B.E.

Fourth Semester Examination, Dec-2006

ENERGY CONVERSION

Note : Attempt any five questions.

Q. 1. (a) Explain various heat-losses in a boiler and prepare heat balance sheet.

Ans. The various way of heat loss are :

1. Steam loss.
2. Hot gases loss.
3. Leakage of pressure.
4. Loss due to fear.
5. Loss in transportation.
6. Loss in treatment of water.
7. Loss in circulation.
8. Loss in mounting & accessored.
9. Loss in fere box.

Q. 1. (b) What are boiler accessories and mountings? Explain in brief.

Ans. Boiler moutings : These are different fittings and devices which are necessary for the operation and safety of a boiler. Usually the devices are mounted over boiler shell.

In accordance with the Indian boiler regulation the following mountings should be fitted to the boilers.

* Two safety valves.
* Two water level indicators.
* A pressure gauge.
* A steam stop valve.
* A feed check valve.
* A blow-off cock.
* An attachment for inspector's test gauge.
* A man hole.
* Mud holes or sight holes.

Boiler or Lancashireand Cornish type should be fitted with a high pressure and low water safety value.

All land boiler should have a fusible plug in each furnace.

Boiler accessories : These are auxiliary plants required for steam boilers for their proper operation and fo the increase of their efficiency. Commonly used boiler accessories are :

* Feed pumps

* Injector
* Economiser
* Air preheater
* Superheater
* Steam separator
* Steam trap.

Water level indicator : The function of a water level indicator is to indicate the level of water in the boiler constantly. It is also called water gauge. Normally two water level indicators are fitted at the front end of every boiler. Where the boiler drum is situated at considerable height from the floor, the water gauge is often inclined to make the water level visible from any position. When the water being heated in the boiler transforms into steam the level of water in the boiler shell goes on decreasing. For the proper working of the boiler, the water must be kept at safe-level. If the water level falls below the safe level and the boiler goes on producing steam without the addition of feed water, great damage like crack and leak can occur to the parts of the boiler which get uncovered from water. This can result in the stoppage of steam generation and boiler operation.

Pressure gauge : The function of a pressure guage is to measure the pressure exerted inside the vessel. The gauge is usually mounted on the front top of the shell or the drum. It is usually constructed to indicate upto double the maximum working pressure. Its dial is graduated to read pressures in kgf / cm^2 (or bar) gauge (i.e., above atmospheric). There are two types of pressure gauges : (i) Bourdon tube pressure gauge and (ii) Diaphragm type pressure gauge. A pointer, which rotates over a circular graduated scale, indicates the pressure.

High steam and low water safety valve : The high steam and low water safety valve serves the following purposes : (i) The steam automatically escapes out when the level of water falls below a certain level. (ii) It automatically discharges the excess steam when the pressure of the steam rises above a certain pressure. This is a single device in which two valves are combined in one to serve the above mentioned purposes.

Injector : The function of an injector is to feed water into the boiler. It is commonly employed for vertical and locomotive boilers and does not find its application in large capacity high pressure boilers. It is also used where the space is not available for the installation of a feed pump.

In an injector the water is delivered to the boiler by steam pressure; the kinetic energy of steam is used to increase the pressure and velocity of the feed water.

Economiser : An economiser is a device in which the waste heat of the flue gases is utilised for heating the feed water.

Economiser are of the two types : (i) Independent type, and (ii) Integral type. Former is installed in chamber apart from the boiler setting. The chamber is situated at the passage of the flow of the flue gases from the boiler or boiler to the chimney. Latter is a part of the boiler heating surface and is installed within the boiler setting.

Q. 2. (a) What do you understand by efficiency of a boiler and equivalent evaporation?

Ans. Efficiency of a reversible heat engine in which heat is received solely at T_1 is found to be

$$\eta_{rev} = \eta_{max} = 1 - \left(\frac{Q_2}{Q_1}\right)_{rew.} = 1 - \frac{T_2}{T_1}$$

$$\eta_{rev} = \frac{T_1 - T_2}{T_1}$$

As T_2 decreases & T_1 increases, the efficiency of reversible cycle increases.

Since n is away less than unity, T_2 is always greater than zero & +ve.

Q. 2. (b) Explain in brief with a neat sketch the constructional features and working of a Water tub boiler.

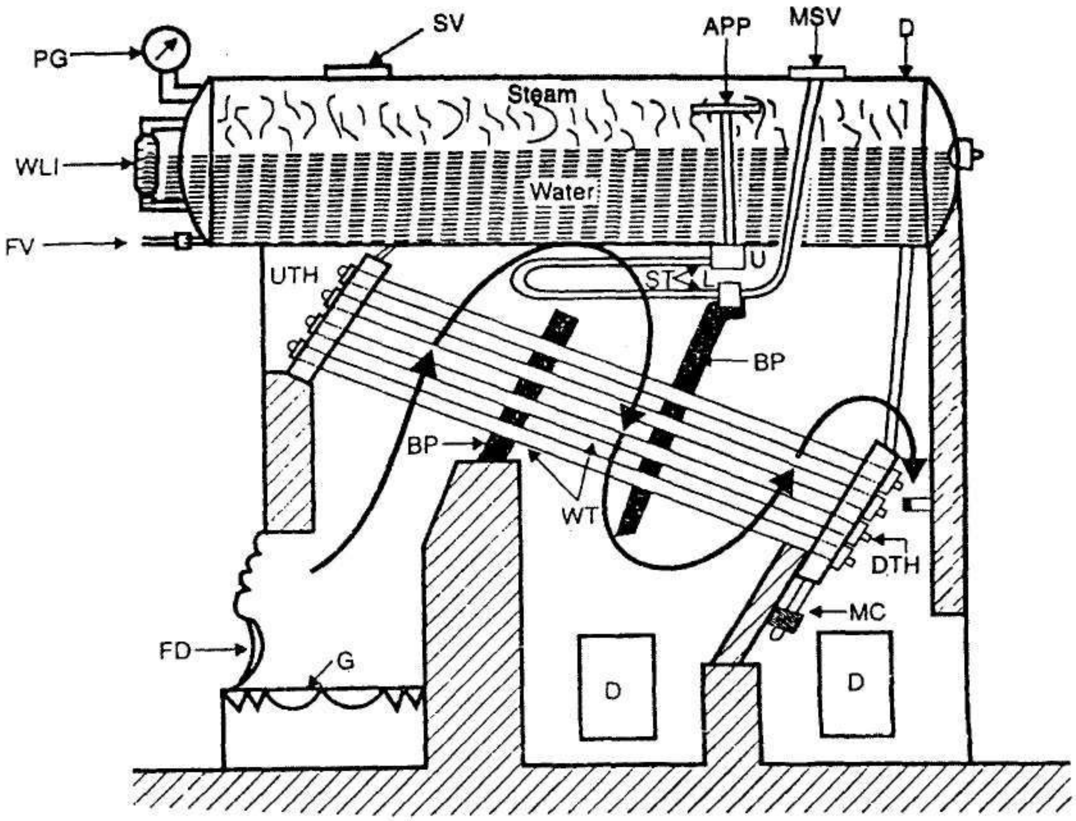
Ans. Babcock and wilcox water-tube boiler : The water tube boilers are used exclusively, when pressur above 10 bar and capacity in excess of 7000 kg of steam per hour is required. Babcock and Wilcox water-tub boiler is an example of horizontal straight tube boiler and may be designed for stationary or marine purpose:

The particulars (dimensions, capacity etc.) relating to this boiler are given below :

Diameter of the drum	....	1.22 to 1.83 m
Length	...	6.096 to 9.144 m
Size of the water tubes	...	7.62 to 10.16 cm
Size of superheater tubes	...	3.84 to 5.71 cm
Working pressure	...	40 bar (max.)
Steaming capacity	...	40000 kg/h (max.)
Efficiency	...	60 to 80%

Fig. 1. shows a Babcock and Wilcox boiler with longitudinal drum. It consists of a drum connected to series of front end and rear end header by short rise tubes. To these headers are connected a series of incline water tubes of solid drawn mild steel.

The angle of inclination of the water tubes to the horizontal is about 15° or more. A hand hole i provided in the header in front of each tube for cleaning and inspection of tubes. A feed valve is provide to fill the demand inclined tubes with water the level of which is indicated by the water level indicato Through the fire door the fuel is supplied to grate where it is burnt. The hot gases are forced to mov upwards between the tubes by baffle plates provided. The water from the drum flows through the incline tubes via downtake header and goes back into the shell in the form of water and steam viz uptake header. Th steam gets collected in the steam space of the drum. The stream then enters through the antipriming pipe an flows in the superheater tube where it is further heated and is finally taken out through the main stop valv and supplied to the engine when needed.



D = Drum

DTH = Down take header

WT = Water tubes

BP = Baffle plates

D = Doors

G = Grate

FD = Fire door

MC = Mud collector

WLI = Water level indicator

PG = Pressure gauge

ST = Superheater tubes

SV = Safety valve

MSV = Main stop valve

APP = Antipriming pipe

L = Lower junction box

U = Upper junction box

FV = Feed valve

Fig. Babcock and Wilcox boiler

At the lowest point of the boiler is provided a mud collector to remove the mud particles through a blow-down-cock.

The entire boiler except the furnace are hung by means of metallic slings or straps or wrought iron girders supported on pillars. This arrangement enables the drum and the tubes to expand or contract freely. The brickwork around the boiler encloses the furnace and the hot gases.

The various mounting used on the boiler are shown in fig. 1.

A Babcock Wilcox water tube boiler with cross draw differs from longitudinal drum boiler in a way that how drum is placed withy reference to the axis of the water tubes of the boiler. The longitudinal drum restricts the number of tubes that can be connected to one drum circumferentially and limits the capacity of the boiler. In the cross drum there is no limitation of the number of connecting tubes.

The pressure of steam in case of cross drum boiler may be as high as 100 bar and steaming capacity utpc 27000 kg/h.

Q. 3. In a simple impulse turbine, the steam velocity at inlet is 500 m/s. The blade speed is 150m/sec. The nozzle angle is 15°. Determine the inlet blade angle. If there is a frictional drop of 8% in the relative velocity at outlet and if the outlet blade angle is 2° more than the angle at inlet determine the power developed and the axial thrust for a flow rate of 10 kg/min.

Ans. Steam velocity $C_1 = 500\,\text{ms}$

Blade sped $C_{pl} = 150\,\text{m/sec}$

Angle $\beta = 80°$

Friction loss in blade channel $= 8\%$

Outlet angle $= 18°$

Now
$$C_{bl} = \frac{\pi DN}{60}$$

$$150 = \frac{\pi}{60}(DN)$$

$$DN = \frac{150 \times 60}{\pi}$$

Draw the velocity diagram for the problem.

Thus calculate CW 1

CW0

Cf1

Cf0

Axial thrust $C = m_s(Cf_1 - Cf_0)$

Power developed

$$= \frac{m_s(C\omega_1 + C\omega_0)]}{1000} bl$$

Q. 4. Explain what is meant by governing and describe the various methods of governing in steam ırbines.

Ans. Steam Turbine Governing and Control : The objective of governing is to keep the turbine speed ıirly constant irrespective of load.

The principal method of steam turbine governing are as follows :

1. Throttle governing.
2. Nozzle governing
3. By-pass governing
4. Combination of 1 and 2 and 1 and 3.

1. Throttle governing : Throttle governing is the most widely used particularly on small turbines, because ; initial cost is less and the mechanism is simple. The object of throttle governing is to throttle the steam henever there is a reduction of load compared to economic or design load for maintaining speed and vice-ːrsa.

Fig. 6 (a) shows a simple throttle arrangement. To start the turbine for full load running valve A is opened. ıe operation of double beat valve B is carried out by an oil servo motor which is controlled by a centrifugal ·vernor. As the steam turbine gains speed the valve B closes to throttle the steam and reduces the supply to zzle.

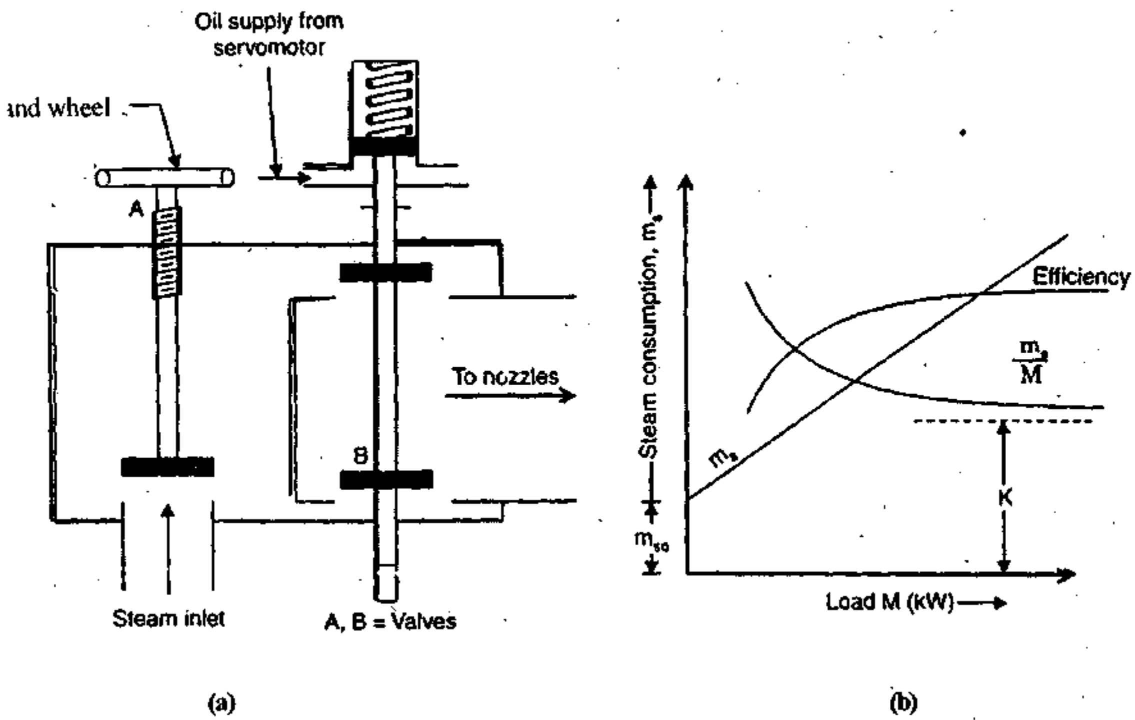


Fig. Throttle governing

For a turbine governed by throttling the relationship between steam consumption and load is given b the well known Willan's line as shown in fig. 19.56 (a). Several tests have shown that when a turbine is governe by throttling, the Willan's line is straight. It is expressed as :

$$m_s = KM + m_{s0} \quad ...($$

Where, $\dot{m}_s$ = Steam consumption in kg/h at any load M,

m_{s0} = Steam consumption in kg/h at no load,

m_{s1} = Steam consumption in kg/h at full load,

M = Any other load in kW,

M_1 = Full load in kW, and

K = Constant.

m_{s0} varies from about 0.1 to 0.14 times the full load consumption. The equations (1) can also be writte as :

$$\frac{m_s}{M} = K + \frac{m_{s0}}{M}, \quad \frac{m_s}{M} \text{ is called the steam consumption per kWh.}$$

2. Nozzle governing : The efficiency of a steam turbine is considerably reduced if throttle governing carried out at low loads. An alternative, and more efficient form of governing is by means of nozzle control. Fi 7 shows a diagrammatic arrangement of typical nozzle control governing. In this method of governing, tl nozzles are grouped together 3 to 5 more groups and supply of steam to each group is controlled by regulatir valves. Under full load conditions the valves remain fully open.

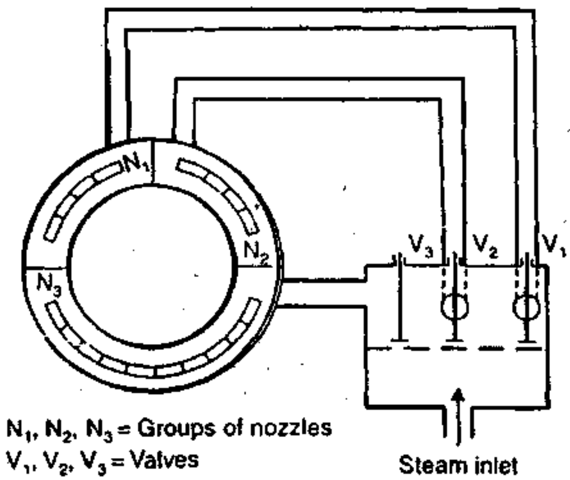


Fig. Nozzle governing

When the load on the turbine becomes more or less than the design value, the supply of steam to a group of nozzles may be varied accordingly so as to restore the original speed.

Nozzle control can only be applied to the first stage of a turbine. It is suitable for simple impulse turbine and larger units which have an impulse stage followed by an impulse-reaction turbine. In pressure compounded impulse turbines, there will be some drop in pressure at entry to second stage when some of the first stage nozzles are cutout.

Q. 5. (a) Define vacuum efficiency and explain how it effects plant performance.

Ans. It is difference between the outlet and inlet temperatures of cooling water to the difference between temperature corresponding to the vacuum in the condenser and inlet the temperature of cooling water, i.e.,

Condenser efficiency :

$$\frac{\text{Rise in kmp. of cooling water}}{\begin{bmatrix}\text{Temperature corresponding to}\\ \text{vacuum in condenser}\end{bmatrix} - \begin{bmatrix}\text{Inlet temperature of}\\ \text{cooling water}\end{bmatrix}}$$

$$\text{Or } \frac{\text{Rise in temperature of cooling water}}{\begin{bmatrix}\text{Temperature corresponding to}\\ \text{absolute pressure in condenser}\end{bmatrix} - \begin{bmatrix}\text{Inlet temperature of}\\ \text{cooling water}\end{bmatrix}}.$$

Q. 5. (b) In a steam condenser, the average temperature is 34°C. The vacuum is 680 mm Hg when the barometer reads 762 mmHg. The water enters at 25° C and leaves at 32°C. Determine the condenser efficiency. Also determine vacuum efficiency.

Ans. $t\omega_1 = 25°C$

$t\omega_2 = 32°C$

Absolute pressure :

$$= 762 - 608 \text{ mm}$$

$$= 154 \text{ mm}$$

$$= 154 \times .001333 \text{ bar}$$

From steam table corresponding to 34°C, 154 × .001333 bar.

Condenser efficiencies

$$= \frac{\text{Rise in temperature}}{\text{Temperature corresponding to vacuum} - \text{Inlet temperature of work}}$$

$$= \frac{32-25}{34-30} = \frac{7}{4}\%.$$

Q. 6. (a) Define volumetric efficiency of reciprocating air compressor and derive an expression for t same.

Ans. Volumetric efficiency : The volumetric efficiency of a compressor is the ratio of free air delivered the displacement of the compressor. It is also the ratio of effective swept volume to the swept volume.

i.e., Volumetric efficiency $= \dfrac{\text{Effective swept volume}}{\text{Swept volume}} = \dfrac{V_1 - V_4}{V_1 - V_3}$ ...(

Because of presence of clearance volume, volumetric efficiency is always less than unity. As a percer age, it usually varies from 60% to 85%.

The ratio, $\dfrac{\text{Clearance volume}}{\text{Swept volume}} = \dfrac{V_3}{V_1 - V_3} = \dfrac{V_c}{V_s} = k$ ...(

It is the clearance ratio.

As a percentage, this ratio will have a value, in general, of between 4% and 10%. The greater the pressu ratio through a reciprocating compressor, then the greater will be the effect of the clearance volume since tl clearance air will now expand through a greater volume before intake conditions are reached. The cylinder si and stroke being fixed, however, will mean that $(V_1 - V_4)$, the effective swept volume, will reduce as tl pressure ratio increases and thus the volumetric efficiency reduces.

Volumetric efficiency, $\eta_{vol.} = \dfrac{V_1 - V_4}{V_1 - V_3}$

$$= \frac{(V_1 - V_3) + (V_3 - V_4)}{(V_1 - V_3)} = 1 + \frac{V_3}{V_1 - V_3} - \frac{V_4}{V_1 - V_3}$$

$$= 1 + \frac{V_3}{V_1 - V_3} - \frac{V_4}{V_1 - V_3} \cdot \frac{V_3}{V_3} = 1 + \frac{V_3}{V_1 - V_3} - \frac{V_3}{V_1 - V_3} \cdot \frac{V_4}{V_3}$$

$$= 1 + k - k \cdot \frac{V_4}{V_3}$$

$$= 1 + k - k\left(\frac{p_3}{p_4}\right)^{1/n} \qquad \left| \begin{array}{l} p_3 V_3^n = p_4 V_4^n \\ \dfrac{V_4}{V_3} = \left(\dfrac{p_3}{p_4}\right)^{1/n} \end{array} \right|$$

Or $$\eta_{vol.} = 1 + k - k\left(\frac{p_2}{p_1}\right)^{1/n} \qquad (\because p_3 = p_2, p_4 = p_1)$$ ...(3

Or $$\eta_{vol.} = 1 + k - k\left(\frac{V_1}{V_2}\right) \qquad ...(4)$$

The above equations are valid if the index of expansion and compression is same. However, it may be noted that the clearance volumetric efficiency is dependent on only the index of expansion of the clearance volume from V_3 to V_4. Thus, if the index of compression $= n_c$ and index of expansion $= n_e$, the volumetric efficiency is given by,

$$\eta_{vol.} = 1 + k - k\left(\frac{p_3}{p_4}\right)^{1/n_e} \qquad ...(5)$$

$$= 1 + k - k\left(\frac{p_2}{p_1}\right)^{1/n_e} \qquad ...(6)$$

$$= 1 + k - k\left(\frac{V_4}{V_3}\right) \qquad ...(7)$$

In this case volumetric efficiency $= 1 + k - k\left(\frac{V_1}{V_2}\right)$.

In practice the air that is sucked in during the induction (suction) stroke gets heated up while passing through the hot valves and coming in contact with hot cylinder walls. There is wire drawing effect through the valves resulting in drop in pressure. Thus the ambient conditions are different from conditions obtained at state 1.

Let $p_{amb.}$ = Pressure of ambient air, and

$T_{amb.}$ = Temperature of ambient air.

$$\therefore \quad \frac{p_{amb.}V_{amb.}}{T_{amb.}0} = \frac{p_1(V_1 - V_4)}{T_1}$$

Thus, $$V_{amb.} = \frac{p_1 \times T_{amb.}}{T_1 \times p_{amb.}} \times (V_1 - V_4)$$

Thus volumetric efficiency referred to ambient conditions may be written as

$$\eta_{vol.(amb.)} = \frac{V_{amb.}}{V_1 - V_3} = \frac{p_1 \times T_{amb.}}{T_1 \times p_{amb.}} \times \frac{V_1 - V_4}{V_1 - V_3}$$

But from equation

$$\frac{V_1 - V_4}{V_1 - V_3} = 1 + k - k\left(\frac{p_2}{p_1}\right)^{1/n}$$

$$\therefore \quad \eta_{vol\,(amb.)} = \frac{p_1 \times T_{amb.}}{T_1 \times p_{amb.}}\left[1 + k - k\left(\frac{p_2}{p_1}\right)^{1/n}\right] \quad ...(8$$

$$= \frac{p_1 \times T_{amb.}}{T_1 \times p_{amb.}}\left[1 + k - k\left(\frac{V_2}{V_1}\right)\right] \quad ...(9$$

Q. 6. (b) A reciprocating compressor has a bore of 25 cm and stroke of 30 cm and runs at 360 rpm. The clearance is 6% of stroke volume. Determine the volume of free air delivered at 1 bar and 20°C, which is the inlet condition. The pressure ratio is 6. If the pressure ratio is increased to 9 determine the percentage change in volume delivered. Also determine the pressure at which there will be no delivery. Assume $pV^{1.4}$ = constant as the law for compression in all cases.

Ans.

$$D = 25\text{cm}$$

$$L = 30\text{cm}$$

$$V = \text{Volume} = \frac{\pi}{4}D^2 V = \frac{\pi}{4} \times 25 \times 25 \times 30$$

$$\text{Clearance} = \frac{6}{100} \times V = \frac{6}{100}\left(\frac{\pi}{4} \times 25 \times 25 \times 30\right)$$

$$\frac{P_2}{P_1} = 6$$

$$\text{Now } \frac{P_2^1}{P_1^1} = 15^{\circ}$$

Now $Cl + \omega + D_0$

$$\omega = mRT\frac{n}{n-1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} - 1\right] \quad ...(1$$

$$\frac{p_2}{p_1} = 15$$

$$P_1 = 1 \text{ bar}$$

$$T_1 = 20^\circ C$$

Thus, solve equation 1.

Q. 7. (a) Discuss the effect of superheat, maximum pressure and exhaust pressure on the performance f Rankine cycle.

Ans. Now, efficiency of Rankine cycle is given by,

$$\eta_{Rankine} = \frac{W_{net}}{Q_1} = \frac{W_T - W_P}{Q_1}$$

$$= \frac{(h_1 - h_2) - (h_{f_4} - h_{f_3})}{(h_1 - h_{f_4})} \qquad ...(1)$$

The feed pump handles liquid water which is incompressible which means with the increase in pressure its ensity or specific volume undergoes a little change. Using general property relation for reversible adiabatic ompression, we get

$$Tds = dh - vdp$$

$\because$ $$ds = 0$$

$\therefore$ $$dh = vdp$$

Or $$\Delta h = v\Delta p \qquad \text{...(since change in specific volume is negligible)}$$

Or $$h_{f_4} - h_{f_3} = v_3(p_1 - p_2)$$

When p is in bar and v is in m^3/kg, we have

$$h_{f_4} - h_{f_3} = v_3(p_1 - p_3) \times 10^5 \text{ J/kg}$$

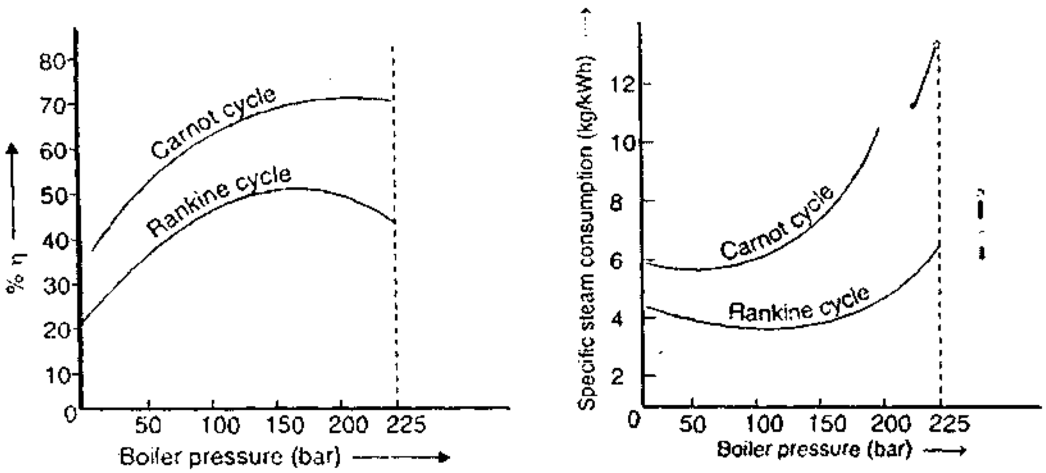
The feed pump term $(h_{f_4} - h_{f_3})$ being a small quantity in comparison with turbine work, W_T, is usually eglected, especially when the boiler pressure are low.

Then, $$\eta_{Rankine} = \frac{h_1 - h_2}{h_1 - h_{f_4}}$$

Effect of Operating Conditions on Rankine Cycle Efficiency : The Rankine cycle efficiency can b improved by :

(i) Increasing the average temperature at which heat is supplied.

(ii) Decreasing/reducing the temperature at which heat is rejected.



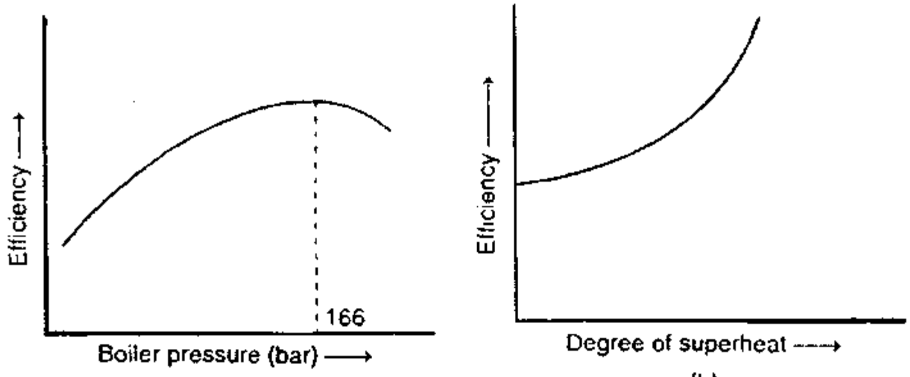
(a) (b)

This can be achieved by making suitable changes in the conditions of steam generation or condensatio as discussed below :

1. Increasing Boiler Pressure : It has been observed that by increasing the boiler pressure (other facto remaining the same) the cycle tends to rise and reaches a maximum value at a boiler pressure of about 166 ba

2. Superheating : All other factors remaining the same, if the steam is superheated before allowing it t expand the Rankine cycle efficiency may be increased [Fig. 15.5 (b)]. The use of superheated steam als ensures longer turbine blade life because of the absence of erosion from high velocity water particles that a suspended in wet vapour.

3. Reducing Condenser Pressure : The thermal efficiency of the cycle can be amply improved by redu ing the condenser pressure (hence by reducing the temperature at which heat is rejected), aseptically in hig vacuums. But the increase in efficiency is obtained at the increased cost of condensation apparatus.



Q. 7. (b) Derive an expression for the air standard efficiency of the otto cycle and comment upon.

Ans. Constant Volume or Otto Cycle : This cycle is so named as it was conceived by 'Otto'. On this cycle, trol, gas and many types of oil engines work. It is the standard of comparison for internal combustion gines.

Fig. (a) and (b) shows the theoretical p-V diagram and T-s diagrams of this cycle respectively.

* The point 1 represents that cylinder is full of air with volume V_1, pressure p_1 and absolute temperature T_1.
* Line 1-2 represents the adiabatic compression of air due to which p_1, V_1 and T_1 change to p_2, V_2 and T_2 respectively.
* Line 2-3 shows the supply of heat to the air at constant volume so that p_2 and T_2 change to p_3 and T_3 (V_3 being the same as V_2).
* Line 3-4 represents the adiabatic expansion of the air. During expansion p_3, V_3 and T_3 change to a final value of p_4, V_4 or V_1 and T_4 respectively.
* Line 4-1 shows the rejection of heat by air at constant volume till original state (point 1) reaches.

Consider 1 kg of air (working substance) :

Heat supplied at constant volume $= c_v(T_3 - T_2)$

Heat rejected at constant volume $= c_v(T_4 - T_1)$.

But, work done = Heat supplied–Heat rejected

$$= c_v = (T_3 - T_2) - c_v(T_4 - T_1)$$

$\therefore$ Efficiency $= \dfrac{\text{Work done}}{\text{Heat supplied}} = \dfrac{c_v(T_3 - T_2) - c_v(T_4 - T_1)}{c_v(T_3 - T_2)}$

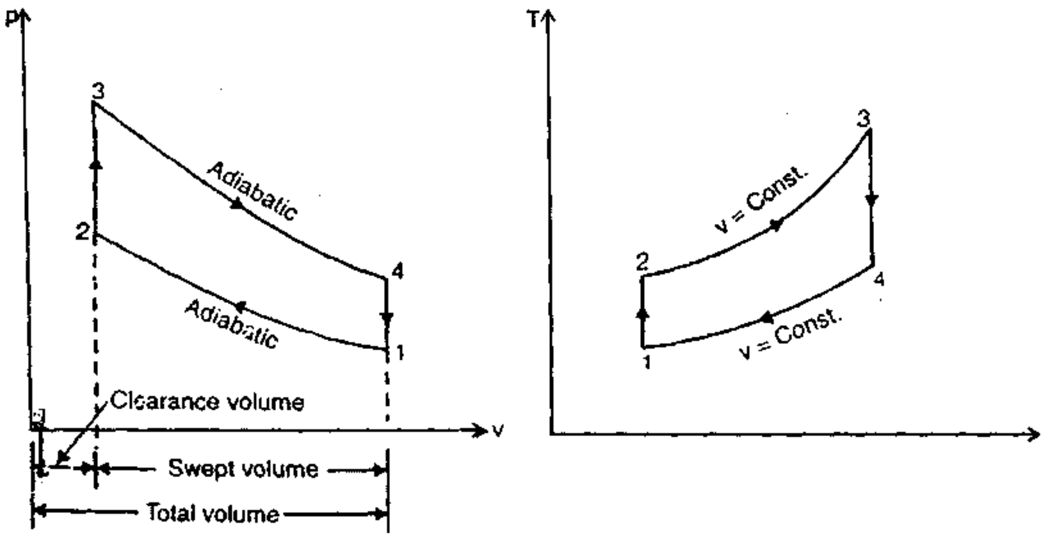
$$= 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

Let compression ratio, $r_c (= r) = \dfrac{v_1}{v_2}$

And expansion ratio, $r_e (= r) = \dfrac{v_4}{v_3}$

(These two ratios are same in this cycle)

As $\dfrac{T_2}{T_1} = \left(\dfrac{v_1}{v_2}\right)^{\gamma - 1}$



Then, $T_2 = T_1.(r)^{\gamma-1}$

Similarly, $\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma-1}$

Or $T_3 = T_4.(r)^{\gamma-1}$

Inserting the values of T_2 and T_3 in equation (i), we get

$$\eta_{otto} = 1 - \frac{T_4 - T_1}{T_4.(r)^{\gamma-1} - T_1.(r)^{\gamma-1}} = 1 - \frac{T_4 - T_1}{r^{\gamma-1}(T_4 - T_1)}$$

This expression is known as the air standard efficiency of the Otto cycle.