[1] Steam enters the turbine of a vapor power plant at 600 lbf/in\(^2\), 1000 \(^\circ\)F and exits as a two-phase liquid-vapor mixture at a temperature of 80 \(^\circ\)F. Condensate exits the condenser at a temperature 5 \(^\circ\)F lower than the turbine outlet and is pumped to 600 lbf/in\(^2\). The turbine and pump isentropic efficiencies are 90 and 80\% respectively. The net power developed is 1 MW. Determine the steam quality at the turbine exit, the steam mass flow rate in lb/h and the thermal efficiency.

[2] A power plant operates on a regenerative vapor power cycle with two feedwater heaters. Steam enters the first turbine stage as 12 MPa, 520 \(^\circ\)C and expands in three stages to the condenser pressure of 6 kPa. Between the first and second stages, some steam is diverted to a closed feedwater heater at 1MPa, with saturated liquid condensate being pumped ahead into the boiler feedwater line. The feedwater leaves the closed heater at 12 MPa, 170 \(^\circ\)C. Steam is extracted between the second and third turbine stages at 0.15 MPa and fed into an open feedwater heater operating at that pressure. Saturated liquid at 0.15 MPa leaves the open feedwater heater. For isentropic processes in the pumps and turbines, determine for the cycle:
(a) the thermal efficiency
(b) the mass flow rate into the first-stage turbine, in kg/h, if the net power developed is 320 MW.
1) Solution

**Schematic & Given Data:**

![Diagram](image)

**Assumptions:**
1. Control volumes enclosing each of the principal components is at steady state.
2. The pump and turbine operate adiabatically.
3. Kinetic/potential energy can be ignored.
4. Condensate exits the condenser and enters the pump as sat. liquid.

**Analysis:** First fix each of the principal states for \( T = 80^\circ\text{F} \): From Table A-4E, \( h_1 = 1517.8\text{ Btu/lb} \), \( s_1 = 1.7155\text{ Btu/lb} \cdot \text{deg.} \). Then, with \( f = 51\) and data from Table A-2G

\[
X_2 = \frac{s_2 - s_f}{s_g - s_f} = \frac{1.7155 - 0.09312}{2.0356 - 0.09312} = 0.835 \Rightarrow h_2 = 48.09 + (0.835)(104.83) = 92.34\text{ Btu/lb}
\]

Then, with

\[
\eta_p = \frac{h_1 - h_2}{h_1 - h_{25}} \Rightarrow h_2 = h_1 - \eta_p (h_1 - h_{25}) = 1517.8 - 0.9(1517.8 - 92.34) = 982.8\text{ Btu/lb}
\]

\[
X_2 = \frac{h_2 - h_5}{h_{25} - h_5} = \frac{982.8 - 980.9}{104.83} = 0.892
\]

At state 3, \( h_3 = h_4\) (75°F) = 43.1 Btu/lb. Then, \( h_{32} = h_2 + v_{2}(P_2 - P_1) \), or

\[
h_{32} = 43.1 + (0.0161\frac{f^2}{16})(600 - 0.43)\left[\frac{105}{1.14} - 1\right] = 44.9\text{ Btu/lb}
\]

Then, with

\[
\eta_p = \frac{h_{32} - h_3}{h_{43}} \Rightarrow h_4 = h_3 + (\frac{h_{32} - h_3}{\eta_p}) = 43.1 + \left(\frac{44.9 - 43.1}{0.8}\right) = 45.4\text{ Btu/lb}
\]

The thermal efficiency is obtained as

\[
\eta = \frac{\dot{W}_{net}}{\dot{m}_1} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4} = \frac{(1517.8 - 982.8) - (45.4 - 43.1)}{1517.8 - 45.4} = 0.362
\]

The mass flow rate is

\[
\dot{m} = \frac{\dot{W}_{net}}{(\dot{W}_{et/m}) - (\dot{W}_{pl/in})} = \frac{10^3\text{ kW}}{3413\text{ Btu/lb} / 1\text{ kW}} = 6.41 \times 10^3\text{ lb/hr}
\]
2) Solution

**Assumptions:**
1. Each component is analyzed as a control volume at steady state.
2. Each process of the working fluid is internally reversible, except in the feedwater heaters and the mixing of streams 9 and 11 to form stream 12.
3. The turbines, pumps, and feedwater heaters operate adiabatically.
4. Kinetic and potential energy effects are negligible.
5. Condensate exits the closed heater and condenser, and feedwater exits the open heater as saturated liquid.

**Analysis:** First, fix each of the principal states.

**State 1:**
- \( P_1 = 120 \text{ bar }, T_1 = 520^\circ \text{C} \)
- \( h_1 = 3401.8 \text{ kJ/kg, } s_1 = 6.5555 \text{ kJ/kg} \)

**State 2:**
- \( P_2 = 10 \text{ bar }, S_2 = S_1 \)
- \( h_2 = 2764.2 \text{ kJ/kg} \)

**State 3:**
- \( P_3 = 1.5 \text{ bar }, S_3 = S_1 \)
- \( h_3 = 2436.9 \text{ kJ/kg} \)

**State 4:**
- \( P_4 = 0.06 \text{ bar }, S_4 = S_1 \)
- \( h_4 = 2018.3 \text{ kJ/kg} \)

**State 5:**
- \( P_5 = 0.06 \text{ bar }, \text{sat. liquid} \)
- \( h_5 = 151.53 \text{ kJ/kg} \)

**State 6:**
- \( h_6 = h_5 + u_3 (P_6 - P_5) \)
- \( = 151.53 \frac{\text{kJ}}{\text{kg}} + (1.0064 \times 10^3) \frac{\text{m}^2}{\text{kg}^2} (1.5 - 0.06) \text{ bar} \)
- \( = 151.53 + 0.14 = 151.67 \text{ kJ/kg} \)

**State 7:**
- \( P_7 = 1.5 \text{ bar }, \text{sat. liquid} \)
- \( h_7 = 467.11 \text{ kJ/kg} \)

**State 8:**
- \( h_8 = h_7 + u_4 (P_8 - P_7) \)
- \( = 467.11 + (1.0528 \times 10^3) (120 - 1.5) \frac{10^5}{\text{N.m}} = 479.59 \frac{\text{kJ}}{\text{kg}} \)

**State 9:**
- \( P_9 = 120 \text{ bar }, T_9 = 170^\circ \text{C} \)
- \( \text{Interpolating in Table A-5: } h_9 = 725.86 \text{ kJ/kg} \)

**State 10:**
- \( P_{10} = 10 \text{ bar }, \text{sat. liquid} \)
- \( h_{10} = 762.81 \text{ kJ/kg} \)
State 11: \( h_{11} = h_{10} + w_e (P_e - P_{10}) = 762.81 + (1.1233 \times 10^3 \times (320 - 10)) = 775.21 \text{ kJ/kg} \)

Applying mass and energy rate balances to the control volume enclosing the closed heater, the fraction of flow \( y' \) extracted at location 2 is

\[
y' = \frac{h_{9} - h_{8}}{h_{9} - h_{10} + h_{9} - h_{7}} = \frac{725.86 - 497.59}{274.2 - 725.86 + 725.86 - 497.59} = 0.1096
\]

This allows the specific enthalpy at 12 to be determined by analyzing the mixing of streams 9 and 11:

\[
o = (1 - y') h_9 + y' h_{11} - h_{12}
\]

or

\[
h_{12} = (1 - y') h_9 + y' h_{11} = (0.8904)(725.86) + (0.1096)(775.21) = 791.27 \text{ kJ/kg}
\]

Next, energy and mass balances for the control volume enclosing the open heater give the fraction \( y'' \) extracted at 3:

\[
o = y'' h_3 + (1 - y' - y'') h_6 - (1 - y'') h_7
\]

or

\[
y'' = \frac{(1 - y')(h_7 - h_6)}{(h_3 - h_6)} = \frac{(0.8904)(6711 - 51.67)}{(2436.9 - 151.67)} = 0.1229
\]

For the control volume enclosing the turbine stages

\[
\dot{W}_T = (h_{11} - h_2) + (1 - y'')(h_3 - h_3) + (1 - y' - y'') (h_6 - h_4)
\]

\[
= (3401.8 - 2764.2) + (1 - 0.1229)(2436.9 - 2436.9) - (0.1229)(1250.3 - 1250.3) = 1250.3 \text{ kJ/kg}
\]

For the pumps

\[
\dot{W}_P = y'' (h_{11} - h_4) + (1 - y'')(h_2 - h_7) + (1 - y' - y'') (h_4 - h_5)
\]

\[
= (0.1229)(775.21 - 762.81) + (0.1229)(479.39 - 467.11) + (0.1229)(151.67 - 151.67)
\]

\[
= 12.58 \text{ kJ/kg}
\]

For the steam generator

\[
\frac{Q}{m_1} = h_{11} - h_{12} = (3401.8) - (791.27) = 2670.5 \text{ kJ/kg}
\]

Thus, the thermal efficiency is

\[
\eta = \frac{\dot{W}_T/m_1 - \dot{W}_P/m_1}{Q/m_1} = \frac{1250.3 - 12.58}{2670.5} = 0.463 (46.3\%)
\]

(b) The mass flow rate into the first turbine stage is

\[
m_1 = \frac{W_{cycle}}{\dot{W}_T/m_1 - \dot{W}_P/m_1}
\]

\[
= \frac{320 \text{ MW}}{(1250.3 - 12.58) \text{ kJ/kg}} \left| \frac{10^3 \text{ kJ/s}}{1 \text{ MW}} \right| \left| \frac{3600 \text{ s}}{1 \text{ h}} \right|
\]

\[
= 9.31 \times 10^5 \text{ kg/h}
\]