6.3 The Rankine Cycle

- Many practical difficulties associated with the Carnot vapor cycle can be eliminated in Rankine cycle. The steam coming out of the boiler is usually in superheated state, and expands in the turbine. After expanding in the turbine, the steam is condensed completely in the condenser.
- The Rankine cycle is the ideal cycle for vapor power plants. The ideal Rankine cycle is shown schematically and on a P-v, T-s & h-s diagrams in Fig. 6.2. The liquid, vapor and wet regions are also indicated with the help of saturation curve.

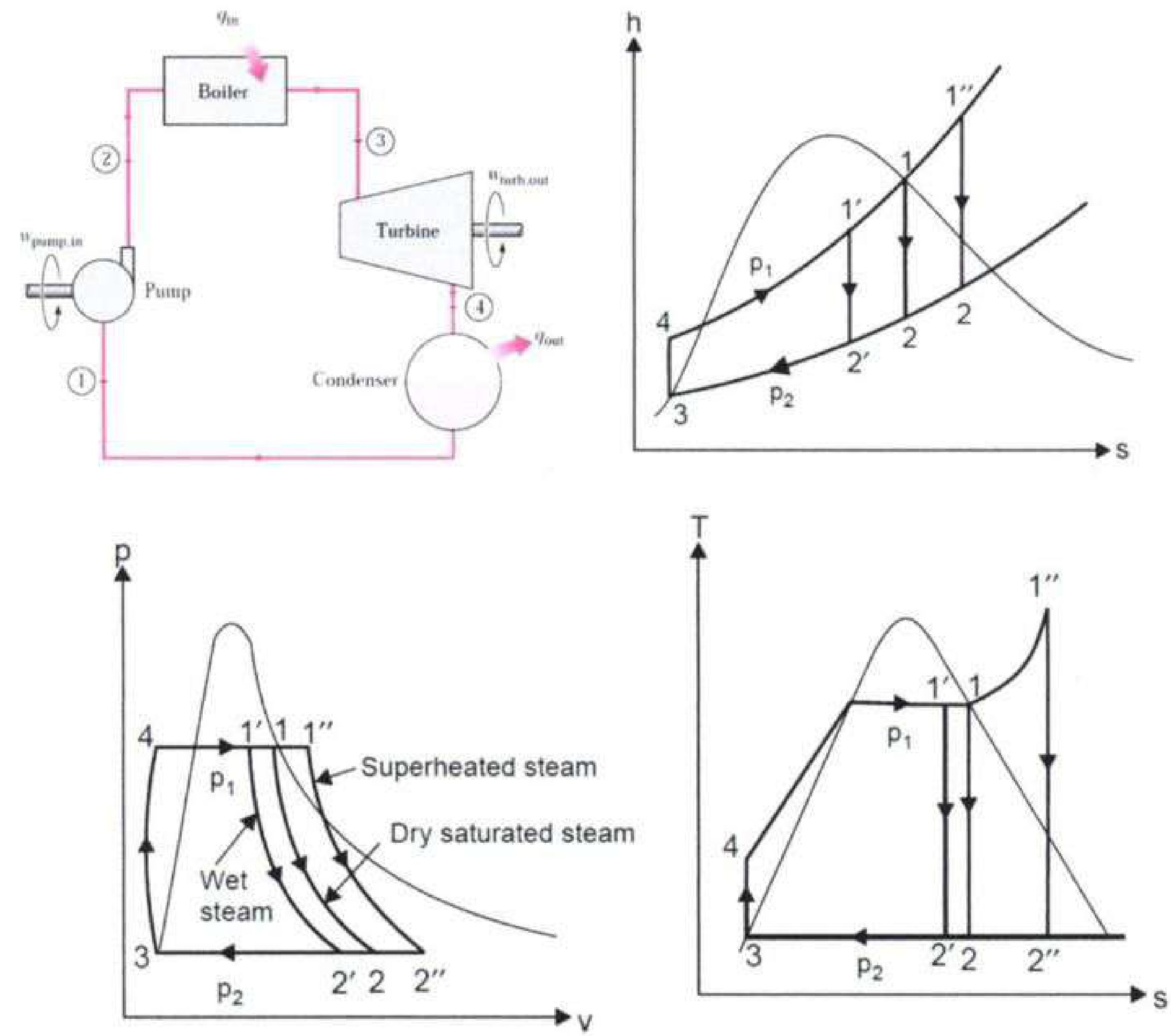

Fig. 6.2 P-v, T-S, h-S and schematic diagram of an ideal Rankine cycle

The ideal Rankine cycle consists of the following four processes:

- **Process 4 – 1: Constant pressure heat addition in the boiler**

  Heat is supplied to the feed water (compressed liquid) in a boiler. Sensible heat and latent heat is supplied to the compressed liquid until the liquid gets converted into superheated steam.
  Heat supplied is given by,

$$q_1 = h_1 - h_4$$

- **Process 1 – 2: Isentropic expansion in the turbine**

  The superheated steam undergoes frictionless adiabatic expansion in the steam turbine and work is done by the system$(+ve)$. Pressure of steam is reduced to condenser pressure.

Turbine work is given by,

$$w_t = h_1 - h_2$$

- **Process 2 – 3: Constant pressure heat rejection in the condenser**

  Steam leaving the turbine (normally wet steam) is condensed at constant pressure in the condenser till the fluid reaches the saturated liquid state 3.

  Heat rejected is given by,

$$q_2 = h_2 - h_3$$

- **Process 3 – 4: Isentropic compression in the pump (Pumping process)**

  The saturated liquid is compressed isentropically in the pump to the boiler pressure at the state 4 and work is done on the liquid($-ve$).

  Pump work is given by,

$$w_p = h_4 - h_3$$

Thermal Efficiency of Rankine Cycle

- Thermal efficiency,

$$\eta = \frac{Net\ Work}{Heat\ Supplied}$$

$$\eta = \frac{w_{net}}{q_1} --------- (6.6)$$

- **Heat supplied** to the working fluid in a boiler during process 4 – 1,

$$q_1 = h_1 - h_4 --------- (6.7)$$

- **Turbine work** during process 1 – 2,

$$w_t = h_1 - h_2 --------- (6.8)$$

- **Heat rejected** during condensation process 2 – 3,

$$q_2 = h_2 - h_3 --------- (6.9)$$

- **Pump work** during process 3 – 4,

$$w_p = h_4 - h_3 --------- (6.10)$$

Where,

$h_3 = h_{f3}$ = Enthalpy of saturated liquid at condenser pressure P_2

h_4 = Enthalpy of compressed liquid at boiler pressure P_1 and can be calculated as,

$$h_4 = h_3 + w_p --------- (6.11)$$

Isentropic compression work for the flow process can be obtained as,

$$w_p = \int_{P_2}^{P_1} v dP = v_{f3}(P_1 - P_2) --------- (6.12)$$

Where,

v_{f3} = Specific volume of liquid at condenser pressure P_2

- The **net work done** of the cycle,

$$w_{net} = w_t - w_p$$

From equation 6.8 and 6.12,

$$\therefore w_{net} = (h_1 - h_2) - v_{f3}(P_1 - P_2) --------(6.13)$$

- From equation 6.6, 6.7 and 6.13,

Thermal efficiency,

$$\eta_{Rankine} = \frac{w_{net}}{q_1} = \frac{(h_1 - h_2) - v_{f3}(P_1 - P_2)}{(h_1 - h_4)} --------(6.14)$$

- Since feed pump work is very small compared to turbine work, w_p is usually neglected.

$$\therefore \eta_{Rankine} = \frac{(h_1 - h_2)}{(h_1 - h_4)} --------(6.15)$$

6.4 Differences Between Carnot and Rankine Cycles

Sr. No.	Carnot Vapor Cycle	Rankine Cycle
1	It is a reversible cycle.	It is an irreversible cycle.
2	It has theoretically maximum efficiency.	It has less thermal efficiency than that of the Carnot vapor cycle.
3	Heat is added at constant temperature.	Heat is added at constant pressure.
4	Use of superheated steam is practically difficult.	It uses superheated steam and performs better.
5	Controlled condensation is required before being saturated liquid.	Complete condensation of steam takes place.
6	Mixture of water and steam exist after condensation.	Only saturated water exists after condensation.
7	It requires a large pump work to handle the two phase mixture.	It requires negligible pump work to handle the liquid water only.
8	Since it uses saturated steam, the moisture content at the end of expansion is much higher which can lead to blade erosion.	It uses superheated steam in the cycle, at the end of expansion; the quality of steam is not objectionable.
9	It is a theoretical cycle and cannot be used in practice.	Almost all thermal power plants operate on Rankine cycle.