

## 5.2 Rankine Cycle:

Rankine cycle is the idealized cycle for steam power plants. This cycle is shown on p-v, T-v, h-s, diagram in the above figures. It consists of following processes:

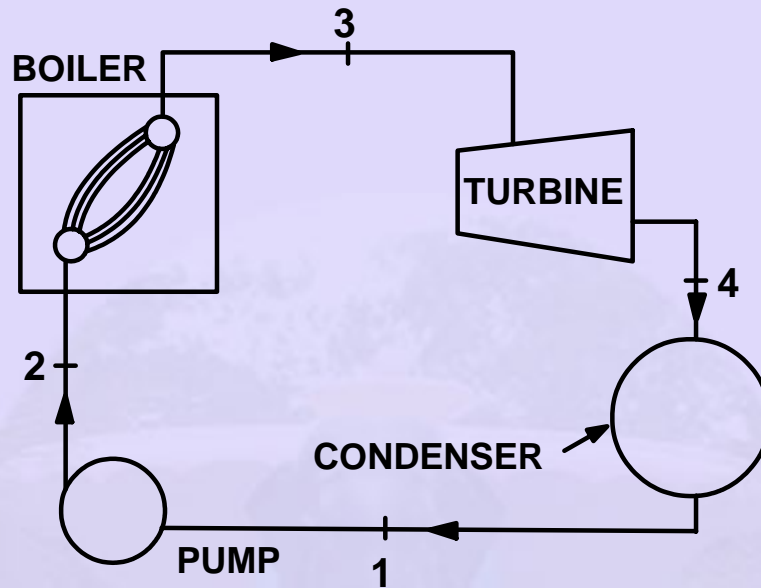


Fig.5.2(a). Rankine vapour power cycle

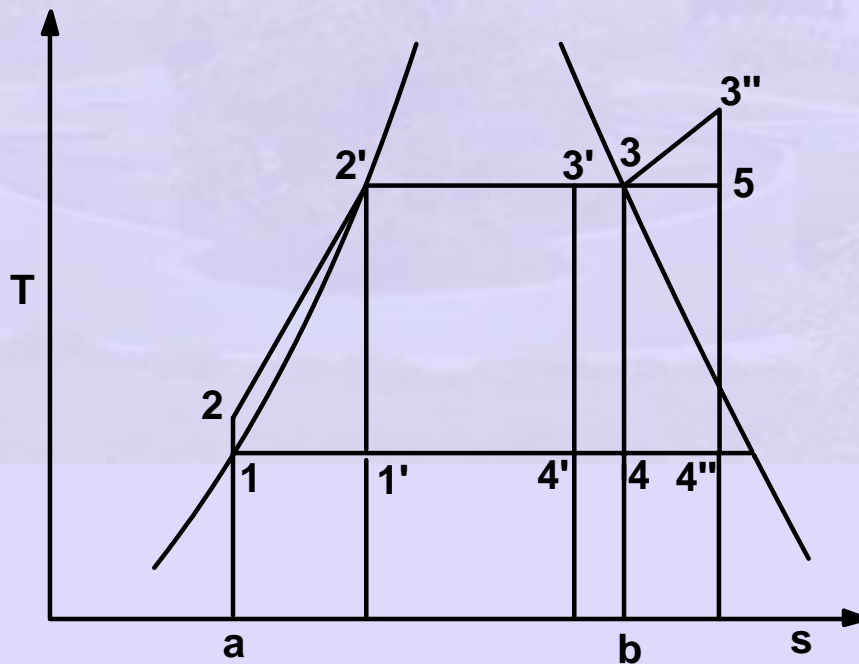
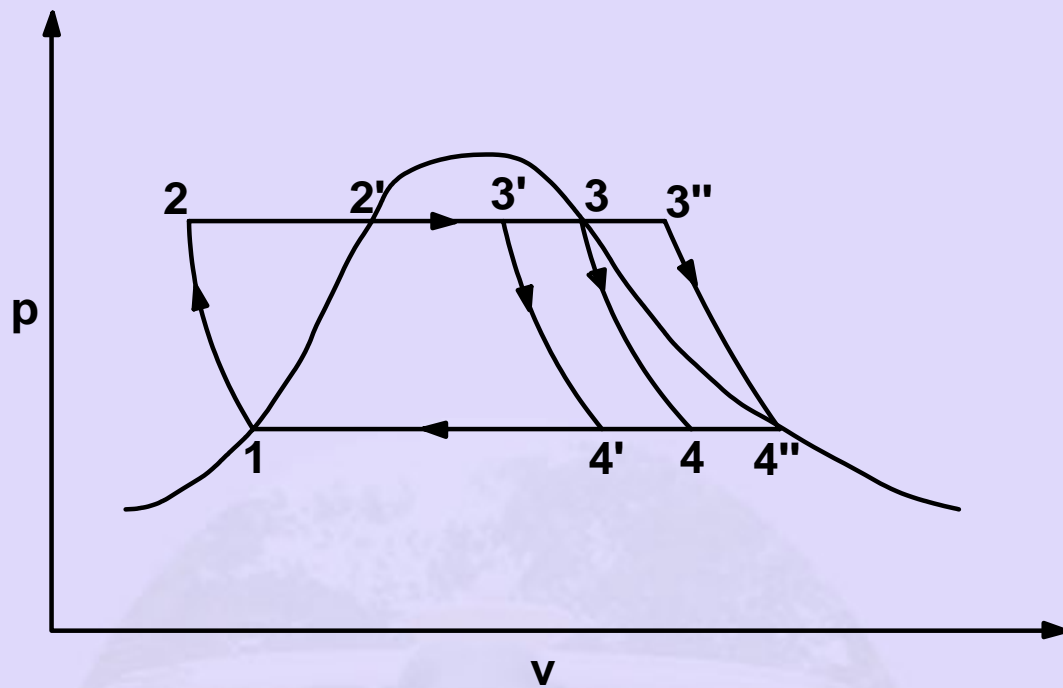
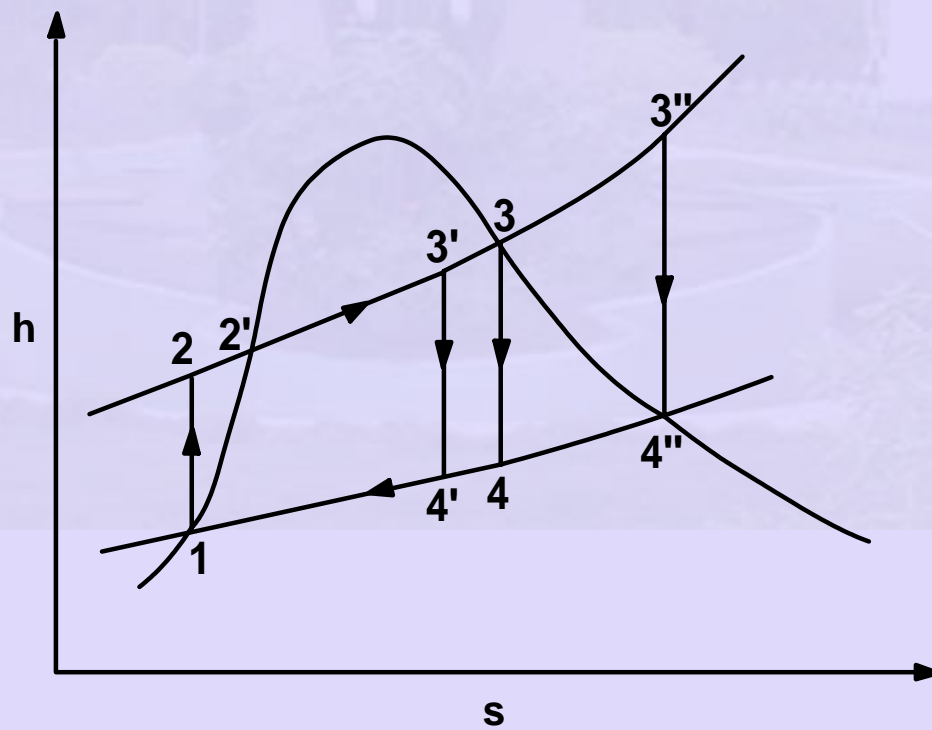


Fig.5.2(b). T-s diagram Rankine power cycle

Fig.5.2(c).  $p$ - $v$  diagram Rankine power cycleFig.5.2(d).  $h$ - $s$  diagram Rankine power cycle

**Process 1-2:** Water from the condenser at low pressure is pumped into the boiler at high pressure. This process is reversible adiabatic.

**Process 2-3:** Water is converted into steam at constant pressure by the addition of heat in the boiler.

**Process 3-4:** Reversible adiabatic expansion of steam in the steam turbine.

**Process 4-1:** Constant pressure heat rejection in the condenser to convert condensate into water.

The steam leaving the boiler may be dry and saturated, wet or superheated. The corresponding T-s diagrams are 1-2-3-4-1; 1-2-3'-4'-1 or 1-2-3''-4''-1.

### Thermal Efficiency of Rankine Cycle:

Consider one kg of working fluid, and applying first law to flow system to various processes with the assumption of neglecting changes in potential and kinetic energy, we can write,

$$\delta q - \delta w = dh$$

For process 2-3,  $\delta w = 0$  (heat addition process), we can write,

$$(\delta q)_{\text{boiler}} = (dh)_{\text{boiler}} = (h_3 - h_2)$$

For process 3-4;  $\delta q = 0$  (adiabatic process)

$$(\delta w)_{\text{turbine}} = -(dh)_{\text{turbine}} = (h_3 - h_4)$$

Similarly,

$$(\delta q)_{\text{cond}} = (h_1 - h_4)$$

$$(\delta w)_{\text{pump}} = (h_1 - h_2)$$

$$(\delta w)_{\text{net}} = (\delta w)_{\text{turbine}} + (\delta w)_{\text{pump}} = (h_3 - h_4) + (h_1 - h_2) = (h_3 - h_4) - (h_2 - h_1)$$

$$\text{Now, Thermal efficiency} = \eta_{\text{th}} = \frac{\text{Net work}}{\text{heat supplied}} = \frac{(\delta w)_{\text{net}}}{(\delta q)_{\text{boiler}}}$$

$$\eta_{\text{rankine}} = \eta_{\text{th}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{(h_3 - h_2)} = \frac{\text{area } 122'341}{\text{area } a22'3ba}$$

The pump work  $(\delta w)_{\text{pump}}$  is negligible, because specific volume of water is very small.

Therefore,

$$\eta_{\text{rankine}} = \frac{h_3 - h_4}{h_3 - h_2} = \frac{\text{area } 12'341}{\text{area } a12'3ba} \quad (\text{Neglecting pump work})$$

Note that the rankine cycle has a lower efficiency compared to corresponding Carnot cycle 2'-3-4-1' with the same maximum and minimum temperatures. The reason is that the average temperature at which heat is added in the rankine cycle lies between  $T_2$  and  $T_1^2$  and is thus less than the constant temperature  $T_1^2$  at which heat is added to the Carnot cycle.

## Reasons for Considering Rankine Cycle as an Ideal Cycle For Steam Power Plants:

- 1) *It is very difficult to build a pump that will handle a mixture of liquid and vapor at state 1' (refer T-s diagram) and deliver saturated liquid at state 2'. It is much easier to completely condense the vapor and handle only liquid in the pump.*
- 2) *In the rankine cycle, the vapor may be superheated at constant pressure from 3 to 3'' without difficulty. In a Carnot cycle using superheated steam, the superheating will have to be done at constant temperature along path 3-5. During this process, the pressure has to be dropped. This means that heat is transferred to the vapor as it undergoes expansion doing work. This is difficult to achieve in practice.*