Course Name: Theory of Fire Propagation (Fire Dynamics)

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Week – 06

Lecture – 05

Module 4 – Burning of Liquid Fuels

Regression rate – effect of pool diameter:

Regression rates of most of the petroleum fuels such as gasoline, diesel, tractor oil and kerosene are available considering pool diameters in the range of 0.4 cm to 2300 cm. For pool diameter in the range of 0.4 cm to 5 cm, the regression rate decreases as the pool diameter is increased. For pool diameter in the range of 5 cm to 12 cm, the regression rate remains almost a constant. Flames over the liquid pool are laminar in these ranges of pool diameter. When the pool diameter is increased above 12 cm, the flame transitions from laminar to turbulent regime. Here, the regression rate increases with increasing pool diameter up to 1 m. Fire becomes turbulent at this stage (> 1 m diameter) and the regression rate reaches an almost constant value: 4 mm/minute.

Regression rate – variation:

Ratio of average flame height to the pan diameter decreases continuously in both laminar and transition regimes and it attains an almost constant value in the turbulent regime. For smaller pools, conduction from flame, walls of the pan and substrate, and convection form the primary heat transfer modes to the pool. Flame stand-off from the surface dictates the conduction heat transfer. Formation of fuel rich vapor between the flame and the fuel surface decreases the regression rate. As transition to turbulence occurs, higher rates of mixing are accomplished and the regression rates increase. For pool diameter > 1 m, radiative heat transfer becomes dominant and the regression rate reaches a constant maximum value irrespective of a further increase in the pool diameter.

Regression rate – asymptotic value:

The asymptotic value of the regression rate ($\dot{r}_{max}$) for pools larger than 1 m, can be calculated as,

$$\dot{r}_{max} = C_1 \times \frac{\Delta h_c}{\Delta h_v}$$

Here, C_1 is an empirical constant (1.27×10^{-6}), Δh_c is the heat of combustion and Δh_v is net heat of vaporization, evaluated as,

$$\Delta h_v = h_{fg} + \int c_{p,l} dT$$

Here, h_{fg} is the latent heat of vaporization at the boiling point of the liquid and the integral term in the right hand side is the sensible heat added to the liquid phase in order to increase its temperature from its initial value to the boiling point.

Mass burning rate – asymptotic value:

Mass burning rate per unit area of the pool ($\dot{m}''$) increases as the pool diameter is increased and reaches an asymptotic (maximum) value. Asymptotic mass burning rate per unit area ($\dot{m}''_{max}$) can be evaluated using the asymptotic regression rate:

$$\dot{m}''_{max} = \dot{r}_{max} \times \rho_l = C_2 \times \frac{\Delta h_c}{\Delta h_v}$$

Here, C_2 is an empirical constant (10^{-3}). Zabetakis and Burgess (1961) developed an expression for mass burning rate per unit area including the pool diameter as follows:

$$\dot{m}'' = \dot{m}''_{max} \times (1 - \exp(-\kappa\beta D))$$

Here, κ is terms as extinction coefficient (1/m), β is the mean beam length correction (unit less) and D is the pool diameter (m), which is the hydraulic diameter for non-circular pools.

Theoretical analysis of steady mass burning rate:

A theoretical analysis of steady mass burning rate is done using the approach to analyse a diffusion flame. Only the gas-phase is solved. Boundary conditions at the fuel surface are the coupling conditions at the interface. An infinitely fast rate chemistry formulation is considered. Since the dynamics are involved in the direction normal to the fuel surface, a one-dimensional (x) coordinate is used.