

Steam power plant

Rankin cycle :-

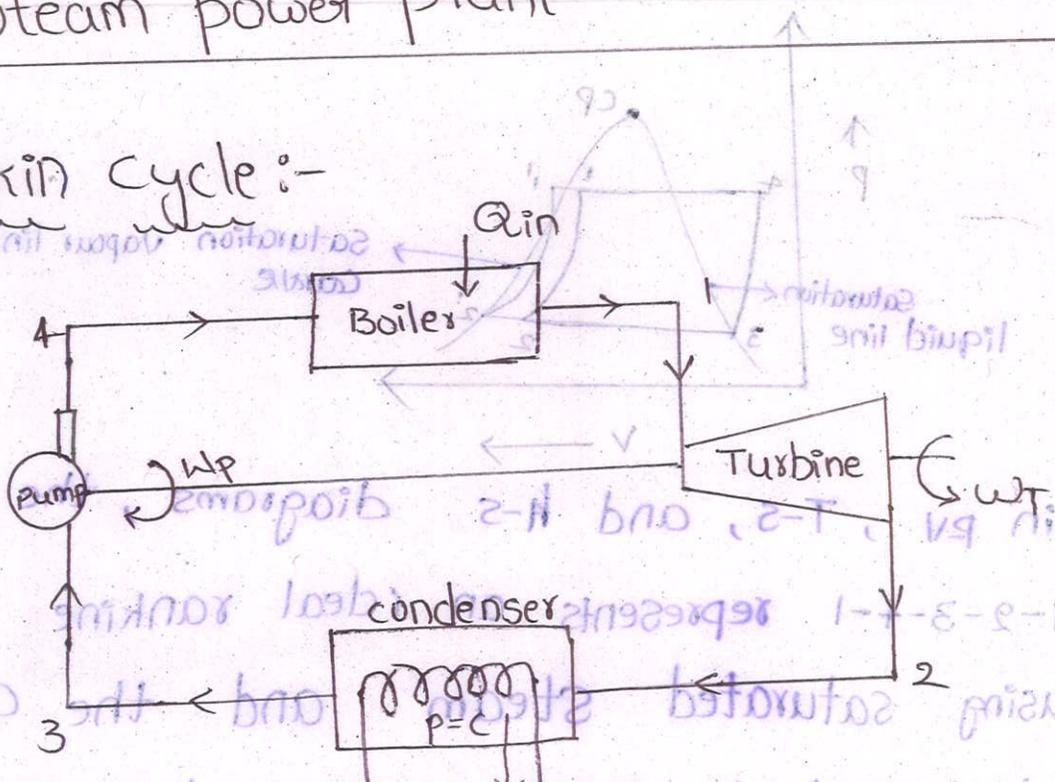


Fig :- Basic components of vapour power cycle

Many of the practical difficulties associated with the Carnot vapour power cycle are eliminated in Rankine cycle.

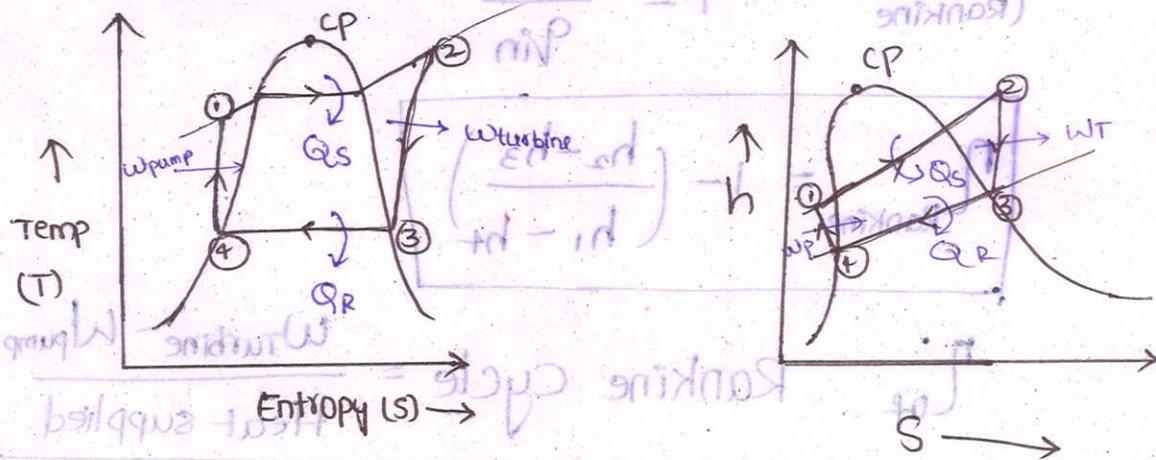
→ The steam coming out of the boiler is usually in superheated state, and expands in the turbine.

→ After expanding in the turbine, the steam is condensed completely in the condenser.

→ The Rankin cycle as shown in figure

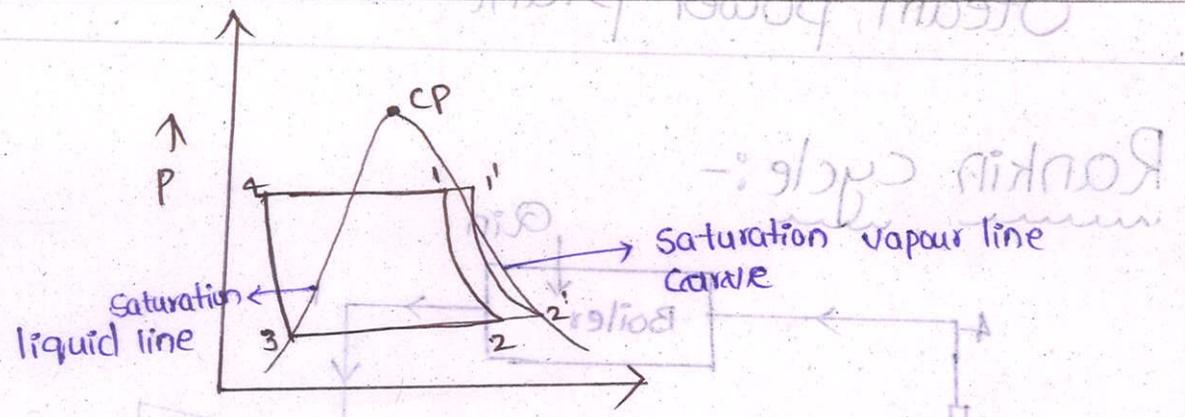
is an ideal vapour power cycle and

is used in steam power plants.



24/11/2024 Unit-1, Pg-1/46

Steam power plant



Rankine cycle:-
 in PV, T-s, and h-s diagrams, the cycle 1-2-3-4-1 represents an ideal Rankine cycle using saturated steam and the cycle 1'-2'-3'-4'-1' represents an ideal Rankine cycle with superheated steam at the entry of turbine.

Rankine cycle consists of four processes:

- (i) Isentropic expansion
- (ii) Heat rejection
- (iii) Isentropic compression
- (iv) Heat addition

Efficiency of Rankine cycle is an ideal vapor cycle.

$$\eta_{Rankine} = \frac{q_{out}}{q_{in}}$$

$$\eta_{Rankine} = 1 - \frac{h_2 - h_3}{h_1 - h_4}$$

$$\eta_{Rankine} = \frac{W_{turbine} - W_{pump}}{\text{Heat supplied}}$$

* Thermodynamic analysis :-
 it is used to understand better performance of system and to identify the source of losses due to irreversibilities in the system.

→ The relationship between energy efficiency and capital cost must be based on an analysis of the overall plant system,

→ Thermodynamic analysis methods are,

(i) Analysis of pitch

(ii) Energy Analysis

(iii) second law analysis

→ these methods are combined to analyze process and energy system.

From T-s and h-s diagrams

①-② → isobaric heat addition $Q_s = h_2 - h_1$

②-③ → isentropic expansion

$$W_T = h_3 - h_2$$

③-④ → isobaric heat rejection

$$Q_R = h_3 - h_4$$

④-① → isentropic compression

$$W_P = h_1 - h_4$$

Efficiency of Rankine cycle = $\frac{\text{output}}{\text{input}}$

$$\eta_{\text{Ran}} = \frac{W_T - W_P}{\text{Heat supplied}}$$

$$= \frac{h_3 - h_2 - (h_1 - h_4)}{h_2 - h_1}$$

$$= \frac{h_3 - h_2 - h_1 + h_4}{h_2 - h_1}$$

$$= \frac{h_3 - h_2}{h_2 - h_1} - \frac{h_1 - h_4}{h_2 - h_1}$$

(or)

$$\eta_{\text{Ran}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}}$$

$$= 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}}$$

$$\eta_{\text{Ran}} = 1 - \frac{h_2 - h_3}{h_1 - h_4}$$

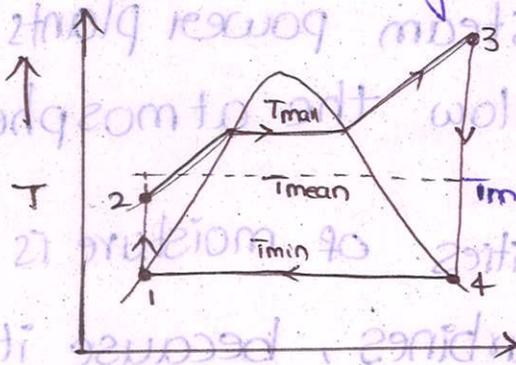
Relative efficiency of Rankine cycle is

$$\eta_{\text{Relative}} = \frac{\text{Actual thermal efficiency}}{\text{Rankin efficiency}}$$

Concept of temperature on heat addition:

Always mean temperature of heat addition is defined with respect to Carnot cycle.

Since it gives maximum efficiency among all standard cycles.



→ We can say that T_m is the constant temperature at which the same amount of heat can be added ($h_2 - h_1$) in ideal Rankine cycle.

→ If the work of turbine can be increased then the efficiency will increase.

→ If we can increase the pressure then the area also increases due to this

increase in area the efficiency of boiler also increases.

→ Colored area on this diagram represents increase in net work output as a result of

Method to improve cycle performance:-

(i) By increasing throttle temperature

(ii) increasing throttle pressure

(iii) decreasing the condenser pressure

→ The condensers of steam power plants usually operate well below the atmospheric pressure.

→ presence of large quantities of moisture is highly undesirable in turbines, because it decreases in the turbine efficiency and destroy the turbine blades.

→ maximum steam temperature at turbine inlet is fixed by the materials used.

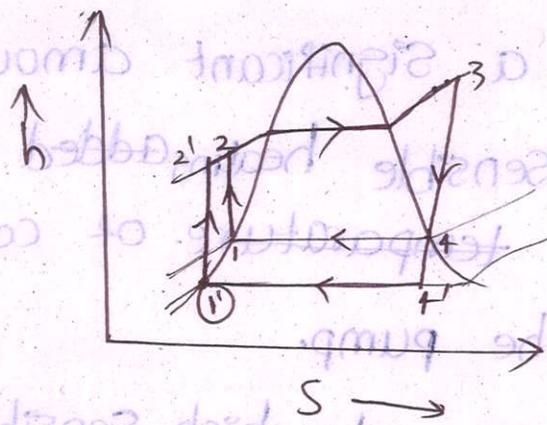
→ minimum temperature of heat rejection is fixed by the ambient conditions.

→ minimum quality of steam at the turbine exhaust is fixed by turbine blade erosion.

→ maximum steam pressure at the turbine inlet also gets fixed.

→ colored area on this diagram^(h-s) represents increase in net work output as a result of

lowering the condenser pressure from p_1 to p_2



Heat input requirements also increase (represented by the area under curve 2-2') but this increase is very small.

Overall effect of lowering the condenser pressure (lowers temperature at which heat is rejected) is an increase in efficiency.

When we increase the throttle temperature work of turbine increases and then efficiency of Rankine cycle is also increased.

When we increase the throttle pressure by increase in length then w_T increases and efficiency also increases.

By decreasing condenser pressure is nearer to atmosphere pressure so, due to more than atmospheric pressure we can't reduce pressure.

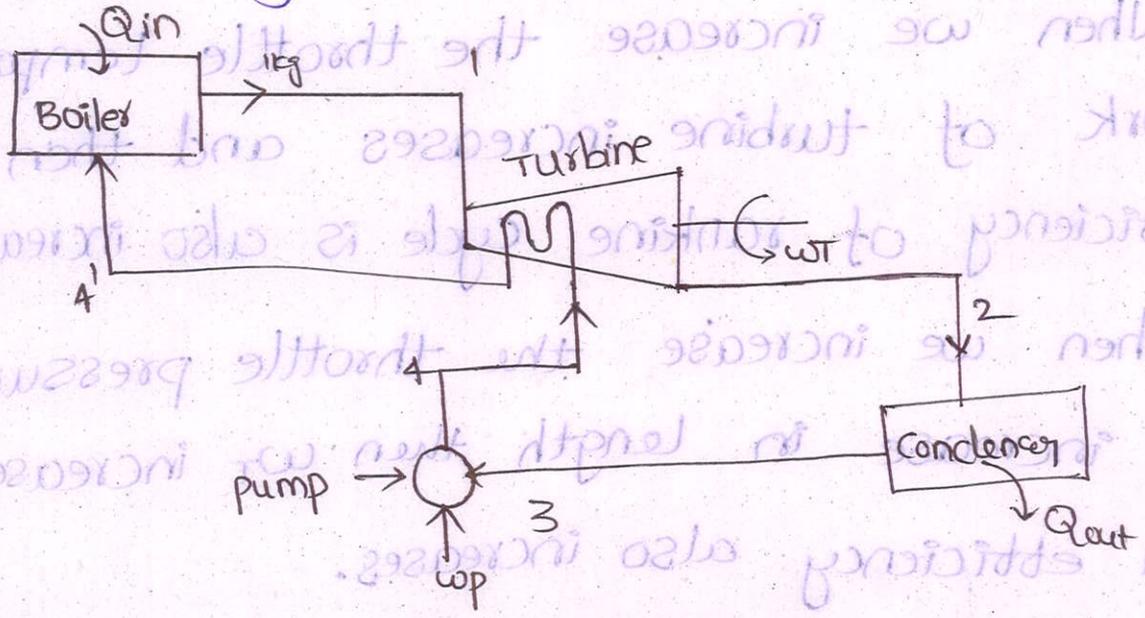
Re-generation :-

In Rankine cycle, a significant amount of heat is added for sensible heating added is much lower than the source temperature of compressed liquid coming out the pump.

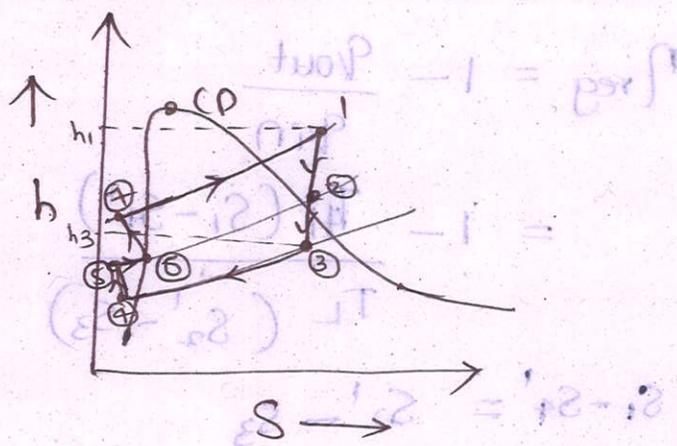
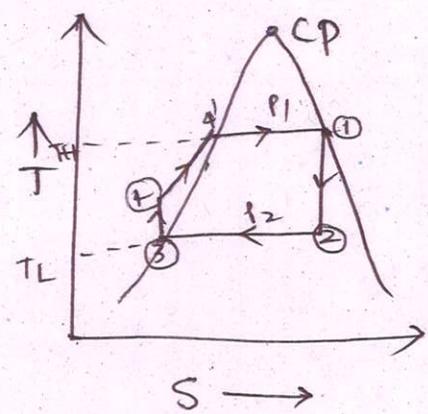
→ The mean temperature at which sensible heat added is much lower than the source temperature.

→ Thus, the η of the Rankine cycle is much lower than that of Carnot vapour power cycle.

→ The η of Rankine cycle can be improved by heating the feed water regeneratively.



Frc :- ideal regenerative cycle.



In ideal regenerative cycle as shown in figure the condensate leaving the pump enters the turbine at the state 4 and flows in a counter flow direction to the steam flow.

→ Thus, it is possible to heat the feed water to steam temperature at inlet to turbine.

→ if at all points the temperature difference b/w steam and feed water is negligibly small then the heat transfer takes place in reversible manner.

for such process

$$(\Delta T)_{\text{water}} = -(\Delta T)_{\text{steam}}$$

$$(\Delta S)_{\text{water}} = -(\Delta S)_{\text{steam}}$$

$$q_{\text{in}} = h_1 - h_4' = T_H (S_1 - S_4')$$

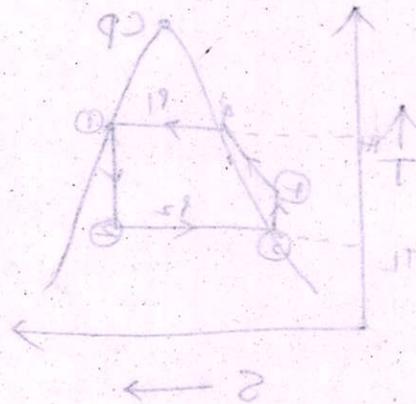
$$q_{\text{out}} = h_2' - h_3 = T_L (S_2' - S_3)$$

$$\text{since } S_1 - S_4' = S_2' - S_3$$

$$\eta_{reg} = 1 - \frac{q_{out}}{q_{in}}$$

$$= 1 - \frac{T_H (S_1 - S_4')}{T_L (S_2' - S_3)}$$

$$S_1 - S_4' = S_2' - S_3$$



$$\eta_{reg} = 1 - \frac{T_H}{T_L}$$

The efficiency of an ideal regenerative cycle is equal to efficiency of the Carnot cycle.

- in this regeneration process,
- The transfer of heat in reversible manner takes place very slowly.
- Heat exchange in the turbine is not mechanically feasible.
- The moisture content of steam in the turbine will be very high.
- Advantage of regenerative heating principle is used by extracting a part of the steam from turbine at a certain stage of the expansion and it is used for heating of feed water in separate feed-water heaters. This arrangement can't reduce the dryness fraction of remaining steam passing through the turbine.

Reheating:-

If the steam expands completely in a single stage then steam coming out the turbine is very wet.

→ The steam carries suspended moisture particles, which are heavier than the vapour particles, thus deposited on the blades and causing its erosion.

→ In order to increase the life of the turbine blades, it is necessary to keep the steam dry during its expansion.

→ It is done by allowing the steam to expand to an intermediate pressure in a high pressure turbine and then taking it out and sending back to the boiler where it is reheated at constant pressure, until it reaches the inlet temperature of the 1st stage as shown in fig.

→ This process is called re-heating during which heat is added to the steam.

→ The reheated steam then further expands in the next stage of the turbine.

→ Due to reheating, the work output of the turbine increases, thus improving the thermal efficiency.

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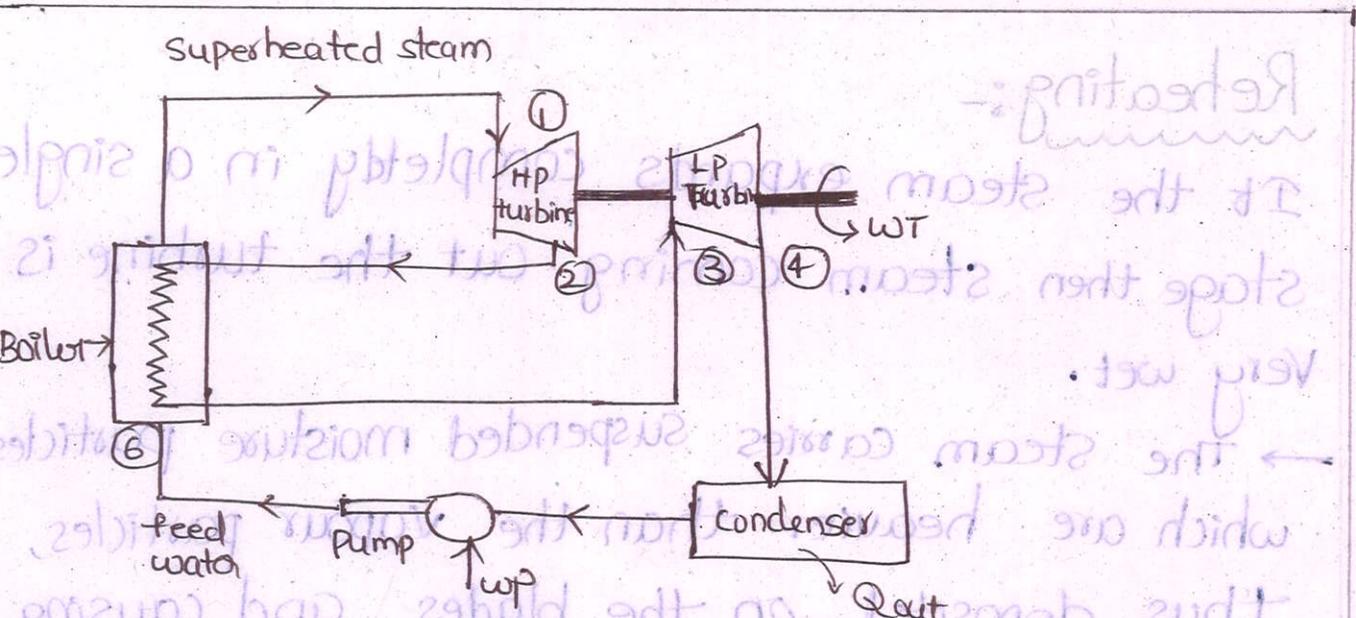


Fig:- power plant with reheating and multistage expansion.

Heat supplied $Q_s = Q_{s1-2} + Q_{s3-4}$

$$Q_s = (h_2 - h_1) + (h_4 - h_3)$$

work of turbine

$$w_T = (w_T)_{2-3} + (w_T)_{4-5} \quad ; \quad w_p = h_6 - h_5$$

$$= h_2 - h_3 + h_4 - h_5$$

efficiency $\eta = \frac{w_T - w_p}{Q_s}$

$$\eta = \frac{(h_2 - h_3) + (h_4 - h_5)}{(h_2 - h_1) + (h_4 - h_3)}$$

Boilers

* Boiler :- Boiler is a cylindrical shell which converts the input water into steam by absorbing latent heat by combustion of the fuel.

→ Boiler is also called as steam generation.

* classification of boilers :-

→ According to axis of boiler, boilers can be classified into two types

(i) Horizontal boiler

(ii) Vertical boiler

(iii) Inclined boiler

→ According to tubes

(i) single tube boiler

(ii) multi tube boiler

→ According to operating pressure

(i) Low pressure boiler

(ii) High pressure boiler

→ According to the heating application

(i) Fire tube boiler

(ii) Water tube boiler

→ According to circulation of water

(i) Natural circulation

(ii) Forced circulation.

Boilers

- * According to purpose of usage :- Boiler :- Boiler is a cylindrical shell which converts the input water into steam of absolute latent heat by combusting the fuel.
- (i) stationary boiler
 - (ii) marine boiler
 - (iii) locomotive boiler
 - (iv) portable boiler.

- * According to draught :- According to draught of boiler, boilers can be classified into two types :-
- (i) Natural draught
 - (ii) Artificial draught.

* Fire-tube boiler :-

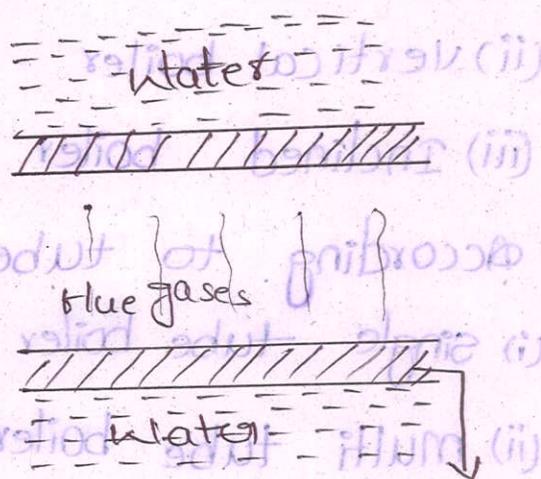
Vertical fire tube boiler is as shown in figure.

→ it is a portable boiler and it requires a small floor space.

→ one or more cross tubes are either flanged or riveted to the water space and are located in the fire box to increase the heating surface area and to improve the water circulation.

→ a short chimney is connected at the top of the fire box to discharge the waste flue gases at some greater height.

→ Fuel burns on the grate in the fire box. The resulting hot flue gases are allowed to



pass around the cross tubes.

→ The water surrounding and cylindrical fire box also receives heat by convection and radiation. Thus steam is produced.

→ The water circulation in the boiler depends on the density difference in the water, created by temperature difference in the water.

* Water tube boiler :-

In water tube boiler water passes through tubes and hot flue gases surround them.

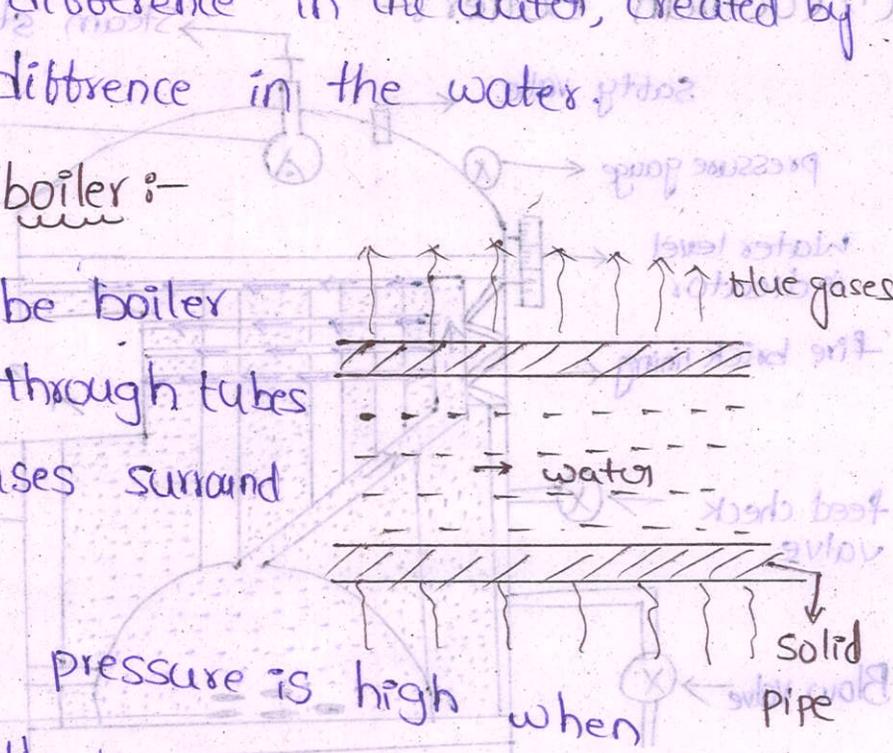
→ The working pressure is high when compared with fire tube boiler, upto 250 bar in super critical boilers.

→ The rate of steam generation and quality of steam are better and suitable for power generation.

→ it requires less floor area for a given output

→ Overall efficiency with an economiser is upto 90%.

→ Treatment of feed water is very essential as small scale deposits inside the tubes



'Can cause overheating and bursting.'

→ water tube boilers are used in large power plants.

Low pressure boilers

(i) Cochran boiler:

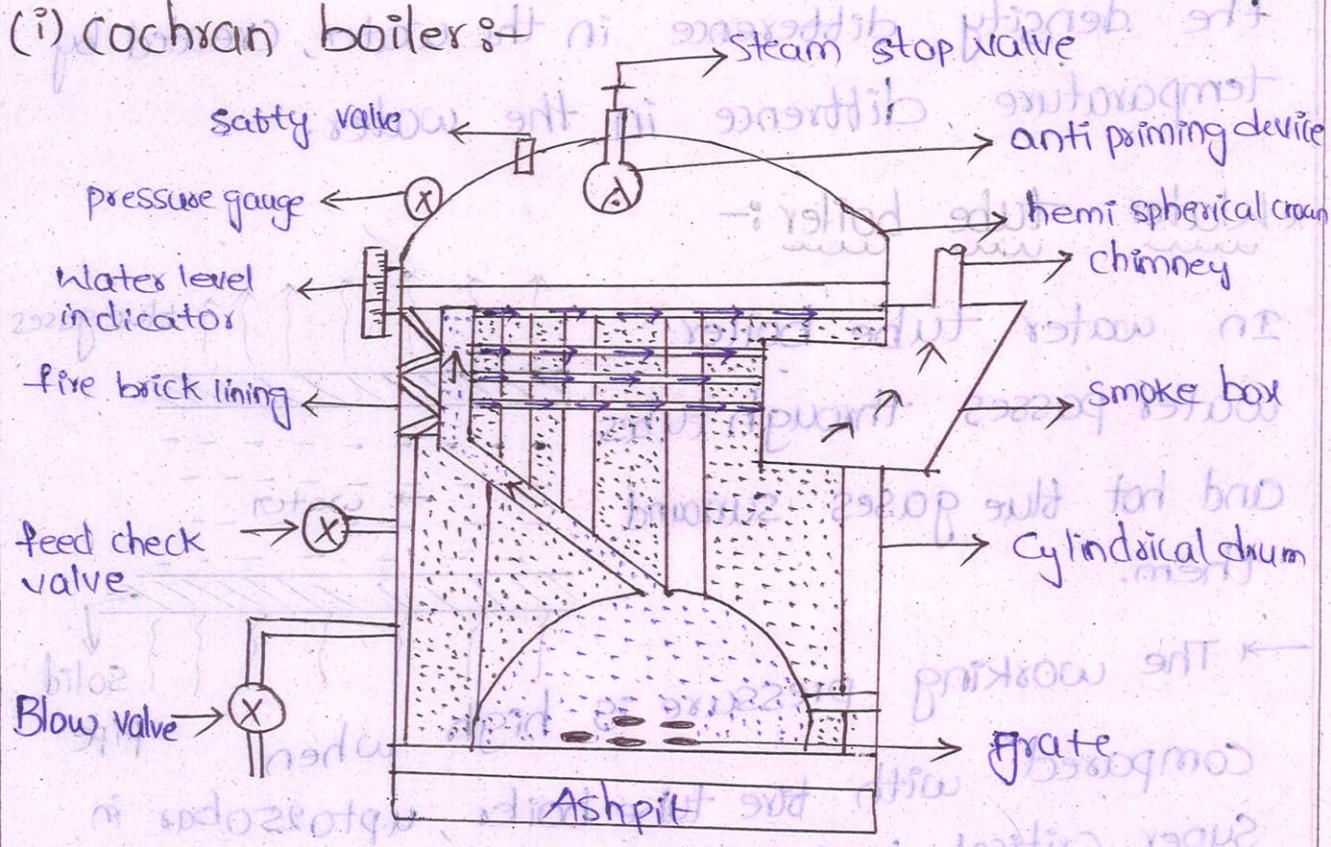


Fig: Cochran boiler

it is a vertical fire tube boiler, the blue gases from the furnace are passed through a no. of small tubes surrounded by water.

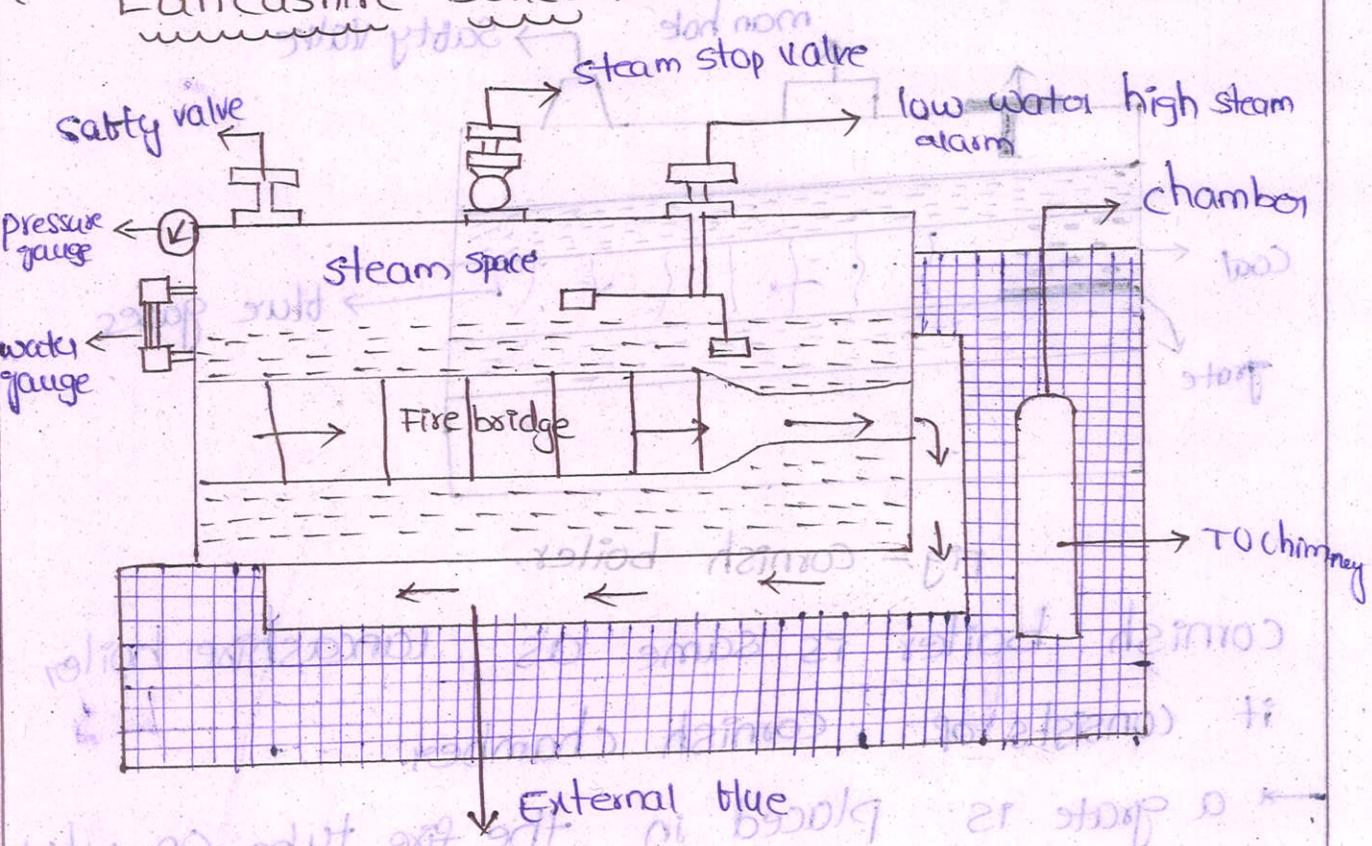
→ The fuel is burnt on grating. The hot blue gases pass through a short blue to a combustion chamber, small horizontal smoke tubes and then collected in a smoke box, and they are discharged to the atmosphere through the chimney.

The Cochran boiler generates steam approximately 3600 kg/hr with working pressure of 11 bar.

Advantages:-

- it is very compact and requires minimum floor area.
- Any type of fuel can burn in the boiler.
- it is well suited for small industries.
- it gives about 70% thermal efficiency with coal firing.

(ii) Lancashire boiler :-



it is a horizontal and internally fired, fire tube boiler. and stationary boiler.

- The fire tubes are slightly conical towards its rear end to increase velocity of hot flue gases.

(i)

then, hot blue gases are allowed to passing through the downward channel towards the front end of the blue gas tubes.

→ now these gases passing through the side channel towards the rear end of the fire tube and finally escape from the chimney.

→ once the boiler is heated adequately water converts to steam it stores at upper position of boiler.

(iii) Cornish boiler:-

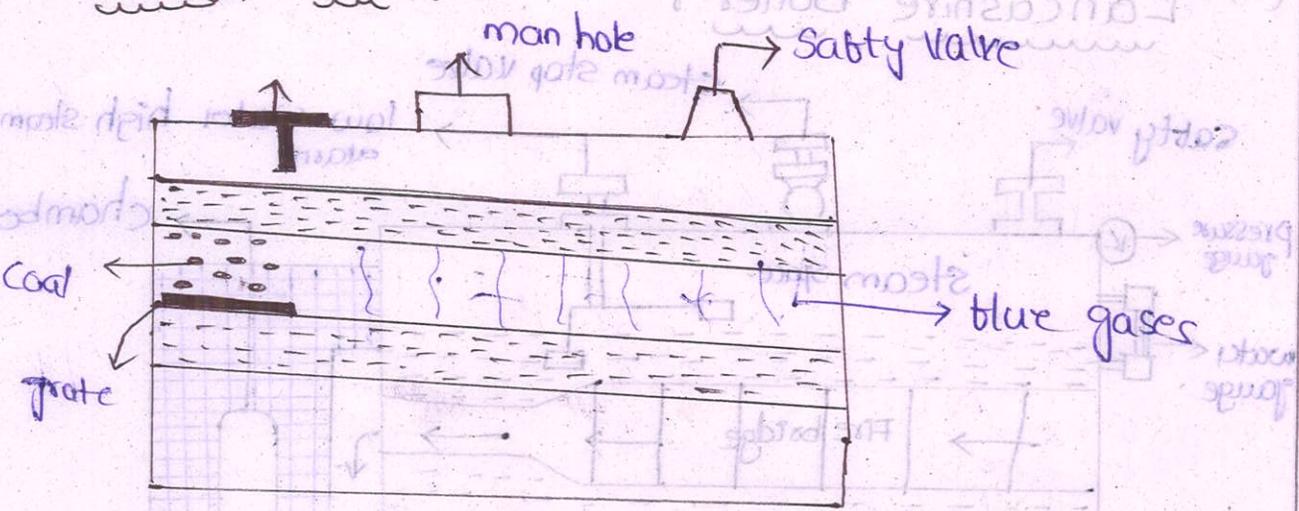


Fig = Cornish boiler.

Cornish boiler is same as Lancashire boiler it consists of Cornish chamber.

→ a grate is placed in the fire tube on which coal is placed and burned.

→ when the coal started burning then exists flue gases from burning of coal it will make the fire tube hot and this heating

will be supplied to surrounding water and it start heating and convert into steam and it goes out from chimney.

(iv) Locomotive boiler :-

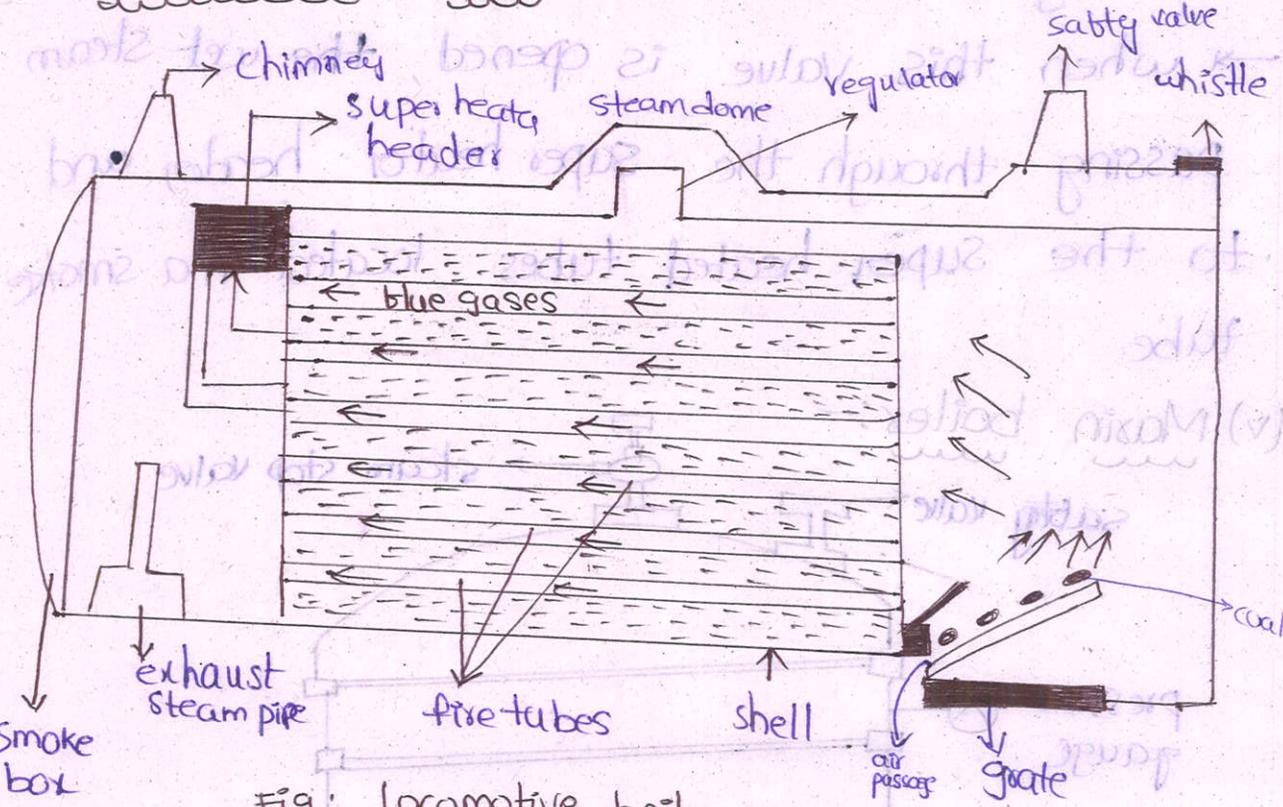


Fig: Locomotive boiler.

it is also internal fired, horizontal multi-tube fire tube boiler.

→ it generates steam at pressure about 25 bar with 60-70 kg/hr per square meters. steam rate of heating surface.

→ The blue gases are formed due to combustion of coal in presence of ~~coal~~ air on the grate.

→ These gases rise up and deflected by a brick arch to their proper distribution to passing through the smoke tubes and over super heater tubes and then finally gets discharged into the atmosphere through chimney.

Steam generated is collected in steam space. A steam regulator is located in the steam dome and is operated by a long regulator rod from engine.

→ when this valve is opened, the wet steam passing through the super heater header and to the super heated tubes located in a smoke tube.

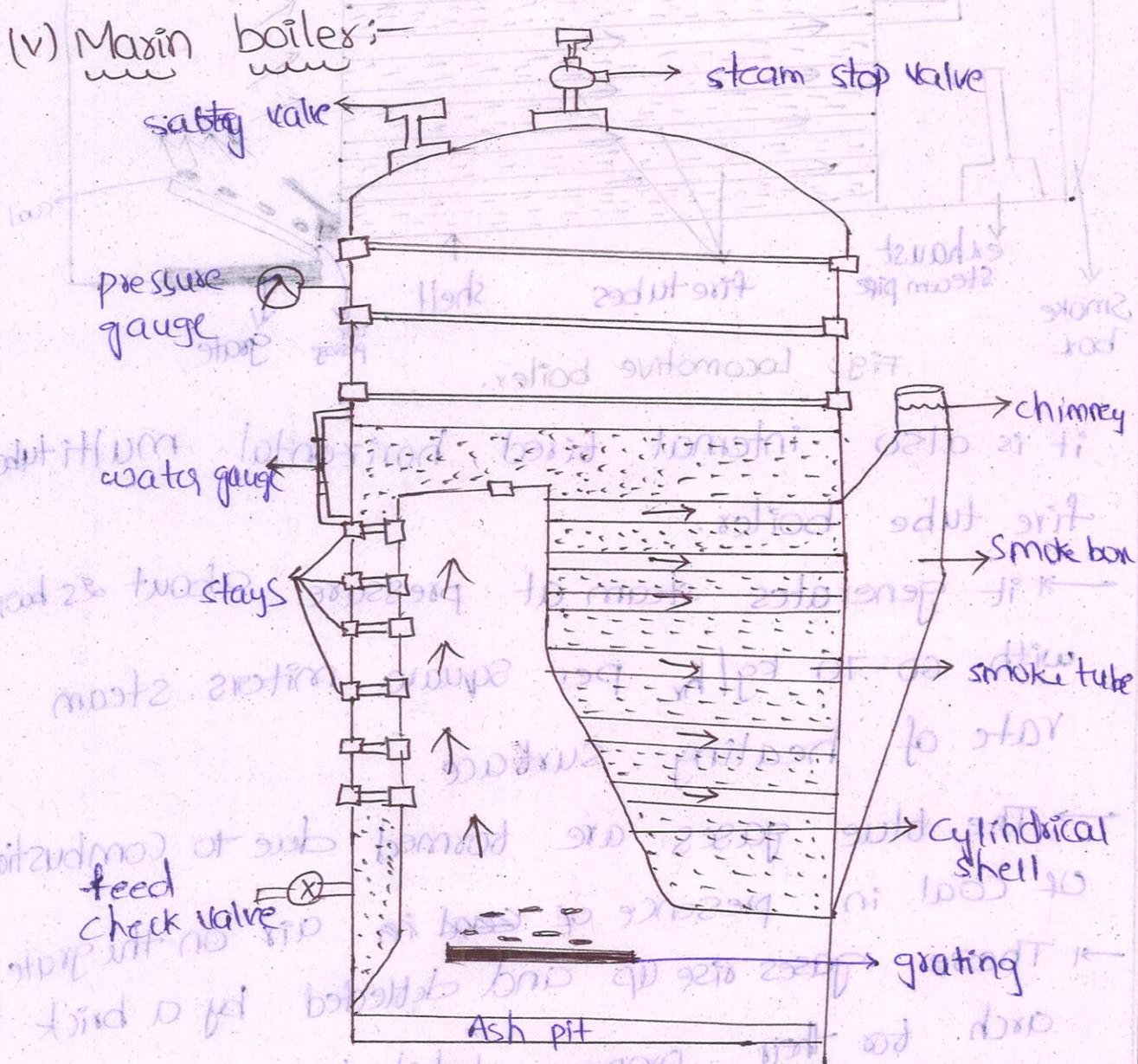


Fig: Maxin boiler.

it is most commonly used fire tube boiler
 it has large heating surface area for space occupied.

→ fuel burns in the furnace on the grate, blue gases are travel to the smoke box through fire tubes and finally discharged to the atmosphere through chimney.

→ heat transferred to water around furnace, combustion chamber and fire tubes and steam is generated.

Bobcock and Wilcox boiler

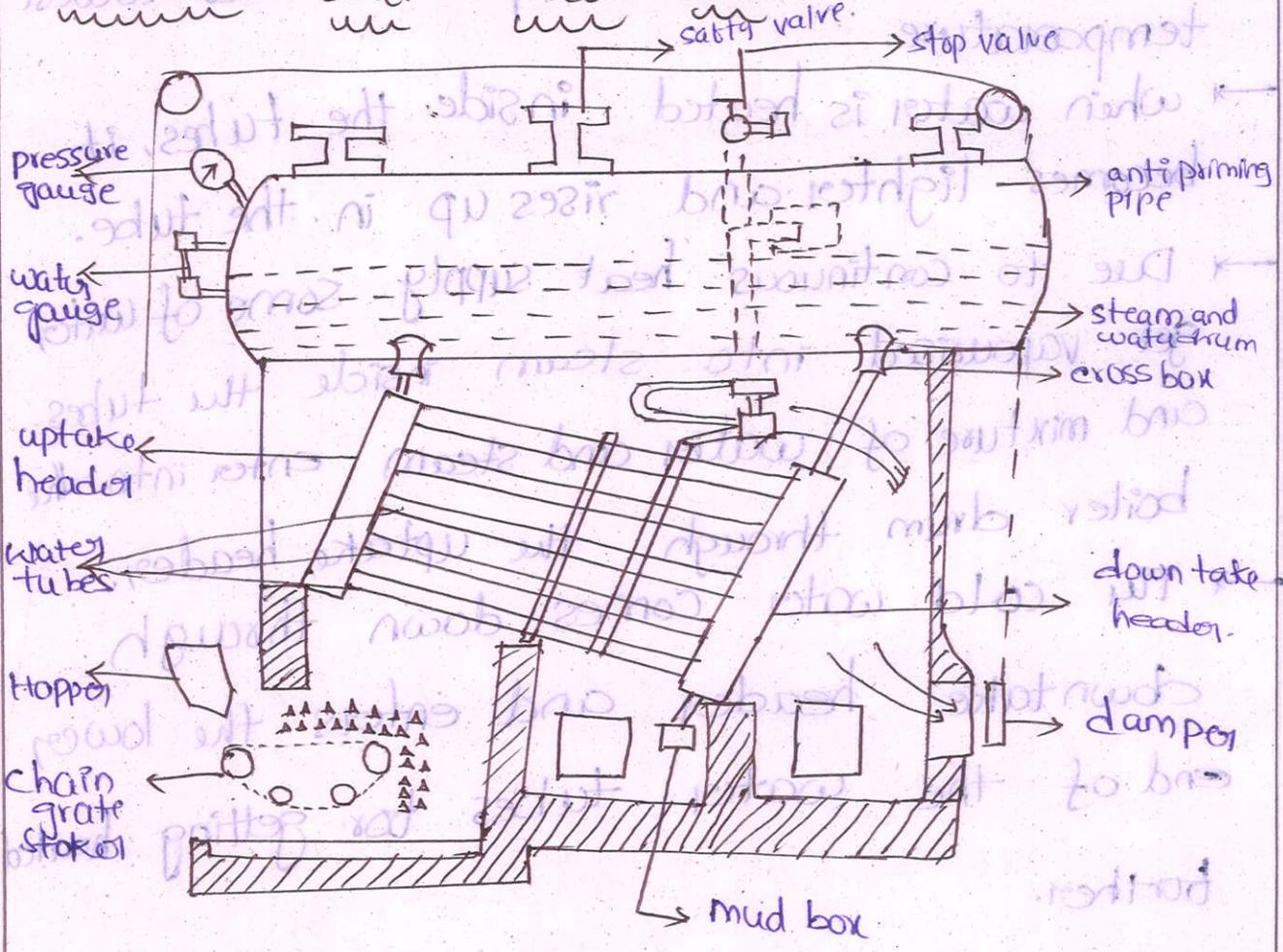


Fig: Bobcock and Wilcox boiler.

(ii)

it is the first water tube boiler.

→ The water is pumped by a feed pump and it enters the drum through the feed check valve upto the pre-specified level so, that the headers and tubes are bled always.

→ when the combustion takes place above the grate the product of hot gases come out and rush through each compartment of combustion chamber.

→ hence, front portion of the tubes has highest temperature and rear portion has lowest temperature.

→ when water is heated inside the tubes, it becomes lighter and rises up in the tube.

→ Due to continuous heat supply some of water get vapourised into steam inside the tubes and mixture of water and steam enter into the boiler drum through the uptake header.

→ The cold water comes down through downtake header and enters the lower end of the water tubes for getting heated further.

→ The steam generated is collected in the steam space.

High pressure boilers :-

(i) La mont boiler :-

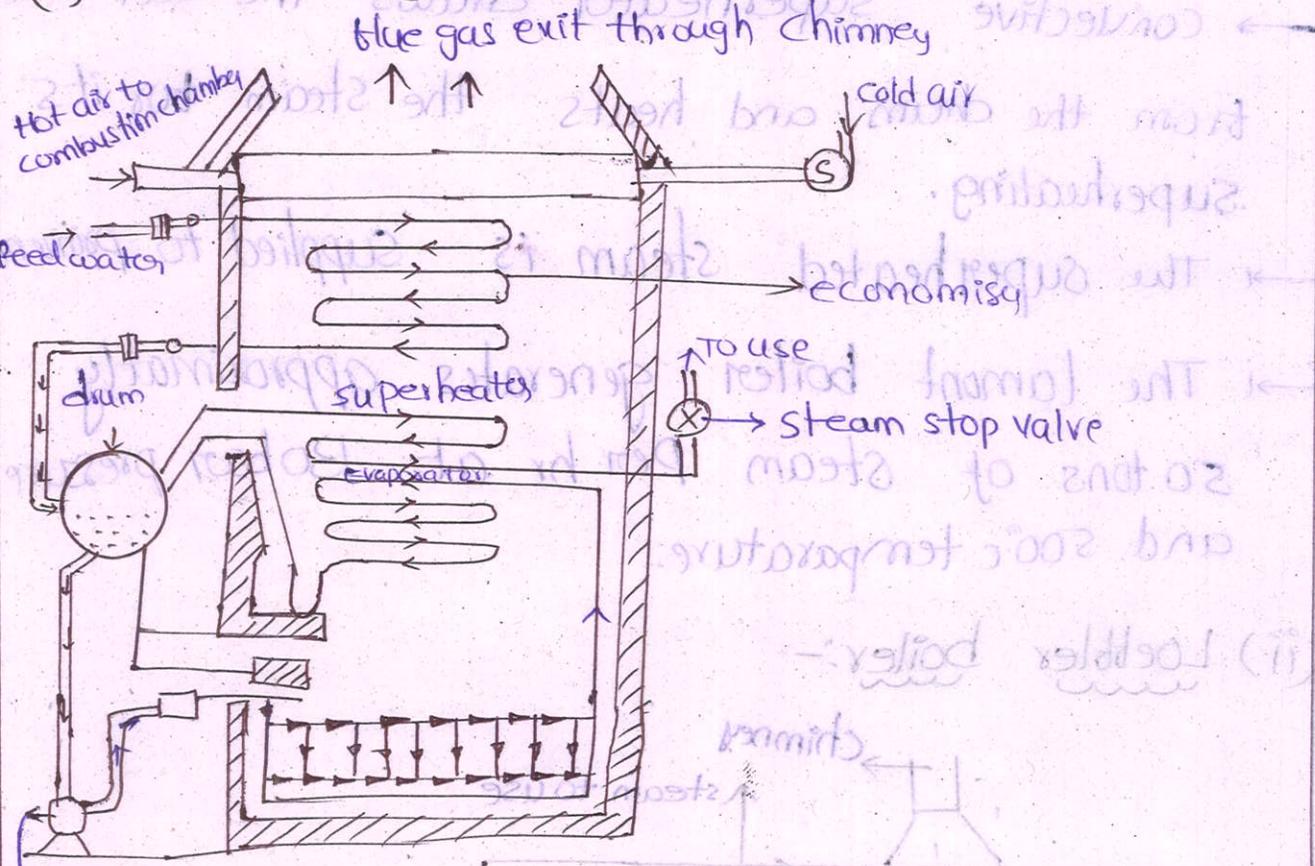


Fig : La mont boiler

it is high pressure water tube boiler, it works on the principle of forced circulation.

→ The water circulation is maintained by a centrifugal pump.

→ The feed water is circulated through the water walls and drums continuously and prevent the tubes from over heating.

→ first the feed water flows through economiser heat supplied to feed water in the economiser then water enters the boiler drum.

→ water circulation pump draws water from

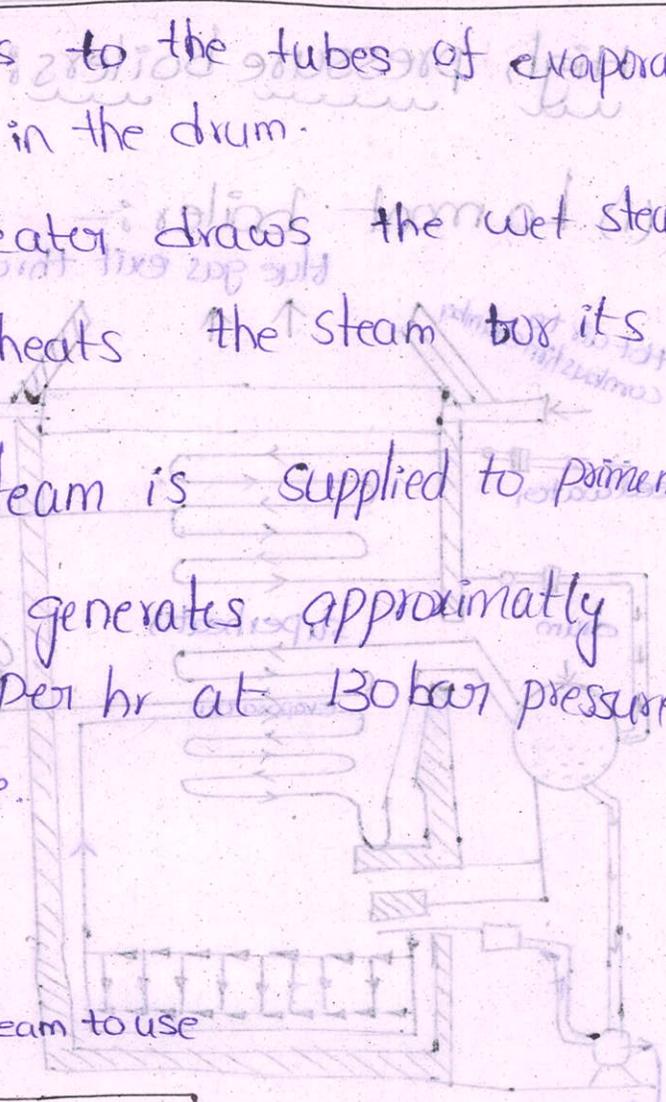
(51)

the drum and delivers to the tubes of evaporating this mixture stored in the drum.

→ convective superheater draws the wet steam from the drum and heats the steam by its superheating.

→ The superheated steam is supplied to prime mover

→ The Lamont boiler generates approximately 50 tons of steam per hr at 130 bar pressure and 500°C temperature.



(ii) Loebbler boiler:-

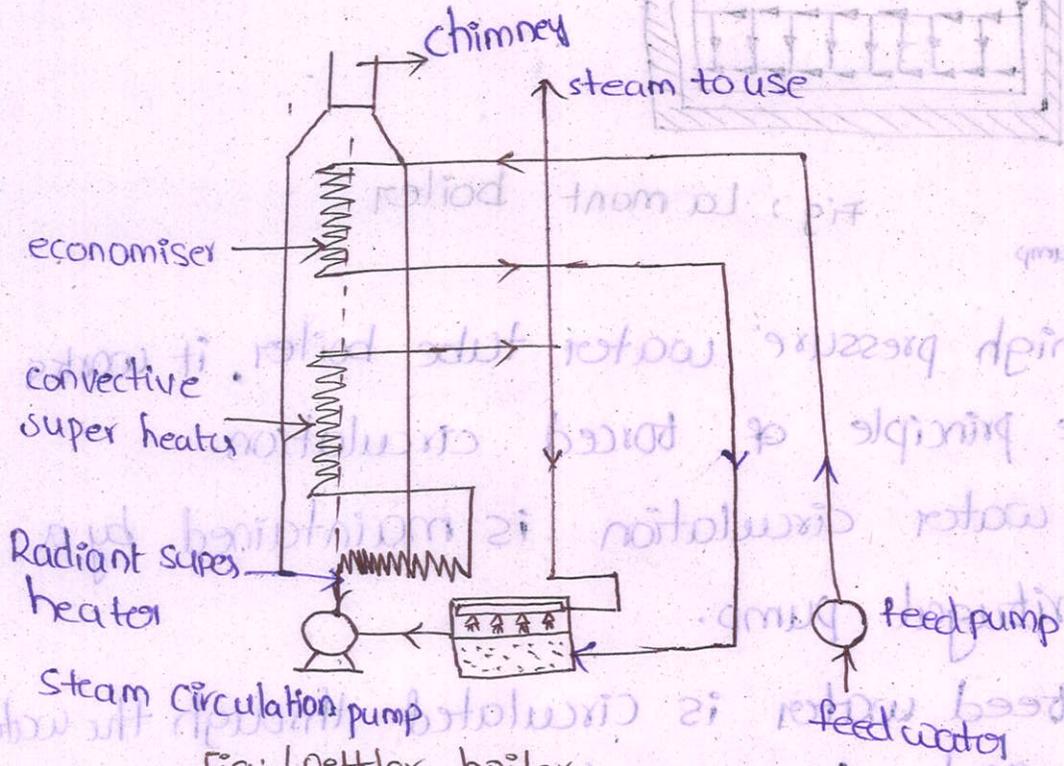


Fig: Loebbler boiler

it is water tube boiler and also forced circulation of water. super heated steam is used for vapourisation of feed water in evaporator. hot flue gases in the furnace are used for super heating of steam.

- H.P. feed pump supplies the water to the economiser where water is heated and then delivered to evaporator.
- in the evaporator feed water is further heated with the help of super heated steam.
- The blue gases from the combustion chamber move to the convective superheater and to the economiser before proceeding to the atmosphere through the chimney.
- The Loebbler boiler generates steam approximately at 100-tons per hr at 140 bar pressure.

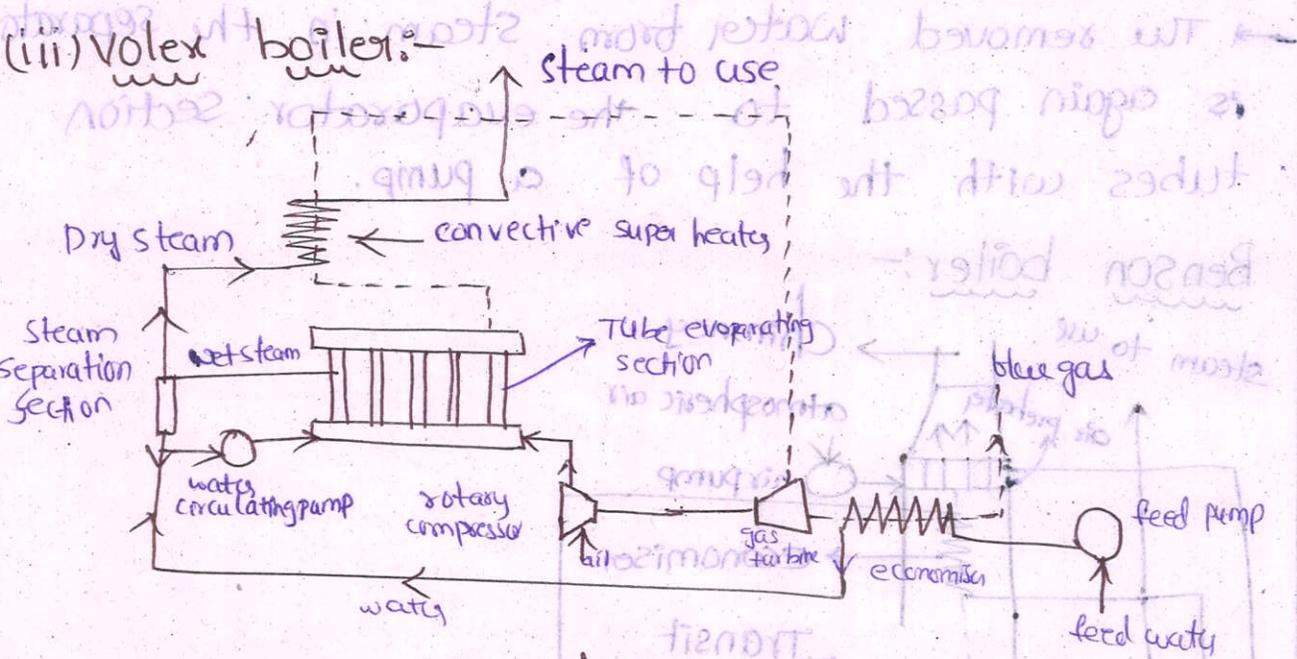


Fig: Volex boiler

- The air is compressed in an compressor to a pressure of 2.5 bar.
- The presence of this pressurised air in the furnace, there is a high combustion rate, and thus a high rate of heat release. The generated blue gases passing through a nozzle section, where the velocity of blue gases increases to sonic velocity.

- The blue gases enter the evaporator section with sonic velocity and heat the water and steam, where the blue gases coming out of the evaporator are further passed over a convective superheater, where a portion of their heat content is used to superheat and are used to drive a gas turbine.
- The circular motion of steam and water mixture thus separates heavier water particles by throwing them outward on the walls.
- The separated steam then enters the convection superheater before going to use.
- The removed water from steam in the separator is again passed to the evaporator section tubes with the help of a pump.

Benson boiler:-

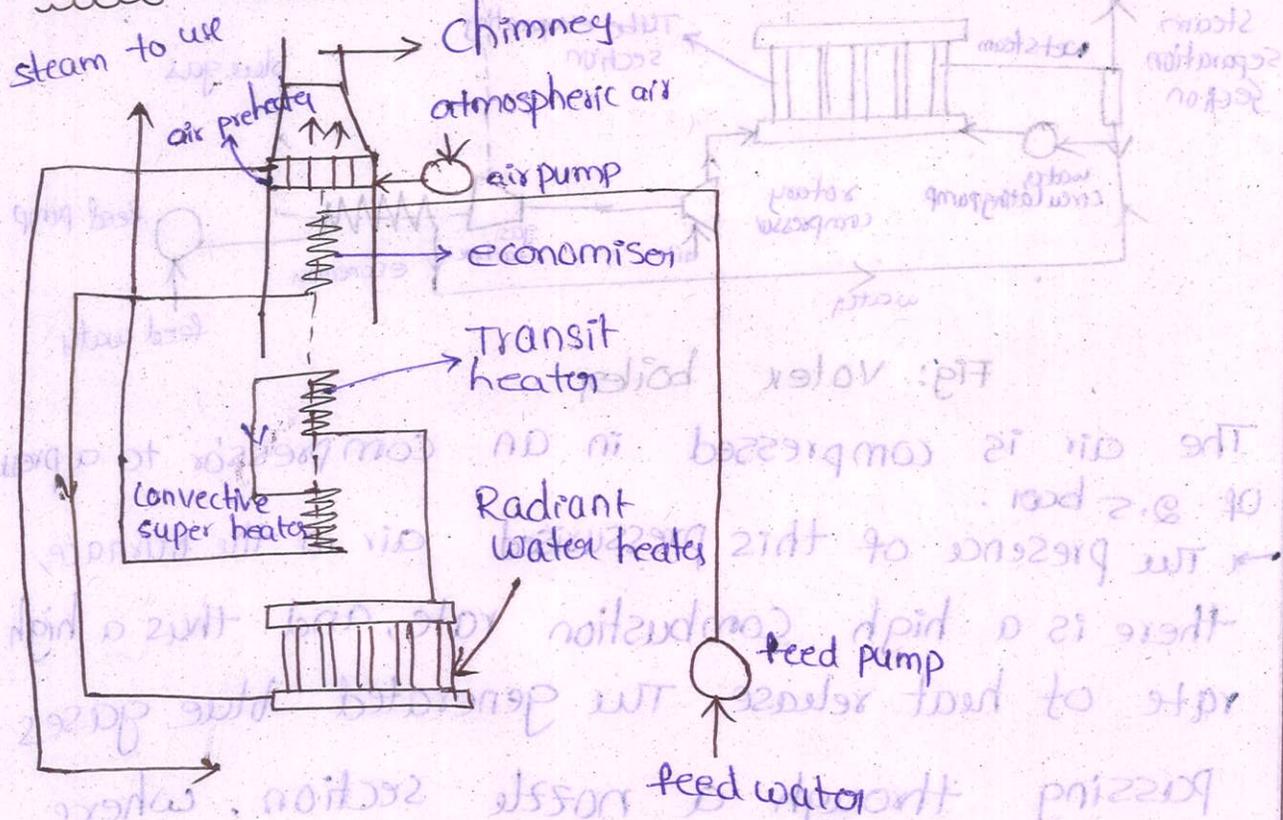


Fig:- Benson boiler.

Benson boiler is a high pressure boiler, drumless, water tube boiler.

→ The boiler uses forced circulation heat-transfer mechanism and uses oil as fuel.

→ it operates at a pressure of 250 bars which is more than the critical pressure of water, and latent heat of vaporisation becomes zero.

→ The feed water enters one end of tube and comes out as super heated steam from the other end, thus it is also called a once-through boiler.

→ The feed pump increases water pressure to super critical pressure and forces the water through tubes.

→ it first passing through economiser, where it is heated then it is passes through radiant water heater where the water is further heated and its temperature increases to almost critical temperature.

→ Then it enters the transit heater, gets converted into steam and then passes through the convective superheater and finally becomes available for applications.

→ The thermal efficiency of Benson boiler is 90% and generates approximately 135 tons of steam per hr.

a boiler working at a pressure of 14 bar evaporates 8 kg of water per kg of coal burnt from the feed water entering at 39°C. The steam at the steam stop valve is 0.95 dry. Determine the equivalent Evaporation.

Given data,

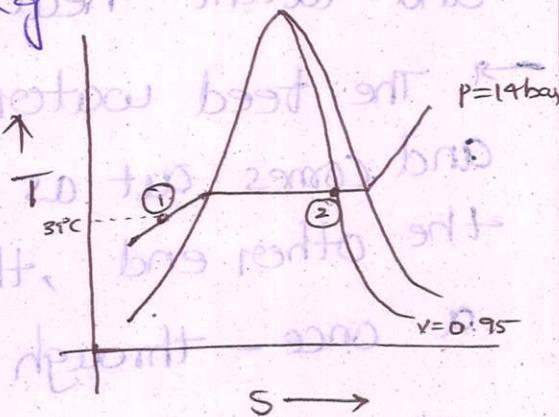
pressure (P) = 14 bar

actual evaporation (m_a) = 8 kg

dryness fraction (x) = 0.95

temperature (T) = 39°C

h₁ = initial condition of water at 39°C.



$$h_{\text{heat}} = mc_p \Delta T$$

$$= 1 \times 4.2 \times (39 - 0)$$

$$h_1 = 163.8 \text{ kJ/kg}$$

h₂ = steam at output at boiler condition

The point ② is in wet region then

$$h_2 = h_{f2} + x_2 \cdot h_{fg2}$$

from steam table at 14 bar

$$h_f = 830.7 \text{ kJ/kg} \quad h_{fg} = 1957.7$$

$$h_2 = 830.7 + (0.95 \times 1957.7)$$

$$h_2 = 2690.51 \text{ kJ/kg}$$

Equivalent evaporation $(m_e) = \frac{m a (h_2 - h_1)}{2257}$

$$m_e = \frac{8 \cdot (2690.51 - 163.8)}{2257}$$

$$m_e = 8.9 \frac{\text{kg of steam}}{\text{kg of fuel}}$$

Duration of boiler trial the following data was recorded. Duration of trial = 8, pressure of steam = 20 bar, dryness fraction = 0.973, feed water evaporated = 26700 kg, Temperature at water inlet = 50°C , coal used = 4260 kg, Calorific value cv of coal = 28900 kJ/kg, air used per kg of coal = 17 kg, Temperature of flue gases = 344°C , Boiler room temperature 21°C , cp of flue gases = 1.1 kJ/kgK. Determine
(i) Boiler efficiency (ii) equivalent evaporation
(iii) Heat lost to flue gases in kJ/kg of coal.

Given data,

Duration of trial = 8

pressure of steam $(P) = 20 \text{ bar}$

dryness fraction $(x) = 0.973$,

Feed water evaporated = 26700 kg

temperature of water inlet $(T) = 50^\circ\text{C}$

Coal used = 4260 kg

Calorific value $(C_v) = 28900 \text{ kJ/kg}$

air used per kg of coal = 17 kg

Temperature of flue gases $(T_f) = 344^\circ\text{C}$

Boiler room temperature $(T_a) = 21^\circ\text{C}$

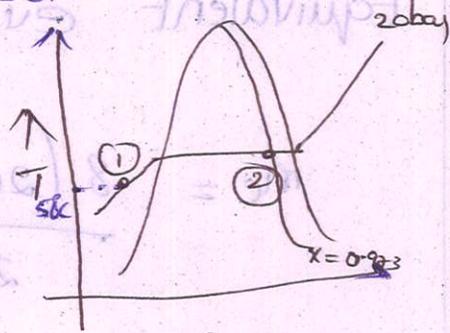
cp of flue gas = 1.1 kJ/kgK.

$h_2 =$ energy of steam at exit of boiler

$h_1 =$ energy of feed water

The final condition of steam at wet region so, enthalpy

$$h_2 = hf_2 + x_2 hfg_2$$



By using steam table at pressure 20 bar.

$$hf = 908.5 \text{ kJ/kg} \quad \therefore \quad hfg = 1888.7 \text{ kJ/kg}$$

$$h_2 = 2746.20 \text{ kJ/kg}$$

By using moiler chart,

$$h_2 = 2745 \text{ kJ/kg}$$

$$h_1 = mcpdT$$

$$= 1 \times 4.2 \times (50 - 0)$$

$$h_1 = 210 \text{ kJ/kg}$$

$$(i) \text{ efficiency of boiler } (\eta_B) = \frac{m_s (h_2 - h_1)}{m_f (CV)}$$

$$= \frac{26700 (2745 - 210)}{4260 \times 28900}$$

$$\eta_B = 54\% \approx 60\%$$

$$(ii) \text{ Equivalent evaporation } m_e = \frac{m_a (h_2 - h_1)}{2257}$$

$$m_a = \frac{m_s}{m_f} = \frac{26700}{4260} = 6.2$$

$$m_e = \frac{6.2 (2746.20 - 210)}{2257} = 7.042 \frac{\text{kg of steam}}{\text{kg of fuel}}$$

$$(iii) \text{ Heat lost } = mcpdT$$

$$= 1 \times 1 \times (344 - 21) = 323 \text{ kJ}$$

a boiler plant supplies 5400 kg of steam per hr at 7.5 bar and 0.98 dry from feed water at 41.5°C when using 670 kg of coal per hr. having a CV of 31000 kJ/kg. Determine
 (i) efficiency of boiler (ii) equivalent evaporation
 (iii) actual evaporation.

Given data

mass of steam (m_s) = 5400 kg/hr

pressure (P) = 7.5 bar

dryness fraction (x) = 0.98

temperature (t) = 41.5°C

mass of coal (m_f) = 670 kg

calorific value of coal (CV) = 31000 kJ/kg

(i) actual evaporation $m_a = \frac{m_s}{m_f}$

$$m_a = \frac{5400}{670} = 8.05 \frac{\text{kg of steam}}{\text{kg of fuel}}$$

(ii) equivalent evaporation

$$(M_e) = \frac{m_a (h_2 - h_1)}{2257}$$

h_1 = feed water energy or enthalpy

$$h_1 = m c_p \Delta T$$

$$= 1 \times 4.2 \times (41.5 - 0)$$

$$h_1 = 174.3 \text{ kJ/kg}$$

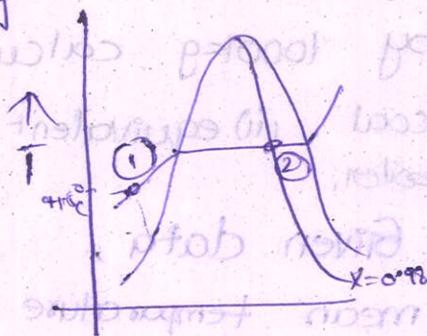
$$h_2 = h_{f2} + x_2 h_{fg2}$$

from steam table at 7.5 bar

$$h_{f2} = 709.3 \text{ kJ/kg} \quad h_{fg2} = 2055.2 \text{ kJ/kg}$$

$$h_2 = 709.3 + (0.98 \times 2055.2)$$

$$h_2 = 2723.6 \text{ kJ/kg}$$



equivalent evaporation $(m_e) = \frac{805 \times (2723.6 - 174.3)}{2257}$

$m_e = 9.09 \frac{\text{kg of steam}}{\text{kg of fuel}}$

(iii) Efficiency of boiler $(\eta_B) = \frac{m_s (h_2 - h_1)}{mf \times CV}$

$= \frac{5400 (2723.6 - 174.3)}{670 \times 31000} = 0.661 \times 100 = 66.1\%$

Factor of evaporation $= \frac{h_2 - h_1}{2257}$

$f_e = \frac{2723.6 - 174.3}{2257}$

$f_e = 1.12$

In a boiler trial following data reading were noted
 mean temperature of feed water = 15°C , mean boiler
 working pipe = 1.2 mpa . mean dryness fraction = 0.95
 mass of coal burnt per hr = 250 kg . mass of water
 supplied to the boiler in 7hr and 14min is equal
 to 16500 kg mass of water in the boiler at the
 end of the test was less than the commencement
 by 1000 kg calculate (i) actual evaporation per kg of
 coal (ii) equivalent evaporation (iii) efficiency of
 boiler.

Given data

mean temperature $(t) = 15^\circ\text{C}$

pressure $(P) = 1.2 \text{ mpa} = 1.2 \times 10^6 \text{ pa} = 1.2 \times 10^5 \text{ bar}$

$P = 12 \text{ bar}$

mass of fuel $(mf) = 250 \text{ kg/hr}$

dryness fraction $(x) = 0.95$

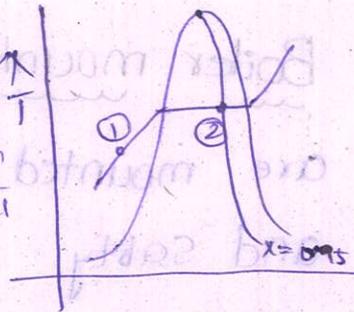
calorific value $(CV) = 32400 \text{ kJ/kg}$

mass of steam $(m_s) = 16500 \text{ kg}$

$$m_s = \frac{16500 + 1000}{7 \times \frac{4}{60}} = 2419.35 \text{ kg/hr}$$

(i) actual evaporation

$$m_a = \frac{m_s}{m_f} = \frac{2419.35}{250} = 9.67 \frac{\text{kg of steam}}{\text{kg of coal}}$$



(ii) equivalent evaporation

$$m_e = \frac{m_a (h_2 - h_1)}{2257}$$

$$h_1 = m c_p \Delta T = 1 \times 4.2 \times (15 - 0)$$

$$h_1 = 63 \text{ kJ/kg}$$

$$h_2 = h_{f2} + x_2 h_{fg2}$$

from steam table at 12 bar pressure

$$h_{f2} = 798.4 \text{ kJ/kg} \quad h_{fg2} = 1984.3 \text{ kJ/kg}$$

$$h_2 = 798.4 + (0.95 \times 1984.3)$$

$$h_2 = 2683.48 \text{ kJ/kg}$$

$$m_e = \frac{9.67 (2683.48 - 63)}{2257}$$

$$= 11.2 \frac{\text{kg of steam}}{\text{kg of fuel}}$$

(iii) efficiency of boiler

$$\eta_{\text{Boiler}} = \frac{m_s (h_2 - h_1)}{m_f \times CV}$$

$$= \frac{16500 (2683.48 - 63)}{250 \times 32400} \times 100$$

$$= 78.2\%$$

Boiler mountings and accessories:-

Boiler mountings:- These are the devices which are mounted on the boiler shell for proper functioning and safety.

(a) Mounting for safety:-

(i) Safety valve

- * dead weight safety valve
- * Spring loaded safety valve
- * Lever loaded safety valve
- * High steam and Low water safety valve

(ii) High pressure and low pressure valve on Lancashire and Cornish boiler.

(iii) water - level indicator

(iv) Fusible plug.

(b) Mounting for control:-

(i) pressure gauge

(ii) steam stop valve

(iii) Feed check valve

(iv) Blow off cock

(v) man hole

(vi) mud box.

Boiler accessories:- These are mounted on the boiler to increase the efficiency.

→ The following accessories are normally

used on a modern boiler

- (i) superheater
- (ii) economiser
- (iii) air pre heater
- (iv) feed water pump
- (v) steam injector
- (vi) steam separator
- (vii) steam trap
- (viii) Boiler draught equipments.

Boiler horse power :-

$$\text{Boiler horse power (Bhp)} = \frac{m_e}{15.65}$$

$$Bhp = \frac{m_a \left(\frac{h_2 - h_1}{2257} \right)}{15.65}$$

1 horse power = 736 W

Equivalent Evaporation :-

$$m_e = m_a \left(\frac{h_2 - h_1}{2257} \right)$$

Efficiency of boiler :-

$$\eta_{Boiler} = \frac{m_s (h_2 - h_1)}{m_f \times CV}$$

Heat balance for boiler:-

We know that,

$$\text{Heat released} = \text{heat utilised.}$$

$$\text{Total heat} = \left\{ \begin{array}{l} \text{heat rised} \\ \text{in the} \\ \text{steam} \end{array} \right\} + \left\{ \begin{array}{l} \text{heat lost} \\ \text{by the blue} \\ \text{gases} \end{array} \right\} + \left\{ \begin{array}{l} \text{incomplete} \\ \text{fuel loss} \end{array} \right\} + \left\{ \begin{array}{l} \text{un accountant} \\ \text{losses} \end{array} \right\}$$

$$\text{(i) Heat gain by the steam} = m_s (h_2 - h_1) \text{ kJ}$$

$$\text{(ii) Heat lost by the flue gases} = (m c_p \Delta T)$$

$$c_p \text{ for blue gases} = 1.005 \text{ kJ/kgK}$$

$$\text{(iii) In complete combustion} = m_{ub} \cdot C_{vub}$$

$$m_{ub} = \text{mass of unburnt fuel}$$

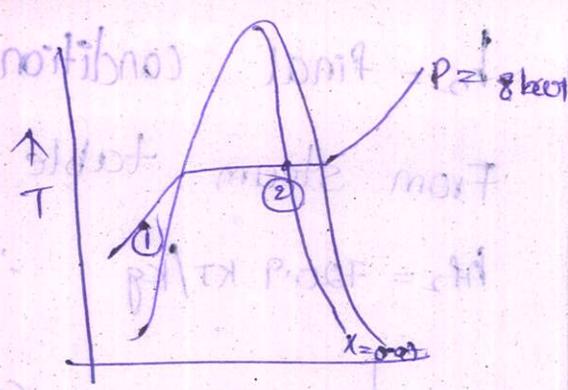
$$C_{vub} = \text{calorific value of unburnt fuel}$$

$$\text{(iv) un accountant loss} = Q_{\text{total}} - (Q_{\text{steam}} + Q_{\text{fuel}} + Q_{\text{out}})$$

The following results were obtained in a boiler trial
trial feed water per hr = 700 kg., feed water
initial temperature = 27°C, steam produced at a pressure
= 8 bar, dryness fraction (x) = 0.97, coal used is
100 kg/hr, calorific value of coal = 25000 kJ/kg.
unburnt coal collected from grate bars = 7.25 kg/hr
C_v of unburnt fuel = 20000 kJ/kg, blue gases
formed per kg of fuel = 17.3 kg, blue gas temperature
= 325°C, temperature of air in the room 16°C
C_p of blue gases = 1.025 kJ/kgK

Given data,

feed water per hr = 700 kg
 feed water initial temperature
 $t = 27^\circ\text{C}$



steam pressure (P_s) = 8 bar

dryness fraction (x) = 0.97

Coal used (m_f) = 100 kg/hr

CV of coal (C_v) = 25000 KJ/kg

unburnt coal mass (m_{un}) = 7.25 kg/hr

CV of unburnt coal = 20000 KJ/kg

blue gases per kg of fuel = 17.3 kg

blue gas temperature (t_f) = 325°C

boiler room temperature (t_a) = 16°C

CP of blue gas = 1.025 KJ/kgK

Total energy released by the coal

$$Q = m_f \times C_v$$

$$Q = 100 \times 25000$$

$$Q = 25 \times 10^5 \text{ KJ/hr}$$

(i) Heat gain by the steam

$$Q_s = m_s (h_2 - h_1)$$

h_1 = feed water enthalpy

$$h_1 = m c_p \Delta T$$

$$= 1 \times 4.2 \times (27 - 0)$$

$$h_1 = 113.4 \text{ KJ/kg}$$

$$h_2 = h_{f2} + x h_{fg2}$$

h_2 = final condition of steam at wet region

From steam table at 8 bar

$h_{f2} = 720.9 \text{ kJ/kg}$; $h_{fg2} = 2046.5 \text{ kJ/kg}$

$h_2 = 720.9 + (0.97 \times 2046.5)$
 $h_2 = 2706.005 \text{ kJ/kg}$

$Q_s = 700 (2706.005 - 113.4)$

$Q_s = 1814823.5 \text{ kJ/hr}$

(ii) Heat lost by blue gases

$Q_{blue\ gases} = m c_p \Delta T$
 $= 17.3 \times 1.025 (325 - 16)$

$Q_{bg} = 5479.34 \text{ kJ/hr}$

(iii) incomplete combustion

$Q = m_{ub} \times C_{vub}$

$= 7.25 \times 2000$

$Q_{un} = 14500 \text{ kJ/hr}$

(iv) unaccountant losses

$Q_{unbu} = Q_{total} - (Q_s + Q_{bg} + Q_{un})$

$= 25 \times 10^5 - 1834802.84$

$Q_{unbu} = 122742.5 \text{ kJ/hr}$

$(0 - f_s) \times 5 \times 1 =$

113.4 kJ/kg

$h_2 = h_{f2} + x h_{fg2}$

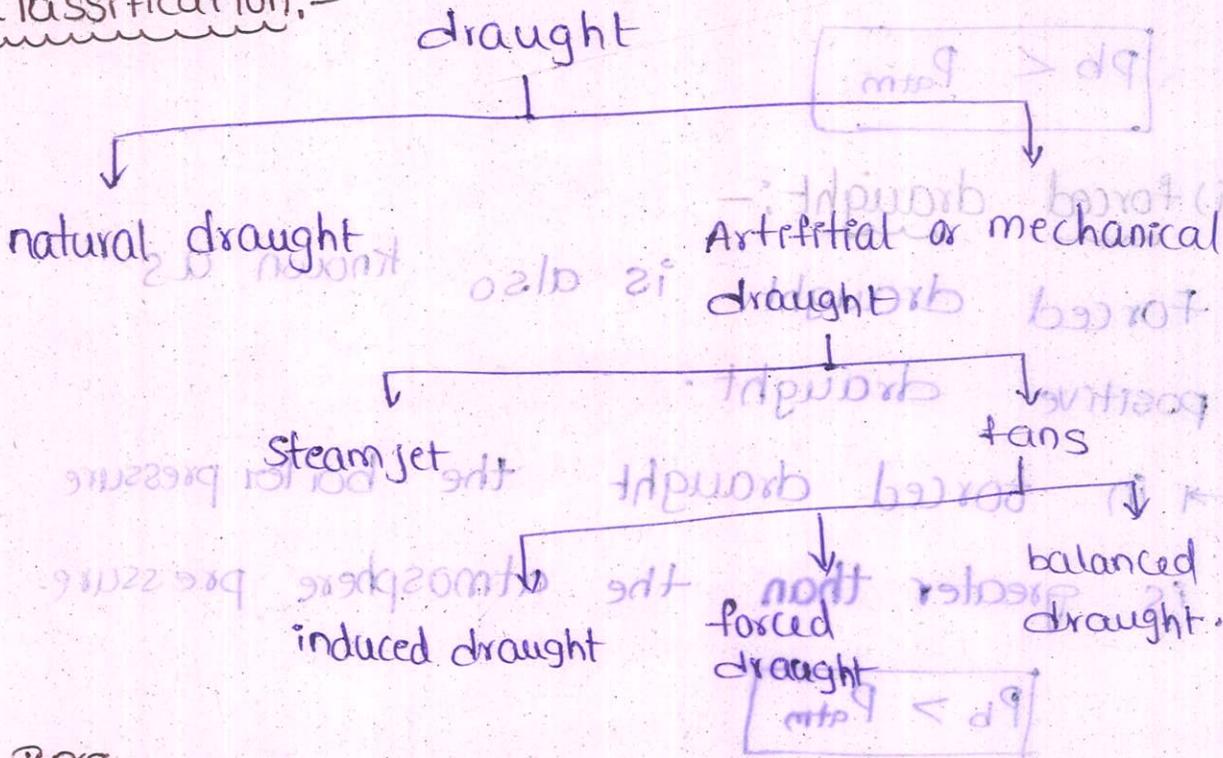
Heat balance sheet:-

S.No	Total energy supplied in KJ/hr	heat utilised in KJ/hr	KJ/hr	% of heat utilisation.
1.	25×10^5	(i) Heat gain by steam	1814823.5 KJ/hr	72.5%
		(ii) Heat loss by flue gases	5479.34×100 KJ/hr 547934	21.9%
		(iii) incomplete combustion loss	14500 $\times 100$ KJ/hr	0.58%
		(iv) unaccountant losses	122742.5 KJ/hr	4.9%

25×10^5 $\frac{79.881}{100} \approx 100\%$

Draught:- Boiler draught is the pressure difference between the atmosphere and the pressure inside the boiler. Generally, a modern coal-fired boiler has balanced draught. Draught is maintained inside boilers using fans.

Classification:-



Advantages of natural draught:-

in natural draught no external power is used.

→ natural draught has long life

→ natural draught has no need for maintenance.

Dis - Advantage of natural draught :-

→ The main disadvantage of natural draught is it depends upon climatic condition.

Artificial draught :-

(i) Induced draught :-

In induced draught the combustible gases exhausted to the atmosphere by using fan and vacuum is created.

→ In induced draught the boiler pressure is less than the atmospheric pressure.

$$P_b < P_{atm}$$

(ii) forced draught :-

forced draught is also known as positive draught.

→ in forced draught the boiler pressure is greater than the atmospheric pressure.

$$P_b > P_{atm}$$

(iii) Balanced draught :-

In balanced draught the boiler pressure is equal to the atmospheric pressure.

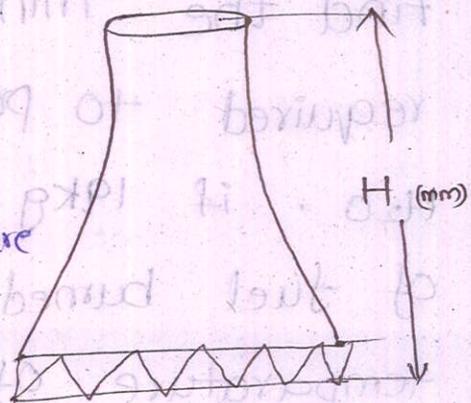
Advantages of forced draught over induced draught

The size and power required by the induced draught is more because it handle more gases.

→ Forced draught consumes less power.

Height of chimney for given draught and discharge :-

- where,
 P_a = actual pressure in boiler
 P_n = standard atmospheric pressure
 T_a = actual temperature in boiler
 T_f = flue gas temperature.



- m = mass of air required to burn 1 kg of fuel
 $(m+1)$ = mass of flue gases produced in combustion
 ρ_g = density of hot gases.
 ρ_a = density of air.

(i) Draught produced in 'mm' of H_2O :-

$$h_w = 353 \times H \times \left[\frac{1}{T_a} - \left(\frac{m+1}{m} \right) \frac{1}{T_f} \right] \frac{P_a}{P_n}$$

(ii) Equivalent height of hot gases:-

$$h_e = H \times \left[\frac{T_f}{T_a} \left(\frac{m}{m+1} \right) - 1 \right]$$

* Condition for maximum discharge from the chimney:-

$$T_f = 2 \left(\frac{m+1}{m} \right) T_a$$

Find the minimum height of chimney required to produce a draught of 16mm of H₂O. if 19kg of air is required per kg of fuel burned on the grate. The mean temperature of blue gases inside the chimney is 330°C.

Given data,
 height of water (h_w) = 16mm
 mass of air (m) = 19 kg.
 temperature of blue gas (T_f) = 330°C

T_f = 330 + 273 = 603K ∴ H = ?

T_a = 300 = 303K

WKT,
$$h_w = 353 \times H \left[\frac{1}{T_a} - \left(\frac{m+1}{m} \right) \frac{1}{T_f} \right] \frac{P_a}{P_n}$$

$$16 = 353 \times H \left[\frac{1}{303} - \left(\frac{19+1}{19} \right) \frac{1}{603} \right]$$

assume P_a = P_n

$$\bullet \frac{16}{353} = H \left[\frac{1}{303} - \left(\frac{20}{19} \right) \frac{1}{603} \right]$$

$$0.045 = H \times 1.55 \times 10^{-3}$$

$$H = 29.24 \text{ m}$$

height of chimney $(H) = 29.24 \text{ m}$.

Readings from boiler drive, height of chimney 100m, ambient temperature 32°C , mass of air 18kg per kg of fuel, blue gas temperature 300°C . Find the natural draught in mm of H_2O .

2:- Given data,

height of chimney $(H) = 100 \text{ m}$

ambient temperature $(t_a) = 32^\circ\text{C} = 305 \text{ K}$

mass of air $(m) = 18 \text{ kg}$

blue gas temperature $(T_f) = 300 + 273 = 573 \text{ K}$

assume $p_a = p_n$, $h_w = ?$

WKT

$$h_w = 353 \times H \times \left[\frac{1}{T_a} - \left(\frac{m+1}{m} \right) \frac{1}{T_f} \right] \frac{p_a}{p_n}$$

$$= 353 \times 100 \times \left[\frac{1}{305} - \left(\frac{18+1}{18} \right) \frac{1}{573} \right]$$

$$h_w = 50.7 \text{ mm}$$

How much air is used per kg of coal in a boiler having a chimney of 35m to create draught of 20mm of water then the temperature of blue gases in chimney is 370°C and the boiler horse temperature is 34°C . Does this chimney satisfies the condition of man discharge?

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Given data,

height of chimney $(H) = 35 \text{ m}$

height of water $(h_w) = 20 \text{ mm}$

blue gas temperature $(T_f) = 370^\circ\text{C} = 643 \text{ K}$

boiler temperature $(T_a) = 34^\circ\text{C} = 307 \text{ K}$

$$h_w = 353 \times H \times \left[\frac{1}{T_a} - \left(\frac{m+1}{m} \right) \frac{1}{T_f} \right] \frac{\rho_a}{\rho_w}$$

assume $\rho_a = \rho_w$

$$20 = 353 \times 35 \left[\frac{1}{307} - \left(\frac{m+1}{m} \right) \frac{1}{643} \right]$$

$$1.618 \times 10^{-3} = 3.25 \times 10^{-3} - \left(\frac{m+1}{m} \right) 1.55 \times 10^{-3}$$

$$1.052 = \left(\frac{m+1}{m} \right)$$

$$\frac{m+1}{m} = 1.052$$

$$m+1 = 1.052m$$

$$\left[\frac{1}{T_a} - \left(\frac{m+1}{m} \right) \frac{1}{T_f} \right] \times H \times 353 = h_w$$

$$m(1.052 - 1) = 1$$

$$m = \frac{1}{0.052}$$

$$m = 19.23 \frac{\text{kg of air}}{\text{kg of fuel}}$$

* maximum discharge from the chimney is given

$$T_f = 2 \left(\frac{m+1}{m} \right) T_a$$

$$= 2 \left(\frac{19.23+1}{19.23} \right) \cdot 307$$

$$T_f = 645.9 \text{ K}$$

chimney satisfies the max. discharge condition.

Find the amount of air used in the boiler per kg of fuel chimney height is 50m draught produced is 25mm of H₂O temperature of flue gases is 353°C and that room temperature is 35°C also determine the equivalent height of hot gas column and check the max. discharge condition.

Given data,

height of chimney (H) = 50m

height of water (h_w) = 25mm

flue gas temperature (T_f) = 353°C
= 626K

ambient temperature (T_a) = 35°C = 308K

m = ?

WKT,

$$h_w = 353 \times H \left[\frac{1}{T_a} - \left(\frac{m+1}{m} \right) \frac{1}{T_f} \right] \frac{\rho_g}{\rho_a}$$

$$25 = 353 \times 50 \left[\frac{1}{308} - \left(\frac{m+1}{m} \right) \frac{1}{626} \right]$$

$$1.416 \times 10^{-3} - 3.246 \times 10^{-3} = - \left(\frac{m+1}{m} \right) \frac{1}{6} \times 1.597 \times 10^{-3}$$

$$\frac{-1.83 \times 10^{-3}}{-1.597 \times 10^{-3}} = \frac{m+1}{m}$$

$$\frac{m+1}{m} = 1.145$$

$$m+1 = 1.145m$$

$$1.145m - m = 1$$

$$m(1.145 - 1) = 1$$

unit-1, pg-45/46

Find the amount of air in the chimney height is constant. $m = \frac{6.8 \text{ kg of air}}{0.195 \text{ kg of fuel}}$

→ equivalent height of hot column

$$H_{e'} = H \left[\frac{T_f}{T_a} \left(\frac{m}{m+1} \right) - 1 \right]$$

$$= 50 \times \left[\frac{626}{308} \left(\frac{6.8}{6.8+1} \right) - 1 \right]$$

$$H_{e'} = 38.59 \text{ m}$$

→ condition for max. discharge

$$T_f = 2 \left(\frac{m+1}{m} \right) T_a$$

$$T_f = 2 \left(\frac{6.8+1}{6.8} \right) 308$$

$$T_f = 706.5 \text{ K}$$

The chimney can't satisfies the

max. discharge condition.

$$\left[\frac{1}{308} \left(\frac{m+1}{m} \right) - \frac{1}{706.5} \right] \times 50 = 0$$

$$\frac{1}{308} \left(\frac{m+1}{m} \right) - \frac{1}{706.5} = 0$$

$$\frac{1+m}{m} = \frac{1.83 \times 10^3}{1.29 \times 10^3}$$

$$2 + \frac{1}{m} = \frac{1+m}{m}$$

$$m + 1 = 1 + m$$

$$1 + m - m = 1$$

$$1 = 1$$