Course Name: Theory of Fire Propagation (Fire Dynamics)

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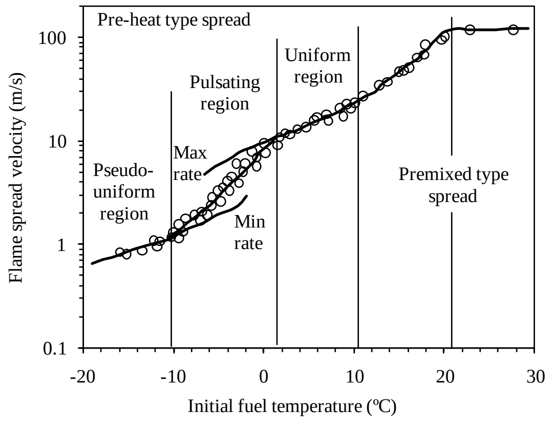
Week – 06

Lecture – 04

Module 4 – Burning of Liquid Fuels

Flame spread – over methanol pool:



Variation of flame spread rate with initial temperature of methanol pool (Flash point = 15ºC, Boiling point = 64ºC)

(Akita, 14^{th} symposium on combustion)

Flame spread – sub-flash point aspects:

In flame propagation over liquid fuels at sub-flash temperatures, the liquid fuel does not remain stationary beneath the flame. A re-circulatory convection current is observed in the liquid fuel surface ahead of the flame, which plays an important role in the flame propagation. This re-circulating subsurface flow causes the liquid to move away from the flame at the surface and return back at a certain depth. Existence of a temperature gradient on the fuel surface induces a surface tension gradient. Temperature decreases and the surface tension increases with distance upstream from the flame location. The surface tension tends to pull the liquid away from the flame. The ensuing liquid-phase convective heat transfer is higher than in-liquid conduction heat transfer.

Flame spread – pool depth and width:

Depth of the pool plays an important role on flame spread rate, next to the fuel type and its initial temperature. Experiments have shown that based on the type of liquid fuel, flame will not spread over its surface if the depth is below a critical value. For instance, for an n-decane pool, if the depth is less than around 2 mm, the flame will not spread. As the pool depth increases, the flame spread rate increases and asymptotically reaches a constant value. Similarly, the fuel width also plays a notable role in determining the fire spread rate up to a certain value. If the temperature is more than the flash point the effect of width becomes insignificant.

Flame spread rate:

Flame spread rate forms a useful data to quantify a developing fire. Area of fire (A_f) can be written in terms of the radius (r) of the flame spread (considering a circular pool ignited at its centre) as,

$$A_f(t) = \pi[\mathrm{r(t)}]^2$$

If the flame spread velocity is V_f, then r(t) can be written as $V_f \times t$, at any given time instant, t. Thus,

$$A_f(t) = \pi[\mathrm{V_f} \times t]^2$$

The heat release rate from the fire is expressed in terms of mass loss rate and heat of combustion, as,

$$\dot{\boldsymbol{Q}} = \dot{\boldsymbol{m}}''\boldsymbol{A_f}(\boldsymbol{t})\Delta\boldsymbol{H_C} = (\dot{\boldsymbol{m}}''\boldsymbol{\pi}\boldsymbol{V_f^2}\Delta\boldsymbol{H_C}) \times \boldsymbol{t^2} = \boldsymbol{\alpha t^2}$$

Here, α is a factor dependent on characteristics of the fuel, which are estimated from flammability tests.

Mass burning rate:

When a flame spreads over a liquid fuel surface, it primarily heats up the liquid surface downstream to evaporate more vapour out of it and continues its propagation. After the flame propagates over the entire fuel surface, based on the thickness of the fuel pool or the fuel availability, the flame starts consuming the fuel beneath it. For thick fuel pools, the rate at which the fuel is consumed becomes almost steady and the fuel surface attains an equilibrium temperature. Combustion is controlled by convection and diffusion processes. Oxygen from the ambient is transported by convection as well as by mass diffusion to the flame. Fuel vapor from the pool surface is transported to the flame predominantly by diffusion. Heat transfer from the flame supports continued evaporation of the fuel.

Mass burning rate and regression rate:

Gradient of the fuel concentration at the interface mainly determines the mass loss rate. Under convective (laminar as well as turbulent) conditions, as the fuel vapor formed over the surface is transported to the flame zone at a faster rate, the mass burning rate increases. For fires under normal gravity conditions, buoyancy flow induced due to density gradients influences the burning rate. Mass burning rate is expressed in terms of fuel surface regression rate ($\dot{\mathbf{r}}$), expressed in m/s, which is the rate of descent of the fuel surface in the vertical direction as the fuel burns.

$$\dot{\boldsymbol{m}} = \boldsymbol{A} \times \dot{\boldsymbol{r}} \times \boldsymbol{\rho_l}$$

Here, A is area of the pool and ρ_l is density of the fuel. Mass burning rate is almost steady if fuel thickness is higher or if the fuel is continuously supplied at the rate at which it burns.