XII JORNADA DE JÓVENES INVESTIGADORES/AS DEL I3A

Unión Europea
Fondo Social Europeo
"El FSE invierte en tu futuro"

Universidad Zaragoza
1542

Instituto Universitario de Investigación de Ingeniería de Aragón
Universidad Zaragoza

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
AGENCIA ESTATAL DE INVESTIGACIÓN

Evaporation of Suspended Heavy Oil/1-Pentanol Droplets in Flame-like Conditions

T. Poonawala, M. Asrardel, Á. Muelas, J. Ballester*

Laboratory of Fluids Engineering and Energy (LIFEn) - Engineering Research Institute of Aragon (I3A), University of Zaragoza, Spain

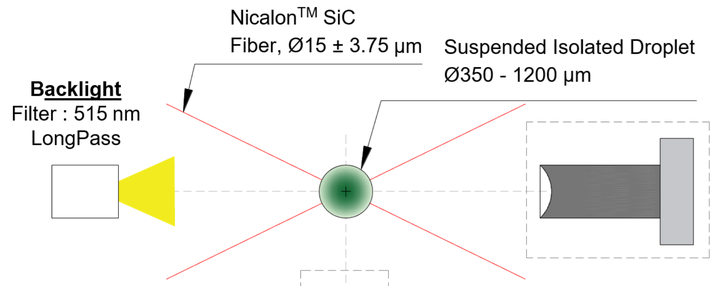
*Email: tpoonawala@unizar.es

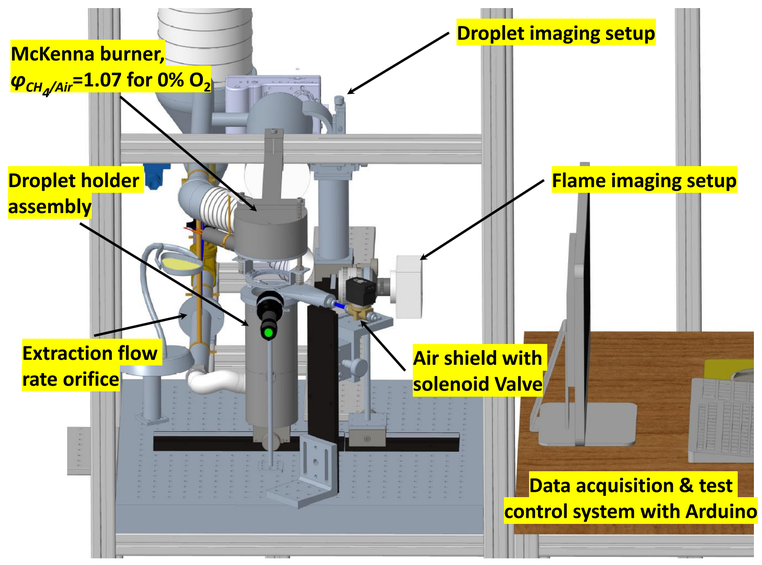
ABSTRACT

- A suspended droplet facility (SDF) is developed to reproduce flame-like conditions for studying evaporation/combustion characteristics of isolated droplets
- Experimental-model validation tests are conducted with 1-pentanol droplets to characterize the repeatability and reliability of this facility
- Evaporation characteristics are obtained for ≈500 µm droplets of HFO/1-pentanol blends with 1-pentanol varying from 0—50% (by wt.) in terms of droplet vaporization curves, micro-explosion intensity and cenosphere size

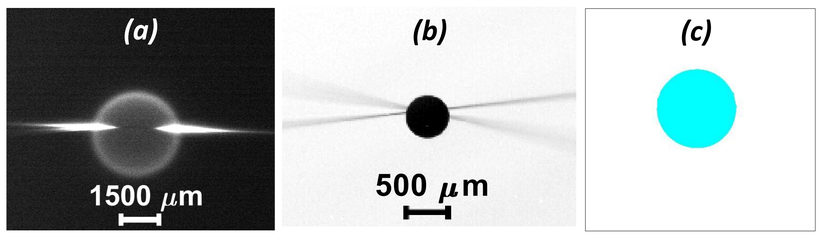
SUSPENDED DROPLET FACILITY (SDF)

- Feasible test droplet size: Φ350 - 1200 µm
- Droplet ambient conditions:
  Cold conditions with Air shield: 325 ± 1 K
  Hot evaporating conditions: **1336 K ± 50 K** at 1 atm with variable $\%O_2$ = 0 - 21% by. vol.
- Minimum effects of natural and forced convection at droplet location, as visible from the spherical envelope of diffusion flame for 1-pentanol droplet at 10% O_2 coflow
- Estimated Reynolds number for a 500 µm droplet is $\mathcal{O}(0.5)$





Schematic and 3D View of SDF



(a) Envelope flame (b) Supended droplet and (c) MATLAB® post-processed image of 1-pentanol at 10% O_2 coflow

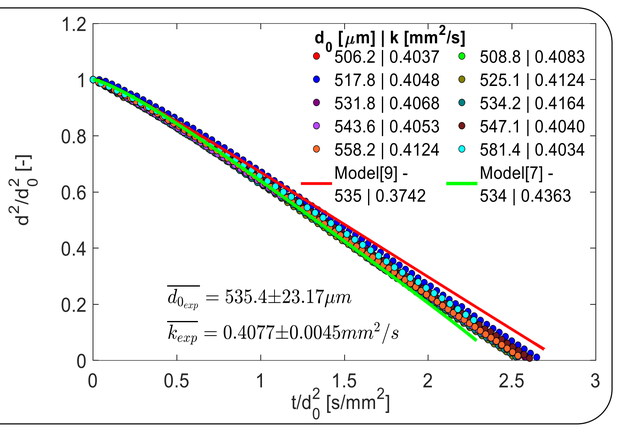
FUELS STUDIED AND DROPLET SIZES

- Five HFO/1-pentanol blends are considered with 10 experimental repetitions in each group
- HFO – representative for difficult-to-burn liquid fuels like residual, pyrolysis, slurry oils, etc.
- 1-pentanol – base volatile fuel for blending to improve evaporation and combustion characteristics

Blend Acronym	HFO *[%wt.]*	1-Pentanol *[%wt.]*	$\overline{d_0}$ *[µm]*	σ_{d_0} *[µm]*	RSD, $\sigma_{d_0}/\overline{d_0}$ *[%]*
HFO100	100	-	515	53	10.29
HFO95-P5	95	5	535	41	7.66
HFO75-P25	75	25	497	32	6.44
HFO50-P50	50	50	523	40	7.65
P100	-	100	535	22	4.11

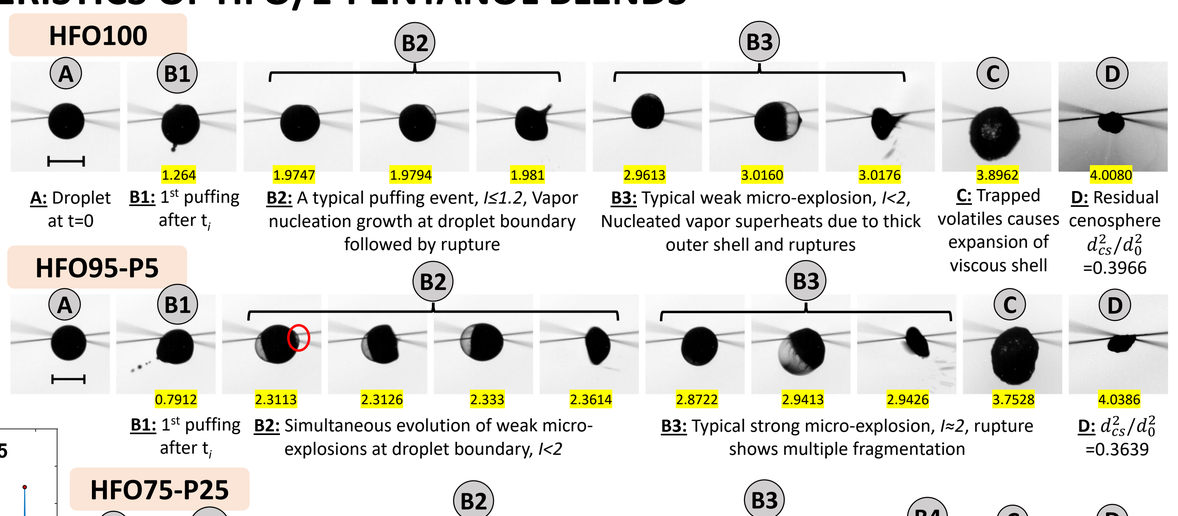
VALIDATION TESTS WITH 1-PENTANOL

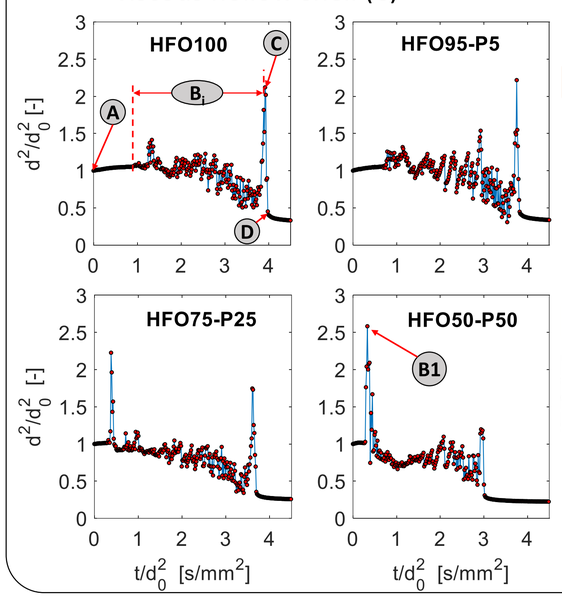
- Experimentally obtained normalized d^2-t curves are compared with:
  [9]: Model based on classical theory of droplet vaporization (ref: Muelas *et. al*, Combust Flame 217 (2020) 38-47)
  [7]: Classical model with radiative heat absorption & fiber heat conduction (ref: Mohamad *et. al*, poster no. 436043, 11th ECM 2023)
- Very low experimental RSD for k = 1.10%
- Quite low deviation in k_{exp} from model predictions, ~10% without any significant departure in the trends



EVAPORATION CHARACTERISTICS OF HFO/1-PENTANOL BLENDS

- As 1-pentanol content increases in the blend:
  i. The violent puffing + strong micro-explosions (B) begins sooner after the initial heat up time (A) and with higher expansion ratios (i.e. d^2/d_0^2)
  ii. Droplet mass loss increases which reduces the size of viscous hollow shell (C)





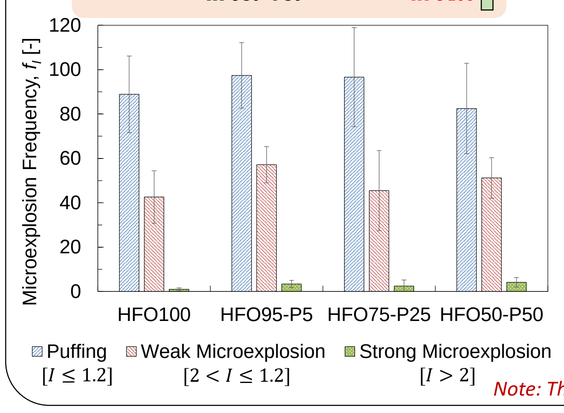
Note:
- *Scale bar refers to 500 µm*
- *Times are normalized as t/d_0^2 [s/mm²] (highlighted in yellow below each image)*

QUANTITATIVE ANALYSIS OF 1-PENTANOL BLENDING ON EVAPORATION OF HFO

Micro-explosion intensity & its classification

- $I = d_e^2/d_v^2$, d_e and d_v are peak and valley droplet size
- Puffing regime peaks at intermediate blend ratios
- No clear trend for weak micro-explosions
- Strong micro-explosions increase with 1-pentanol content

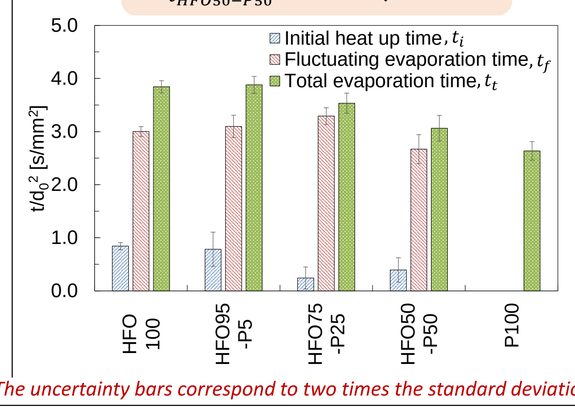
For I > 2, $f_{I_{HFO50-P50}} \approx 4 \times f_{I_{HFO100}}$



Normalized Time Metrics

- t_i – time elapsed for first onset of puffing since test start
- t_t – time where final droplet hollow shell peaks
- $t_f = t_t - t_i$
- t_t monotonically decreases

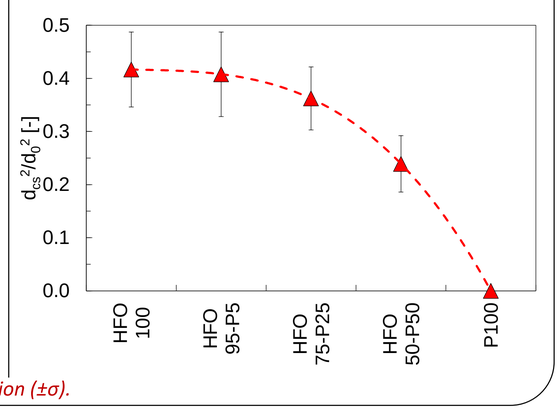
$\Delta t_{t_{HFO75-P25}} = 8.1\%$
$\Delta t_{t_{HFO50-P50}} = 25\%$ ↓ $t_{t_{HFO100}}$



Normalized Cenosphere Size Ratio

- d_{cs} – equivalent diameter of the residual cenosphere formed at the end of evaporation

$\Delta d_{cs_{HFO95-P5}}^2 = 2.2\%$
$\Delta d_{cs_{HFO75-P25}}^2 = 13.1\%$
$\Delta d_{cs_{HFO50-P50}}^2 = 42.6\%$ ↓ $d_{cs_{HFO100}}^2$



Note: The uncertainty bars correspond to two times the standard deviation (±σ).

CONCLUSIONS

- The developed SDF allows evaporation studies for isolated droplets at flame-like high temperature conditions with minimum influence of external effects
- Validation tests with 1-pentanol confirms the repeatability and precise control of these conditions in every test
- Increased puffing and strong micro-explosions regimes are observed in HFO when 1-pentanol blending ratio is 25-50%
- For 25% and 50% 1-pentanol blended HFO droplets, the normalized evaporation time reduces by 8.1% and 25%, while the mean cenosphere area reduces by 13.1% and 42.6%, respectively

FUTURE WORK

- Investigate HFO/1-pentanol blends for isolated droplet combustion tests up to 21% O_2 at these flame-like conditions

Acknowledgements

This work was supported by the grant PID2019-109747RB-I00, funded by MCIN/AEI/10.13039/501100011033. The financial support for T.P. and M.A. through the pre-doctoral fellowships, PRE2020-094620 and BES-2017-080224, respectively, funded by MCIN/AEI and by "ESF Investing in your future", are gratefully acknowledged. The authors are also grateful to Luis Ojeda for his assistance with the experimental tasks.