Course Name: Theory of Fire Propagation (Fire Dynamics)

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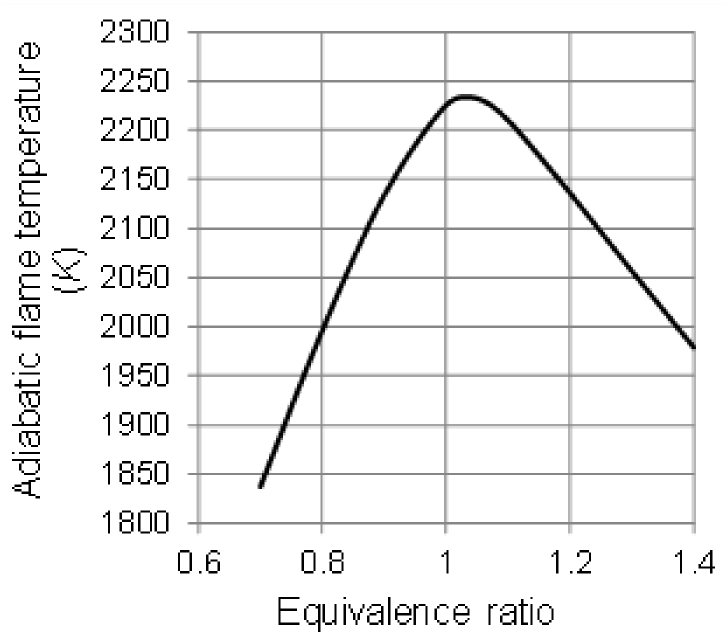
Week – 04

Lecture – 03

Module 3 – Review of Premixed and Diffusion Flames

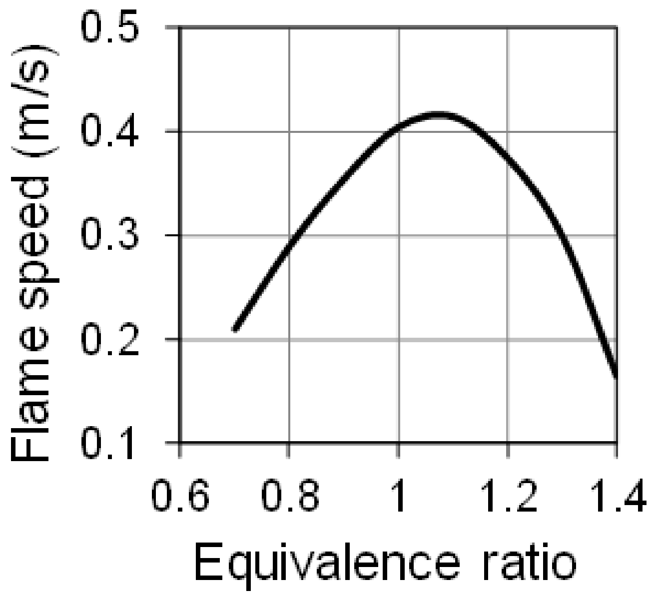
Adiabatic flame temperature vs. equivalence ratio:

Flame temperature, which depends on the heat of reaction, attains a maximum value for a mixture having equivalence ratio slightly greater than unity. There is a shift in the value of equivalence ratio corresponding to maximum heat of combustion and maximum flame temperature due to the dependency of thermal conductivity, specific heat and diffusivity of the gases on temperature. (Figure shows the T_{ad} vs. ϕ for methane – air flames)



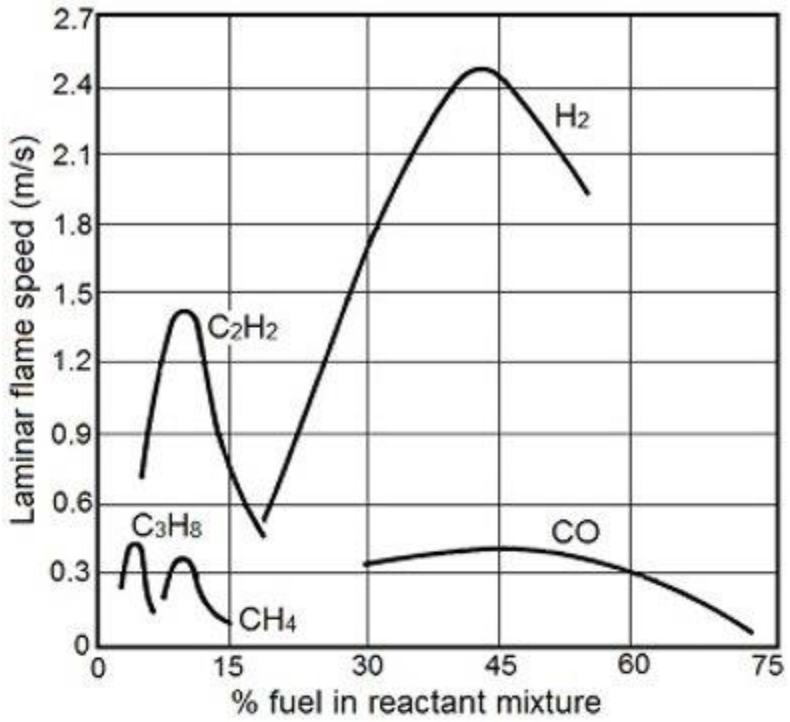
Laminar flame speed vs. equivalence ratio:

As a result of temperature variation, the laminar flame speed, which strongly depends on the flame temperature, also depicts a similar variation with equivalence ratio. On the richer side, both heat release and flame temperature decreases as the equivalence ratio is increased. Several researchers reported varying values of S_L; but, S_L attains a maximum value when ϕ is in the range of 1.05 to 1.1. (Figure shows the S_L vs. ϕ for methane-air flames)



Laminar flame speed for various fuels:

Similar trends are observed in fuels such as acetylene, CO, ethylene, H_2 and propane. However, the equivalence ratio at which the maximum laminar flame speed is obtained is different between these fuels. The laminar flame speeds for several fuels are comparatively shown as a function of percentage fuel in the reactant mixture.

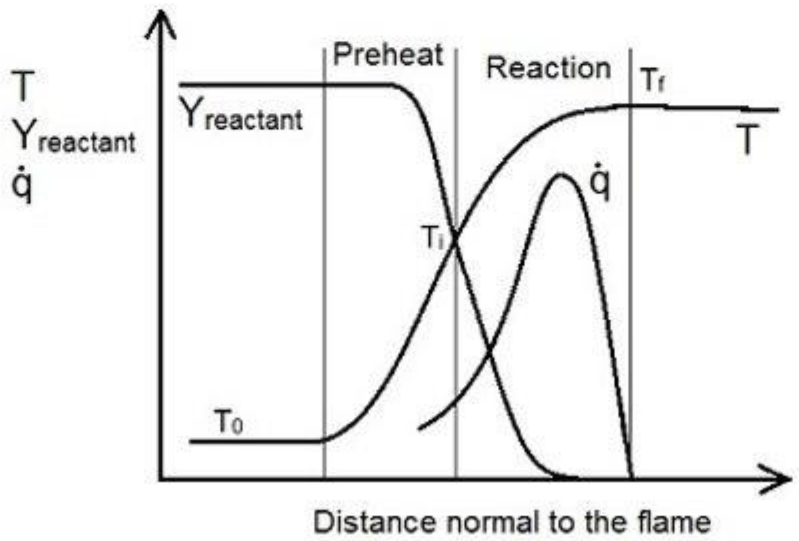


Laminar flame speed for various fuels:

For CH_4 and C_3H_8, the equivalence ratio at which SL becomes a maximum is around 1.08 and for C_2H_2, it is around 1.2. For H_2, it around 1.8 and for CO, it is around 2, implying that a richer mixture is required for attaining the maximum flame speed for these fuels. One important point to note here is that the occurrence of the maximum adiabatic flame temperature for hydrogen-air mixture happens around an equivalence ratio of 1.07, which is almost the same as that of methane. However, the maximum flame speed occurs around an equivalence ratio of 1.8. This is due to the variation of thermal and mass diffusivities, or their ratio called Lewis number, Le, with the composition of the reactant mixture.

Structure of premixed flame:

Premixed reactant approaches the flame in the direction normal to it. Due to heat transfer from flame, its temperature increases from initial value of T_0 to ignition temperature, T_i.



This zone is called the preheat zone. Reaction zone exists next to it.Reaction zone has a very small thickness; order of a milli-meter. Towards the end of the reaction zone, a bright or luminous zone is present. Here, the temperature is maximum (flame temperature, T_f).

Preheat and reaction zones:

Radicals such as H, O, OH and so on, are also transported from the reaction to the preheat zone. Reactants heated to the ignition temperature, react with these radicals through the chain initiation reactions, and enable the onset of chain propagation and chain branching reactions in the reaction zone. For lean to stoichiometric mixtures, this causes a reduction in the mass fraction of the reactants and a further rise in the temperature in the reaction zone. When the reaction proceeds and the reactants are consumed, by chain termination reactions, the heat release rate rapidly increases and attains a maximum value. As the major reactant species are consumed at this point, the heat release rate decreases to zero rapidly.

Formation of diffusion flame:

Recombination of the species occurs downstream of the reaction zone. Depending on the initial composition of the reactant mixture, a plume of burned gas or a diffusion (non-premixed) flame is present in this zone. Intermediate species are formed towards the end of preheat zone and are consumed before the end of the reaction zone. In the case of rich mixtures, the fuel transported out of the reaction zone burns in a diffusion flame mode.

Flammability limits:

In an isolated system, when the fuel and oxidizer are mixed in proper proportions and ignited using a localized high temperature source, sustained reaction may take place. Such a reactant mixture, in which a flame can be initiated is called a flammable mixture. In other words, any reactant mixture, which can burn without additional oxidizer or fuel, is called a flammable mixture. A reactant mixture, based on the type of fuel or oxidizer used, will be flammable only in certain proportions and under certain conditions of temperature and pressure. The heat released during combustion will also vary based on the composition of the mixture. Limits of flammability are determined by using standard test.