Chapter 3
steam Generators

Part 3

The Stack

The stack has two major functions:

1. Assist the fans in overcoming the pressure losses
2. Help dispersing the gas effluent into the air

The stack design is greatly affected by the metallurgical conditions, such as the:

1. Altitude
2. Wind velocity
3. Stability conditions

Driving pressure The *driving pressure* Δp_d, in lb_f/ft^2 or N/m^2, supplied by a stack is given by an equation similar to Eq. (3-1)

$$\Delta p_d = (\rho_a - \bar{\rho}_s)H\frac{g}{g_c} \tag{3-13}$$

where

ρ_a = atmospheric air density, lb_m/ft^3 or kg/m^3

$\bar{\rho}_s$ = average stack gas density, lb_m/ft^3 or kg/m^3

H = height of the stack, ft or m

Because both air and gas obey the perfect-gas law, Eq. (1-19*a*), from which $\rho = m/V = P/RT$, Eq. (3-13) becomes

$$\Delta p_d = \left(\frac{P_a}{R_aT_a} - \frac{P_s}{R_s\bar{T}_s}\right)H\frac{g}{g_c} \tag{3-14}$$

where

P_a and P_s = absolute pressures of atmospheric air (barometric pressure) and stack gas, respectively, lb_f/ft^2 or N/m^2

R_a and R_s = gas constants for air and stack gas, respectively, $ft \cdot lb_f/(lb_m \cdot {}^\circ R)$ or $J/(kg \cdot K)$

T_a and $\bar{T}_s$ = air and average stack gas temperatures respectively, °R or K

Table 3-1 The variation of barometric pressure with altitude

	Altitude, ft									
P_a:	0	1000	2000	3000	4000	5000	6000	7000	8000	10,000
inHg	29.92	28.86	27.82	26.82	25.84	24.90	23.98	23.09	22.22	20.58
psia	14.70	14.17	13.66	13.17	12.69	12.23	11.78	11.34	10.91	10.11
bar	1.013	0.977	0.942	0.908	0.875	0.843	0.812	0.782	0.752	0.697

P_a and P_s differ only slightly. $R_a = 53.34\ \text{ft} \cdot \text{lb}_f/(\text{lb}_m \cdot {}^\circ\text{R})$. R_s depends upon the gas composition* and hence upon the fuel used and is about 52.2 for bituminous coal, 53.2 for fuel oil, and 55.6 for natural gas. Equation (3-14) can then be rewritten with good accuracy into the form

$$\Delta P_d = \frac{P_a}{R_a}\left(\frac{1}{T_a} - \frac{1}{\bar{T}_s}\right)H\frac{g}{g_c} \qquad (3\text{-}15)$$

In any one location P_a is a function of:

1. The *altitude of the location as seen in table 3-1.*
2. *Weather conditions, which strongly affect the T_a .*

T_s average depends on:

1. *Temperature variation of the gas a long the stack.*
2. *Heat losses through the stack walls.*
3. *Infiltration of cold outside air.*

The exact value of T_s average is obtained by integrating the stack local temperature as a function of height and dividing by H as given in the following equation:

$$\overline{T}_s = \frac{T_o + T_H}{2} \quad (3\text{-}16)$$

T_o and T_H are the stack inlet and exit temperatures, respectively in R or K.

Values of T_H depend on:

1. *T_o*
2. *Stack height H*
3. *Internal diameter D*
4. *Outside atmospheric conditions such as the wind temperature and velocity.*

T_H directly proportional to D and T_o and inversely proportional to H.

Stacks have also pressure drop due to the wall friction and the kinetic energy of the gases leaving the stack. The result is a few percent of driving force.

Dispersion

It is the second major function of the stack and it is defined as the movement of the flue gases horizontally and vertically and their dilution by the atmosphere.

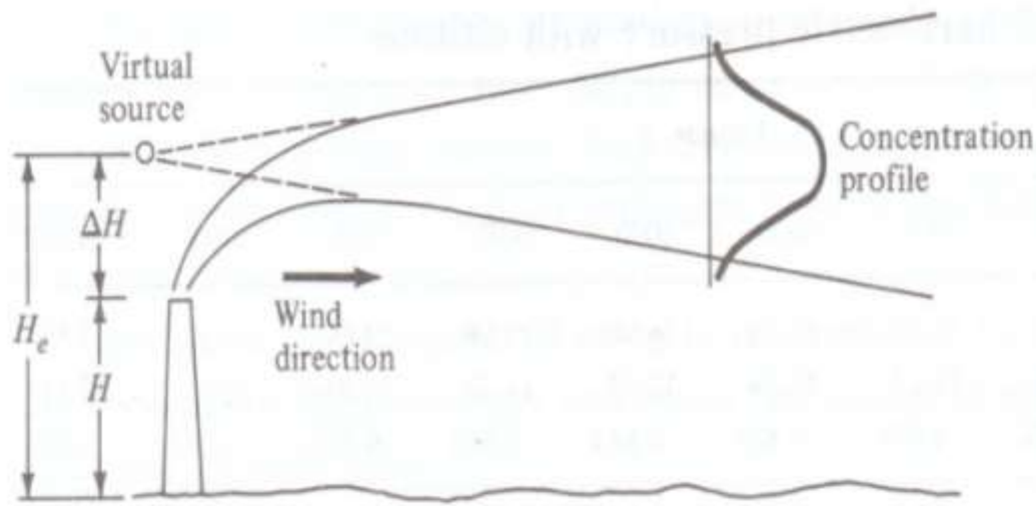
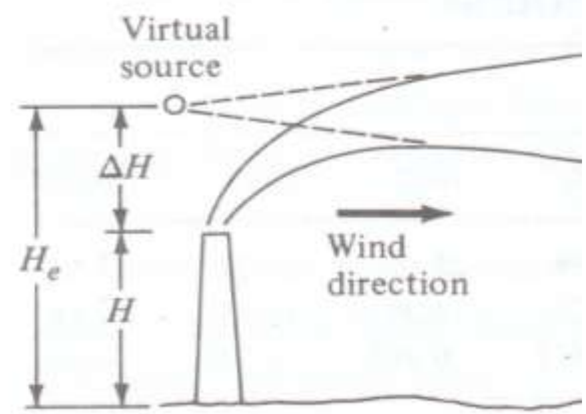


Figure 3-21 Dispersion model forms a stack of height H and plume ΔH.

The horizontal motion is a result of the existing wind.

The vertical motion is a result from the upward motion of high-velocity warm stack exit gases to much higher elevations, which results in a plume rise above the actual stack. This gives the effective stack height definition, which is given in the following equation.

$$H_e = H + \Delta H$$



The proper design of a stack depends on:

a) Local topography, such as valleys and mountains b) airflow pattern

∇H can be calculated using different mathematical models based on the gasses momentum and the buoyancy forces due to densities difference between the stack gases and the atmospheric air.

1. Carson and Moses [21]

where

$$\Delta H = -0.029 \frac{V_s D}{V_w} + 2.62 \frac{(Q_e)^{0.5}}{V_w}$$

V_w = wind velocity at stack exit, m/s

Q_e = heat emission, J/s, given by

$$Q_e = \dot{m} c_p (T_s - T_a) \quad (3\text{-}19)$$

$\dot{m}$ = gas mass-flow rate, kg/s

c_p = specific heat of gas = 1005 J/(kg · K) for dry ai at low temperature)

T_s = gas temperature at stack exit, K

T_a = air temperature at stack exit, K.

2. Brigges model

$$\Delta H = \frac{114CF^{1/3}}{V_w} \tag{3-20}$$

where

C = dimensionless temperature gradient parameter = $1.58 - 41.4(\Delta\theta/\Delta z)$

$\Delta\theta/\Delta z$ = air potential temperature gradient, K/m = 0 for neutral atmospheric stability conditions*

F = buoyancy flux = $gV_sD^2(T_s - T_a)/4T_a$, m^4/s^3

g = gravitational acceleration = 9.8 m/s^2

3. TVA model

TVA model [24]

$$\Delta H = \frac{173F^{1/3}}{V_w} e^{-(64\ \Delta\theta/\Delta z)} \tag{3-21}$$

One of the most sever hazard to dispersion is the atmospheric inversion that occurs when the temperature of the atmosphere increases with elevation, when there is little wind and strong stability that results in the reduction of vertical dispersion and thence trapping the local emissions.

Briggs model cares about the various stability conditions via C. Also TVA accounts for the stability issue.