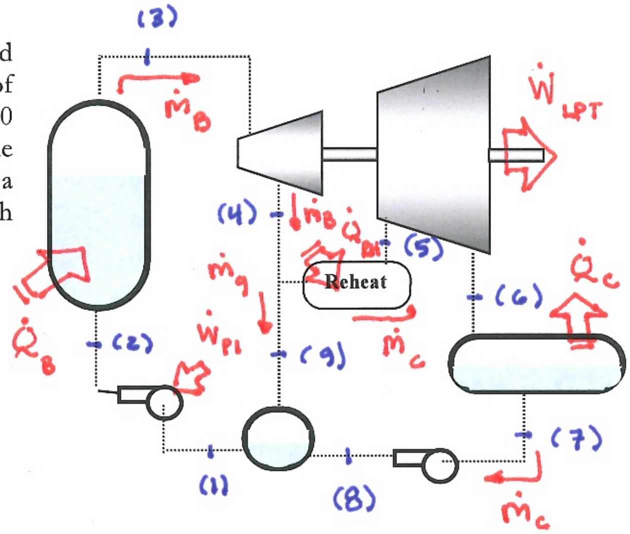
ROSE-HULMAN Institute of Technology
Department of Mechanical Engineering

ME 301 Thermodynamics II

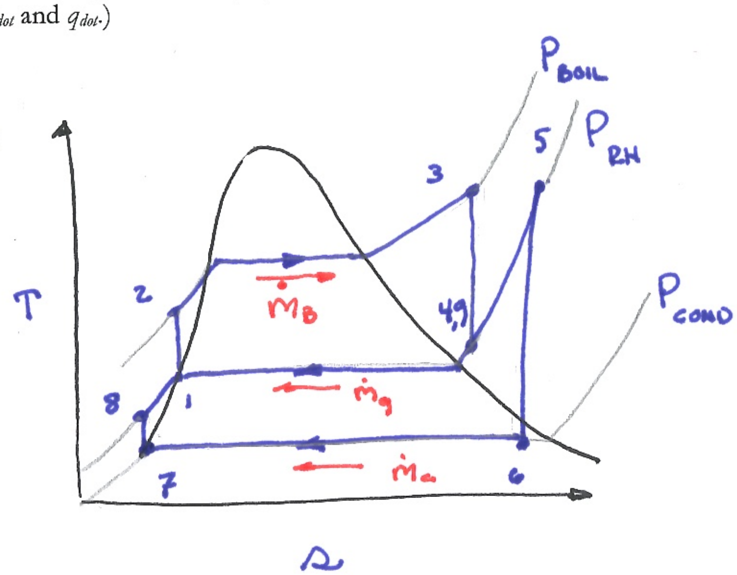
Example

An (almost) ideal Rankine cycle is modified to include reheat and regeneration using an open feedwater heater. The mass flow rate of steam through the boiler is 1.25 kg/s. The boiler operates at 10 MPa, the open feedwater heater operates at 6 MPa, and the condenser operates at 10 kPa. The water enters both pumps as a saturated liquid. The temperature of the steam entering both turbines is 700°C.

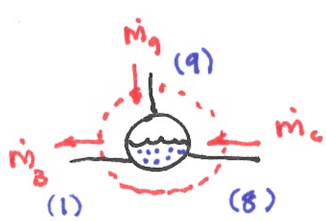


a) Sketch the cycle on a *T-s* diagram.
b) Find the power or heat transfer rate in/out of each device. (Hint: Start with an analysis of the open feedwater heater.)
c) Find the cycle efficiency. (Hint: Careful with W_{dot} and Q_{dot} vs. w_{dot} and q_{dot}.)

(a)



(b) OPEN FEEDWATER HEATER



CONS. of MASS

$$\frac{d}{dt}(m_{sys}) = \sum \dot{m}_{in} - \sum \dot{m}_{out}$$

$\frac{d}{dt}(m_{sys}) \to 0$

$$0 = \dot{m}_c + \dot{m}_9 - \dot{m}_B \qquad (1)$$

CONS. of ENERGY

$$\frac{d}{dt}(E_{SYS}) = \dot{Q}_{IN,NET} - \dot{W}_{NET,OUT} + \sum \dot{m}_{in}(h + \ldots) - \sum \dot{m}_{out}(h + \ldots)$$

($\frac{d}{dt}(E_{SYS}) \to 0$ (SS), $\dot{Q}_{IN,NET} \to 0$, $\dot{W}_{NET,OUT} \to 0$)

$$0 = \dot{m}_c(h_8) + \dot{m}_9(h_9) - \dot{m}_8(h_1) \qquad (2)$$

$$h_1 = h(P_{RH}, x=0) = \underline{1213 \quad kJ/kg}$$

$$h_9 = h(P_{RH}, s = s_3) = \underline{3658 \quad kJ/kg}$$

$$s_3 = s(P_{BOIL}, T = 700°) = \underline{7.167 \quad kJ/kg \cdot K}$$

$$h_8 = h(P_{RH}, s = s_7) = \underline{197.8 \quad kJ/kg}$$

$$s_7 = s(P_{COND}, x=0) = \underline{0.6489 \quad kJ/kg \cdot K}$$

(1) & (2) GIVE $\dot{m}_c = 0.8831$ kg/s

$\dot{m}_9 = 0.3669$ kg/s

CONTINUE W/ CONS. of ENERGY & PROPERTY RELATIONS FOR EACH COMPONENT AROUND CYCLE. RESULTS FOLLOW.

Given

$P_{cond} = 10$ [kPa]

$P_{boil} = 10000$ [kPa]

$P_{reheat} = 6000$ [kPa]

$T_3 = 700$

$\dot{m}_B = 1.25$ [kg/s]

Pump 1 energy

$\dot{W}_{p,1} = \dot{m}_B \cdot [h_2 - h_1]$

$h_1 = \mathbf{h}['Steam', P = P_{reheat}, x = 0]$

$s_1 = \mathbf{s}['Steam', P = P_{reheat}, x = 0]$

$h_2 = \mathbf{h}['Steam', P = P_{boil}, s = s_1]$

Boiler energy

$\dot{Q}_B = \dot{m}_B \cdot [h_3 - h_2]$

$h_3 = \mathbf{h}['Steam', T = T_3, P = P_{boil}]$

$s_3 = \mathbf{s}['Steam', T = T_3, P = P_{boil}]$

HP Turbine energy

$\dot{W}_{HPT} = \dot{m}_B \cdot [h_3 - h_4]$

$h_4 = \mathbf{h}['Steam', P = P_{reheat}, s = s_3]$

Reheater energy

$\dot{Q}_{reheat} = \dot{m}_C \cdot [h_5 - h_4]$

$h_5 = \mathbf{h}['Steam', T = T_3, P = P_{reheat}]$

LP turbine energy

$\dot{W}_{LPT} = \dot{m}_C \cdot [h_5 - h_6]$

$s_5 = \mathbf{s}['Steam', T = T_3, P = P_{reheat}]$

$h_6 = \mathbf{h}['Steam', P = P_{cond}, s = s_5]$

Condensor energy

$\dot{Q}_C = \dot{m}_C \cdot [h_6 - h_7]$

$h_7 = \mathbf{h}['Steam', P = P_{cond}, x = 0]$

Pump 2 energy

$$\dot{W}_{p,2} = \dot{m}_C \cdot [h_8 - h_7]$$

$$s_7 = \mathbf{s}['Steam', P = P_{cond}, x = 0]$$

$$h_8 = \mathbf{h}['Steam', P = P_{reheat}, s = s_7]$$

Open feedwater heater

Mass

$$0 = \dot{m}_C + \dot{m}_9 - \dot{m}_B$$

Energy

$$0 = \dot{m}_9 \cdot h_4 + \dot{m}_C \cdot h_8 - \dot{m}_B \cdot h_1$$

Cycle efficiency. Notice that we use power and rate of heat tranfer (big W and Q, not little w and q) because the mass flow rates are different through different components.

$$\eta = \frac{\dot{W}_{HPT} + \dot{W}_{LPT} - \dot{W}_{p,1} - \dot{W}_{p,2}}{\dot{Q}_B + \dot{Q}_{reheat}}$$

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$\eta = 0.4581$

$h_1 = 1213$ [kJ/kg]

$h_2 = 1219$ [kJ/kg]

$h_3 = 3869$ [kJ/kg]

$h_4 = 3658$ [kJ/kg]

$h_5 = 3894$ [kJ/kg]

$h_6 = 2352$ [kJ/kg]

$h_7 = 191.8$ [kJ/kg]

$h_8 = 197.9$ [kJ/kg]

$\dot{m}_9 = 0.3669$ [kg/s]

$\dot{m}_B = 1.25$ [kg/s]

$\dot{m}_C = 0.8831$ [kg/s]

$P_{boil} = 10000$ [kPa]

$P_{cond} = 10$ [kPa]

$P_{reheat} = 6000$ [kPa]

$\dot{Q}_B = 3313$ [kW]

$\dot{Q}_C = 1908$ [kW]

$\dot{Q}_{reheat} = 208.2$ [kW]

$s_1 = 3.027$ [kJ/kg-K]

$s_3 = 7.167$ [kJ/kg-K]

$s_5 = 7.423$ [kJ/kg-K]

$s_7 = 0.6493$ [kJ/kg-K]

$T_3 = 700$ [C]

$\dot{W}_{HPT} = 263.9$ [kW]

$\dot{W}_{LPT} = 1361$ [kW]

$\dot{W}_{p,1} = 6.579$ [kW]

$\dot{W}_{p,2} = 5.338$ [kW]

No unit problems were detected.