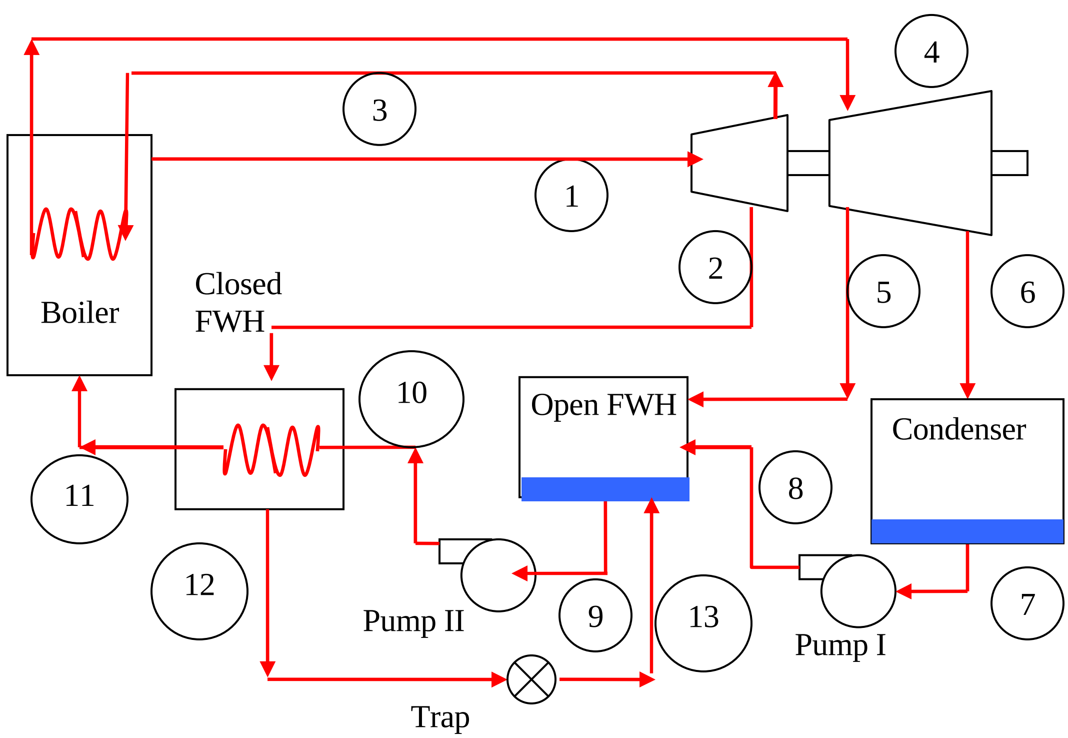
ENSC 461

Assignment #8 (Vapor Power Cycles)

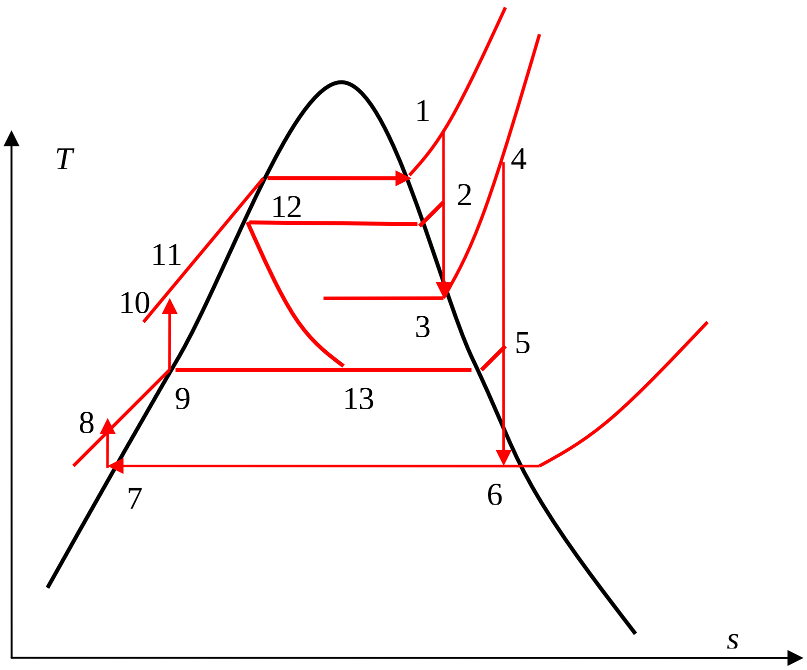
Assignment date:

Due date:

Consider a reheat-regenerative vapor power cycle with two feedwater heaters, a closed FWH and an open FWH. Steam enters the first turbine at 8.0 MPa, 480C and expands to 0.7 MPa. The steam is reheated to 440C before entering the second turbine, where it expands to the condenser pressure of 0.008 MPa. Steam is extracted from the turbine at 2 MPa and fed to the closed feedwater heater. Feedwater leaves the closed heater at 205C and 8.0 MPa, and condensate exits at 2 MPa. The condensate is trapped into the open feedwater heater. Steam extracted from the second turbine at 0.3 MPa. The stream exiting the open feedwater is saturated liquid at 0.3 MPa. The net power output of the cycle is 100 MW. There is no stray heat transfer from any component to its surroundings. If the working fluid experiences no irreversibilities as it passes through the turbines, pumps, steam generator, reheater, and condenser, determine: a) the thermal efficiency, b) the mass flow rate of the steam entering the first turbine, in kg/h.



Solution:



Assumptions:

1. Each components in the cycle is analyzed as a CV at steady state.
2. There is no stray heat transfer from any components to its surroundings.
3. The working fluid undergoes internally reversible processes as it passes through the turbines, pumps, steam generator, reheater, and condenser.
4. The expansion through the trap is a throttling process.
5. Kinetic and potential energy effects are negligible.
6. Condensate exits the closed FWH as a saturated liquid at 2 MPa, Feedwater exits the open heater as a saturated liquid at 0.3 MPa. Condensate exits the condenser as a saturated liquid.

We start the solution with finding the enthalpies at the principal states of the cycle. State 1 is superheated steam → h_1 = 3384.4 kJ/kg and s_1 = 6.6586 kJ/kg.K.

State 2 is fixed by P_2 = 2.0 MPa and specific entropy $s_2 = s_1$. With interpolating, h_2 = 2953.5 kJ/kg.

The state at the exit of the first turbine is fixed by P_3 = 0.7 MPa and $s_3 = s_1$ → h_3 = 2741.8 kJ/kg.

State 4 is superheated vapor at 0.7 MPa, 440°C→ h_4 = 3353.3 kJ/kg and s_4 = 7.7571 kJ/kg.K. With P_5 = 0.3 MPa and $s_5 = s_4$ = 7.7571 kJ/kg.K → h_5 = 3101.5 kJ/kg. Using $s_6 = s_4$, the quality at state 6 is found to be x_6 = 0.9382. So,

$h_6 = h_f + x_6 h_{fg}$ = 2403.1 kJ/kg

At the condenser exit, h_7 = 173.88 kJ/kg. The specific enthalpy at the exit of the first pump is:

$h_8 = h_7 + v_7 (P_8 - P_7) = 174.17$ kJ/kg

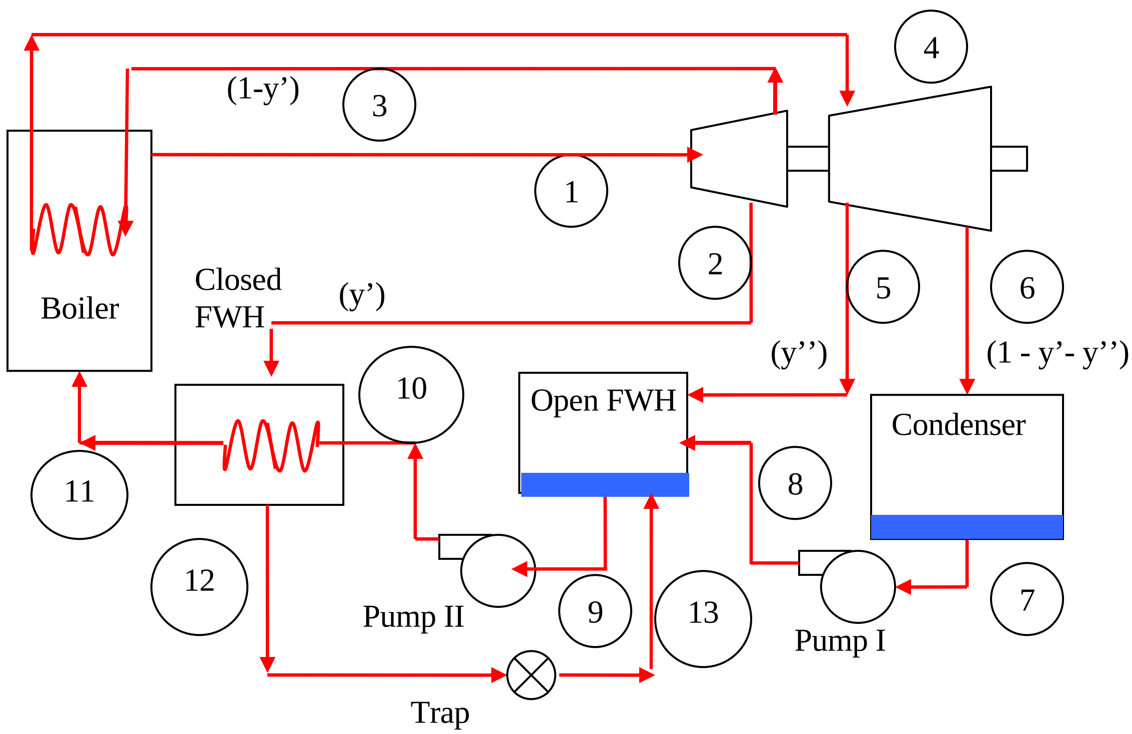
The liquid leaving the open FWH at state 9 is saturated liquid at 0.3 MPa. The specific enthalpy is h_9 = 561.47 kJ/kg. The specific enthalpy at the exit of the second pump is:

$h_{10} = h_9 + v_9 (P_{10} - P_9) = 569.73$ kJ/kg

The condensate leaving the closed heater is saturated at 2 MPa → h_{12} = 908.79 kJ/kg. The fluid passing through the trap undergoes a throttling process, so h_{13} = 908.79 kJ/kg. The specific enthalpy of the feedwater exiting the closed heater (compressed liquid) at 8.0 MPa and 205°C should be modified for the pressure:

$h_{11} = h_f + v_f (P_{11} - P_{sat}) = 882.4$ kJ/kg

where h_f and v_f are the saturated liquid specific enthalpy and specific volume at 205°C, and P_{sat} is the saturation pressure in MPa at this temperature.



The schematic diagram of the cycle is labeled with the fractions of the total flow into the turbine that remain at various locations. The fractions of the total flow diverted to the closed heater and open heater, respectively are $y' = \dot{m}_2 / \dot{m}_1$ $y'' = \dot{m}_5 / \dot{m}_1$ where $\dot{m}_1$ denotes the mass flow rate entering the first turbine.

The fraction y' can be determined by application of mass and energy rate balances to a control volume enclosing the closed heater. The result is:

$$y' = \frac{h_{11} - h_{10}}{h_2 - h_{12}} = \frac{882.4 - 569.73}{2963.5 - 908.79} = 0.1522$$

The fraction y'' can be determined by application of mass and energy rate balance to a control volume enclosing the open heater, resulting in:

$$0 = y''h_5 + (1 - y' - y'')h_8 + y'h_{13} - h_9$$

$$y'' = \frac{(1 - y')h_8 - y'h_{13} - h_9}{h_8 - h_5} = 0.0941$$

a) The following work and heat transfer values are expressed on the basis of a unit mass entering the first turbine. The work developed by the first turbine per unit mass entering is the sum:

$$\frac{\dot{W}_{t1}}{\dot{m}_1} = (h_1 - h_2) + (1 - y')(h_2 - h_3) = 572.9\ kJ/kg$$

Similarly, for the second turbine:

$$\frac{\dot{W}_{t2}}{\dot{m}_1} = (1 - y')(h_4 - h_5) + (1 - y' - y'')(h_5 - h_6) = 720.7\ kJ/kg$$

For pumps:

$$\frac{\dot{W}_{p1}}{\dot{m}_1} = (1 - y' - y'')(h_8 - h_7) = 0.22\ kJ/kg$$

$$\frac{\dot{W}_{p1}}{\dot{m}_1} = (h_{10} - h_9) = 8.26\ kJ/kg$$

The total added heat is the sum of the energy added by heat transfer during boiling/superheating and reheating. When expressed on the basis of a unit mass entering the fist turbine, this is:

$$\frac{\dot{Q}_{in}}{\dot{m}_1} = (h_1 - h_{11}) + (1 - y')(h_4 - h_3) = 2984.4\ kJ/kg$$

With the foregoing values, the thermal efficiency is:

$$\eta = \frac{\dot{W}_{t1}/\dot{m}_1 + \dot{W}_{t2}/\dot{m}_1 - \dot{W}_{p1}/\dot{m}_1 - \dot{W}_{p2}/\dot{m}_1}{\dot{Q}_{in}/\dot{m}_1} = 0.431\ (43.1\%)$$

b) the mass flow rate entering the first turbine can be determined using the given value of the net power output.

$$\dot{m}_1 = \frac{\dot{W}_{cycle}}{\dot{W}_{t1}/\dot{m}_1 + \dot{W}_{t2}/\dot{m}_1 - \dot{W}_{p1}/\dot{m}_1 - \dot{W}_{p2}/\dot{m}_1} = 2.8 \times 10^5\ kg/h$$