Problem-1 (40%)
Consider a steam turbine power plant as shown with the given properties below. Enter state of pump is compressed liquid and isentropic pump efficiency is 75%. Assume no heat exchange between turbine and ambient and between pump and ambient (adiabatic process). And also neglecting any changes in kinetic and potential energies,
calculate:
a. The maximum turbine work output rate for mass flow rate of 100 kg/s.
b. The turbine isentropic efficiency if the turbine exit state is saturated vapor.
c. The pump work input rates and enthalpy values (isentropic and adiabatic) at the pump exit states
d. The thermal efficiency of the cycle
e. Draw the cycle in T-s diagrams and label states properly as isentropic and adiabatic states.
Properties: \( P_1 = P_4 = 20 \text{ MPa}, \ T_1 = 800 ^\circ \text{C}, \ P_2 = P_3 = 30 \text{ kPa} \)

Solution:
Process: 1-2 and 3-4 (isentropic, \( Q = 0, \Delta S = 0 \)), 1-2' and 3-4' (adiabatic, \( Q = 0, \Delta S \neq 0 \))
\( h_1 = 4069.80 \text{ kJ/kg}, \ s_1 = s_2 = 7.0544 \text{ kJ/kg-K} \) (30 KPa \( s_g = 7.7686 \text{ kJ/kg-K} > 7.0544 \text{ kJ/kg-K} \)), So, state-2 is saturated (mix state). Find quality: \( s_2 = s_f + xs_f \)
\( \eta = \frac{h_f}{h_{fg}} \)
\( x = \frac{7.0544-0.9439}{6.8247} = 89.5\% \)
\( h_2 = h_f + xh_{fg} = 289.21 + 0.895 \times 2336.07 = 2379.99 \text{ kJ/kg} \)
a. System: Turbine: Continuity eq: \( \dot{m}_2 = \dot{m}_1 = \dot{m} = 100 \text{ kg/s} \)
First law (open system): \( \dot{W}_{T(max)} = h_1 - h_2 = 4069.80 - 2379.99 = 1689.81 \text{ kJ/kg} \)
The max. turbine work output rate, \( \dot{W} = \dot{m} \dot{W}_{T(max)} = 168981 \text{ KW} \approx 169 \text{ MW} \)
b. \( \eta_T = \frac{\dot{W}_{T(adiabatic)}}{\dot{W}_{T(isentropic)}} = \frac{h_1 - h_2}{1689.81}, \quad h_2 = h_g = 2625.28 \text{ kJ/kg} \)
\( \eta_T = 85.5\% \)
c. System: Pump: Continuity eq: \( m_2 = m_1 = m = 100 \text{ kg/s} \)

First law (open system): 
\[-w_p(\text{isentropic}) = h_4 - h_3 = v(P_4 - P_3) \quad v = v_f = 0.001022 \text{ m}^3/\text{kg}, \quad h_3 = h_f = 289.21 \text{ kJ/kg} \]
\[-w_p = 0.001022(20000 - 30) = 20.41 \text{ kJ/kg} = h_4 - 289.21 \]
\( h_4 = 309.62 \text{ kJ/kg} \)

\[ \eta_p = \frac{w_p(\text{isentropic})}{w_p(\text{adiabatic})} = \frac{h_4 - h_3}{h_4 - h_3} = \frac{20.41}{289.1} = 0.75, \quad h_4 = 316.31 \text{ kJ/kg} \]

d. \( \eta_{TH} = \sum w \frac{w_T - w_p}{h_3 - h_4} = \frac{1689.81 \times 0.855 - 20.41/0.75}{4069.80 - 316.31} = 37.8\% \)

**Problem-2 (25%)**

A house in the winter would be heated with a heat pump. The house is to be maintained at 21°C at all times. When the ambient temperature outside at the time of the coldest night drops to −16°C, the minimum electrical power required to drive the heat pump is 5 KW. What would be the maximum rate of heat lost from the house?

![Diagram](image)

**Solution:**

\[ \beta' = \frac{\dot{Q}_H}{\dot{W}_{IN}} = \frac{T_H}{T_H - T_L} \]

\[ \beta' = \frac{273 + 21}{21 - (-16)} = 7.95 \]

\[ \dot{Q}_H = 7.95 \times 5 = 39.75 \text{ KW} = \dot{Q}_{\text{leak}} \]
**Problem-3** (35%)  
A counter flowing heat exchanger has one line with 5 kg/s at 110 kPa, 1050 K entering and the air is leaving at 100 kPa, 420 K. The other line has 1.0 kg/s water coming in at 200 kPa, 30°C and leaving at 200 kPa. What are the exit temperature of the water and the total rate of entropy generation?

![Heat exchanger diagram](image)

**Solution:**

Energy Eq.6.10: \( m_{\text{AIR}} \Delta h_{\text{AIR}} = m_{\text{H2O}} \Delta h_{\text{H2O}} \)

From A.7: \( h_1 - h_2 = 1103.48 - 421.59 = 681.89 \) kJ/kg

From B.1.2 \( h_3 = 125.77 \) kJ/kg; \( s_3 = 0.4369 \) kJ/kg K

\[
h_4 - h_3 = (m_{\text{AIR}}/m_{\text{H2O}})(h_1 - h_2) = (5/1)681.89 = 3409.45 \text{ kJ/kg}
\]

\[
h_4 = h_3 + 3409.45 = 3535.22 \text{ kJ/kg} > h_g = 2706.63 \text{ kJ/kg at 200 kPa}
\]

So, exit state of water is superheated:

\( h_4 = 3535.22 \text{ kJ/kg}, \text{ between } T=500 \text{ C and } T=600 \text{ C} \) (Table B.1.3 at \( P=200 \) KPa)

After interpolations; \( T_4 = 522.2 \text{ C}, s_4=8.5720 \text{ kJ/kg-K} \)

From entropy Eq.9.7

\[
S_{\text{gen}} = m_{\text{H2O}} (s_4 - s_3) + m_{\text{AIR}}(s_2 - s_1)
\]

\[
= 1(8.5720 - 0.4369) + 5(7.20875 - 8.19081 - 0.287 \ln (100/110))
\]

\[
= 3.36 \text{ kW/K}
\]