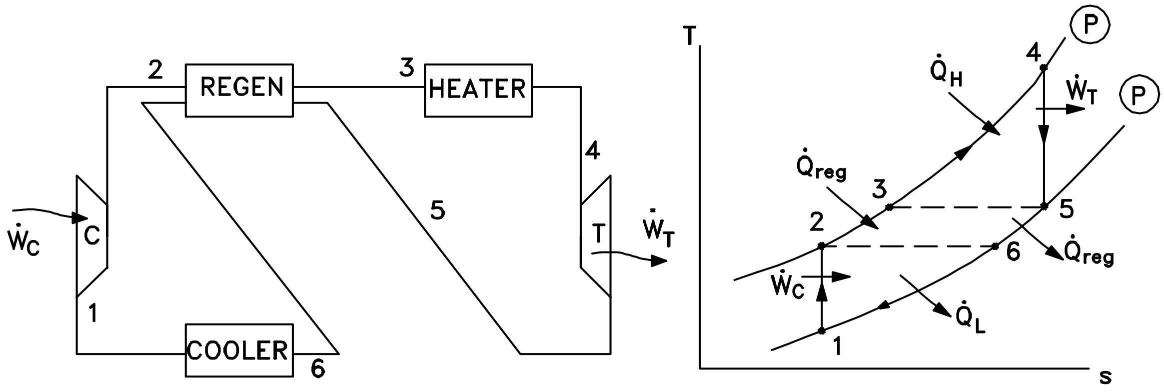
Problem: 9-73

Given: Ideal Brayton cycle with regeneration but no reheat or intercooling and a compressor inlet temperature of 60 $°F$
Full load conditions: turbine inlet 1540 $°F$, pressure ratio of 6.0
Part load conditions: turbine inlet 1100 $°F$, pressure ratio of 3.0
Maximum possible regeneration

Find: Thermal efficiency and net work output per lbm flow



Assumptions

- air - perfect gas, $k = 1.4$, c_p = constant
- $\eta_r = 1$, therefore $T_3 = T_5$, $T_2 = T_6$
- isentropic compressor and turbine
- constant pressure heaters
- $\Delta ke = \Delta pe = 0$
- steady state

Full Load

1 $T_1 = 520\ R, P_1 = 1\ atm$

$1 \rightarrow 2$ isentropic compressor

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (540\ R)(6)^{.4/1.4}$$
$$= 867.6\ R$$

$\underline{4 \rightarrow 5}$ isentropic turbine

$$\begin{aligned} T_5 = T_4 \left(\frac{P_5}{P_4}\right)^{(k-1)/k} &= (2000\ R)(1/6)^{.4/1.4} \\ &= 1199\ R \end{aligned}$$

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

$$\begin{aligned} \frac{\dot{W}_t}{\dot{m}} &= (h_4 - h_5) = c_p(T_4 - T_5) = 0.24(2000 - 1199) = 192\ Btu/lbm \\ \frac{\dot{W}_c}{\dot{m}} &= (h_2 - h_1) = c_p(T_2 - T_1) = 0.24(867.6 - 520) = 83.4\ Btu/lbm \\ \frac{\dot{Q}_{in}}{\dot{m}} &= (h_4 - h_3) = c_p(T_4 - T_3) = \frac{\dot{W}_t}{\dot{m}} = 192\ Btu/lbm \end{aligned}$$

$$\begin{aligned} \eta_t &= \frac{192 - 84.3}{192} \\ &= \boxed{56.2\%} \end{aligned}$$

$$\frac{\dot{W}_{net}}{\dot{m}} = \frac{\dot{W}_t - \dot{W}_c}{\dot{m}} = \boxed{109\ Btu/lbm}$$

Part Load

$\underline{1 \rightarrow 2}$ isentropic compressor

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = 711.7\ R$$

$\underline{4 \rightarrow 5}$ isentropic turbine

$$T_5 = T_4 \left(\frac{P_5}{P_4}\right)^{(k-1)/k} = 1139.8\ R$$

$$\begin{aligned} \frac{\dot{W}_t}{\dot{m}} &= c_p(T_4 - T_5) = 0.24(1560 - 1140) = 101\ Btu/lbm \\ \frac{\dot{W}_c}{\dot{m}} &= c_p(T_2 - T_1) = 0.24(711.7 - 520) = 46\ Btu/lbm \\ \frac{\dot{Q}_{in}}{\dot{m}} &= \frac{\dot{W}_t}{\dot{m}} = 101\ Btu/lbm \end{aligned}$$

$$
\begin{aligned}
\eta_t &= \frac{101 - 46}{101} \\
&= \boxed{54.4\%}
\end{aligned}
$$

$$
\frac{\dot{W}_{net}}{\dot{m}} = 101 - 46 = \boxed{55\ Btu/lbm}
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