Course Name: Theory of Fire Propagation (Fire Dynamics)

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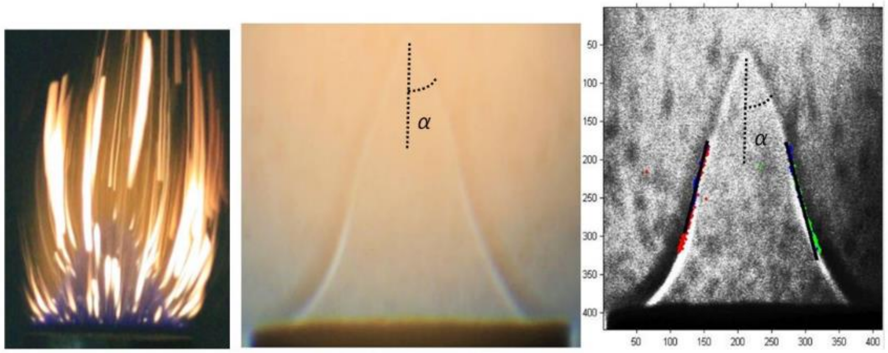
Week – 12

Lecture – 01

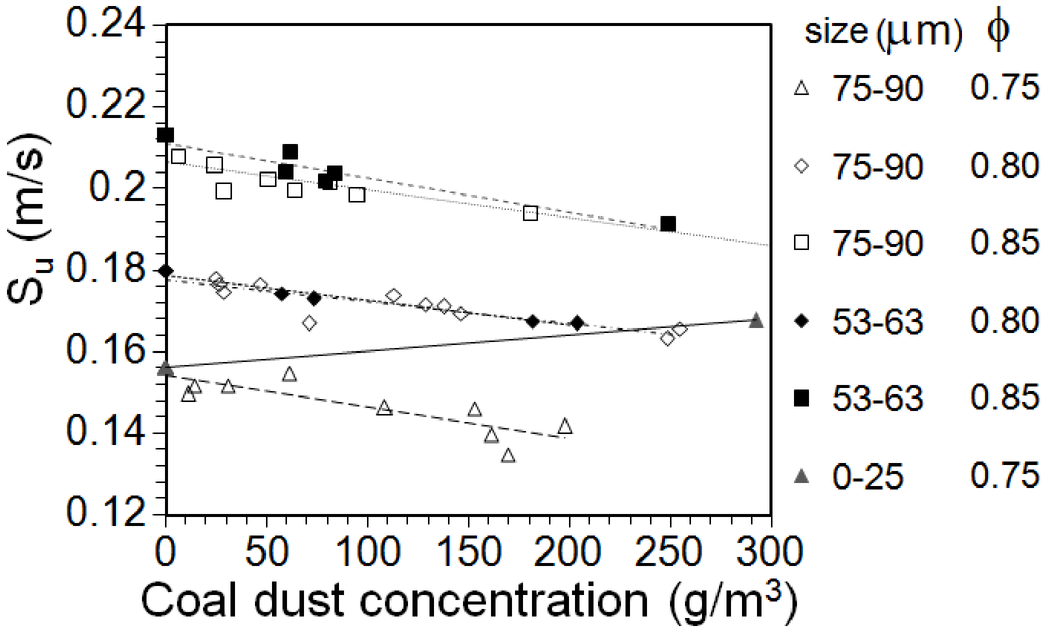
Module 8 – Introduction to dust ignition, dust explosion and forest fires

Coal dust combustion in premixed flame:



Actual Flame Image (a) | Shadowgraph (b) | Image in Matlab (c)

Coal dust-CH_4-air flame; Xie et al. (2012)



Variation of laminar burning velocity; Xie et al. (2012)

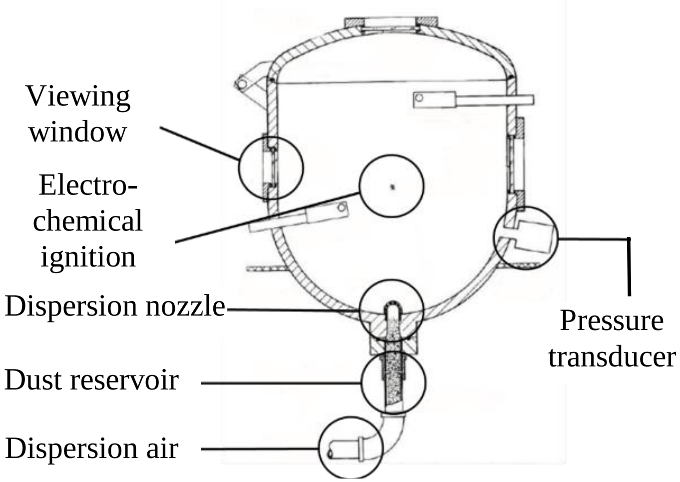
Particles draw heat from flame and flame temperature decreases. Volatiles are added to the gas-phase; changes equivalence ratio.

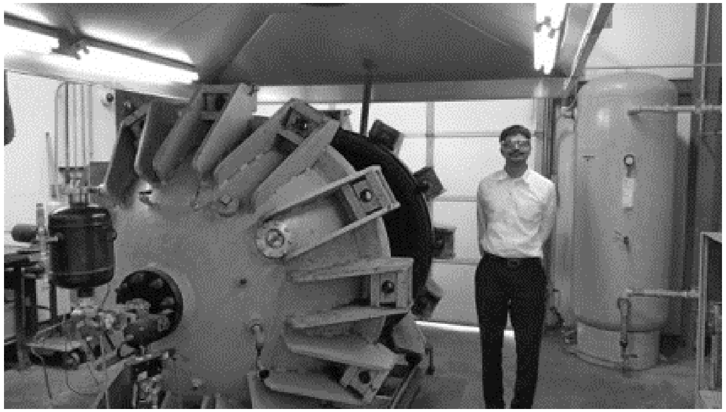
Dust explosion:

Reactivity of explosive gas-air mixtures, flammable vapours, mists, and dust clouds in confined spaces is characterized by the rate of pressure rise also called deflagration index (K_{st}) and maximum pressure (p_{max}) determined in constant volume explosion vessels, which are approximately spherical with 20 L to 1000 L capacity. Concept of using an explosion sphere for flammability studies with premixed flames is based on the earlier works by several authors, where burning velocities of gas flames were measured by initiating a flame from a central spark and recording the spherical flame propagation in a closed vessel optically (via a quartz window) or by recording the pressure-time trace by placing a pressure transducer at the vessel walls.

Dust explosion apparatus:

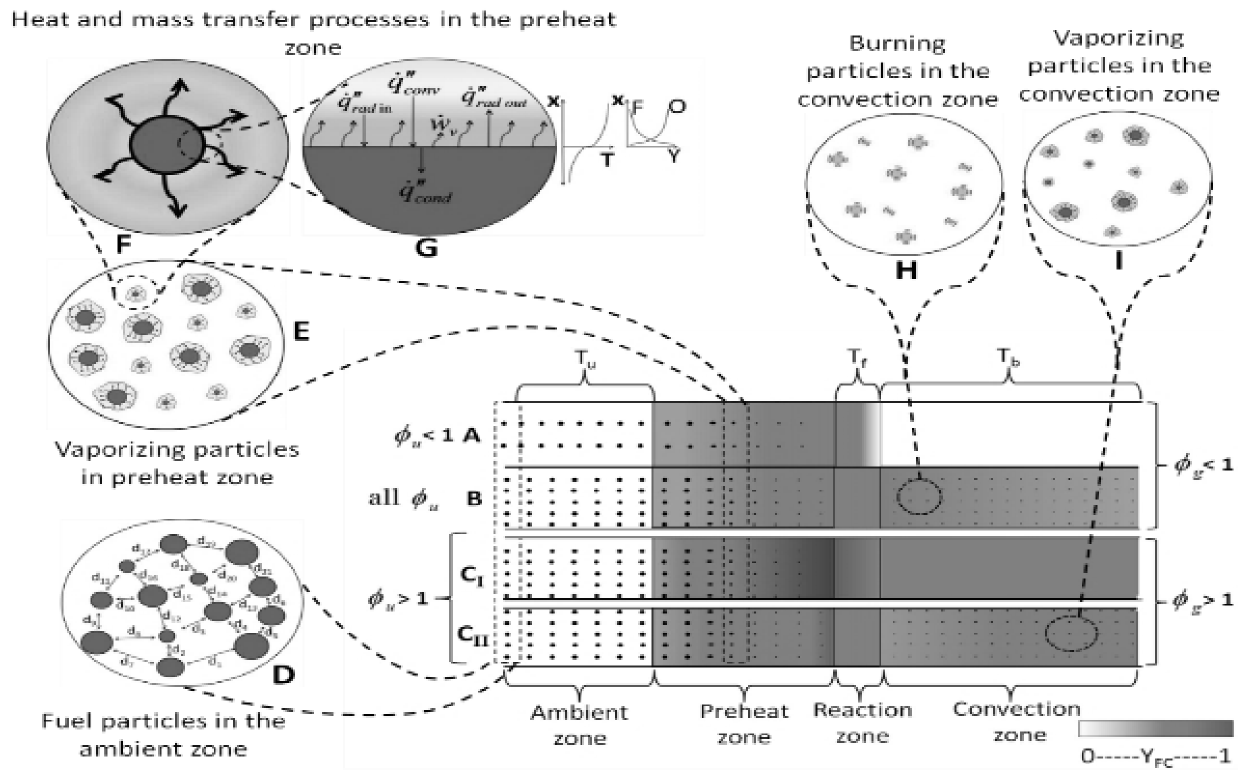
Diagram of a 20 L explosion sphere (Image from ASTM E1515, 2010) and 1 m^3 explosion sphere at Fike Corporation, Bluesprings, MO, USA. Standard dust explosion vessel is equipped with **vacuum, dust dispersion, ignition, and pressure sensor** systems.





Dust explosion experimental procedure:

A measured quantity of a dust sample is placed in the reservoir. Dust-air mixture is discharged into the vessel through a fast-acting valve and a rebound nozzle. Dispersed dust cloud is ignited after a specified ignition delay time. Ignition source is typically two chemical igniters, 5 kJ each, positioned near the centre of the vessel. Pressure-time history is recorded.



Dust explosion – deflagration index:

Explosion mitigating measures (explosion vents, suppression systems) rely on empirical correlations involving deflagration indices (K_g for gas and K_{st} for dusts) and p_{max}. K_g or K_{st} is determined based on maximum rate of pressure rise and the volume of the explosion sphere (V_0) given as (Dahoe et al, 1996):

$$K_{st} = \left[\frac{dp(t)}{dt}\right]_{max} V_0^{1/3}$$

Deflagration index changes as the size of the explosion sphere changes. This makes the investigation of a dust flame rather difficult and also complicates the hazard classification as the quantity used to characterize the hazard is now dependent on the experimental apparatus. This is mainly due to onset of turbulence.

Effect of turbulence:

Problem arises mainly due to the increase in turbulent intensity caused by the expanding combustion products in a constant volume vessel [Ranganathan et al., 2015] and the initial turbulence from the dispersal of dusts.

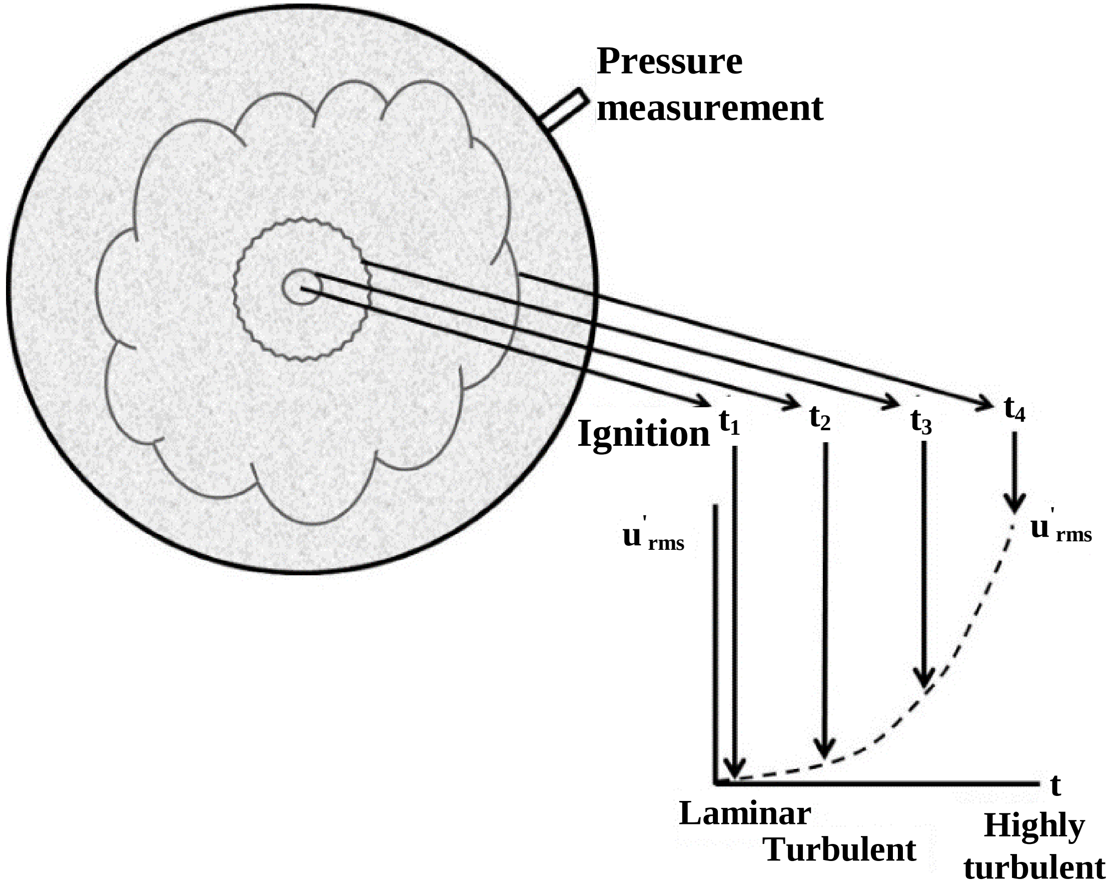


Figure (Rockwell and Rangwala, 2011) shows schematic of an expanding flame front at four different times inside of a typical explosion sphere. With flame acceleration, the turbulent intensity increases.

Particle – turbulence interaction:

Categories of particle-turbulence interactions; inert (Type 1), pyrolyzing (Type 2) & chemically reacting (Type 3). In Type 1, composition and shape of particle not changed; affects the turbulent mixing processes. In Type 2, a gas layer of pyrolysis products exists between particle and gas-phase; affects local turbulence coupled with pyrolysis rate. In Type 3, interaction is more complicated; it further affects local flow characteristics, pyrolysis & reaction rates.