Dispersion, ignition and combustion characteristics of hydrogen-methane blends

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Introduction

- Hydrogen blended with natural gas is of interest due to its potential to reduce the carbon intensity and provide a pathway to a sustainable energy future.
- The United States has an extensive network of NG pipelines spanning about 3 million miles.
- Dispersion of fuels (hydrogen, natural gas and blends) into air can be a safety hazard, as it can create a flammable mixture.
- A better understanding of the ignition and flame properties of blends is needed to provide a basis for safety, codes, and standards.

HyBlend
U.S. DEPARTMENT OF ENERGY

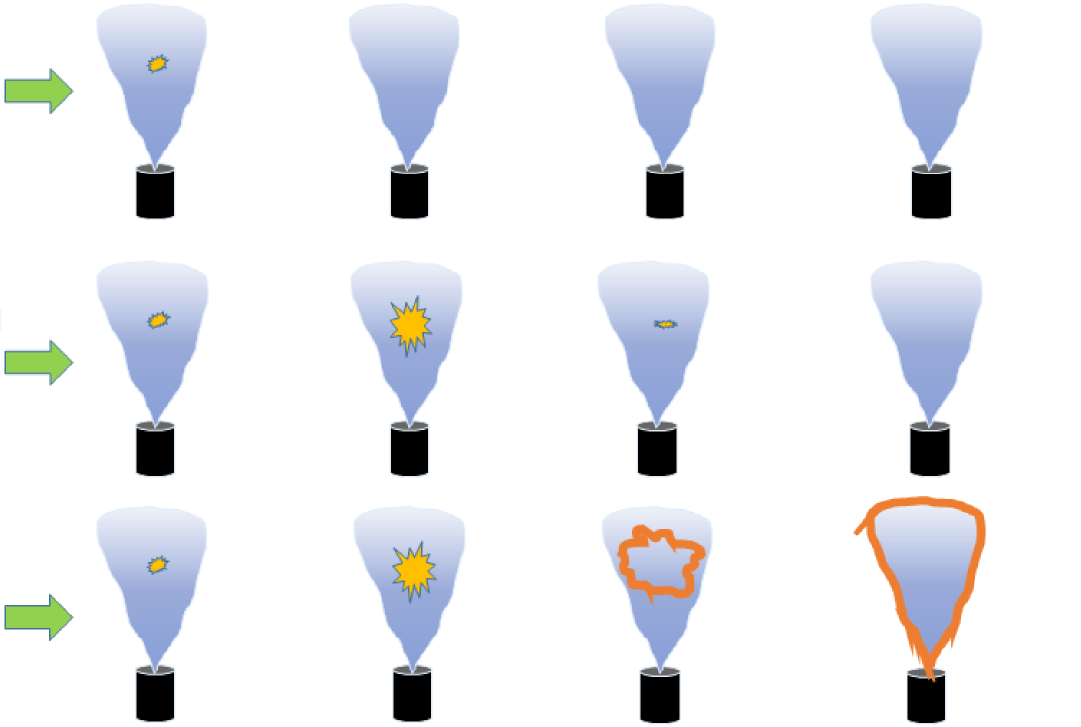
Possible events when a flammable jet encounters a spark

a) Spark | b) Ignition | c) Kernel evolution | d) Flame light-up

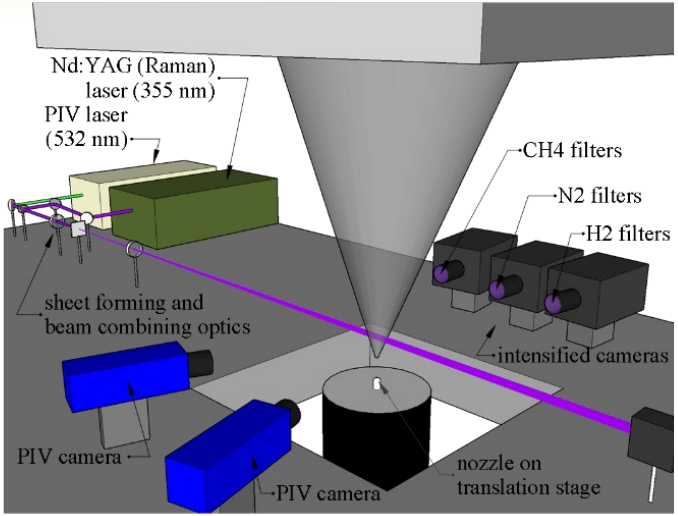
1) No ignition

2) Ignition occurs but doesn’t lead to light-up because of kernel extinction

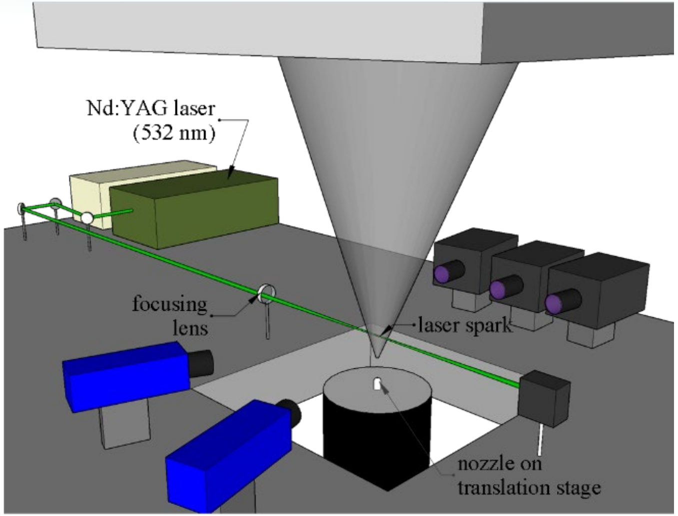
3) Kernel growth leads to flame light-up



Experimental setup for concentration measurements and ignition studies



i) Planar Raman Scattering Setup



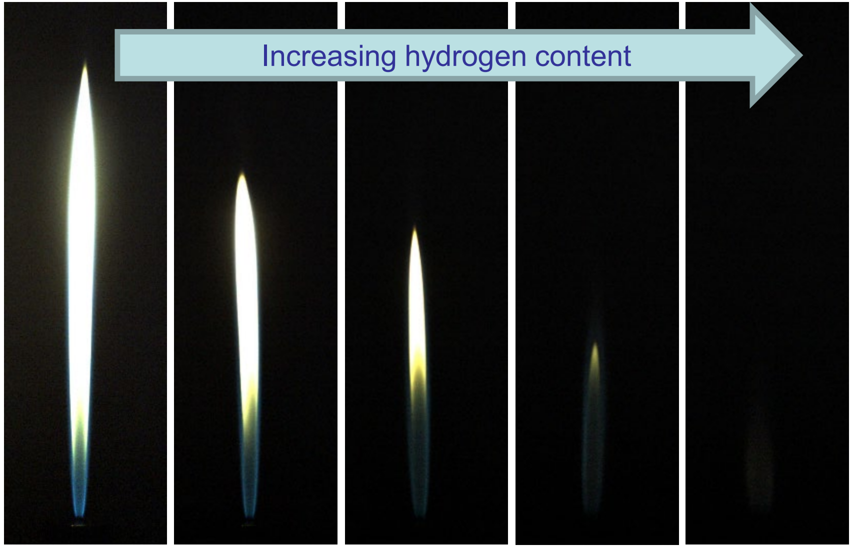
ii) Ignition Setup

Repetition rate: 10 Hz
Laser sheet height: 30 mm
Orifice diameter: 1 mm

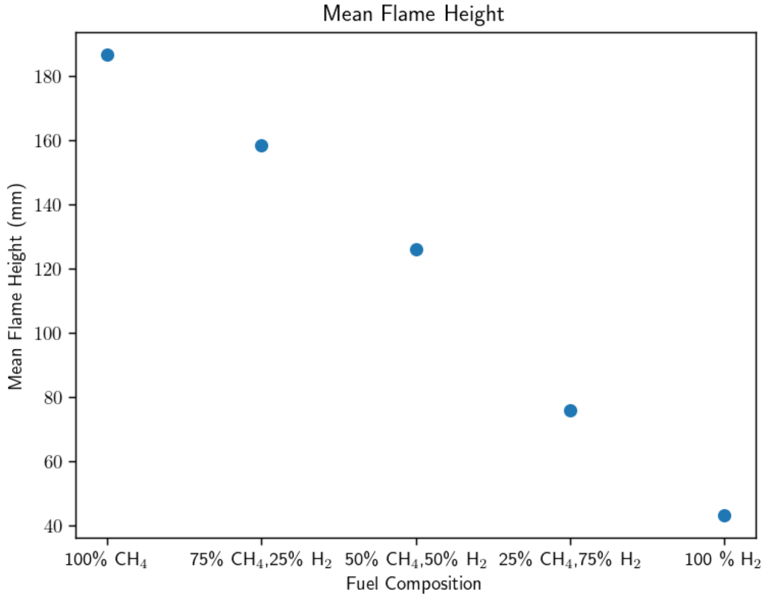
Repetition rate: 10 Hz
Focusing lens: f = 50 mm

Flame height measurements

- Jet flame height is an important parameter for safety, and is related to the convective and radiative output.
- With increase in hydrogen content, there is a monotonic, nearly linear reduction in the flame height.

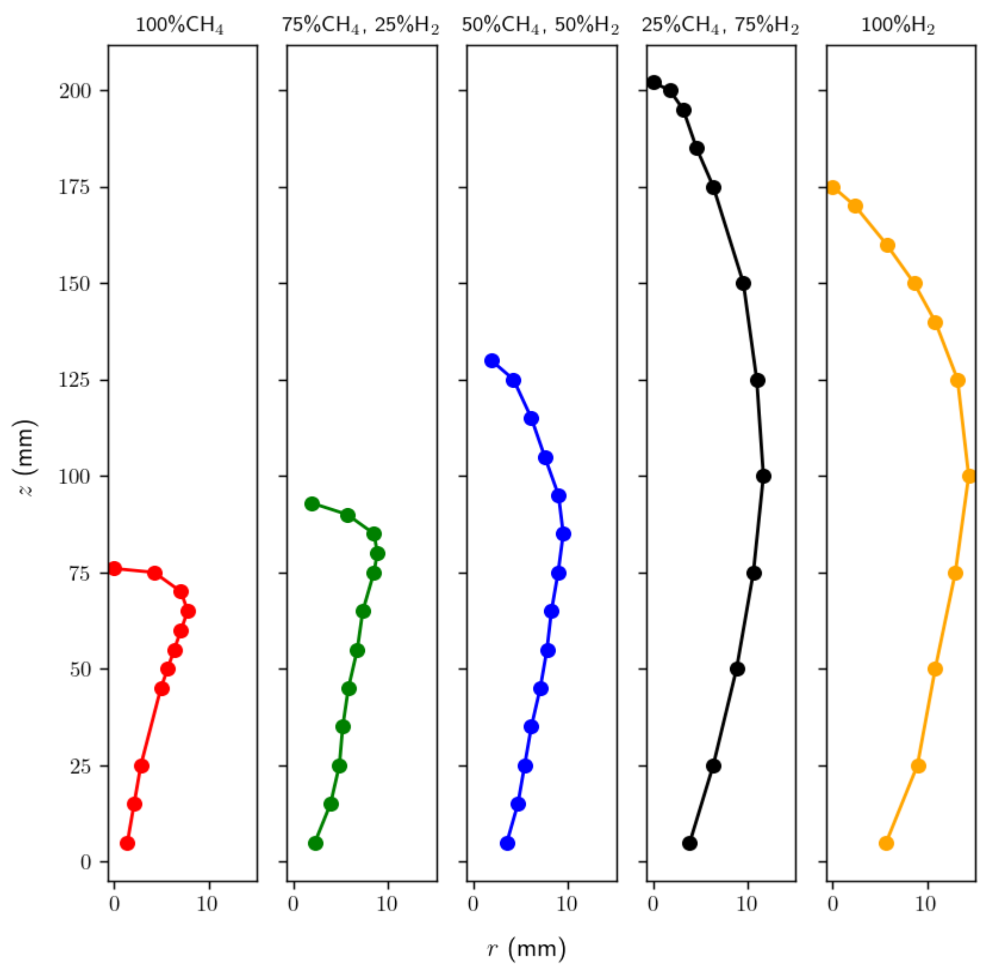


100% CH_4 | 75% CH_4 25% H_2 | 75% CH_4 25% H_2 | 75% CH_4 75% H_2 | 100% H_2



Light-up boundary

- Light-up boundary is a spatial location that separates flame light-up and flame extinction zones.
- Light-up boundary is determined by translating the setup in radial direction for a given axial position.
- Radial and axial dimensions of the light-up boundary increase with the percentage of hydrogen in the blend.
- Pure H_2 being an exception regarding the maximum jet height.

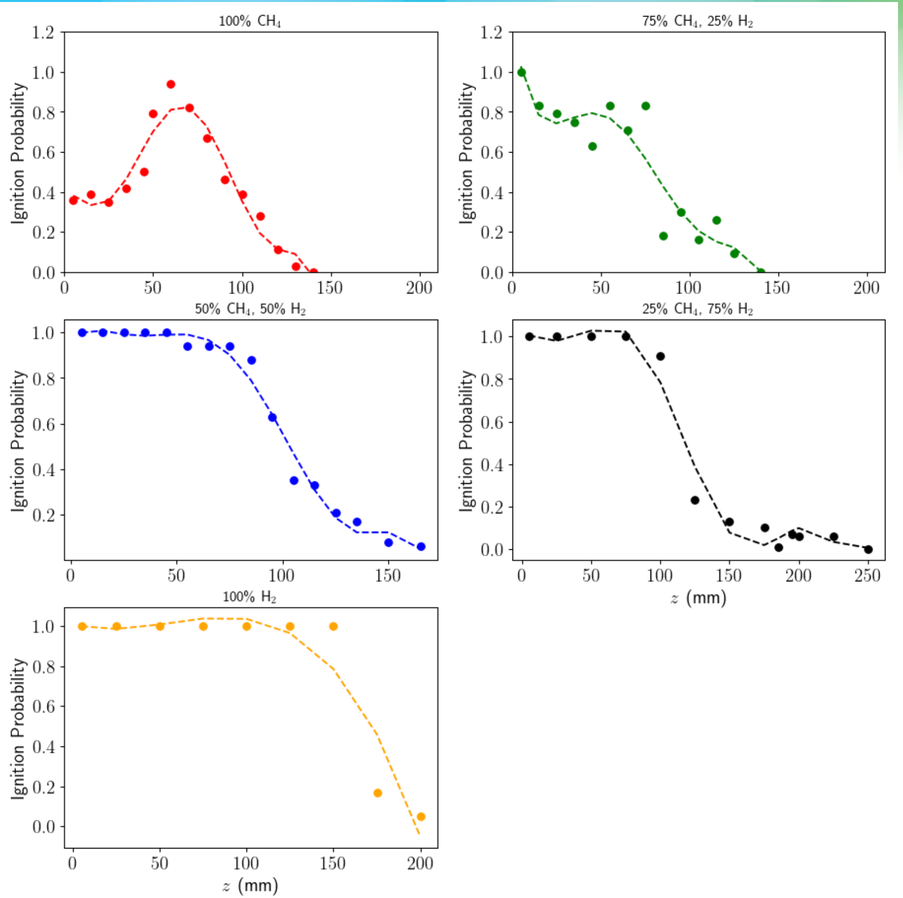


Ignition Probability

- Ignition probability determines the possibility of forming an ignition kernel when a combustible mixture encounters a spark.

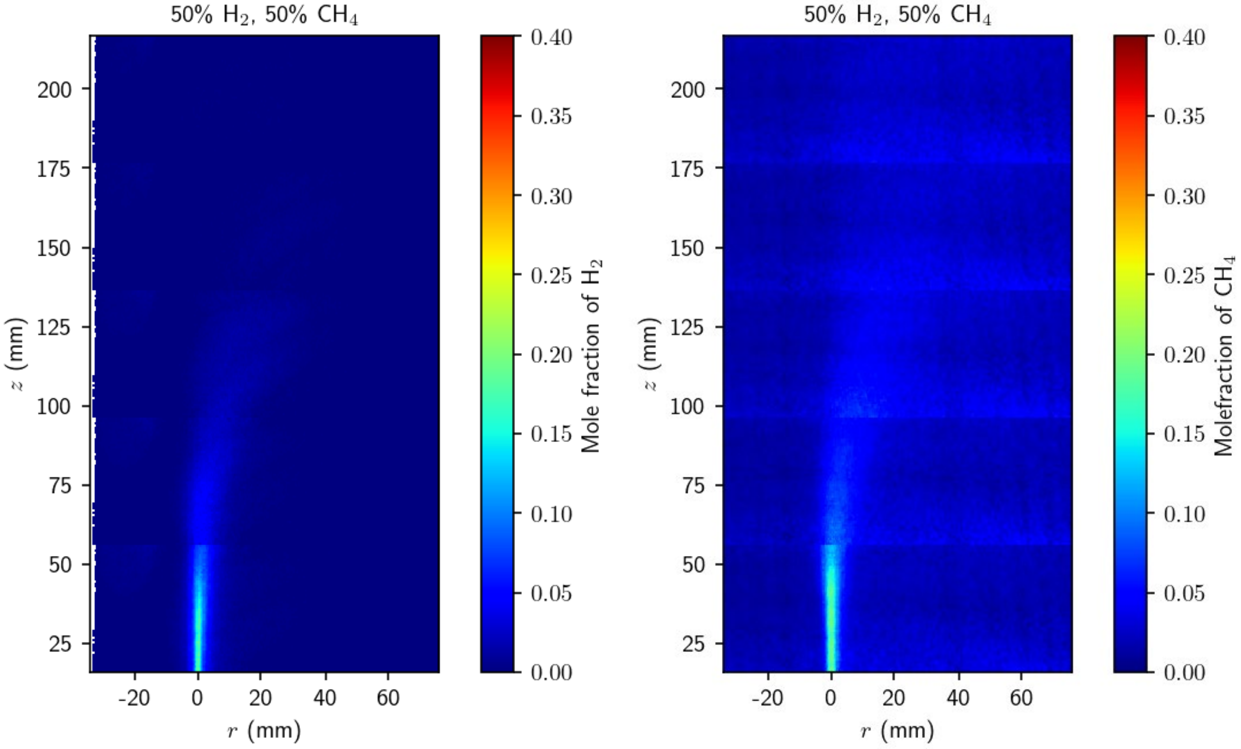
- **Near the orifice exit,**

- Pure hydrogen and the blends with a hydrogen mole fraction ≥ 50% have an ignition probability of 100%.
- Methane has a lower probability (around 40 %) due to insufficient mixing and the much lower upper flammability limit compared to H_2.
- Once sufficient mixing has occurred, the ignition probability of methane increases up to 94 % (at z = 60 mm).

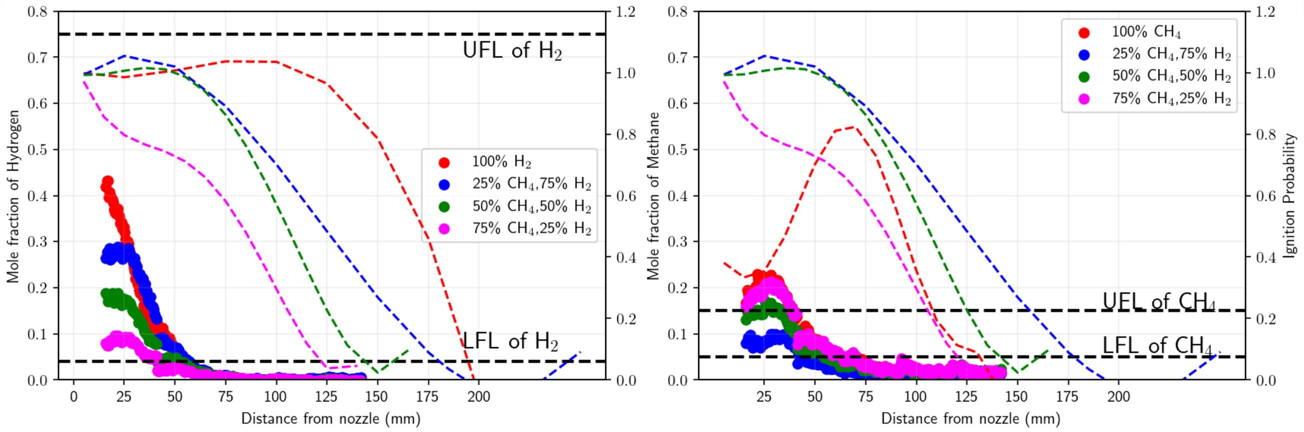


Mole fraction fields

- For good SNR, laser sheet size is kept at 30 mm
- Measurement starts from z=16 mm and extends up to z= 210 mm.
- 400 images are obtained at 10 Hz.
- Spurious air currents may have caused some tilting to the right.



Centerline mole-fractions of hydrogen and methane for different blends

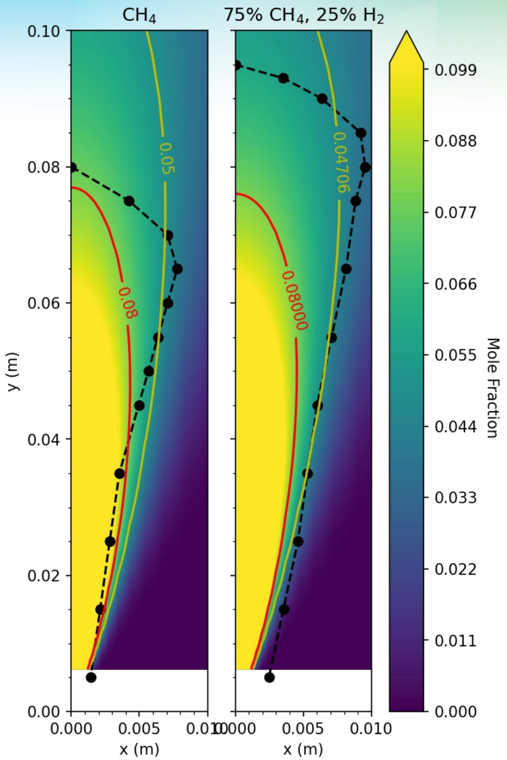


- Concentration gradient is maximum in the near vicinity of the orifice.
- Species mole fractions decrease rapidly along the axis and asymptotically approach zero
- Ignition probabilities are non-zero even in the region below the lower flammability limits.
- Turbulent fluctuations brings pockets of flammable mixtures well downstream of where the average concentration has dropped below the lower flammability limit.

We have implemented the physics of blended gases into HyRAM+

- Pure fuels (H2, CH_4, C_3H_8) or mixtures, (i.e., real natural gas compositions or natural gas/hydrogen blends) can be simulated
- Laboratory data to be used for validation
- Ignition information can be mapped onto dispersion profiles
- Trying to develop ignition map based on velocity and concentration information

```
CH4 = phys.Fluid('CH4', P = 101325, T = 298)
blend = phys.Fluid({'CH4':.75, 'H2':.25}, P = 101325, T = 298)
air = phys.Fluid('air', P = 101325, T = 298)
orifice = phys.Orifice(.001)
jet_CH4 = phys.Jet(CH4, orifice, air, theta0 = np.pi/2, mdot = 0.75*constants.liter/constants.minute*CH4.rho)
jet_blend = phys.Jet(blend, orifice, air, theta0 = np.pi/2, mdot = 0.75*constants.liter/constants.minute*blend.rho)
```



Measured ignition boundaries (black) mapped onto calculated dispersion profiles for pure methane and methane/hydrogen blend

Conclusions

- Mean flame height is inversely proportional to the concentration of hydrogen in the mixture.
- Radial and axial extend of light-up boundary increases with the percentage of H_2 in the blend.
- Ignition probability increases with an increase in hydrogen concentration.
- For 100% H_2 and those blends with 50 % or more hydrogen, the ignition probability is 100% near the nozzle while pure methane showed a lower value (approximately 40%).
- Concentration profiles exhibit a hyperbolically decaying trend and asymptotically approach zero.

QUESTIONS?

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