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Investigating fuel staging influence on the stabilization process of a turbulent swirling flame using two-phase flow large eddy simulation

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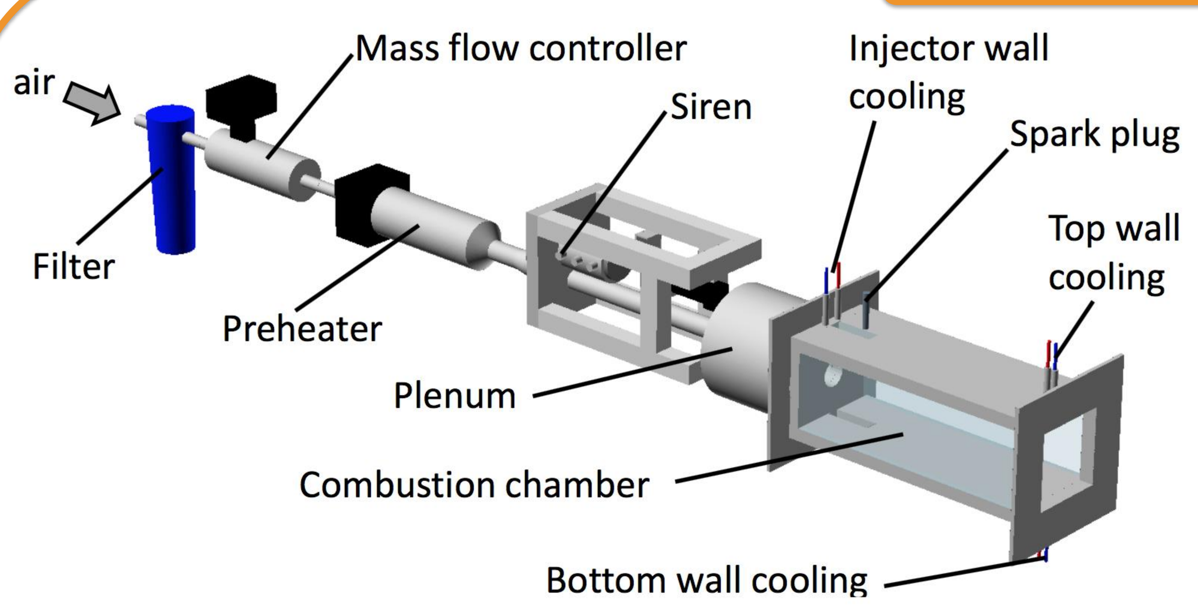
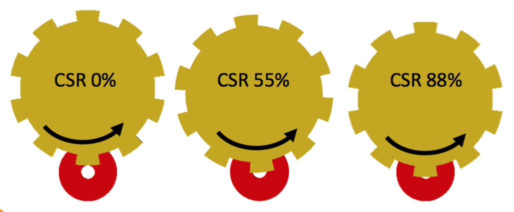
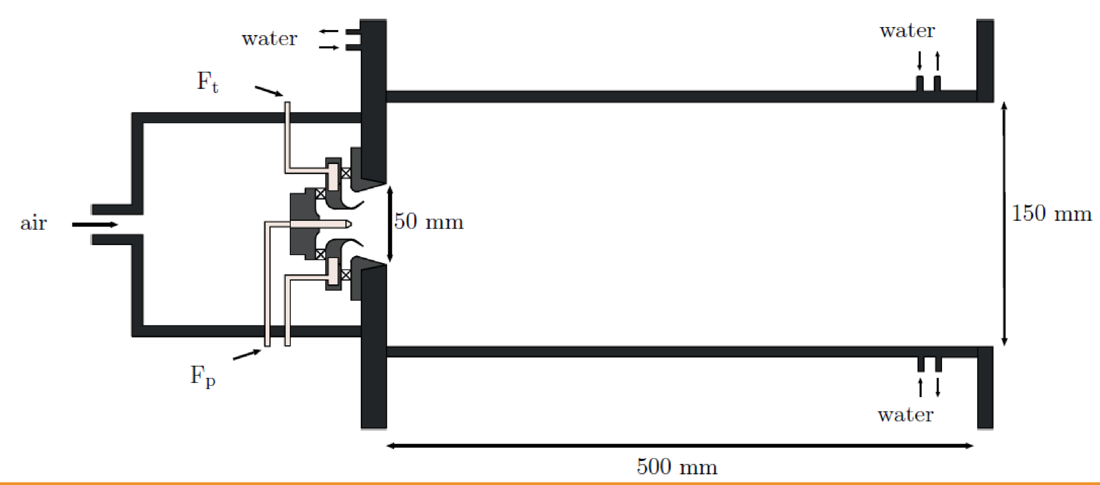
The two stage BIMER combustor[1,2,3]



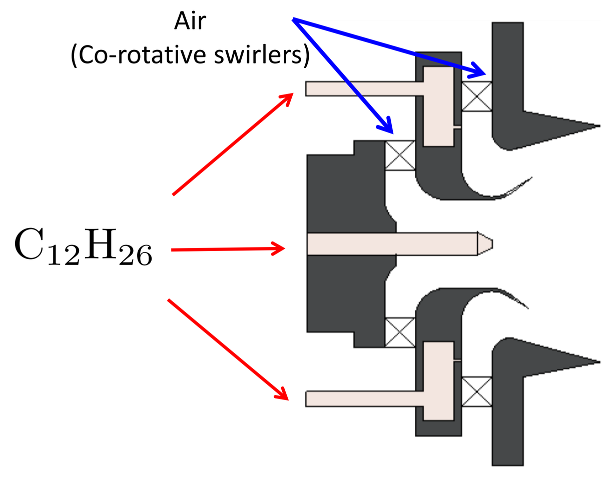


- Siren mechanism used to produce air flow rate modulations
- Flow can be blocked from 0% to 88% by a rotating toothed wheel

- Built to better understand LPP burners
- Two swirling stages with two types of liquid fuel injection:
  - Multipoint: 85% of air mass flow and 10 fuel jets in cross-flow to achieve LPP regime
  - Pilot: 15% of air mass flow and hollow cone fuel spray to stabilize combustion
- High swirl numbers (S≈1)
- **Liquid fuel:** Dodecane ($C_{12}H_{26}$) as kerosene surrogate



Schematic view of the injection device:

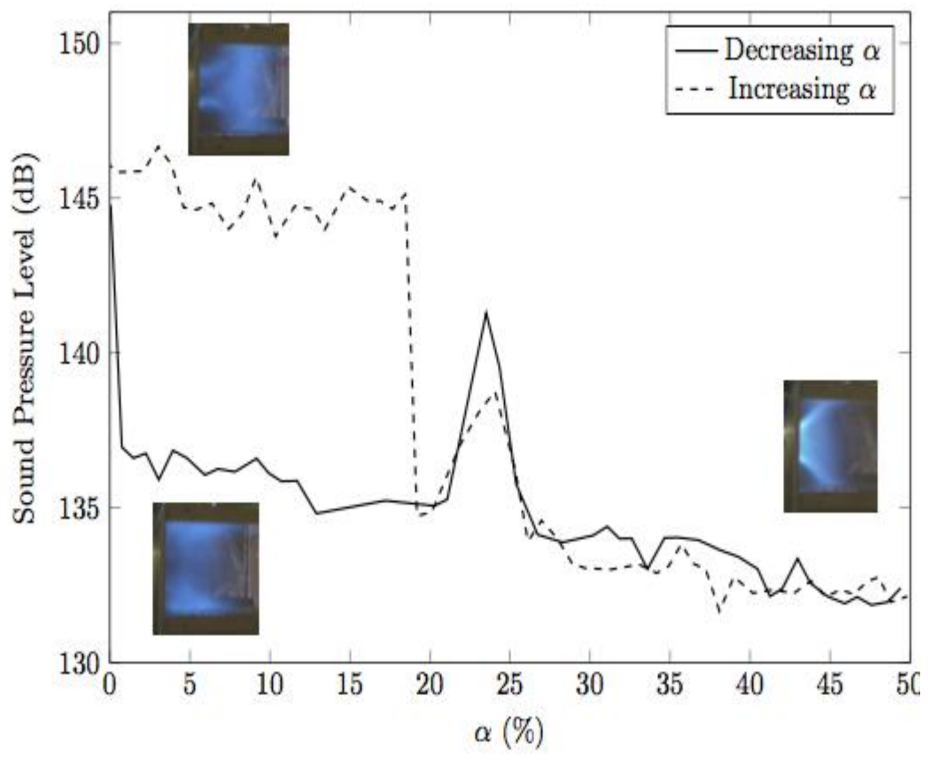


Staging parameter:

$$\alpha = \frac{\text{PILOT INJECTION Fuel mass flow rate}}{\text{TOTAL Fuel mass flow rate}}$$

Most recent experimental data[1,2] and numerical comparisons

- Staging factor α varied from 100% to 0% and back
- Hysteresis cycle below α = 20%
- The flame is stabilized in a V shape throughout all operating points with decreasing α
- However, when pilot injection is ceased, the flame detaches and stabilizes in a M lifted shape
- This flame transition can also be forced by the operation of the siren
- Two operating points were extensively studied:
  - **α = 15%:** two states, sV or Lifted
  - **α = 100%:** V flame



Experimental data available:

Air: m_{air} = 43.1g/s, T=433K
Fuel: m_{fuel} =1.64 g/s, T=300K

- **α = 15% (non-reacting and reacting)**
  - Mie-scattering spray
  - PIV (velocity)
  - PDA (SMD, size distribution, velocity)
  - CH* chemiluminescence (Abel)
- **α = 20% (reacting)**
  - Mie-scattering spray
  - PIV (velocity)
  - PDA (SMD, size distribution, velocity)
  - CH* chemiluminescence (Abel)

Air: m_{air} = 32.3g/s, T=473K
Fuel: m_{fuel} =1.02 g/s, T=300K

- **α = 100% (non-reacting and reacting)**
  - Mie-scattering spray
  - PIV (velocity)
  - PDA (SMD, size distribution, velocity)
  - CH* chemiluminescence (Abel)

AVBP LES compressible solver[4,5,6]

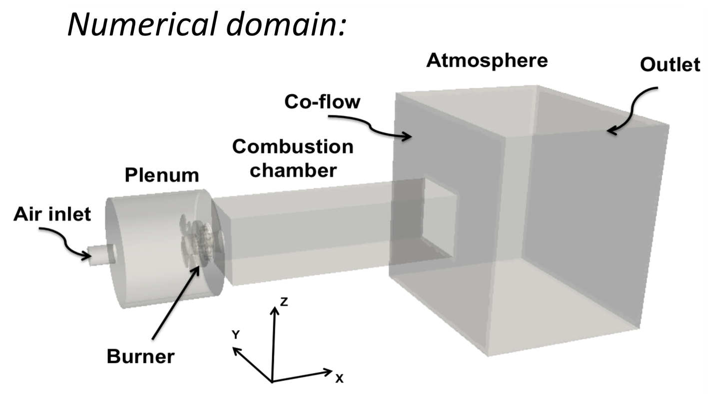
Modeling

- WALE for subgrid scale modeling
- Polydisperse Lagrangian modeling for the liquid phase
- BFER two-step chemistry model
- DTF-LES combustion model

Numerics & boundary conditions

- 26 M tetrahedra mesh
- TTGC scheme for both gas and liquid phases
- Pilot injection: FIMUR injection model
- Multipoint injection: imposed mass flow rate
- NSCBC boundary conditions for inlets and outlets

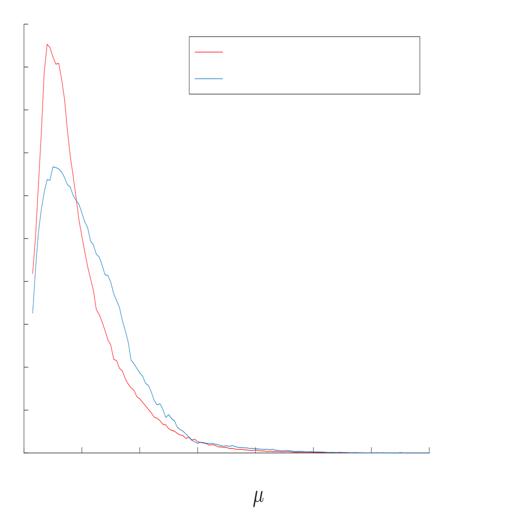
Numerical domain:



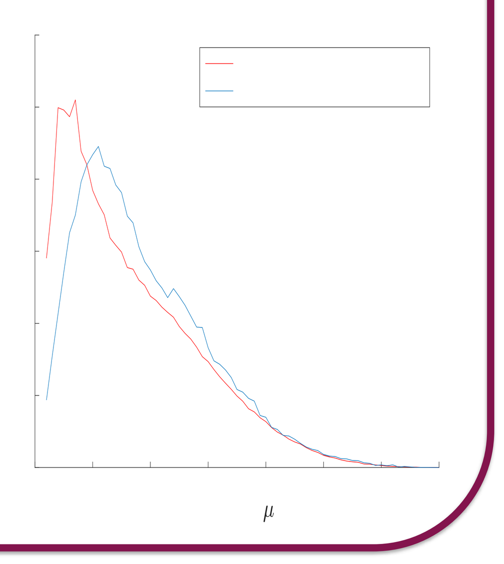
Polydisperse Lagrangian modeling for the liquid phase

- Non-reacting data used
- For the pilot injector distribution
  - Experimental PDF available
- For the multipoint distribution
  - Only mixed injection point α = 15% available
  - Pilot injector PDF is known and considered unchanged with regime
  - Multipoint PDF is deduced by subtraction

α = 15%



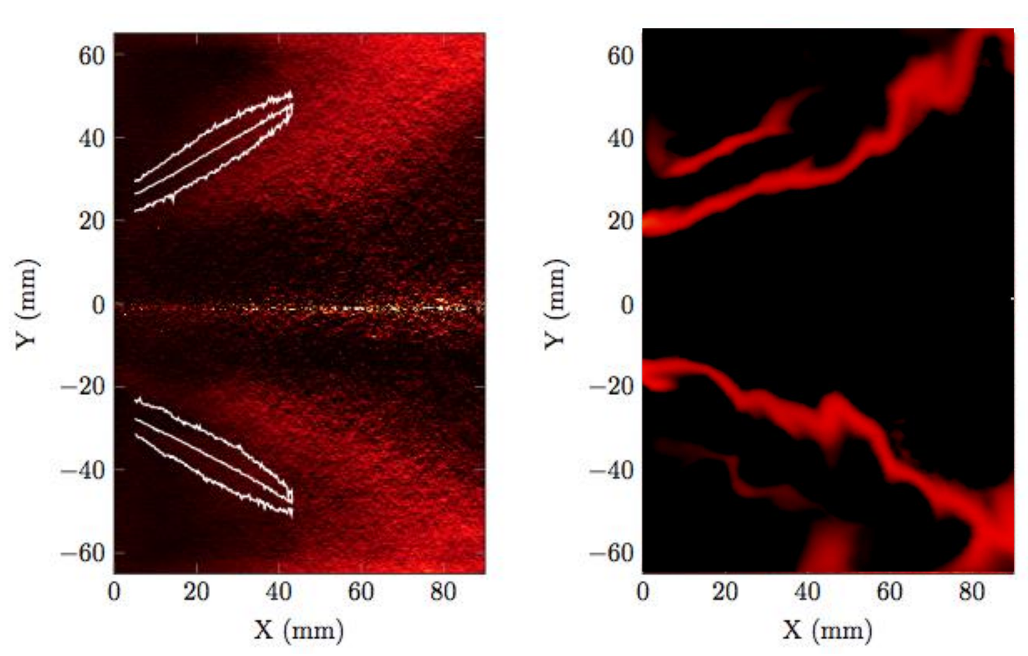
α = 100%



α = 15%

sV flame

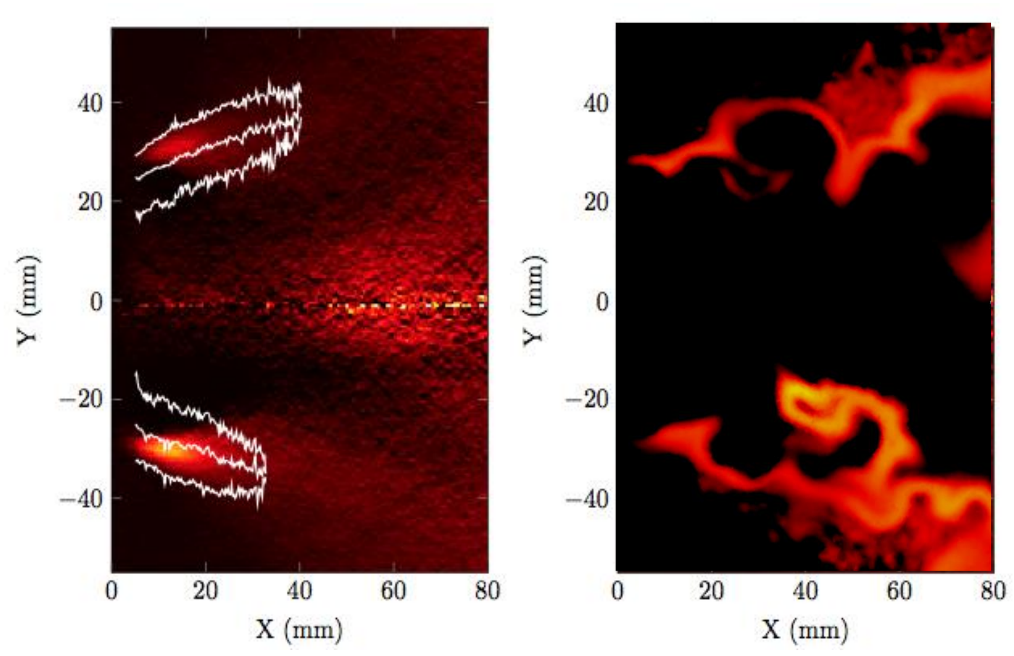
- Mostly in premixed regime
- Pilot flame at injectors exit stabilizes combustion
  - Multi-regime flame



Abel inverted mean CH* chemiluminescence image for the sV flame (left). Heat release for the sV flame (right).

Lifted flame

- Mostly in premixed regime
- Strong combustion instability observed
  - Longitudinal 300hz mode

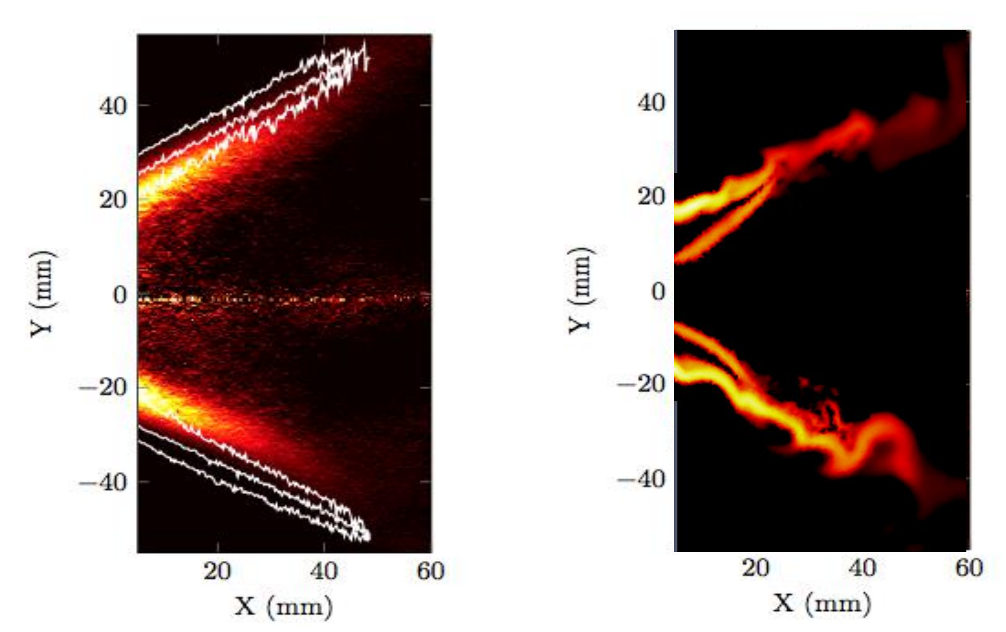


Abel inverted mean CH* chemiluminescence image for the lifted flame (left). Heat release for the lifted flame (right).

α = 100%

V flame

- Strong interaction between spray, flame and recirculation zone
- Two flame zones according to spray penetration or not in the recirculation zone



Abel inverted mean CH* chemiluminescence image for the pilot-only V flame (left). Heat release for the V flame (right).

To summarize

- A laboratory-scale two-stage swirling burner fueled with liquid dodecane has been studied experimentally and numerically using large eddy simulations
  - Using lagrangian polydispersed approach
  - Other studies[7] were done using eulerian monodispersed approach
- Simulations were compared to existing experimental results
- The simulated flames show different shapes and dynamics

Future developments:

- Investigating flame dynamics to determine the physics of the hysteresis phenomenon evidenced in the experiments

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