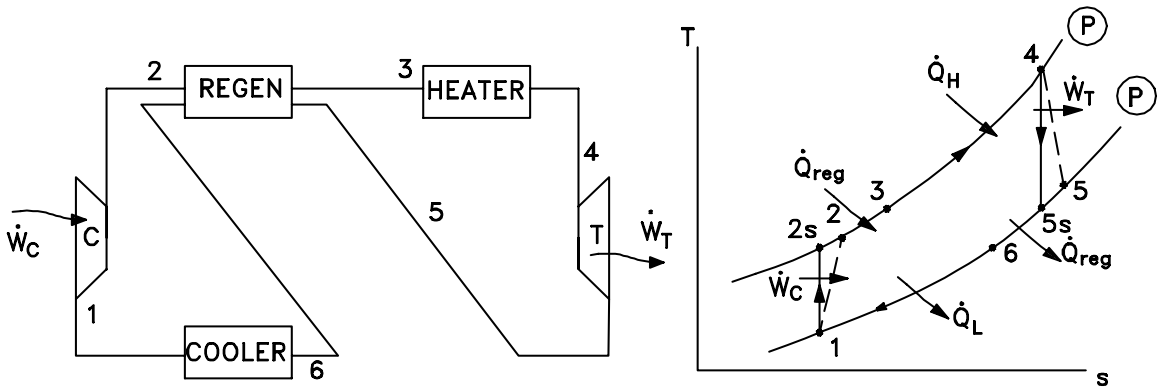
Problem: 9-75

Given: Same as Problem 9-73 except
$\eta_c = 0.8$
$\eta_t = 0.85$
$\eta_r = 0.85$

Find: Thermal efficiency and net work output per lbm flow



Full Load

From Problem 9-73,

$$T_{2s} = 867.6\ R$$
$$T_{5s} = 1199\ R$$

compressor:

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{\cancel{c_p}\ (T_{2s} - T_1)}{\cancel{c_p}\ (T_2 - T_1)}$$
$$T_2 = T_1 \left(\frac{T_{2s} - T_1}{\eta_c} \right) = (520 + (867.6 - 520)/0.8) = 954.5\ R$$

turbine:

$$\eta_t = \frac{h_4 - h_5}{h_4 - h_{5s}} = \frac{\cancel{c_p}\ (T_4 - T_5)}{\cancel{c_p}\ (T_4 - T_{5s})}$$
$$T_5 = T_4 - \eta_t (T_4 - T_{5s}) = 2000 - 0.85(2000 - 1199) = 1320\ R$$

regenerator:

$$\begin{aligned}\eta_r &= \frac{h_3 - h_2}{h_5 - h_2} = \frac{\cancel{c_p}\ (T_3 - T_2)}{\cancel{c_p}\ (T_3 - T_2)} \\ T_3 &= \eta_r (T_5 - T_2) + T_2 = 0.85(1320 - 954.5) + 954.5 = 1265\ R\end{aligned}$$

$$\eta_t = \frac{\dot{W}_t - \dot{W}_c}{\dot{Q}_{in}}$$

$$\begin{aligned}\frac{\dot{W}_t}{\dot{m}} &= c_p(T_4 - T_5) = 0.24(2000 - 1320) = 163.2\ Btu/lbm \\ \frac{\dot{W}_c}{\dot{m}} &= c_p(T_2 - T_1) = 0.24(954.5 - 520) = 104.3\ Btu/lbm \\ \frac{\dot{Q}_{in}}{\dot{m}} &= c_p(T_4 - T_3) = 0.24(2000 - 1265) = 176.4\ Btu/lbm\end{aligned}$$

$$\begin{aligned}\eta_t &= \frac{163.2 - 104.3}{176.4} \\ &= \boxed{33.3\%}\end{aligned}$$

$$\frac{\dot{W}_{net}}{\dot{m}} = 163.2 - 104.3 = \boxed{58.9\ Btu/lbm}$$

Part Load

From Problem 9-73,

$$\begin{aligned}T_{2s} &= 711.7\ R \\ T_{5s} &= 1140\ R\end{aligned}$$

compressor:

$$T_2 = T_1 \left(\frac{T_{2s} - T_1}{\eta_c} \right) = (520 + (711.7 - 520)/0.8) = 759.6\ R$$

turbine:

$$T_5 = T_4 - \eta_t(T_4 - T_{5s}) = (1560 - 0.85(1560 - 1140) = 1203\ R$$

regenerator:

$$T_3 = T_2 + \eta_r(T_5 - T_2) = 795.6 + 0.85(1203 - 759.6) = 1136\ R$$

$$\eta_t = \frac{\dot{W}_t - \dot{W}_c}{\dot{Q}_{in}}$$

$$\begin{aligned}
\frac{\dot{W}_t}{\dot{m}} &= c_p(T_4 - T_5) = 0.24(1560 - 1203) = 85.7\ Btu/lbm \\
\frac{\dot{W}_c}{\dot{m}} &= c_p(T_2 - T_1) = 0.24(759.6 - 520) = 57.5\ Btu/lbm \\
\frac{\dot{Q}_{in}}{\dot{m}} &= c_p(T_4 - T_3) = 0.24(1560 - 1136) = 101.8\ Btu/lbm
\end{aligned}$$

$$\begin{aligned}
\eta_t &= \frac{85.7 - 57.5}{101.8} \\
&= \boxed{27.7\%}
\end{aligned}$$

$$\frac{\dot{W}_{net}}{\dot{m}} = 85.7 - 57.5 = \boxed{28.2\ Btu/lbm}$$