.33 \longrightarrow h_6 = h_8 = 946.36kJ/kg$$

$$w_{C,in} = 2(h_2 - h_1) = 2(411.26 - 300.19) = 222.14kJ/kg$$

$$w_{T,out} = 2(h_5 - h_6) = 2(1277.79 - 946.36) = 662.86kJ/kg$$

Thus, $r_{bw} = \frac{w_{C,in}}{w_{T,out}} = \frac{222.14\,kJ/kg}{662.86\,kJ/kg} = \mathbf{33.5\%}$

$$q_{in} = (h_5 - h_4) + (h_7 - h_6) = (1277.79 - 411.26) + (1277.79 - 946.36) = 1197.96 kJ/kg$$

$$w_{net} = w_{T,out} - w_{C,in} = 662.86 - 222.14 = 440.72 kJ/kg$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{440.72 kJ/kg}{1197.96 kJ/kg} = \mathbf{36.8\%}$$

(b) When a regenerator is used, r_{bw} remains the same. The thermal efficiency in this case becomes

$$q_{regen} = \varepsilon(h_8 - h_4) = (0.75)(946.36 - 411.26) = 401.33 kJ/kg$$

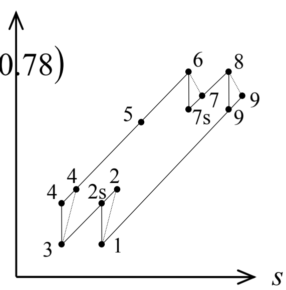
$$q_{in} = q_{in,old} - q_{regen} = 1197.96 - 401.33 = 796.63 kJ/kg$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{440.72 kJ/kg}{796.63 kJ/kg} = \mathbf{55.3\%}$$

4 Air at specified conditions can be treated as an ideal gas with constant specific heats. The work inputs to each stage of compressor are identical, so are the work outputs of each stage of the turbine.

$$T_{4s} = T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (300K)(3.5)^{0.4/1.4} = 429.1K$$

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{C_p(T_{2s} - T_1)}{C_p(T_2 - T_1)} \longrightarrow T_4 = T_2 = T_1 + (T_{2s} - T_1)/\eta_C = 300 + (429.1 - 300)/(0.78) = 565.5K$$



$$T_{9s} = T_{7s} = T_6\left(\frac{P_7}{P_6}\right)^{(k-1)/k} = (1200K)\left(\frac{1}{3.5}\right)^{0.4/1.4} = 838.9K$$

$$\eta_T = \frac{h_6 - h_7}{h_6 - h_{7s}} = \frac{C_p(T_6 - T_7)}{C_p(T_6 - T_{7s})} \longrightarrow T_9 = T_7 = T_6 - \eta_T(T_6 - T_{7s}) = 1200 - (0.86)(1200 - 838.9) = 889.5K$$

$$\varepsilon = \frac{h_5 - h_4}{h_9 - h_4} = \frac{C_p(T_5 - T_4)}{C_p(T_9 - T_4)} \longrightarrow T_5 = T_4 + \varepsilon(T_9 - T_4) = 465.5 + (0.72)(889.5 - 465.5) = 770.8K$$

$$w_{C,in} = 2(h_2 - h_1) = 2C_p(T_2 - T_1) = 2(1.005 kJ/kg\cdot K)(465.5 - 300)K = 332.7 kJ/kg$$

$$w_{T,out} = 2(h_6 - h_7) = 2C_p(T_6 - T_7) = 2(1.005 kJ/kg\cdot K)(1200 - 889.5)K = 624.1 kJ/kg$$

Thus, $r_{bw} = \dfrac{w_{C,in}}{w_{T,out}} = \dfrac{332.7 kJ/kg}{624.1 kJ/kg} = \mathbf{53.3\%}$

$$q_{in} = (h_6 - h_5) + (h_8 - h_7) = C_p[(T_6 - T_5) + (T_8 - T_7)] = (1.005 kJ/kg\cdot K)[(1200 - 770.8) + (1200 - 889.5)]K = 743.4 kJ/kg$$

$$w_{net} = w_{T,out} - w_{C,in} = 624.1 - 332.7 = 291.4 kJ/kg$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{291.4 kJ/kg}{743.4 kJ/kg} = \mathbf{39.2\%}$$