Course Name: Theory of Fire Propagation (Fire Dynamics)

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Week – 10

Lecture – 05

Module 7 – Enclosure Fires

Simplified expression for air flow rate:

Since the expression to evaluate Z_L is known, the mass flow rate of air under steady conditions, in a steady fire, can be written as,

$$\dot{m}_{in} = \frac{2}{3} C_d W \rho_a \sqrt{\frac{2g(\rho_a - \rho_g)}{\rho_a}} \left(\frac{H_0}{1 + (\rho_a/\rho_g)^{\frac{1}{3}}} \right)^{\frac{3}{2}}$$

This can be simplified as,

$$\dot{m}_{in} = \frac{2}{3} C_d A_0 \sqrt{H_0} \sqrt{2g} \rho_a \sqrt{\frac{(\rho_a - \rho_g)\rho_a}{\left(1 + (\rho_a/\rho_g)^{\frac{1}{3}}\right)^3}}$$

Here, A_0 = W × H_0 is the area of the vent. Parameter in square-root is called density factor. The mass flow rate of the out going gases will be equal to the mass flow rate of incoming air.

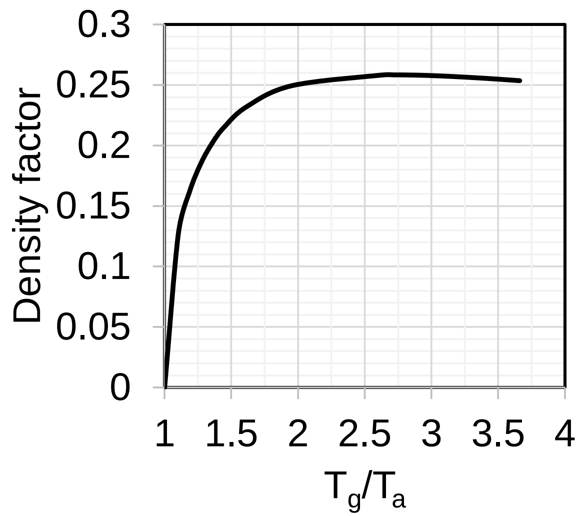
Density factor:

Quantity in square-root in the expression of air mass flow rate is density factor (DF) and is written as a function of temperature as,

$$DF = \sqrt{\frac{(\rho_a - \rho_g)\rho_a}{\left(1 + (\rho_a/\rho_g)^{\frac{1}{3}}\right)^3}} = \left(\frac{353}{T_a}\right)\sqrt{\frac{(T_g - T_a)}{\left(1 + (T_g/T_a)^{\frac{1}{3}}\right)^3}}$$

This is derived using ideal gas law:

p = ρRT. Here, p is the atmospheric pressure = 101325 N/m^2, R is the specific gas constant for air = R_u/M = 8314/28.9 = 287.7 J/kg-K, T in K and ρ = 101325/(287.7×T) ≈ 353/T.



At $T_g/T_a = 2.72$, DF reaches its maximum value and remains almost a constant.

Air flow rate in regime I fully developed fire:

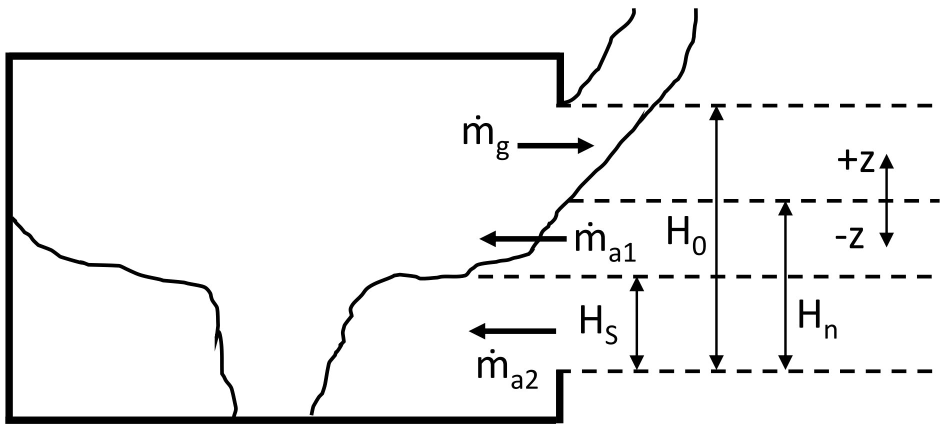
For fully developed compartment fires, the value of density factor can be taken as 0.214. Further, using $C_d = 0.7$, $\rho_\infty = 1.2$ kg/m^3, mass flow rate of air can be expressed as,

$$\dot{m}_{in} = 0.5\, A_0\sqrt{H_0}$$

The equation shows that the mass flow rate of air into a compartment during the fully developed Regime I fire is only a function of the vent height and vent area. This equation gives an estimate of the mass flow rate for fires with gas temperature being at least two times the ambient temperature (in Kelvin). Also, it is assumed that the gases inside the enclosure are well-mixed and its temperature is uniform within the enclosure volume. This equation is quite useful in analysing post-flashover fires.

Gas and air flow for developing stage:

When the fire is developing, depending on the fire strength and vent opening height, H_0, stratified smoke layer forms, as shown.



Smoke layer has descended to a particular height from the ceiling, H_S. measured from the bottom of the vent. Below this, air from atmosphere enters. Above this level, a neutral plane is formed at a height of H_n, measured from bottom of the vent. Above H_n, hot gas leaves and below H_n, air comes in.

Mass flow rates of gas & air in developing stage:

Proceeding like before, Rockett (1976) has derived expressions for mass of the gases going out of the enclosure above the neutral plane as:

$$\dot{m}_g = \frac{2}{3} C_d A_o \sqrt{H_0} \sqrt{2g} \rho_a \left[\frac{T_a}{T_g} \left(1 - \frac{T_a}{T_g} \right) \right]^{1/2} \left[\frac{1 - H_n}{H_0} \right]^{3/2}$$

Here, integration of velocity is performed between H_n and H_0. For air mass flow rates, two integrations are performed – one between H_S and H_n, and second, between 0 and H_S. Total mass flow rate of air, $\dot{m}_a = \dot{m}_{a1} + \dot{m}_{a2}$, is expressed as,

$$\dot{m}_a = \frac{2}{3} C_d A_o \sqrt{H_0} \sqrt{2g} \rho_a \left[1 - \frac{T_a}{T_g} \right]^{1/2} \left(\frac{H_n}{H_0} - \frac{H_s}{H_0} \right)^{1/2} \left(\frac{H_n}{H_0} + \frac{H_s}{2H_0} \right)$$

Heights H_n and H_S are to be determined. A two-zone model is required for this. A numerical approach is used for this.

Correlation by McCaffrey, Quintiere & Harkleroad:

McCaffrey, Quintiere and Harkleroad (1981) further explored the ventilation factor, and developed the famous MQH correlation.

Using energy balance, convective heat release rate is written as,

$$\dot{Q}_c = (\dot{m}_a + \dot{m}_f) c_p (T_g - T_a) + h_k A_T (T_g - T_a)$$

Here, A_T is the total internal surface area of the enclosure (walls, ceiling, floor), neglecting openings and h_k is a global heat transfer coefficient, which has been a subject of several experimental studies in compartment fire literature. Assuming h_k to be a constant and neglecting $\dot{m}_f$, since $\dot{m}_a >> \dot{m}_f$, $T_g - T_a = \Delta T$, is,

$$\frac{\left(T_g - T_a\right)}{T_a} = \frac{\Delta T}{T_a} = \frac{\dot{Q}_c}{\left(\dot{m}_a c_p + h_k A_T\right) T_a} = \frac{\frac{\dot{Q}_c}{\dot{m}_a c_p T_a}}{\left(1 + \frac{h_k A_T}{\dot{m}_a c_p}\right)}$$