Experimental Study of Burning Rate in Jet-Fuel Pool Fires

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Introduction:

Computational fluid dynamics (CFD) simulations of JP-8 pool fires require a simplified chemical surrogate, which must match key pool fire physical characteristics, such as:

- ✓ Burning Rate
- ✓ Vaporization behavior
- ✓ Sooting propensity

Earlier investigation on open hydrocarbon pool fire burning rates left many unknowns:

- ✓ Few available data on jet fuel
- ✓ Difference between Transient and Steady State Pool Fire

New In This Work:

- Real Time Burning Rate Measurements
- Detailed Comparison between Transient & Steady State Pool Fire
- Proof of Composition Change and Its Effect to Pool Fire

Experimental Setup:

Univ. of Utah pool fire facility

- 0.30 m diameter pool (up to 1 m)
- Closed 4.5x4.5m chamber w/floor-mounted dampers for flow control
- Steady-state and batch pool fires

Fuels Tested:

- Jet-A/JP-8 (Salt Lake City Airport)
- Jet-A Surrogate (C-SAFE)
- Norpar-15 (Exxon Chemicals Inc.)

Fire Measurements

- Burning rate
- Total and radiant heat flux
- Temperature profile
- Real-time & high-speed video

Capabilities:

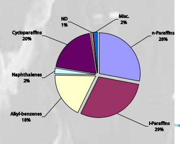
Compositional Analysis

- GC/GC-MS
- ^{1}H and ^{13}C NMR

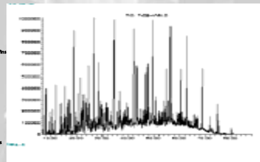
Fuel Property Measurements

- Volatility/Boiling Curve
- Smoke point
- Flash point estimation
- VLE calculations
- Soot index estimation

Jet-A/JP-8 Composition



Hydrocarbon Classes Distribution in Jet-A



GC-MS Spectrum of Jet-A

- More than 300 compounds determined, ranging from n-C_7 to n-C_{18}.
- Paraffin (& cycloparaffin) is ~80%, and aromatics is ~ 20%.
- The top three components are: n-C_{11}, n-C_{10} and n-C_{12} (4.43%, 4.43% and 3,63%)

Discussion of Burning Rate

Definition

The "burning rate" is an AMBIGUOUS but useful expression.

-Babrauskas V., 1995 SFPE Handbook, 2nd ed

Expressions of Burning Rate

- Mass loss rate (kg/s), measured indirectly by volumetric technique or directly by load cell
- Heat release rate (kW), measured by oxygen consumption calorimeter

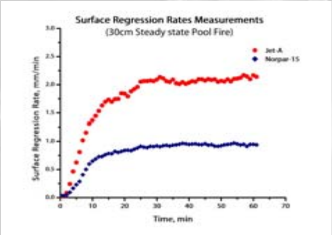
Predicted & Literature Values

$$m'' = m''_\infty \cdot \left[1-\exp(-k\cdot\beta\cdot d)\right]$$

For D = 0.3 m Jet Fuel Pool fire,

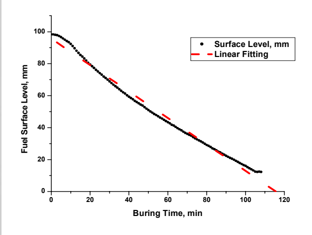
$$m'' = 0.0258 kg/m^2\cdot s = 1.91\ mm/min$$

Steady State Pool Fire Experiments



- Jet-A steady-state burning rate: 2.07 mm/ min (Norpar-15: 0.95 mm/min).
- Measurements for Jet-A in agreement with prediction
- Measurements for Jet-A match literature value

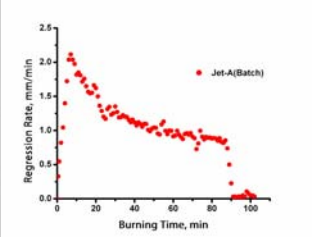
Transient Pool Fire Experiments



In situ Measurement of fuel level change, Jet-A, 30 cm transient pool fire

The rate of level change = surface regression rate

- Using linear fitting give a $R^2 = 0.98$, slope = 0.83
- Then transient test yields constant Jet-A burning rate = 0.83 mm/min, true?



Computed regression rate of Jet-A (derivative of level change), 30 cm transient pool fire

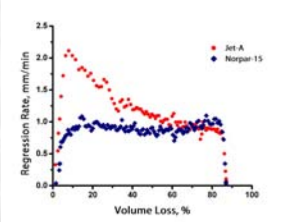
- Burning rate first increases rapidly then falls off
- Peak burning rate is 2.07 mm/min, mean burning rate is 0.81 mm/min

Possible Explanations

- Edge effects: heat feed back in the induction period accelerate vaporization
- Equilibrium: a short period required to burn light species first before reaching steady state

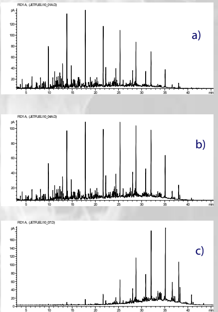
Discussion

- If edge effects important, a similar curve would occur for pure fuel
- If true steady state exists, fuel composition will remain constant during the process

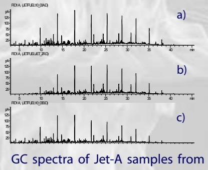


Computed regression rate of Jet-A (red) and Norpar-15 (blue), 30 cm transient pool fire

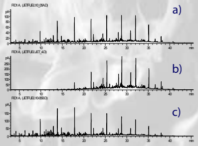
The computed surface regression rates from transient tests of Norpar-15 are consistent with the measurements from its steady state tests



GC spectra of Jet-A samples at 80 vol% burn off: a) from surface of pan; b) from bottom of pan, and c) distillation



GC spectra of Jet-A samples from a transient 30 cm pool fire: a) unburned fuel; b) 40% burn off, and c) 95% burn off



GC spectra of Jet-A samples at 40% vol. Off: a) from surface of pan; b) from bottom of pan, and c) distillation

Compositional analysis confirms a preferential burning of lighter, more volatile species, as well as the difference between preferential burning and conventional distillation

Summary:

The surface regression rates of jet fuel, Norpar-15 and Jet-A surrogate (not shown) have been studied in a 30 cm pool fire under both steady-state tests & transient tests

- Steady state burning rates were obtained for all three fuels
- Steady states tests of Jet-A matched well with predicted & literature values for similar fuel
- The transient burning rate profile of Jet-A shows a high peak value early in the experiment, followed by a gradual decrease as the balance of the fuel was consumed.
- The magnitude of the steady-state jet fuel burning rate was consistent with the peak value measured in the transient experiment

The composition changes of the liquid fuel in the pool fire pan clearly demonstrate a preferential burning in transient tests

- Norpar-15 tests under both conditions eliminate the possibility of a thermal transient being responsible for the initially high burning rate.
- The steady state experiments, with a continual replenishment of fresh fuel and thus lighter components, were able to maintain a steady-state burning rate equivalent to the early peak burning rate.

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