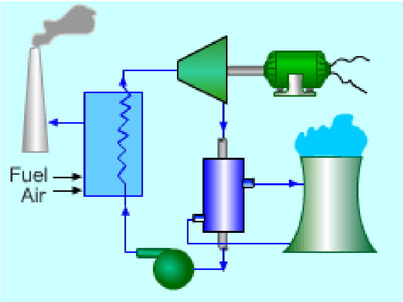
بسم الله الرحمن الرحيم

Thermal Power Stations



Lecture (7)

on

Schematic of a Thermal Power Plant

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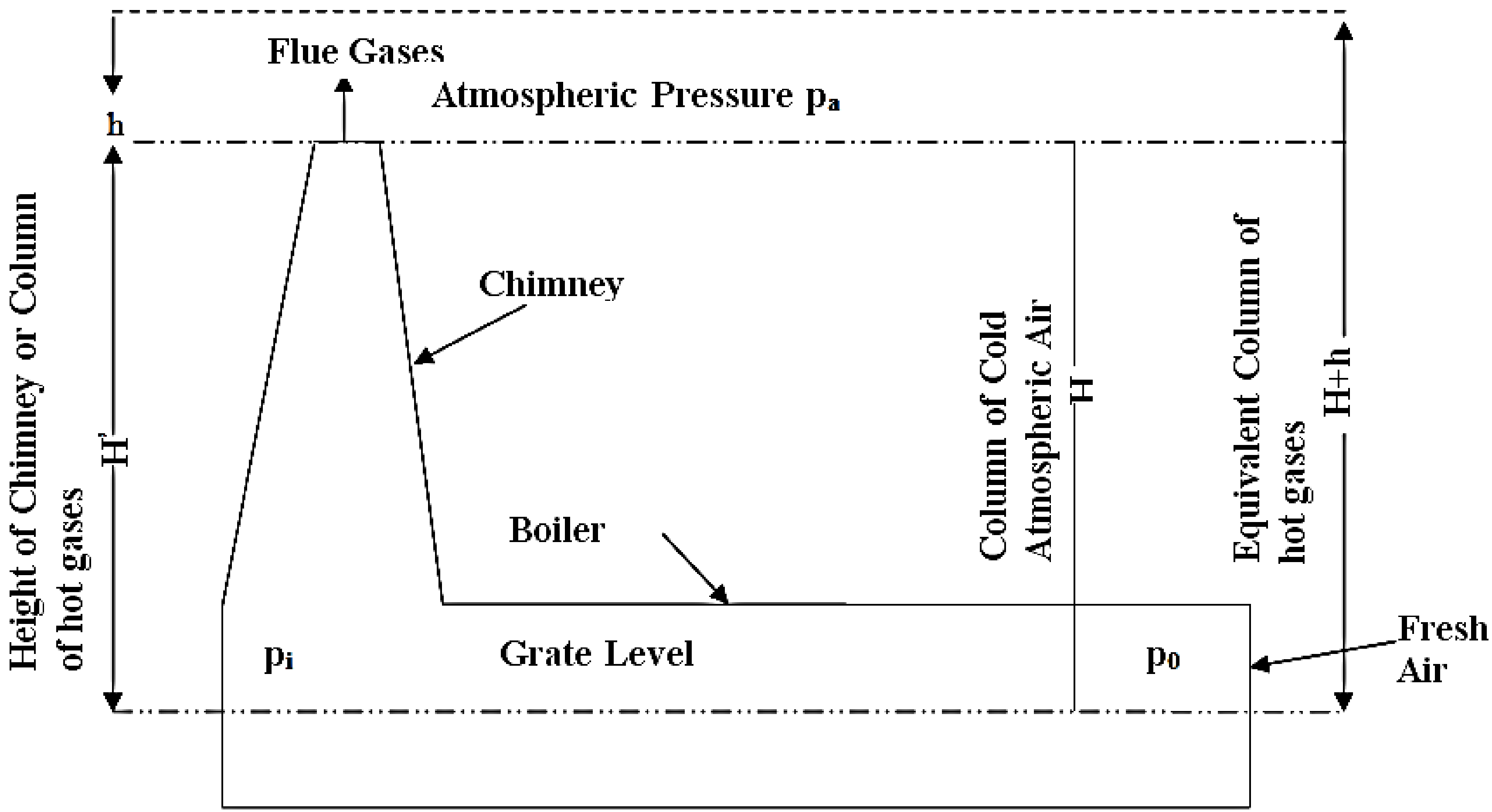
Natural Draught And Design Of Chimney



Natural Draught And Design Of Chimney

Grate

It is a platform in the combustion chamber, upon which the solid fuel (wood or coal) is burnt. It generally consists of cast iron bars which are space apart so that air (required for combustion) can pass through them. The surface area of the grate, over which the fire takes place, is called grate surface.

Natural Draught And Design Of Chimney

Chimney height

The natural draught is obtained with the use of tall chimney which may be sufficient or insufficient.

Let, p_1 = pressure at grate level (chimney base)

p_2 = pressure at top of chimney

When fire is not lighted, the chimney is filled by atmospheric air, the pressure at grate level is given by

$$p_1 = p_2 + \text{pressure due to atmospheric air column of height H}$$

$$\therefore p_1 = p_a + \rho_a gH$$

where p_a = atmospheric air pressure, ρ_a = density of atmospheric air

When the fire is lighted up on the grate, the hot gases will fill up the chimney as well as the flue gases passage, the pressure at the grate level is given by

$$p_1' = p_2 + \text{pressure due to the hot flue gases column height of chimney}$$

$$\therefore p_1' = p_a + \rho_g gH$$

where, ρ_g = density of hot flue gases

Natural Draught And Design Of Chimney

Chimney Height

net pressure difference at the grate level

$$\Delta p = p_1 - p_1'$$

$$= (p_a + \rho_a g H) - (p_a + \rho_a g H)$$

$$\therefore \Delta p = (\rho_a - \rho_g) g H$$

$$\Delta p = 353 g H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_g}{m_a}\right)\right] = 353 g H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a + m_f}{m_a}\right)\right] N/m^2$$

T_a = absolute temperature of atmospheric air, K of flue gases inside the chimney, K.
T_g = absolute temperature of flue gases inside the chimney, K
H = height of chimney, m
m_g = mass of flue gases (kg/kg of fuel)
m_f = mass of fuel supplied = 1 kg (assumed)

As we know that mass of flue gases produced is equal to sum of mass of air supplied and mass of fuel supplied.

$$\therefore m_g = m_a + 1 \quad (\because m_f = 1\ kg)$$

$$\Delta p = 353 g H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a + 1}{m_a}\right)\right] N/m^2$$

Natural Draught And Design Of Chimney

$$\frac{\text{Mass of hot gases}}{\text{Mass of air}} = \frac{m_a + 1}{m_a},$$

temperature and pressure being same.

$$\text{Now, } \rho_a = \frac{p}{RT_a} = \frac{1.01325 \times 10^5}{287} \cdot \frac{1}{T_a} = 353 \cdot \frac{1}{T_a}$$

$$\rho_g = \frac{p}{RT_g} \cdot \left(\frac{m_a + 1}{m_a}\right)$$

$$= \frac{1.033 \times 10^5}{287} \cdot \frac{1}{T_g} \cdot \left(\frac{m_a + 1}{m_a}\right)$$

$$= 353 \cdot \frac{1}{T_g} \cdot \left(\frac{m_a + 1}{m_a}\right)$$

Chimney Height

$$\Delta p = (\rho_a - \rho_g) g H$$

$$\Delta p = 353 g H \left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a + 1}{m_a}\right)\right] N/m^2$$

Natural Draught And Design Of Chimney

Chimney Height

In terms of mm of water column $(h_w) = \dfrac{\Delta p}{\rho g}$ metre of water column

$$= \frac{\Delta p}{1000 \times g} = \frac{\Delta p}{g} \text{ mm of water column}$$

Height of chimney

The draught produced by chimney in terms of mm of water column is given by

$$h_w = 353H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a+1}{m_a}\right)\right] \text{ mm of water} \qquad (1 \text{ mm of water} = 9.81\ Pa)$$

Draught produced by chimney in terms of metre of flue gases column is given by

$$H_1 = H\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]$$

Natural Draught And Design Of Chimney

Assuming draught pressure (ΔP) is equivalent to (H_1)m height of burnt gases

$$\Delta p = \rho_g \cdot gH_1 = 353\left(\frac{m_a+1}{m_a}\right)\cdot\frac{1}{T_g}\,g\,H_1$$

Equating the two expressions for (ΔP)

$$353\left(\frac{m_a+1}{m_a}\right)\frac{1}{T_a}\,g.\,H_1 = 353\,g\,H\left[\frac{1}{T_a}-\frac{1}{T_g}\left(\frac{m_a+1}{m_a}\right)\right]$$

$$\frac{353}{T_a}\left(\frac{m_a+1}{m_a}\right)g\,H_1 = \frac{353}{T_g}\,g\,H - \frac{353}{T_g}\,g\,H\left(\frac{m_a+1}{m_a}\right)$$

$$\frac{353}{T_a}\left(\frac{m_a+1}{m_a}\right)g\,H_1 = \frac{353}{T_g}\left(\frac{m_a+1}{m_a}\right)g\,H\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a}-1\right]$$

$$\therefore \quad H_1 = H\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a}-1\right]$$

Natural Draught And Design Of Chimney

Chimney diameter

Assuming no losses, the velocity of the gases passing through the chimney is expressed as:

$$U = \sqrt{2gH_1}$$

If there is losses, then the pressure loss in the chimney is equivalent to a hot gas column of (h'), then

$$U = \sqrt{2g(H_1 - h')} = 4.43\sqrt{H_1}\sqrt{1 - \frac{h'}{H_1}}$$

$$U = \left(4.43\sqrt{1 - \frac{h'}{H_1}}\right)\sqrt{H_1} = K\sqrt{H_1}$$

Where

K = 0.825 for brick chimney

= 1.1 for steel chimney

Natural Draught And Design Of Chimney

The mass of the gases flowing through any cross section of the chimney is given by

$$\dot{m}_g = \rho_g A.U, \ kg/s$$

where, $A = \frac{\pi}{4} D^2$, D = diameter of chimney at any cross section

$$\therefore \ D = 1.128\sqrt{\frac{\dot{m}_g}{\rho g.U}}$$

Example: 1

Draught produced by chimney is 2 cm of water column. Temperature of flue gas is 300°C and ambient temperature is 33°C. The flue gases formed per kg of fuel burnt is 24 kg. Neglect the losses and take the diameter of chimney as 1.75 m.

Calculate : (i) Height of chimney in m and (ii) Mass of flue gases flowing through the chimney in kg/min.

Solution : Given data : $h_w = 2$ cm $= 20$ mm of water column, $T_g = 300°C = 573$ K, $T_a = 33°C = 306$K, $(m_a + 1) = 24$ kg/kg of fuel burnt, $D = 1.75$ m, $H = ?$, $m_g = ?$ (kg/min)

(i) Height of chimney

The draught produced by chimney in terms of mm of water column is given by

$$h_w = 353H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a+1}{m_a}\right)\right] \text{ mm of water}$$

$$m_a + 1 = 24 \text{ kg}, \therefore\ m_a = 23 \text{ kg}$$

$$\therefore\ 20 = 353H\left[\frac{1}{306} - \frac{1}{573}\times\left(\frac{24}{23}\right)\right]$$

$$\therefore\ H = 39.158 \text{ m}$$ *Ans*

Example: 1

(ii) Mass of flue gases

Draught produced by chimney in terms of metre of flue gases column is given by

$$m_g = \text{mass flow rate of flue gases} = \rho_g \cdot A \cdot U$$

The velocity of flue gases $U = \sqrt{2gH_1}$ (if no losses)

$$H_1 = H\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right] = 39.158 \times \left[\left(\frac{23}{24}\right)\times\left(\frac{573}{306}\right) - 1\right]$$

$$\therefore H_1 = 31.112 \text{ m of flue gases column}$$

$$\therefore U = \sqrt{2 \times 9.81 \times 31.112} = 24.71\, m/s$$

Density of flue gases

$$\rho_g = \left(\frac{m_a+1}{m_a}\right) \times \frac{353}{g} = \left(\frac{24}{23}\right)\times\left(\frac{353}{573}\right) = 0.643\, kg/m^3$$

$$\therefore m_g = 0.643 \times \frac{\pi}{4}(1.75)^2 \times 24.71 = 38.207\, kg/s = 2292.41 \text{ kg/min}$$

Example: 2

A boiler is provided with a chimney of 26 m height. The boiler house temperature is 30°C and temperature of flue gases leaving chimney is 300°C. If air supplied to the boiler is 20 kg/kg of fuel. Estimate : (i) Draught in mm of water. (ii) Velocity of gases passing through chimney with 50% loss of draught in chimney

Solution : Given data : $H = 26\text{m}$, $T_a = 30°\text{C} = 303\text{ K}$, $T_g = 300°\text{C} = 573\text{ K}$, $m_a = 20$ kg/kg of fuel, $h_w = ?$, $U = ?$, $h' = 50\%$ of total draught $= 0.5H_1$

(i) Draught in mm of water

The draught in mm of water is given by

$$h_w = 353H\left[\frac{1}{T_a} - \frac{1}{T_g}\left(\frac{m_a+1}{m_a}\right)\right] \text{ mm of water}$$

$$\therefore\ h_w = 353 \times 26 \times \left[\frac{1}{303} - \frac{1}{573}\left(\frac{20+1}{20}\right)\right]$$

$$= \mathbf{13.47\ mm\ of\ water} \qquad \textit{Ans}$$

Example: 2

(ii) Velocity of gases passing through chimney

The draught produced in terms of height of a column of the flue gases in metre is given by

$$H_1 = H\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]$$

$$= 26\times\left[\left(\frac{20}{20+1}\right)\cdot\frac{573}{303} - 1\right] = 20.83 \text{ m of flue gases column}$$

The velocity of flue gases passing through chimney is given by

$$U = \sqrt{2g(H_1 - h')}$$

$$= \sqrt{2\times 9.81\times(20.83 - 0.5\times 20.83)} \qquad = 14.29 \text{ m/s}$$

Example: 3

Determine height and diameter of chimney to produce static draught of 18 mm of water column if mean flue gas temperature and flow rate are 300 C and 2100 kg/min respectively, the atmospheric air temperature is 25 C. The gas constant for air is 287 KJ/ Kg K. and for flue gas 250 KJ/Kg K. Assume no loss of draught in chimney and barometer reading is 760 mm of mercury.

Solution : Given data : $h_w = 18$ mm of water, $T_g = 300^oC = 573$ K, $m_g = 2100$ kg/min $= 35$ kg/s, $T_a = 25^oC = 298$ K, $R_a = 287$ kJ/kg K, $R_g = 250$ kJ/kg K, $p_a = 758$ mm of Hg $= 1.01325$ bar, H = ?, D = ?

(i) Height of chimney (H)

$$\text{Density of air } \rho_a = \frac{p_a}{R_a T_a} = \frac{1.01325\times10^5}{287\times298} = 1.185 \text{ kg/m}^3$$

$$\text{Density of flue gases } \rho_g = \frac{p_a}{R_g T_g} \quad \frac{1.01325\times10^5}{250\times573} = 0.707 \text{ kg/m}^3$$

Now, draught produced by chimney

$\Delta p = (\rho_a - \rho_g)gH$, where $\Delta p =$ in N/m^2

$\therefore h_w \times g = (\rho_a - \rho_g)gH$, where $h_w =$ in mm of water

Example: 3

$$\therefore h_w = (\rho_a - \rho_g)H$$

$$\therefore 18 = (1.185 - 0.708) \times H$$

$$\therefore \text{ H} = \text{height of chimney} = \mathbf{37.65\ m}$$

(ii) Diameter of chimney

Density of flue gases $\rho_g = \left(\dfrac{m_a + 1}{m_a}\right) \times \dfrac{353}{T_g}$

$$\therefore 0.707 = \frac{m_a + 1}{m_a} \times \frac{353}{573}$$

$\therefore (m_a + 1) = 1.1444 m_a \qquad \therefore m_a = 6.77$ kg/kg of fuel

Draught in terms of hot gases column

$$H_1 = H\left[\left(\frac{m_a}{m_a + 1}\right)\frac{T_g}{T_a} - 1\right] = 37.65\left[\left(\frac{6.77}{6.77 + 1}\right) \times \frac{573}{298} - 1\right]$$

Example: 3

$$= 25.426 \text{ m of flue gases column}$$

The velocity of flue gases $U = \sqrt{2gH_1}$

$$= \sqrt{2 \times 9.81 \times 25.426} = 22.33 \text{ m/s}$$

Mass flow rate of flue gases is given by

$$\dot{m}_g = \rho_g \cdot A \cdot U = \rho_g \times \frac{\pi}{4} D^2 \times U$$

$$\therefore 35 = 0.707 \times \frac{\pi}{4} D^2 \times 22.33$$

$\therefore$ D = diameter of chimney = **1.68 m** *Ans*

Artificial Draught

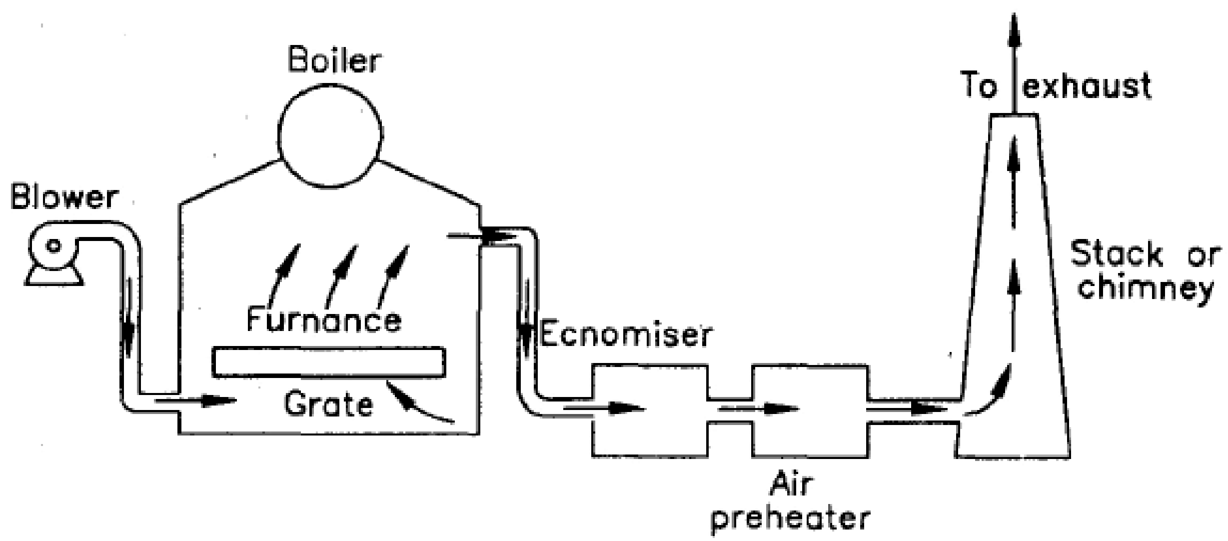
Because of insufficient head and lack of flexibility, The use of natural draught is limited to small capacity boilers only. The draught required in actual power plant is sufficiently high (300 mm of water) and to meet high draught requirements, some other system must be used [known as artificial draught].

The artificial draught is more economical when the required draught is above 40 mm of water.

Artificial Draught

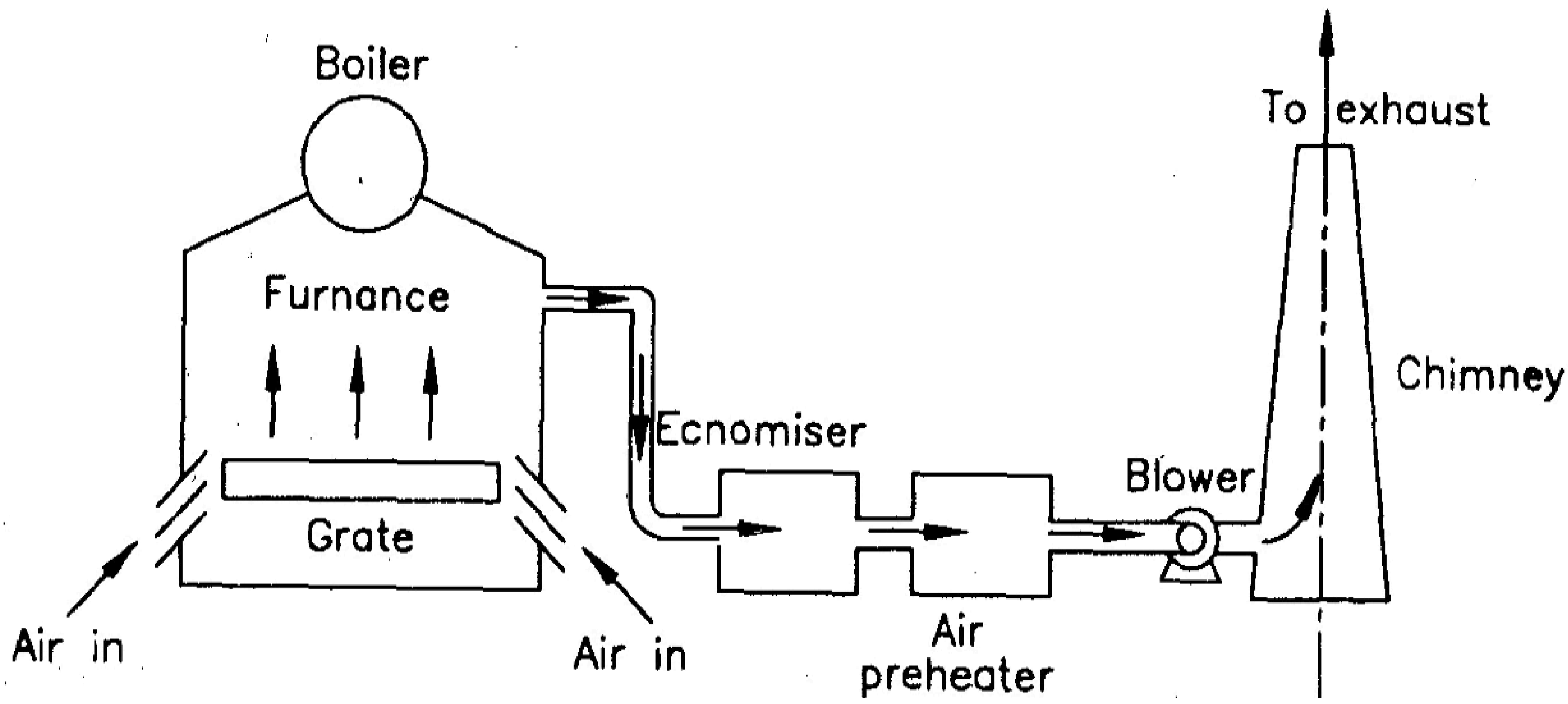
Forced Draught

In a forced draught system, a blower is installed near the base of the boiler. This draught system is known as positive draught system or forced draught system because the pressure of air throughout the system is above atmospheric pressure and air is forced to flow through the system. The arrangement of the system is shown in figure.



Artificial Draught

Induced Draught



Artificial Draught

Induced Draught

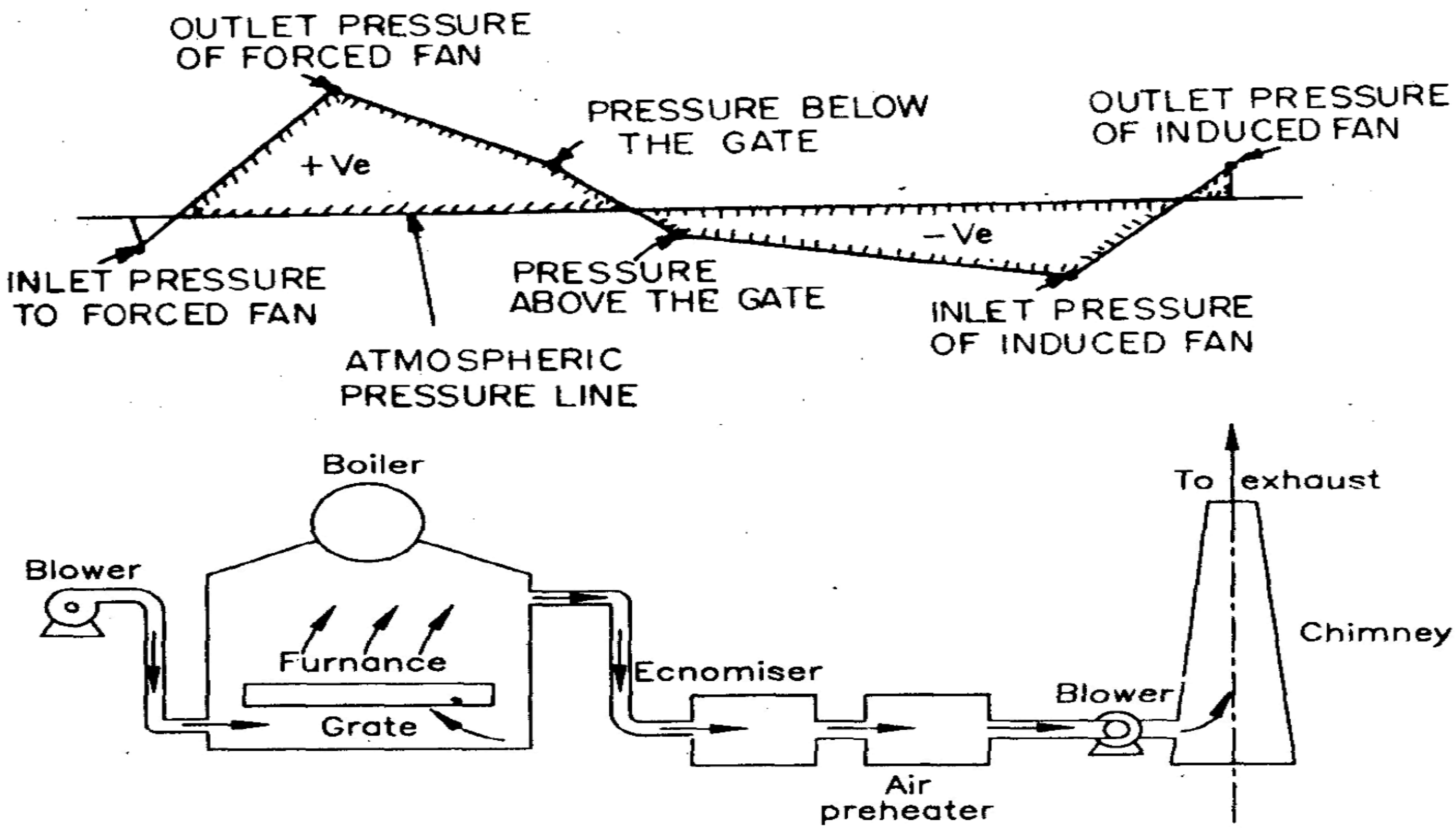
In this system, the blower is located near the base of the chimney instead of near the grate. The air is sucked in the system by reducing the pressure through the system below atmosphere.

The action of the induced draught is similar to the action of the chimney. The draught produced is independent of the temperature of the hot gases therefore the gases may be discharged as cold as possible after recovering as much heat as possible in air-preheater and economizer.

The chimney is also used in this system and its function is similar as mentioned in forced draught but total draught produced in induced draught system is the sum of the draughts produced by the fan and chimney. The arrangement of the system is shown in Figure.

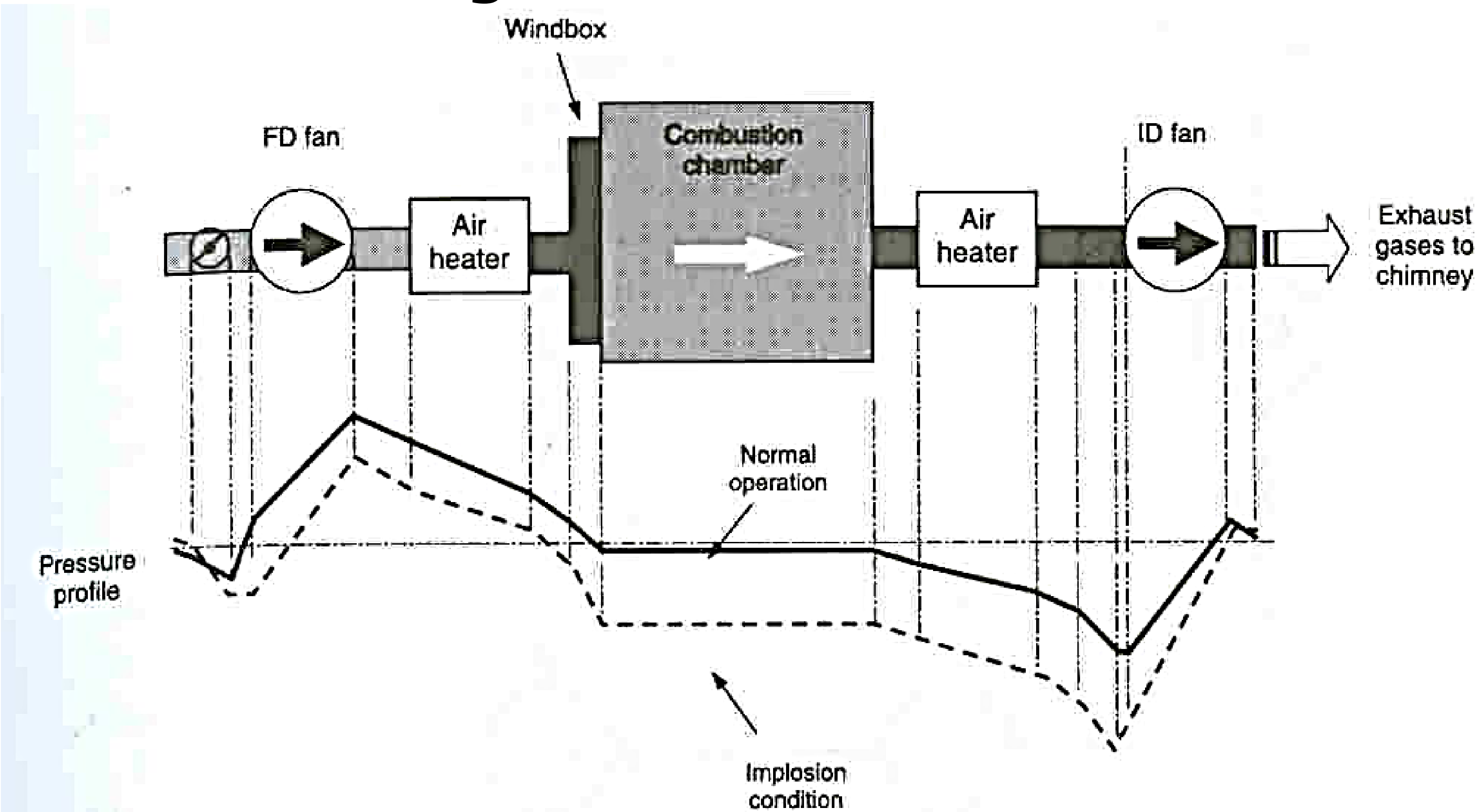
Artificial Draught

Balanced Draught



Artificial Draught

Balanced Draught



Artificial Draught

Balanced Draught

The balanced draught is a combination of forced and induced draught.

If the forced draught is used alone, then the furnace cannot be opened either for firing or inspection because the high pressure air inside the furnace will try to blow out suddenly and there is every chance of blowing out the fire completely and furnace stops.

If the induced draught is used alone, then also furnace cannot be opened either for firing or inspection because the cold air will try to rush into the furnace as the pressure inside the furnace is below atmospheric pressure.

This reduces the effective draught and dilutes the combustion.

To overcome both the difficulties mentioned above either using forced draught or induced draught alone, a balanced draught is always preferred.

Advantages of mechanical draught over natural draught

1. The artificial mechanical draught is better in control and more economical than natural draught.
2. The rate of combustion is high as the available draught is more. The better distribution and mixing of air with fuel is possible therefore the quantity of air required per kg of fuel is less.
3. The air flow can be regulated according to the requirement by changing the draught pressure.
4. The efficiency of the artificial draught is nearly 7% whereas the efficiency of the chimney draught is hardly 1%.

Advantages of mechanical draught over natural draught

5. The chimney draught is produced at the cost of thermal efficiency of the plant because it is necessary to exhaust the gases at high temperature to produce the draught. In mechanical draught, the exhaust gases can be cooled to lowest possible temperature before exhaust and improves the overall thermal efficiency of the plant.
6. The height of the chimney used in mechanical draught can be reduced sufficiently as the function of the chimney is only to exhaust the gases high in the atmosphere to prevent the contamination.

Advantages of mechanical draught over natural draught

7. The fuel consumption per kW due to artificial draught is 15% less than the natural draught.
8. The fuel burning capacity of the grate is 200 to 300 kg/m2 in area of the grate per hour with mechanical draught whereas it is hardly 50 kg/m2-hr with natural draught.
9. It prevents the formation of smoke as complete combustion is possible even with less excess air.

The major disadvantage of the artificial draught is the high capital cost required and high running and maintenance costs of the fans used.

Thank You