PROBLEM 6.101

An inventor has provided the steady-state operating data shown in Fig. P6.101 for a cogeneration system producing power and increasing the temperature of a stream of air. The system receives and discharges energy by heat transfer at the rates and temperatures indicated on the figure. All heat transfers are in the directions of the accompanying arrows. The ideal gas model applies to the air. Kinetic and potential energy effects are negligible. Using energy and entropy rate balances evaluate the thermodynamic performance of the system.

**Schematic & Given Data:**

\[ \dot{Q}_1 = 800 \text{ kW} \]
\[ T_1 = 1000 \text{ K} \]
\[ \dot{Q}_2 = 108 \text{ kW} \]
\[ T_2 = 540 \text{ K} \]
\[ \dot{Q}_3 = 209 \text{ kW} \]
\[ T_3 = 400 \text{ K} \]
\[ \dot{Q}_4 = 500 \text{ kW} \]
\[ p_0 = p_4 \]

**Fig. P6.101**

**KNOWN:** Steady-state operating data are provided for a cogeneration system.

**PROBLEM:** Evaluate the thermodynamic performance of the system using energy and entropy balances.

**ENGINEERING MODEL**

1. The control volume shown in the schematic is at steady state.
2. The only heat transfers are those shown on the schematic.
3. Kinetic and potential energy effects are negligible.
4. The air is modeled as an ideal gas.

**Analysis 1**

For the control volume under consideration, \( m_{h_4} = m_{h_5} = m \). An energy rate balance reads:

\[
\dot{O} = \left[ \dot{Q}_1 + \dot{Q}_2 - \dot{Q}_3 \right] - \dot{W} + m \left[ h_4 - h_5 \right].
\]

Thus:

\[
\dot{W} = \left[ \dot{Q}_1 + \dot{Q}_2 - \dot{Q}_3 \right] + m \left[ h_4 - h_5 \right],
\]

where \( h_4 \) and \( h_5 \) are obtained from Table A-22.

\[
= [800 + 108 - 209] \text{ kW} + \frac{2280}{2} \left[ 503.02 - 601.02 \right] \text{ kJ/kg} \times \frac{1 \text{ kW}}{1 \text{ kJ/kg}} = 500 \text{ kW}
\]

Accordingly, the given data agree with the conservation of energy principle.

An entropy rate balance reads:

\[
\dot{O} = \left[ \frac{\dot{Q}_1}{T_1} + \frac{\dot{Q}_2}{T_2} - \frac{\dot{Q}_3}{T_3} \right] + m \left[ s_4 - s_5 \right] + \dot{S} - \dot{S}_{R}
\]

\[
= 0 \text{ (R = Pa)}
\]

\[
\dot{S} = \left[ \frac{\dot{Q}_3}{T_3} + \frac{\dot{Q}_2}{T_2} - \frac{\dot{Q}_1}{T_1} \right] + m \left[ s_3 - s_4 - R \frac{P_4}{P_4} \right]
\]

\[
= [\frac{200}{400} - \frac{100}{500} - \frac{168}{600} \text{ kW}] + \frac{2280}{2} \left[ 2.4091 - 2.2195 \right] \text{ kJ/kg} \text{ kJ/kg} \times \frac{1 \text{ kW}}{1 \text{ kJ/kg}} = 0.12 \text{ kW/K}
\]

Since the entropy production rate is negative, the given data do not agree with the second law. In summary, the system cannot perform in accordance with the operating data provided.