Lecture 6. Laminar Non-premixed Flames

part 1

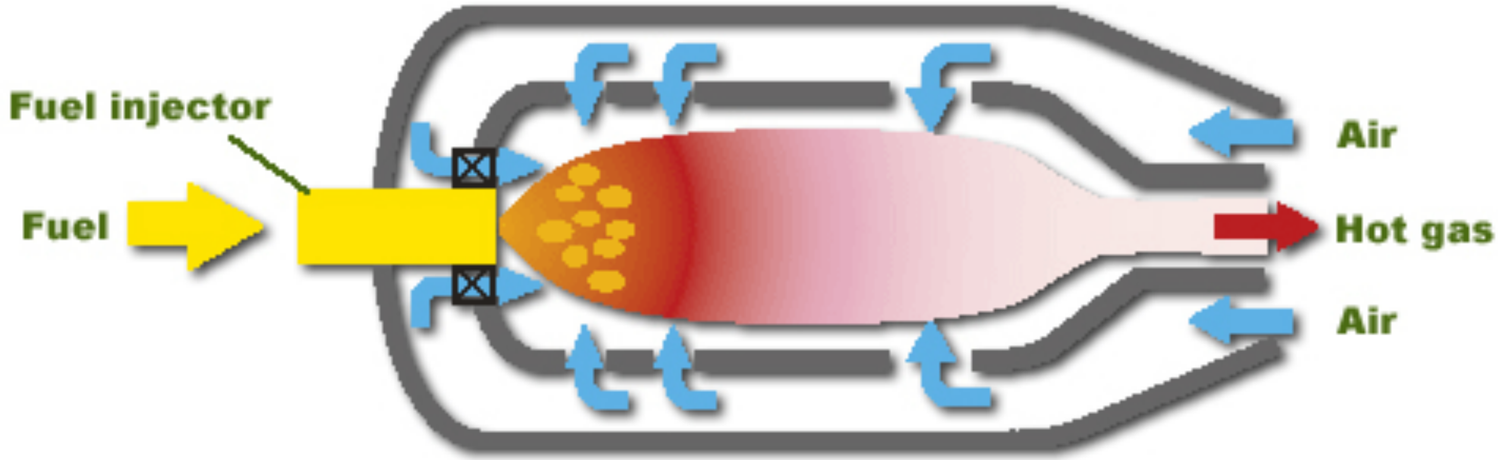
Space shuttle

TNF
in rocket
engines

Airbus A380 engine

Rolls Royce Trent 900

Gas turbine combustor

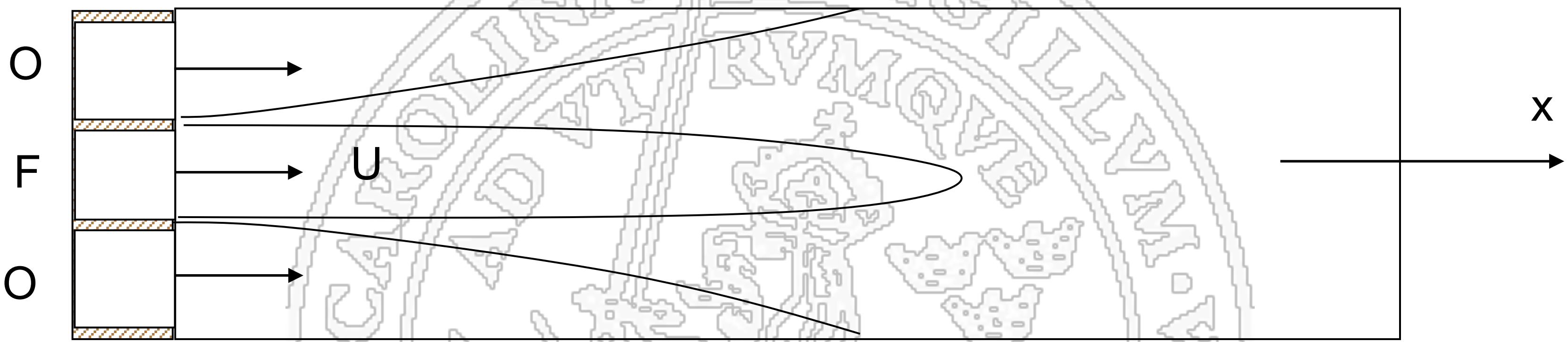


Laminar diffusion flame

Peclet number → $Pe = \frac{Ud}{D}$

d ← Diameter of the fuel jet

D ← Diffusion coefficient



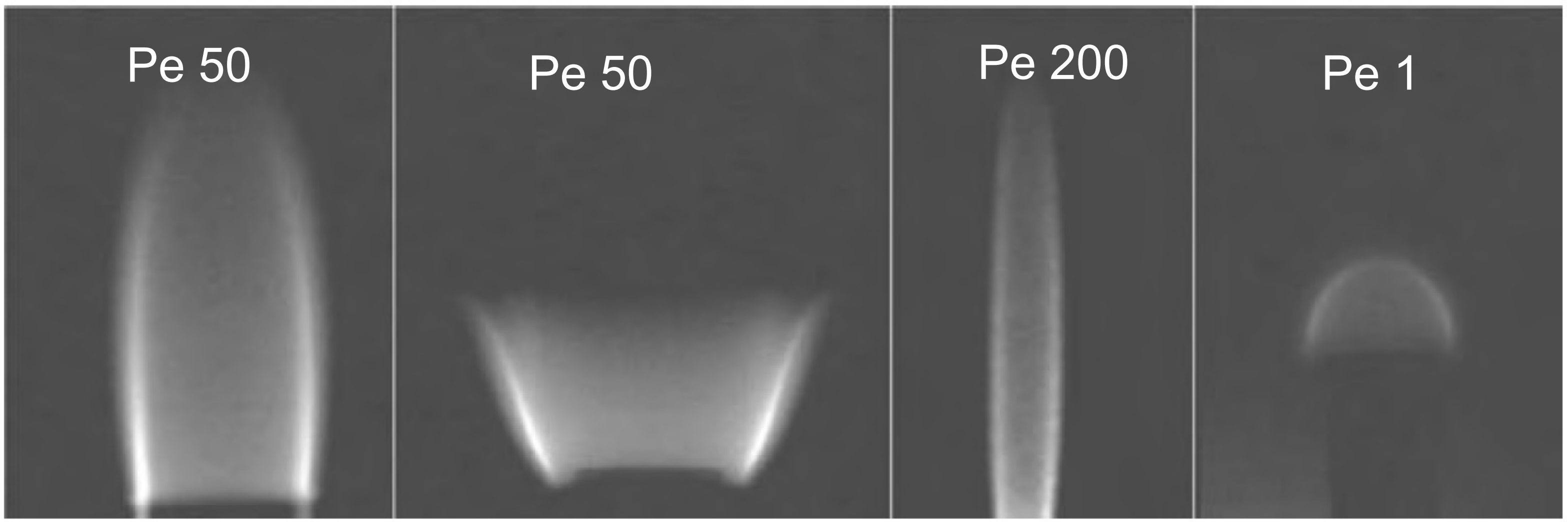
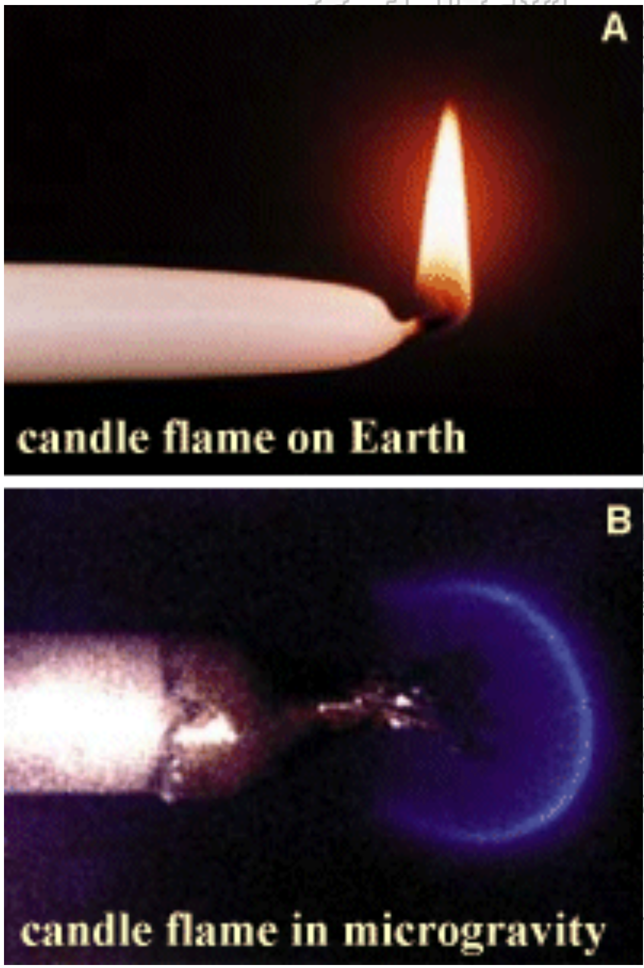
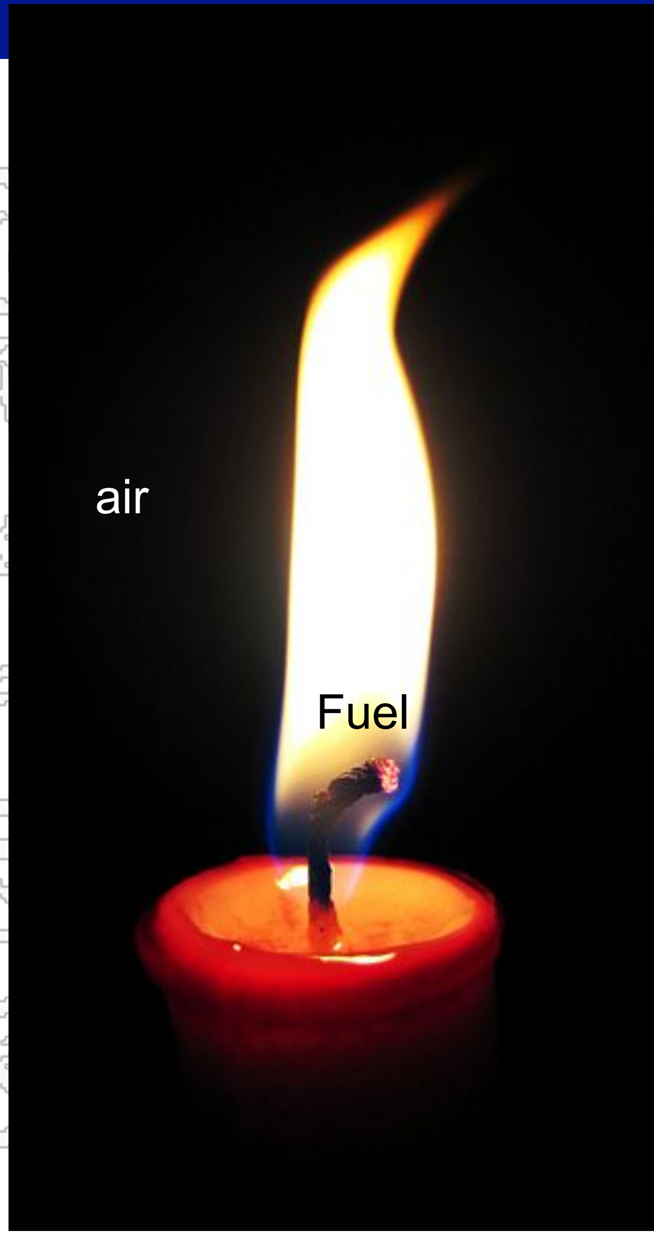


Photo taken in November 2008

Candel flame





Non-premixed flames

- Diesel engine flames
- Industrial furnace firing solid fuels
- Aircraft engines
- Gas turbines
- Space rocket engines
- Fires

- Hot combustion temperature – not good for NOx control
- Fuel rich combustion – not good for soot and particle control

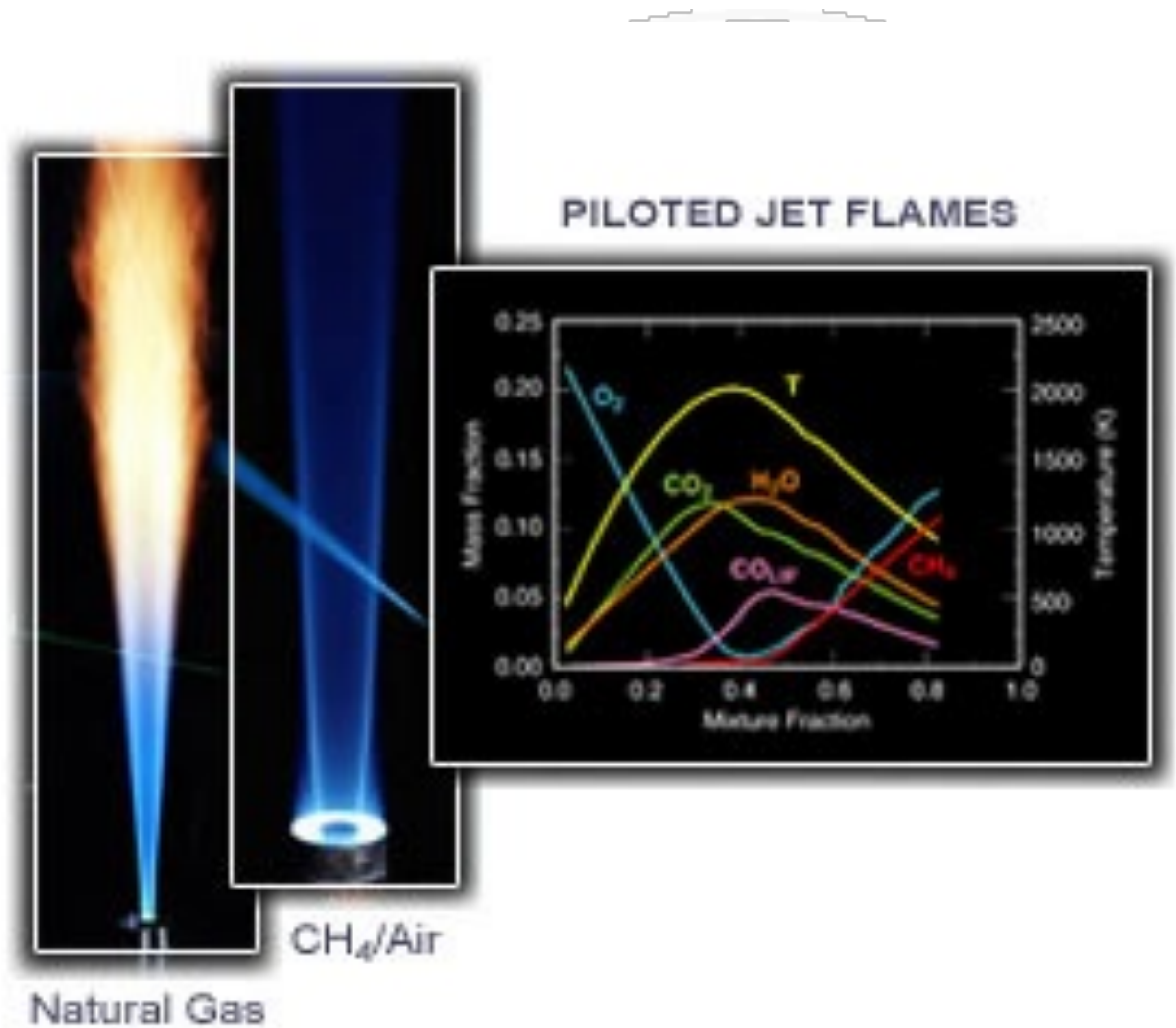
- Safety is high – aeronautical and aerospace engines

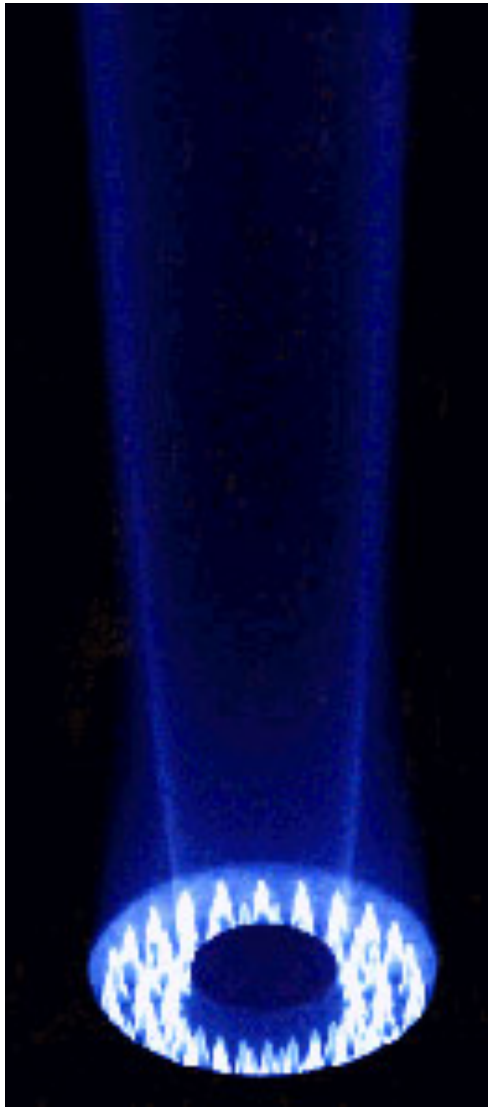
Content

- Structures of laminar non-premixed flames
- Mixture fraction
- Burke-Schumann flame-sheet model
- Jet diffusion flames
- Laminar diffusion flame athigh mixing rate

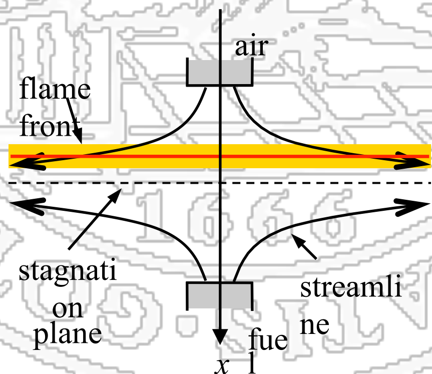
Experimental observations of laminar non-premixed flames

Piloted jet flame: Sandia, Delft TU, TU Darmstadt, TNF workshop

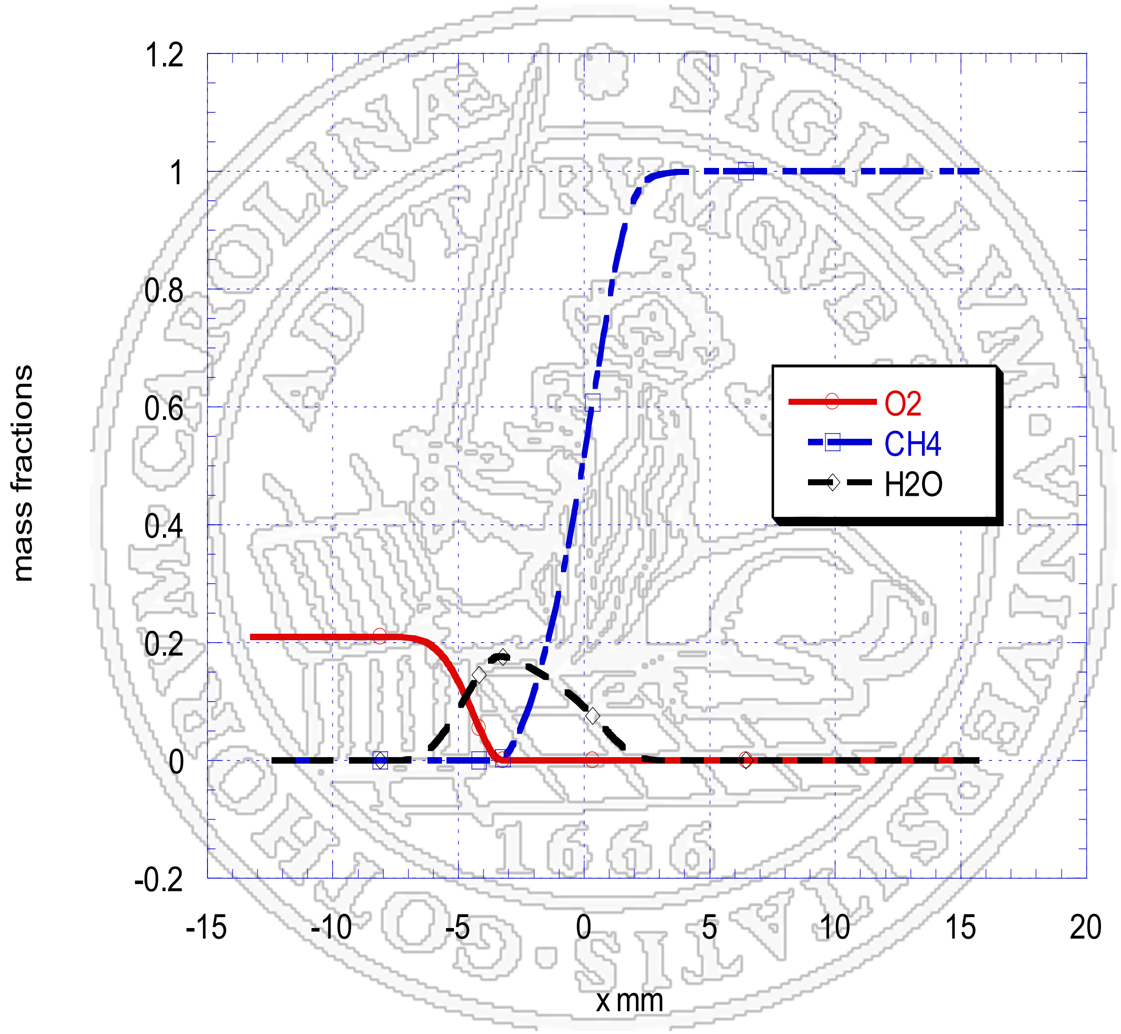




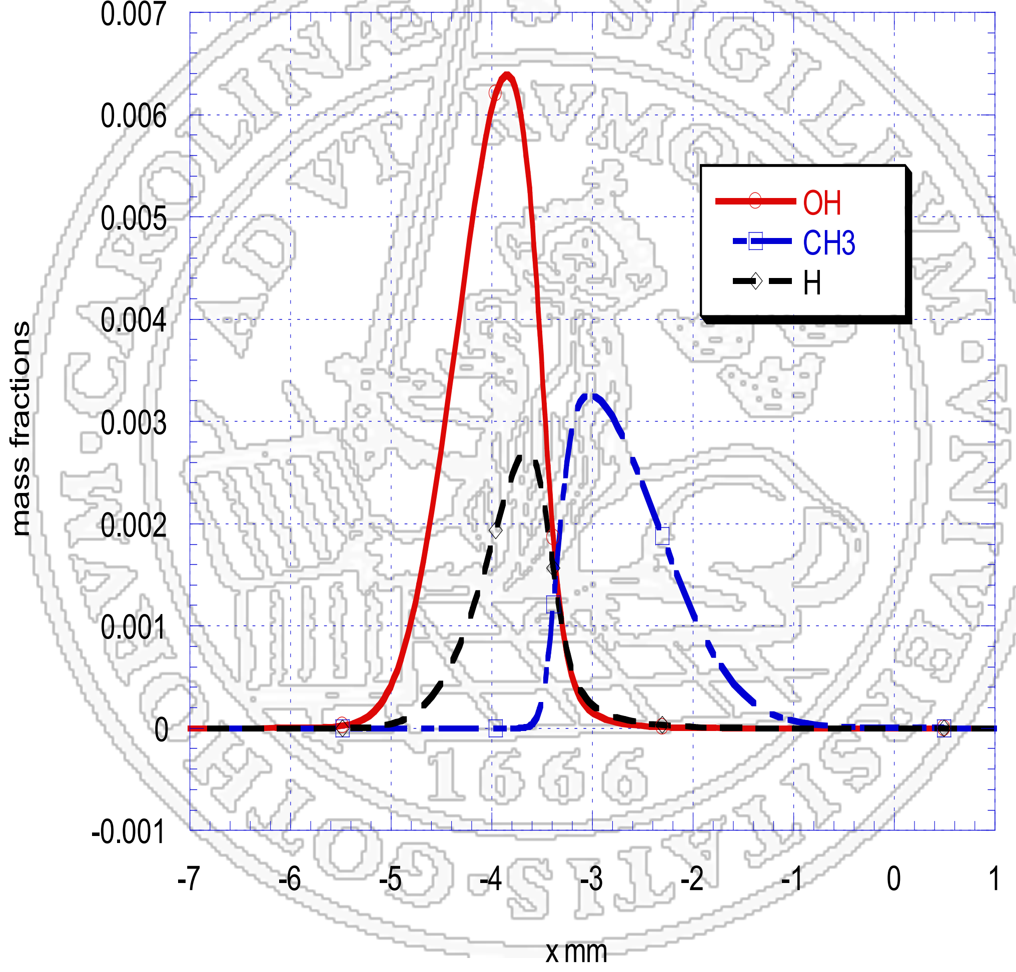
Counterflow diffusion flame



Structure of non-premixed flames



Structure of non-premixed flames



Structure of non-premixed flames

- Fuel rich zone: between the fuel stream and the reaction zone
- Reaction zone: between the fuel rich zone and oxygen rich zone
- Oxygen rich zone: between the oxygen stream and reaction zone

Laminar diffusion flames

- Laminar non-premixed flame: fuel and air supplied to combustor separately
- Fuel diffuses to the reaction zone from the fuel rich side
- Oxygen diffuses to the reaction zone from the fuel lean side
- Products diffuses from the reaction zone to the fuel and oxygen stream
- Temperature (energy) diffuses from the reaction zone to the fuel and oxygen streams
- Chemical reactions occur as soon as the fuel and oxygen mix

- Diffusion is slower than chemical reaction
- The process depends thus on the mixing rate by diffusion
- Non-premixed flames are also called diffusion flames

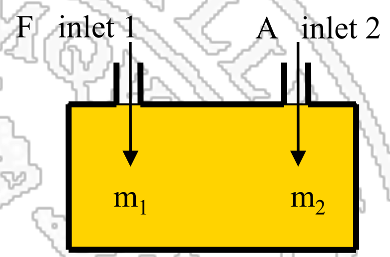
Mathematical description of laminar non-premixed flames

Mixture fraction

$$Z = \frac{m_1}{m_1 + m_2}$$

$$Z_{st} = \frac{1}{1 + \gamma_A}$$

$$Z = \frac{\phi}{\phi + \gamma_A}, \quad \phi = \frac{Z}{1 - Z}\frac{1 - Z_{st}}{Z_{st}}$$



Mixture fraction is defined as the ratio of the total sum of the mass of materials that are originated from the fuel stream to the total mass.

Using Z to denote mixture fraction

Z = mass originated from the fuel / total mass

- Mixture fraction is conserved during combustion

Conserved scalar

- A scalar that is not changed during chemical reactions
  - It may change as a result of flow mixing
- Element mass fraction is a conserved scalar
  - Y_C, Y_O, Y_H, Y_N
- Mixture fraction is a conserved scalar
  - Mass originated from the fuel does not change due to mass conservation law
- Equivalence ratio is not a conserved scalar
  - Both mass of fuel and mass of oxidizer can change during chemical reactions
- One can trace back the equivalence ratio of the original unburned mixture using mixture fraction

$$Z = \frac{\phi}{\phi + \gamma_A}, \quad \phi = \frac{Z}{1-Z}\frac{1-Z_{st}}{Z_{st}}$$