One has to pursue questions earnestly,

Like a faithful shadow meticulously,

One should bear questions in mind,

Like a small innocent inquisitive child.

-Dr. D.P. Mishra

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Module 5: Premixed Flame

Lecture 22: Introduction

The Lecture Contains:

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Premixed Flame

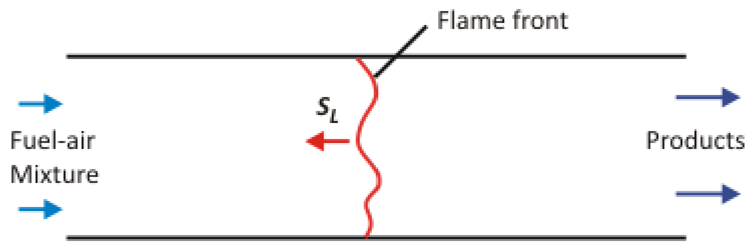
Introduction

Premixed Flame: Fuel and oxidizer are mixed well at the molecular level before combustion

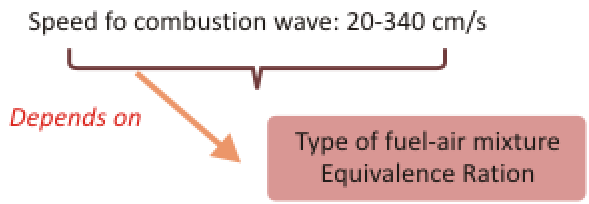
Examples of premixed flame :

Bunsen burner, LPG domestic burner, SI Engine, Afterburner in jet engine

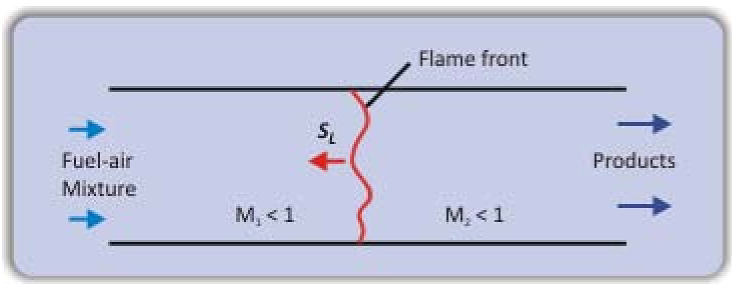
One-dimensional Combustion Wave



(Figure 22.1)

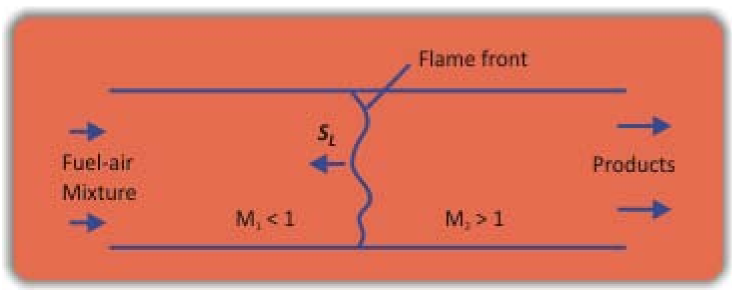


(Figure 22.2)



Deflagration

(Figure 22.3)



Detonation

(Figure 22.4)

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Analysis of 1D Flame

Continuity Equation : $\rho_1 V_1 = \rho_1 V_1 = \dot{m}$

Momentum Equation : $\rho_1 + \rho_1 V_1^2 = P_2 + \rho_1 V_1^2$

Energy Equation : $C_{p1} T_1 + \frac{V_1^2}{2} + q = C_{p2} T_2 + \frac{V_2^2}{2}$

State Equations:

$P_1 = \rho_1 R T_1$

$P_2 = \rho_2 R T_2$

ρ, V, P, T are the density, velocity, pressure and temperature

q is the heat release per unit mass $= \sum Y_i \Delta h_{f,i}^0$

Y_i is the mass fraction of i^{th} species

$\Delta h_{f,i}^0$ heat of formation of i^{th} species

Combining Continuity and Momentum Equations and expressing them in terms of Mach number,

$$P_1^2 V_1^2 = \frac{P_2 - P_1}{\left(\frac{1}{\rho_1} - \frac{1}{\rho_2}\right)} = \dot{m}^2$$

Rayleigh Relation

$$M_1^2 = \frac{1}{\gamma}\left(\frac{P_1/P_2 - 1}{1 - \rho_1/\rho_2}\right)$$

Rearranging the energy equation, we can get

$$q = \frac{\gamma}{\gamma - 1}\left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right) - \frac{1}{2}(P_2 - P_1)\left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right)$$

Rankine - Hugoniot Relation

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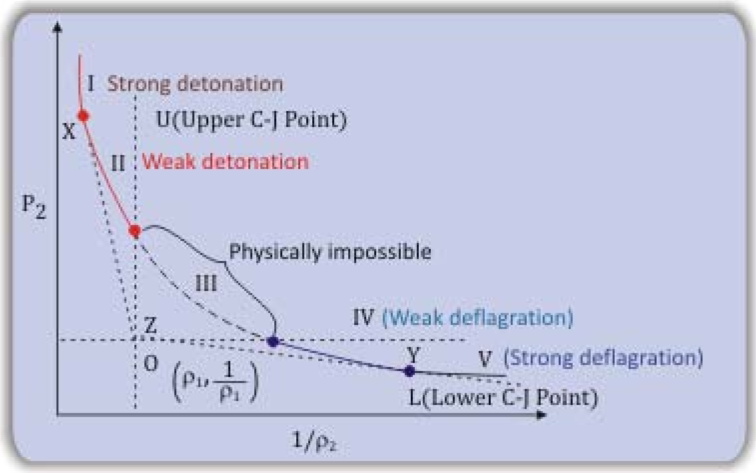
Hugoniot Curve ..

Hugoniot Curve : P_2 vs. $1/\rho_2$ for a fixed value of q, inlet pressure D_1, and inlet density ρ_1

Region I: Pressure of burned gas $(P_2) > $ Pressure of C-J detonation wave (P_U); Strong detonation
→ Gasvelocity relative to wave front is slowed to subsonic speed
→ $M_2 < 1.0$
→ Pressure and density increases significantly
for $P_2 \rightarrow \infty$, M_1 will be ∞; rarely observed



O: Origin of the plot
(Figure 22.5)

Region II: Pressure of burned gas $(P_2) <$ Pressure of C-J detonation wave (P_U); Weak detonation
→ Gas velocity relative to wave front is slowed to subsonic speed
→ Burned gas velocity > speed of sound at isochoric condition $(1/\rho_2 \approx 1/\rho_1)$, weak detonation attains infinite velocity

Region III: In this region $P_2 < P_1$; Therfore $1/\rho_2 \gg 1/\rho_1$
Hence M_1 in this region is imaginary and physically impossible

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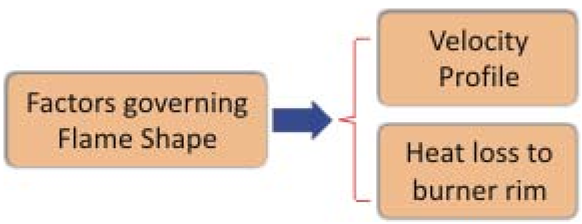
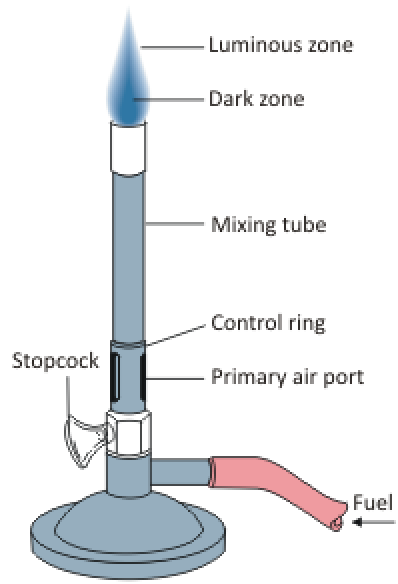
Laminar Premixed Flame



(Figure 22.6)



Bunsen Brner

(Figure 22.7)

First laboratory premixed

Glame burner : Invented by

Robert Bunsen in 1855

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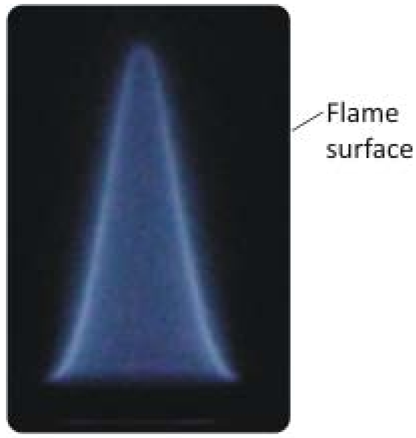
Luminous Zone

Portion of flame in which temperature is high and has several radicals to emit radiation

Flame radiation: 3300 to 4400 A°



LPG - air Bunsen flame Photograph

(Figure 22.8)