ECN 6: TOPIC 6

SAND2018-9924PE

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STANDARDIZATION OF SOOT NON-DIMENSIONAL EXTINCTION COEFFICIENT FOR ECN

- Diffused back-illumination extinction imaging seeing widespread use throughout ECN community and beyond
- Increased availability of quantitative soot data…but…
- Uncertainty in soot optical properties leads to uncertainty in soot quantities

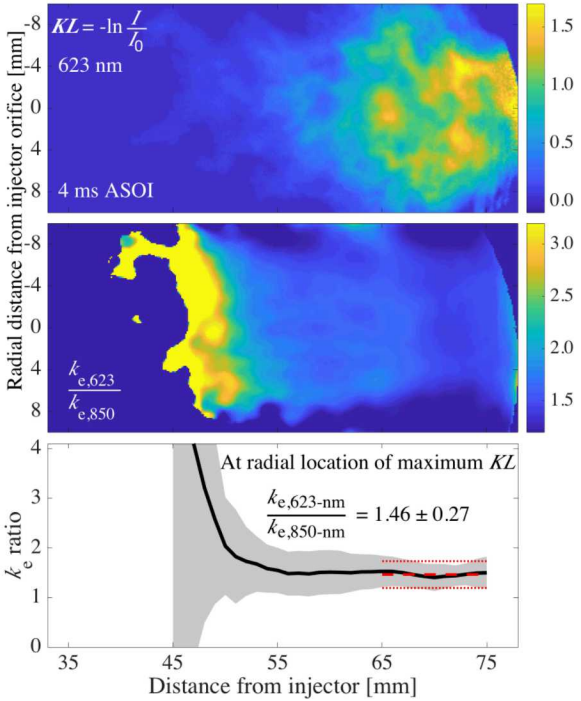
$$f_v L = -\ln\left({}^{I}/_{I_0}\right) \cdot {}^{\lambda}/_{k_e} = KL \cdot {}^{\lambda}/_{k_e}$$ where k_e is the non-dimensional extinction coeff.

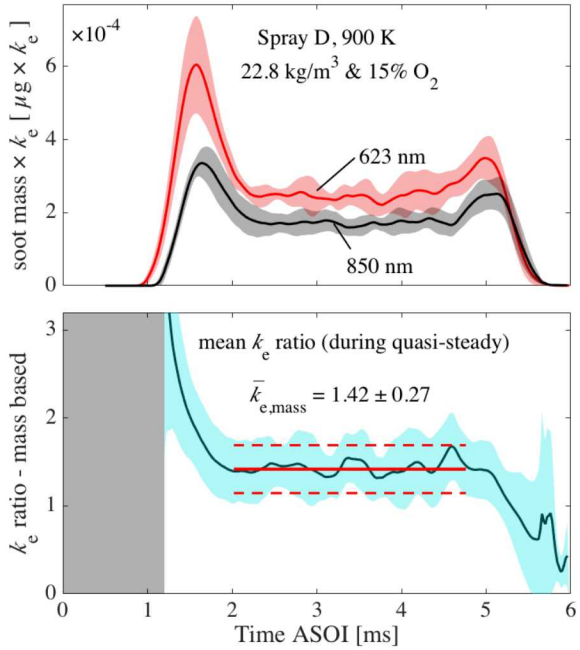
$$k_e = 6\pi \cdot E(m)(1 + \alpha_{sa})$$ and α_{sa} is the ratio of the scattering and absorption cross sections computed from RDG-FA and $E(m)$ is the soot absorption function, $-Im[(m^2-1)/(m^2+2)]$.

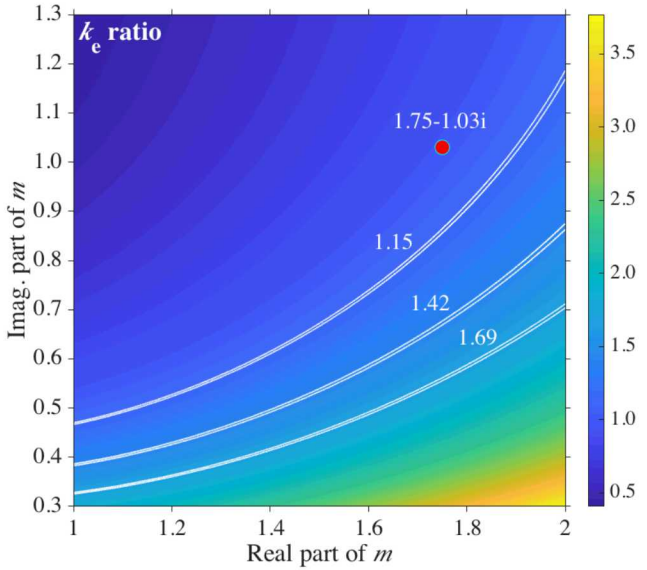
- Consideration of all refractive indexes yields unacceptable uncertainty; however, much of the old data have been deemed erroneous
- $E(m)$ measurements over the visible spectrum have converged toward 0.35-0.40, thus for very small particles where $\alpha_{sa} = 0$, $k_e = 0.40 \times 6\pi = 7.54$
- NIST measurements converged toward k_e between 8 and 10
- Williams, Shaddix, et al. measured k_e values between 9 and 10 and proposed a refractive index of m = 1.75-1.03i at 633 nm.

ENGINE COMBUSTION NETWORK

STANDARDIZATION OF SOOT NON-DIMENSIONAL EXTINCTION COEFFICIENT FOR ECN







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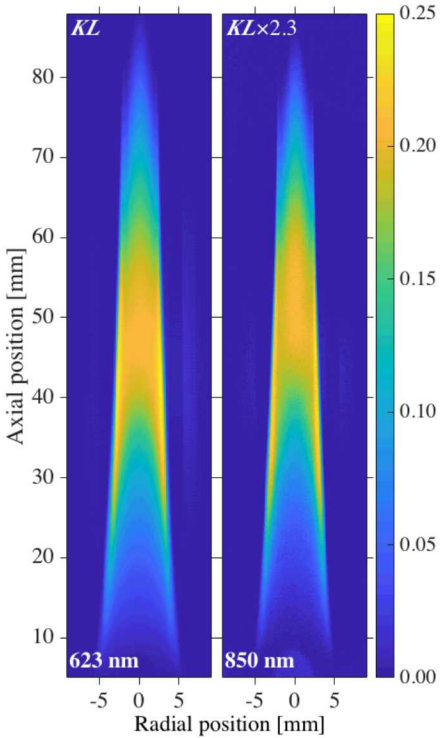
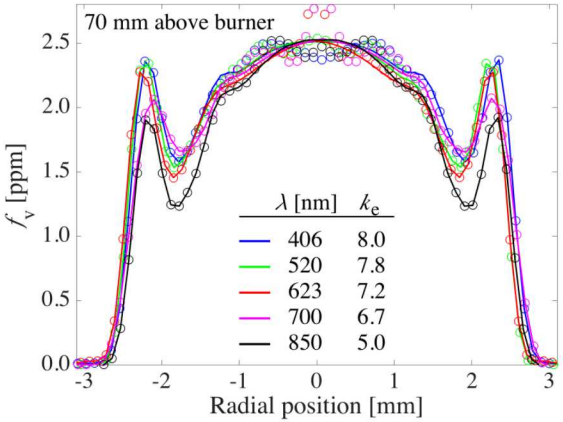
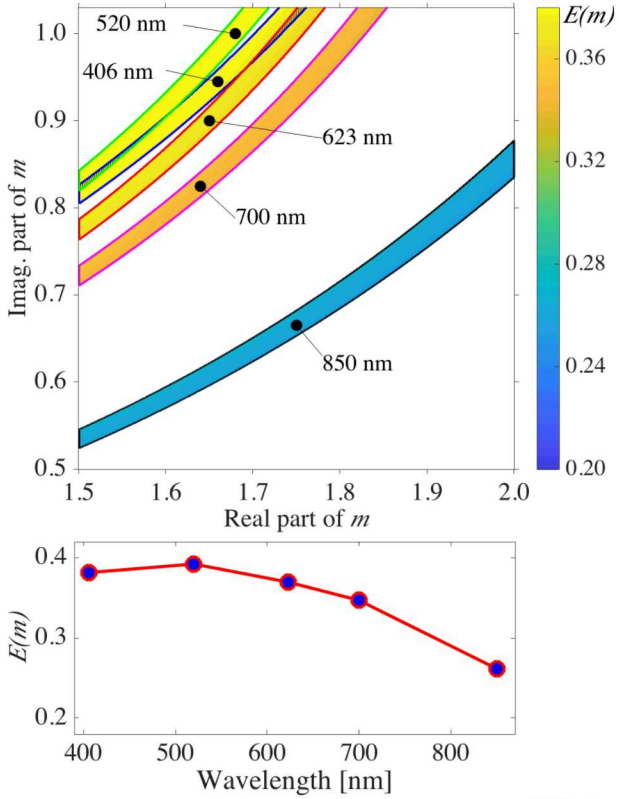
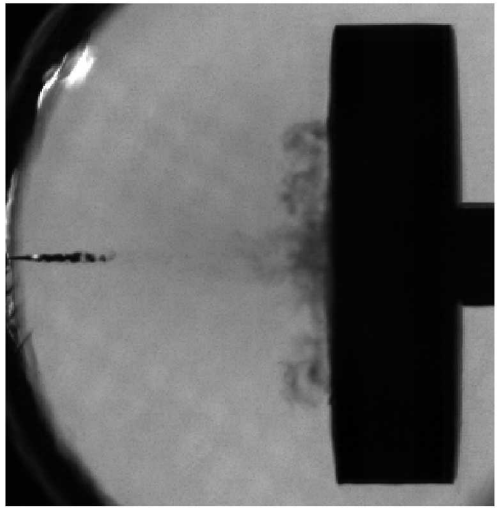
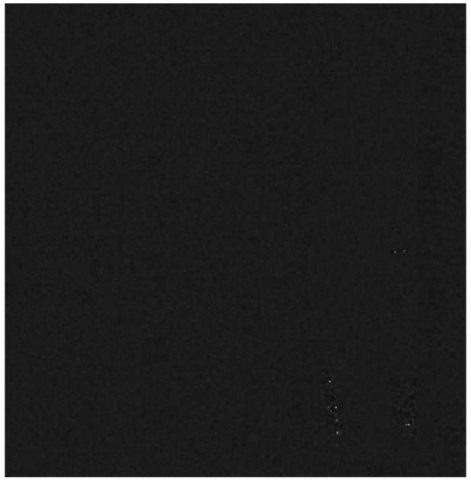






FREE VS. WALL-IMPINGING SPRAYS WITH MULTIPLE INJECTIONS





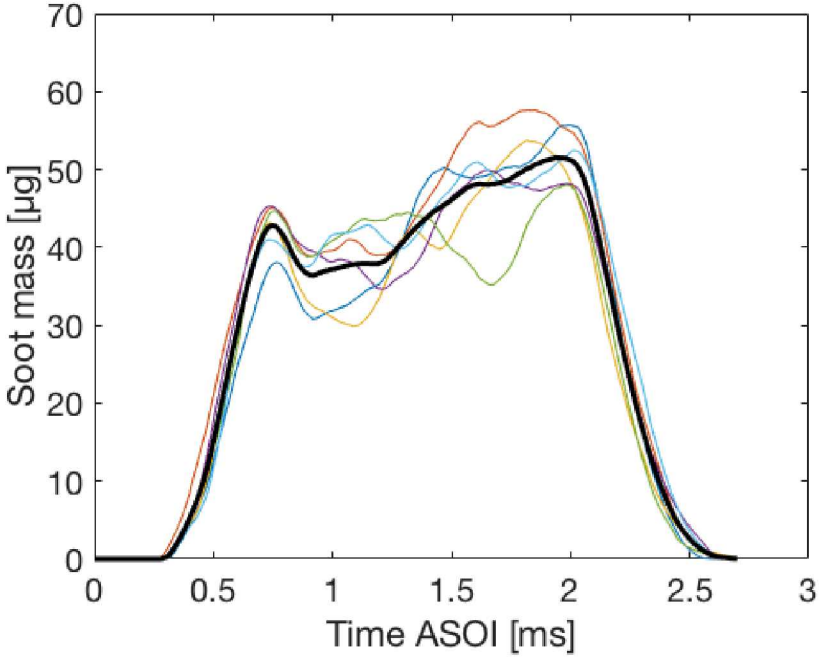
- Stainless steel cylinder “wall”
- 12 mm thick, 50 mm diameter
- DBI camera centered at wall face plane
- 623-nm LED
- Piezo injector
- 7 mg of fuel injected
  - 7 mg
  - 6/1 mg (200,1000 µs dwell)
  - 5/2 mg
  - 2/5 mg
  - 3.5/3.5 mg
- Electronic schedule determined via Moehwald

ENGINE COMBUSTION NETWORK

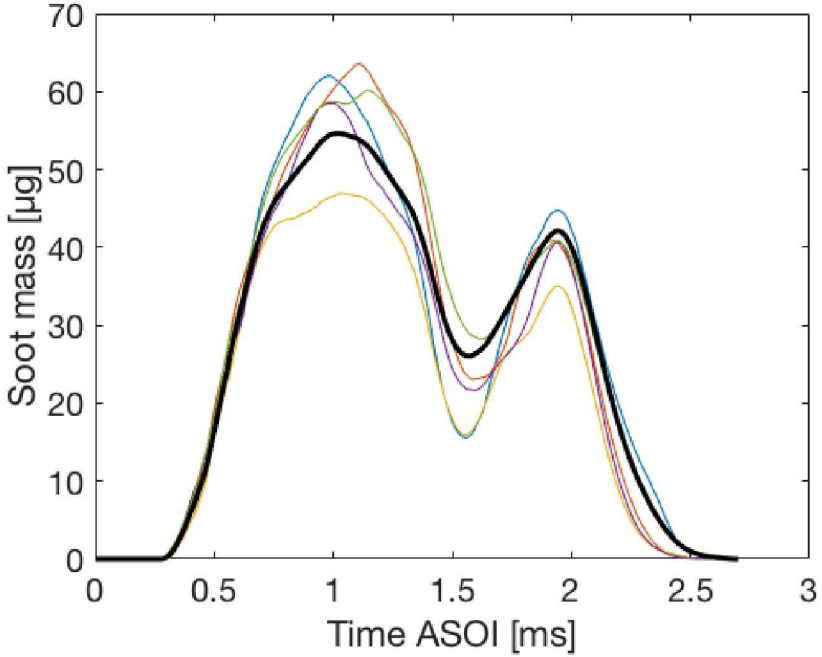
FREE VS. WALL-IMPINGING SPRAYS WITH MULTIPLE INJECTIONS

Free Spray

2 mg / 5 mg 200 µs dwell

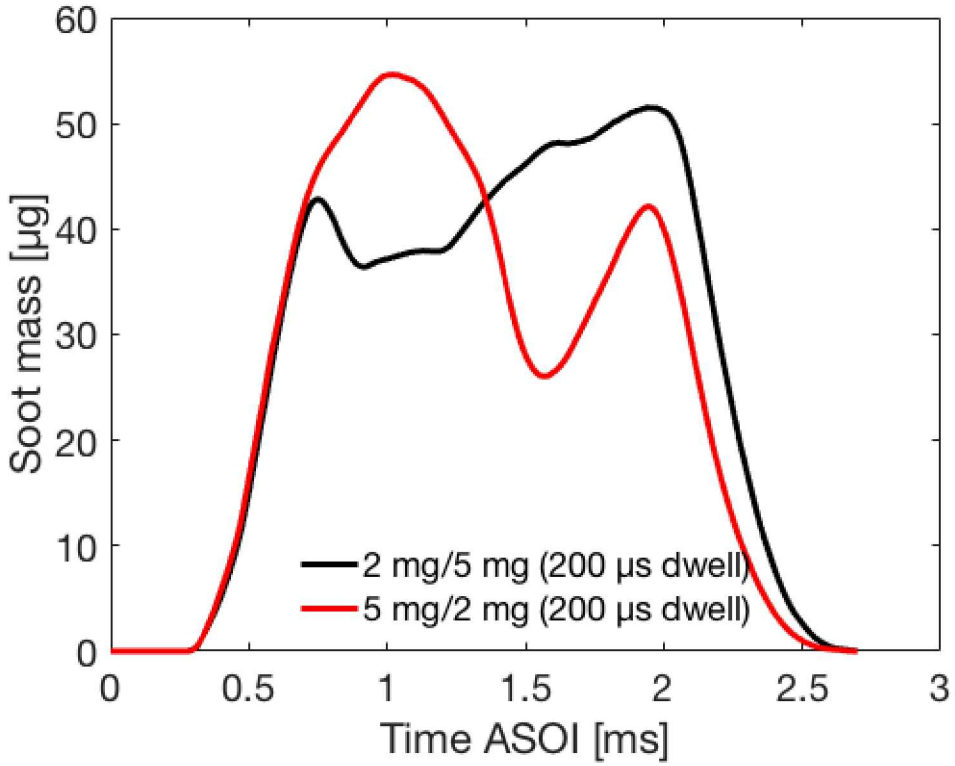


5 mg / 2 mg 200 µs dwell



FREE VS. WALL-IMPINGING SPRAYS WITH MULTIPLE INJECTIONS

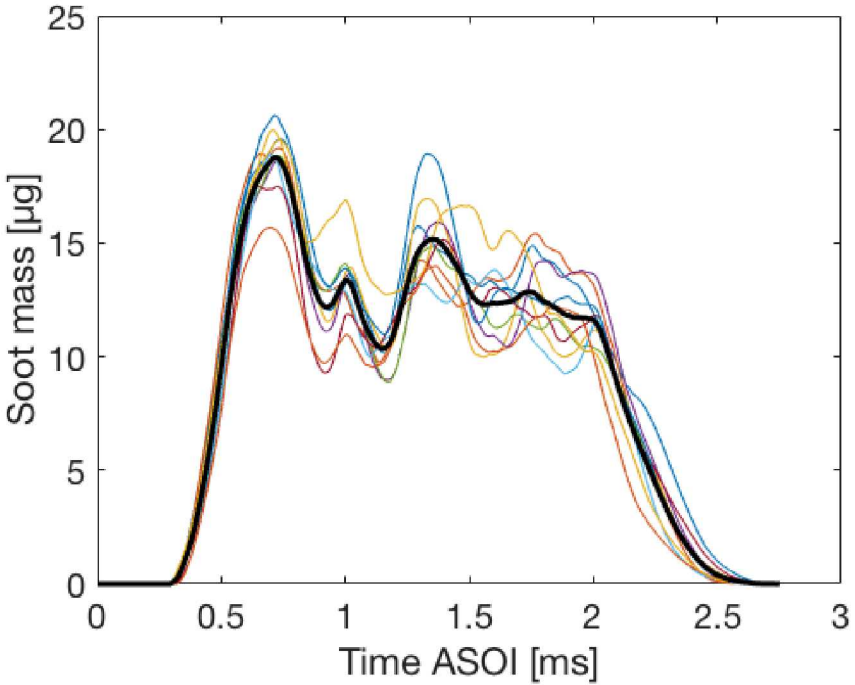
Free Spray



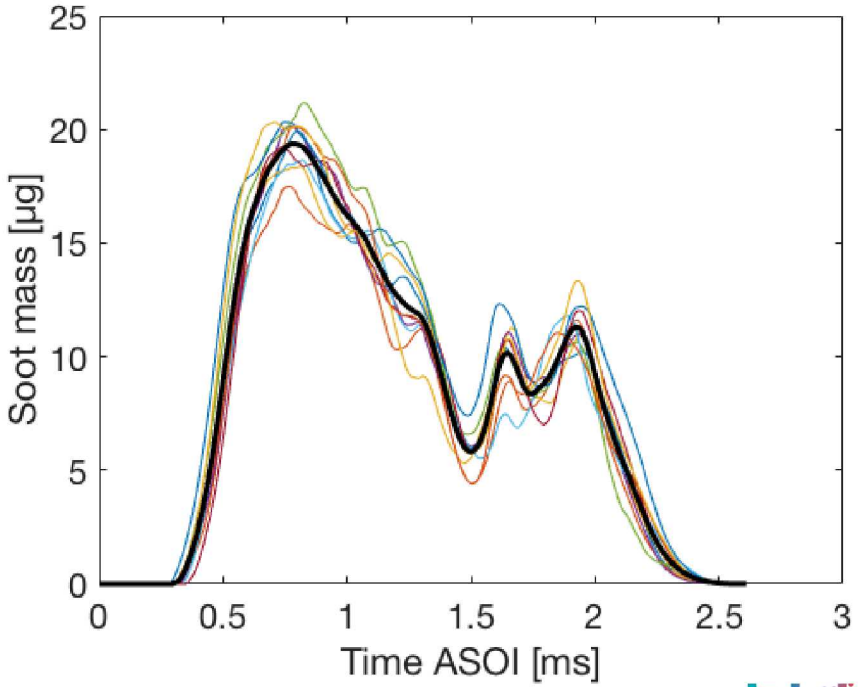
FREE VS. WALL-IMPINGING SPRAYS WITH MULTIPLE INJECTIONS

Free vs. Wall Spray

2 mg / 5 mg 200 µs dwell



5 mg / 2 mg 200 µs dwell



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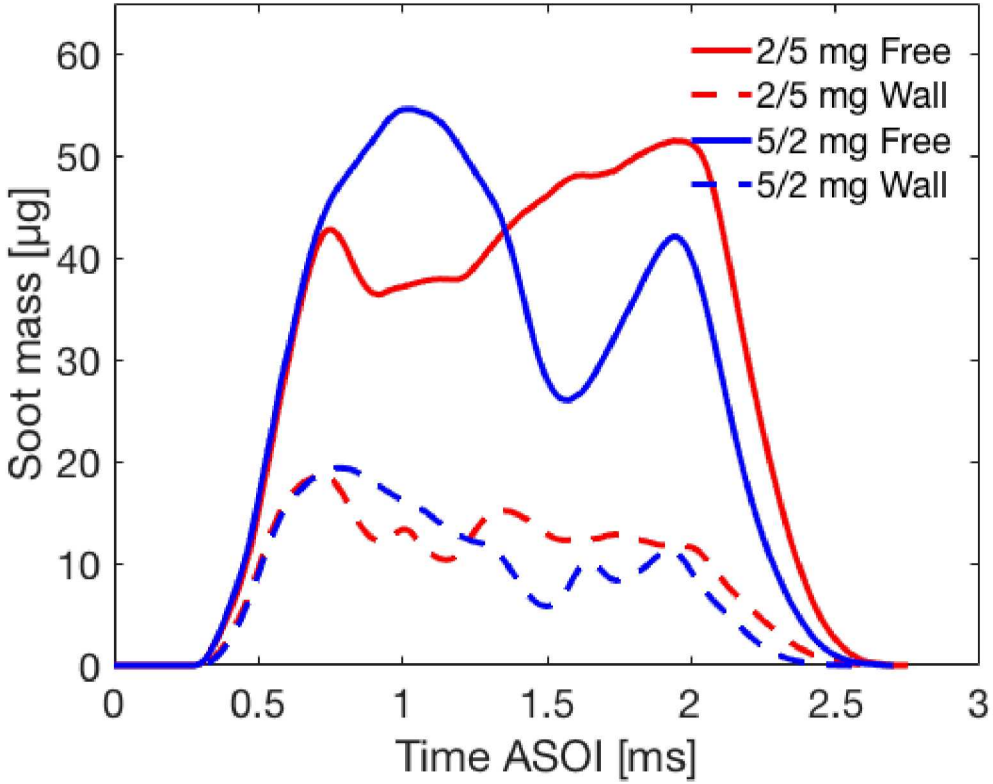

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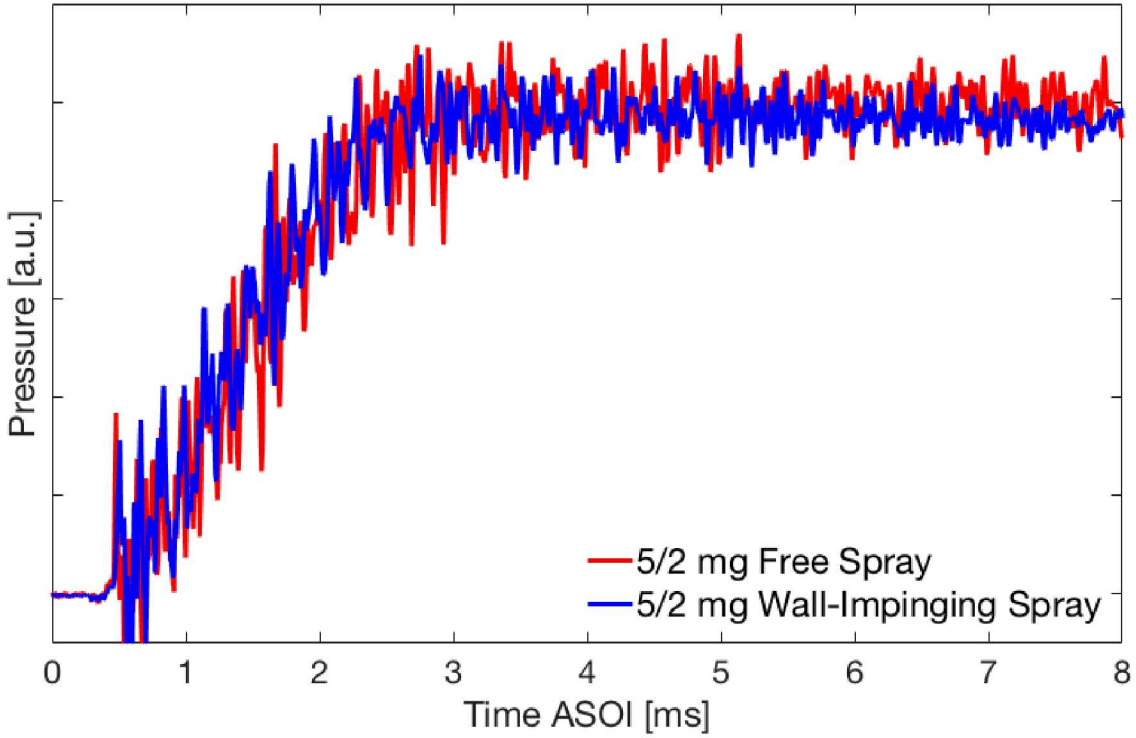
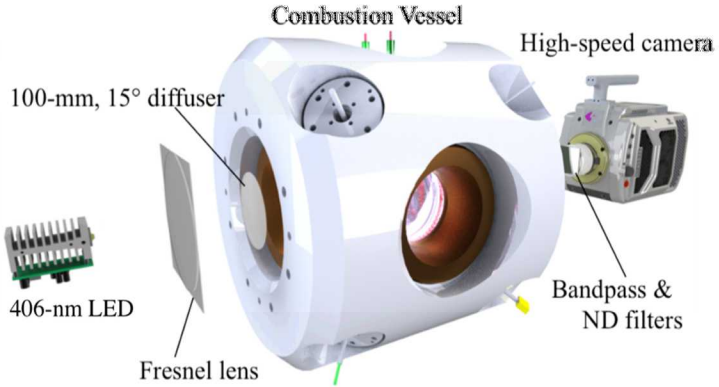
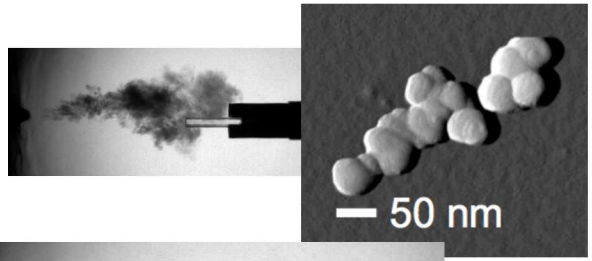
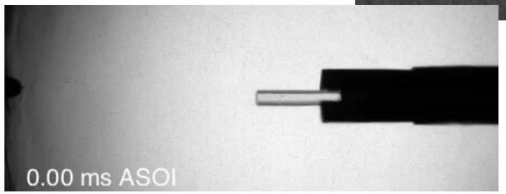


HIGH-PRESSURE SPRAY PYROLYSIS



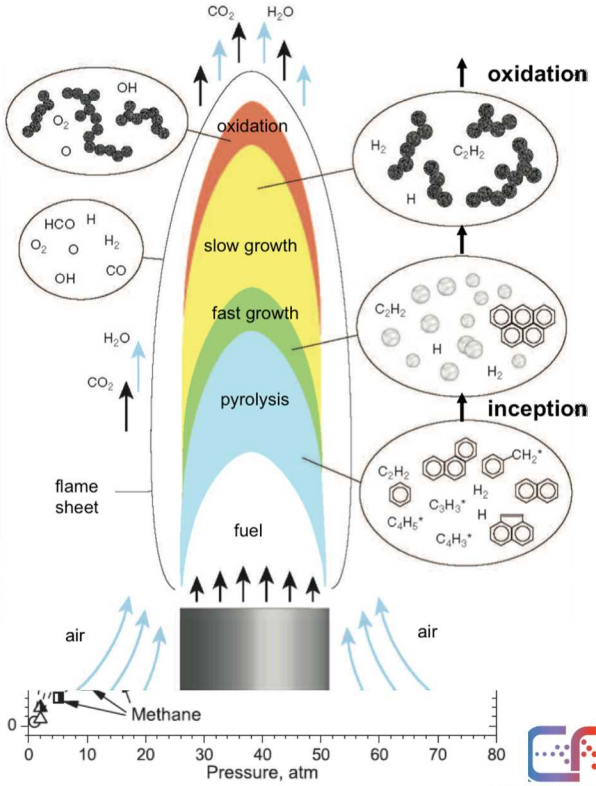




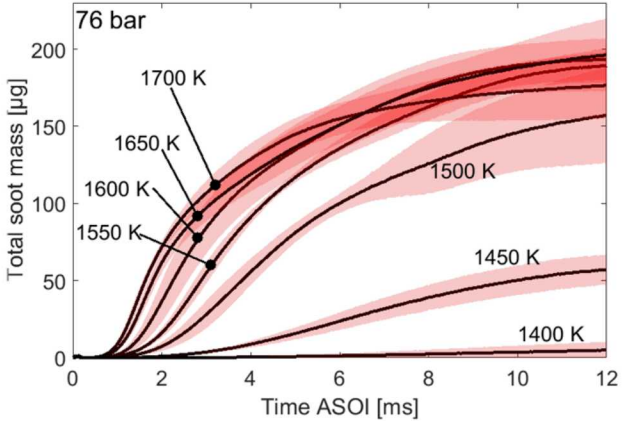
- Short injections (200-350 μs) limits penetration, rapid mixing after entrainment wave, limits optical thickness
- Small fuel injection has little impact on ambient gas temperature
- Pyrolysis (no oxygen) may eliminate need to include oxygen chemistry when modeling
- Comparisons can be made with shock-tube & flame data

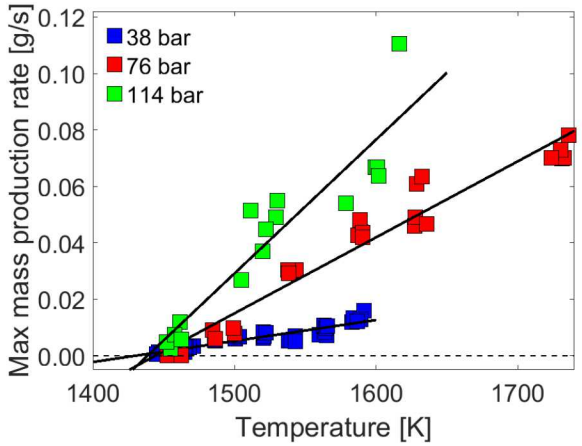
PREVIOUS STUDIES RELEVANT TO THIS WORK INCLUDE CO-FLOW DIFFUSION FLAME AND SHOCK TUBE EXPERIMENTS

Gomez et al. and Saito et al. measured a soot “onset” temperature between 1330-1400 K along the centerline of co-flow diffusion flames for a variety of hydrocarbon fuels (centerline conditions closest to pyrolysis)

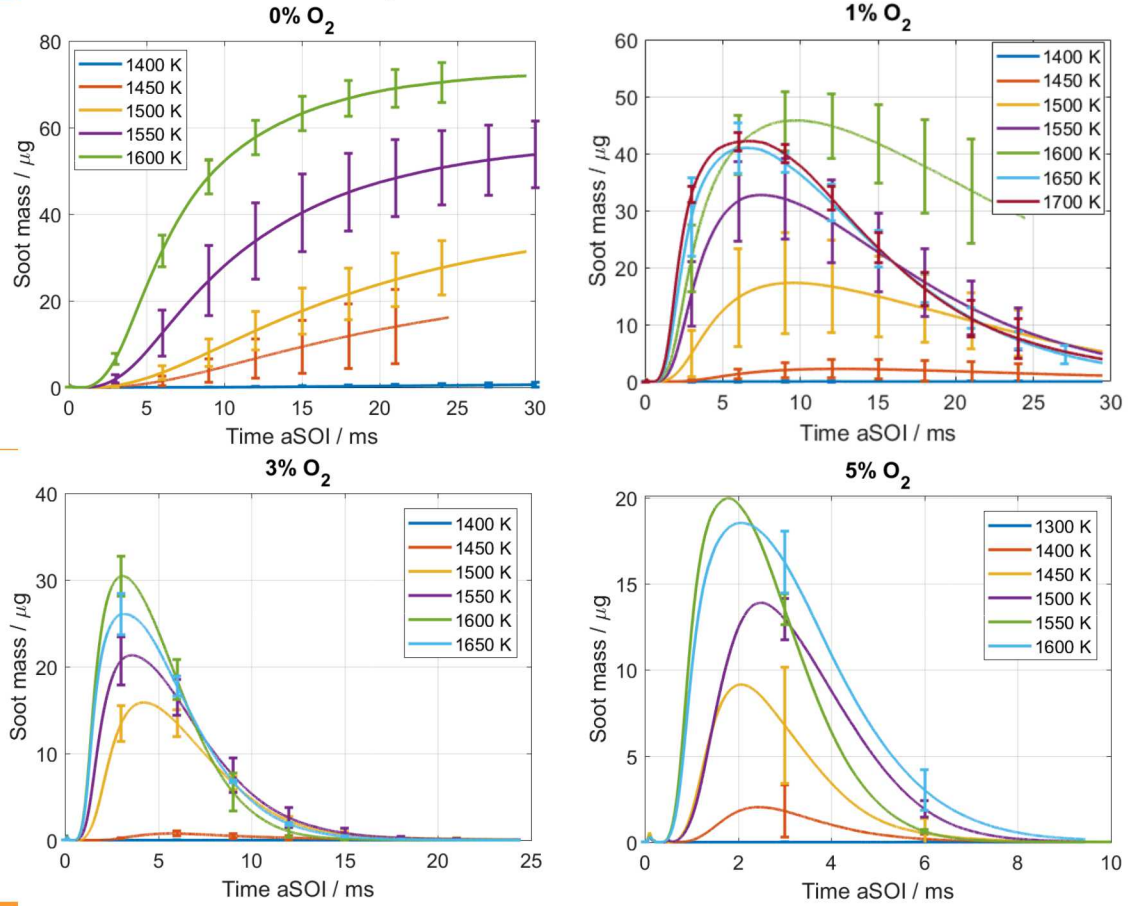


SPRAY PYROLYSIS DEMONSTRATING PRESSURE INDEPENDENT SOOT ONSET TEMPERATURE



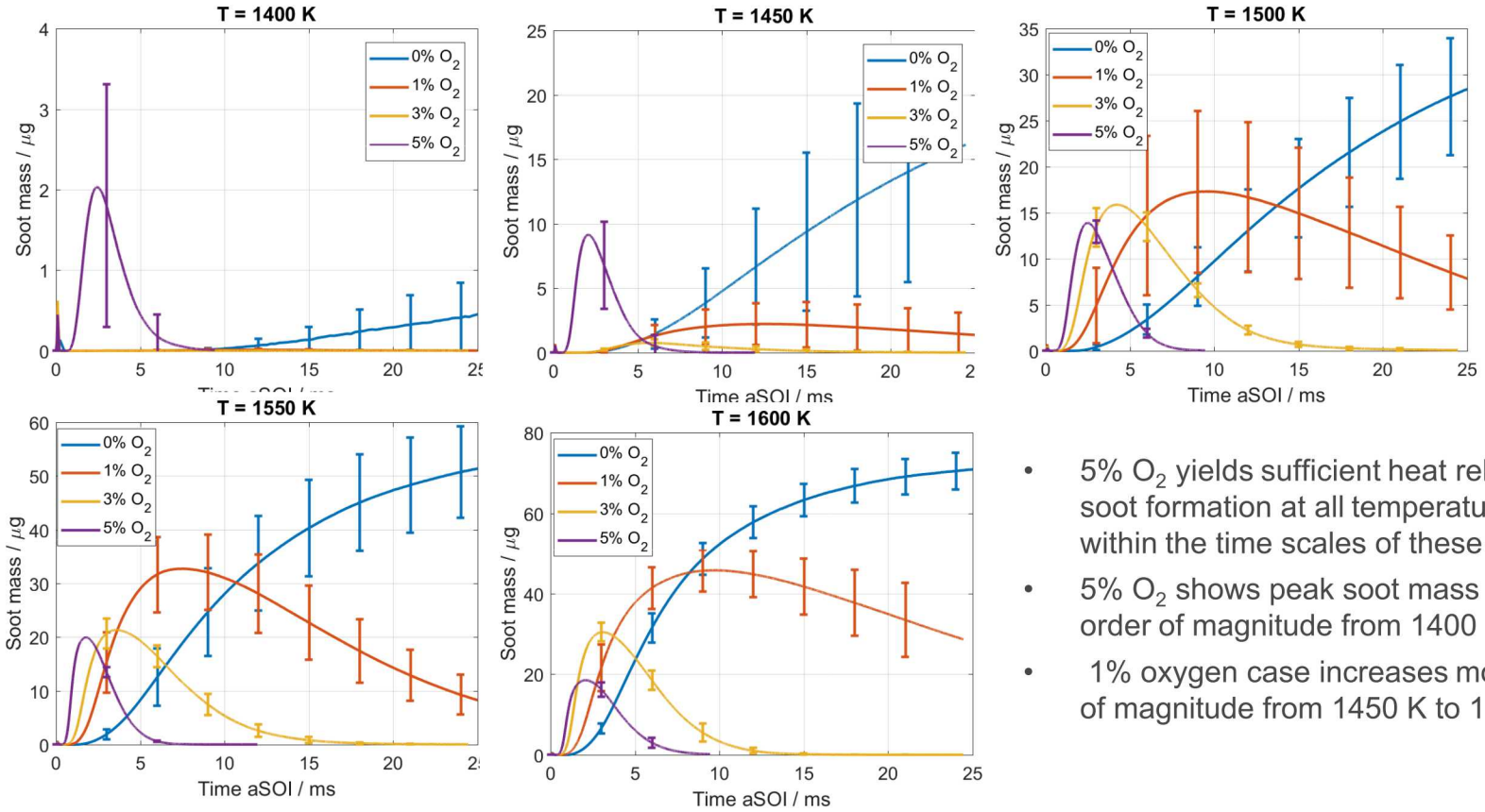


ADDITION OF SMALL QUANTITIES OF O_2 ACCELERATES SOOT ONSET TIME, COMPLETE OXIDATION WITH 3% O_2



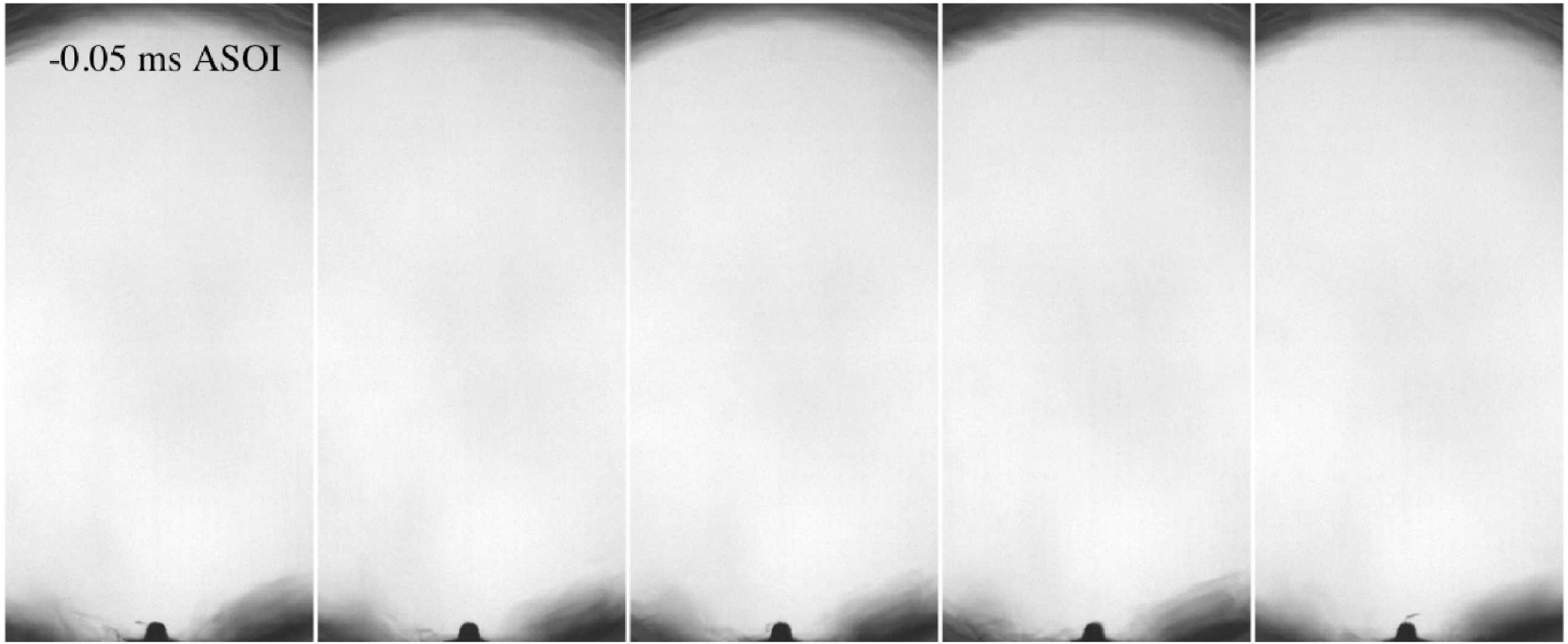
- 1450 K critical temperature demonstrated for 0% O_2
- Addition of oxygen greatly accelerates soot formation; oxygen reduces peak soot mass due to greater competition with formation
- At 1% oxygen, exothermic heat release at 1550 K and above leads to similar temporal profiles with different initial ambient temperatures; soot would likely reach complete oxidation given sufficient time
- 3% O_2 onset temperature (ambient) still 1450 K; heat release (in lean regions?) not impacting soot
- At 3% and 5% O_2, increased oxygen yields more heat release and more soot until 1650 K, where oxidation begins to overcome formation

ADDITION OF SMALL QUANTITIES OF O_2 ACCELERATES SOOT ONSET TIME, COMPLETE OXIDATION WITH 3% O_2



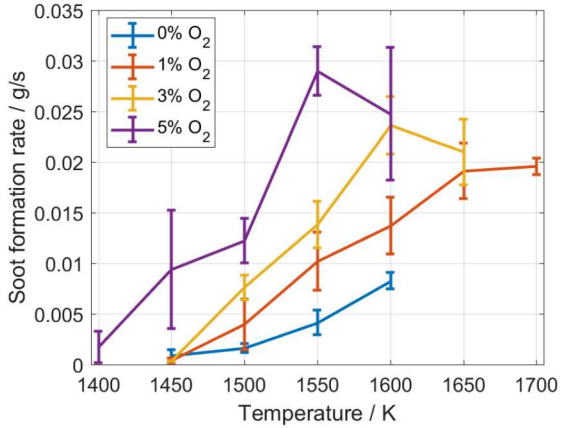
- 5% O_2 yields sufficient heat release to initiate soot formation at all temperatures above 1400 K within the time scales of these experiments
- 5% O_2 shows peak soot mass increases an order of magnitude from 1400 K to 1550 K
- 1% oxygen case increases more than an order of magnitude from 1450 K to 1600 K

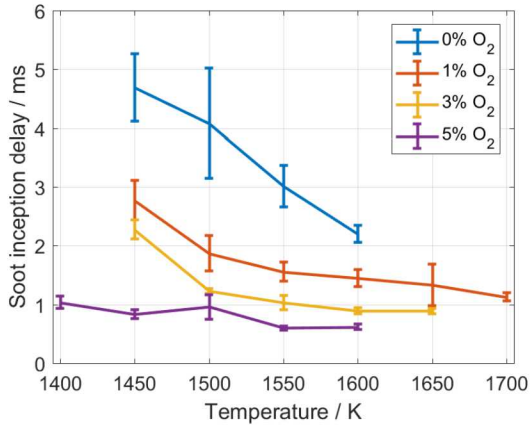
ADDITION OF SMALL QUANTITIES OF O_2 ACCELERATES SOOT ONSET TIME, COMPLETE OXIDATION WITH 3% O_2



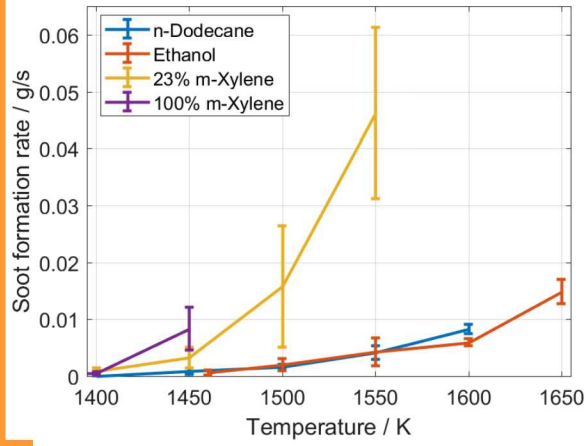
ADDITION OF O_2 DOES NOT REDUCE THE ONSET TEMPERATURE UNTIL O_2 > 3%

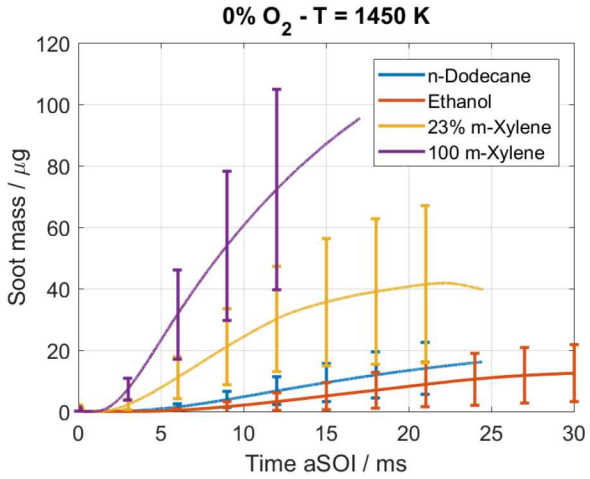
- (Top) 0-3% O_2, soot onset limit temperature remains 1450 K, consistent with original experiments
- (Top) Peak formation rate decreases at highest temperature for 3% and 5%; oxidation overcomes formation
- (Btm) Dramatic reduction in inception delay time (onset time) with addition of oxygen
- (Btm) At 5% O_2 we observe only a small effect on the inception timing or delay; mixing limited behavior?
- (Btm) At 3% O_2 an asymptote may be observed above 1500 K; above 1550 K for 1% O_2
- (Btm) At 0% O_2 there is no indication that system approaches an asymptote, need to reach higher temperatures

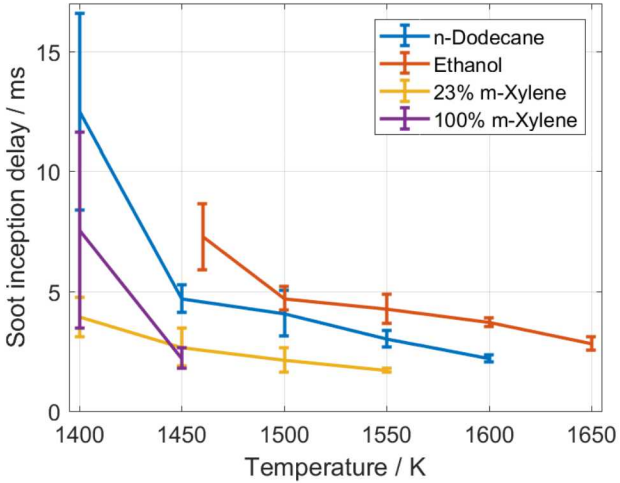




ADDITION OF M-XYLENE (AN AROMATIC) REDUCES THE ONSET TEMPERATURE AND THE INCEPTION DELAY WHILE INCREASING THE SOOT YIELD; EFFECT OF OXYGENATE MAY NOT BE DISTINGUISHABLE



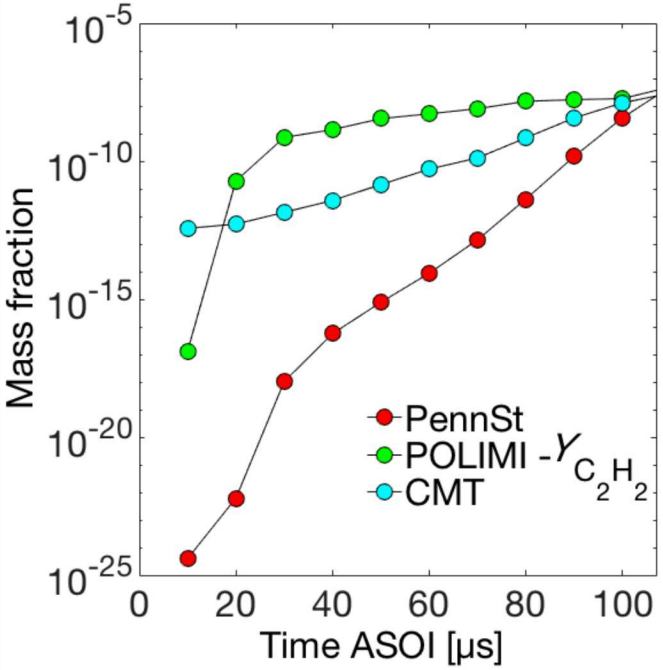


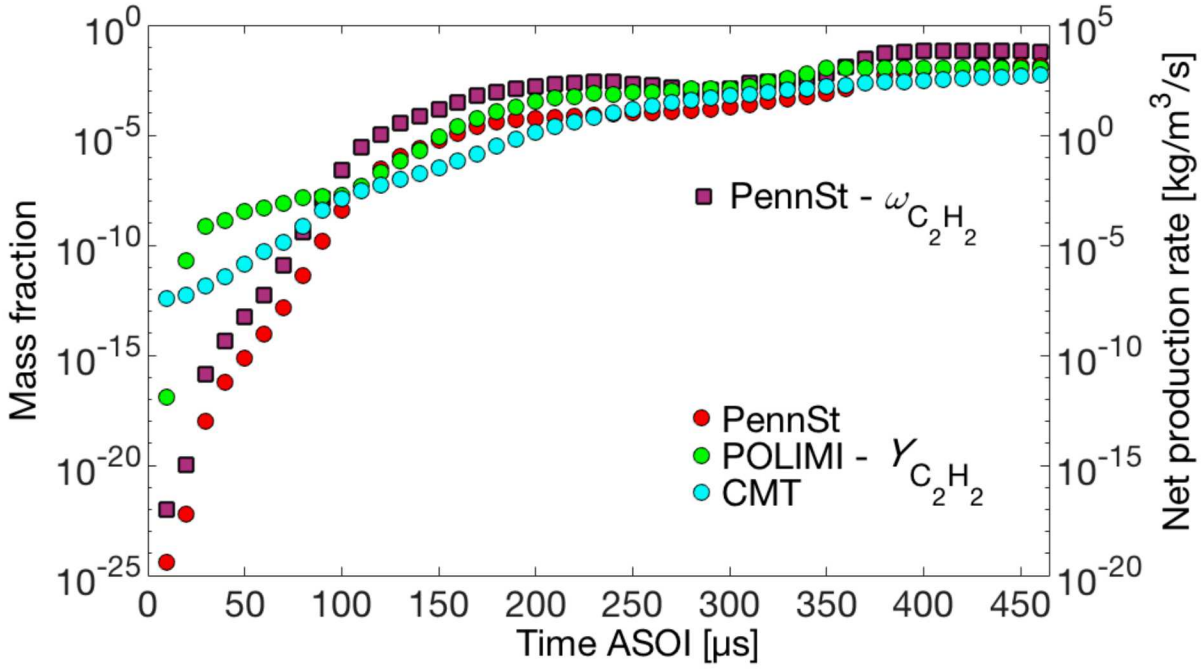


- Pure m-xylene above 1450 K resulted in complete attenuation in the DBI diagnostic
- Ethanol and n-dodecane were characterized by the same peak soot formation rates as a function of temperature
- Ethanol and n-dodecane showed the same peak soot mass, within the uncertainty of the measurements
- Given sufficient time, n-dodecane would occasionally form a small amount of soot when targeting 1400 K; however, ethanol did not yield soot in the time available for observation

ENGINE COMBUSTION NETWORK

COMPARISON OF EARLY MAXIMUM ACETYLENE MASS FRACTION ACROSS SIMULATIONS





COMPARISON OF EARLY MAXIMUM SVF ACROSS SIMULATIONS