Thermal Engineering (1625404) Unit – 4 (4.2)

Lecture Notes by Dr. Thakur Sanjay Kumar Date: - 19-04-20

CARNOT CYCLE

Figure 1 shows a Carnot cycle on T-s and p-V diagrams. It consists of

(i) two constant pressure operations (4-1) and (2-3) and

(ii) two frictionless adiabatics (1-2) and (3-4).

These operations are discussed below:

1. Operation (4-1). 1 kg of boiling water at temperature T_1 is heated to form wet steam of dryness fraction x_1. Thus heat is absorbed at constant temperature T_1 and pressure P_1during this operation.

2. Operation (1-2). During this operation steam is expanded isentropically to temperature T_2 and pressure P_2. The point '2' represents the condition of steam after expansion.

3. Operation (2-3). During this operation heat is rejected at constant pressure P_2 and temperature T_2. As the steam is exhausted it becomes wetter and cooled from 2 to 3.

4. Operation (3-4). In this operation the wet steam at '3' is compressed isentropically till the steam regains its original state of temperature T_1 and pressure P_1. Thus cycle is completed.

From T-s diagram:

Heat supplied at constant temperature T_1 [operation (4-1)] = area 4-1-b-a = $T_1 (s_1 - s_4)$ or $T_1 (s_2 - s_3)$.

Heat rejected at constant temperature T_2 (operation 2-3) = area 2-3-a-b = $T_2 (s_2 - s_3)$.

Since there is no exchange of heat during isentropic operations (1-2) and (3-4)

Net work done = Heat supplied – heat rejected = $T_1 (s_1 - s_4) - T_2 (s_2 - s_3) = (T_1 - T_2) (s_2 - s_3)$.

Carnot cycle η = Work done / Heat supplied

$$\frac{(T_1-T_2)(s_2-s_3)}{(T_1)(s_2-s_3)} = \frac{(T_1-T_2)}{T_1}$$

RANKINE CYCLE

Rankine cycle is the theoretical cycle on which the steam turbine (or engine) works.

The Rankine cycle is shown in Figure. 2. It comprises of the following processes:

Process 1-2: Reversible adiabatic expansion in the turbine (or steam engine).

Process 2-3: Constant-pressure transfer of heat in the condenser.

Process 3-4: Reversible adiabatic pumping process in the feed pump.

Process 4-1: Constant-pressure transfer of heat in the boiler.

Figure .3 shows the Rankine cycle on p-v, T-s and h-s diagrams (when the saturated steam enters the turbine, the steam can be wet or superheated also).

Considering 1 kg of fluid: Applying steady flow energy equation (S.F.E.E.) to boiler, turbine, condenser and pump:

(i) For boiler (as control volume), we get

$h_{f4} + Q_1 = h_1$

$\therefore Q_1 = h_1 - h_{f4}$

(ii) For turbine (as control volume), we get

$h_1 = W_T + h_2$, where W_T = turbine work $\therefore W_T = h_1 - h_2$

(iii) For condenser, we get

$h_2 = Q_2 + h_{f3} \therefore Q_2 = h_2 - h_{f3}$

(iv) For the feed pump, we get

$h_{f3} + W_P = h_{f4}$, where, W_P = Pump work

$\therefore W_P = h_{f4} - h_{f3}$

Now, efficiency of Rankine cycle is given by

$$\eta_{Rankine} = \frac{w_{net}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{(h_1 - h_2) - (h_{f4} - h_{f3})}{(h_1 - h_{f4})}$$

The feed pump handles liquid water which is incompressible which means with the increase in pressure its density or specific volume undergoes a little change.

Using general property relation for reversible adiabatic compression, we get

$Tds = dh - vdp$

$ds = 0 \quad \therefore dh = vdp$ or

$\Delta h = v \Delta p$ (since change in specific volume is negligible)

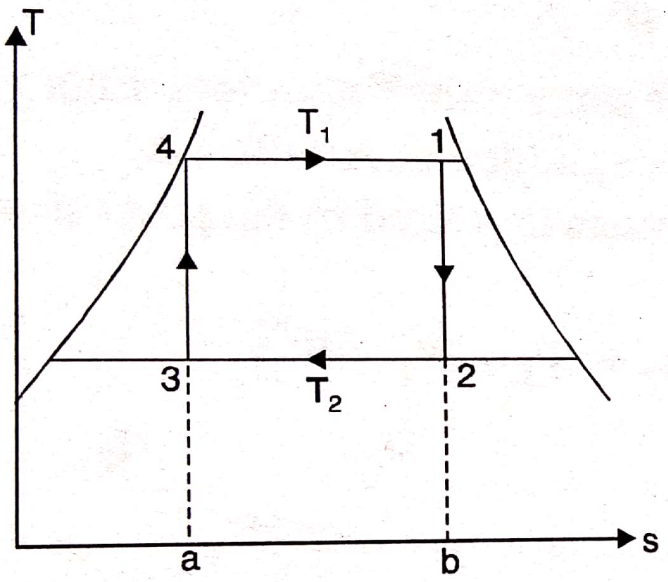
or $h_{f4} - h_{f3} = v_3 (P_1 - P_2)$

When p is in bar and v is in m3/kg,

we have $h_{f4} - h_{f3} = v_3 (P_1 - P_2) \times 10^5$ J/kg

The feed pump term ($h_{f4} - h_{f3}$) being a small quantity in comparison with turbine work, WT, is usually neglected, especially when the boiler pressures are low.

Then $\eta_{Rankine} = \frac{(h_1 - h_2)}{(h_1 - h_{f4})}$



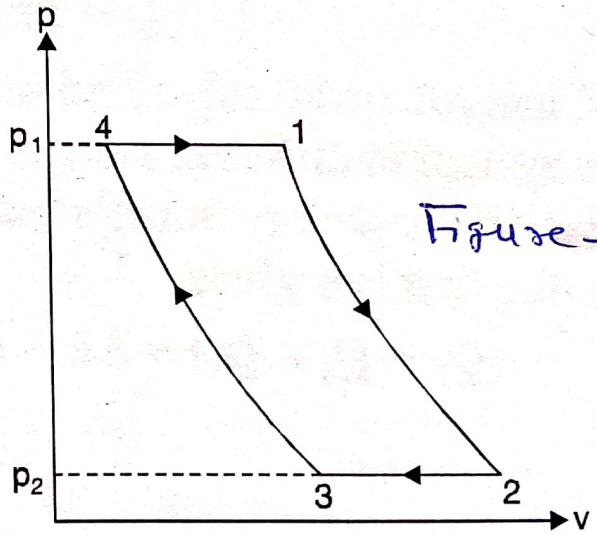


Figure-1

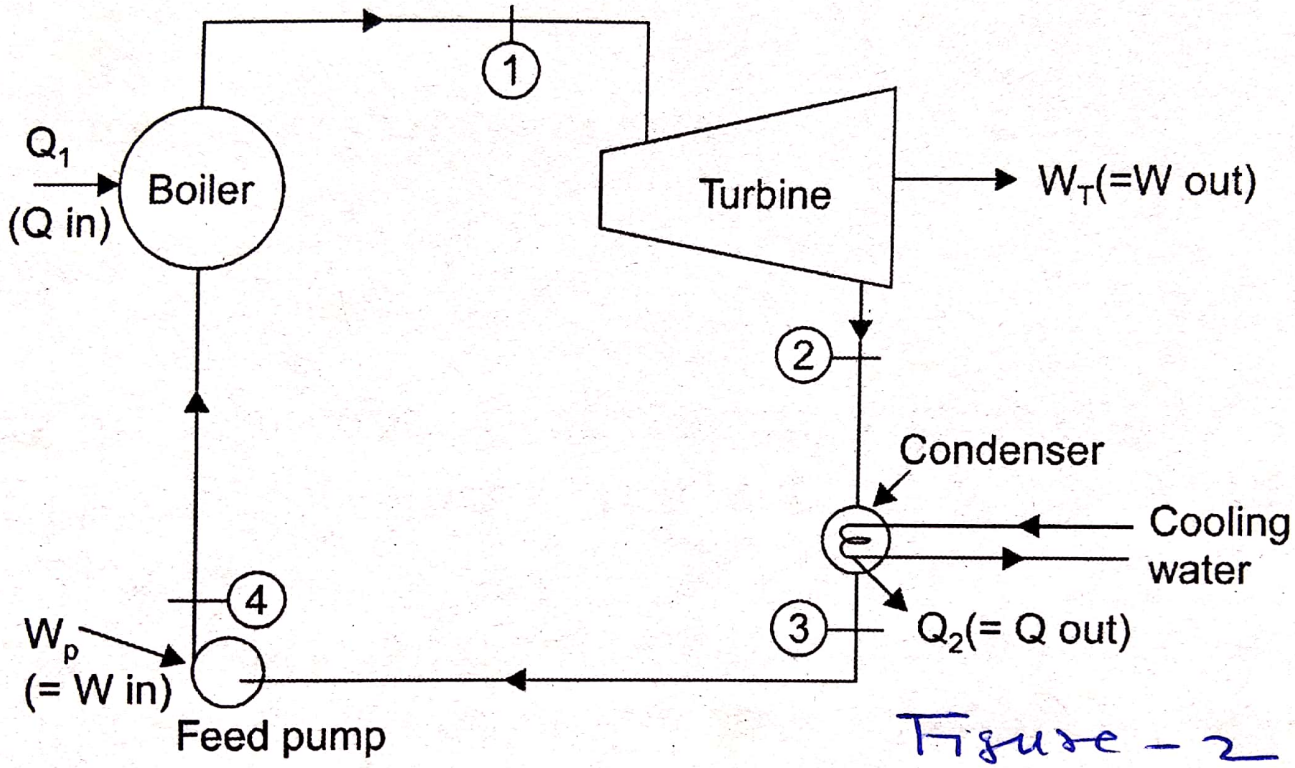


Figure – 2

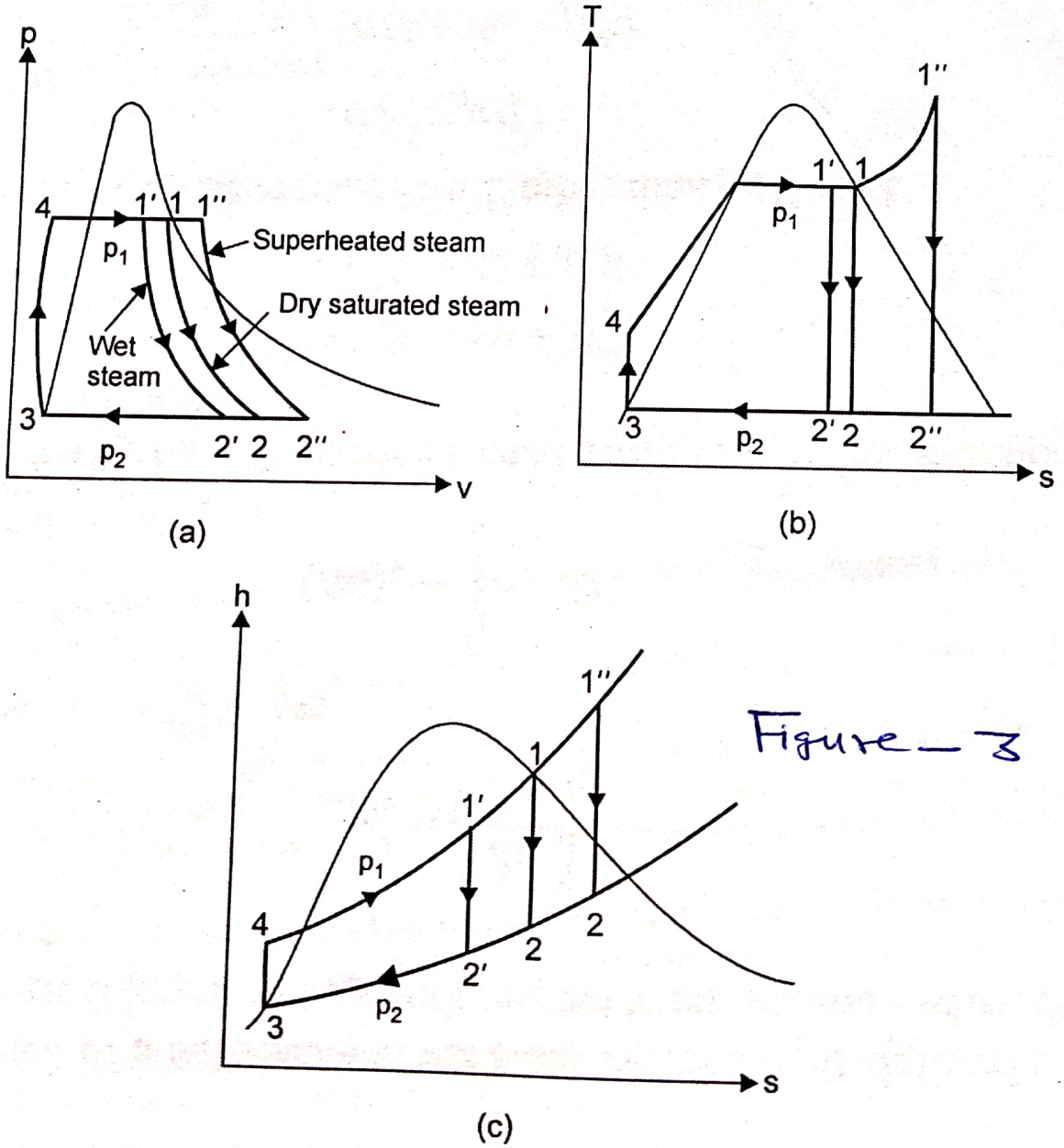


Figure – 3