Rankine Cycle Optimization

Abstract:

This Project focuses on enhancing the performance of a power plant operating on a Rankine cycle. The existing cycle exhibits a thermal efficiency of 41% and a steam quality of 76% at the condenser inlet. Our objective is to optimize the given ideal Rankine cycle efficiency to above 46% and raise the steam quality to above 85% by maintaining condenser pressure at 10 kPa, the boiler pressure at 15 MPa, and ensuring the turbine temperature stays below 500 °C. By modifying the given ideal Rankine cycle we have got the enhanced performance level.

Aim:

In this project, our objective is to improve the performance of a power plant operating on the fundamental Rankine cycle. Additionally, we aim to enhance efficiency and network output by varying the boiler pressure (Pb) and condenser pressure (Pc) within the specified ranges of 12 MPa < Pb < 15 MPa and 5 kPa < Pc < 10 kPa. The goal is to create a plot visually representing the impact of changes in these pressures on the thermal efficiency and net work output of the modified ideal Rankine cycle.

Introduction:

The Rankine cycle is a practical and ideal alternative to the Carnot cycle in steam power plants, overcoming challenges in handling water and steam mixtures. So in response to these challenges, the Rankine cycle appears as a sensible and perfect alternative. The Rankine cycle solves the problems that the Carnot cycle cannot by ensuring full condensation of water vapor in the condenser and then isentropically pumping the water to the boiler pressure. The efficiency of the Rankine cycle, which is based on the principles of mass and energy conservation, is affected by variables like temperature and pressure at different stages of the cycle. Although the ideal Rankine cycle offers a theoretical framework, improvements and alterations are frequently brought about by practical factors including irreversibilities and the nature of real-world components.

So as a result the Rankine cycle has become a fundamental model for evaluating the efficiency or the performance of the steam power plants. Now to overcome the task of increasing the efficiency of the ideal Rankine cycle we can do it in 3 ways:

1. Lowering the Condenser Pressure:

- The Rankine cycle includes a condenser where the steam exiting the turbine is condensed back into liquid form. Lowering the condenser pressure reduces the temperature at which the steam is condensed, increasing the efficiency of the cycle.

- As the condenser pressure decreases, the temperature difference between the steam and the cooling water in the condenser increases. This higher temperature difference allows for more heat transfer, improving the efficiency of the overall cycle.
- However, practical limitations exist, such as the need to avoid subcooling (condensing the steam below the saturation temperature) and the ability of the cooling water to absorb the heat.

2. Superheating the Steam to High Temperatures:
   - Superheating involves raising the temperature of the steam beyond its saturation point at a given pressure. This is usually done in the boiler before the steam enters the turbine.
   - Superheating the steam increases its enthalpy, which means that more energy is available for conversion into work in the turbine. This results in a higher cycle efficiency.
   - However, there are practical limitations to superheating. Excessive superheating can lead to material issues with the turbine blades and increases the complexity and cost of the system.

3. Increasing the Boiler Pressure:
   - Increasing the boiler pressure raises the saturation temperature of the steam. This higher temperature results in a larger temperature difference between the heat source (boiler) and the heat sink (condenser), which increases the efficiency of the cycle.
   - However, increasing the boiler pressure also requires a higher-strength material for the boiler and other components, which can lead to increased costs. There are also practical limits to how much pressure can be used due to safety concerns.

But our objective is to enhance the performance of a power plant by maintaining condenser pressure at 10 kPa, the boiler pressure at 15 MPa, and ensuring the turbine temperature stays below 500 °C. Also increasing the boiler pressure increases the thermal efficiency of the Rankine cycle, but it also increases the moisture content of the steam to unacceptable levels. To tackle this issue we came up with 4 possibilities by constructing/adding

1. One reheater
2. Two reheaters
3. One reheater combined with one regenerator
4. Two reheaters combined with one regenerator

Through a systematic evaluation process, we have identified that the configuration with two reheaters and one regenerator yields an efficiency exceeding 46% and a steam quality exceeding 85%. This report shows in detail calculations including T-S diagrams for these four configurations.

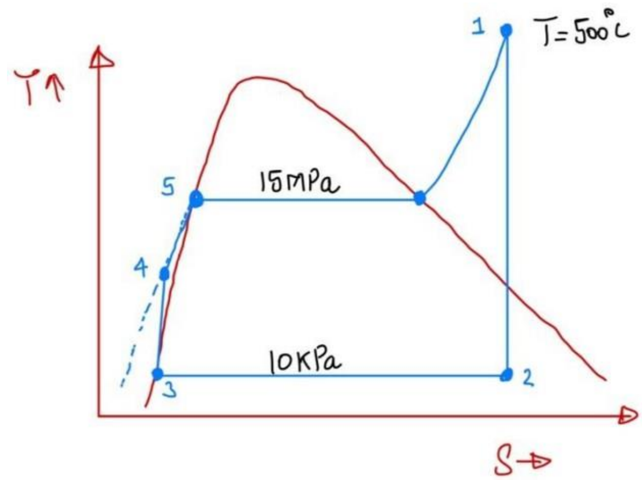
Reheater:

A reheater is a component in a steam power plant that reheats steam coming out of the turbine, allowing for additional expansion and energy extraction before the steam is condensed back into water and returned to the boiler. This process helps to maximize the efficiency of the power generation system.

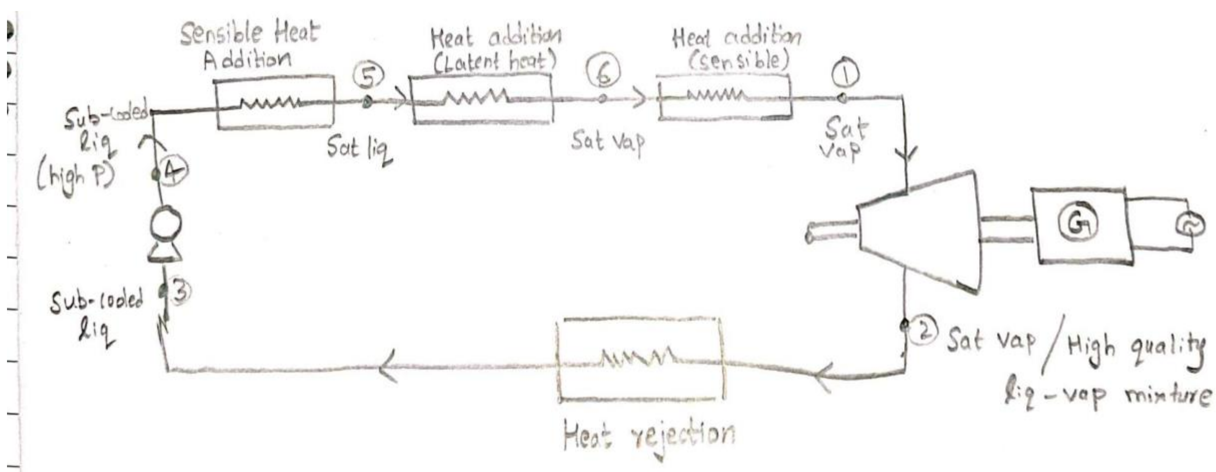
Regenerator:

A regenerator, in the context of heat transfer and thermodynamics, is a device or system that recovers heat from one part of a process and uses it to preheat a fluid or a substance entering the process. The primary purpose of a regenerator is to improve the overall efficiency of a system by reducing energy losses.

Given Rankine Cycle:
(T - S (Temperature-Entropy) Diagram):



Schematic diagram:



Assumptions:

1) Steady-state
2) No heat loss with the surroundings (Adiabatic)
3) No mechanical or thermal loss
4) Mass flow rate of the working fluid through the cycle is assumed to be constant

Given ideal conditions:

1) Boiler pressure = 15 MPa
2) Condenser pressure =10 kPa
3) Turbine temperature <= 500 °C

Stage	Process	State
3→4	Isentropic compression in pump	Saturated liquid to supercooled liquid
4→1	Constant pressure heat addition in boiler	Supercooled liquid to Saturated liquid to Superheated vapor
1→2	Isentropic expansion in a turbine	Superheated vapor to Saturated liquid-vapor mixture
2→3	Constant pressure heat rejection in a condenser	Saturated vapor to Saturated liquid

Here ideally we see: *[All these values are obtained from TABLES A5 and A6. Alternatively, this can be done using Cantera.]*

<u>At State 3:</u>

P3 = 10kPa (Sat. Liq)

h3 = $h_{f\ @\ 10kPa} = 191.81\ kJ/kg$

v3 = $v_{f\ @\ 10kPa} = 0.00101\ m^3/kg$

<u>At State 4:</u>

P4 = 15MPa

s4 = s3

$W_{Pump,in}$ = v3(P4 - P1) = ($0.00101\ m^3/kg$)[(15000 - 10) kPa]($\frac{1\ kJ}{1\ kPa \cdot m^3}$) = 15.1399 kJ/kg

h4 = h3 + $W_{Pump,in}$ = 191.81 + 15.1399 = 206.9499 kJ/kg

<u>At State 5:</u>

P5 = 15MPa (Sat. Liq)

h5 = $h_{f\ @\ 15MPa} = 1610.3\ kJ/kg$

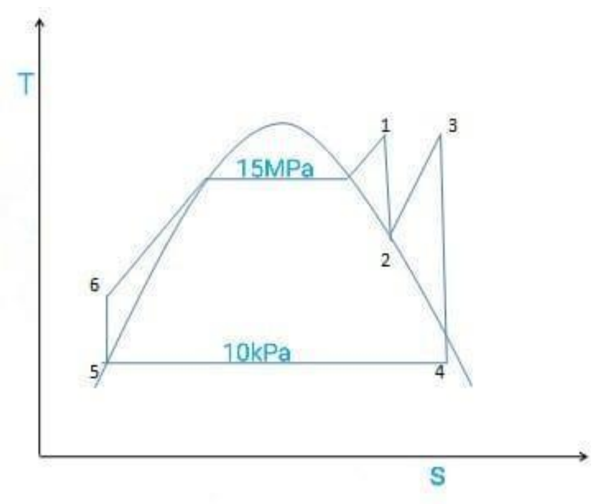
At State 1:
P1 = 15MPa
T1 = 500 °C
h1 = 3310.8 kJ/kg
s1 = 6.3480 kJ/kg·K

At State 2:
P2 = 10kPa
s2 = s1
x2 = (s2 - sf) / (sfg) = (6.3480 - 0.6492) / (7.4996) = 0.75417
Steam Quality = x2 x 100% = **75.417%**
h2 = hf + (x2 x hfg) = 191.81 + (0.75417) (2392.1) = 1995.8685563 kJ/kg
qout = h2 - h3
qin = h1 - h5
Efficiency = 1 - ($\frac{qout}{qin}$) = 1 - ($\frac{h2 - h3}{h1 - h5}$) = **41%**

Final method we used to increase efficiency and quality:

PT We have modified the ideal Rankine cycle by incorporating two reheaters and one regenerator, as highlighted in comparison (4). Additionally, for enhanced efficiency, we can also propose another modification to the ideal Rankine cycle by including one reheater and two regenerators. It is anticipated that the insertion of one reheater and two regenerators can lead to a substantial increase in overall efficiency, potentially by 47%. However, it is worth noting that this modification may result in a decrease in the quality of steam.

Comparison:1: Inserting ONE Reheater:



At State 5:

P5 = 10kPa (Sat. Liq)

h5 = $h_{f\,@\,10kPa} = 191.81\ kJ/kg$

v5 = $v_{f\,@\,10kPa} = 0.00101\ m^3/kg$

At State 6:

P6 = 15MPa

s6 = s5

$W_{Pump,in}$ = v5(P6 - P5) = ($0.00101\ m^3/kg$)[(15000 - 10) kPa]($\frac{1\ kJ}{1\ kPa\cdot m^3}$) = 15.1399 kJ/kg

h6 = h5 + $W_{Pump,in}$ = 191.81 + 15.1399 = 206.9499 kJ/kg

At State 7:

P7 = 15MPa (Sat. Liq)

h7 = $h_{f\,@\,15MPa} = 1610.3\ kJ/kg$

v7 = $v_{f\,@\,15MPa} = 0.0017\ m^3/kg$

At State 8:

P8 = 15MPa (Sat. Vap)

h8 = $2610.8\ kJ/kg$

v8 = $0.0103\ m^3/kg$

At State 1:

P1 = 15MPa

T1 = 500 °C

h1 = 3310.8 kJ/kg

s1 =6.3480 kJ/kg·K

At State 2:

s2 = s1

P2 = 4MPa (Assumption)

h2 = 3245.62 kJ/kg

At State 3:

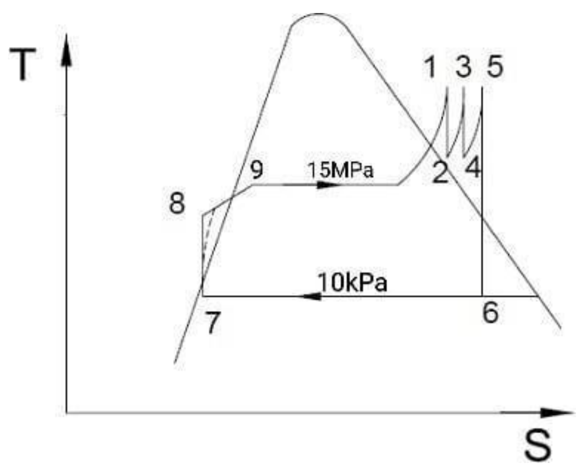
P3 = 4MPa

T3 = 500 °C

$h3 = 3446$ kJ/kg
$s3 = 7.0992$ kJ/kg·K

At State 4:
P4 = 10kPa
s4 = s3
x4 = (s4 - sf) / (sfg) = 0.8586
Steam Quality = x4 x 100% = **85.86 %**
h4 = hf + (x4 x hfg) = 2246.31kJ/kg
qin = (h1-h6)+(h3-h2) = 3304.23 kJ/kg
qout = (h4-h5) = 2054.5 kJ/kg
Efficiency = 1 - ($\frac{qin}{qout}$) =(1 - ($\frac{2054.5}{3304.5}$))*100 = **37.82 %**

2: Inserting TWO Reheaters:



At State 7:
P7 = 10kPa (Sat. Liq)
h7 = $h_{f\ @\ 10kPa} = 191.81\ kJ/kg$
v7 = $v_{f\ @\ 10kPa} = 0.00101\ m^3/kg$

At State 8:
P8 = 15MPa
s8 = s7
$W_{Pump,in}$ = v7(P8 - P7) = ($0.00101\ m^3/kg$)[(15000 - 10) kPa]($\frac{1\ kJ}{1\ kPa\cdot m^3}$) = 15.1399 kJ/kg
h8 = h7 + $W_{Pump,in}$ = 191.81 + 15.1399 = 206.9499 kJ/kg

At State 9:
P9 = 15MPa (Sat. Liq)
h9 = $h_{f\,@\,15MPa} = 1610.3\ kJ/kg$
v9 = $v_{f\,@\,15MPa} = 0.0017\ m^3/kg$

At State 10:
P10 = 15MPa (Sat. Vap)
h10 = 2610.8 kJ/kg
v10 = $0.0103\ m^3/kg$

At State 1:
P1 = 15MPa
T1 = 500 °C
h1 = 3310.8 kJ/kg
s1 =6.3480 kJ/kg·K

At State 2:
s2 = s1
P2 = 4MPa (Assumption)
h2 = 3245.62 kJ/kg

At State 3:
P3 = 4MPa
T3 = 500 °C
h3 = 3446 kJ/kg
s3 = 7.0992 kJ/kg·K

At State 4:
s4 = s3
P4 = 3MPa (Assumption)
h4 = 3344.9 kJ/kg

At State 5:
P5 = 3MPa
T5 = 500 °C
h5 =3457.8 kJ/kg
s5 =7.2359 kJ/kg·K

At State 6:

P6 = 10kPa

s6 = s5

x6 = (s6 - sf) / (sfg) = 0.8778

Steam Quality = x6 x 100% = **87.78%**

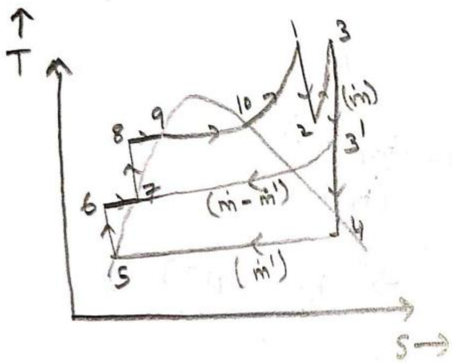
h6 = hf + (x6 x hfg) = 2292.11 kJ/kg

qin = (h1-h8) + (h3-h2) + (h5-h4) = 3417.13 kJ/kg

qout = (h6-h7) = 2100.3kJ/kg

Efficiency = 1 - ($\frac{qin}{qout}$) =(1 - ($\frac{2100.3}{3417.13}$)) *100 = **38.53 %**

3: Inserting ONE Reheater and ONE Regenerator:



Mass conservation:-

$$h_6(\dot{m}') + (\dot{m} - \dot{m}')h_3' = h_7 \cdot \dot{m}$$

$$(h_6 - h_3')\cdot \dot{m}' = \dot{m}(h_7 - h_3')$$

$$\boxed{z = \frac{\dot{m}'}{\dot{m}} = \frac{h_7 - h_3'}{h_6 - h_3'}}$$

$$\text{efficiency} = 1 - \left(\frac{\dot{m}'(h_4 - h_5)}{\dot{m}(h_1 - h_8 + h_3 - h_2)}\right)$$

Cantera Code:

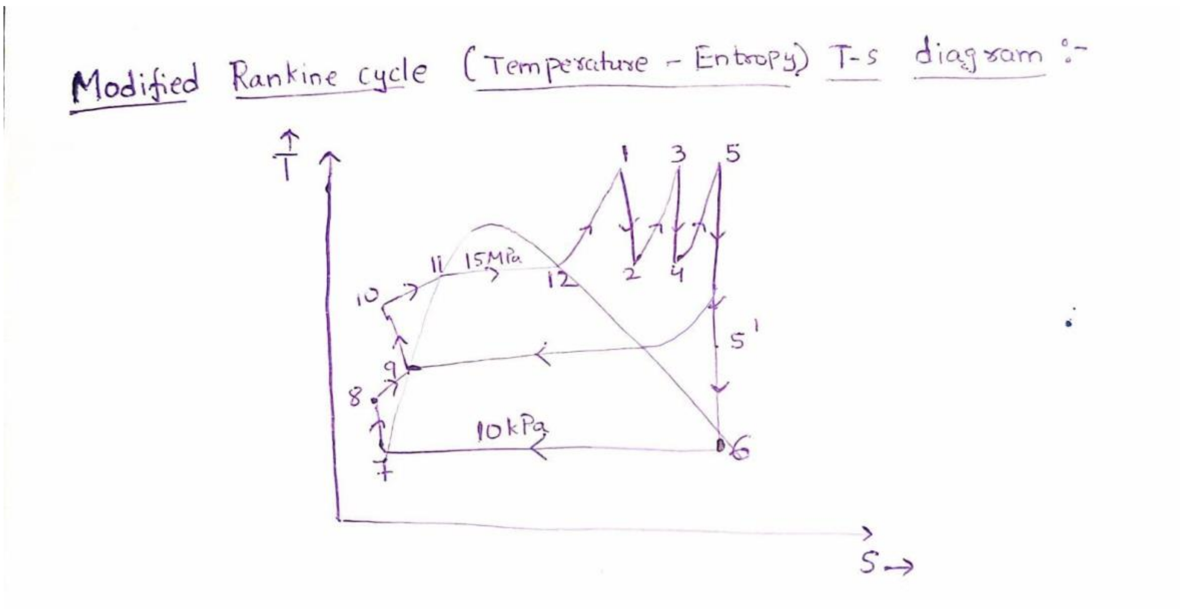
```
clc;
clear all;
w = Solution('liquidvapor.cti', 'water');
P5 = 10e+3;   % pressure (in Pa)
P6 = 0.8e+6;
P7 = P6;
P8 = 15e+6;
P9 = P8;
P10 = 15e+6;
P1 = P10;
P2 = 7e+6;      %after going to reheater low pressure assumption
P3 = P2;
P3d = P7;
P4 = P5;
```

```
T1 = 499 + 273.15;  %temperature (in K)
T3 = 499 + 273.15;
% State 5
x5 = 0;
setState_Psat(w, [P5, x5]);
v5 = 1/density(w);      % specific volume (in m^3/kg)
h5 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State 6
w_pin1 = v5*(P6 - P5);
h6 = h5 + w_pin1;      % enthalpy (in J/kg)
% State 7
x7 = 0;
setState_Psat(w, [P7, x7]);
v7 = 1/density(w);      % specific volume (in m^3/kg)
h7 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State 8
w_pin2 = v7*(P8 - P7);
h8 = h7 + w_pin2;
% State 9
x9 = 0;
setState_Psat(w, [P9, x9]);
v9 = 1/density(w);      % specific volume (in m^3/kg)
h9 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State 10
x10 = 1;
setState_Psat(w, [P10, x10]);
v10 = 1/density(w);      % specific volume (in m^3/kg)
h10 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State  1
set(w, 'P', P1, 'T', T1);
h1 = enthalpy_mass(w);
s1 = entropy_mass(w);
% State 2
s2 = s1;
setState_SP(w, [s2, P2]);
h2 = enthalpy_mass(w);
% State 3
set(w, 'P', P3, 'T', T3);
h3 = enthalpy_mass(w);
s3 = entropy_mass(w);
% State 3d
s3d = s3;
setState_SP(w, [s3d, P3d]);
h3d = enthalpy_mass(w);
% State 4
s4 = s3d;
setState_SP(w, [s4,P4]);
% sf = entropy_mass(w);
% setState_Psat(w, [P4, 1.0]);
% sg = entropy_mass(w);
% sfg = sg - sf;
```

```
% setState_SP(w, [s4, P4]);
h4 = enthalpy_mass(w);
% x4 = (s4 - sf)/sfg;
x4 = vaporFraction(w);
% efficiency
z = (h7 - h3d)/(h6 - h3d);
efficiency = 1 - ((h4 - h5)/(h1 - h8 + h3 - h2) * z);
fprintf("quality is %.4f\n", x4*100);
fprintf("efficiency is %.4f\n", efficiency*100);
```

By running this code we have obtained:
Steam Quality = **81.9200%**
Efficiency = **45.7555%**

4: Inserting TWO Reheaters and ONE Regenerator:



Assumptions:

1) Steady-state
2) No heat loss with the surroundings (Adiabatic)
3) No mechanical or thermal loss
4) Mass flow rate of the working fluid through the cycle is assumed to be constant
5) Low pressure turbine1 (P2 = 7 MPa)
6) Low pressure turbine2 (P4 = 3 MPa)

Calculations:

<u>At State 7:</u>
P7 = 10kPa (Sat. Liq)
h7 = $h_{f\,@\,10kPa} = 191.81\ kJ/kg$

v7 = $v_{f\,@\,10kPa} = 0.00101\ m^3/kg$

At State 8:

P8 = 0.8MPa

s8 = s7

$W_{Pump,in1}$ = v7(P8 - P7) = ($0.00101\ m^3/kg$)[(800 - 10) kPa]($\frac{1\ kJ}{1\ kPa \cdot m^3}$) = 0.7981096

h8 = h7 + $W_{Pump,in1}$ = 191.81 + 0.7981096 = 192.608 kJ/kg

At State 9:

P9 = 0.8 MPa (Sat. Liq)

h9 = $h_{f\,@\,15MPa} = 1610.3\ kJ/kg$

v9 = $v_{f\,@\,15MPa}$ = 0.0017 @from Cantera

s9 = 7.2051kJ/kg-K

At State 10:

P10 = 15MPa

s10 = s9

$W_{Pump,in2}$ = v9(P10 - P9) = 15.831 kJ/kg

h10 = h9 + $W_{Pump,in2}$ = 1626.131kJ/kg @from Cantera

At State 11:

P11 = 15MPa (Sat. Liq)

h11 = $h_{f\,@\,15MPa} = 1610.3\ kJ/kg$ @from Cantera

v11 = $v_{f\,@\,15MPa} = 0.0017\ m^3/kg$ @from Cantera

At State 12:

P12 = 15MPa (Sat. Vap)

h12 = $2610.8\ kJ/kg$

v12 = $0.0103\ m^3/kg$ @from Cantera

At State 1:

P1 = 15MPa

T1 = 500°C

h1 = 3310.8 kJ/kg

s1 = 6.3480 kJ/kg·K @from Cantera

At State 2:

s2 = s1

P2 = 7MPa (Assumption) # Reheater

h2 = 3092.48 kJ/kg @from Cantera

At State 3:

P3 = P2

T3 = 500°C

h3 =3411.4 kJ/kg

s3 = 6.800 kJ/kg·K @from Cantera

At State 4:

s4 = s3

P4 = 3MPa (Assumption) # Reheater

h4 = 3150.85 kJ/kg @from Cantera

At State 5:

P5 = 3MPa

T5 = 500°C

h5 = 3457.2 kJ/kg

s5 = 7.2359 kJ/kg·K @from Cantera

At State 5dash:

P5dash = 0.8 MPa

s5dash = s5

h5dash =3057.72 kJ/kg @from Cantera

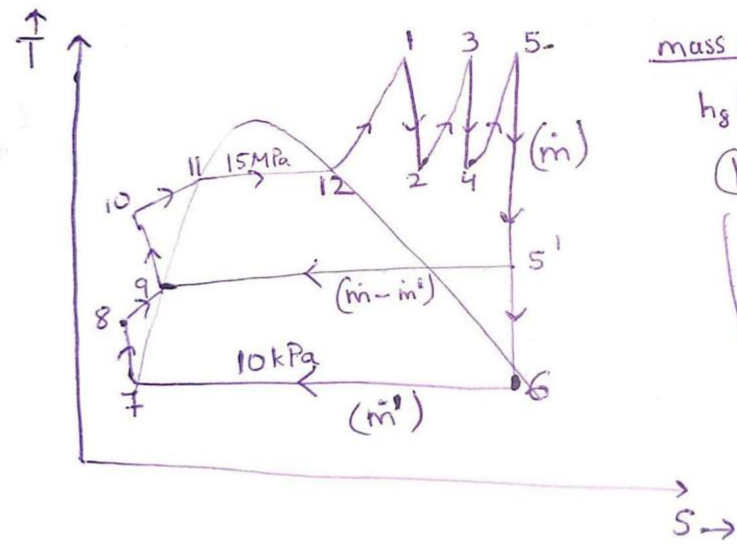
At state6:

P6 = 10kPa

s6 = s5dash

x6 = Steam Quality =0.8778

h6 @from Cantera



mass conservation :-

$$h_8(\dot m') + (\dot m - \dot m')h_{5'} = h_9 \cdot \dot m$$

$$(h_8 - h_{5'})\,\dot m' = \dot m\,(h_9 - h_{5'})$$

$$\boxed{\frac{\dot m'}{\dot m} = \frac{h_9 - h_{5'}}{h_8 - h_{5'}}}$$

Mass conservation:

$m_1 + (m - m_1) = m$

Applying energy conservation

$m_1 * h8 + (m - m_1) * h5dash = m * h9$

$(h8 - h5dash)\ m_1 = m * (h9 - h5dash)$

$m_1 / m = (h9 - h5dash) / (h8 - h5dash)$

Total work done:

$W_{net} = q_{in} - q_{out}$

$q_{in} = m * (h1 - h10) + m * (h3 - h2) + m * (h5 - h4)$

$q_{out} = (m_1) * (h6 - h7)$

Efficiency of the system:

$\eta = W_{net} / q_{in} = (q_{in} - q_{out}) / q_{in}$

$\eta = 1 - (q_{out} / q_{in})$

$$\eta = 1 - \left(\frac{m1\,(h6 - h7)}{m * (h1 - h10 + h3 - h2 + h5 - h4)}\right)$$

Cantera Code:

```
clc;
clear all;
w = Solution('liquidvapor.cti', 'water');
P7 = 10e+3;    % pressure (in Pa)
P8 = 0.8e+6;
P9  =  P8;
P10 = 15e+6;
P11 = P10;
P12 = 15e+6;
P1 = P12;
```

```
P2 = 7e+6;      %after going to reheater low pressure assumption
P3 = P2;
P4 = 3e+6;      %after going to reheater low pressure assumption
P5 = P4;
P5d = P9;
P6 = P7;
T1 = 500 + 273.15;  %temperature (in K)
T3 = 500 + 273.15;
T5 = 500 + 273.15;
% State 7
x7 = 0;
setState_Psat(w, [P7, x7]);
v7 = 1/density(w);      % specific volume (in m^3/kg)
h7 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State 8
w_pin1 = v7*(P8 - P7);
h8 = h7 + w_pin1;       % enthalpy (in J/kg)
% State 9
x9 = 0;
setState_Psat(w, [P9, x9]);
v9 = 1/density(w);      % specific volume (in m^3/kg)
h9 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State 10
w_pin2 = v9*(P10 - P9);
h10 = h9 + w_pin2;
% State 11
x11 = 0;
setState_Psat(w, [P11, x11]);
v11 = 1/density(w);      % specific volume (in m^3/kg)
h11 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State 12
x12 = 1;
setState_Psat(w, [P12, x12]);
v12 = 1/density(w);      % specific volume (in m^3/kg)
h12 = enthalpy_mass(w);  % enthalpy (in J/kg)
% State  1
set(w, 'P', P1, 'T', T1);
h1 = enthalpy_mass(w);
s1 = entropy_mass(w);
% State 2
s2 = s1;
setState_SP(w, [s2, P2]);
h2 = enthalpy_mass(w);
% State 3
set(w, 'P', P3, 'T', T3);
h3 = enthalpy_mass(w);
s3 = entropy_mass(w);
% State 4
s4 = s3;
setState_SP(w, [s4, P4]);
h4 = enthalpy_mass(w);
```

```
% State 5
set(w, 'P', P5, 'T', T5);
h5 = enthalpy_mass(w);
s5 = entropy_mass(w);
% State 5d
s5d = s5;
setState_SP(w, [s5d, P5d]);
h5d = enthalpy_mass(w);
% State 6
s6=s5d;
setState_SP(w, [s6,P6]);
% sf = entropy_mass(w);
% setState_Psat(w, [P6, 1.0]);
% sg = entropy_mass(w);
% sfg = sg - sf;
% setState_SP(w, [s6, P6]);
h6 = enthalpy_mass(w);
% x6 = (s12 - sf)/sfg;
x6 = vaporFraction(w);
% efficiency
z = (h9 - h5d)/(h8 - h5d);
efficiency = 1 - ((h6 - h7)/(h1 - h10 + h3 - h2 + h5 - h4) * z);
fprintf("quality is %.4f\n", x6*100);
fprintf("efficiency is %.4f\n", efficiency*100);
```

Result:

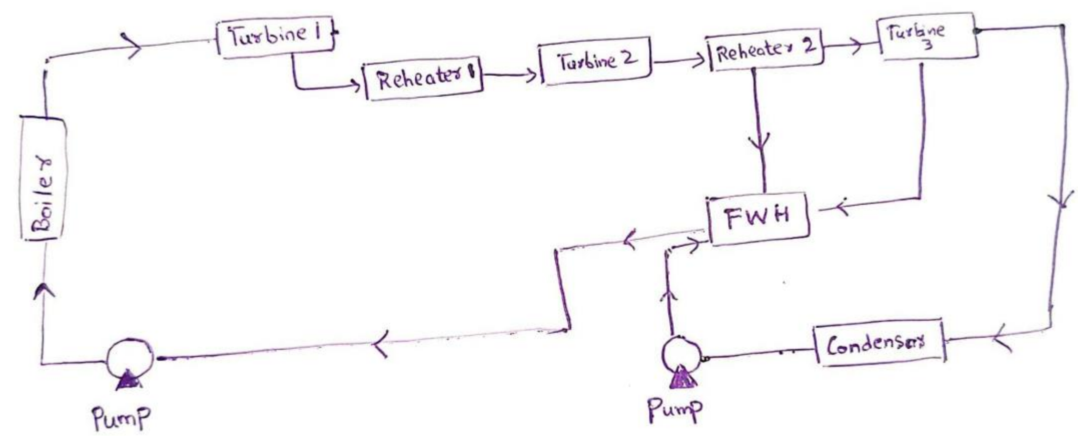
Quality: 87.7788 %

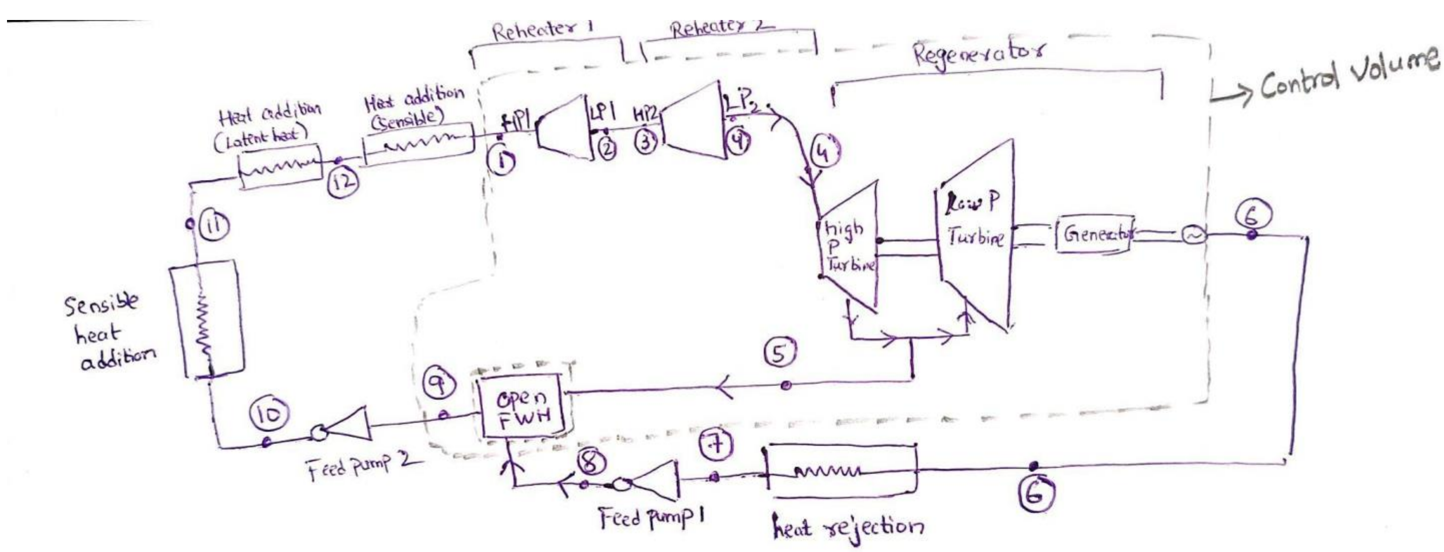
Efficiency: 46.4549 %

Table Of Comparison:

Modified Rankine Cycle	Steam Quality	Efficiency
ONE Reheater	85.86%	37.82%
TWO Reheaters	87.78%	38.53%
ONE Reheater and ONE Regenerator	81.92%	45.7555%
TWO Reheaters and ONE Regenerator	87.77%	46.454%

Control Volume for modified Rankine cycle with TWO Reheaters and ONE Regenerator:





Energy balance equation:
System: Open feedwater heater

Mass conservation:

$m_1 + (m - m_1) = m$

Applying energy conservation

$m_1 * h8 + (m - m_1) * h5dash = m * h9$

$(h8 - h5dash)\ m_1 = m * (h9 - h5dash)$

$m_1 / m = (h9 - h5dash) / (h8 - h5dash)$

Total work done:

$W_{net} = q_{in} - q_{out}$

$q_{in} = m * (h1 - h10) + m * (h3 - h2) + m * (h5 - h4)$

$q_{out} = (m_1) * (h6 - h7)$

Efficiency of the system:

$\eta = W_{net} / q_{in} = (q_{in} - q_{out}) / q_{in}$

$\eta = 1 - (q_{out} / q_{in})$

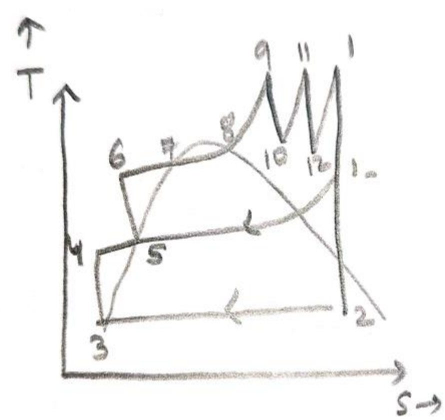
$\eta = 1 - (\frac{m1\ (h6 - h7)}{m * (h1 - h10 + h3 - h2 + h5 - h4)})$

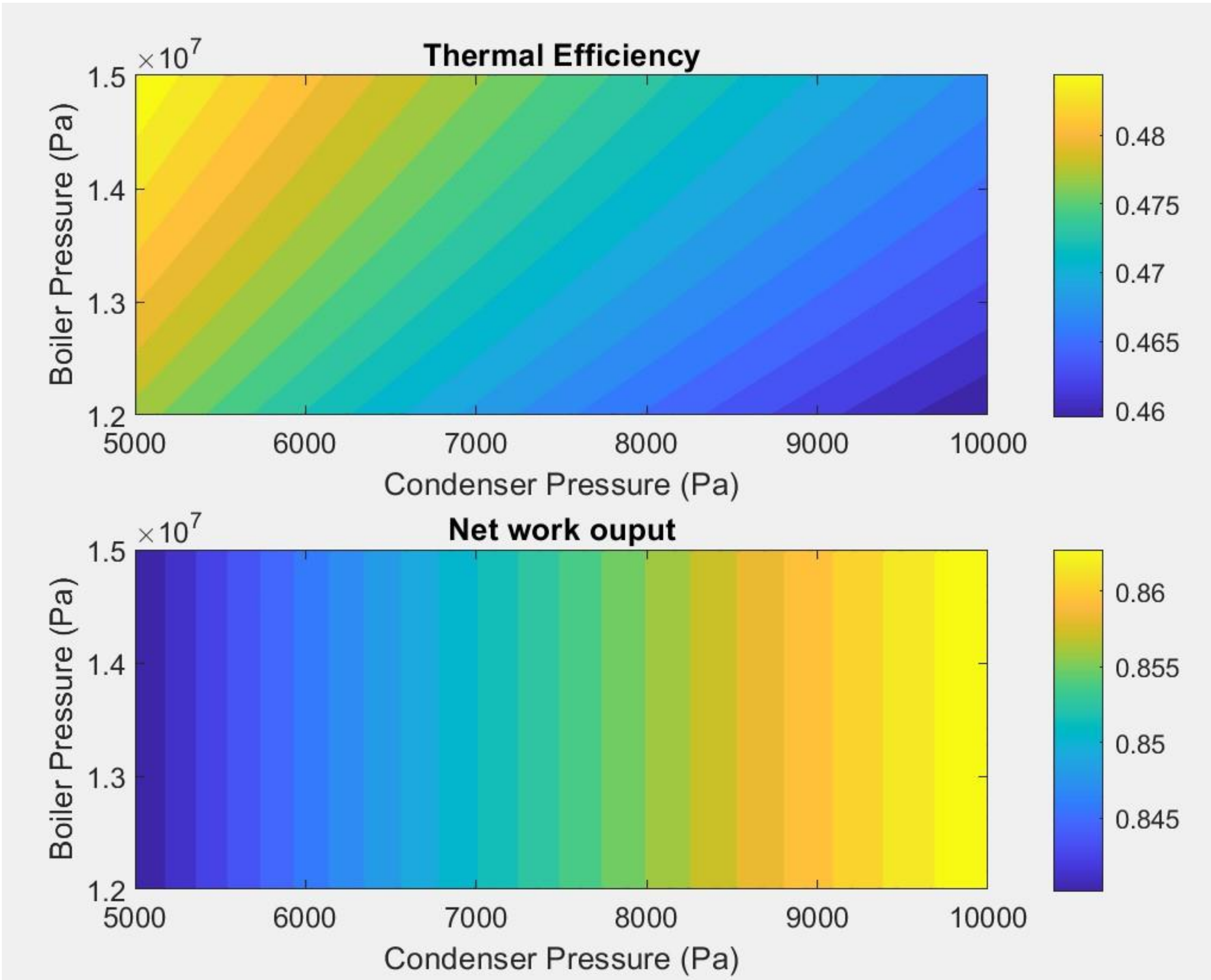
<u>Part(B) Plots:</u>
From the previous

Obtained efficiency = 46.454%

Obtained quality = 87.77%

Let modified Rankine cycle (T - S Diagram)is:





Cantera code:

```
clc;
clear all;
Pb_range = linspace(12E+6, 15E+6, 20); % Range of boiler pressures from 12 MPa < Pb <
15 MPa
Pc_range = linspace(5E+3, 10E+3, 20);  % Range of condenser pressures from 5 kPa < Pc
< 10 kPa
eta_result = zeros(length(Pc_range), length(Pb_range));
wnet_result = zeros(length(Pc_range), length(Pb_range));
%looping
for i = 1:length(Pb_range)
   for j = 1:length(Pc_range)
       % Seting boiler and condenser pressures
       P8 = Pb_range(i);
       P3 = Pc_range(j);
       [efficiency, w_net] = calculate_cycle_performance(P3, P8);
       eta_result(j, i) = efficiency;
       wnet_result(j, i) = w_net;
   end
```

```
end
%ploting
figure;
subplot(2, 1, 1);
contourf(Pc_range, Pb_range, eta_result', 20, 'LineColor', 'none');
colorbar;
xlabel('Condenser Pressure (Pa)');
ylabel('Boiler Pressure (Pa)');
title('Thermal Efficiency');
subplot(2, 1, 2);
contourf(Pc_range, Pb_range, wnet_result', 20, 'LineColor', 'none');
colorbar;
xlabel('Condenser Pressure (Pa)');
ylabel('Boiler Pressure (Pa)');
title('Net work output');
function [efficiency, x] = calculate_cycle_performance(P3, P8)
   h = Solution('liquidvapor.cti','water');
   % State 3
   setState_Psat(h,[P3,0]);
   h3 = enthalpy_mass(h);
   s3 = entropy_mass(h);

   % State 4
   P4 = 0.8E+6;
   s4 = s3;
   setState_SP(h,[s4,P4]);
   h4 = enthalpy_mass(h);

   % State 5
   P5 = P4;
   setState_Psat(h,[P5,0]);
   h5 = enthalpy_mass(h);
   s5 = entropy_mass(h);

   % State 6
   P6 = 3.7E+6;
   s6 = s5;
   setState_SP(h,[s6,P6]);
   h6 = enthalpy_mass(h);

   %State 7
   P7 = P6;
   setState_Psat(h,[P7,0]);
   h7 = enthalpy_mass(h);
   s7 = entropy_mass(h);

   % State 8
   s8 = s7;
   setState_SP(h,[s8,P8]);
   h8 = enthalpy_mass(h);
```

```
% State 9
P9 = P8;
setState_Psat(h,[P9,0]);
h9 = enthalpy_mass(h);

% State 10
P10 = P8;
setState_Psat(h,[P10,1]);
h10 = enthalpy_mass(h);

% State 11
P11 = P8;
T11 = 500+273.15;
set(h,'P',P11,'T',T11);
h11 = enthalpy_mass(h);
s11 = entropy_mass(h);

% State 12
P12 = P6;
s12 = s11;
setState_SP(h,[s12,P12]);
h12 = enthalpy_mass(h);

% State 1
P1 = P6;
T1 = 500+273.15;
set(h,'P',P1,'T',T1);
h1 = enthalpy_mass(h);
s1 = entropy_mass(h);

% State 1_
P1_ = P4;
s1_ = s1;
setState_SP(h,[s1_,P1_]);
h1_ = enthalpy_mass(h);

% State 2
P2 = P3;
s2 = s1;
setState_SP(h,[s2,P2]);
h2 = enthalpy_mass(h);

setState_Psat(h,[P2,0]);
hf = enthalpy_mass(h);

setState_Psat(h,[P2,1]);
hg = enthalpy_mass(h);
hfg = hg-hf;
x = ((h2-hf)/hfg);
m4_6 = ((h1_-h5)/(h1_-h4));
m7_6 = ((h6-h12)/(h7-h12));
```

```
    qout = m4_6*(h2-h3);
    qin = (m7_6*(h11-h8))+h1-h12;
    w_net = qin - qout;
    efficiency = (1-(qout/qin));
end
```

This code is simulating a Rankine cycle, which is a thermodynamic cycle that converts heat into work. The heat is supplied externally to a closed loop, which typically uses water as working fluid. This cycle is commonly used in power generation, such as in coal-fired or nuclear power plants.
The code focuses on adjusting the pressures at the high-pressure (HP) turbine's inlet and the condenser's inlet. These pressure variations play a crucial role in influencing the thermal efficiency and net work output of the Rankine cycle. By manipulating these pressures, the code allows for an exploration of how changes in the system's operating conditions impact its overall efficiency and work output. This is particularly relevant for optimizing the performance of power generation processes, offering insights into the effects of pressure variations on the cycle's efficiency and power production.
Here, the temperature and enthalpy of the steam entering the high-pressure turbine rise along with the boiler pressure, increasing the turbine's work output. Thermal efficiency rises as a result of this increase in work output exceeding the rise in heat input needed by the boiler. For the same reasons, the cycle's net work output likewise rises with boiler pressure.

Observation in the Plots:

In the above case, we varied the boiler pressure (Pb) and condenser pressure (Pc) within the specified ranges of 12 MPa < Pb < 15 MPa and 5 kPa < Pc < 10 kPa. Increasing the pressure at the inlet of the turbine raises the temperature and enthalpy of the steam entering the turbine, potentially increasing the turbine's work output. As boiler pressure increases, there is an improvement in thermal efficiency up to a certain point, suggesting that higher temperatures contribute positively to the cycle. However, excessively high boiler pressure may lead to adverse effects due to increased pump work. Decreasing the pressure at the condenser inlet lowers the temperature at which heat is rejected in the condenser, potentially increasing the thermal efficiency of the cycle.
Conversely, lowering condenser pressure generally enhances the cycle's efficiency by allowing the working fluid to reject heat at a lower temperature. Finding the optimal balance between Pb and Pc is crucial, as extreme values for either parameter can negatively impact overall performance. The ideal pressure ranges are further influenced by reheaters and regeneration, which may cause shifts depending on how they affect cycle efficiency.

Conclusion:

Analyzing the Rankine cycle with added reheaters and regeneration, and adjusting boiler pressure (Pb) and condenser pressure (Pc) can significantly impact how well the system works. Increasing boiler pressure tends to make things better, improving how efficiently the cycle operates. On the other hand, lowering condenser pressure is also good, as it helps the system get rid of heat more effectively.

References:

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