Lecture Notes

Subject- Thermal Engineering and Gas Dynamics

Topic- Boiler Draught and Height of Chimney

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Boiler draught

- Difference in gas pressure at any point in a flow passage and the ambient (same elevation) atmospheric pressure.
- Draught is achieved by a small pressure difference which causes the flow of air or gas to take place.
- It is measured in millimetre (mm) or water.
- To move the air through the fuel bed and to produce a flow of hot gases through the boiler economiser, preheater and chimney require a difference of pressure.
- Draught can be achieved by the use of chimney, fan, steam or air jet or a combination of these.

Purpose of Boiler Draught

1. To provide an adequate supply of air for fuel combustion.
2. For throw out the exhaust gases of combustion from the combustion chamber.
3. To discharge these gases to the atmosphere through the chimney.

Types of Draught

1. Natural Draught

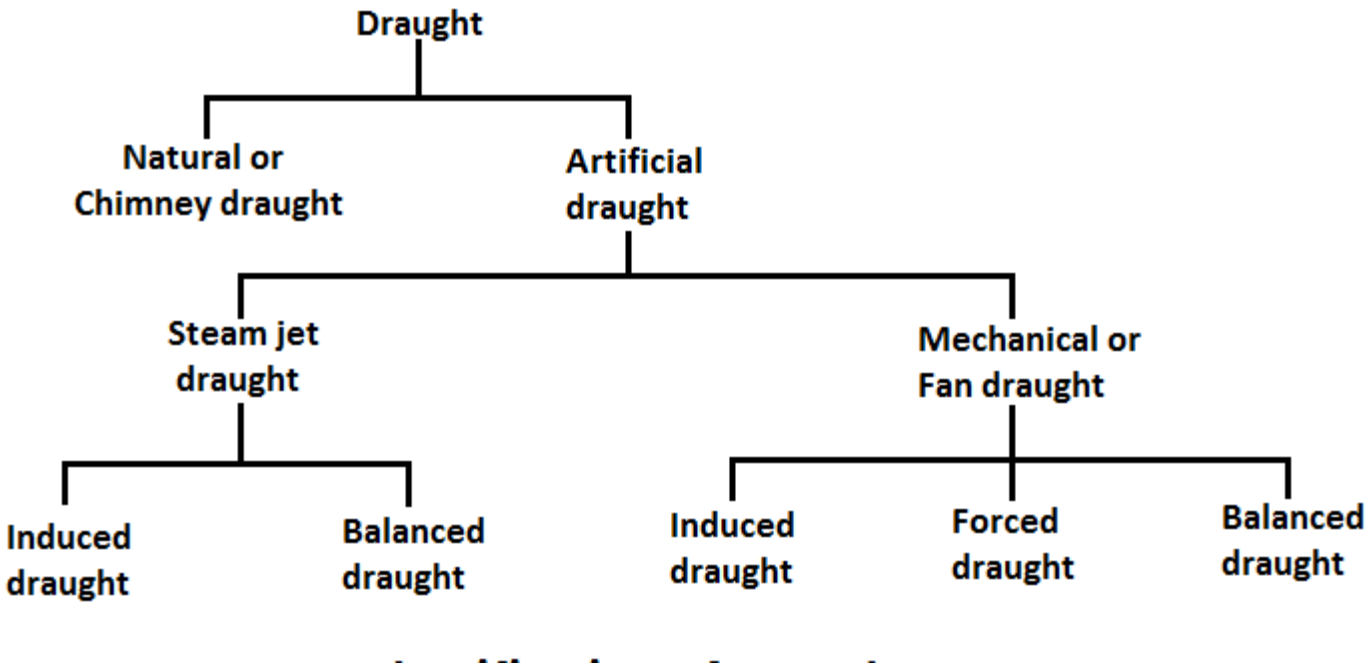
2. Artificial Draught

Measurement of Draught

The amount of draught produce depends upon:

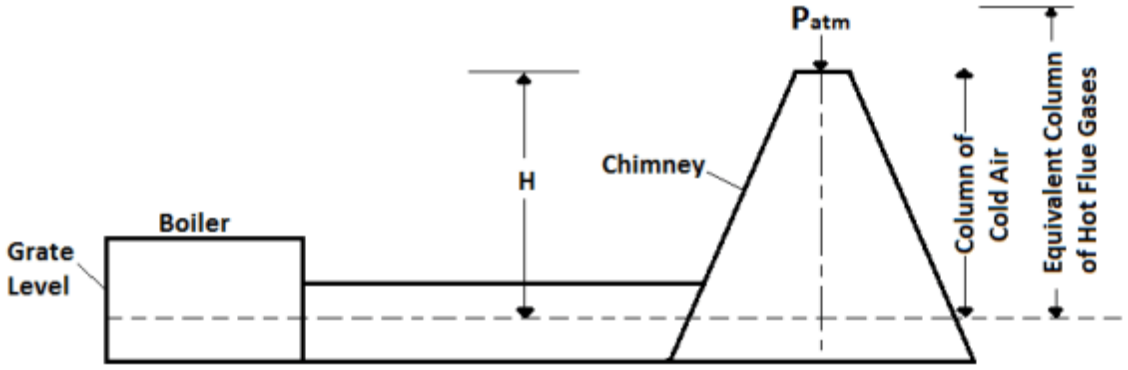
1. The nature and depth of fuel at the furnace.
2. Design of combustion chamber or firebox.
3. The rate of combustion required.
4. Resistance is allowed in the system due to baffles, tubes, superheaters, economizers, air pre-heaters etc.

Classification of Boiler Draught



Natural Draught

Natural draught system employs a tall chimney as shown in the figure. The chimney is a vertical tubular masonry structure or reinforced concrete. It is formed for enclosing a column of flue gases to produce the draught.



Natural Draught

It removes the gases high enough to prevent air pollution. The draught is produced by this tall chimney due to the temperature difference of hot gases in the chimney and cold external air outside the chimney.

Advantages of Natural Draught

1. No external power requires.
2. Less capacity investment
3. The maintenance cost is low as there is no mechanical part.
4. Chimney keeps the flue gases at a high place in the atmosphere which prevents the contamination of the atmosphere.
5. it has a long life.

Disadvantages of Natural Draught

1. The maximum pressure available for producing natural draught by the chimney is hardly 10 to 20 mm of water under the normal atmospheric and flue gas temperatures.
2. The available draught reduces with increases in outside air temperature and for generating enough draught, the exhaust gases have to be discharged at relatively high temperatures resulting in the loss of overall plant efficiency. Thus maximum utilization of Heat is not possible.

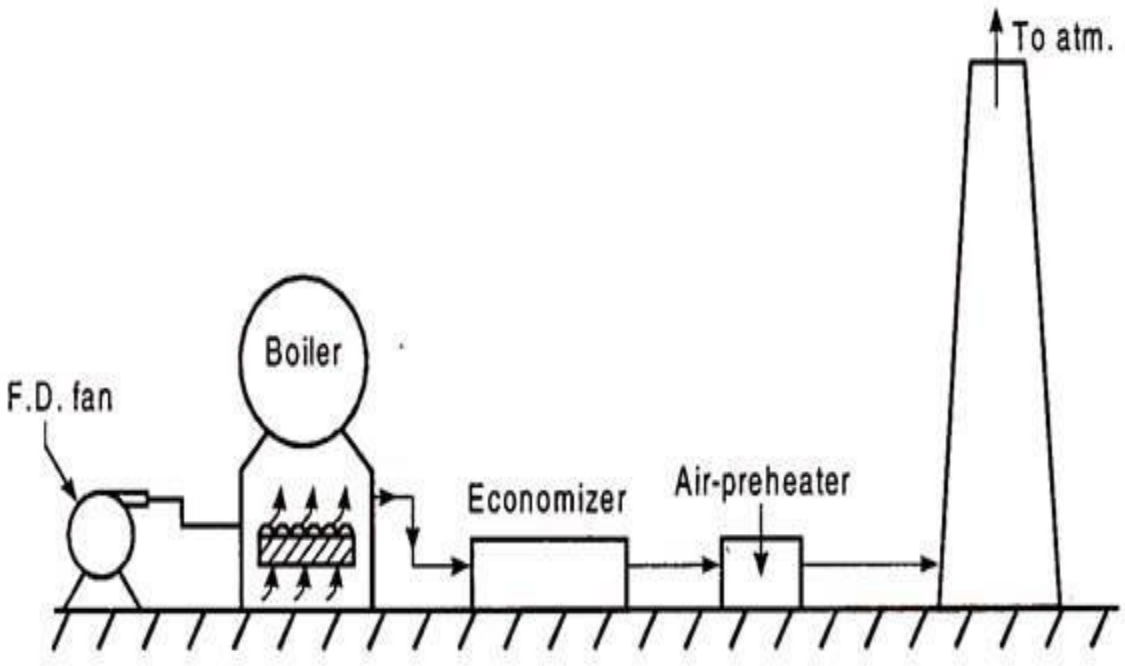
Artificial Draught:

In bigger power plants, the draught of the order of 25-350 mm of H_2O column is required. Far producing this much draught, the chimney height has to be increased considerably, which is neither convenient nor economical. Also, since the draught depends upon the climatic conditions, some mechanical equipments are used for producing the required draught and the draught so produced is called as the artificial draught.

1. **Forced Draught:**

In a Forced draught system, a Fan or Blower is provided is shown in figure which forces the air in the combustion chamber. In the combustion chamber combustion of air and fuel takes place and hot gases generated. These gases are forced to pass through the flues, economiser, air pre-heater and then they are exhausted after recovering heat of flue gases. This draught system is known positive draught system, since the pressure of gases throughout the system is above atmospheric pressure.

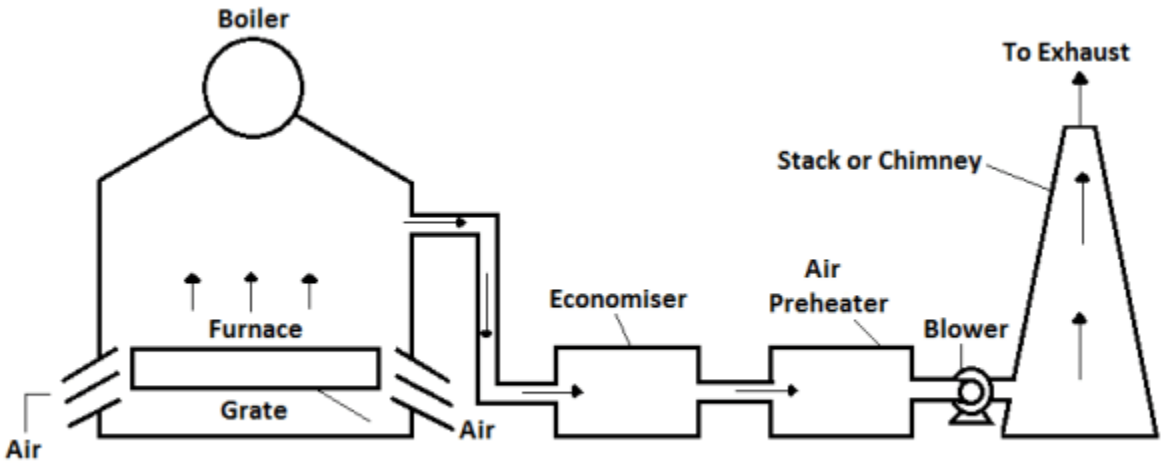
It is to be noted that, the function of chimney use is to discharge the gases high in the atmosphere to reduce air pollution and it is not much significant for producing draught.



ii. Induced Draught:

In this system, the Blower or Induced Draught fan is located near the base of chimney. The air is sucked in the system, by reducing the pressure through the system below atmosphere. The flue gases, generated after combustion are drawn through the system and after recovering heat in the economiser, air-preheater, they are exhausted through the chimney to the atmosphere.

Here it is to be noted that the draught produced is independent of the temperature of hot gases, so the gases may be discharged as cold as possible after recovering as much heat as possible.



Induced Draught System

Advantages of Forced Draught (F.D.) over Induced Draught (I.D.):

i. The size and power required by I.D. fan is more because this fan handles more gases.

ii. Since the I.D. fan handles hot gases, water cooled or air cooled bearings are to be used.

iii. F.D. fan consumes less power and normal bearing can be used.

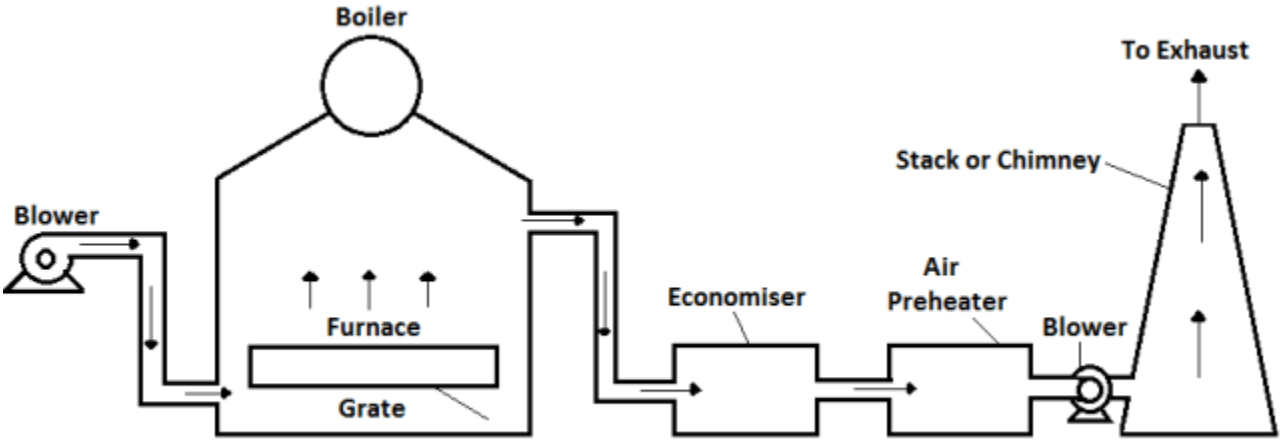
iii. Balanced Draught:

It is always preferable to use combinations of I.D. and F.D. instead of Forced or Induced draught alone.

If Forced Draught alone is used then the furnace cannot be opened for firing or for inspection. Because the high pressure air/gases inside the furnace will try to blow out, and there is every chance of blowing out of the fire completely and the furnace may stop.

If Induced Draught fan alone is used, then also furnace cannot be opened either for firing or for inspection. Because the cold air will try to rush into the furnace, which reduces the effective draught.

To overcome both these difficulties Balanced Draught is used. In this case I.D. fan and F.D. fan are provided as shown.



Balanced Draught System

Steam Jet Draught

It is a very simple and easy method of producing artificial draught without the need for an electric motor. It may be forced or induced depending on where the steam jet is installed. Steam under pressure is available in the boiler.

When a small position of steam is passed through a jet or nozzle, pressure energy converts to kinetic energy and steam comes out with a high velocity. This high-velocity steam carries, along with it, a large mass of air or flue gases and makes it flow through the boiler. Thus steam jet can be used to produce draught and it is a simple and cheap method.

Actually the steam jet is directed towards a fix direction and carries all its energy in kinetic form. It creates some vacuum in it's surrounding and attracts the air of flue gases either by carrying along with it. Thus it has the capacity to make the flow of the flue gases either by carrying or including towards chimney. It depends on the position of the steam jet.

Types of Steam Jet Draught

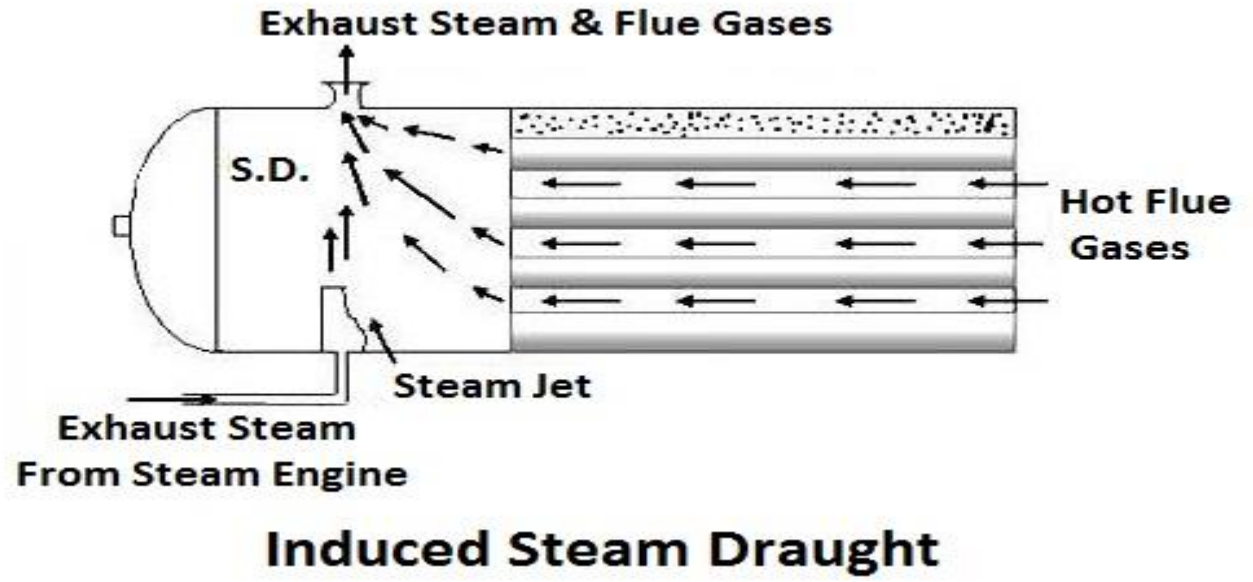
The following are the main two types of steam jet draught:

1. Induced steam jet draught.
2. Forced steam jet draught.

If the steam jet is directed into the smoke box, near, the chimney, the air is sucked through the system, into the smoke box. If the jet is Located before grate, air is forced through the system. Induced type is favoured as forced draught increases heat losses.

1. **Induced Steam Jet Draught**

The jet of steam is turned into a smoke box or chimney. The kinetic head of the steam is high but static head is low i.e., it produces a partial vacuum which brings the air through the grate, ash pit, flues and then to motor box and chimney.



Induced Steam Draught

Induced draught is produced by steam jet in case of Locomotive boiler. When the Locomotive in stationary, steam from the boiler may be supplied to the smoke box through the nozzle to create draught. While locomotive is running, due to motion, the air flows to the furnace.

2. **Forced Steam Jet Draught**

Steam from the boiler after having been throttled to a gauge pressure of 1.5 to 2 bar is supplied to the jet or nozzle installed in the ash pit. The steam rising out of nozzles with a great velocity drags air by the fuel bed, furnace, flue passage and then to the chimney. Here the steam jet is pushing or forcing the air and flue gases to flow through boiler hence it is forced steam jet draught.

Advantages of Induced Steam Jet Draught

1. It is quite simple and cheap.
2. The induced steam jet draught has the capability of using low-grade fuels.
3. It occupies very less space.
4. It is quite simple and cheap.
5. The initial cost is low.
6. Maintenance cost is low.
7. Exhaust steam from the steam engine or turbine can be used easily in the steam jet draught.

Disadvantages of Steam Jet Draught

1. It can operate only when some steam is generated.
2. Draught produced very low.

Comparison Between Forced Draught and Induced Draught

Forced Draught	Induced Draught
Fan or blower is placed before the grate	Fan or blower is placed after the grate
The pressure inside the flue gases is slightly more than atmospheric pressure	The pressure inside the flue gases is slightly less than atmospheric pressure
Fan requires less power	Fan requires more power
The flow of the flue gases through the boiler is more uniform	The flow of the flue gases through the boiler is less uniform
The danger of fire in case pf leakage of flue gases.	No danger of fire in case of leakage of flue gases.

Height of Chimney :

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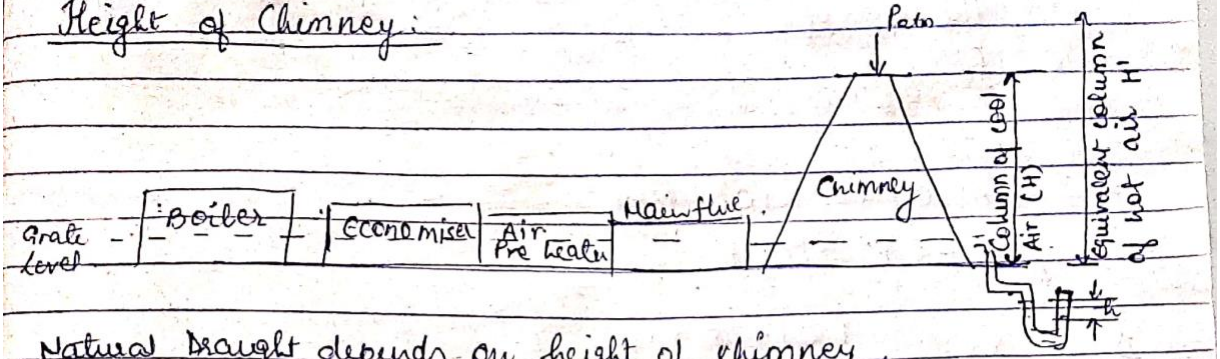

Natural Draught depends on height of chimney.

Let,

m_a = Mass of air supplied in kg/kg of fuel.

m_{a+1} = Mass of chimney gases (kg/kg of fuel)

T_a = Absolute temperature of atmosphere

T_g = Average absolute temperature of chimney gases

P_a = Atmospheric pressure (N/m^2)

H = Height of chimney (m)

ρ_a = Mass density of air outside chimney

ρ_g' = Avg. Mass density of hot gases

∴ Static ~~Pressure~~ draught : Difference of pressure causing the flow of gases. Its value is small & generally measured by a water manometer.

$\Delta P < 12$ mm of H_2O

Static Draught = Pressure at grate on open side (P_2)
− Pressure at chimney side (P_1)

We have,

$P_1 = P_a + \rho_g' \cdot g H$ [$\rho_g \cdot gH$ = Pressure exerted by column of hot gases of height 'H' m

$P_2 = P_a + \rho_a g H$ [$\rho_a \cdot gH$ = Pressure due to column of cold air out side chimney of height 'H' m

So,

$$\Delta p = P_2 - P_1 = (\rho_a - \rho_g') g H \quad \text{(1)}$$

Specific volume of air at N.T.P.

$$v_o = \frac{RT_o}{P_o}$$

$$= \frac{0.287 \text{ kJ/kg/K} \times 273 \text{ K}}{101.325 \text{ kPa}}$$

$$= 0.7732 \text{ m}^3/\text{kg}$$

∵ The volume of fuel ~~gases~~ is negligible as compared to volume of air supplied per kg of fuel

∴ Volume of flue gases can be taken equal to volume of air

From Charles Law: ($V \propto T$)

$$\frac{V_a}{T_a} = \frac{V_o}{T_o} = \frac{m_a v_o}{T_o}$$

$$V_a = \frac{m_a \times 0.7732}{273} T_a$$

So,

$$\rho_a = \frac{m_a}{V_a} = \frac{273}{0.7732} \times \frac{1}{T_a} = \frac{353}{T_a}$$

~~Similarly volume of~~

As per Avagadro's Law, the flue gas at NTP occupies same volume as air used at NTP

Similarly value of flue gases inside chimney :-

$$\frac{V_g}{T_g} = \frac{V_0}{T_0} \Rightarrow V_g = \frac{0.7732}{273} m_a T_g$$

So, $$\rho_g = \frac{m_g}{V_g} = \frac{m_a+1}{V_g} = \frac{m_a+1}{0.7732 m_a} \times \frac{273}{T_g}$$

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

So, From eqn (A) (B) & (C)

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

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

In terms of water column (mm of H_2O column)

$$\Delta P = (\rho g h)_w \quad \text{where } \rho_w = 1000 \text{ kg/m}^3$$

$h_w = h$ (mm of water) $= \frac{h}{1000}$ meter

$\Rightarrow$

$$\Delta P = 1000 \text{ kg/m}^3 \times g \times \frac{h}{1000} \text{ m}$$

$$\Delta P \Rightarrow 1000\, g\, h \text{ kg/m}^2 \quad \text{(5)}$$

So from eqn (D) & (5)

we have

$$1000\, g h = 353 g H \left[\frac{1}{T_a} - \left(\frac{m_a+1}{m_a}\right)\frac{1}{T_g}\right]$$

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

Now assuming draught ΔP produced is equivalent to H_1 meter of burnt gases, we have

$$\Delta P = \rho_g g H_1 = 353 \left(\frac{m_a+1}{m_a}\right) \frac{1}{T_g} g H_1 \quad \text{---(6)}$$

From eq^n (D) & (6)

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

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

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

Now

Diameter of Chimney :

∴ The theoretical velocity of hot flue gases flows through chimney

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

Consider h_f = frictional losses in column of hot flue gases than

$$C_g = \sqrt{2g(H_1 - h_f)}$$

$$C_g = 4.43\sqrt{H_1 - h_f} \Rightarrow C_g = 4.43\sqrt{H_1} \times \sqrt{1 - \frac{h_f}{H_1}}$$

$$C_g = 4.43\sqrt{H_1} \times \sqrt{\left(1 - \frac{h_f}{H_1}\right)}$$

$C_g = k\sqrt{H_1}$ where, $k = 4.43\sqrt{1 - \frac{h_f}{H_1}}$

Experimentally –

$k = 0.825$ for brick chimney

$= 1.1$ (steel chimney)

Mass of flue gases flowing through chimney

$$\dot{m}_g = \rho_g A C_g \quad (kg/s)$$

$$= \rho_g \left(\frac{\pi}{4} D^2\right) C_g$$

$$D^2 = \frac{4\,\dot{m}_g}{\pi \rho_g C_g}$$

$$D = 1.128\sqrt{\frac{\dot{m}_g}{\rho_g C_g}}$$

Condition for maximum discharge through chimney

$C_g = \sqrt{2gH'}$ where $h_f = 0$

$$C_g = \sqrt{2gH\left[\left(\frac{m_g}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]}$$

$$\dot{m}_g = \rho_g A C_g$$

$$= A\,\rho_g \sqrt{2gH\left[\left(\frac{m_a}{m_a+1}\right)\frac{T_g}{T_a} - 1\right]}\left[\frac{P}{RT_g}\right]$$

For maximum discharge $\frac{d\dot{m}_g}{dT_g} = 0$

Final Result $\Rightarrow \boxed{\frac{T_g}{T_a} = 2\,\frac{m_a+1}{m_a}}$

$\Rightarrow (H_1)_{max} = H \quad \Big| \quad (h_w)_{max} = \frac{176.5}{T_a} H$ mm of water