Course Name: Theory of Fire Propagation (Fire Dynamics)

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Week – 08

Lecture – 01

Module 5 – Burning of Solid Fuels

Ignition of thermally thick solid – typical solution:

An approximate solution for thermally thick solid at a high heat flux (neglecting the heat loss) is given as:

$$t_{ig} = \frac{\left(\frac{\pi}{4}\right) k\rho c \left(T_{ig} - T_{\infty}\right)^2}{\left(\dot{q}_i''\right)^2}$$

Here, $\dot{q}_i''$ is > critical heat flux. T_{ig} is ignition or pyrolysis temperature. A thermal response parameter (TRP) can be defined and the ignition time is written as:

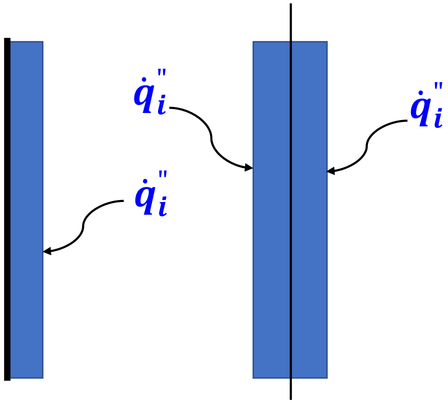
$$TRP = \left(T_{ig} - T_{\infty}\right)\sqrt{\left(\frac{\pi}{4}\right) k\rho c}$$

$$t_{ig} = \frac{(TRP)^2}{\left(\dot{q}_i''\right)^2}$$

Unit of TRP is [W/m^2-s$^{0.5}$]. Value of TRP can be determined for various materials using ignition experiments.

Ignition of thermally thin solid – heat balance:

Consider a solid heated in two configurations. In one, it has a given physical thickness (t_p) and is heated from one side, and the other side is insulated. In the second, it has a physical thickness of 2t_p and is heated symmetrically from both sides.

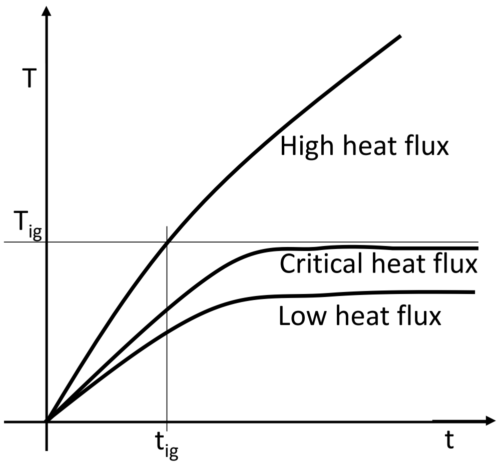


The energy storage capacity of the material is $\rho \times c \times t_p$. Its unit is J/m^3-K. For a thermal thin solid, the heat conduction within the solid is neglected. Heat balance for ignition problem is:

$$\rho c t_p (T - T_\infty) = \left(\dot{q}_i'' - \dot{q}_L''\right) t$$

Ignition of thermally thin solid – ignition time:

Heat loss from surface ($\dot{q}_L''$) depends on surface temperature, which increases as a result of heating ($\dot{q}_i''$). However, an approximate solution can be obtained if the heat loss flux is taken to be a constant, valid for early time during onset of ignition.



$$T = T_\infty + \frac{\left(\left(\dot{q}_i'' - \dot{q}_L''\right)t\right)}{\rho c t_p}$$

$$t_{ig} = \frac{\rho c t_p\left(T_{ig} - T_\infty\right)}{\left(\dot{q}_i'' - \dot{q}_L''\right)}$$

$$t_{ig} = \frac{\rho c t_p\left(T_{ig} - T_\infty\right)}{\dot{q}_{net}''}$$

Ignition of thermally thin solid – factors:

Thermally thin criterion can also be calculated from Biot (Bi) number. If $\mathbf{Bi = ht_p/k < 0.1}$, the material is considered thermally thin. Thermally thin materials have $\mathbf{t_p}$ of the order of 1 mm in thickness and hence most practical materials are usually thermally thick. Solution for ignition of thermally thin materials does not include conduction in solid as well as fuel degradation and fuel exhaustion. If the material is so thin and is exposed to heat fluxes of relatively high magnitude (~ 50 kW//m^2), it may produce smoke and char but need not ignite. This is because there may not be enough material to release enough pyrolyzate (volatiles) to produce a mixture above Lower Flammability Limit (LFL) condition.

Flame spread:

Flame spread is the phenomenon of a moving flame in close proximity to the source of the fuel vapor or gas originating from the condensed phase (solid or liquid). Fuel gas or vapor originates because of pyrolysis or vaporization of the fuel because of heat transfer from the flame itself. Figure shows photograph of a flame moving on 2.5 mm thick PMMA slab with an air flow velocity of 0.8 m/s. Region of the fuel surface that is pyrolyzing is the pyrolysis length x_p as shown. Portion being heated by the flame is shown as l_h, called the heated length.