Module 6: Diffusion Flame

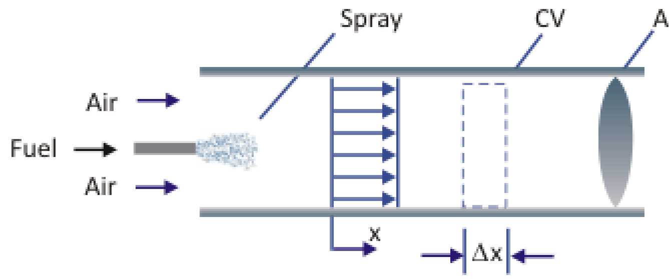
Lecture 33: Spray Combustion Model

The Lecture Contains:

Spray Combustion Model

Assumption:

- Steady, 1-D flow, Laminar, inviscid
- Mono-dispersed droplets.
- Pressure remains constant during combustion.
- Droplets move with same velocity as that of air.
- Vaporization and ignition begins at x=0.
- Mixing and chemical reaction times are quite small as compared to droplet vaporization time.
- Constant thermophysical properties.
- Dilute spray.



(Figure 33.1)

Stoichiometric fuel-air ratio:

$$f = \frac{(N_0 \rho_l \pi D_0^3/6)Adx}{\rho_0 Adx - (N_0 \rho_l \pi D_0^3/6)Adx} \quad \text{-------(1)}$$

ρ_l =Density of liquid

A = Cross sectional area

N_0 = Number of droplets

D_0 = Initial diameter

Previous Next

Spray Combustion Model

Number of droplets,

$$N_0 = \frac{f}{1+f}\frac{\rho_0}{\rho_l}\frac{6}{\pi D_0^3} \qquad \text{-------(2)}$$

From mass conservation,

$$\rho_0 \bar{V}_0 A = \rho \bar{V} A \qquad \text{-------(3)}$$

ρ - Density of droplet laden air

$$N_0 \bar{V}_0 A = N \bar{V} A \qquad \text{-------(4)}$$

From above two equations,

$$N = N_0 \frac{\rho}{\rho_0} \qquad \text{-------(5)}$$

Energy equation across the element dx

$$\rho \bar{V} C_p \frac{dT}{dx} A dx = \dot{q}''' A dx \qquad \text{-------(6)}$$

$\dot{q}'''$ - Heat release rate

Previous Next

Spray Combustion Model

Simplifying,

$$\rho C_\rho \frac{dT}{dt} = \dot{q}''' \qquad \text{-------(7)}$$

Heat release rate per unit volume,

$$\dot{q}''' = N(\dot{m}_F)_{droplet} \Delta \widehat{H}_c \qquad \text{-------(8)}$$

Relationship for quasi-steady state droplet vaporization,

$$\dot{m}_F = 2\pi D\alpha \, ln(B+1) = \pi D \rho_l \frac{K}{4} \qquad \text{-------(9)}$$

Where, K – droplet combustion rate constant that can be experienced as

$$K = \frac{8k_g}{\rho_l C_p} ln(B+1) \qquad \text{-------(10)}$$

By using Eqs. (7) , and (10), we can have,

$$\frac{dT}{dt} = \frac{3f}{2(1+f)} \frac{K\Delta \widehat{H}_c}{C_\rho D_0^3} D \qquad \text{-------(11)}$$

Spray Combustion Model

Droplet diameter will vary by D^2 law

$$D = \sqrt{D_0^2 - Kt} \qquad \text{-------(12)}$$

Boundary and initial conditions

$$t = 0, D = D_{0,} T = T_0 \qquad \text{-------(13)}$$

By using above condition in Eq. 6.11 and integrating it, we can get

$$T = T_0 + \left(\frac{f}{1+f}\right)\frac{\Delta H_c}{C_\rho}\left[1 - \left(\frac{D}{D_0}\right)^3\right] \qquad \text{-------(14)}$$

Adiabatic flame temperature is given as

$$T_{ad} = T_0 + \left(\frac{f}{1+f}\right)\frac{\Delta \widetilde{H}_c}{C_\rho} \qquad \text{-------(15)}$$

By using Eng. (14), we get

$$T = T_0 + (T_{ad} - T_0)\left[1 - \left(\frac{D}{D_0}\right)^3\right] \qquad \text{-------(16)}$$

Previous Next

Spray Combustion Model

Zone length is given by

$$L_R = \int_0^{t_b} \bar{V}\, dt \qquad \text{-------(17)}$$

Integrating Eq. (17), we can get

$$L_R = \frac{\bar{V}_0 D_0^2}{K}\left(\frac{2}{5} + \frac{3}{5}\frac{T_{ad}}{T_0}\right) \qquad \text{-------(18)}$$

Combustion Intensity is given by

$$I = \dot{q}'''' = \frac{\rho_0 \bar{V}_0 C_p (T_{ad} - T_0)}{L_R} \qquad \text{-------(19)}$$

Previous Next