INDIAN INSTITUTE OF TECHNOLOGY GANDHINAGAR

ES211 - THERMODYNAMICS

APPLICATION OF WATER

ANALYSING THE GRAPHS OF WATER

UNDER THE GUIDANCE OF:
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INTRODUCTION

The majority of the world's electricity is still generated by thermal power plants. The fuel utilized in these thermal power plants might range from coal to gas to nuclear materials, but the basic premise is to burn heat-producing fuel and convert it to electrical energy. The use of water, on the other hand, is left out of the equation. Almost all of these thermal power plants use enormous amounts of water for cooling and steam to power turbines and hence, they are generally made on the banks of rivers.

Fig.1 Power Plant Near A Water Body

Many operations in these thermal power plants require water, including the steam cycle, pollution control, and ash handling. Despite this, the most bulk of water, nearly 90 per cent of total water, is utilized for cooling. According to research, thermoelectric plants use 40 per cent of all freshwater withdrawn in the United States each year, and practically all of it is used for cooling. However, because the term used is water removed rather than water consumed, this data is a little deceptive. These power plants take in vast amounts of water, use it, and then dump the majority of it at a slightly higher temperature into a water body. However, as compared to water removed, net water consumption is substantially lower. The ratio of water consumed to water withdrawn is significantly more dependent on the type of setup used. However, in a country where there is a drought and water scarcity, making such a vast amount of water available to a power plant at once is a difficult task.

THEORETICAL ANALYSIS

The T-V diagram of water in a thermal power plant is well-known. High-pressure water is supplied out by the compressor which is then delivered to the boiler. Here, the coal is burnt to sensibly heat the water at a constant pressure. The temperature of the water rises from 35°C to the boiling point, resulting in an increase in volume. Once the water temperature reaches boiling point, it is further heated in the boiler so that the temperature will remain constant until all of the water has turned to vapour, but the volume will increase until all of the liquid water has turned to vapour. Further heating will raise both the temperature and volume in the boiler because it is now steam, and the temperature can reach a maximum limit of 550°C beyond which the turbine of the thermal power plant can no longer tolerate the increased temperature. So, at this point in the thermal power plant, the water has been superheated to the point of vaporization, and the steam has been passed to the high-pressure turbine at high pressure. The turbine generates energy by expanding high-pressured steam, and the exhaust gases from the turbine are at low pressure and temperature. This is then sent to a reheater, which raises the temperature to 550°C. This steam is now delivered to the intermediate-pressure turbine. As the steam expands through the turbine and the exhaust steam is at low pressure and temperature, electricity is created once more. Now, for the last time, to generate energy, this is transmitted to the low-pressure turbine. The exhaust steam is now delivered to the condenser, which condenses the vapours into a liquid state to complete the cycle, with the liquid water temperature at 30-35°C. We do so in order to improve the thermal power plant's efficiency. This cycle is generally used in power plants and is known by the name, Rankine cycle.

All of this analysis was done assuming a constant pressure at the boiler; now consider the entire cycle for a variety of pressure values at the boiler. When the pressure in the boiler is increased, the boiling temperature rises, and the specific volume at which the water begins to boil falls.

The Rankine cycle is a perfect application of water's thermodynamic properties. It uses the properties of the vapour dome to keep the temperature constant during the boiling of water in the liquid-vapour mixture phase. Below is a T-S graph of water which depicts a complete Rankine cycle.

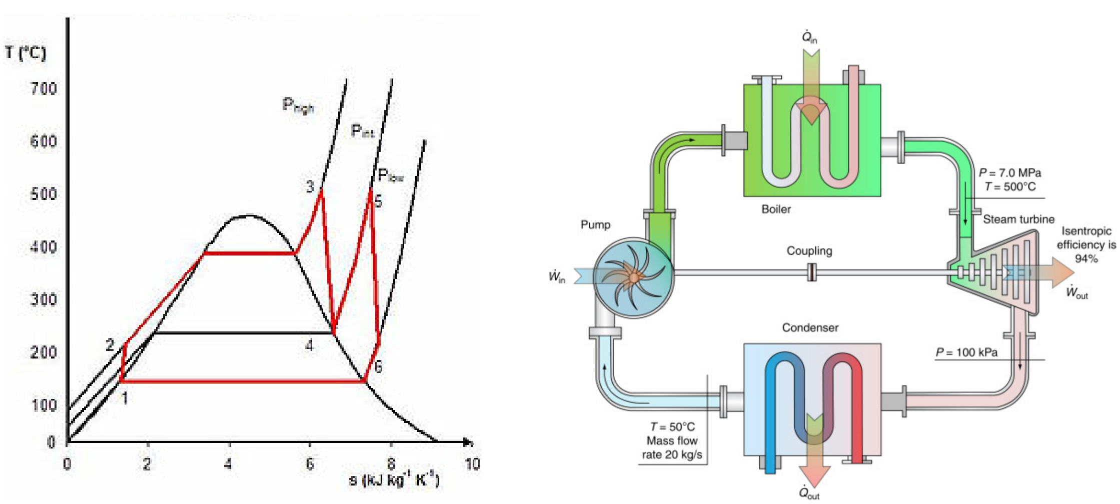


Fig.2 Rankine cycle for power generation

2.1 IDEAL RANKINE CYCLE

Generally, in a Rankine cycle, there are four processes. Numbers in the given T-s diagram identify the states.

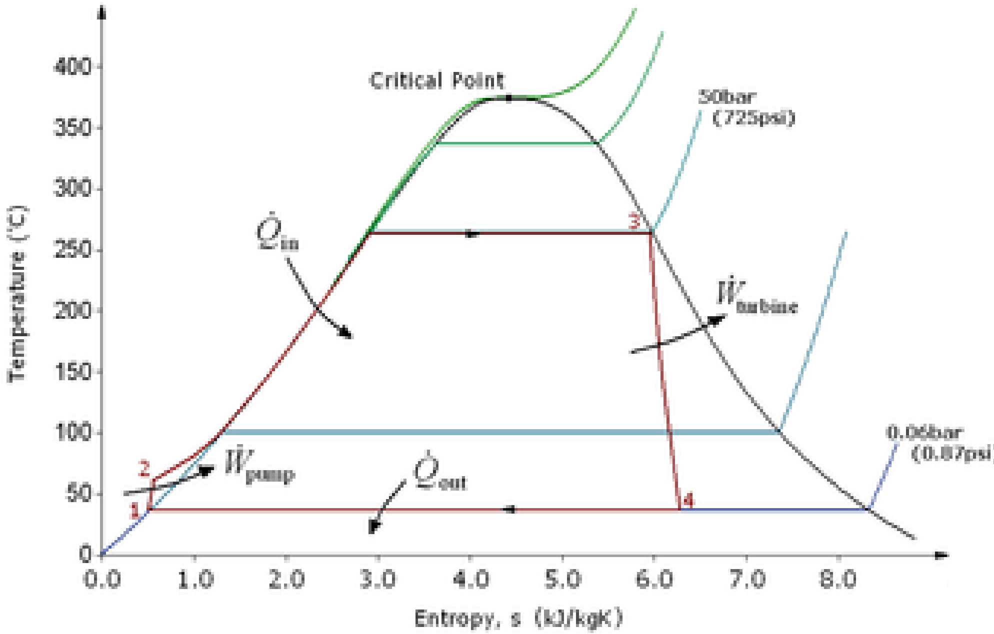


Fig. 3 T-s diagram of a Rankine cycle

- **Process 1–2**: Water(fluid) is pumped from low to high pressure. There is a minimum requirement of energy as the fluid is a liquid at this stage. It is an isentropic compression process.

- **Process 2–3**: The high-pressure water(liquid) is heated by a boiler at constant pressure to become a dry saturated vapor. It is a heat addition process at constant pressure.

- **Process 3–4**: The saturated vapor from the boiler expands through a turbine for generating power. During this process, there is a decrease in the temperature and pressure of the steam. It is an isentropic expansion process.

- **Process 4–1**: The wet vapor is then condensed in a condenser at a constant pressure to convert it into saturated liquid. It is a heat rejection process at constant pressure.

The pump and turbine in an ideal Rankine cycle are isentropic. Hence, there is no entropy generation from the pump and turbine; thus, maximum work is done.

2.2 REAL RANKINE CYCLE

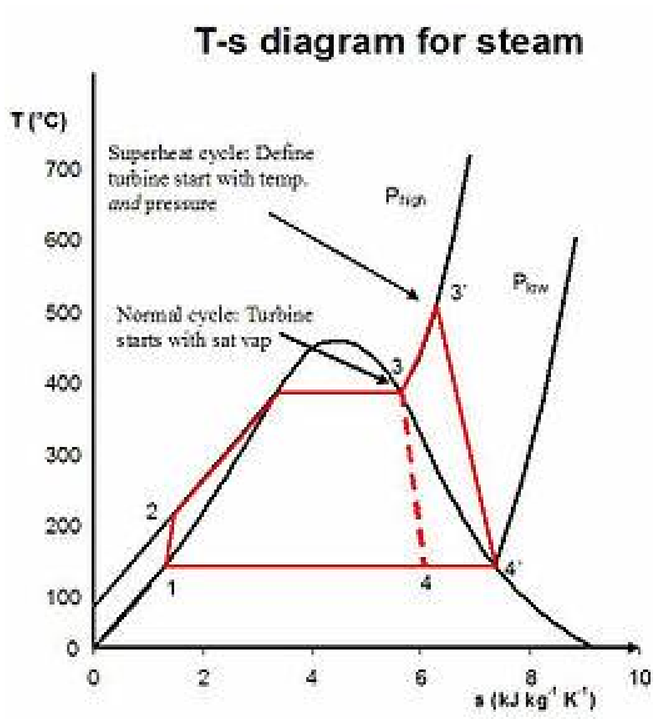


Fig. 4 Real Rankine cycle for steam

The pump's compression and the turbine's expansion are not isentropic in the actual Rankine cycle. As these processes are non-reversible, entropy is increased during the two methods. This, as a result, decreases the power generated by the turbine.

As water vapor condenses, the efficiency of the steam turbine is also limited by water-droplet formation. As the water condenses, water droplets hit the turbine blades at high speed, causing pitting and erosion. This, as a result, decreases the life of turbine blades and the efficiency of the turbine. One of the ways to overcome this problem is by superheating the steam.

2.3 VARIATION OF THE RANKINE CYCLE

1) Rankine cycle with reheat

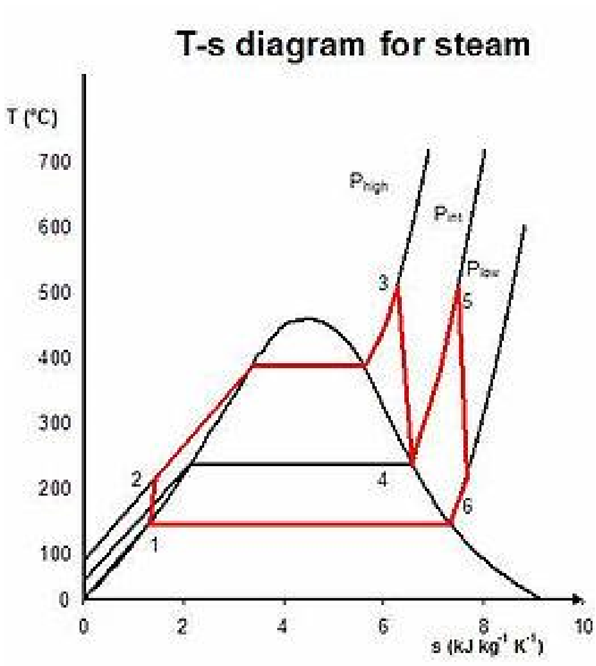


Fig. 5 Rankine cycle with reheat

The main idea of a reheating cycle is to remove the moisture carried by the steam. Two turbines work in series in this process. The first turbine accepts vapor from the boiler at high pressure. Water vapor from the first turbine re-enters the boiler and is reheated before passing through a second, lower-pressure turbine. This also reduces the damage to the turbine blades and furthermore increases the efficiency of the cycle. More than two reheating stages are generally unnecessary since the next stage increases the cycle efficiency only half as much as the previous stage.

2) Regenerative Rankine cycle

Water vapor emerging from the condenser as a subcooled liquid is heated by steam tapped from the hot portion of the cycle. The Regenerative Rankine cycle with slight variation is commonly used in actual power stations. Regeneration increases the efficiency of the cycle as more of the heat flow into the process occurs at higher temperatures.

3) Organic Rankine cycle

In the Organic Rankine cycle, in place of water and steam organic fluid such as n-pentane or toluene in place of water and steam. This helps in using lower-temperature heat sources, such as solar ponds. Although the efficiency of the cycle is much lower, it can be worthwhile because of the lower cost involved in gathering heat at a lower temperature.

4) Supercritical Rankine cycle

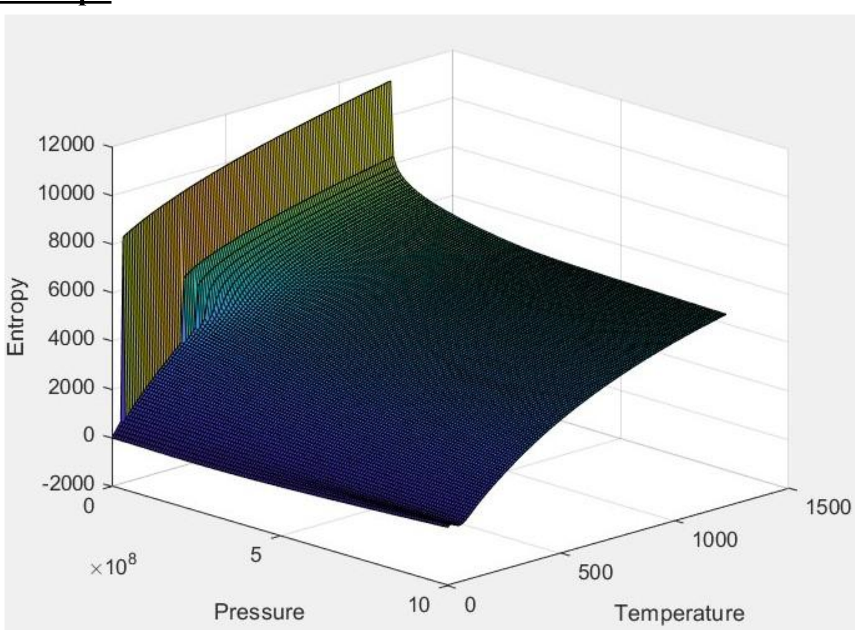
The Rankine cycle using a supercritical uses the concepts of heat regeneration and supercritical Rankine cycle into a combined process called the regenerative supercritical cycle (RGSC). It is used for temperature sources 125–450°C.

GRAPHS

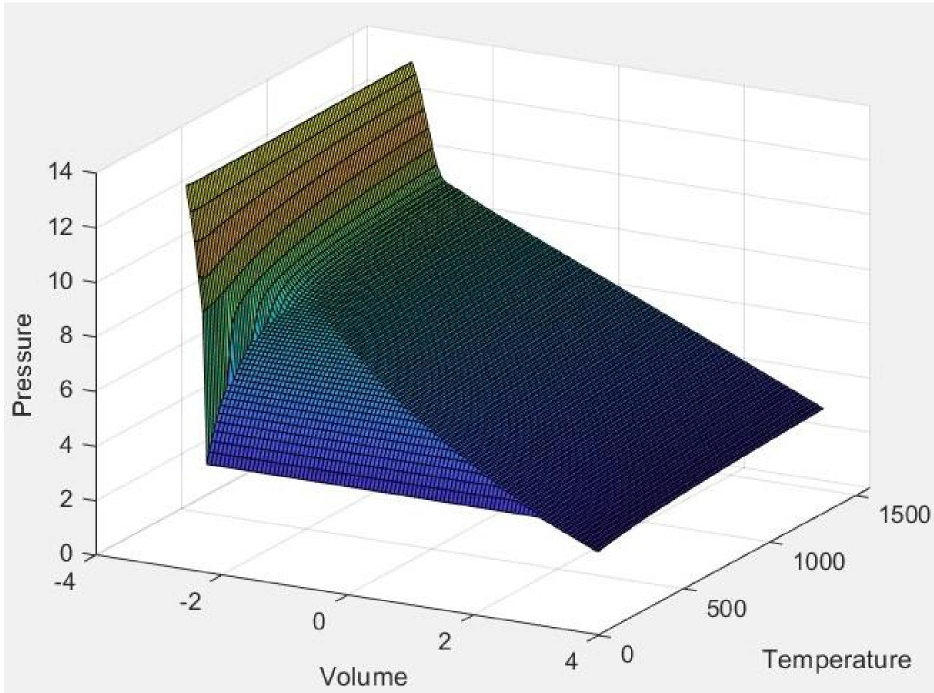
3.1 3-D Graph of P-S-T

Fig. 6 3-D model for water

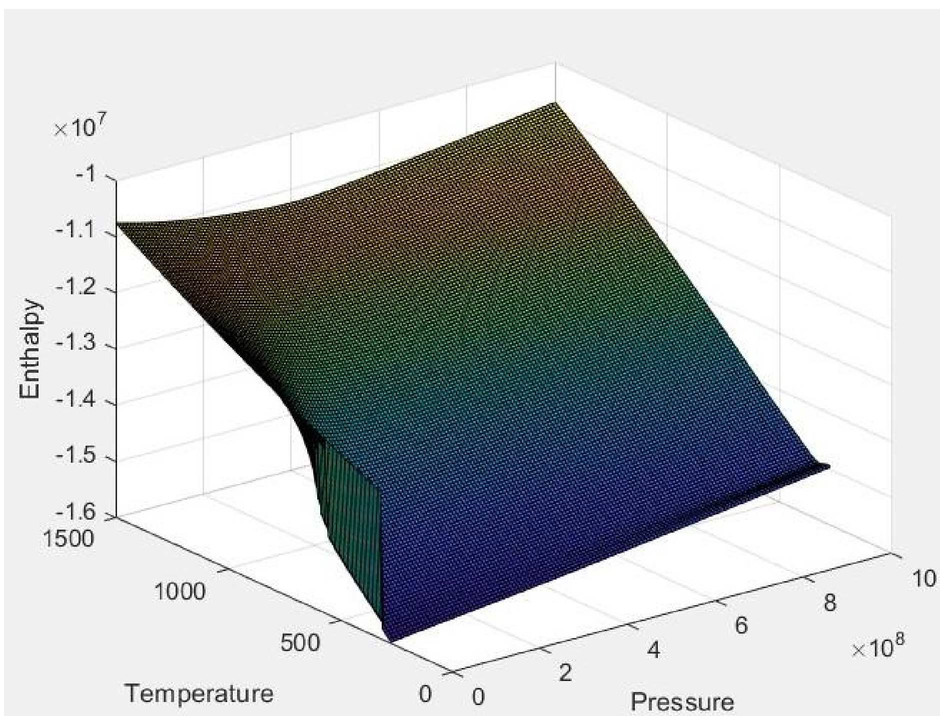
3.2 P-S-T Graph



3.3 P-V-T Graph



3.4 P-H-T Graph



CODE

4.1 P-S-T

```
clc;
clear all;
a=Solution('liquidvapor.xml', 'water');

T1=274:4*2.45:1500;
P1=10000:4*1999980:1000000000;
[x,y]=meshgrid(P1,T1);
S=zeros(126);
count=0;
c=0;

for T=T1
   c=c+1;
   count=0;
   for P=P1
      count=count+1;
      set(a, 'P', P, 'T', T);
      s=entropy_mass(a);
      S(count,c)=s;
   end
end
z=S;
surf(x,y,z.');
```

4.2 P-V-T

```
clc;
clear all;
sub=Solution('liquidvapor.xml', 'water');
tmax = maxTemp(sub) - 0.01;
tmin = minTemp(sub) + 0.01;

set(sub, 'T',tmin,'Liquid',1.0);
vmin = 0.5/density(sub);
set(sub, 'T',tmin,'Vapor',1.0);
vmax = 10.0/density(sub);
nt = 100; dt = (tmax - tmin)/nt;
nv = 100;
dlogv = log10(vmax/vmin)/nv;
logvmin = log10(vmin);

v = zeros(nv,1);
t = zeros(nt,1);
```

```
p = zeros(nt,nv);
for n = 1:nv
        logv(n) = logvmin + (n-1)*dlogv;
        v = 10.0^(logv(n));
        for m = 1:nt
                t(m) = tmin + (m-1)*dt;
                set(sub, 'T', t(m), 'V', v);
                logp(m,n) = log10(pressure(sub));
        end
end

y=t*logv;
[X,Y]= meshgrid(logv,t);
Z=logp;
surf( X,Y,Z);
s.FaceColor = 'interp';
%surf2stl('testit.stl', X, Y, Z);
```

4.3 P-H-T

```
clc;
clear all;
a=Solution('liquidvapor.xml', 'water');

T1=274:4*2.45:1500;
P1=10000:4*1999980:1000000000;

[x,y]=meshgrid(P1,T1);
H=zeros(126);
count=0;
c=0;

for T=T1
   c=c+1;
   count=0;
   for P=P1
      count=count+1;
      set(a, 'P', P, 'T', T);
      h=enthalpy_mass(a);
      H(count,c)=h;
   end
end
z=H;
surf(x,y,z.');
```

CONCLUSION

Thermodynamics requires the presence of water. It's employed in a number of thermodynamic processes, including thermal power plants. In a thermal power plant, electricity is generated by burning coal to transform liquid water into superheated vapours, which are then used for power turbines (high-pressure turbines, intermediate pressure turbines, and low-pressure turbines). Water passes through several phases, including liquid, liquid-vapour mixture, saturated vapours, superheated vapours, and then back to saturated vapours, and so on, until it reverts to liquid. Thermal power plants have a variety of components that help to make the process run smoothly. Pulverizers are used to convert coal to pulverized coal for better combustion, compressors are used to keep water and air at high pressures, boilers are used to heat liquid water to superheated vapours, turbines are used to generate electricity from the work done while high-pressure steam expands through them, and condensers are used to condense exhaust steam into liquid (at 30-35°C) to complete the cycle and improve the plant's efficiency in generating electricity. The quality of each of these components has an impact on the plant's efficiency.

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