



SAND2019-11825C

Crude Oil Characterization Research Study

Task 3: Combustion Experiments

Part II: Pool Fire & Fireball Testing

Crude Oil Quality Association Fall Meeting

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Overview



- The experiments focused on combustion events most likely to arise from a severe rail accidents, namely, pool fires and fireballs.
- Main objective of the study was to determine whether vapor pressure affects thermal hazard distances for these combustion events.
- Flammability or the potential to ignite was not studied since:
 - In crash scenarios the most probable outcome will be the production of very high energy sources to cause ignition, far exceeding any hydrocarbon flammability classification threshold. Jet-A fuel is an example of this.
 - Flammability classification is useful for operational handling.

Pool Fire Experiments



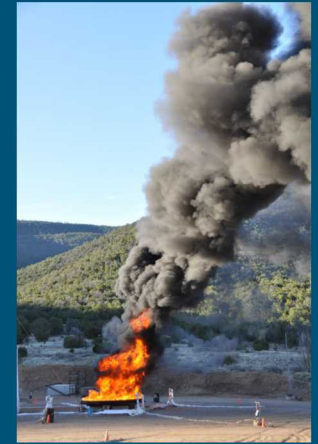
- Tests include:
 - Outdoor 5-m diameter pool fires (all oils)
 - Indoor 2-m pool fire tests for scoping purposes (SPR oil only).
- Measurements include:
 - burn rate,
 - surface emissive power
 - flame height
 - heat flux to an engulfed object
- Measured parameters were used to evaluate thermal hazard distances.



2-m SPR
(cold)



2-m SPR
(hot)



5-m SPR
(hot)



5-m SPR
(ambient)



5-m Bakken



5-m Texas Shale

Pool Fire Dynamics Affected by Scale



Surface Emissive Power:

- Surface emissive power is the thermal radiation emitted from the flame per unit time per unit surface area.
- Radiating soot particles are responsible for a flame's luminosity and is the major player in the surface emissive power
- Soot radiation will reach a maximum at a particular diameter, dependent upon the fuel. The flame is then considered optically thick.
- With increasing diameter, soot oxidation cannot keep up with soot production. Soot particles then exit the flame envelope and cool to form black smoke.
- Smoke provides a radiative barrier which decreases hazard distances

Flame Height:

- The ratio of luminous flame height to pool diameter decreases mainly due to smoke obscuration

Burn rate:

- Burn rate changes with scale and approaches a constant value for diameters above 3-m.

Fire Dynamics Affected by Scale



2-m diameter
SPR pool fire

Height to
diameter ratio
about 3



5-m diameter
SPR pool fire

Height to diameter
ratio is about 1 due to
smoke obscuration

Smoke
production
much higher
than the 2-m
pool fire

Boilover and Residue



- Boilover can occur when water is introduced. Water was introduced inadvertently in SPR and Texas Shale tests.
- The water will be in a layer below the liquid fuel due to its higher density.
- If water reaches vaporization temperature than its rapid expansion will cause fuel to ‘cascade’ over the edge of the pan.
- Significant amounts of residue for SPR tests



Boilover 5-m SPR pool fire

Unclassified Unlimited Release (UUR)

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Residue 5-m SPR pool fire



Fireball Experiments



- Experiments were performed by releasing and igniting 400-gallons of oil.
- The pressure vessel was designed to:
 - allow control of the oil's temperature and pressure
 - prevent air contact within the vessel
 - control time of release
- Measurements include:
 - diameter
 - height
 - duration
 - surface emissive power
- Measurements of parameters were used to evaluate thermal hazard distances



Bakken



SPR



Texas Shale



Custom 1000-gallon pressure vessel

Release and Ignition Method



- Method designed to fail on demand due to diagnostic requirements
- Challenges include:
 - Designing charge (protect tank and prevent interference with fireball)
 - Thermally protecting charge while maintaining performance
 - Achieving coordinated ignition



Set-up of mock test to verify timing of linear shaped charge and C-4

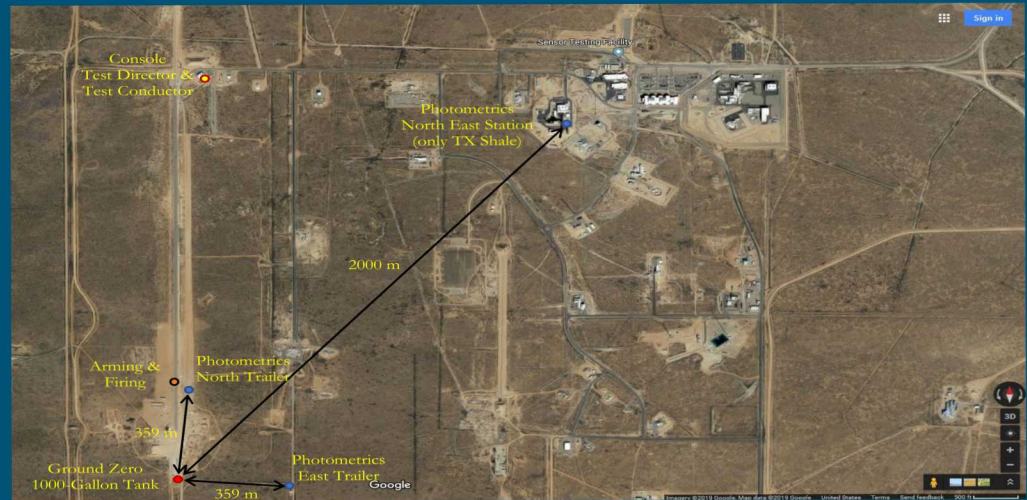


Coordinated ignition of both charges



Disc post-test

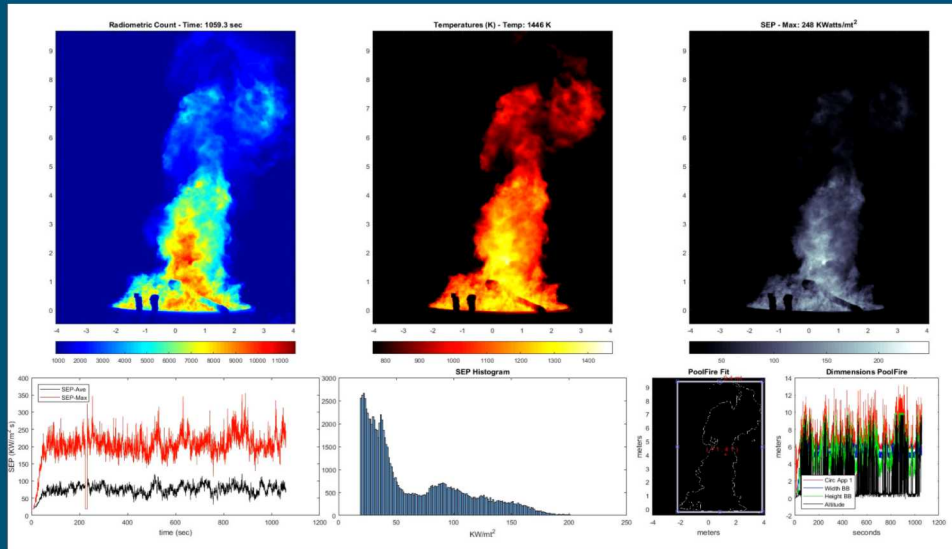
High-speed and Real-time Cameras



Infrared Imaging

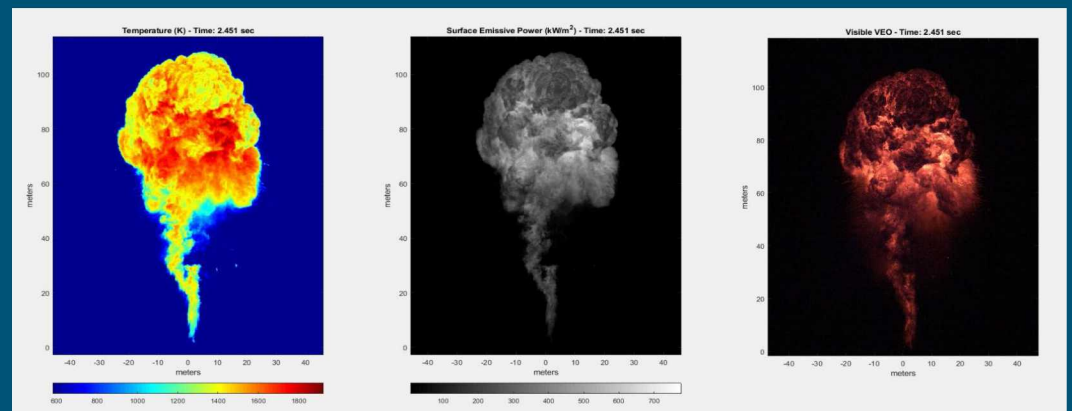


IR camera measurements allowed for surface emissive power and dimensions to be determined



IR images of 5-m pool fire

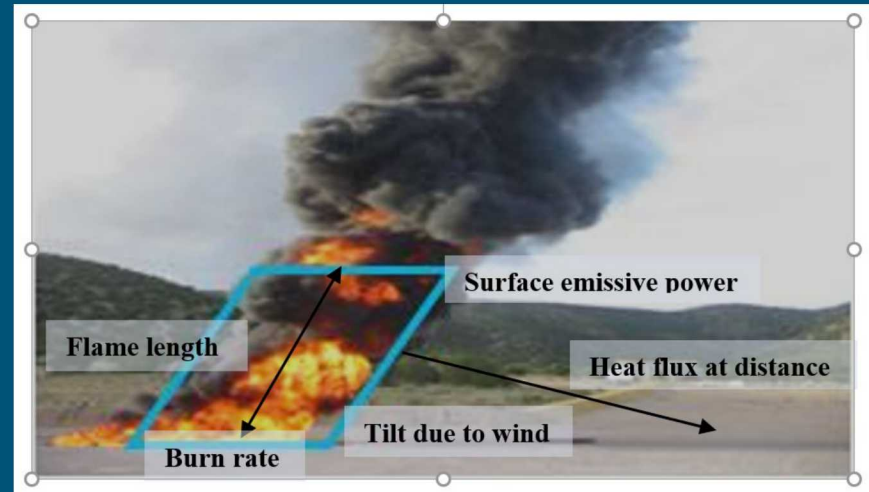
IR images of fireball



Pool Fire Thermal Hazard Calculations

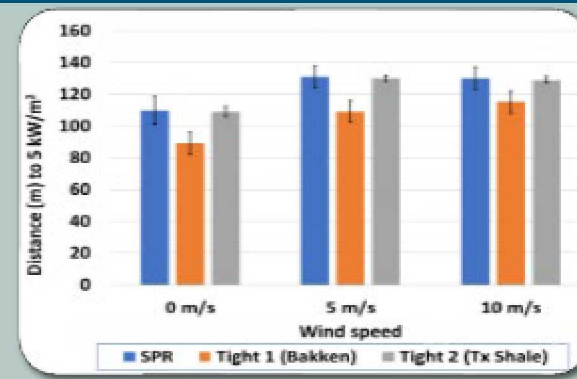
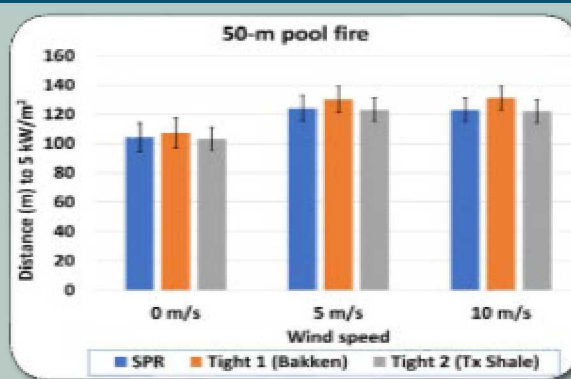
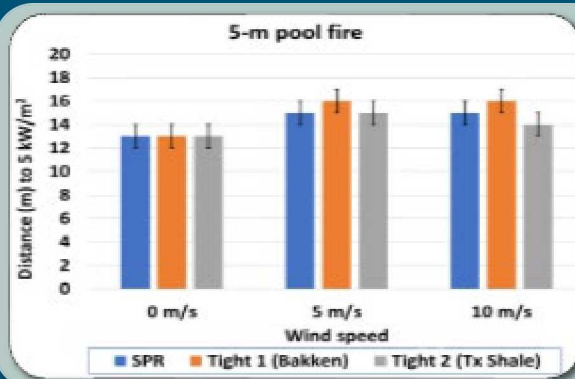


- Distances evaluated using the measured parameters and an integral model
- Distance based on injury criterion of 2nd degree burns after 30-second exposure to a radiant heat flux of 5 kW/m²
- Distances evaluated as a function of size (5-m and a 50-m diameter), wind speed, contained and uncontained pools.
- A 50-m pool diameter is representative of a 114-m³ (30,000-gallon) release.



Radiant heat flux (kW/m ²)	Pain or Injury
1.0	No harm – solar constant on a summer day.
2.1	Pain after 1 minute.
5	Pain after 10 s. 1 st degree burn after 20 s. 2 nd degree burn after 30 s exposure to bare skin.
10	2 nd degree burns after 20 s.
30	3 rd degree burns to bare skin and 50% lethality after 30 seconds exposure.

Pool Fire Thermal Hazard Distances



5-m diameter pool fire

50-m diameter pool fire

30,000-gallon release
uncontained pool fire

Pool Fire calculations using measured parameters

Distance based on injury
criterion of 2nd degree burns
after 30-second exposure to a
radiant heat flux of 5 kW/m²

Fireball Thermal Hazard Calculations



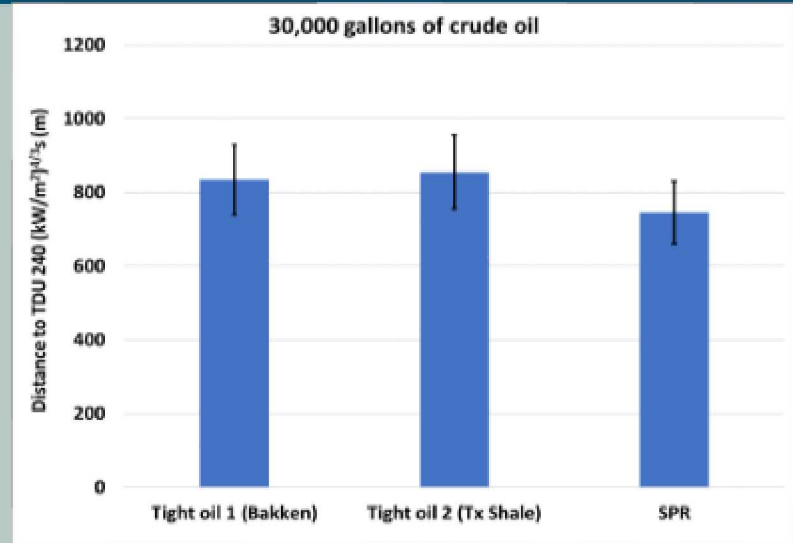
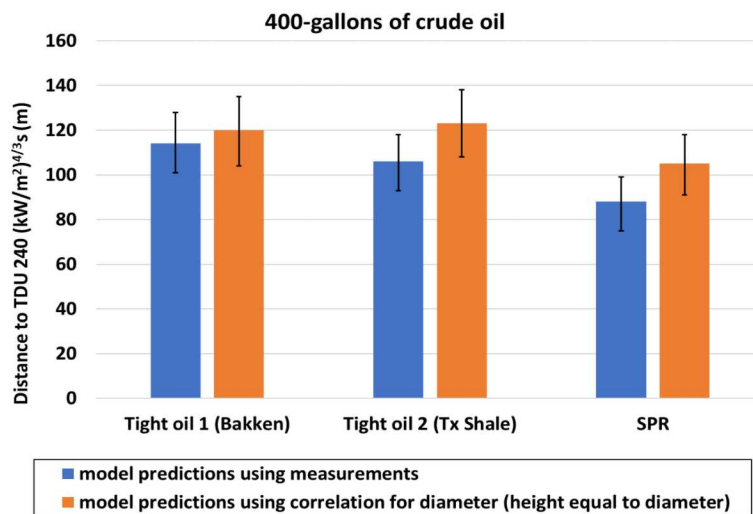
- Distances evaluated using the measured parameters and an integral model
- Distances based on injury criterion of 2nd degree burns after 30-second exposure to a thermal dose level of 240 (kW/m²)^{4/3}s
- Distances evaluated for a 400-gallon and a 30,000 gallon release for all oils tested

Injury	Thermal dose (kW/m ²) ^{4/3} s	
	mean	range
pain	92	86-103
Threshold 1 st degree burn	105	80-130
Threshold 2 nd degree burn	290	240-350
Threshold 3 rd degree burn	1000	870-2600

Common measure for events that involve exposure to high heat flux levels of short duration is the thermal dose unit

$$(TDU) = \int_0^t q(t)^{4/3} dt$$

Fireball Thermal Hazard Distances



400-gallon fireball

30,000-gallon fireball

Fireball calculations using measured parameters

Distances based on injury criterion of 2nd degree burns. Corresponds to a thermal dose level of $240 \text{ (kW/m}^2\text{)}^{4/3}\text{s}$

Context of Thermal Hazard Distances



- Thermal hazard distances presented for pool fires and fireballs are for comparative purposes only.
- Actual rail accidents can exceed the calculated distances as historic accidents have demonstrated.
- Damage of numerous railcars leading to significant amounts of oil contributing to a fire which can then propagate to surrounding fuels sources, such as wooden structures, vegetation, and other hydrocarbons.

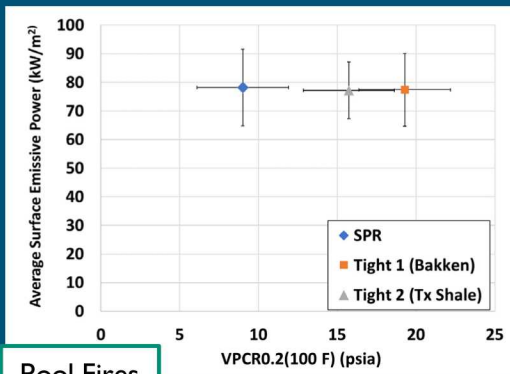


**Lac-Mégantic, Canada accident site
July 6, 2013**

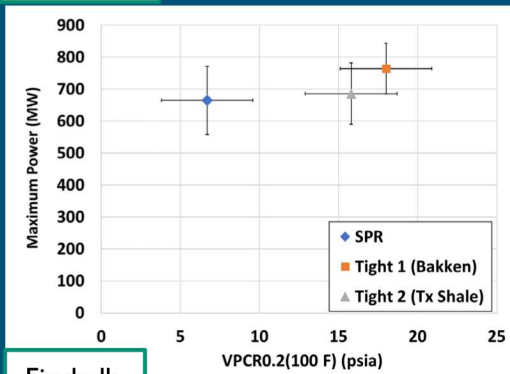
General conclusion #1



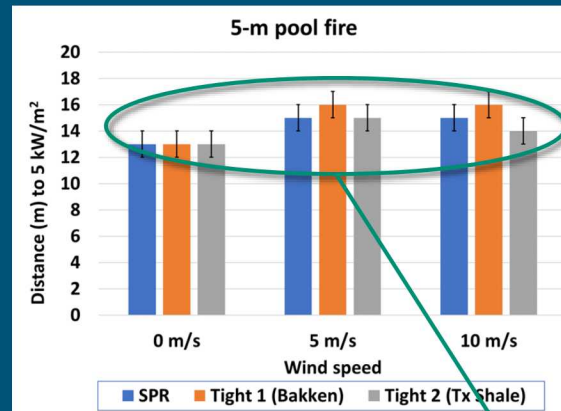
The similarity of pool fire and fireball burn characteristics pertinent to thermal hazard outcomes of the three oils studied indicate that vapor pressure is not a statistically significant factor in affecting these outcomes. Thus, the results from this work do not support creating a distinction for crude oils based on vapor pressure with regards to these combustion events.



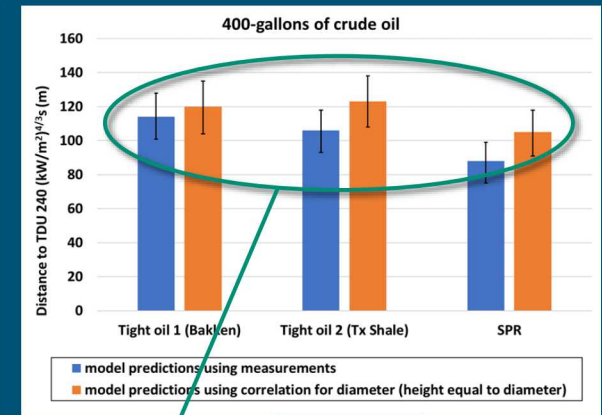
Pool Fires



Fireballs



Pool Fires



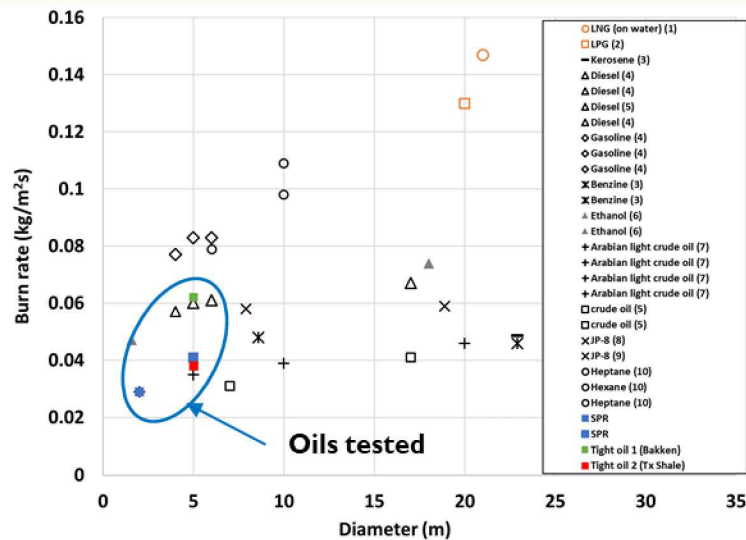
Fireballs

Distances not statistically different
Overlapping error bars

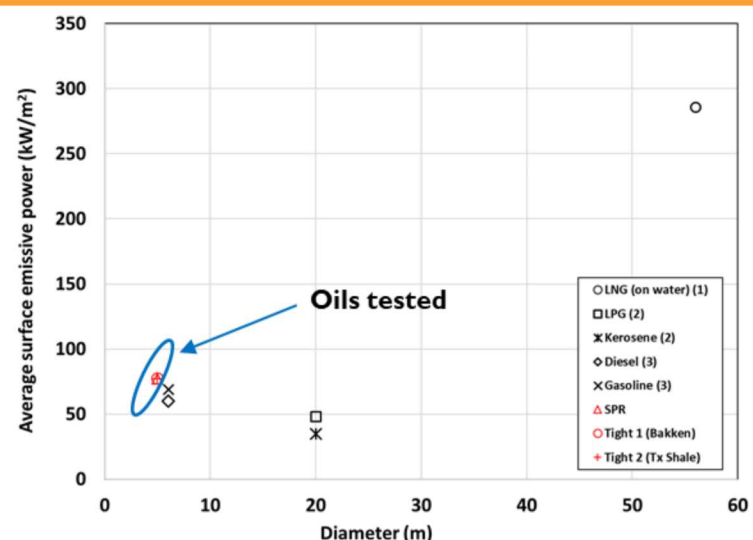
General conclusion #2 (pool fires)



Based on comparison to combustion data from public literature on common liquid fuels (primarily commercial grade propane and butane), the results of this study are considered to be pertinent to crude oils and most hydrocarbon liquids that exceed the vapor pressures of the crude oils tested here.



Burn rate

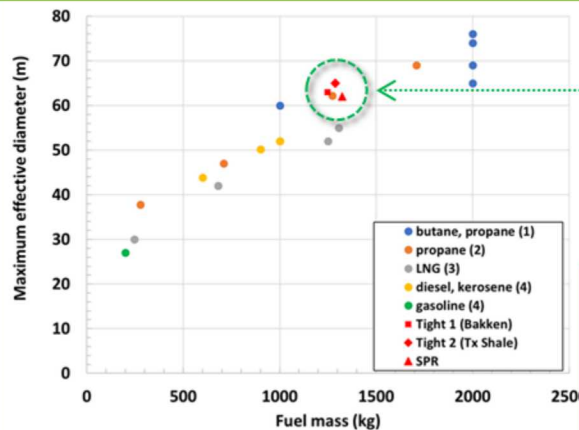


Surface emissive power

General conclusion #2 (fireballs)

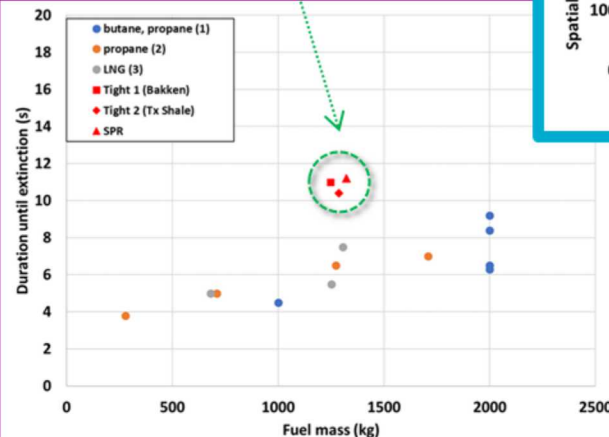


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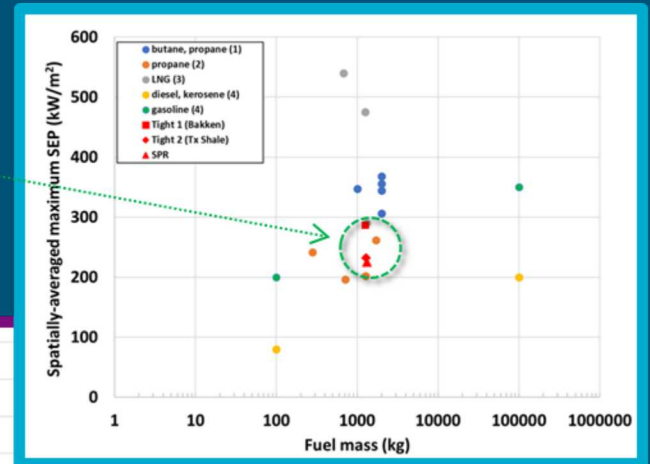


Diameter

Duration



Oils tested



Surface emissive power



Questions