Module 5: Premixed Flame

Lecture 27: Flame Stabilization

The Lecture Contains:

Turbulent Flame Regimes

Turbulent Flame Regimes

Reynolds number for turbulent flame:

$$Re_l = \frac{V'_{rms} l_0}{\upsilon}$$

Chemical reaction time:

$$\tau_{ch} = \frac{\delta_L}{S_L}$$

Chemical reaction time:

$$\tau_t = \frac{l_0}{V'_{rms}}$$

Damkohler number

$$Da = \frac{t_m}{t_{ch}} = \frac{l_0/V'_{rms}}{\delta_L/S_L}$$

If Da >> 1, fast chemistry regime

If Da <<1, fast mixing regime

Previous Next

The Borghi Diagram

Borghi Diagram

- The plot of Da against Re_1 on a log-log scale
- Depicts various regimes of turbulent flames

Weak turbulent flame

- Upper region of the Borghi diagram

Wrinkled laminar flame

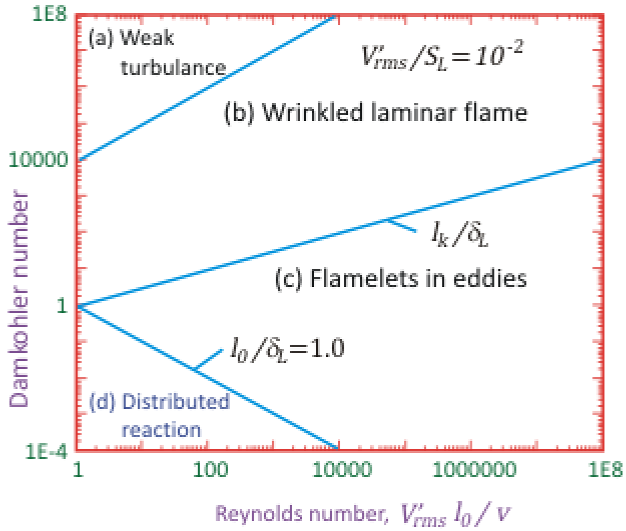
- Region between $V'_{rms}/S_L = 10^{-2}$ and l_k/δ_L
- Chemical reaction takes place in a thin zone

Flamelets in eddies

- Region between upper bold line $l_k/\delta_L = 1$ and $l_0/\delta_L = 1$

Distributed reaction regime

- Region below $l_0/\delta_L = 1$
- Reaction sheets are distributed in the turbulent flame surface $(Da < 1)$
- This type of combustion can be established in a well stirred reactor.



(Figure 27.1)

Previous Next

Turbulent Burning Velocity

Turbulent burning Velocity (S_T)

- Depends on characteristics of fluid flow
- Velocity at which unburnt mixture enters the flame zone
- Difficult to measure velocity of unburnt gas near the turbulent flame

How to measure (S_T) ?

From the reactant flow rate

$$S_T = \frac{\dot{m}}{\bar{A}\rho_u}$$

Turbulent Burning Velocity

$$\frac{S_T}{S_L} = \left(\frac{\alpha_T}{\alpha_L}\right)^{0.5}$$

$\dot{m}$ is the reactant flow rate

$\bar{A}$ is the time average flame surface area

ρ_u is the density of unburnt gas

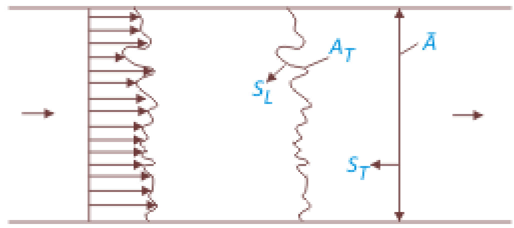
Weak Turbulent Flame

- Extension of laminar flame (low turbulence level)
- Smooth flame
- Turbulence scale ≈ Laminar flame thickness
- $S_T > S_L$ ....Why? increase in **thermal diffusion**

Previous Next

Wrinkled Laminar Flame

- Flamelets in flame surface propagate at laminar burning velocity
- Turbulence only causes wrinkling of flame



(Figure 27.2)

Turbulent burning velocity is given by,

$$m = \rho_u \bar{A} S_T = \rho_u A_{F1} S_L \Rightarrow \frac{S_T}{S_L} = \frac{A_{F1}}{\bar{\bar{A}}}$$

According to Damkohler, for constant laminar burning velocity

$$\frac{A_{Fl}}{A} = \frac{V_u}{S_L}$$

Similarly for turbulent flame,

$$\frac{A_w}{A} = \frac{A'_{rms}}{S_L}$$

$$\frac{S_T}{S_L} = \frac{\bar{A} + A_W}{\bar{A}} = \left(1 + \frac{V'_{rms}}{S_L}\right)$$

According to Klimov,

$$\frac{S_T}{S_L} = 3.5\left(\frac{V'_{rms}}{S_L}\right)^{0.7}$$

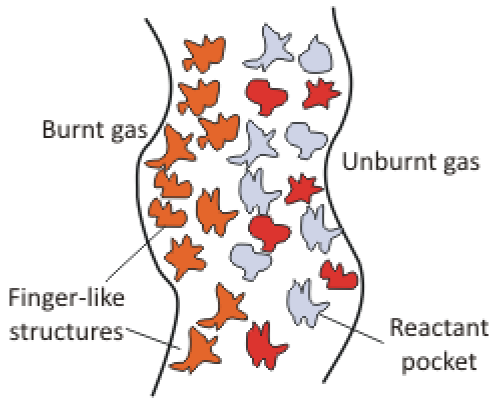
According to Calvin and William,

$$\frac{S_T}{S_L} = \left[0.5\left\{1 + \left(1 + \frac{8C{V'}^{2}_{rms}}{S_L^2}\right)\right\}^{0.5}\right]^{1/2}$$

Previous Next

Distributed Reaction

- For high intensities of wrinkling, distinct regime with small pockets of reactants are formed.
- In Borghi's diagram, this lies in the regime where integral length scale and Damkohler number are less than unity.
- Quite difficult to occur in practical devices.
- In laboratory, such situation can be created by using stirred reactor.
- Chemical reactions are not completed in reaction zone; rather occur in post-flame region.
- This regime needs more understanding.



(Figure 27.3)

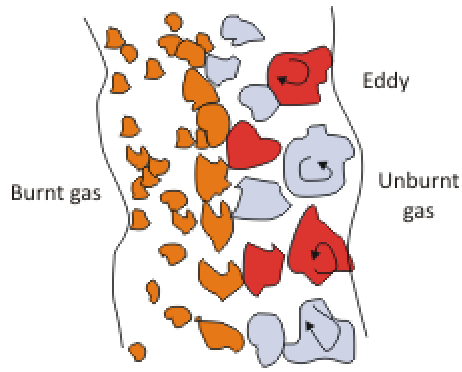
Turbulent burning velocity is given by,

$$S_T = 6.4\, V'_{rms} \left(\frac{\overline{V}}{V'_{rms}} \right)^{3/4}$$

Previous Next

Flamelet in Eddies

Regime in Borghi's diagram	Region between upper bold line (l_k/δ_L=1) and lower bold line (l_0/δ_L=1)
Reaction zone	parcels of unburned gas and fully burnt gases



(Figure 27.4)

Fuel mass burning rate,

$$\dot{m}_F''' = -\rho C_F Y'_{F,rms} \varepsilon_o / ke_t$$

Typically, $C_F = 1$; $Y'_{F,rms}$ is root mean square of fluctuating fuel mass fraction, ke_t is the turbulent kinetic energy per unit.

$$\dot{m}_F''' = -\rho C_F Y'_{F,rms} V_{rms} / l_o$$

Examples:
- SI Engines
- Premixed burner
- High velocity burner

References

1. D. P. Mishra, Fundamentals of Combustion, PHI leaming, Pvt Ltd., New Delhi, 2010.
2. Stephen R. Turns, An Introduction to Combustion, McGraw Hill Publication, Singapore, 1996.
3. Irvin Glassman, Combustion, Academic Press, New York, 1977.

Previous Next