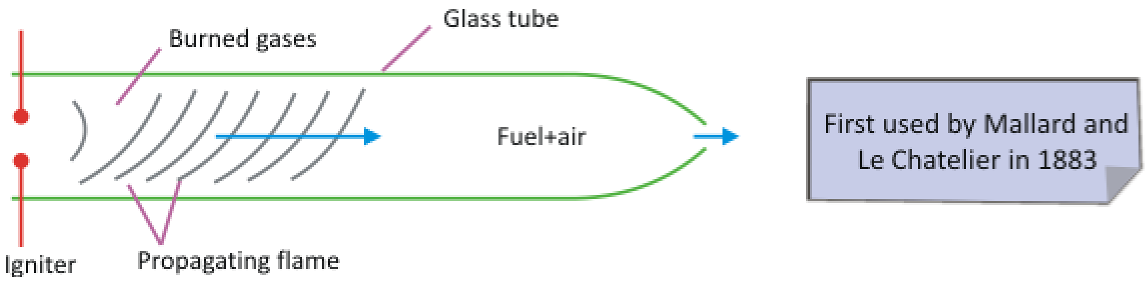
Module 5: Premixed Flame

Lecture 24: Tube Method

The Lecture Contains:

- Tube Method
- Combustion Bomb Method
- Soap Bubble Method
- Stationary Flame Method (Bunsen Burner)
- Flat Flame Burner
- Effect of Equivalence Ratio on S_L

Tube Method



(Figure 24.1)

Procedure:

- Combustible mixture is filled in the tube
- On ignition at one end, the flame propagates through the tube

Features:

- Inner dia of tube should be greater than the quenching diameter
- The flame is planar in the beginning and curved towards downstream, due to buoyancy
- Natural convection distorts the planar flame front due to difference in densities
- Friction at the tube wall is also a reason for parabolic shape of the flame

The burning velocity is given by $S_L = (V_F - V_g)A_t/A_F$

V_F : Flame front velocity

V_g : Unburnt gas velocity

A_t : Cross-sectional area of tube

A_F : Flame surface area

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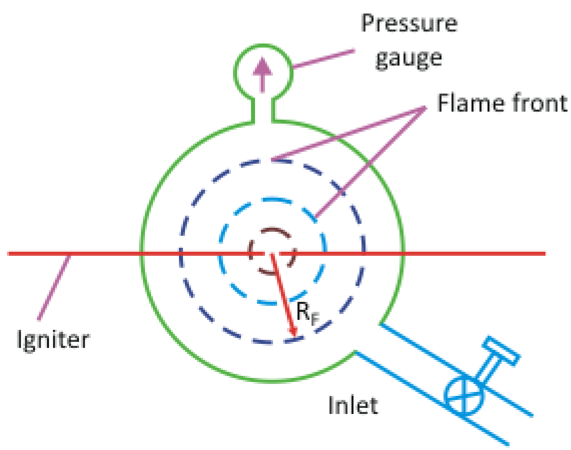
Combustion Bomb Method

- Combustible mixture is ignited at the center of spherical vessel (constant volume)
- Flame propagates towards the wall
- Pressure and temperature increases due to adiabatic compression
- If the flame front radius is known, then

$$S_L = \frac{dR_F}{dt}\frac{\rho_b}{\rho_u} = V_F\frac{\rho_b}{\rho_u}$$

R_F : instantaneous radius of spherical flame
ρ_b : density of gas mixture at burnt state
ρ_u : density of unburnt mixture



(Figure 24.2)

Assumptions:

- Effect of flame front thickness and curvature are negligibly small
- Pressure at any instant is uniform throughout the vessel
- No heat loss including radiation
- Chemical equilibrium is achieved behind the flame

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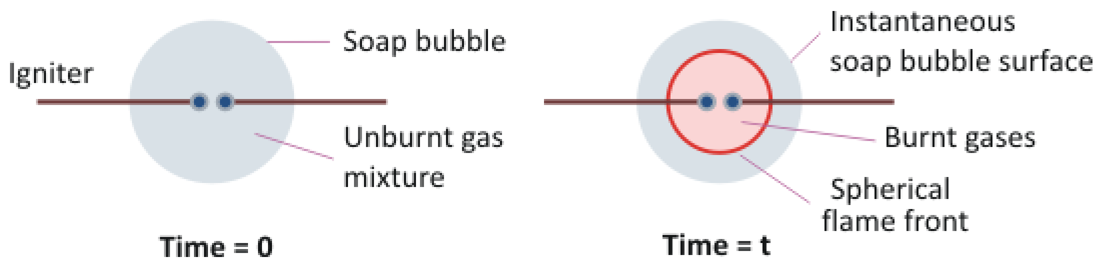
Soap Bubble Method



(Figure 24.3)

- Homogenous fuel-oxidizer mixture is confined in a soap bubble.
- On ignition at the center, spherical flame propagates.
- Pressure of burnt gas remains constant as the flame propagates .
- Assuming flame to be spherical and pressure remaining constant, a mass flux balance yields,

$$S_L A \rho_u = V_F A \rho_b \qquad S_L = V_F\left(\frac{\rho_b}{\rho_u}\right) = V_F\left(\frac{T_u}{T_b}\right)$$

V_F: flame front velocity, ρ_b : density of gas mixture at burned state, ρ_u: unburnt gas density

- This method cannot be used for dry mixture.
- Flame front may not retain the spherical shape.
- Flame front would not be smooth for fast flames.
- Heat loss to electrodes and ambient environment incurs error.

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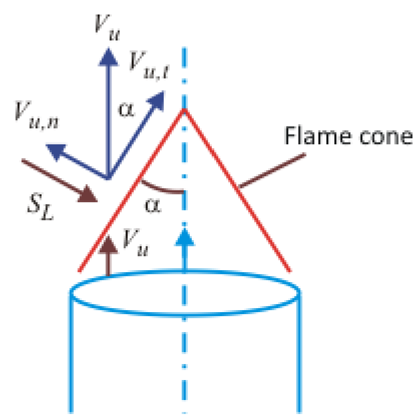
Stationary Flame Method (Bunsen Burner)

- The gas burns at the exit of the tube and a conical flame is established
- For flame to be stationary, the local burning velocity must be equal to the local flow velocity
- Flame shape will be influenced by the exit velocity profile and heat loss to the tube wall
- Lengthy tube ensures fully developed flow
- For a stationary flame,
  mass balance provides expression for S_L

$$S_L = V_t\left(\frac{A_t}{A_F}\right)$$

V_t: average flow velocity in tube, A_t : tube cross sectional area, A_F: conical surface area of flame

This method is known as ***area method***



(Figure 24.4)

This kind of burner is suitable for mixture having low burning velocity (≤15 cm/s)

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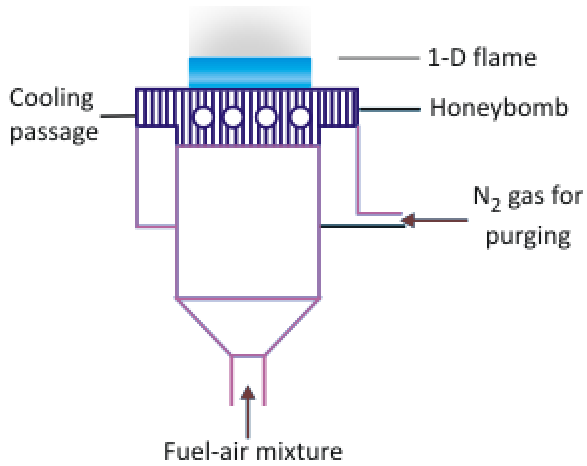
Flat Flame Burner

- 1D steady flame can be easily established
- 1D velocity profile is obtained using a honey comb or a metal porous plug
- Inert gas curtain can be used to prevent diffusion of atmospheric air
- Grid can be used to stabilize the flame
- Area of flat flame- measured by photo
- Flame area is same for visible, shadow schlieren photographs
- Simplest and most accurate of all the methods discussed so far



(Figure 24.5)

This kind of burner is suitable for mixture having low burning velocity ($\lesssim$15 cm/s)

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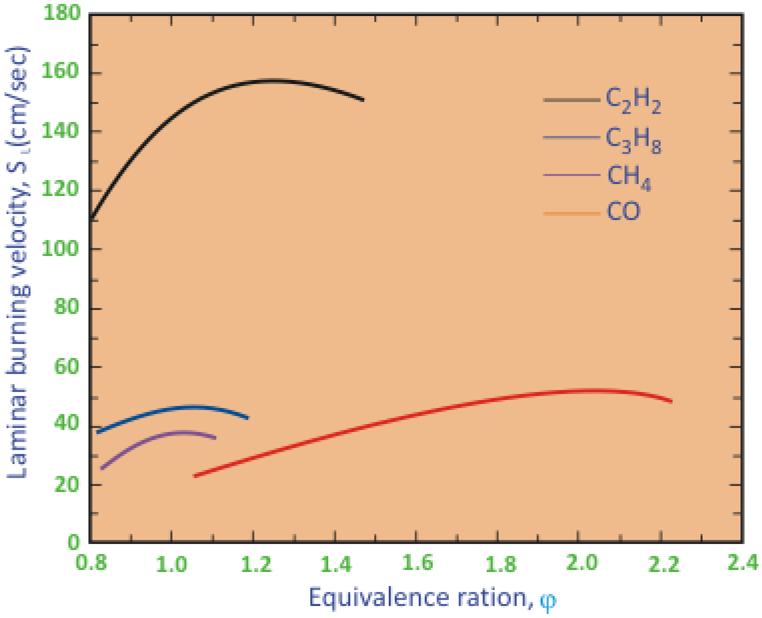
Effect of Equivalence Ratio on S_L

- For hydrocarbon fuels, $S_L \approx 25 - 50$ cm/s
- Peak burning velocity occurs at $\phi = 1.05$
- For hydrogen-air mixture,
  - Peak burning velocity occurs at $\phi = 1.8$
- Since $S_L \propto MW^{-1}$; maximum S_L occurs under fuel-rich conditions
- For CO-air mixture also maximum S_L occurs under fuel-rich conditions
- CO-air burning velocity data is *not understood* due to complex chemical kinetics
- The peak burning velocity for H_2, C_2H_2 and CO are quite different and *cannot be explained* in terms of *molecular weight*



(Figure 24.6)

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