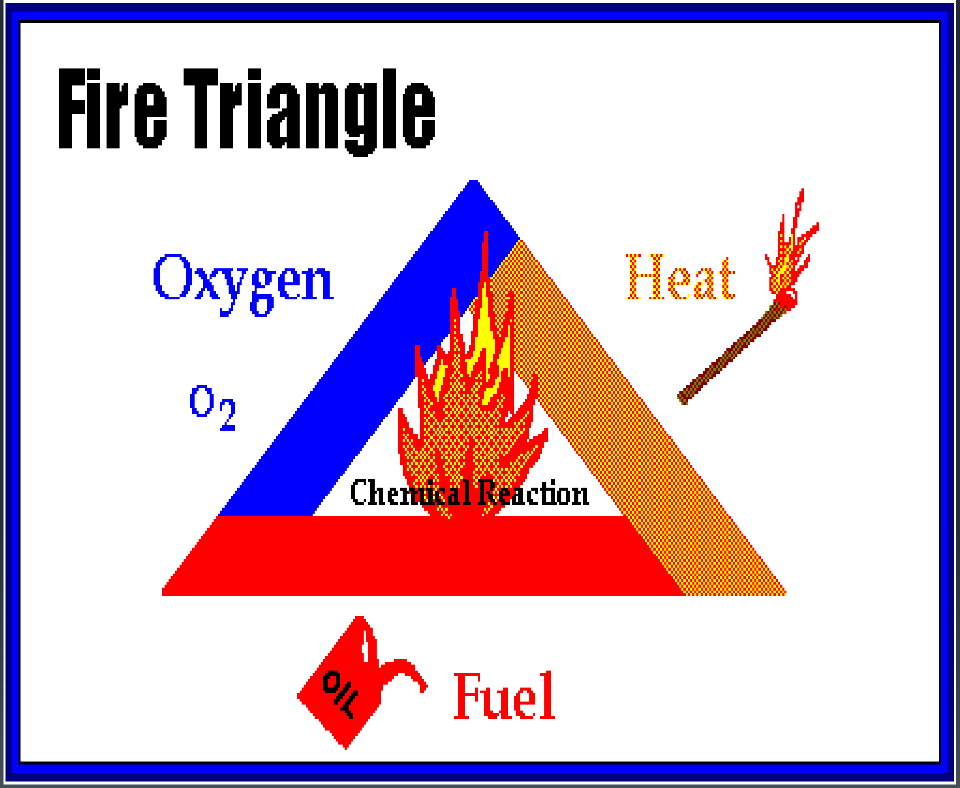
Combustion Theory
premixed and diffusion flames
part (1)

Ignition

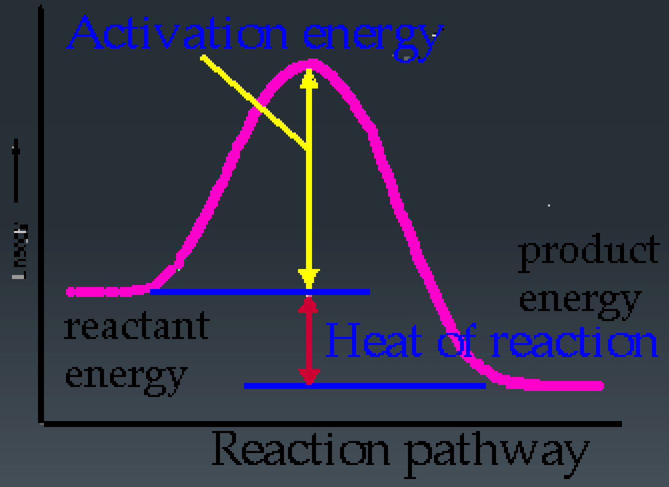
Three things must be present at the same time
in order to produce fire:

- Enough **oxygen** to provide combustion,
- Enough **heat** to raise the material temperature to its ignition temperature,
- **Fuel** or combustible material which produces high **exothermic reaction** to propagate heat to not-yet- burnt material nearby


Fire Triangle
Oxygen
O2
Heat
Chemical Reaction
OIL
Fuel

Activation energy

The energy that is required to activate molecules for a chemical reaction is the activation energy of the reaction.



Introduction

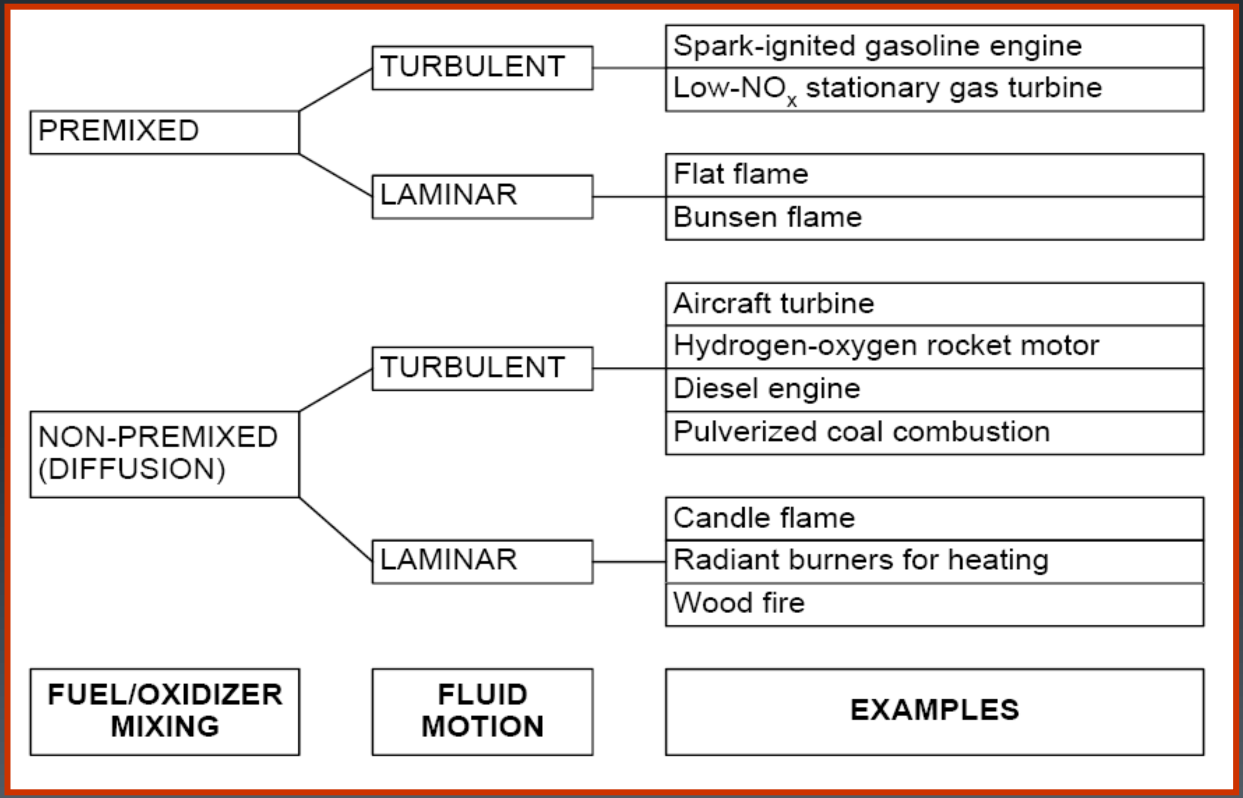
Basic Flame Types:

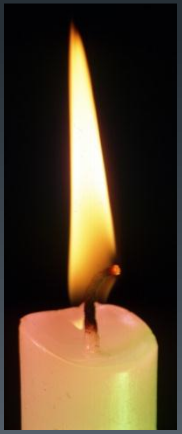
- Premixed flames: fuel and oxidizer are homogeneously mixed before reaction occurs.

  Laminar and turbulent premixed flames

- Non premixed flames: fuel and oxidizer come into contact during combustion process.

  Laminar and turbulent diffusion flames

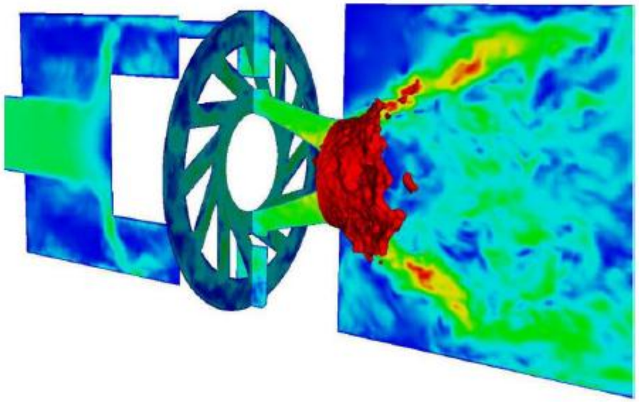




1. Laminar premixed flames

- Premixed combustion used in combustion devices when high heat release rates are desired
  - Small devices
  - Low residence times
- Examples:
  - SI engine
  - Stationary gas turbines
- Advantage → Lean combustion possible
  - Smoke-free combustion
  - Low NO_x
- Disadvantage: Danger of
  - Explosions
  - Combustion instabilities

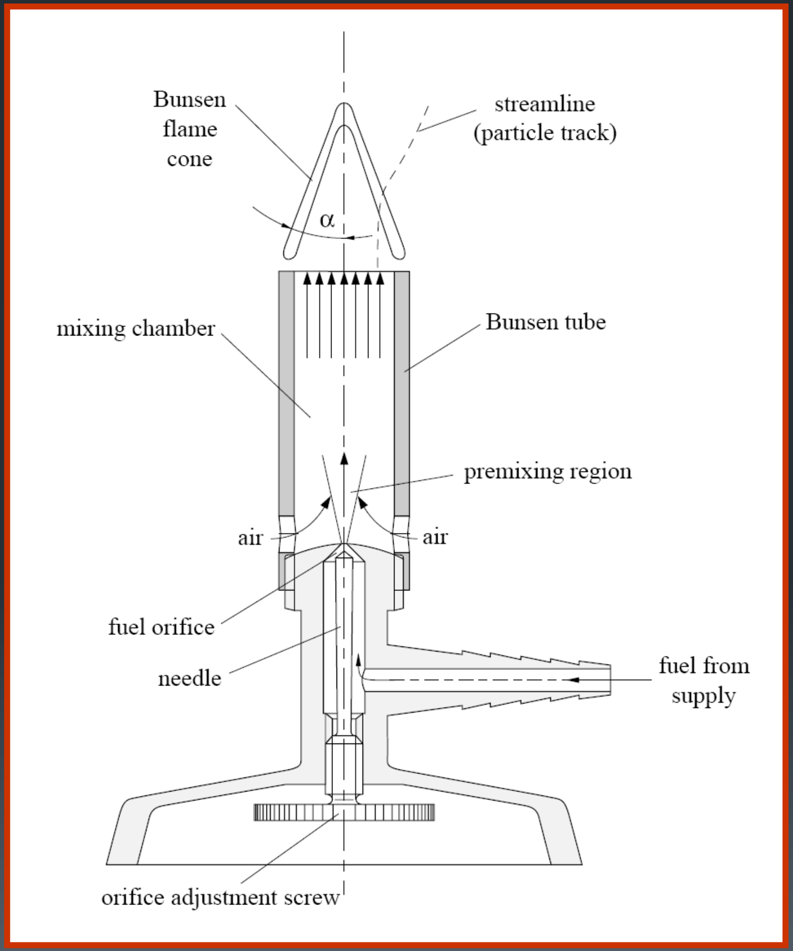
    → Large-scale industrial furnaces and aircraft engines are typically non-premixed



Laminar premixed flames

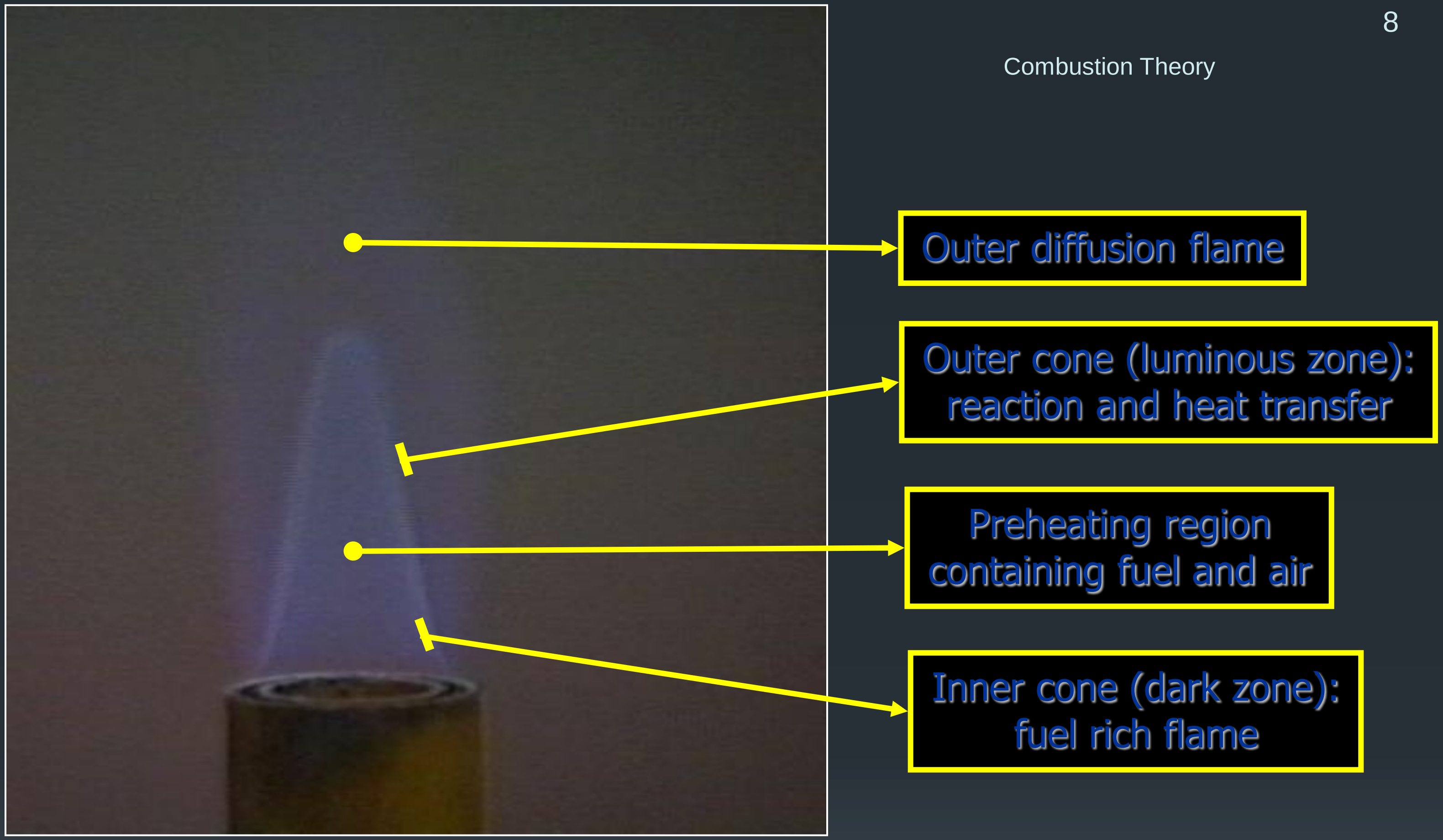
A premixed flame is a self-sustaining propagation of a localized combustion zone at subsonic velocities (deflagration regime)

The classical device to generate a laminar premixed flame is the Bunsen burner:



Typical Bunsen burner flame

Example: Typical Bunsen-burner CH_4/Air flame

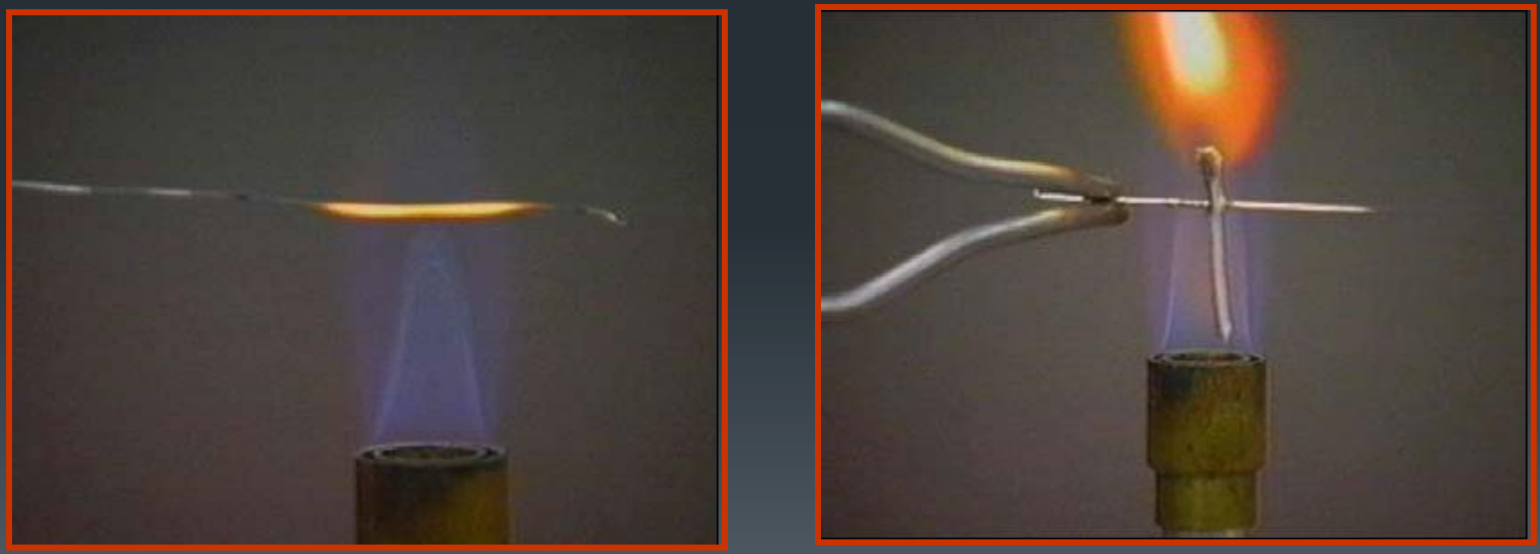


Typical Bunsen-burner flame is a dual flame:

- a fuel-rich premixed inner flame
- a diffusion outer flame: CO and H_2 from inner flame encounter ambient air

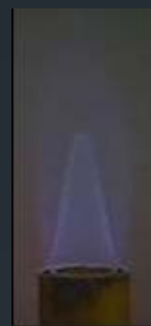
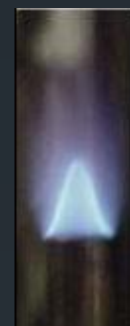
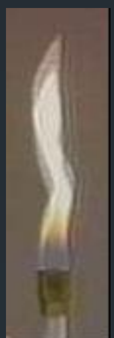
- Experimental evidence for the presence of a cool inner preheating region

A wire to reveal the presence of a cool preheating region containing unburned CH_4 and O_2



A match in preheating region does not ignite until it is moved to the inner cone

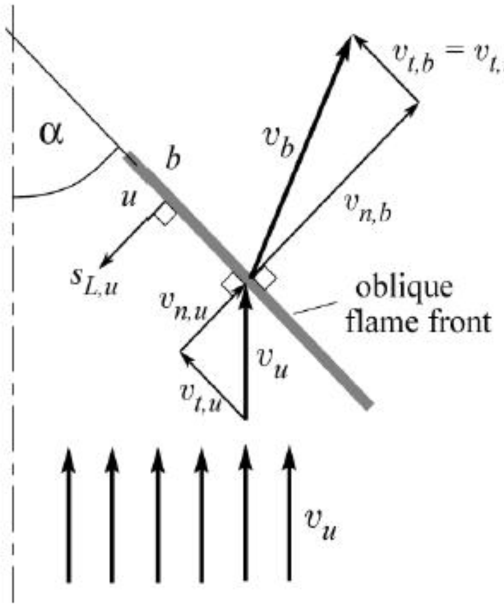
- **Basic features of laminar premixed flames**

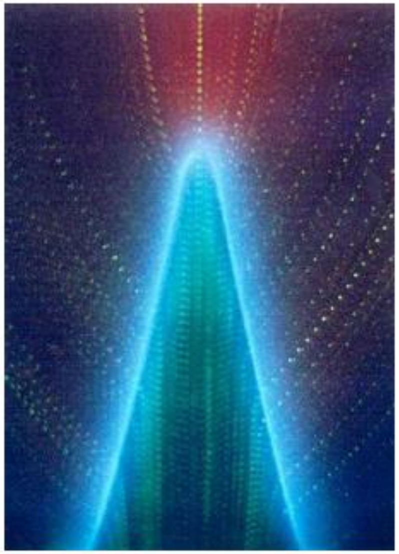
Fuel/Air Ratio	Fuel lean	Stochiometric	Fuel rich	Very fuel rich
Flame colour, *i.e. colour of the outer cone*	Deep Violet due to large concentrations of excited CH radicals 	Blue 	Green due to large concentrations of C_2 species High-T burned gases usually show a reddish glow due to radiation from CO_2 and H_2O	Yellow due to carbon particles 

Flame characteristics for hydrocarbon-air stoichiometric mixtures

- The flame is ~1 mm thick and moves at ~0.5 m/s
- Pressure drop through the flame is very small: ~1 Pa
- Temperature in reaction zone is ~2200-2600 K
- Density ratio of reactants to products is ~7

- Kinematic balance for a steady oblique flame




Laminar Bunsen flame

Thermal expansion through the flame front

- Normal component of velocity vector

$$(\rho v_n)_u = (\rho v_n)_b \qquad v_{n,b} = v_{n,u}\frac{\rho_u}{\rho_b}$$

- Tangential component of velocity vector

$$v_{t,u} = v_{t,b}$$

- At steady-state the burning velocity equals the flow velocity of the unburnt mixture normal to the flame front

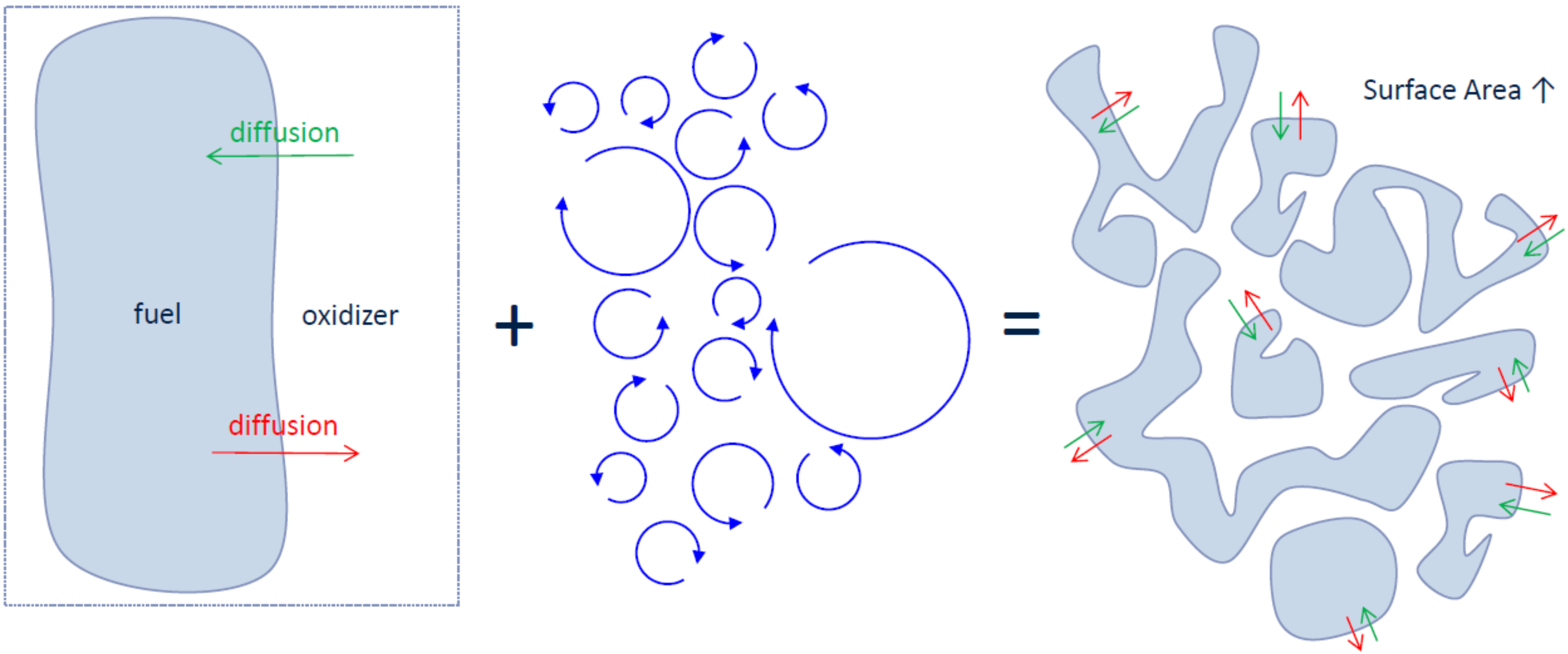
$$S_{L,u} = v_{n,u} = v_u \sin\alpha$$

2- Turbulent flames

- Most of combustion devices operate in turbulent flow regime, i.e. internal combustion or aircraft engines, industrial burners and furnaces. Laminar combustion applications are almost limited to candles, lighters and some domestic furnaces. Turbulence increases the mixing processes thus enhancing combustion.
- Also combustion influences turbulence. Heat release due to combustion causes very strong flow accelerations through the flame front (flame-generated turbulence). Moreover, huge changes in kinematic viscosity associated with temperature changes may damp turbulence leading to flow re-laminarization

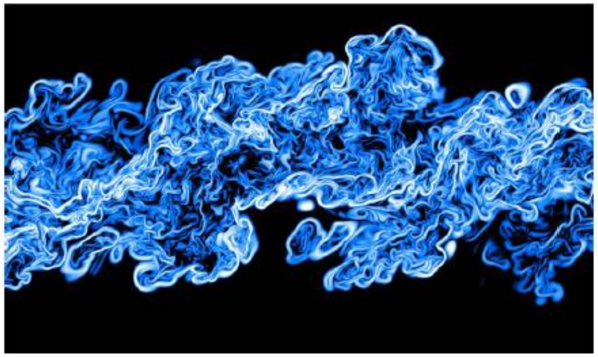
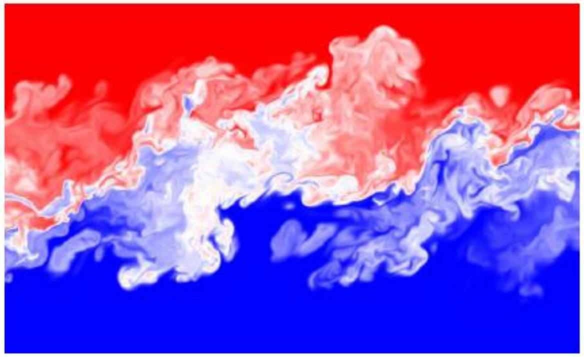
Turbulence

- Combustion requires mixing at the molecular level
- Turbulence: convective transport ↑ → molecular mixing ↑

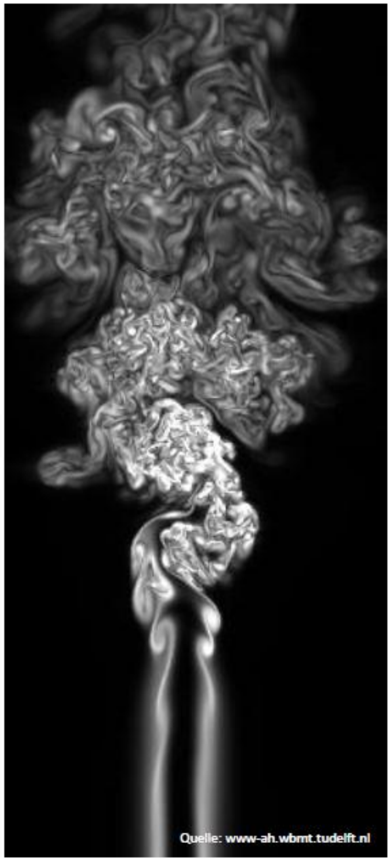


Turbulent shear flows

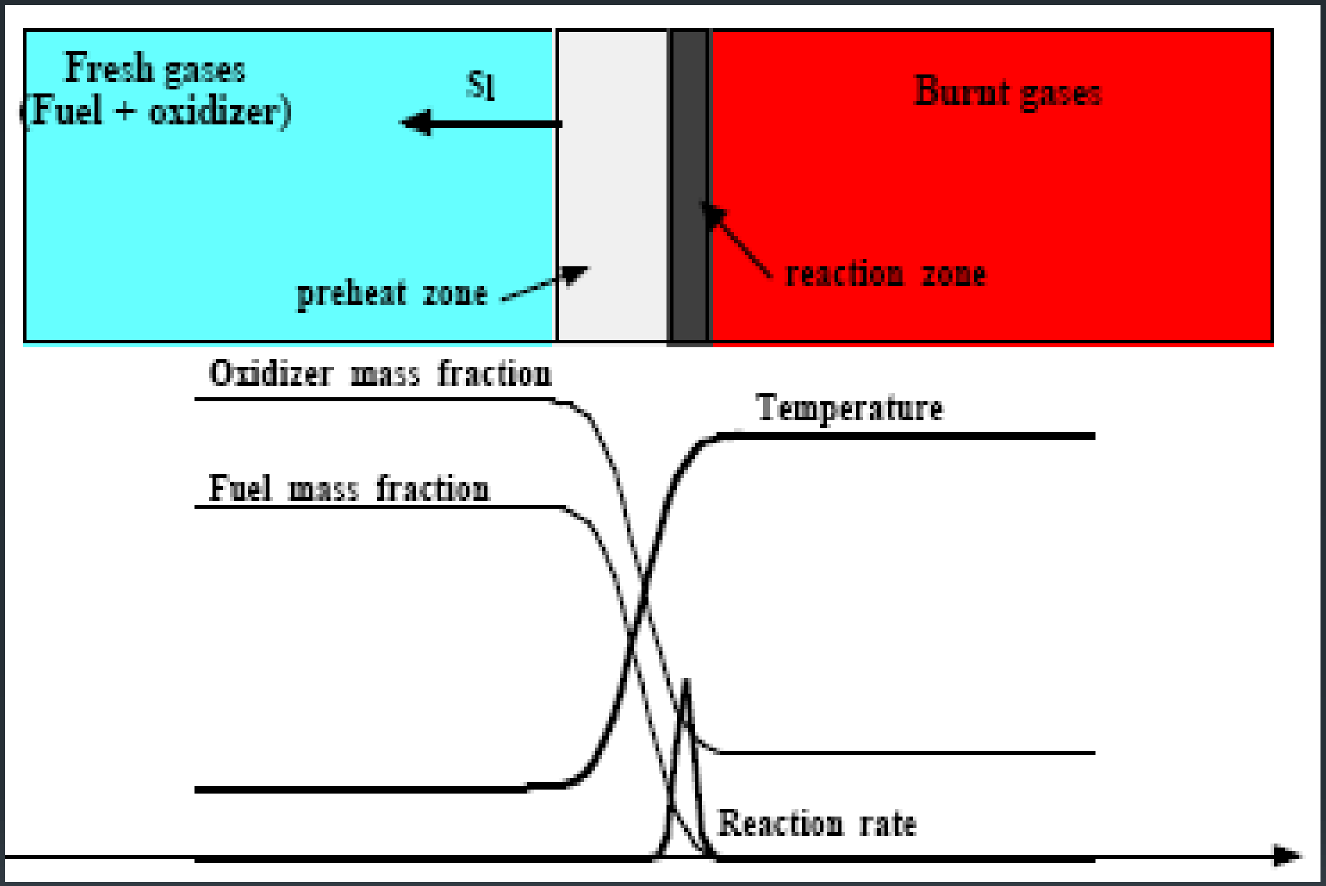
- Relevant flow cases in technical systems
  - Round jet
  - Flow around airfoil
  - Flows in combustion chamber
- Due to the complexity of these turbulent flows they cannot be described theoretically

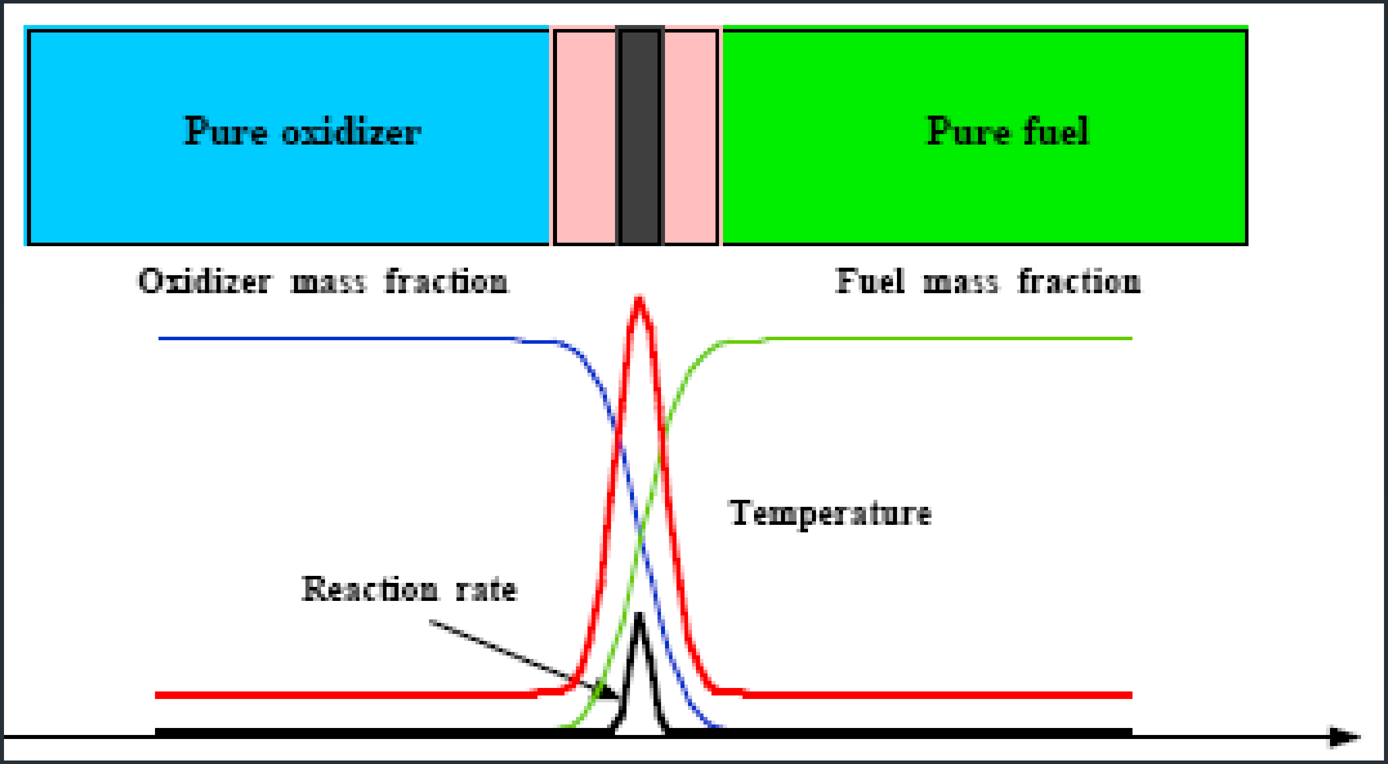
„Temporally evolving shear layer“: Scalar dissipation rate χ (left), mixture fraction Z (rechts)



Turbulent jet: magnitude of vorticity



- Figure 3. Structure of a one-dimensional premixed laminar flame.



- Figure 4. Structure of a one-dimensional non-premixed laminar flame. Here fuel and oxidizer streams are assumed to have the same temperature.