Course Name: Theory of Fire Propagation (Fire Dynamics)

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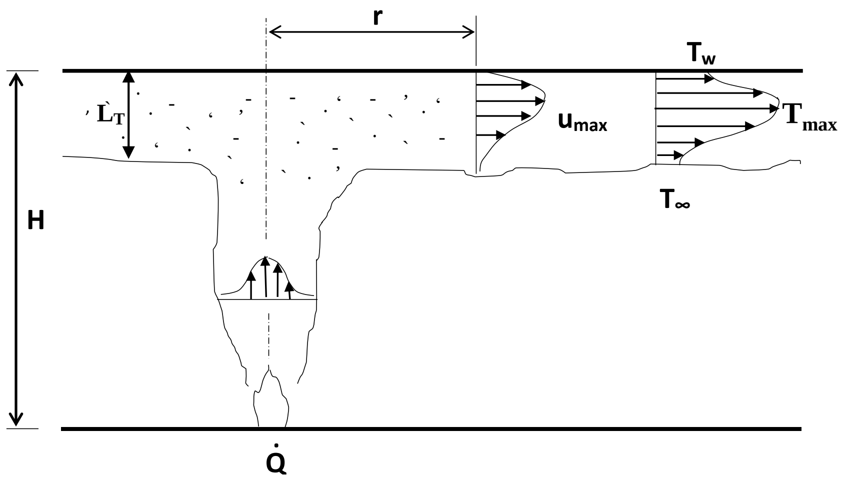
Week – 09

Lecture – 05

Module 6 – Analysis of Fire Plumes

Ceiling jet flow:

A schematic of the steady ceiling jet flow is shown in the figure.



Ceiling jet thickness:

When the steady flame height is much smaller than the ceiling height, H, the resulting plume is considered to be a weak plume. Thickness of the ceiling jet, L_T, at any radial location, r, from the impinging centreline is correlated by Alpert (2016) as,

$$\frac{L_T}{H} = 0.112\left[1 - \exp\left(-2.24\frac{r}{H}\right)\right]$$

Locations of the maximum temperature and velocity are dependent on fire size. Correlations are proposed by Alpert (2016), based on experiments, for temperature and velocity, involving heat release rate in the range of 668 kW to 98 MW and ceiling height in the range of 4.6 m to 15.5 m.

Ceiling jet – Alpert correlations:

Temperature and velocity in ceiling jet is correlated as:

$$T - T_\infty = 16.9\,\dot{Q}^{2/3}/H^{5/3} \quad \text{for } r/H \le 0.18$$

$$T - T_\infty = 5.38\frac{\dot{Q}^{2/3}/H^{5/3}}{(r/H)^{2/3}} \quad \text{for } r/H > 0.18$$

$$u = 0.96\left(\dot{Q}/H\right)^{1/3} \quad \text{for } r/H \le 0.15$$

$$u = 0.195\frac{\left(\dot{Q}/H\right)^{1/3}}{(r/H)^{5/6}} \quad \text{for } r/H > 0.15$$

In these, $\dot{Q}$ is in kW, r and H are in m and u in m/s.

Ceiling jet temperature and velocity near to the plume impingement region, called the turning region, do not depend on the value of radius. Outside the turning region, the correlations are expressed in terms of radius. These are for steady fires.

Ceiling jet – Heskestad correlations:

Alpert correlations are generally applied after a time period after ignition, when the hot gases accumulation in the ceiling is not high and fire is not affected by the radiation from the walls. For near-wall or near-corner fires, these correlations have to be modified. General practice is to multiply the heat release by 2 for near wall fire and by 4 for corner fire and use it in Alpert correlations. Heskestad [15] reported non-dimensional weak plume ($h_f < H$) correlations in terms of total heat release rate as follows:

$$\dot{Q}_0^* = \frac{\dot{Q}}{\rho_\infty c_p T_\infty g^{0.5} H^{2.5}}; \Delta T_0^* = \frac{\Delta T/T_\infty}{\left(\dot{Q}_0^*\right)^{2/3}}; u_0^* = \frac{u/\sqrt{gH}}{\left(\dot{Q}_0^*\right)^{1/3}}$$

Here, $\Delta T = T - T_\infty$. These are for steady fires.

Ceiling jet – Combined correlations:

Combining Alpert's theory and Heskestad's correlation, the following expressions are obtained:

$$\Delta T_0^* = \left(0.225 + 0.27\frac{r}{H}\right)^{-4/3} \quad \text{for } 0.2 \le r/H \le 4.0$$

$$\Delta T_0^* = 6.3 \qquad \text{for } r/H \leq 0.2$$

$$u_0^* = 1.06\left(\frac{r}{H}\right)^{-0.69} \qquad \text{for } 0.17 \leq r/H \leq 4.0$$

$$u_0^* = 3.61 \qquad \text{for } r/H \leq 0.17$$

The dependency on radius is present only outside the turning region. These are also for steady fires.

Ceiling jet – strong plume correlations:

When the height of the fire is comparable to the height of the ceiling ($h_f \approx H$), then the ceiling jet is termed as strong plume driven jet. For steady fires, correlations are available. Correlation for temperature for these cases has been reported by Heskestad and Hamada (1993), by normalizing the radius, r, by plume radius, b, rather than the ceiling height, H. It is of the form:

$$\frac{\Delta T}{\Delta T_P} = 1.92\left(\frac{r}{b}\right)^{-1} - \exp\left[1.61\left(1 - \frac{r}{b}\right)\right] \qquad \text{for } 1 \leq \frac{r}{b} \leq 40$$

Here, $\Delta T_P = T_P - T$, is the excess temperature of the plume axis at z = H and b is the radius at which the velocity is one-half of the centreline value at the height of impingement; b is expressed as:

$$b = 0.42\left[\left(c_p \rho_\infty\right)^{0.8} T_\infty^{0.6} g^{0.4}\right]^{-0.5} \frac{T_P^{0.5} \dot{Q}_c^{2/5}}{\Delta T_P^{0.6}}$$

Ceiling jet – using the correlations:

Correlations for steady fires can be used in the case of slowly growing unsteady fires, by replacing the constant heat release rate to time dependent heat release rate. Further, these correlations are for unconfined ceiling jets and applicable for large storage facilities and industries. In a typical smaller compartment fire, these correlations cannot be applied without modifications. Here, the smoke layer accumulates under the ceiling and completely submerge the ceiling jet. Correlations for convective heat transfer from plumes and ceiling jets to ceilings are reported by several researchers in literature. Similarly, researchers have worked on ceiling jets over sloped ceilings and have proposed correlations for temperature and velocity as a function of slope angle.