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REE 406: Advanced Thermodynamics

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Project #2

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Contents

Introduction

It is required to build a steam power plant operates on an ideal reheat–regenerative Rankine cycle with one reheater and one open feedwater heaters. Select the maximum cycle pressure and the intermediate pressures for the reheat and open feed water heater that:
a) Maximize cycle efficiency.
b) Maximize the net work.

The fractions of steam extracted from the turbine and the thermal efficiency are to be determined.

Givens

- The maximum steam temperature for the high- and low-pressure turbine is 600^{O}C.
  Max T_5=T_7=600 ^{O}C
- The maximum pressure in the cycle is 290 bars= 29 MPa.
  Max P_5= 29 MPa
- The minimum condenser pressure is 10 kPa.
  Min P_1=P_9= 10 kPa
- The minimum steam quality allowed after the turbine is 0.9.
  Min x_6=0.9

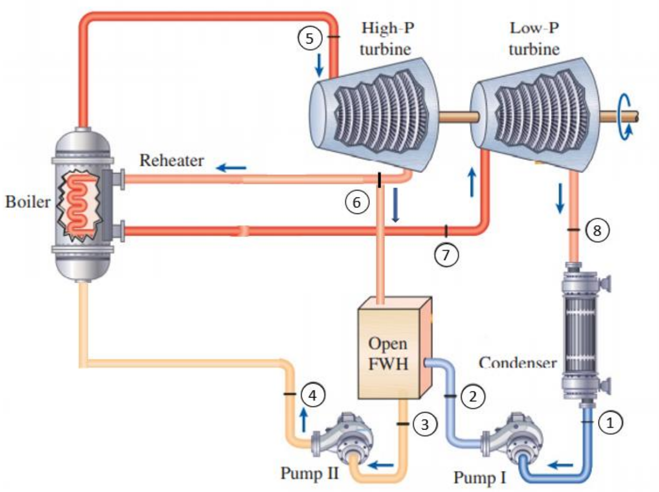
Assumptions

1. Steady operating conditions exist.
2. Kinetic and potential energy changes are negligible.
3. In the open feedwater heater, feedwater is heated to the saturation temperature at the feedwater heater pressure.

Analysis

Case 1: Extraction for Open Feed Water is at Point 6 (reheat entrance)

The schematic of the power plant and the T-s diagram of the cycle is shown below. The power plant operates on the ideal reheat–regenerative Rankine cycle and thus the pumps and the turbines are isentropic; there are no pressure drops in the boiler, reheater, condenser, and feedwater heaters; and steam leaves the condenser and the feedwater heaters as saturated liquid.



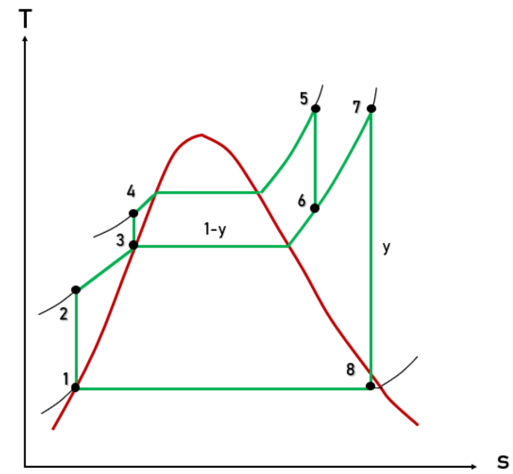


Figure 1 A schematic and the T-s diagram of the problem

The enthalpies at the various states and the pump work per unit mass of fluid flowing through them are:

$$w_{pump\ I,in} = y v_1 (p_2 - p_1) = y\,(h_2 - h_1) \quad (1)$$
$$w_{pump\ II,in} = v_3 (p_4 - p_3) = h_4 - h_3 \quad (2)$$
$$w_{turb,1} = h_5 - h_6 \quad (3)$$
$$w_{turb,2} = y(h_7 - h_8) \quad (4)$$
$$q_{in,1} = h_5 - h_4 \quad (5)$$
$$q_{in,2} = y(h_7 - h_6) \quad (6)$$
$$q_{out} = y(h_8 - h_1) \quad (7)$$

$$v_1 = v_{f@p_1}, h_1 = h_{f@p_1}, s_1 = s_{f@p_1} = s_2$$
$$p_2 = p_3 = \mathrm{p}_6 = \mathrm{p}_7$$
$$v_3 = v_{f@p_3}, h_3 = h_{f@p_3}, s_3 = s_{f@p_3} = \mathrm{s}_4$$
$$p_4 = \mathrm{p}_5$$
$$s_6 = s_5$$
$$T_7 = T_5$$
$$p_8 = p_1$$
$$s_8 = s_7$$

$$yh_2 + (1 - y)h_6 = h_3$$
$$yh_2 + h_6 - yh_6 = h_3$$
$$y = \frac{(h_3 - h_6)}{(h_2 - h_6\ )}$$

$$\Delta\ w = [w_{turb,2} + w_{turb,1}] - [w_{pump,2} + w_{pump,1}]$$
$$q_{in} = q_{in,1} + q_{in,2}$$
$$\eta = 1 - \frac{q_{out}}{q_{in}} = \frac{\Delta w}{q_{in}}$$

Code

Using all these laws and the open MATLAB library XSteam, we created the following code:

```
clc;
clear;
eff_max = 0;
T5=600; % maximum temperature
p4=290; % maximum pressure

        for p1=20:-0.1:0.1
            for p2=p1:0.1:p4
                v1=XSteam('vL_p',p1);
                h1=XSteam('hL_p', p1);
                s1=XSteam('sL_p',p1);
                T1=XSteam('Tsat_p',p1);
                s2=s1;
                h2=XSteam('h_ps',p2,s2);
                T2=XSteam('T_ps',p2,s2);
                p3=p2;
                v3=XSteam('vL_p',p3);
                s3=XSteam('sL_p',p3);
                h3=XSteam('hL_p',p3);
                T3=XSteam('Tsat_p',p3);
                s4=s3;
                h4=XSteam('h_ps',p4,s4);
                T4=XSteam('T_ps',p4,s4);
                p5=p4;
                h5=XSteam('h_pT',p5,T5);
                s5=XSteam('s_pT',p5,T5);
                p6=p2;
                s6=s5;
                h6=XSteam('h_ps',p6,s6);
```

```
                x6=XSteam('x_ps',p6,s6);
                T6=XSteam('T_ps',p6,s6);
                p7=p2;
                T7=T5;
                h7=XSteam('h_pT',p7,T7);
                s7=XSteam('s_pT',p7,T7);
                p8=p1;
                s8=s7;
                h8=XSteam('h_ps',p8,s8);
                x8=XSteam('x_ps',p8,s8);
                T8=T1;
                y= (h3-h6)/(h2-h6);

                if x8 >= 0.9
                    W_pump = (y*v1*(p2-p1)+ v3*(p4-p3))*100;
                    W_turb = (h5-h6)+ y*(h7-h8);
                    W_net = W_turb - W_pump;
                    q_in = (h5-h4) + y*(h7-h6);
                    eff = (W_net/q_in)*100 ;

                    if eff > eff_max
                        eff_max=eff;
                        T_max = T5; % already const
                        P_max = p4; % already const
                        P_min = p1;
                        P_mid = p2;
                        W_delta=W_net;
                        y_ofw = 1-y;
                        Q_in=q_in;
                        S1=s1;S2=s2;S3=s3;S4=s4;S5=s5;S6=s6;S7=s7;S8=s8;
                        t1=T1;t2=T2;t3=T3;t4=T4;t5=T5;t6=T6;t7=T7;t8=T8;
                        P1=p1;P2=p2;P3=p3;P4=p4;P5=p5;P6=p6;P7=p7;P8=p8;
                        H1=h1;H2=h2;H3=h3;H4=h4;H5=h5;H6=h6;H7=h7;H8=h8;
                    end
                end
            end
        end
disp('maximum efficiency %'); disp(eff_max);
disp('maximum temperature in celsius'); disp(T_max);
disp('maximun pressure in bar'); disp(P_max);
disp('minimum pressure in bar'); disp(P_min);
disp('intermediate pressure in bar'); disp(P_mid);
disp ('maximum network in Kj/Kg'); disp(W_delta);
disp('open feed water steam fraction'); disp(y_ofw);
S=[S1,S2,S3,S4,S5,S6,S7,S8];
t=[t1,t2,t3,t4,t5,t6,t7,t8];
H=[H1,H2,H3,H4,H5,H6,H7,H8];
```

```matlab
P=[P1,P2,P3,P4,P5,P6,P7,P8];
disp(' s values')
disp(S);
disp(' T values')
disp(t);
disp(' h values')
disp(H);
disp(' p values')
disp(P);
```

Results

```
maximum efficiency %
   49.5910

maximum temperature in celsius
   600

maximun pressure in bar
   290

minimum pressure in bar
     0.1000

intermediate pressure in bar
   37.7000

maximum network in Kj/Kg
   1.4309e+03

open feed water steam fraction
     0.3246
```

Figure 2 Screenshot from MATLAB

Table 1 Point Results from MATLAB

Point	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
*Entropy (s) [kJ/kg*K]*	0.6492	0.6492	2.7648	2.7648	6.2616	6.2616	7.3994	7.3994
Temperature (T) [^{o}C]	45.8075	45.9283	246.8701	252.9312	600	272.9586	600	45.8075
Enthalpy (h) [MJ/kg]	0.1918	0.1956	1.0705	1.1016	3.4563	2.8910	3.6767	2.3448
Pressure (p) [bar]	0.1	37.7	37.7	290	290	37.7	37.7	0.1

Plot

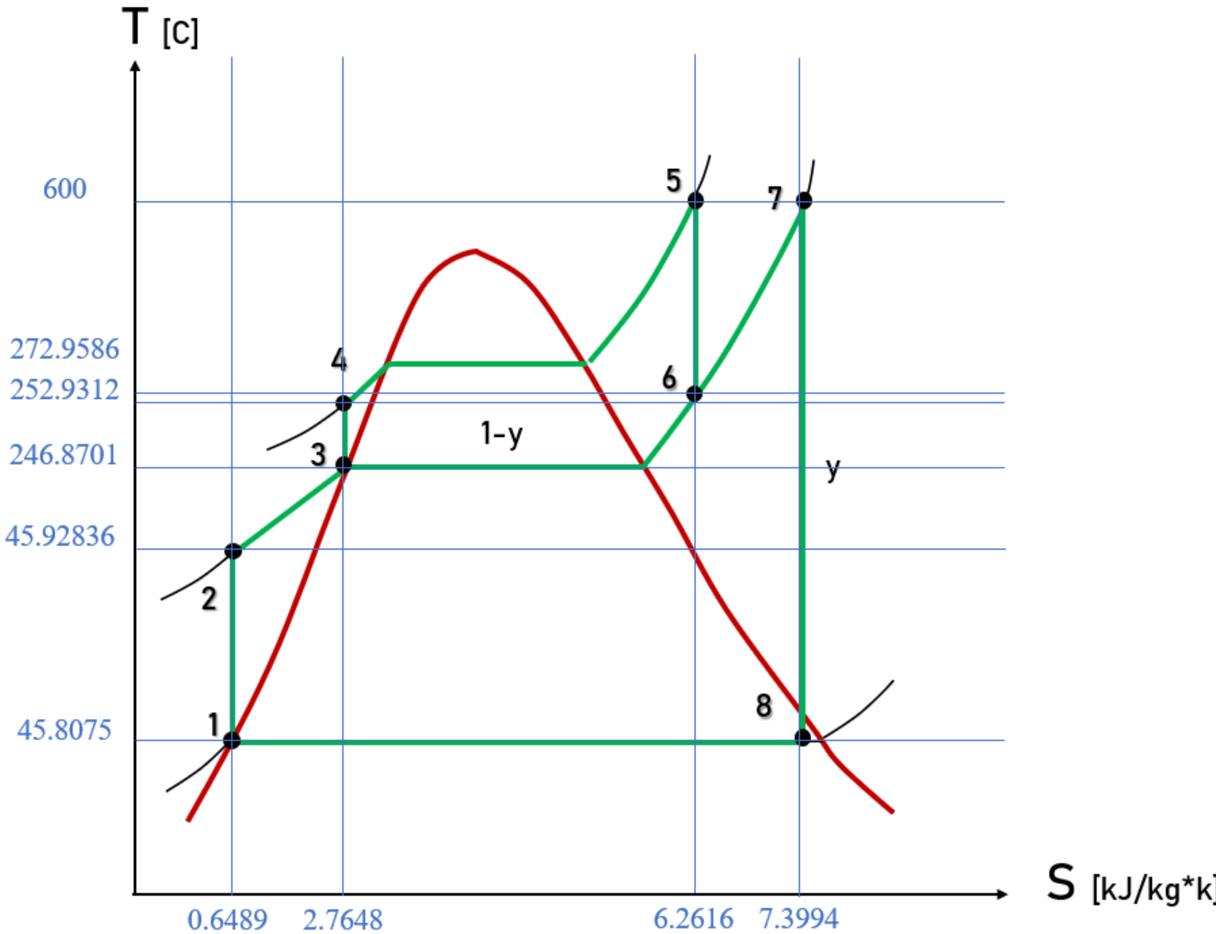


Figure 3 Plot with axes not to scale

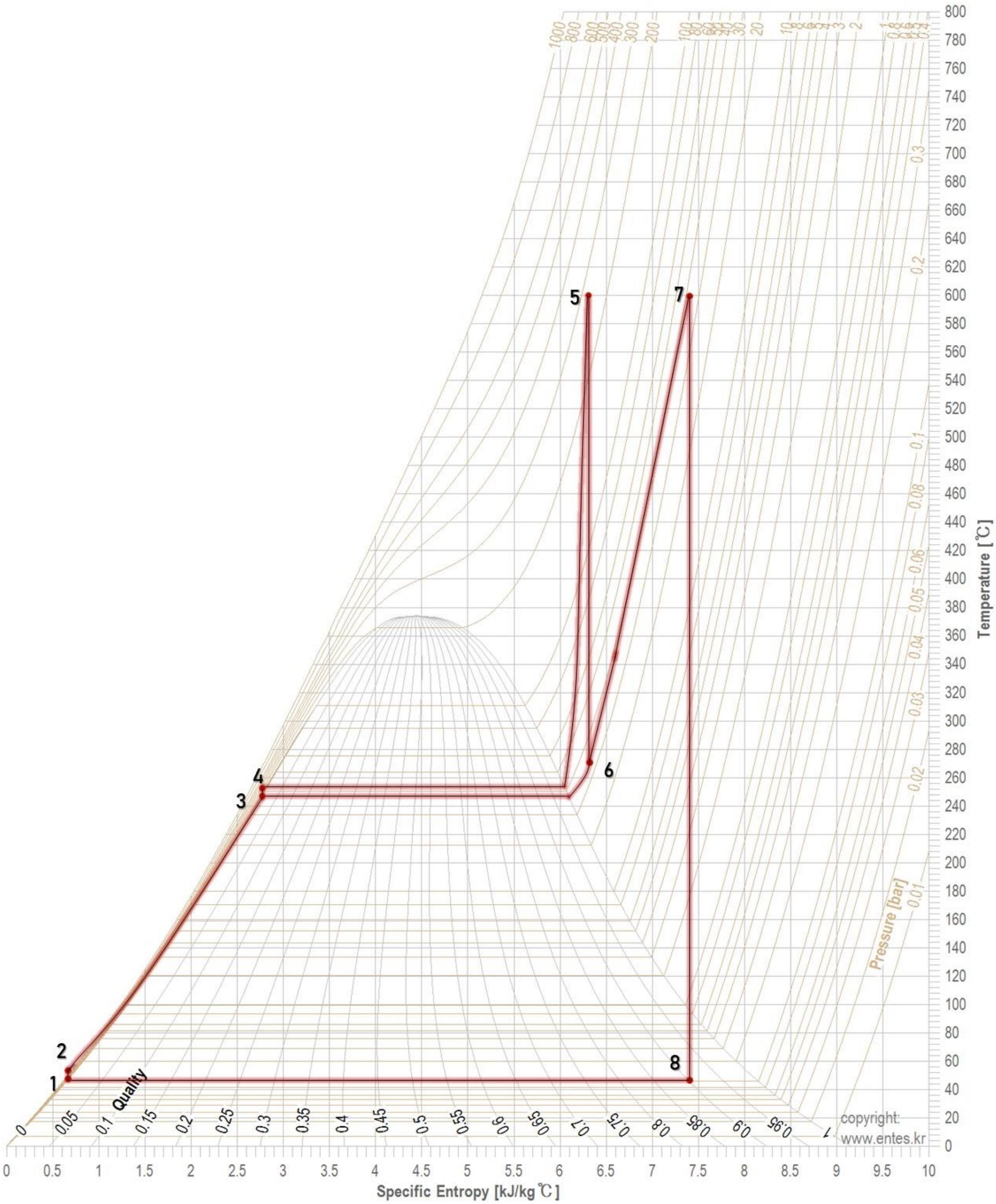


Figure 4 Real Plot with axes to scale. Same for case 2 as well.

Case 2: Extraction for Open Feed Water is at Point 7 (reheat exit)

The work is the same as the previous case expect for text in dark blue.

$$
\begin{aligned}
w_{pump\ I,in} &= yv_1(p_2 - p_1) = y\,(h_2 - h_1) && (1)\\
w_{pump\ II,in} &= v_3(p_4 - p_3) = h_4 - h_3 && (2)\\
w_{turb,1} &= h_5 - h_6 && (3)\\
w_{turb,2} &= y(h_7 - h_8) && (4)\\
q_{in,1} &= h_5 - h_4 && (5)\\
q_{in,2} &= (h_7 - h_6) && (6)\\
q_{out} &= y(h_8 - h_1) && (7)
\end{aligned}
$$

$$
\begin{aligned}
&v_1 = v_{f@p_1}, h_1 = h_{f@p_1}, s_1 = s_{f@p_1} = s_2\\
&p_2 = p_3 = \mathrm{p}_6 = \mathrm{p}_7\\
&v_3 = v_{f@p_3}, h_3 = h_{f@p_3}, s_3 = s_{f@p_3} = \mathrm{s}_4\\
&p_4 = \mathrm{p}_5\\
&s_6 = s_5\\
&T_7 = T_5\\
&p_8 = p_1\\
&s_8 = s_7
\end{aligned}
$$

$$
\begin{aligned}
&yh_2 + (1-y)h_7 = h_3\\
&yh_2 + h_7 - yh_7 = h_3\\
&y = \frac{(h_3 - h_7)}{(h_2 - h_7)}
\end{aligned}
$$

$$
\begin{aligned}
&\Delta\, w = [w_{turb,2} + w_{turb,1}] - [w_{pump,2} + w_{pump,1}]\\
&q_{in} = q_{in,1} + q_{in,2}\\
&\eta = 1 - \frac{q_{out}}{q_{in}} = \frac{\Delta w}{q_{in}}
\end{aligned}
$$

Code

The code is the same except for lines 41 & 47. They are replaced by:

```
41 -                y= (h3-h7)/(h2-h7);

47 -                   q_in = (h5-h4) + (h7-h6);
```

Results

```
maximum efficiency %
   48.6620

maximum temperature in celsius
   600

maximun pressure in bar
   290

minimum pressure in bar
    0.1000

intermediate pressure in bar
   37.7000

maximum network in Kj/Kg
   1.5282e+03

open feed water steam fraction
    0.2513
```

Figure 5 Screenshot from MATLAB

Discussion

Work 1

s values

0.6492 0.6492 1.4335 1.4335 6.2616 6.2616 8.9123 8.9123

T values

45.8075 45.8080 111.3500 113.5366 600.0000 111.3500 600.0000 45.8075

h values

1.0e+03 *

0.1918 0.1919 0.4671 0.4973 3.4563 2.3235 3.7052 2.8831 p values

0.1000	1.5000	1.5000	290.0000	290.0000	1.5000	1.5000	0.1000