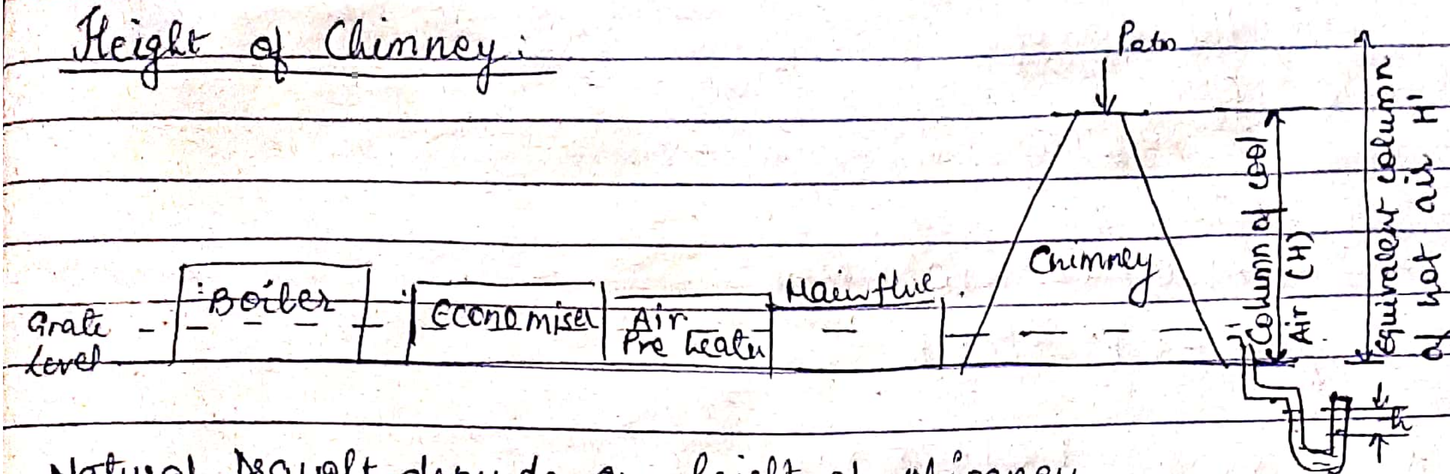
Height of Chimney:



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,

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

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

So,

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

Specific volume of air at N.T.P.

$$v_0 = \frac{R T_0}{P_0}$$

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

$$= 0.7732 \ m^3/kg$$

∵ The volume of ~~flued 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: $(V \propto T)$

$$\frac{V_a}{T_a} = \frac{V_0}{T_0} = \frac{m_a v_0}{T_0}$$

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

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 volume 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,

$$\rho_g = \frac{m_g}{V_g} = \frac{m_a + 1}{V_g} = \frac{m_a + 1}{0.732 m_a} \times \frac{273}{T_g}$$

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

So, From eq^n (A) (B) & (C)

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

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

In terms of water column (mm of H_2O column)

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

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

$\Rightarrow$

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

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

So from eq^n (D) & (5)

we have

$$\cancel{1000\, g h =}$$

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

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

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Now assuming draught ΔP produced is equivalent to H_1 meters 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)

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

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

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

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

then

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

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

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

$C_g = k\sqrt{H_1}$ 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 $h_f = 0$

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

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

$$= A C_g \rho_g$$

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

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

Final Result

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

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