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The effect of droplets in an acetone-methane flame

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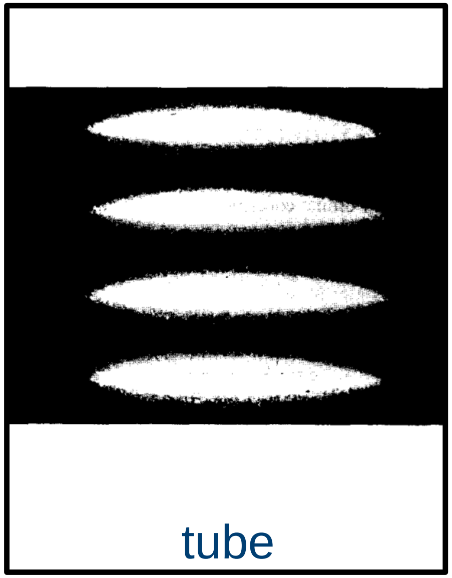
Introduction: motivation and previous studies

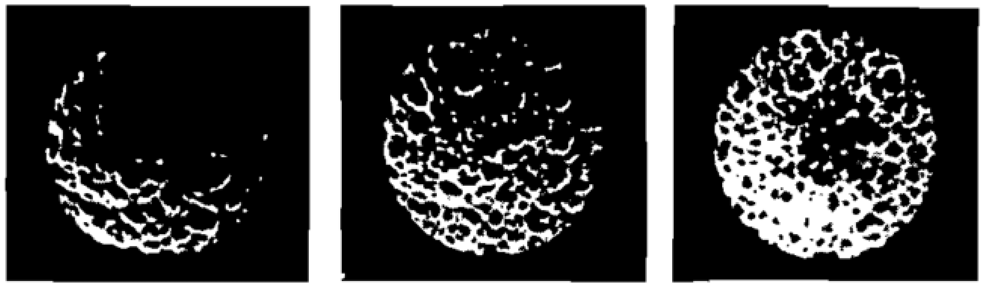
- Spray combustion involves mixture of gaseous and liquid fuels
- There are almost no controlled experiments on laminar gas + droplet combustion

Previous efforts: flame speed measurements for droplet-laden mixtures:



(Ballal and Lefebvre, *PCI,* 1981)

Combustion chamber



(Hayashi *et al*, *CST*, 1977)

Disadvantages:

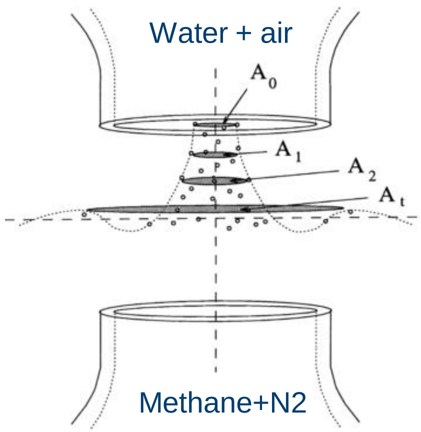
- Transient phenomenon, laser diagnostics cannot be applied
- Influence of gravity

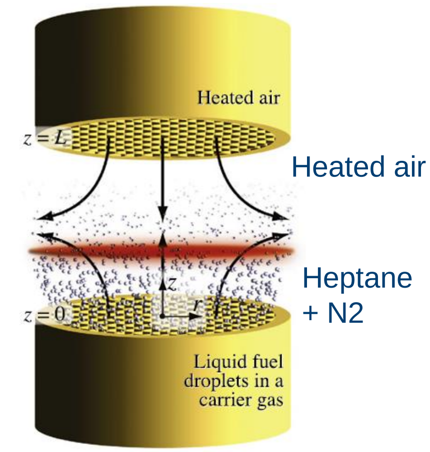
Counterflow configuration and numerical models

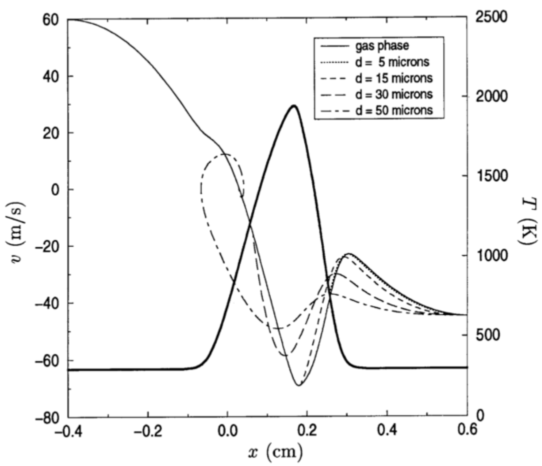
Counterflow configuration:

- Steady state
- Model for droplet-laden flame has been produced
- Gravitational effect and slip velocity are taken into consideration by the model
- Detailed chemistry added to the model

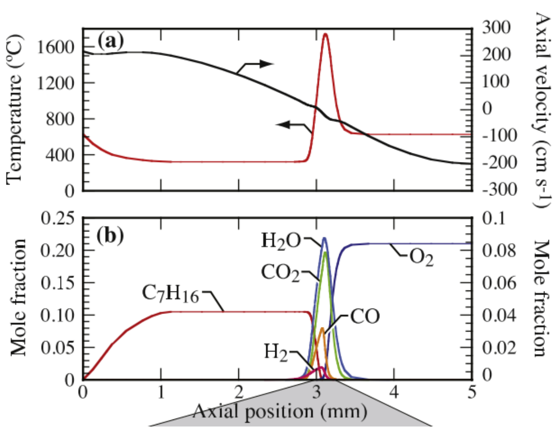
There are very few experimental data !







(Lentati & Chelliah, *CNF,* 1998)

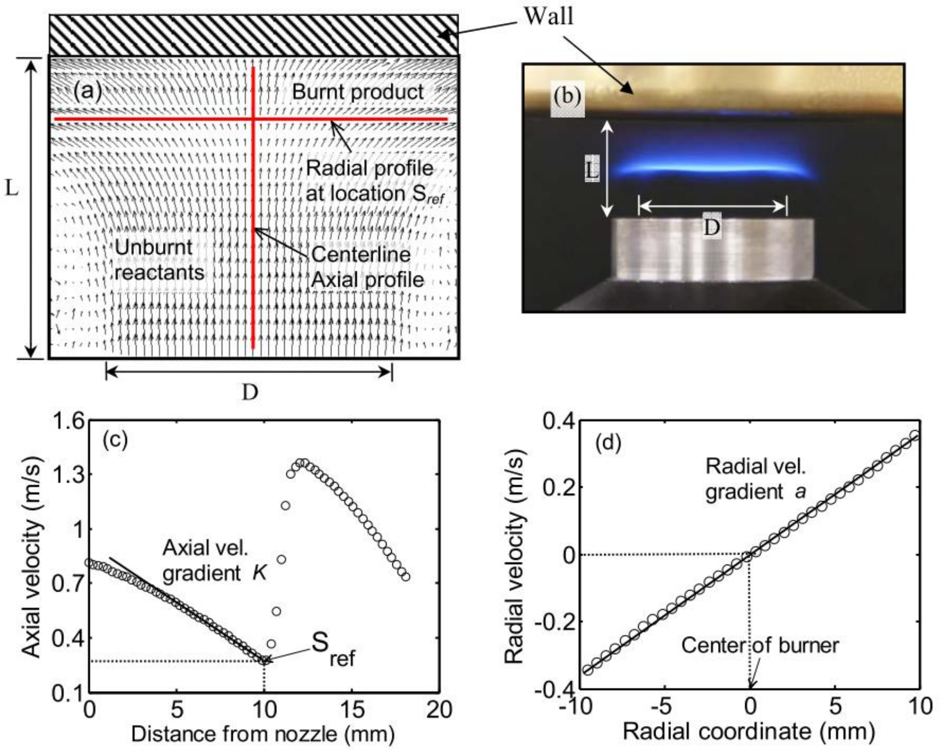


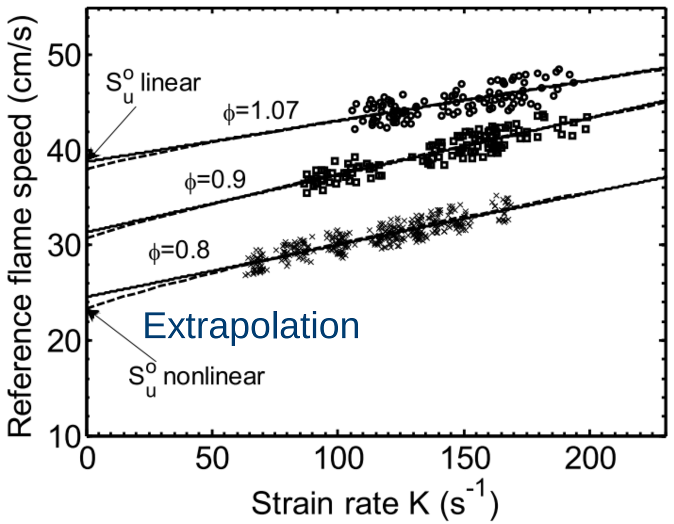
(Kee *et al*, *CNF,* 2011)

Previous work: a gaseous acetone-methane flame

- Droplet-laden flame cannot be sustained under atmospheric conditions. A dual-fuel system is considered.

- Previous work: Acetone(gas)-methane flame speed measurement on a stagnation burner.





(Chong *et al, CNF, 2011*)

Acetone-methane flame with droplets

Use previous gas phase result as the reference case

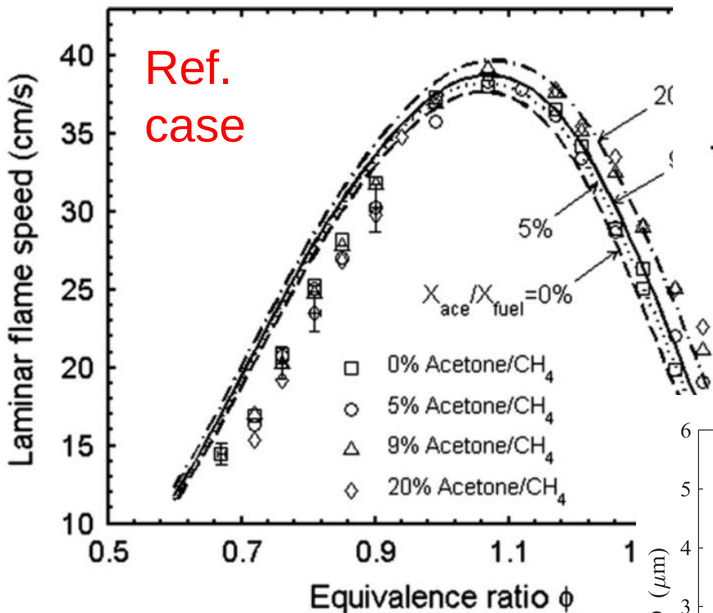
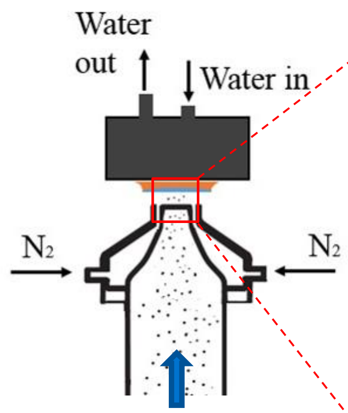
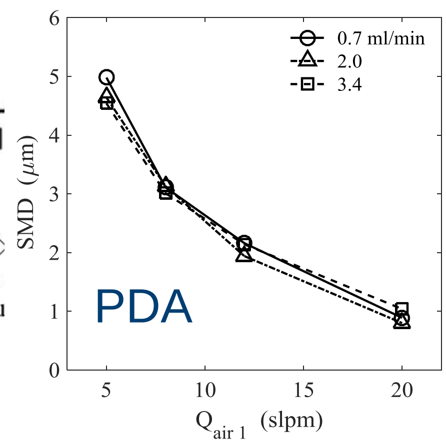


Fig. 6. Laminar flame speed for (□) 0%, (○) 5%, (△) 9% and (◇ methane/air mixture at 298 K and 1 atm. Lines are simulation (······) 5%, (—) 9% and (–·–·) 20% acetone /methane/air mixture u

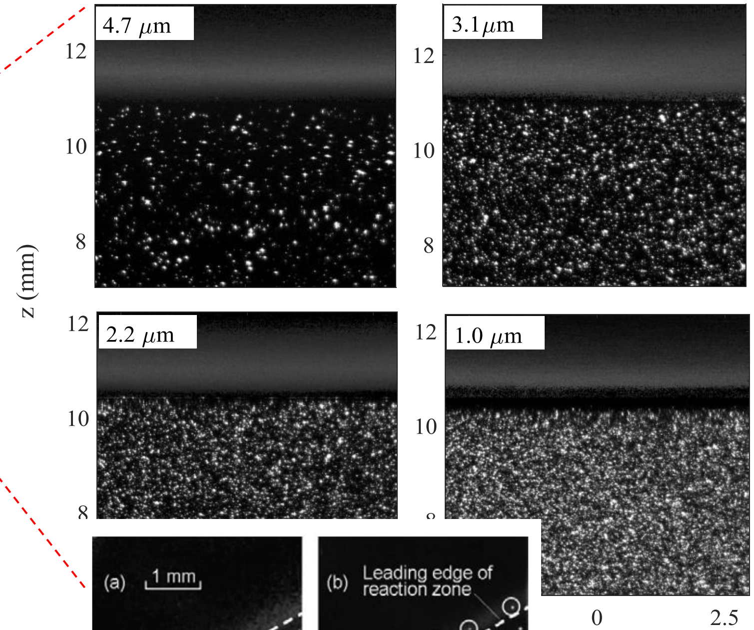
(Chong *et al, CNF, 2011*)

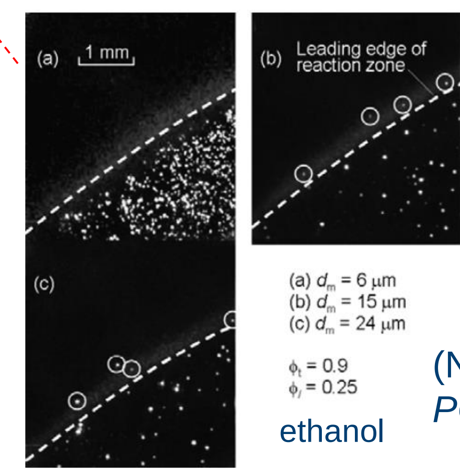


Methane/air + acetone (droplets)



PDA





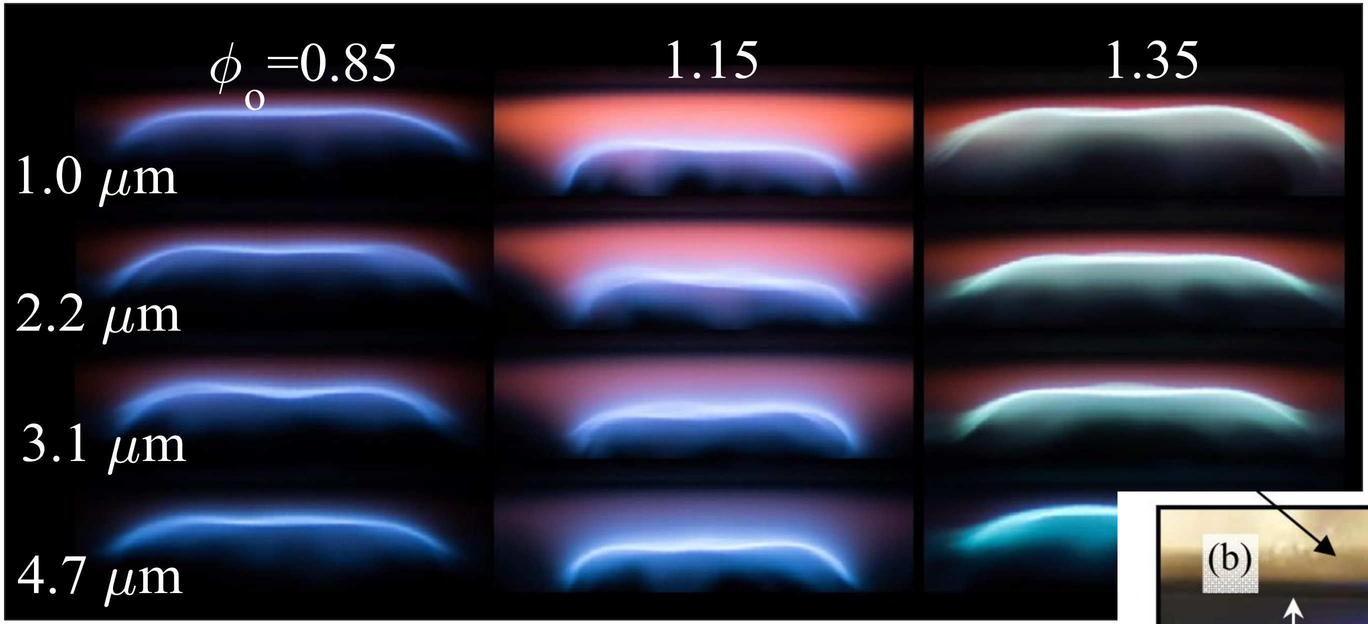
(a) d_m = 6 μm
(b) d_m = 15 μm
(c) d_m = 24 μm

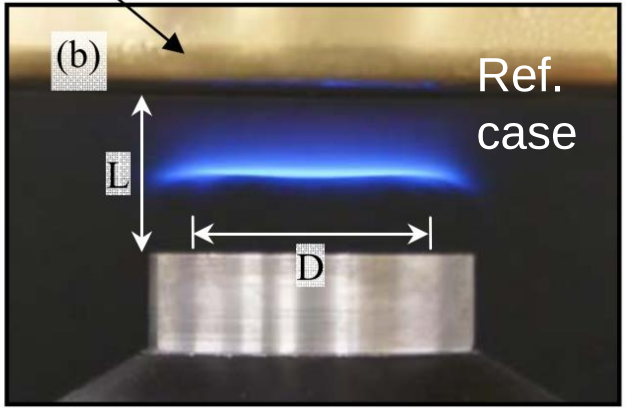
ϕ_t = 0.9
ϕ_l = 0.25

ethanol

(Nomura *et al, PCI, 2007*)

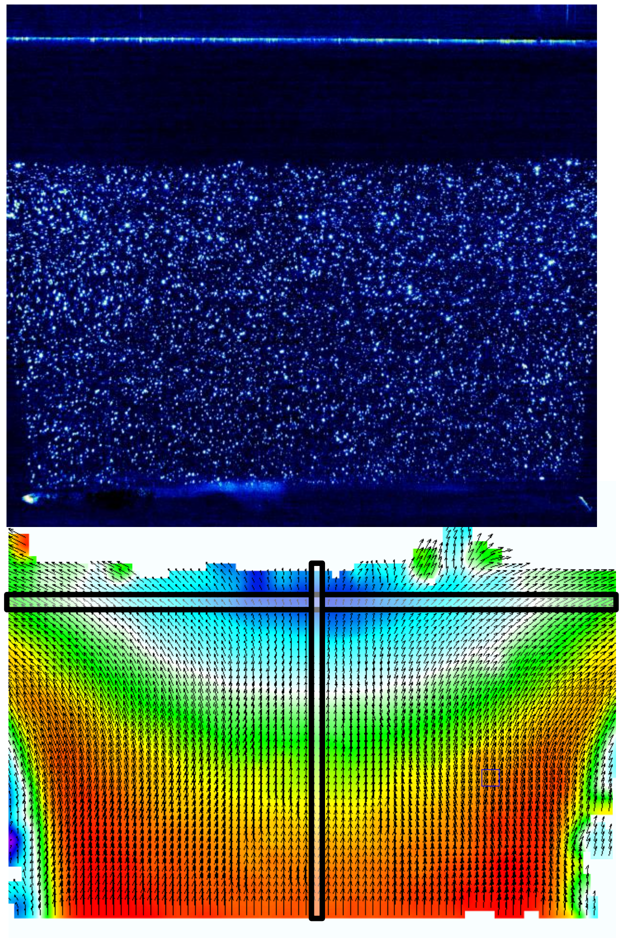
Flame appearance: double layer structure

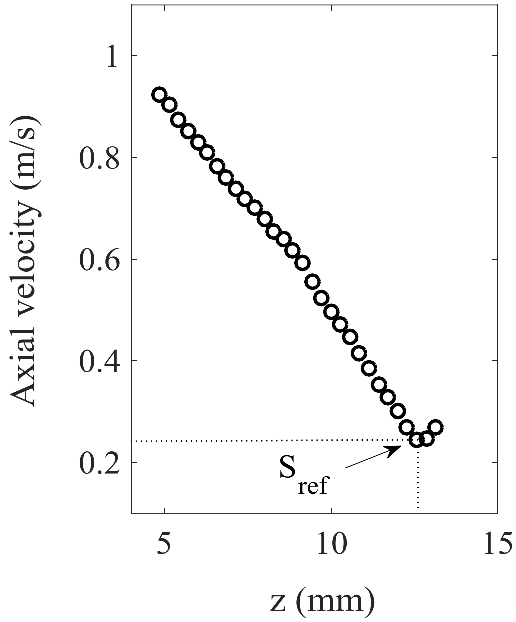


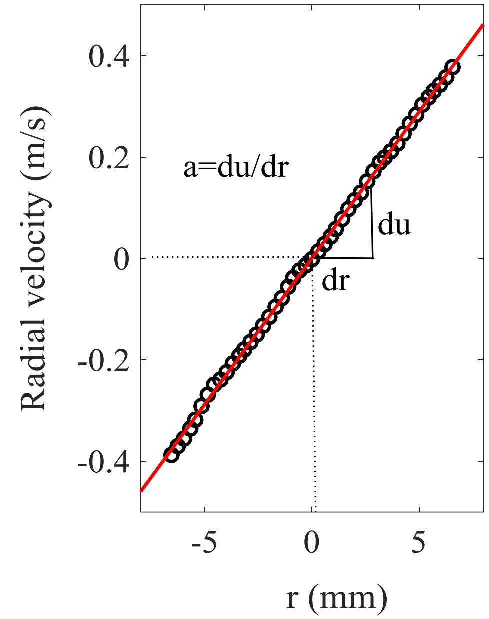


- Orange post-flame zone: probably soot or C_2^* swan-bands
- Local mixture fraction gradient due to vaporization
- Further investigation by LII and LIF needed

Methodology: Reference flame speed and strain rate



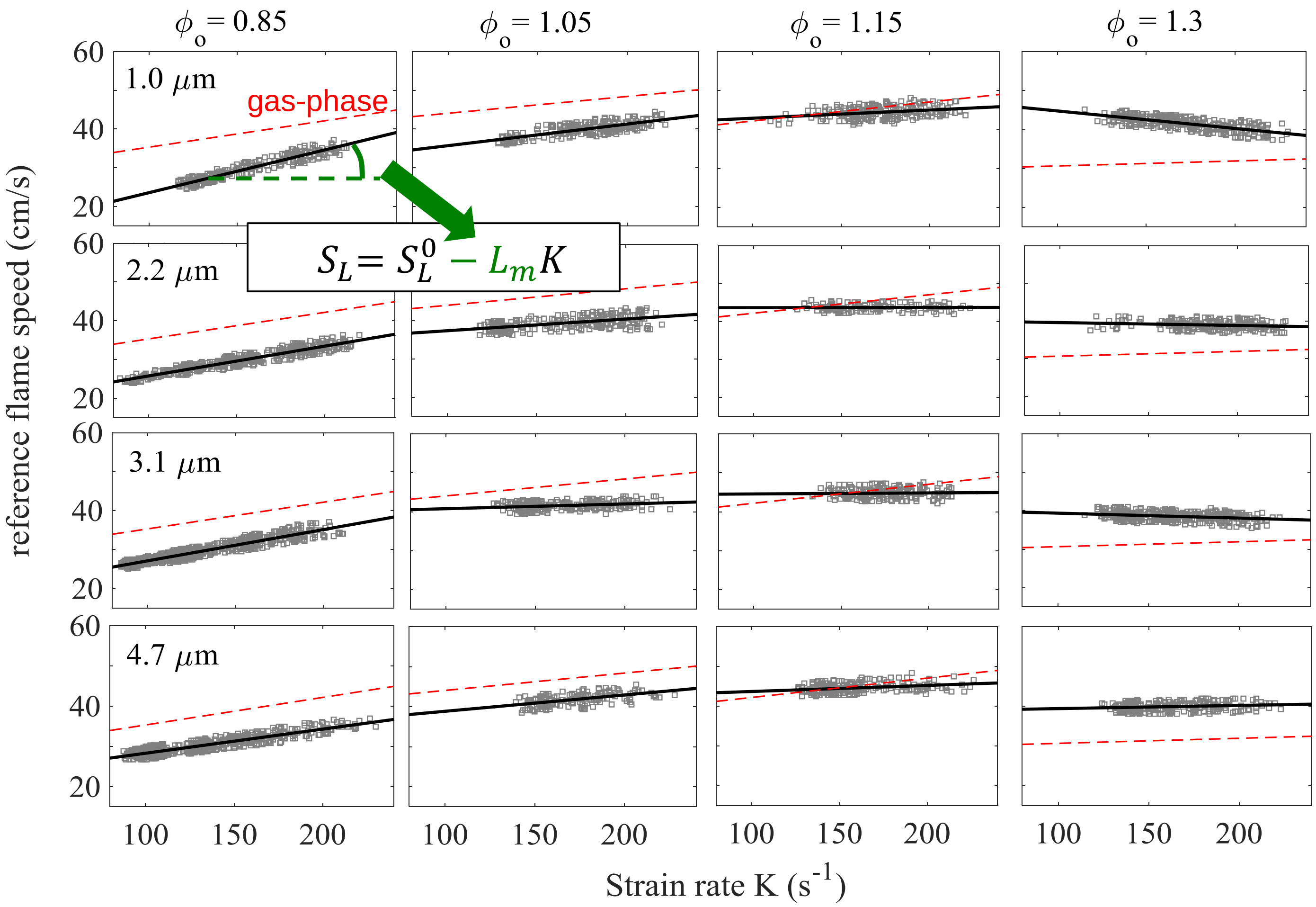




Strain rate $K=2a$

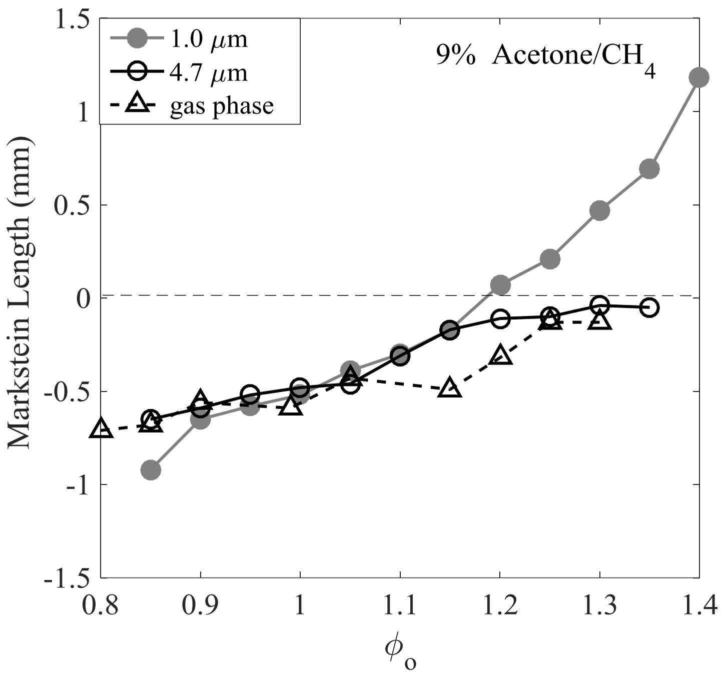
Flame speed results: 9% acetone

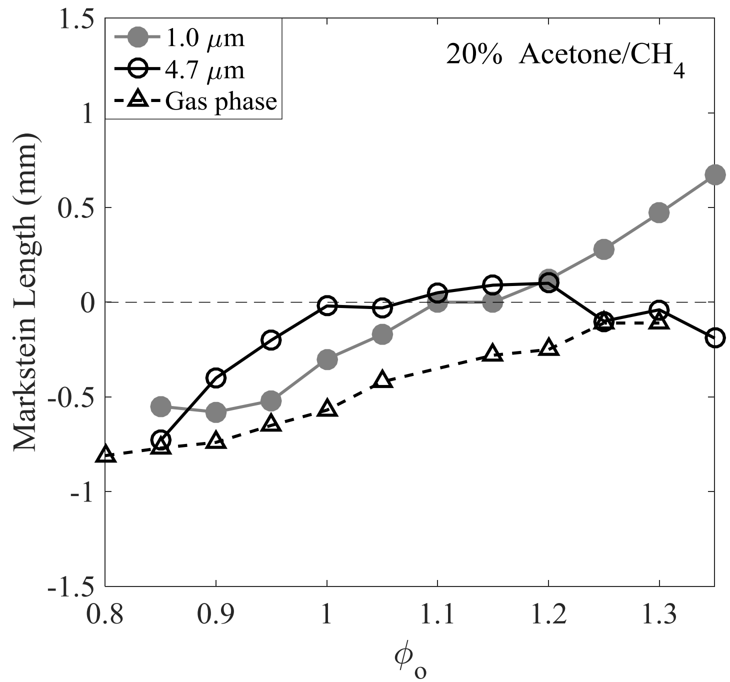
- Negative gradient for rich cases. Similar trend for 20% acetone
- Usually seen in the case of water droplets or other flame suppressants.
- Suppressing of fine droplets: heat sink effect. All liquid fuel evaporate in the preheated zone.
- Large droplets penetrate the flame front and experience longer vaporization time.



Markstein length: slope of flame speed with strain

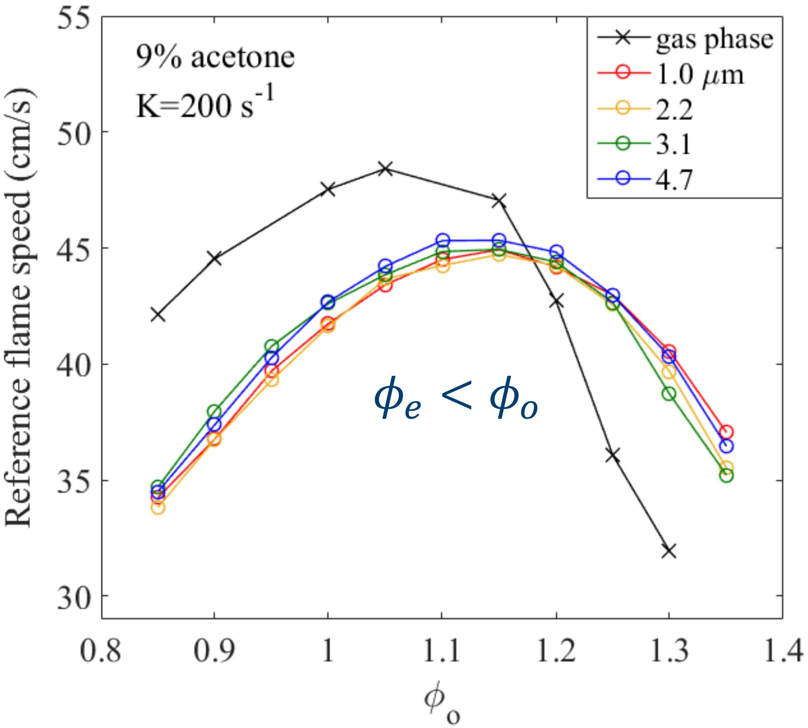
Markstein length L_m: $S_L = S_L^0 - L_m K$

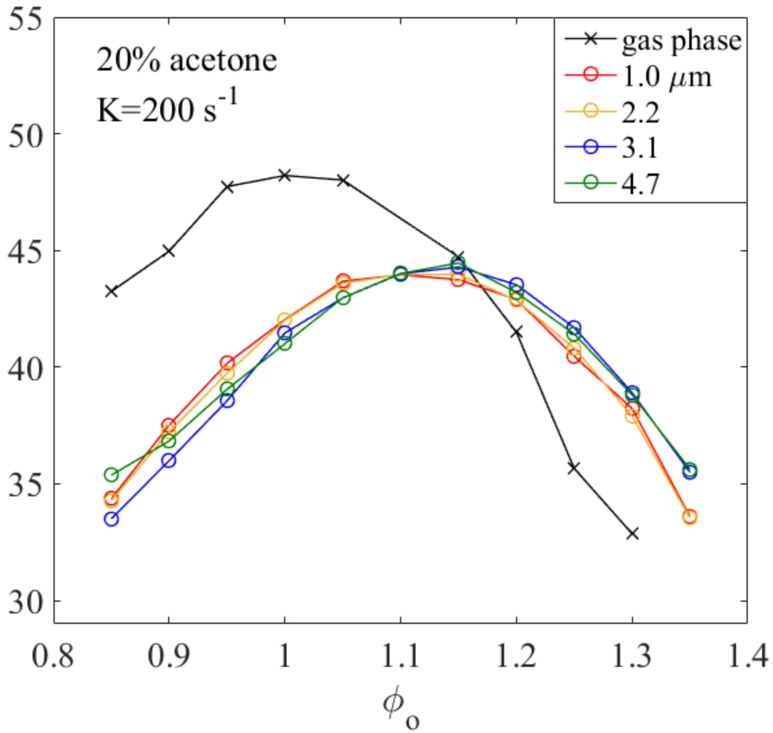




Flame speed at 200 s^{-1}

- Flame speed curve shift to the rich side:
  effective equivalence ratio ϕ_e < Overall equivalence ratio ϕ_o
- Increasing fraction of acetone droplets further suppresses the peak flame speed





On-going work

Modelling acetone (droplets)/ methane flame on the stagnation burner using Cosilab

Challenges in the simulation:

- **Fraction of acetone vapor.** Droplet concentration measurement is usually not very accurate by PDA. Uncertainty in estimating the fraction of pre-vaporized acetone needs to be better established.

- **Pre-vaporization.** Vaporization starts far before a droplet enters the simulation domain. An outer-layer of saturated acetone vapor has already formed around the droplet, which prevents further vaporization.

$$B_M = \frac{Y_s - Y_\infty}{1 - Y_s}$$

Conclusions

An acetone-methane flame is stabilized on a stagnation burner to investigate the effect of droplets on the flame propagation speed.

- **Two-layer flame structure** : a thin blue flame front followed by an orange post-flame zone. This may suggest a two-stage reaction: lean premixed flame – vaporization – diffusion flame.
- **Negative slope of reference velocity to strain rates at rich conditions**. This may be attributed to the heat sink effect of fine droplets, which suppresses the flame propagation.
- **Flame speed curves shift towards the rich side**, because the effective equivalence ratio at the flame front is lower than the overall equivalence ratio.
- **Increasing fractions of acetone droplet reduce** the peak burning velocity.

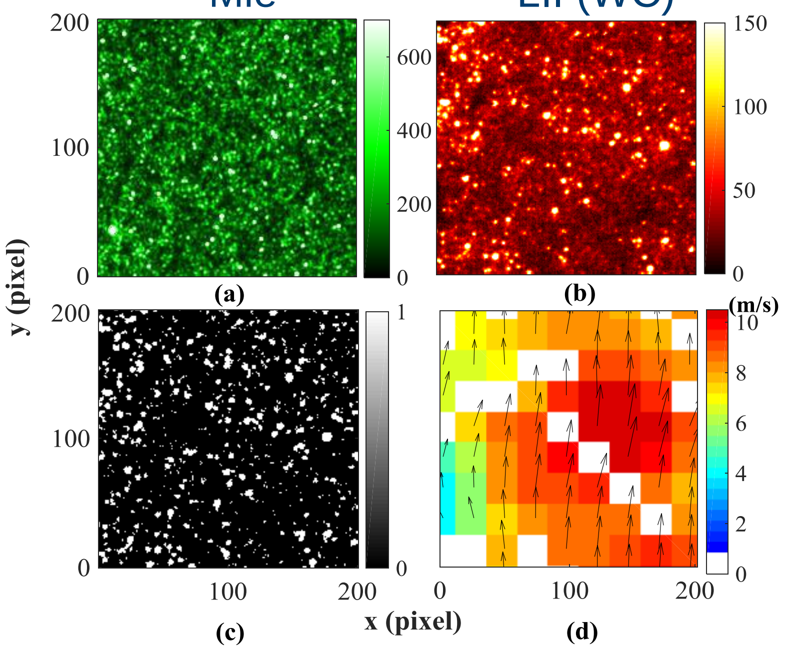
Future work: larger droplets

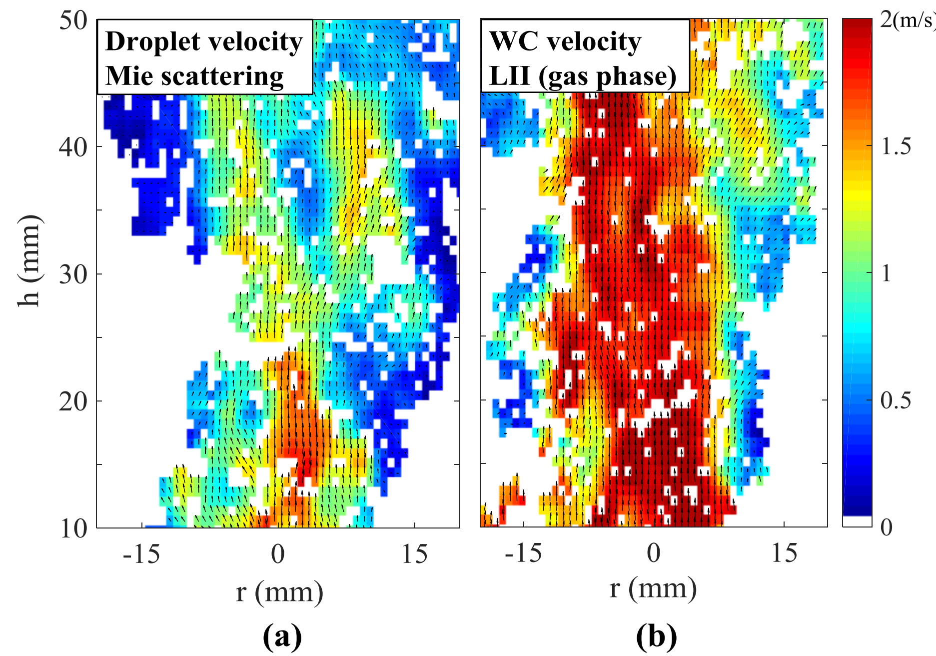
Slip velocity: for a large droplet at tens of micrometres, the stokes number is larger than unity for the investigated velocity range, i.e. large droplets cannot follow the flow, hence cannot be used as PIV tracer.

The **LII-PIV technique** based on WC particles has been developed to resolve the velocity for each phase.

Mie

LII (WC)





(Fan *et al. EiF*, 2018)

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Q&A

Thank you for your attention.