Course Name: Theory of Fire Propagation (Fire Dynamics)

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Week – 05

Lecture – 05

Module 4 – Burning of Liquid Fuels

Burning of liquids:

Several industries and laboratories handle many types of flammable liquids and use them as solvents and chemicals. Occurrences of small flames over an accidentally spilled fuel surface and its growth to a larger fire have been encountered. The petroleum industry that handles crude oil has encountered several scenarios of accidental crude oil spills, and the best way to clean up this oil spill is to burn it in an in-situ manner. Liquid fuels have also been used to create pool fires for research purposes in labs and certain industries.

Properties of liquid fuels:

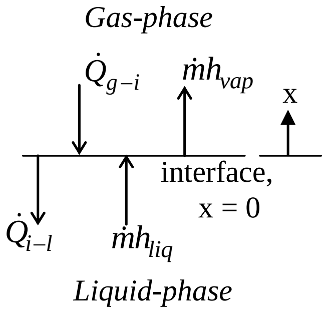
Calorific value of a fuel governs the amount of heat released. Vaporization of a liquid fuel is dictated by its volatility; governed by boiling point, latent heat of vaporization and specific heat. Ignition of the liquid fuel and formation of a flame over its surface are dictated by its flash and fire points. Flash point of a liquid fuel is the minimum temperature of the liquid when sufficient vapours are produced, and mixes with atmospheric air to produces a flash or instantaneous flame, upon pilot ignition; formation of a momentary premixed flame occurs. Fire point is a temperature of liquid higher than the flash point, when a pilot ignition source is introduced, a diffusion flame is established and sustains over the liquid surface. Boiling point is a temperature higher than the fire point and it is the saturation temperature of the liquid at the given pressure.

Liquid fuel classification:

Liquid fuels can be divided into various classes based on their flash point (FP). Flash point value of a liquid fuel lies in a certain range based on the type of apparatus (open cup apparatus or closed cup apparatus) used to measure their values and the ambient conditions. Spillage of class I fuels (FP < 38 °C) is extremely hazardous with regard to spread of fire. Spillage of class II fuels (38 °C < FP < 60 °C) is considered dangerous from fire point of view, only if an ignition source is present. The class III fuels (FP > 60 °C) are generally safe, unless a very large heat source, capable of raising the fuel temperature significantly, exists.

Liquid fuel evaporation:

Evaporation of the liquid fuel is the first step in its burning process.



In pool fire scenarios, generally the heat from the ambient (flame) is incident over the liquid fuel surface (interface).

This heat is partly transferred into the liquid phase (based on depth of the pool) and partly used to evaporate the liquid. Mass evaporated, $\dot{m}$, is transferred into the gas-phase.

Energy balance is as shown:

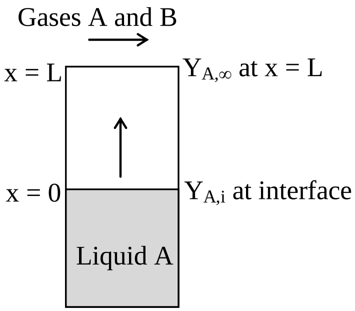
$\dot{Q}_{g-i}$: heat transferred from gas to interface

$\dot{Q}_{i-l}$: heat transferred from interface to liquid

h_{fg}: latent heat of vaporization = $h_{vap} - h_{liq}$.

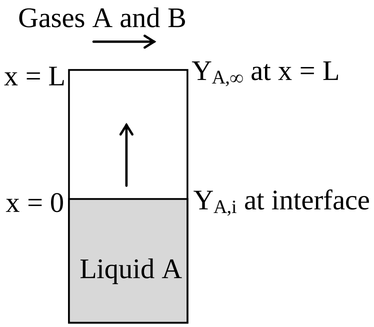
$$\dot{Q}_{g-i} - \dot{Q}_{i-l} = \dot{m}\left(h_{vap} - h_{liq}\right) = \dot{m}h_{fg}$$

Steady evaporation:



Consider a liquid fuel, A, contained in a vessel in an ambient, where a mixture of gas B and vapours of liquid A flow in the direction parallel to the liquid surface. Gas B is insoluble in A. Mass fraction of vapor, A, ($Y_{A,\infty}$) flowing across is less than that at the interface ($Y_{A,i}$). Steady evaporation is attained by supplying liquid at the rate at which it evaporates; fuel does not regress and interface remains at same x-location.

Steady evaporation – Fick's law:



At the interface, the mass flux of A considering the ordinary diffusion is:

$\rho_A v_A = \rho V Y_A - \rho D_{AB} dY_A/dx$

For species B, since it is not soluble in the liquid, the net flux of B in the interface is zero:

$0 = \rho V Y_B - \rho D_{BA} dY_B/dx$

Since, the sum of diffusion fluxes of A and B is zero, it can be written as, $\rho V = \rho A v A$. Bulk velocity in x-direction is the velocity of species A. Species B is transported by diffusion in the column with a zero species velocity ($vB = 0$).