Premixed Flames

Transient Behavior

• There are three important aspects to consider:
  1. Quenching distance – is the critical diameter of a circular tube where a flame will self extinguish and not propagate.
  2. Flammability limits -
     LFL: leanest mixture ($\phi<1$) that will allow steady flame propagation.
     UFL: richest mixture ($\phi>1$) that will allow steady flame propagation
  3. Minimum ignition energy

• For each of these aspects, heat loss is the controlling factor.

Premixed Flames

Transient Behavior

• Ignition and Quenching Criteria (also referred to as the Williams' criteria):
  1. Ignition will only occur if enough energy is added to the flammable gaseous mixture to raise the temperature of a small slab of gas (approximately the thickness of a steadily propagating laminar flame) to the adiabatic flame temperature.
  2. The rate of heat liberation by chemical reactions inside the slab must approximately balance the rate of heat loss from the slab by thermal conduction.

• Keep in mind that (1) and (2) are just rules-of-thumb.
Premixed Flames

Comments on Flame Stabilization

• Flame Stabilization – is an important safety concern that can lead to flashback and liftoff if not properly considered in equipment design.

• Both flashback and liftoff are related to matching the local laminar flame speed to local flow velocity.

Comments on Flame Stabilization

• **Flashback** occurs when a flame enters and propagates upstream through a burner tube without undergoing quenching.

• Flashback:
  - a safety concern that can lead to an explosion
  - occurs when local flame speed exceeds local flow velocity
  - can occur when the flow of fuel is being decreased or turned off; during a transient event.
  - controlling parameters are: fuel type, equivalence ratio, flow velocity, and burner geometry
  - note these are the same parameters that control flame quenching
Premixed Flames

Comments on Flame Stabilization

- **Liftoff** - the condition where a flame is no longer attached to the burner tube, but is stabilized at some distance above the burner port.

- Although a good way thermally protect the burner nozzle from the high flame temperature, this condition can lead to:
  - an escape or loss of unburned gases
  - incomplete combustion
  - ignition difficulties above the lifting limit
  - inability to accurately control flame position
  - noisy flames with poor heat transfer

Figure 4.15: Measured and calculated lift-off heights (H) of methane/air jet diffusion flames.
Premixed Flames

Characteristics of stability diagram for a premixed open burner flame, Wohl, et al.,

Premixed Flame Blowoff vs Flashback.mp4

Premixed Flames

Flame Quenching

- Tests performed to demonstrate flame quenching of a propane/air mixture and estimate flame propagation speed.
Example 8.4. Class Exercise

Consider the design of a laminar-flow, adiabatic flat-flame burner consisting of an arrangement of thin-walled tubes as illustrated.

- Fuel-air mixture flows through both the tubes and the interstices between the tubes (next slide).

- It is desired to operate the burner with a stoichiometric methane-air mixture exiting the tubes at 300 K and 5 atm.

Where:

\[ MW_{CH_4} = 16.04 \text{ kg/kmol} \]
\[ MW_{air} = 28.85 \text{ kg/kmol} \]
and mole fraction \( \chi = 0.0948 \) (from \( C_{st,1} \) Chapt 3 slide 20)

Determine the following:

1. the mixture mass flowrate per unit cross-sectional area at the design condition.

2. the maximum tube diameter that should be utilized so that flashback will be prevented.
Premixed Flames

Flame Quenching

Solution (Part 1): Class Exercise

- To establish a flat flame the mean flow velocity must equal the laminar flame speed at the design T and P.
- From Fig. 8.14, or eqn 8.32 in Section 4D(slide 1)
### Flammability Limits

**Flame Quenching**

<table>
<thead>
<tr>
<th>Family</th>
<th>Name</th>
<th>Formula</th>
<th>Molecular weight</th>
<th>ATC (cm²)</th>
<th>Specific gravity</th>
<th>Ignition point °F</th>
<th>Flammability Limit °F</th>
<th>CH₄ %</th>
<th>H₂ %</th>
<th>CO %</th>
<th>CO₂ %</th>
<th>H₂O %</th>
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*Note: All data were obtained from Selected Values of Properties of Hydrocarbons, 3rd ed. Johns, J. C., and Othmer, D. G., New York: A. I. E. E. Research Project 466, 1951. Properties of Selected Hydrocarbons (Chapter 3 slide 39)
Premixed Flames

Flame Quenching

--- End of Part 1 ---

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Premixed Flames

Flame Quenching

Solution (Part 2):

• Now assuming that if the tube diameter < the quench distance (d), with the addition of a factor-of-safety, the burner will operate without any significant danger of flashback.

• Thus, we need to find the quench distance at the design conditions.
Premixed Flames

Flame Quenching

Solution (Part 2):
- Note the temperature is constant for both cases:
Premixed Flames

Flame Quenching

Solution (Part 2):

• Remember in an actual design application a 50% or greater safety factor should be included.