Module 5: Premixed Flame

Lecture 26: Flammability Limits

The Lecture Contains:

- Flammability Limits
- Effect of Pressure on Limit Mixture
- Ignition
- Flame Stabilization
- Flame Stabilization by Burner Rim
- Turbulent Premixed Flame

Flammability Limits

Limit mixture
Flame can propagate only within a range of fuel-oxidizer ratio

Instrument to determine flammability limit

Vertical glass tube of 1.2 m length and 50 mm ID

(Figure 26.1)

➢Flammability limit is determined by upward propagation of flame from ignition source.

➢Mixture is said to be flammable only when it travels above half of the tube.

➢Large dia tube is preferred as it provides consistent results and is free from quenching.

➢Direction of flame propagation affects the flammability limit.

➢Flammability limit varies linearly with temperature.

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Module 5: Premixed Flame

Lecture 26: Flammability Limits
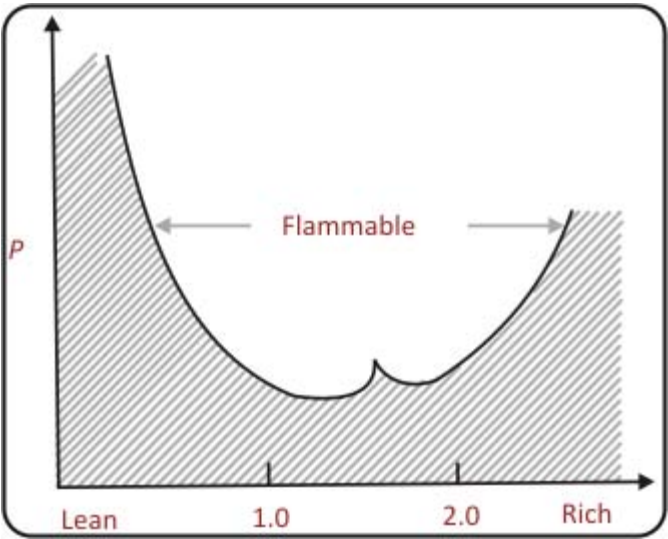
Effect of Pressure on Limit Mixture

> Pressure has significant effect on flammability limit
> Lean side is not affected significantly by pressure
> Rich limit becomes much wider with increase in pressure

(Figure 26.2)

Fuel	Oxidizer	Stoichiometry (% Fuel)	LFL (%)	UFL (%)
Methane	Air	9.5	5	15
Ethane	Air	5.6	2.8	12.4
Propane	Air	5.6	2.1	9.1
CO	Air	29.5	12	74.2
Hydrogen	Air	29.2	4	74.2

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Ignition

Ignition
Rate of heat liberation near the ignition zone
> rate of heat loss by conduction

Energy generated in flame = Ensible enthalpy $\times$ Mass

$$MIE = C_p(T_F - T_w)\left[\left(\frac{\pi}{4}d_q^2\right)S_L\rho_u\right]$$
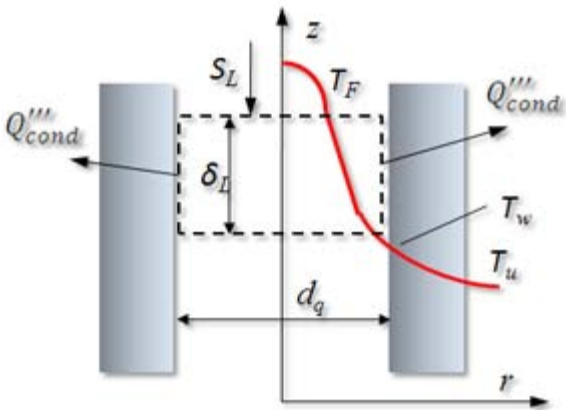
Substituting quenching diameter

$$MIE = 2\pi C\rho_u C_p(T_F - T_u)S_L^3$$

Substituting flame thickness

(Figure 26.3)

$$MIE = \frac{128\pi}{27}\frac{C(T_F - T_w)\alpha^2 k_g}{S_L^3}$$

Dependence on pressure

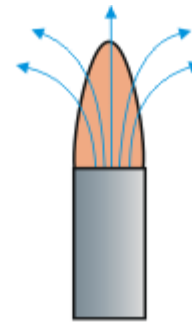$$MIE \approx \frac{1}{\rho_u^2 S_L^3} \approx p^{-(3n/2-1)}$$

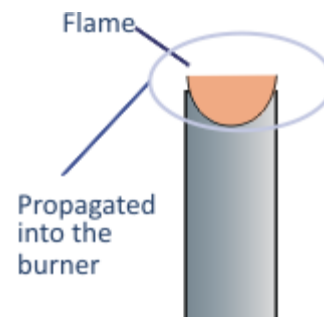| Fuel-Air	MIE (mJ)
Methane-air	0.47
Ethane-air	0.4
Butane-air	0.34
Acetylene-air	0.03
CO-air	0.05
Hydrogen-air	0.02

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Flame Stabilization

Local gas flow velocity = Local burning velocity
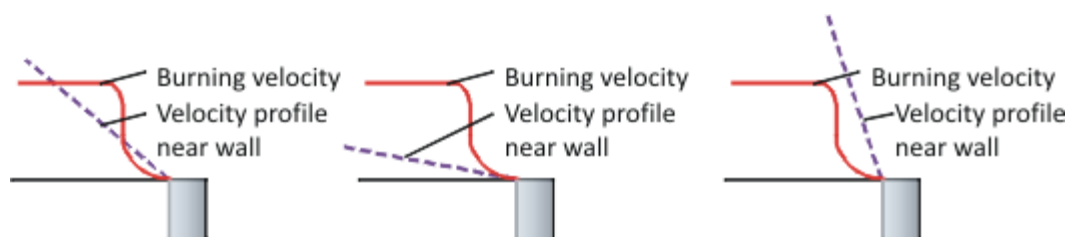

Stream lines through the
laminar premixed flame

(Figure 26.4)

Flame

Propagated
into the
burner

(Figure 26.5)

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Flame Stabilization by Burner Rim

(Figure 26.6)

Stability of flame front near the rim of Bunsen burner

➢ At burner rim, flow velocity ≈ burning velocity; flame likely to get stabilized here
➢ Heat loss and radical loss at the burner rim is the cause for flame stabilization
➢ Laminar velocity profile can be obtained at low Reynolds number
➢ When flow velocity (V_F) < burning velocity (S_L),

    ➢ Flame enters to burner, leading to flash back
    ➢ At the critical condition, the velocity gradient (g_F) is $\quad g_F = \lim_{r \to R} \left(-\frac{dV}{dr} \right)$

The parabolic velocity profile is $V = n\,(R^2 - r^2)$; R-tube radius;

$$n = -\frac{1}{4\mu}(\Delta P/L)$$

ΔP is pressure difference across tube length, μ is the fluid viscosity

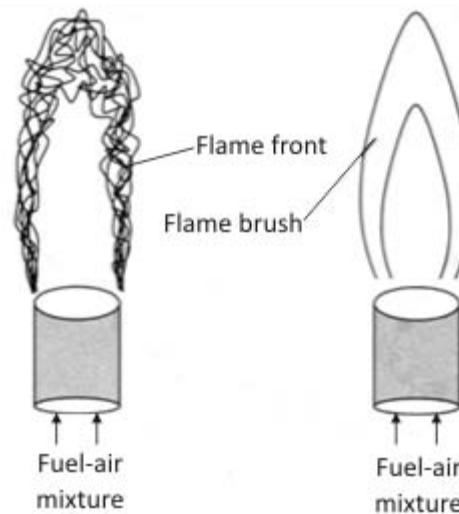At flash back, $\quad g_b = 8\dfrac{V_{av}}{d}$

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Turbulent Premixed Flame

Turbulence in flame	➢ Affects flame propagation rate
	➢ Does not alter chemistry
	➢ Mixing occurs due to random motion of eddies

➢ Turbulent flames are chaotic in nature
➢ Instantaneous flame front is highly convoluted
➢ Actual position of reaction zone moves rapidly in space w.r.t time
➢ This makes flame to appear thick
➢ **Turbulent flame brush:** Virtual turbulent flame thickness
➢ **Laminar flamlets:** Instantaneous reaction zone

(Figure 26.7)

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