[redacted] An open Brayton-cycle engine operates with a compressor-pressure ratio of 4.5 and inlet temperature of 20 °C, and a turbine-inlet temperature of 950 °C. The engine drives an electric generator that produces 25 MW_e with a generator efficiency of 90 percent. For the following systems, find the thermal efficiency, the specific work, and the air-mass-flow rate, if the compressor and turbine efficiencies are 80 percent.

(a) A simple Brayton cycle. [redacted]

(b) A regenerative Brayton cycle with a regenerator effectiveness of 80 percent.

(c) A Brayton cycle using two stages of compression with intercooling to 20 °C.

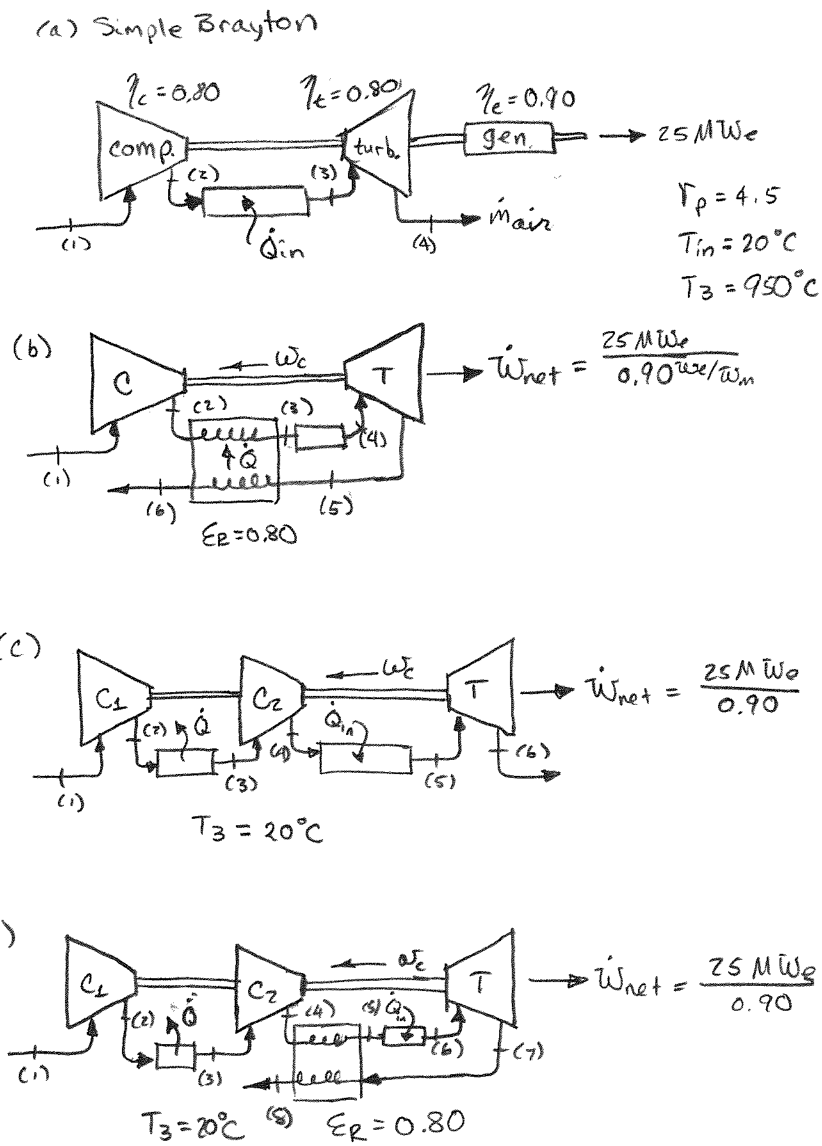
[redacted]

(d) A Brayton cycle that employs both the regenerator of (b) and the intercoolor of (c).

$\eta_{th} = ?$

$w_{net} = ?$

$\dot{m}_{air} = ?$



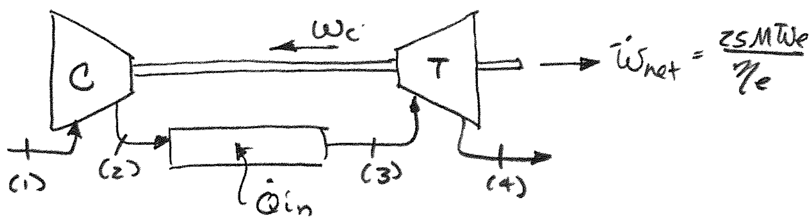
34. (cont.)

- Assume the air is an ideal gas with constant specific heats,

$C_p = 1.005 \ kJ/kgK$

$k = 1.40$

(a) Simple Brayton,



$r_p = 4.5$ $\eta_c = \eta_t = 0.80$

$T_1 = 20°C = 293 K$

$T_3 = 900°C = 1173 K$

$\frac{T_{2s}}{T_1} = r_{p_c}^{\frac{k-1}{k}} \longrightarrow T_{2s} = 450K$

$T_2 = T_1 + \frac{1}{\eta_c}(T_{2s} - T_1) = 490K$

$w_c = C_p(T_2 - T_1) = 197.6 \ \frac{kJ}{kg}$

$q_{in} = C_p(T_3 - T_2) = 686.63 \ \frac{kJ}{kg}$

$\frac{T_{4s}}{T_3} = \left(\frac{1}{r_{p_t}}\right)^{\frac{k-1}{k}} \longrightarrow T_{4s} = 763K$

$T_4 = T_3 - \eta_t(T_3 - T_{4s}) = 845K$

$w_t = C_p(T_3 - T_4) = 329.4 \ kJ/kg$

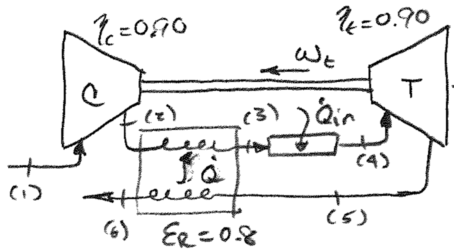
$w_{net} = 131.8 \ kJ/kg$

$\eta_{th} = \frac{w_{net}}{q_{in}} = 0.192$

$\dot{W}_{net} = 27.78 \times 10^3 \ kW_m$

$\dot{m}_{air} = \frac{\dot{W}_{net}}{w_{net}} = 210.7 \ kg/s$

(b) Regenerative Brayton



$\dot{W}_{net} = \frac{25 MW_e}{\eta_e}$

$r_p = 4.5$

$T_1 = 293\ k$

$T_4 = 1173\ k$

$T_1 = 293\ k$

$T_{2s} = T_1 r_p^{\frac{k-1}{k}} = 450\ k$

$T_2 = T_1 + \frac{1}{\eta_c}(T_{2s} - T_1) = 490\ k$

$\omega_c = c_p(T_2 - T_1) = 197.6\ \frac{kJ}{kg}$

$T_4 = 1173\ k$

$T_{5s} = T_4 \left(\frac{1}{r_p}\right)^{\frac{k-1}{k}} = 763\ k$

$T_5 = T_4 - \eta_t (T_4 - T_{5s}) = 845\ k$

$\omega_t = c_p(T_4 - T_5) = 329.4\ kJ/kg$

Regenerator:

$$\dot{Q} = \frac{h_3 - h_2}{h_5 - h_2} = \frac{h_5 - h_6}{h_3 - h_2} = \frac{c_p(T_3 - T_2)}{c_p(T_5 - T_2)} = \frac{c_p(T_5 - T_6)}{c_p(T_3 - T_2)}$$

$T_3 = T_2 + \varepsilon_R(T_5 - T_2) = 774\ k$

$T_6 = T_5 - \varepsilon_R(T_5 - T_2) = 561\ k$

$q_{in} = c_p(T_4 - T_3) = 400.9\ kJ/kg$

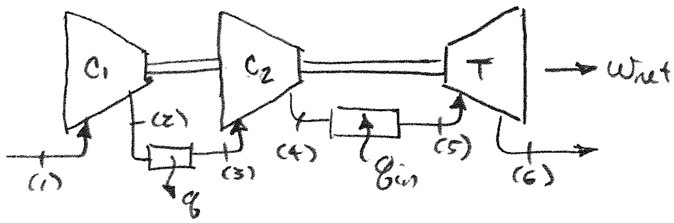
$\omega_{net} = \omega_t - \omega_c = 153\ kJ/kg$

$\eta_{th} = 0.3288$

$\dot{m}_{air} = \frac{\dot{W}_{net}}{\omega_{net}} = 210.7$

(cont.)

(c) 2-Stage Compression with Intercooling



$r_p = 4.5$

$\eta_c = \eta_t = 0.80$ $\quad \eta_e = 0.90$

$T_1 = 293\,k$

$T_5 = 1173\,k$

$\dot{W}_{net} = \dfrac{25\,MWe}{\eta_e}$

$r_{p_1} = r_{p_2} = \sqrt[2]{r_p} = 2.121$

$T_{2s} = T_1 (r_{p_1})^{\frac{k-1}{k}} = 363\,k$

$T_2 = T_1 + \frac{1}{\eta_c}(T_{2s} - T_1) = 381\,k$

$w_c = 2 \cdot c_p \cdot (T_2 - T_1) = 176.5\ kJ/kg$

$T_3 = T_1 = 293\,k$

$T_4 = T_2 = 381\,k$

$T_{6s} = T_5 \left(\frac{1}{r_p}\right)^{\frac{k-1}{k}} = 763\,k$

$T_6 = T_5 - \eta_t (T_5 - T_{6s}) = 845\,k$

$w_t = c_p (T_5 - T_6) = 329.4\ kJ/kg$

$q_{in} = c_p (T_5 - T_4) = 796.2\ kJ/kg$

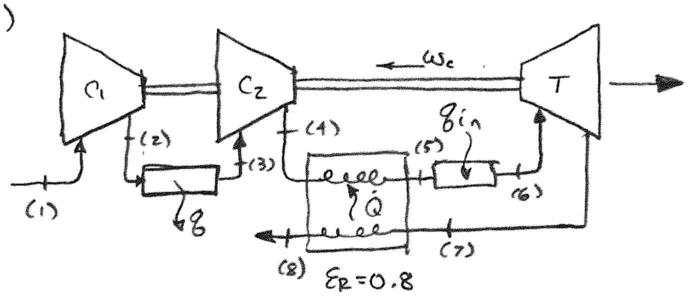
$w_{net} = w_t - w_c = 153\ kJ/kg$

$\eta_{th} = \dfrac{w_{net}}{q_{in}} = 0.192$

$\dot{m}_{air} = \dfrac{\dot{W}_{net}}{w_{net}} = 181.6\ kg/s$

(cont.)

(d)



$r_p = 4.5$

$\eta_t = \eta_c = 0.80$

$\varepsilon_R = 0.80$

$T_1 = 293k$

$T_3 = 293k$

$T_6 = 1173k$

$r_{p_1} = r_{p_2} = \sqrt[2]{r_p} = 2.121$

$T_{2s} = T_1 (r_{p_1})^{\frac{k-1}{k}} = 363k$

$T_{7s} = T_6 \left(\frac{1}{r_p}\right)^{\frac{k-1}{k}} = 736k$

$T_2 = T_1 + \frac{1}{\eta_c}(T_{2s} - T_1) = 381k$

$T_7 = T_6 - \eta_t (T_6 - T_{7s}) = 845k$

$w_c = 2C_p (T_2 - T_1) = 176.5 \frac{kJ}{kg}$

$w_t = C_p (T_6 - T_7) = 329.4 \text{ kJ/kg}$

$T_3 = T_1 = 293k$

$T_4 = T_2 = 381k$

$T_5 = T_4 + \varepsilon_R (T_7 - T_4) = 752k$

$T_8 = T_7 - \varepsilon_R (T_7 - T_4) = 474k$

$w_{net} = w_t - w_c = 153 \text{ kJ/kg}$

$q_{in} = C_p (T_6 - T_5) = 422.8 \text{ kJ/kg}$

$\eta_{th} = \frac{w_{net}}{q_{in}} = 0.3618$

$\dot{m}_{air} = \frac{\dot{W}_{net}}{w_{net}} = 181.6 \frac{kg}{s}$

(cont.)

$r_p = 4.5$

	η_{th}	w_{net} [kJ/kg]	$\dot{m}$ [kg/s]
(a) simple Brayton	0.192	131.8	210.7
(b) regenerative Brayton $\varepsilon_R = 0.80$	0.3288	131.8	210.7
(c) 2 intercooled stages $T_{intercooling} = 20°C$	0.192	153	181.6
(d) Brayton w/ (b) & (c)	0.3618	153	181.6