Project 2 Part A: Cycle Design

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Optimal Reheat Pressure Calculation

The optimal reheat pressure was found to be 4750 kPa. This is .2375 * P_{Max}. See figure 1 and table 1 for the data and corresponding graph showing the peak efficiency. See appendix A for the MATLAB code.

Table I: The data showing the reheat pressure values and their corresponding efficiences.

P_{Reheat} (kPa)	Effiency (%)
2500	.4921
3000	.4929
3500	.4933
4000	.4935
4500	.4936
4750	.4936
5000	.4936
5500	.4934
6000	.4932
6500	.4929
7000	.4926
7500	.4922

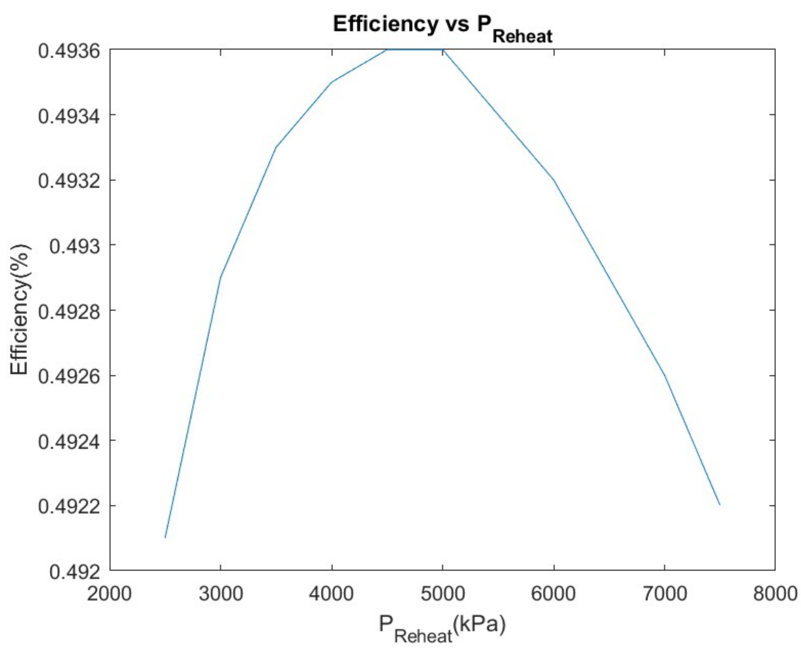

Figure 1: Graph of efficiencies for various reheat pressures between 2000 and 8000 kPa.

Schematic of the improved cycle with reheat and regenerations

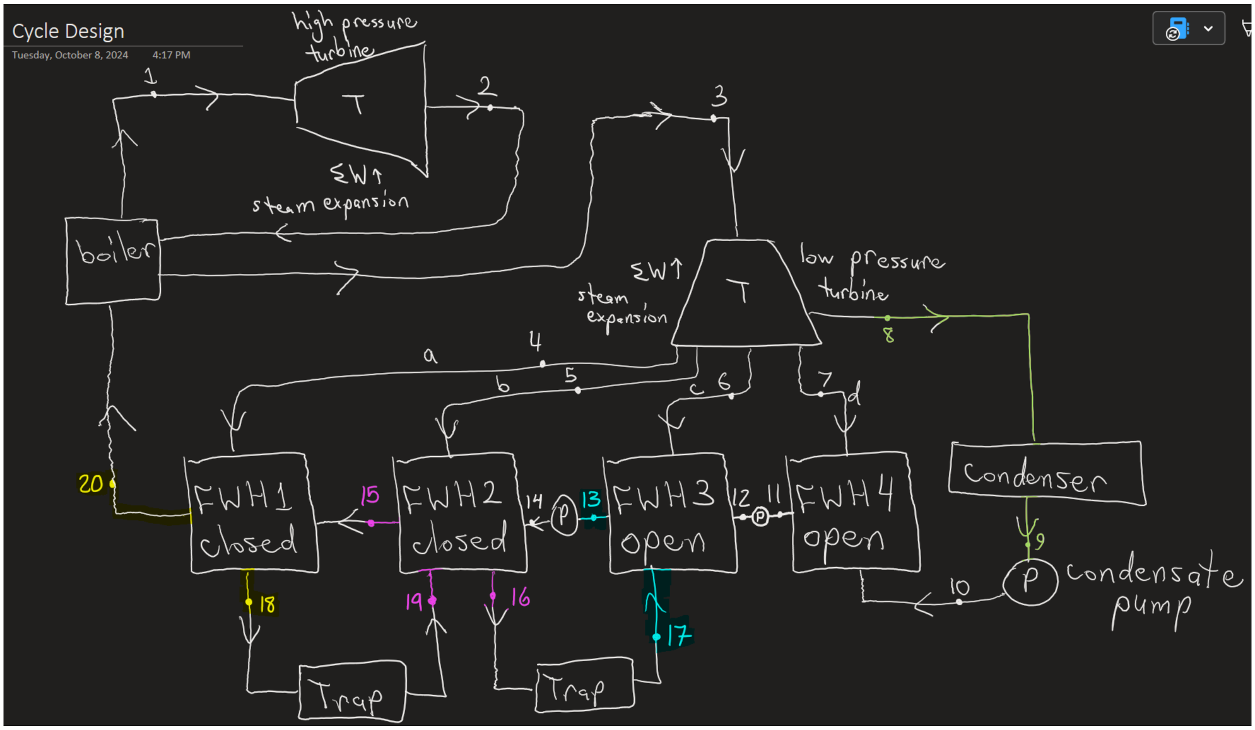

Figure 2: The cycle design schematic including the reheat and regeneration processes.

T-S diagram of the enhanced cycle

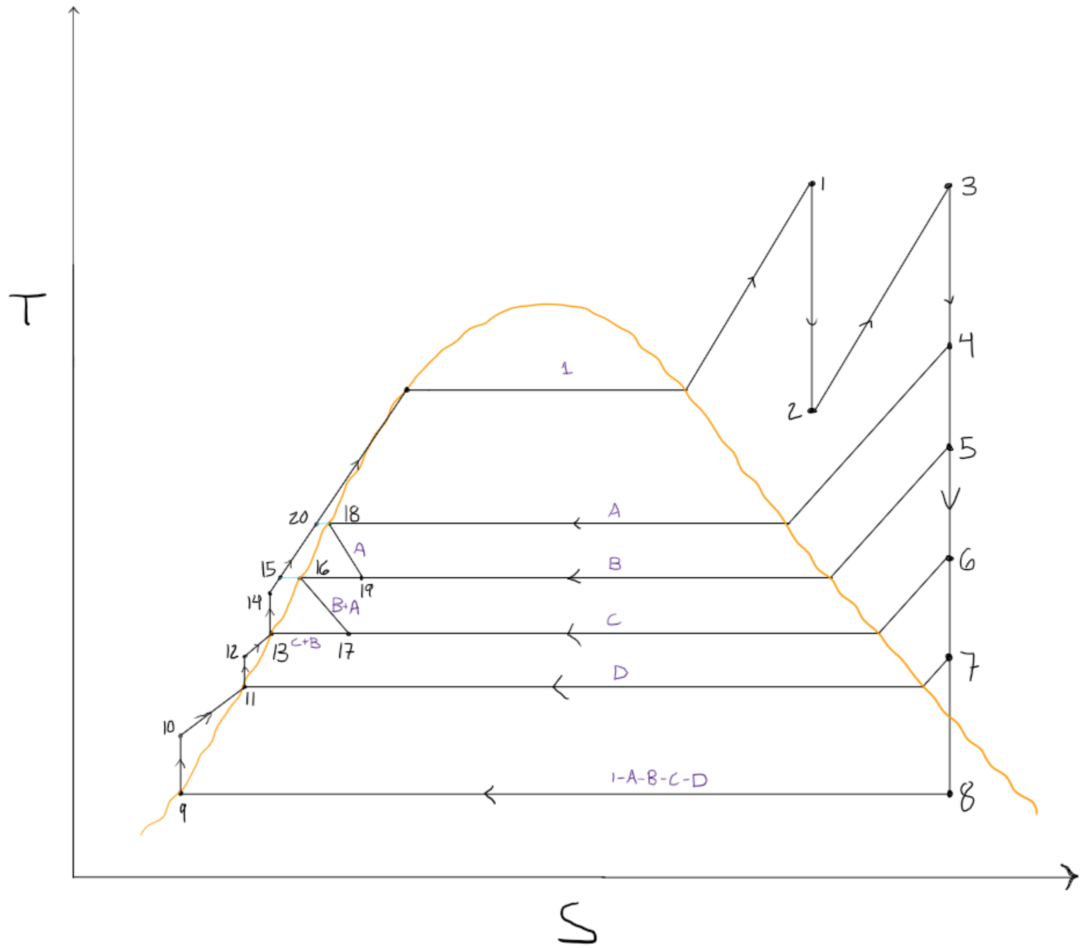

Figure 3: T-s Graph of Designed Cycle.

The calculation of enthalpies (actual values) and mass flow rates for steam extraction

See the values in Table 2. The steam fractions are included in the right column next to their corresponding states. Further, both the theoretical and actual enthalpy values are included, where states 2, 4, 5, 6, 7, 8, 10, 12, and 14 have different values. See appendix B for the MATLAB code.

Table II: Enthalpy values at each state.

State	Theoretical Enthalpy	Actual Enthalpy	Steam Fraction
1	3.37E+06	3.37E+06	
2	3.01E+06	3.05E+06	
3	3.52E+06	3.52E+06	
4	3.94E+06	3.90E+06	a = 2.48E-03
5	3.81E+06	3.78E+06	b = 6.01E-02
6	3.65E+06	3.64E+06	c = 7.82E-02
7	3.40E+06	3.41E+06	d = 2.69E-01
8	1.97E+06	2.12E+06	
9	2.93E+04	2.93E+04	
10	3.33E+04	3.37E+04	
11	1.09E+06	1.09E+06	
12	1.09E+06	3.49E+04	
13	1.32E+06	1.32E+06	
14	1.33E+06	1.34E+06	
15	1.47E+06	1.47E+06	
16	1.49E+06	1.49E+06	
17	1.49E+06	1.49E+06	
18	1.49E+06	1.49E+06	
19	1.49E+06	1.49E+06	
20	1.48E+06	1.48E+06	

Total heat, work, and steam mass flow rate calculation

See appendix C for the MATLAB code including the calculations.

Variable	Value
W_{in}	1.88e+04 J/kg
W_{out}	5.65e+05 J/kg
Q_{in}	2.39e+06 J/kg
Q_{out}	1.14e+06 J/kg
Efficiency	0.2281
Mass Flow Rate for 80 MW of Power	1.42e+02 kg/sec

Mass Flow Rate = (80 MW * 1000000 W/MW) / (W_out)

Exergy analysis and second law efficiency

See appendix D for the MATLAB code with calculations.

Component	Exergy Destroyed (W)
Boiler	1.48e+08
High Pressure Turbine	2.40e+06
Low Pressure Turbine	3.03e+08
Condenser	1.68e+08
Pump 1	3.88e+04
Pump 2	3.25e+07
Pump 3	1.32e+05

Second Law Efficiency = 0.357

Appendix A

Code for *Optimal Reheat Pressure Calculation*:

```
clc; clear; close all
p_min = 1; % kPa
p_max = 20000; % kPa
T = 813.15; % K

[h1,s1] = refpropm('HS','P',p_min,'Q',0,'water');
h2 = refpropm('H','P',p_max,'S',s1,'water');
[h3,s3] = refpropm('HS','T',813.15,'P',p_max,'water');
h4 = refpropm('H','P',4750,'S',s3,'water');
[h5,s5] = refpropm('HS','T',813.15,'P',4750,'water');
h6 = refpropm('H','P',p_min,'S',s5,'water');

n_reheat = ((h3-h4)+(h5-h6)-(h2-h1))/((h3-h2)+(h5-h4))

efficiencies = [.4921,.4929,.4933,.4935,.4936,.4936,.4936,.4934,.4932,.4929,.4926,.4922];
p_reheat = [2500,3000,3500,4000,4500,4750,5000,5500,6000,6500,7000,7500];
plot(p_reheat,efficiencies);
xlabel("P_{Reheat}(kPa)")
ylabel("Efficiency(%)")
title("Efficiency vs P_{Reheat}")
```

Appendix B

Code for *The calculation of enthalpies (actual values) and mass flow rates for steam extraction*:

```
clc; clear; close all
p_min = 1; % kPa
p_max = 20000; % kPa
t_max = 813.15; % K



% 4. finding enthalpies for all points of ideal cycle
[h1,s1] = refpropm('HS','T',t_max,'P',p_max,'water');
s2 = s1;
[h2,t2] = refpropm('HT','P',5700,'S',s2,'water');
[h3,s3] = refpropm('HS','T',t_max,'P',5700,'water');
[h4,t4] = refpropm('HT','P',16000,'S',s3,'water');
[h5,t5] = refpropm('HT','P',12000,'S',s3,'water');
[h6,t6] = refpropm('HT','P',8000,'S',s3,'water');
[h7,t7] = refpropm('HT','P',4000,'S',s3,'water');
[h8,t8] = refpropm('HT','P',p_min,'S',s3,'water');
[h9,s9] = refpropm('HS','P',p_min,'Q',0,'water');
[h10,t10] = refpropm('HT','P',4000,'S',s9,'water');
[h11,s11] = refpropm('HS','P',4000,'Q',0,'water');
[h12,t12] = refpropm('HT','P',8000,'S',s11,'water');
[h13,s13] = refpropm('HS','P',8000,'Q',0,'water');
[h14,t14] = refpropm('HT','P',p_max,'S',s13,'water');
[h16,t16] = refpropm('HT','P',12000,'Q',0,'water');
[h19,s19] = refpropm('HS','T',t16,'P',12000,'water');
[h15,s15] = refpropm('HS','T',t16,'P',p_max, 'water');
h17 = h16;
```

```
h18 = h19;
[t17,s17] = refpropm('TS','H',h17,'P',8000,'water');
[t18,s18] = refpropm('TS','H',h18,'P',16000,'water');
[h20,s20] = refpropm('HS','T',t18,'P',p_max,'water');


% 5. finding actual enthalpies for turbine and pump outlets
n_pump = .9;
n_turbine = .9;

h10_actual = h9 + (h10-h9)/n_pump;
h12_actual = h9 + (h12-h11)/n_pump;
h14_actual = h13 + (h14-h13)/n_pump;
h2_actual = h1 - n_turbine*(h1-h2);
h4_actual = h3 - n_turbine*(h3-h4);
h5_actual = h3 - n_turbine*(h3-h5);
h6_actual = h3 - n_turbine*(h3-h6);
h7_actual = h3 - n_turbine*(h3-h7);
h8_actual = h3 - n_turbine*(h3-h8);

s10_actual = refpropm('S','H',h10_actual,'P',4000,'water');
s12_actual = refpropm('S','H',h12_actual,'P',8000,'water');
s14_actual = refpropm('S','H',h14_actual,'P',p_max,'water');
s2_actual = refpropm('S','H',h2_actual,'P',5700,'water');
s4_actual = refpropm('S','H',h4_actual,'P',16000,'water');
s5_actual = refpropm('S','H',h5_actual,'P',12000,'water');
s6_actual = refpropm('S','H',h6_actual,'P',8000,'water');
s7_actual = refpropm('S','H',h7_actual,'P',4000,'water');
s8_actual = refpropm('S','H',h8_actual,'P',p_min,'water');
```

```
% 6. 1st law for FWHs and steam fractions in each extraction line
syms a b c d
fwh1 = a*h4 + h15 == a*h18 + (1-a)*h20;
fwh2 = b*h5 + h14 + a*h19 == (a+b)*h16 + h15;
fwh3 = c*h6 + (1-a-b-c)*h12 + (a+b)*h17 == h13;
fwh4 = (1-a-b-c-d)*h10 + d*h7 == (1-a-b-c)*h11;
[a,b,c,d] = vpasolve([fwh1,fwh2,fwh3,fwh4],[a,b,c,d])
```

Appendix C

Code for *Total heat, work, and steam mass flow rate calculation*:

```
% 7. Calculate total work in/out and heat in/out of cycle and determine efficiency
W_in = (h14-h13) + (1-a-b-c-d)*(h10-h9);
W_out = (h2-h1)+(h3-h4)+(1-a)*(h4-h5)+(1-a-b)*(h5-h6)+(1-a-b-c)*(h6-h7)+(1-a-b-c-d)*(h7-h8);
Q_in = (h1-h20)+(h3-h2);
Q_out = (h8-h9)*(1-a-b-c-d);
n = (W_out-W_in)/Q_in


% 8. Find mass flow rate given power
m_dot = (80*1000000) / (W_out) % kg/sec
```

Appendix D

Code for *Exergy analysis and second law efficiency:*

```
% 9. Calculate exergy destroyed in main components of cycle
t_amb = 293;
p_amb = 101;
[h_amb,s_amb] = refpropm('HS','T',t_amb,'P',p_amb,'water');

% Boiler / Reheater
E_boiler_in20 = m_dot * ((h20-h_amb)- t_amb*(s20-s_amb));
E_boiler_in2 = m_dot * ((h2-h_amb) - t_amb*(s2-s_amb));
E_boiler_out1 = m_dot * ((h1-h_amb) - t_amb*(s1-s_amb));
E_boiler_out3 = m_dot * ((h3-h_amb) - t_amb*(s3-s_amb));

E_boiler_destroyed = Q_in*m_dot+(E_boiler_in20+E_boiler_in2)-
(E_boiler_out1+E_boiler_out3);

% High Pressure Turbine
E_turbine1_in = m_dot * ((h1-h_amb)- t_amb*(s1-s_amb));
E_turbine1_out = m_dot * ((h2_actual-h_amb) - t_amb*(s2_actual-s_amb));

E_turbine1_destroyed = E_turbine1_in-E_turbine1_out-m_dot*(h1-h2_actual);

% Low Pressure Turbine
E_turbine2_in = m_dot * ((h3-h_amb)- t_amb*(s3-s_amb));
E_turbine2_out4 = m_dot * a * ((h4_actual-h_amb) - t_amb*(s4_actual-s_amb));
E_turbine2_out5 = m_dot * b * ((h5_actual-h_amb) - t_amb*(s5_actual-s_amb));
E_turbine2_out6 = m_dot * c * ((h6_actual-h_amb) - t_amb*(s6_actual-s_amb));
E_turbine2_out7 = m_dot * d * ((h7_actual-h_amb) - t_amb*(s7_actual-s_amb));
E_turbine2_out8 = m_dot * (1-a-b-c-d) * ((h8_actual-h_amb) - t_amb*(s8_actual-s_amb));
```

E_turbine2_destroyed = E_turbine2_in-(E_turbine2_out4+E_turbine2_out5+E_turbine2_out6+E_turbine2_out7+E_turbine2_out8)-m_dot*(h3-h4_actual-b*(h4_actual-h5_actual)-c*(h5_actual-h6_actual)-d*(h6_actual-h7_actual)-(1-a-b-c-d)*(h7_actual-h8_actual));

% Condensor

E_condensor_in = m_dot * (1-a-b-c-d) * ((h8-h_amb)- t_amb*(s3-s_amb));

E_condensor_out = m_dot * (1-a-b-c-d) * ((h9-h_amb) - t_amb*(s9-s_amb));

E_condensor_destroyed = E_condensor_in-E_condensor_out + m_dot*(1-a-b-c-d)*(h8_actual-h9);

% Pump 1

E_pump1_in = m_dot * (1-a-b-c-d) * ((h9-h_amb)- t_amb*(s9-s_amb));

E_pump1_out = m_dot * (1-a-b-c-d) * ((h10_actual-h_amb) - t_amb*(s10_actual-s_amb));

E_pump1_destroyed = E_pump1_in-E_pump1_out + m_dot*(1-a-b-c-d)*(h10_actual-h9);

% Pump 2

E_pump2_in = m_dot * (1-a-b-c) * ((h11-h_amb)- t_amb*(s11-s_amb));

E_pump2_out = m_dot * (1-a-b-c) * ((h12_actual-h_amb) - t_amb*(s12_actual-s_amb));

E_pump2_destroyed = E_pump2_in-E_pump2_out + m_dot*(1-a-b-c)*(h12-h11);

% Pump 3

E_pump3_in = m_dot * ((h13-h_amb)- t_amb*(s13-s_amb));

E_pump3_out = m_dot * ((h14_actual-h_amb) - t_amb*(s14_actual-s_amb));

E_pump3_destroyed = E_pump3_in-E_pump3_out + m_dot*(h14_actual-h13);

```
% 10. Calculate second law efficiency

n_secondLaw = (W_out-W_in)/(Q_in*(1-t_amb/t_max))
```