Course Name: Theory of Fire Propagation (Fire Dynamics)

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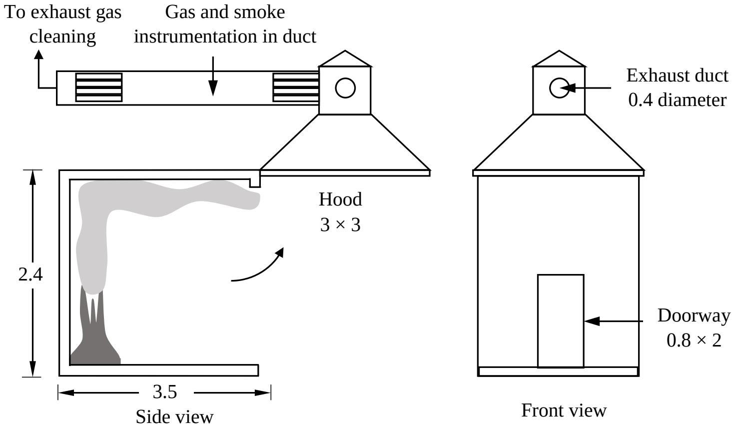
Week – 02

Lecture – 04

Module 1 – Basics of Fires

Compartment fire test facility:

Fire in a compartment (an enclosed space) is studied using a standard compartmental test facility.



Typical exhaust hood dimensions:

A conical exhaust hood is used to receive the combustion products, and its dimensions are coupled with the power rating of the fire. For example, an FPA capable of testing a 10 MW fire is constructed in a compartment with a ceiling height of 18.3 m, and the inlet diameter of the exhaust hood is 6.1 m, as per ASTM E2058 standards. Similarly, there exist standards for dimensions of piping, burning platform, and many other aspects. Convective heat transported by the product gases is estimated by Gas Temperature Rise (GTR) calorimetry. Here, the temperature difference between the exhaust and incoming gas mixture is measured.

Estimation of useful quantities:

The mass flow rate of the product gases and its specific heat (product mixture) is used to determine the convective heat release. The difference between the net heat release and convective heat release is calculated as the radiative heat release. Calorimetry can also be used to measure the smoke point, which is the minimum laminar volumetric flow rate of the fuel at which smoke just escapes from the flame tip. Smoke point values have been reported for several gas, liquid, and solid fuels. Combustion efficiency and CO generation efficiency are correlated to the smoke point. Apart from these, corrosion hazards due to fire can be estimated using this apparatus.

Estimation of useful quantities:

Fire can be as small as a room heating fire (order of meters) to as high as a forest fire (order of 100+ meters). Fire hazards in a given structure cannot be easily understood just by constructing a scaled-down model of the structure. There are several aspects related to the scaling procedure.

Length scale (m)	10^{-3}	10^{-2}	10^{-1}	1	10^{1}	10^{2}
Fire:	Smolder	Candle	Waste bin	Room	Building	Forest

From conservation equations of mass, momentum, energy, and species used to model incompressible reactive flows, several non-dimensional groups can be identified using Buckingham's Pi theorem.

Non-dimensional numbers for fire study:

Let U_∞, p_∞, T_∞ and L be the reference velocity, pressure, temperature, and length, respectively. The reference time (t_R) is written as

$$t_R = L/U_\infty$$

Velocity appropriate to buoyancy-driven flow and related reference time are estimated as,

$$U_\infty = (gL)^{0.5} \text{ and } t_R = (L/g)^{0.5}$$

Table: Non-dimensional numbers

Definition	Equation
Reynolds number (inertia to viscous force)	$\frac{\rho_\infty U_\infty L}{\mu}$
Froude number (inertia to gravity force)	$\frac{U_\infty^2}{gL}$
Euler number (pressure force to inertial force)	$\frac{p_\infty}{\rho_\infty U_\infty^2}$
Prandtl number (momentum to thermal diffusivity)	$\frac{\mu c}{k} = \frac{\nu}{\alpha}$
Biot number (conductive to convective resistance)	$\frac{h\delta_w}{k_w}$
Nusselt number (convective to conductive heat transfer)	$\frac{hL}{k_f}$
Radiation energy/Convective thermal energy	$\frac{\sigma T_\infty^3}{\rho_\infty c(gL)^{0.5}}$
Physical length/Radiation absorption length	κL

Potential energy/Enthalpy	$\frac{gL}{cT_\infty}$
Zukoski number (Fire power to enthalpy flow rate)	$\frac{\dot{Q}}{\rho_\infty c T_\infty L^2 (gL)^{0.5}}$
Schmidt number (momentum to mass diffusivity)	$\frac{\mu}{\rho_\infty D} = \frac{\nu}{D}$
Fuel flow rate/Convective flow rate of mixture	$\frac{\dot{m}_{fuel}}{\rho_\infty L^2 (gL)^{0.5}}$
Transient conduction normal to the wall surface	$\frac{\rho_w c_w \delta_w^2}{k_w t_R}$
Surface radiation/Conduction	$\frac{\varepsilon \sigma T_\infty^3 \delta_w}{k_w}$

Table: Nomenclature

Symbol	Definition	Units
t_R	Reference time	s
μ	Dynamic viscosity	Pa-s
ρ_∞	Reference density	kg/m^3
c	Specific heat	J/kg-K
k_w	Thermal conductivity of solid wall	W/m-K
k_f	Thermal conductivity of fluid	W/m-K
σ	Stefan-Boltzmann constant	W/m -K
κ	Absorption coefficient	m^{-1}
$\dot{Q}$	Heat release rate $(\dot{m}''' \times \Delta h_c \times Volume)$	W
Δh_c	Heat of combustion	J/kg
D	Mass diffusivity (Diffusion coefficient)	m^2/s

$\dot{m}_{fuel}$	Mass flow rate of the fuel gases (pyrolysate)	kg/s
δ_w	Wall thickness (w - wall)	m