CANKAYA UNIVERSITY
FACULTY OF ENGINEERING AND ARCHITECTURE
MECHANICAL ENGINEERING DEPARTMENT
ME 212 THERMODYNAMICS II

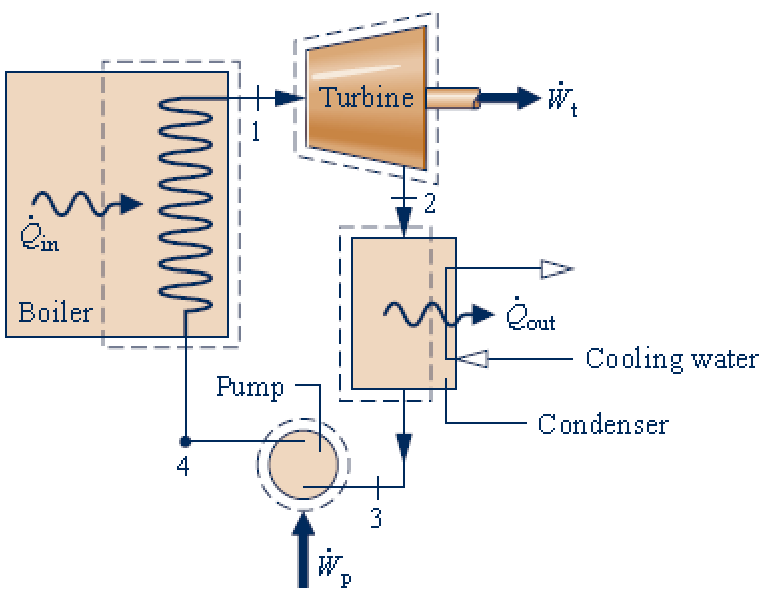
CHAPTER 8

EXAMPLES SOLUTIONS

Example 1:

Consider a steam power plant that operates on a simple ideal Rankine cycle. Steam enters the turbine at 7 MPa and 450 ^{o}C and is condensed in the condenser at a pressure of 10 kPa by running cooling water from a lake through the tubes of the condenser at a rate of 1600 kg/s. Rankine cycle has a net power output of 40 MW. Show the cycle on T-s diagram with respect to saturation lines, and determine (a) the thermal efficiency of this cycle, (b) the back work ratio, (c) the mass flow rate of the steam, in kg/s, and (d) the temperature rise of the cooling water, in ^{o}C.

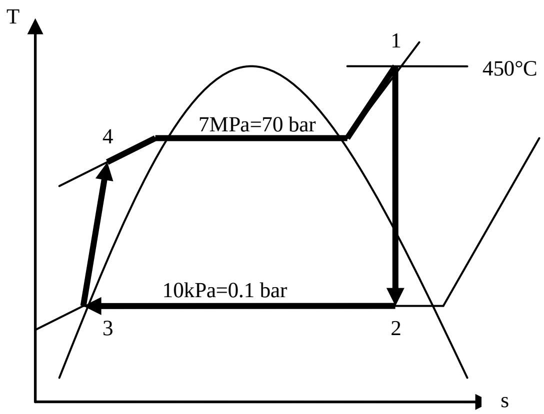
Solution:



Assumptions : (1) Steady state conditions exits.

(2) Kinetic and Potential energy changes are negligible.

Analysis:



State 1

For P_1=7 MPa and T_1=450 °C , Table A-4 gives

$$h_1 = 3286.57\frac{kJ}{kg} \quad \text{and} \quad s_1 = 6.6359\frac{kJ}{kg.K}$$

State 2

$$s_2 = s_1 = 6.6359\frac{kJ}{kg.K}$$

From Table A-3

$$s_{g@10kPa} = 8.1502\frac{kJ}{kg.K}$$

$$s_{f@10kPa} = 0.6493\frac{kJ}{kg.K}$$

$$x_2 = \frac{s_2 - s_{f@10kPa}}{s_{fg@10kPa}} = \frac{6.6359 - 0.6493}{8.1502 - 0.6493} = 0.7981$$

So,

$$h_2 = h_{f@10kPa} + x_2 h_{fg@10kPa}$$

From Table A-3, $h_{f@10kPa} = 191.83\frac{kJ}{kg}$ and $h_{fg@10kPa} = 2392.8\frac{kJ}{kg}$

Thus,

$$h_2 = 191.83 + 0.7981(2392.8) = 2101.52\frac{kJ}{kg}$$

State 3: From table A-3

$$h_3 = h_{f@10kPa} = 191.83\frac{kJ}{kg} \quad \text{and} \quad \upsilon_3 = \upsilon_{f@10kPa} = 1.0102\times10^{-3}\frac{m^3}{kg}$$

State 4:

$$\frac{\dot{W}_p}{\dot{m}} = h_4 - h_3 = \upsilon_3(P_4 - P_3)$$

$$h_4 = h_3 + \upsilon_3(P_4 - P_3)$$

$$h_4 = 191.83\frac{kJ}{kg} + (1.0102\times10^{-3}\frac{m^3}{kg})(7000-10)\frac{kN}{m^2} = 198.89\frac{kJ}{kg}$$

Thus;

$$\frac{\dot{W}_t}{\dot{m}} = h_1 - h_2 = (3286.57) - (2101.52) = 1185.05\frac{kJ}{kg}$$

$$\frac{\dot{W}_p}{\dot{m}} = h_4 - h_3 = (198.89) - (191.83) = 7.06\frac{kJ}{kg}$$

$$\frac{\dot{Q}_{in}}{\dot{m}} = h_1 - h_4 = (3286.57) - (198.89) = 3087.68\frac{kJ}{kg}$$

$$\frac{\dot{Q}_{out}}{\dot{m}} = h_2 - h_3 = (2101.52) - (191.83) = 1909.69 \frac{kJ}{kg}$$

$$\frac{\dot{W}_{net}}{\dot{m}} = \frac{\dot{Q}_{in}}{\dot{m}} - \frac{\dot{Q}_{out}}{\dot{m}} = \frac{\dot{W}_{t}}{\dot{m}} - \frac{\dot{W}_{p}}{\dot{m}} = 3087.68 - 1909.69 = 1177.99 \frac{kJ}{kg}$$

(a) The thermal efficiency of the cycle is

$$\eta = 1 - \frac{\dfrac{\dot{Q}_{out}}{\dot{m}}}{\dfrac{\dot{Q}_{in}}{\dot{m}}} = 1 - \frac{1909.69}{3087.68} = 0.382 \quad (\%38.2)$$

(b) The back-work ratio is determined from

$$bwr = \frac{\dfrac{\dot{W}_{p}}{\dot{m}}}{\dfrac{\dot{W}_{t}}{\dot{m}}} = \frac{7.06}{1185.05} = 0.0060 \quad (\%0.60)$$

(c) The mass flow rate of the steam is

$$\dot{m} = \frac{\dot{W}_{net}}{\dfrac{\dot{W}_{net}}{\dot{m}}} = \frac{40000 \dfrac{kJ}{s}}{1177.99 \dfrac{kJ}{kg}} = 33.96 \frac{kg}{s}$$

(d) The rate of heat rejection to the cooling water and its temperature rise are

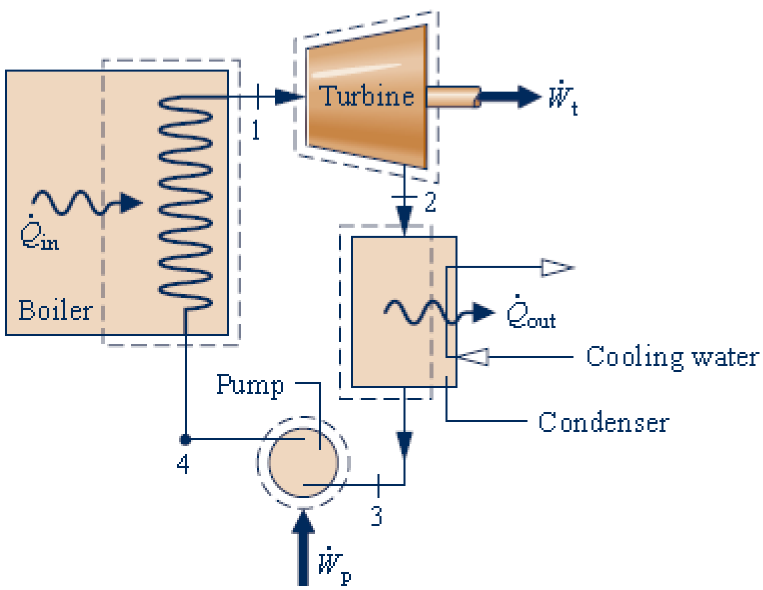
$$\dot{Q}_{out} = \dot{m}\frac{\dot{Q}_{out}}{\dot{m}} = (33.96\frac{kg}{s})(1909.69\frac{kJ}{kg}) = 64{,}853.07\frac{kJ}{s}$$

$$\Delta T_{\substack{cooling \\ water}} = \frac{\dot{Q}_{out}}{(\dot{m}\,c_p)_{\substack{cooling \\ water}}} = \frac{64{,}853.07\frac{kJ}{s}}{(1600\frac{kg}{s})(4.18\frac{kJ}{kg.K})} = 9.70\ ^{o}C$$

Example 2:

A Rankine steam power plant uses water as the working fluid. Steam enters the turbine at 7 MPa and 450 ^{o}C and is condensed in the condenser at a pressure of 10 kPa by running cooling water from a lake through the tubes of the condenser at a rate of 1600 kg/s. Cycle has a net power output of 40 MW. Isentropic efficiency of the turbine is 85 percent, and the isentropic efficiency of the pump is 90 percent. Assuming no pressure losses in the condenser and boiler, show the cycle on T-s diagram with respect to saturation lines, and determine (a) the thermal efficiency of this cycle, (b) the back work ratio, (c) the mass flow rate of the steam, in kg/s, and (d) the temperature rise of the cooling water, in ^{o}C.

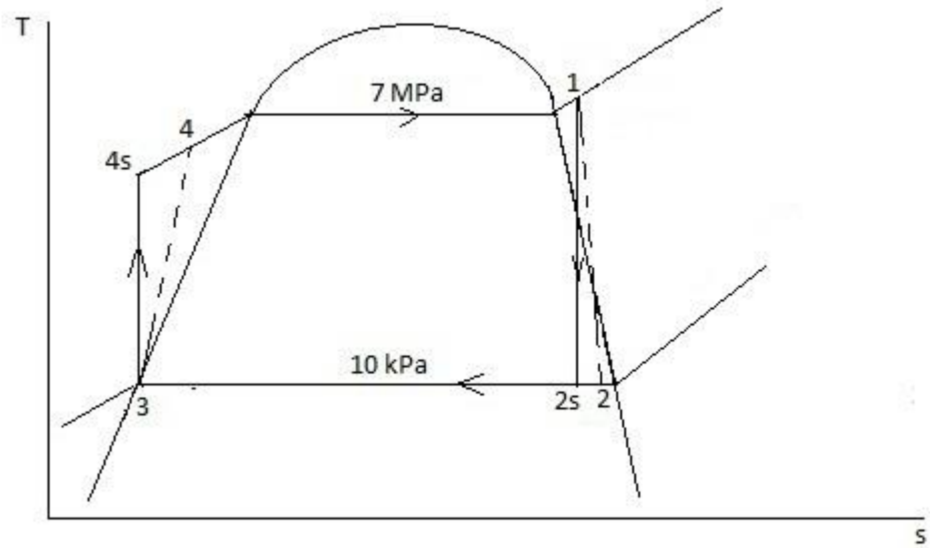
Solution:



Assumptions: (1) Steady state conditions exist.

(2) Kinetic and potential energy changes are negligible.

Analysis:



<u>State 1:</u>

With P_1 = 7 MPa and T_1 = 450 ^{0}C, Table A-4 gives

h_1 = 3286.57 kJ/kg and s_1 = 6.6359 kJ/kg

<u>State 2:</u>

$s_{2s} = s_1$ = 6.6359 kJ/kg

From Table A-3

$s_{g@10kPa}$ = 8.1502 kJ/kg.K

$s_{f@10kPa}$ = 0.6493 kJ/kg.K

$X_{2s} = \frac{s_{2s} - s_{f@10kPa}}{s_{fg@10kPa}} = \frac{6.6359 - 0.6493}{8.1502 - 0.6493} = 0.7981$

So,

$h_{2s} = h_{f@10kPa} + X_{2s}.h_{fg@10kPa}$

From Table A-3

$h_{f@10kPa}$ = 191.83 kJ/kg

$h_{fg@10kPa}$ = 2392.8 kJ/kg

Thus,

h_{2s} = 191.83 + 0.7981(2392.8) = 2101.52 kJ/kg

Isentropic turbine efficiency is

$$\eta_t = \frac{\dot{W}_t/\dot{m}}{(\dot{W}_t/\dot{m})_s} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

$h_2 = h_1 - \eta_t (h_1 - h_{2s})$

= 3286.57-0.85(3286.57-2101.52)

= 2279.28 kJ/kg

<u>State 3:</u>

$h_3 = h_{f@10kPa}$ = 191.83 kJ/kg

$v_3 = v_{f@10kPa} = 1.0102 \times 10^{-3}\ m^3/kg$

<u>State 4:</u>

$(\frac{\dot{W}_p}{\dot{m}})_s = h_{4s} - h_3 = v_3(P_{4s} - P_3)$

$h_{4s} = h_3 + v_3(P_{4s} - P_3)$

$= 191.83\ kJ/kg + (1.0102 \times 10^{-3}\ m^3/kg)\ (7000 - 10)\ kN/m^2$

= 198.89 kJ/kg

Isentropic pump efficiency is

$$\eta_p = \frac{(\dot{W}_p/\dot{m})s}{\dot{W}_p/\dot{m}} = \frac{h_{4s} - h_3}{h_4 - h_3}$$

$h_4 = \frac{h_{4s} - h_3}{t} + h_3 = \frac{198.89-191.83}{0.90} + 191.83$

h_4 = 199.67 kJ/kg

Hence,

$\frac{\dot{W}_t}{\dot{m}} = h_1 - h_2$ = 3286.57 – 2279.28 = 1007.29 kJ/kg

$\frac{\dot{W}_p}{\dot{m}} = h_4 - h_3$ = 199.67 – 191.83 = 7.84 kJ/kg

$\frac{\dot{Q}_{in}}{\dot{m}}$ = $h_1 - h_4$ = 3286.57 – 199.67 = 3086.9 kJ/kg

$\frac{\dot{Q}_{out}}{\dot{m}}$ = $h_2 - h_3$ = 2279.28 – 191.83 = 2087.45 kJ/kg

$\frac{\dot{W}_{net}}{\dot{m}} = \frac{\dot{Q}_{in} - \dot{Q}_{out}}{\dot{m}} = \frac{\dot{W}_t - \dot{W}_p}{\dot{m}}$ = 3086.7 - 2087.45 = 999.25 kJ/kg

(a) The thermal efficiency of the cycle is

$\eta = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}} = 1 - \frac{2087.45}{3086.9}$ = 0.324 or % 32.4

(b) The back-work ratio is determined from

bwr = $\frac{\dot{W}_p}{\dot{W}_t} = \frac{7.84}{1007.29}$ = 0.0078

(c) The mass flow rate of the steam is

$\dot{m} = \frac{\dot{W}_{cycle}}{\dot{W}_{net}} = \frac{40000\ kJ/s}{999.25 \frac{kJ}{kg}}$ = 40.03 kg/s

(d) The rate of heat rejection to the cooling water and its temperature rise are

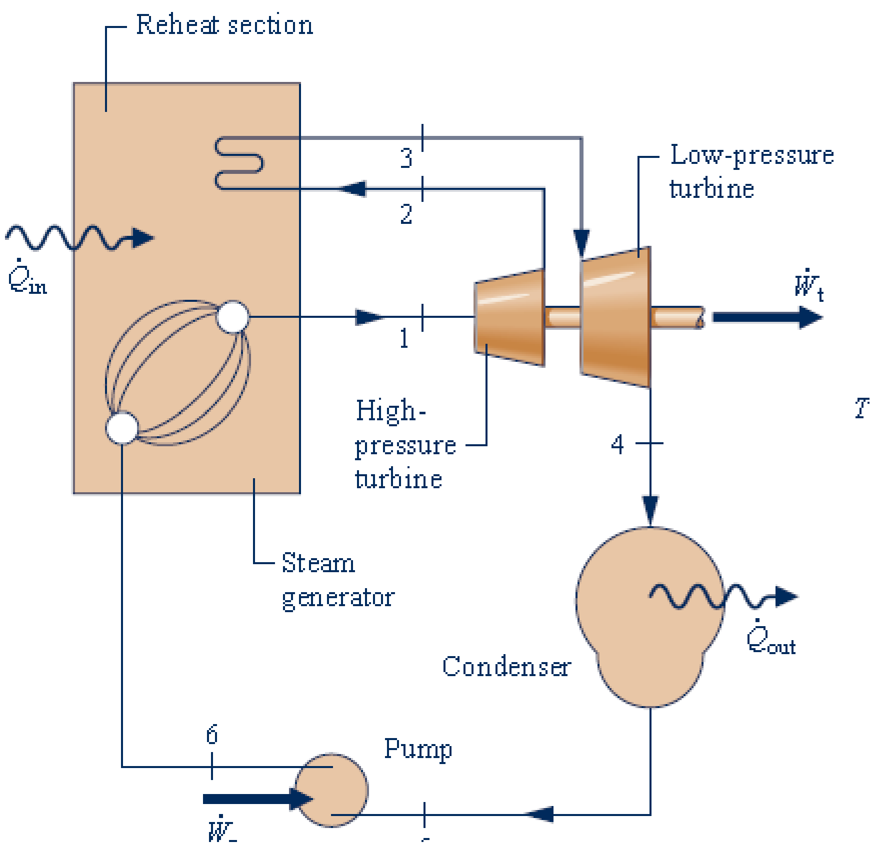
$\dot{Q}_{out} = \dot{m} . \dot{Q}_{out}$ = (40.03 kg/s) (2087.45 kJ/kg) = 83,560.62 kJ/s

$\Delta T_{\substack{cooling \\ water}} = \frac{\dot{Q}_{out}}{(\dot{m}C_p)_{\substack{cooling \\ water}}} = \frac{83{,}560.62\ kJ/s}{\left(1600 \frac{kg}{s}\right)\left(4.18 \frac{kJ}{kg.C}\right)}$ = 12.49 ^{0}C

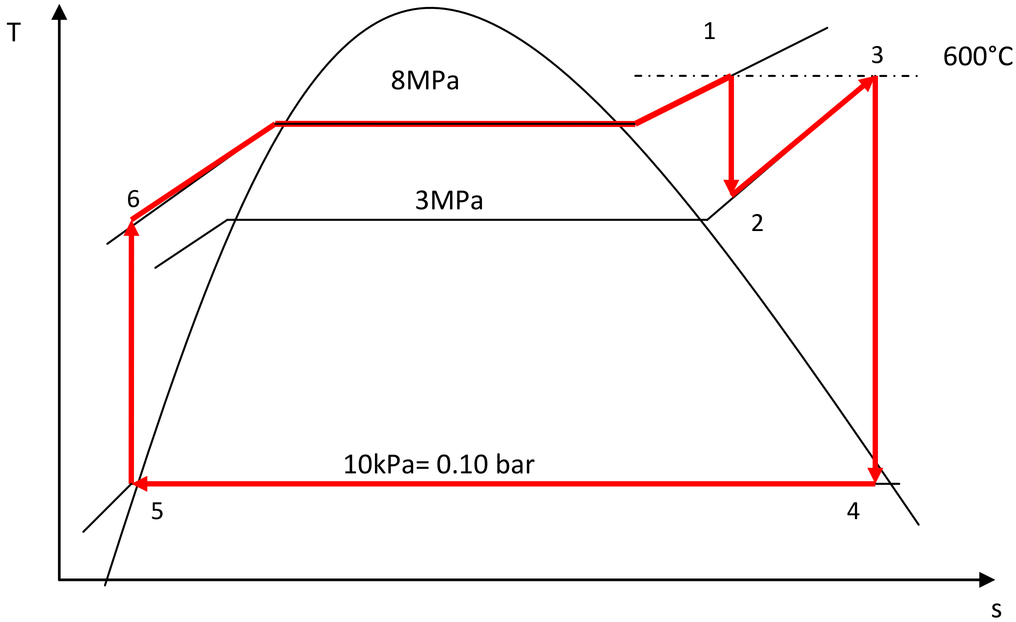
Example 3:

In a Rankine cycle, saturated liquid water at 10 kPa is compressed in a pump isentropically to 8 MPa. It is then heated, first in a boiler and then by superheating at a constant pressure of 8 MPa, to a temperature of 600 ^{o}C. After an adiabatic reversible expansion to 3 MPa, the steam is reheated to 600 ^{o}C, and a second adiabatic reversible expansion to 10 kPa occurs.This is essentially a reheat cycle. (a) What is the total work (kJ/kg) generated. (b) What is the efficiency of the cycle (%)? (c) Sketch the cycle on a T-s diagram.

Solution:



(c)



State 1;

P_1=7MPa

T_1=700°C Table A-4 gives

$$h_1 = 3642.0\frac{kj}{kg} \quad \text{and} \quad s_1 = 7.0206\frac{kj}{kg.K}$$

State 2:

P_2=3MPa

$$s_2 = s_1 = 7.0206\frac{kj}{kg.K}$$

$$s_{g@3MPa} = 6.1869\frac{kj}{kg.K}$$, From Table A-3,

$$s_2 > s_{g@3MPa}$$

P_2=3MPa

$$s_2 = 7.0206 \frac{kj}{kg.K} \quad , \quad h_2 = 3299.8 \frac{kj}{kg}$$, From Table A-4

<u>State 3;</u>

P_1=3MPa

T_1=600°C Table A-4 gives

$$h_3 = 3682.3 \frac{kj}{kg} \quad \text{and} \quad s_1 = 7.5085 \frac{kj}{kg.K}$$

<u>State 4;</u>

$$s_{g@10kPa} = 8.1502 \frac{kj}{kg.K}$$ From Table A-3

$$s_{f@10kPa} = 0.6493 \frac{kj}{kg.K}$$

$$s_4 = s_3 = 7.50853 \frac{kj}{kg.K}$$

$$s_{f@10kPa} < s_4 < s_{g@10kPa}$$

$$x_4 = \frac{s_4 - s_{f@10kPa}}{s_{g@10kPa} - s_{f@10kPa}} = \frac{7.5085 - 0.6493}{8.1502 - 0.6493} = 0.9145$$

$$h_4 = h_{f@10kPa} + x_4 h_{fg@10kPa}$$

$$h_4 = 191.83 + (0.9145)(2392.8) = 2380.1 \frac{kj}{kg}$$ (Table A-3)

<u>State 5;</u>

$$h_5 = h_{f@10kPa} = 191.83 \frac{kj}{kg}, \quad \upsilon_5 = \upsilon_{f@10kPa} = 1.0102 \times 10^{-3} \frac{m^3}{kg}$$

State 6;

$$\frac{\dot{W}_p}{\dot{m}} = h_6 - h_5 = \upsilon_5 (P_6 - P_5)$$

$$h_6 = h_5 + \upsilon_5 (P_6 - P_5)$$

$$h_6 = 191.83 \frac{kj}{kg} + (1.0102 \times 10^{-3} \frac{m^3}{kg})(8000 - 10)\frac{kN}{m^2} = 199.9 \frac{kj}{kg}$$

(a) The total work generated

$$\frac{\dot{W}^{total}_{generated}}{\dot{m}} = \frac{\dot{W}_{t_1}}{\dot{m}} + \frac{\dot{W}_{t_2}}{\dot{m}}$$

$$\frac{\dot{W}_{t_1}}{\dot{m}} = h_1 - h_2 = (3642.0) - (3299.8) = 342.2 \frac{kj}{kg}$$

$$\frac{\dot{W}_{t_2}}{\dot{m}} = h_3 - h_4 = (3682.3) - (2380.1) = 1302.2 \frac{kj}{kg}$$

$$\frac{\dot{W}^{total}_{generated}}{\dot{m}} = 342.2 + 1302.2 = 1644.4 \frac{kj}{kg}$$

(b)

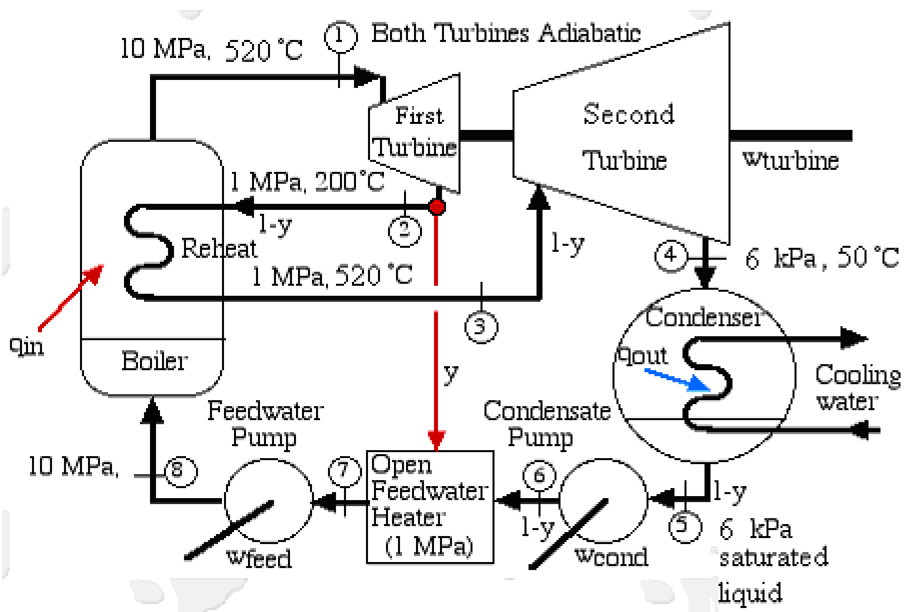
$$\frac{\dot{Q}_{in}}{\dot{m}} = (h_1 - h_6) + (h_3 - h_2) = (3642.0 - 199.9) + (3682.3 - 3299.8) = 3824.6 \frac{kj}{kg}$$

$$\frac{\dot{W}_p}{\dot{m}} = h_6 - h_5 = (199.9) - (191.83) = 8.07 \frac{kj}{kg}$$

$$\eta = \frac{\dfrac{\dot{W}_{net}}{\dot{m}}}{\dfrac{\dot{Q}_{in}}{\dot{m}}} = \frac{\dfrac{\dot{W}_{t_1}}{\dot{m}} + \dfrac{\dot{W}_{t_2}}{\dot{m}} - \dfrac{\dot{W}_{p}}{\dot{m}}}{\dfrac{\dot{Q}_{in}}{\dot{m}}} = \frac{342.2 + 1302.2 - 8.07}{3824.6} = 0.428 \quad \text{or} \quad (\%42.8)$$

Example 4:

Consider the steam power plant with an open feedwater heater operating under the conditions shown in the following diagram. Saturated liquid exits the open feedwater heater at 1 MPa, and saturated liquid exits the condenser. Each pump operates isentropically. Net power output of the cycle is 100 MW.



Using the conditions shown on the diagram above and values obtained from the steam tables, determine

a. the enthalpy values at all eight stations,

b. the mass fraction, y, of steam bled from the turbine set at station (2),

c. the thermal efficiency, η, of this power plant, and

d. the mass flow rate of steam entering the first turbine stage, in kg/h.

e. Show the cycle on T-s diagram with respect to saturation lines.

Solution:

Assumptions: (1) Steady-state

(2) Each pump operates isentropically.

(3) The turbines, pumps, and feedwater heater operate adiabatically.

(4) Kinetic and potential energy changes are negligible.

(5) Saturated liquid exits the open feedwater heater, and saturated liquid exits the condenser.

Analysis:

a) **State 1:** $T_1 = 520\ ^0$Cand $P_1 = 10$ MPa, Table A-4 gives $h_1 = 3425.1$ kJ/kg

State 2: With $P_2 = 1$ MPa and $T_2 = 200\ ^0$C, Table A-4 gives $h_2 = 2827.9$ kJ/kg

State 3: With 1 MPa and 520 ^{0}C, Table A-4 gives $h_3 = 3522.1$ kJ/kg

State 4: With 6 kPa and 50 ^{0}C, Table A-4 gives $h_4 = 2593.5$ kJ/kg

State 5: With 6 kPa, Table A-3 gives $h_5 = h_{f@6kPa} = 151.53$ kJ/kg

$$v_5 = v_{f@6kPa} = 1.0064 \times 10^{-3}\ m^3/kg$$

State 6: $h_6 = h_5 + v_5 (P_6 – P_5)$

$$= 151.53\ kJ/kg + (1.0064 \times 10^{-3}\ m^3/kg)\ (1000 – 6)\ kN/m^2$$

$$= 152.53\ kJ/kg$$

State 7: With 1 MPa, Table A-3 gives

$$h_7 = h_{f@10bar} = 762.81\ kJ/kg$$

$$v_7 = v_{f@10bar} = 1.1273 \times 10^{-3}\ m^3/kg$$

State 8: $h_8 = h_7 + v_7 (P_8 – P_7) = 762.81\ kJ/kg + (1.1273 \times 10^{-3}\ m^3/kg)\ (10000 – 1000)\ kN/m^2$

$= 772.96$ kJ/kg

(b) Energy rate balance for open feedwater heater gives

$yh_2 + (1-y)h_6 = h_7$

$$y = \frac{h_7 - h_6}{h_2 - h_6} = \frac{762.81 - 151.53}{2827.9 - 152.53} = 0.2281$$

(c) On the basis of a unit of mass passing through the high pressure turbine, the total turbine work output is

$$\frac{\dot{W}_t}{\dot{m}_1} = (h_1 - h_2) + (1-y)(h_3 - h_4)$$

$$= (3425.1 - 2827.9) + (1 - 0.2281)(3522.1 - 2593.5)$$

$$= 1314.0 \text{ kJ/kg}$$

The total pump work per unit mass passing through the high pressure turbine is

$$\frac{\dot{W}_p}{\dot{m}_1} = (h_8 - h_7) + (1 - y)(h_6 - h_5)$$

$$= (772.96 - 762.81) + (1 - 0.2281)(152.53 - 151.53)$$

$$= 10.92 \text{ kJ/kg}$$

The heat added in the steam generator per unit of mass passing through the high pressure turbine is

$$\frac{\dot{Q}_{in}}{\dot{m}_1} = (h_1 - h_8) + (1 - y)(h_3 - h_2)$$

$$= (3425.1 - 772.96) + (1 - 0.2281)(3522 - 2827.9)$$

$$= 3187.9 \text{ kJ/kg}$$

The thermal efficiency is then

$$\eta = \frac{\frac{W_t}{\dot{m}_1} - \frac{W_p}{\dot{m}_1}}{\frac{Q_{in}}{\dot{m}_1}} = \frac{1314 - 10.92}{3187} = 0.409 \text{ or } \% \, 40.9$$

(d) The mass flow rate of the steam entering the high pressure turbine, $\dot{m}_1$, can determined using the given value for the net output, 100 MW. Since $\dot{W}_{cycle} = \dot{W}_t - \dot{W}_p$

and

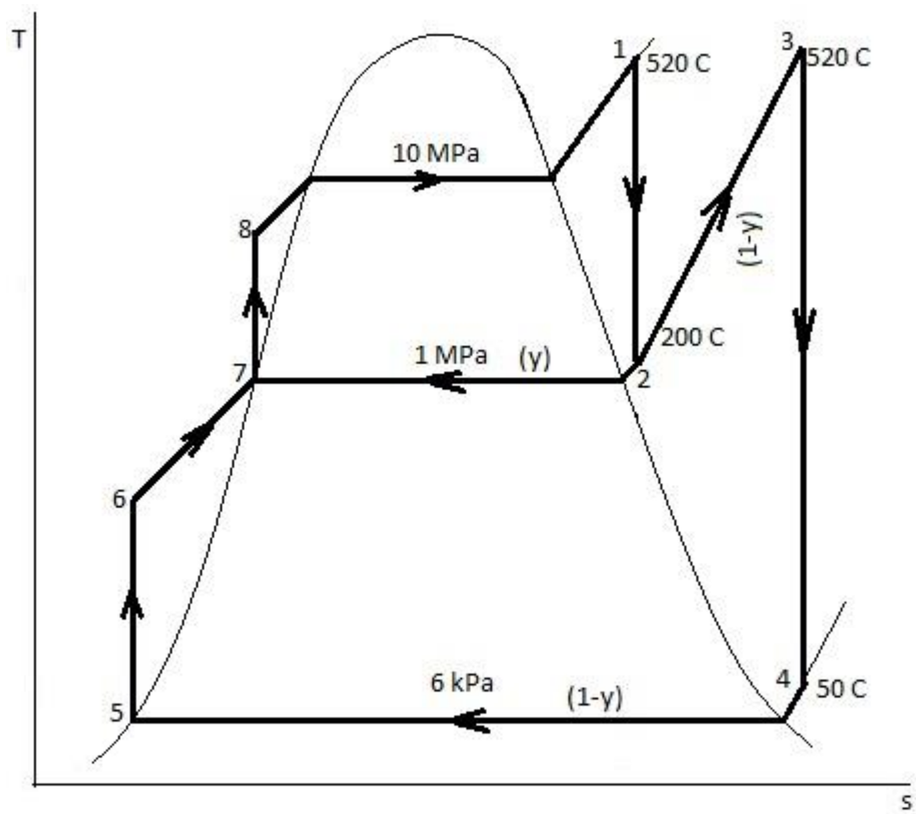
$\frac{\dot{W}_t}{\dot{m}_1} = 1314.0$ kJ/kg and $\frac{\dot{W}_p}{\dot{m}_1} = 10.32$ kJ/kg

it follows that

$$\dot{m}_1 = \frac{\dot{W}_{cycle}}{\frac{\dot{W}_{cycle}}{\dot{m}_1}} = \frac{(100 \text{ MW})}{(1314 - 10.92)\frac{\text{kJ}}{\text{kg}}} \left(\frac{1000 \frac{\text{kJ}}{\text{s}}}{1 \text{ MW}}\right) = 76.74 \text{ kg/s}$$

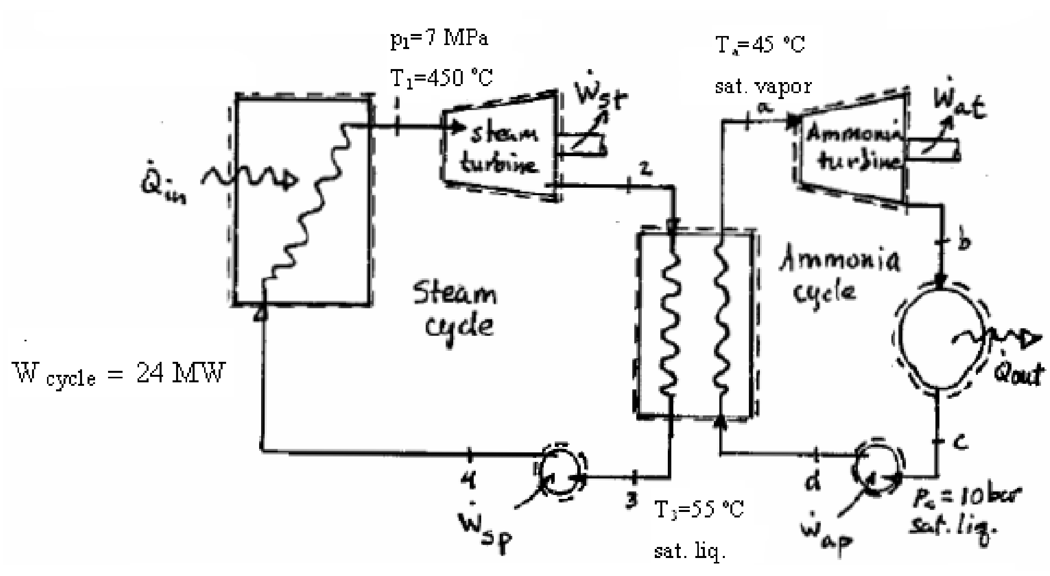
$= 2.76 \times 10^5$ kg/h

(e)



Example 5:

Consider a water-ammonia binary vapor cycle consisting. In the steam cycle, superheated vapor enters the turbine at 7 MPa, 450 ^oC, and saturated liquid exits the condenser at 55 ^oC. The heat rejected from the steam cycle is provided to the ammonia cycle, producing saturated vapor at 45 ^oC, which enters the ammonia turbine. Saturated liquid leaves the ammonia condenser at 1 MPa. For a net power output of 24 MW from the binary cycle, determine (a) the mass flow rates for the steam and ammonia cycles, respectively, in kg/s, (b) the power output of the steam and ammonia turbines, respectively, in MW. (c) the rate of heat input to the ammonia cycle, in MW, (d) the rate of heat addition to the binary cycle, in MW, and (e) the thermal efficiency of the binary vapor cycle. (f) Show the cycle on T-s diagram with respect to saturation lines.



Solution:

Assumptions: (1) Each component is analyzed as a control volume at steady state

(2) All process of the working fluids is internally reversible, except in the interconnecting heat exchanges.

(3) There are no stray heat transfers from the turbines or the heat exchanger.

(4) Kinetic and potential energy effects can be neglected.

Analysis: First, fix each of principle states. For steam, use tables A-2 and A-4.

State 1:

$P_1 = 70$ bar, $T_1 = 450\ ^0C$ $\rightarrow$ $h_1 = 3286.57$ kJ/kg

$s_1 = 6.6359$ kJ/kg.K

State 2:

$T_2 = T_3 = 55\ ^0C$, $s_2 = s_1 = 6.6359$ kJ/kg

$s_{g@55C} = 7.9913$ kJ/kg.K

$s_{f@55C} = 0.7679$ kJ/kg.K

$$X_2 = \frac{s_2 - s_{f@55C}}{s_{fg@55C}} = \frac{6.6359 - 0.7679}{7.9913 - 0.7679} = 0.8124$$

$h_{f@55C} = 230.23$ kJ/kg

$h_{fg@55C} = 2370.7$ kJ/kg

$h_2 = h_{f@55C} + X_2.h_{fg@55C}$

$h_2 = 2309.23 + 0.8124\ (2370.7) = 2156.19$ kJ/kg

State 3:

$T_3 = 55\ ^0C$, saturated liquid.

$h_3 = 230.23$ kJ/kg

$v_3 = 1.0146 \times 10^{-3}\ m^3/kg$

$P_3 = 0.1576$ bar = 15.76 kPa

State 4:

$$\frac{\dot{W}_p}{\dot{m}_s} = h_4 - h_3 = v_3\ (P_4 - P_3)$$

$h_4 = h_3 + v_3\ (P_4 - P_3)$

$= 230.23 + (1.0146 \times 10^{-3}\ m^3/kg)\ (7000 - 15.76)\ kN/m^2$

$= 237.32$ kJ/kg

Now, for Ammonia, use Tables A-13 and A-14

State a:

T_a = 45 ^{0}C, saturated vapor

h_a = 1470.96 kJ/kg

s_a = 4.8125 kJ/kg.K

P_a = 17.819 bar = 1781.9 kPa

State b:

$P_b = P_c$ = 10 bar

$s_b = s_a$ = 4.8125 kJ/kg.K

$s_{f@10bar}$ = 1.1191 kJ/kg.K

$s_{g@10bar}$ = 5.0294 kJ/kg.K

$X_b = \frac{s_b - s_{f@10bar}}{s_{fg@10bar}} = \frac{4.8125-1.1191}{5.0294-1.1191} = 0.9445$

$h_b = h_{f@10bar} + X_b.h_{fg@10bar}$

$h_{f@10bar}$ = 297.76 kJ/kg

$h_{fg@10bar}$ = 1165.42 kJ/kg

h_b = 297.76 + 0.9445 (1165.22) = 1398.50 kJ/kg

State c:

P_c = 10 bar, saturated liquid.

h_c = 297.76 kJ/kg

v_c = 1.6584 x 10^{-3} m^3/kg

State d:

$h_d = h_c + v_c (P_d – P_c)$

= 297.76 + (1.6584 x 10^{-3} m^3/kg) (1781.9 - 1000) kN/m^2

= 299.06 kJ/kg

(a) The mass flow rates of the steam and ammonia can be obtained using mass and energy rate balances for the inter-connecting heat exchanges.

$$0 = \dot{m}_s(h_2 - h_3) + \dot{m}_a(h_a - h_d)$$

or

$$\frac{\dot{m}_a}{\dot{m}_s} = \frac{h_2 - h_3}{h_a - h_d} = \frac{2156.19 - 230.23}{1470.96 - 299.06} = 1.6435$$

For the steam cycle

$$\dot{W}_{cycle,s} = \dot{W}_{st} - \dot{W}_{sp} = \dot{m}_s[(h_1 - h_2) - (h_4 - h_3)]$$

And, for the ammonia cycle

$$\dot{W}_{cycle,a} = \dot{W}_{at} - \dot{W}_{ap} = \dot{m}_a[(h_a - h_b) - (h_d - h_c)]$$

Noting that $\dot{W}_{cycle} = \dot{W}_{cycle,s} + \dot{W}_{cycle,a}$ and combining

$$\dot{W}_{cycle} = \dot{m}_s[(h_1 - h_2) - (h_4 - h_3)] + \frac{\dot{m}_a}{\dot{m}_s}[(h_a - h_b) - (h_d - h_c)]$$

Solving

$$\dot{m}_s = \frac{\dot{W}_{cycle}}{[(h_1 - h_2) - (h_4 - h_3)] + \frac{\dot{m}_a}{\dot{m}_s}[(h_a - h_b) - (h_d - h_c)]}$$

$$= \frac{24000 \text{ kW}}{[(3286.57 - 2156.19) - (237.32 - 230.23)] + (1.6435)[(1470.96 - 1398.50) - (299.06 - 297.76)]}$$

$$\dot{m}_s = 19.35 \text{ kg/s}$$

$$\dot{m}_a = 31.80 \text{ kg/s}$$

(b) The power output of the steam and ammonia turbines are

$$\dot{W}_{st} = \dot{m}_s(h_1 - h_2) = \left(19.35 \frac{\text{kg}}{\text{s}}\right)(3286.57 - 2156.19)\frac{\text{kJ}}{\text{kg}} = 21.87 \text{ MW}$$

$$\dot{W}_{at} = \dot{m}_a(h_a - h_b) = \left(31.80 \frac{\text{kg}}{\text{s}}\right)(1470.96 - 1398.50)\frac{\text{kJ}}{\text{kg}} = 2.30 \text{ MW}$$

(c) The rate of heat input to the ammonia cycle is

$$\dot{Q}_{a,in} = \dot{Q}_{s,out} = \dot{m}_s(h_2 - h_3) = \left(19.35\frac{kg}{s}\right)(2156.19 - 230.23)\frac{kj}{kg}$$

= 37.27 MW

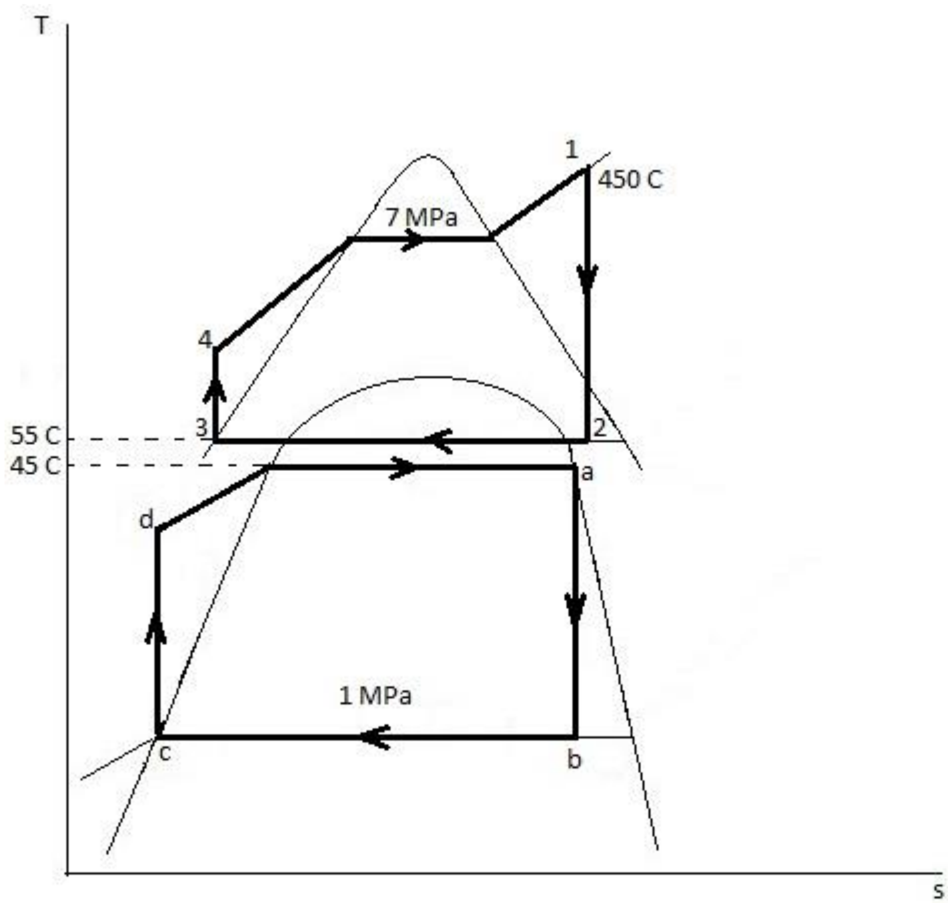
(d) The rate of heat addition to the binary cycle is

$$\dot{Q}_{in} = \dot{m}_s(h_1 - h_4) = \left(19.35\frac{kg}{s}\right)(3286.57 - 237.32)\frac{kj}{kg} = 59.00\ \text{MW}$$

(e) The thermal efficiency of the binary cycle is

$\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_{in}} = \frac{24}{59.00} = 0.407$ or % 40.7

(f)



6) Water is the working fluid in a Rankine cycle. Superheated vapor enters the turbine at 10 MPa, 480 ^{0}C, and the condenser pressure is 6 kPa. The turbine and pump have isentropic efficiencies of 80 and 70%, respectively. Determine the rate of exergy input, in kJ per kg of steam flowing, to the working fluid passing through the steam generator. Perform calculations to account for all outputs, losses, and destructions of this exergy. Let $T_0 = 15\,^0C$ and $p_0 = 0.1 MPa$ *T*0 5 158C, *p*0 5 0.1 MPa