High-speed Visualisation of Methanol Sprays under Flash Boiling Conditions

MariNH3
Clean, green ammonia engines for maritime

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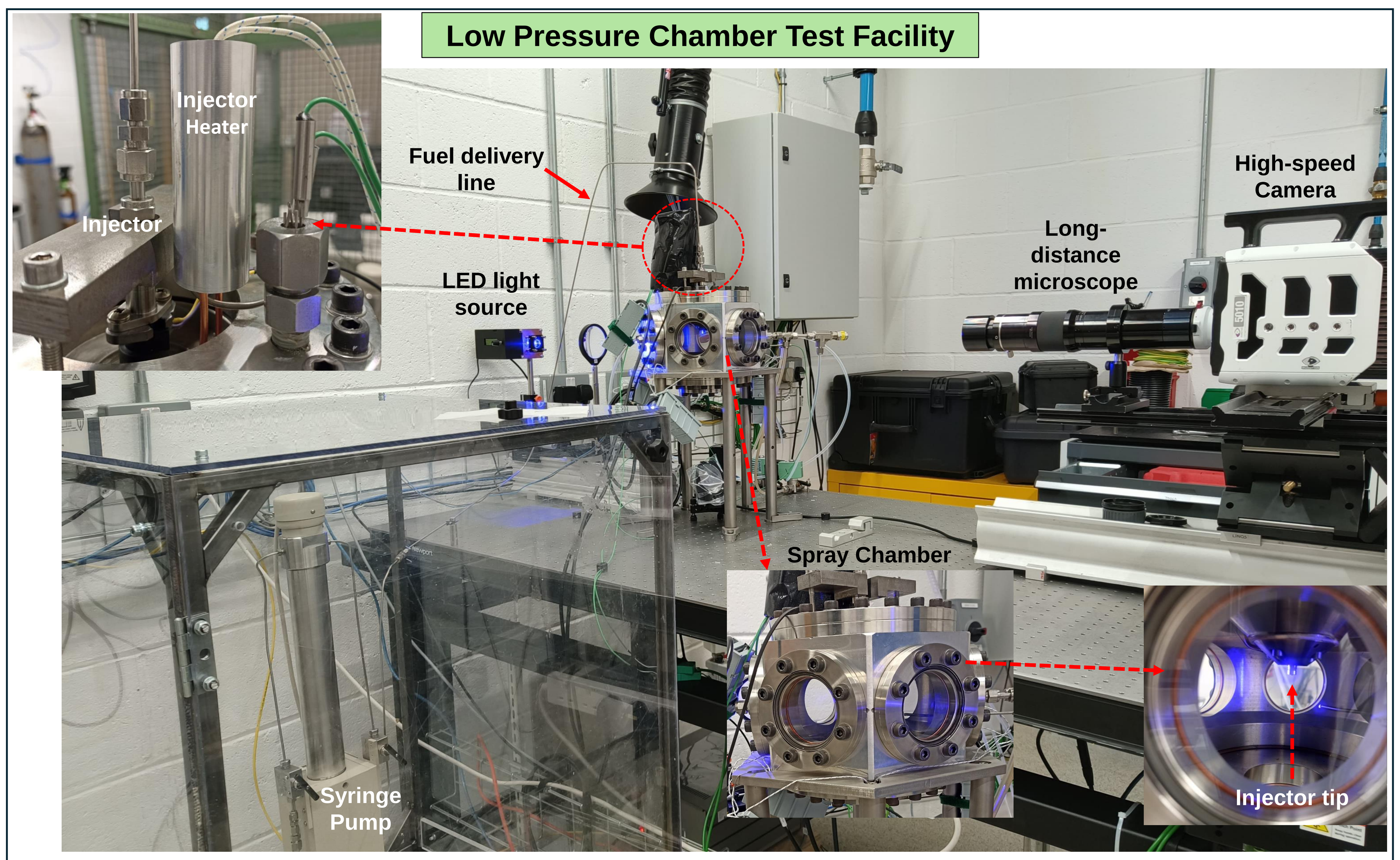
Motivation: Methanol is widely considered as a promising route to carbon reduction for maritime applications as a drop-in fuel to meet future IMO targets.
Low boiling point of methanol at 338 K can contribute to flash boiling and atomisation at the injector leading to flash boiling and unpredictable fuel spray behaviour.
Understanding the influence of the degree of superheat upon the spray characteristics is key to the optimisation of the combustion system.

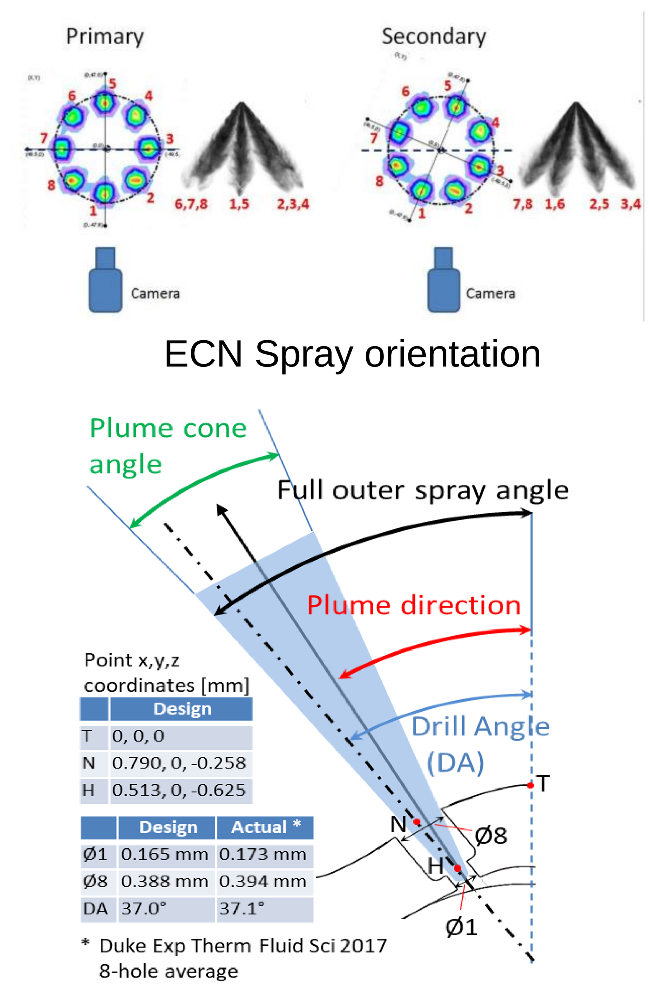
Aim: To conduct an experimental study to examine the spray characteristics of the Sandia National Laboratories, Engine Combustion Network (ECN) standard multi-hole injector (spray G) under flash boiling conditions. The eight hole ECN injector chosen has a wide cone angle, advantageous for larger bore engines.

Methodology: Experiments were performed in an optically accessible sealed chamber at gas pressures below ambient conditions.
Methanol between 50-200 bar was precisely metered by a syringe pump. The injector temperature was controlled at 363 K by a heating jacket.
Chamber wall (and gas) temperatures were controlled to 333 K. ECN standard test conditions G2 and G3 were studied.
High-speed shadowgraphy images were captured using a Phantom TMX 5010 and long-range microscope (K2 Infinity) and back lit LED illumination.
Image processing using in-house code was used to measure spray penetration, cone angle and maximum width of spray envelope.

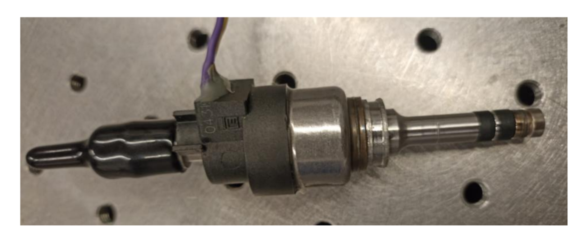
Low Pressure Chamber Test Facility



ECN Spray G Injector Specification & Operating Conditions

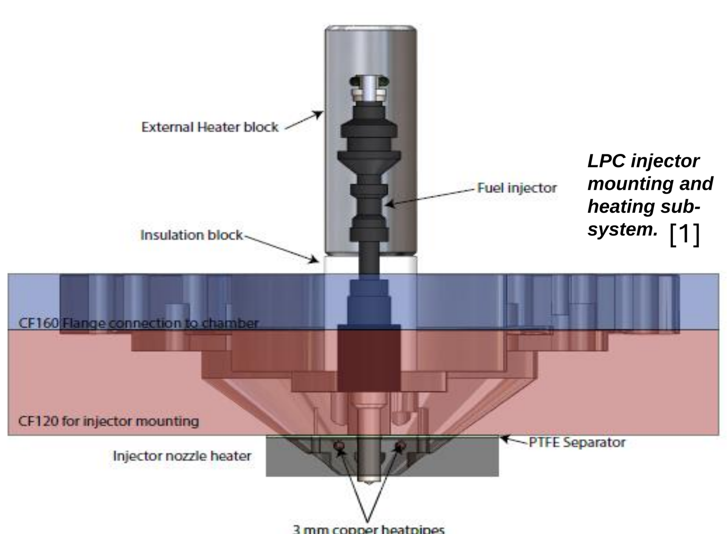


Spray G operating conditions of ECN	
Ambient gas temperature	300 °C (573 K)
Ambient gas pressure	near 6.0 bar (600 kPa)
Ambient gas density	3.5 kg/m3
Ambient gas velocity	Near-quiescent, less than 1 m/s
Fuel injector	Delphi solenoid-activated
Nozzle	8-hole (see detailed nozzle geometry
Fuel injection pressure	20 MPa (200 bar), prior to start of the injection
Fuel temperature at nozzle	363 K (90 °C)
Injection mass	10 mg*
Electronic injection duration	680 µs
Actual injection duration	780 µs



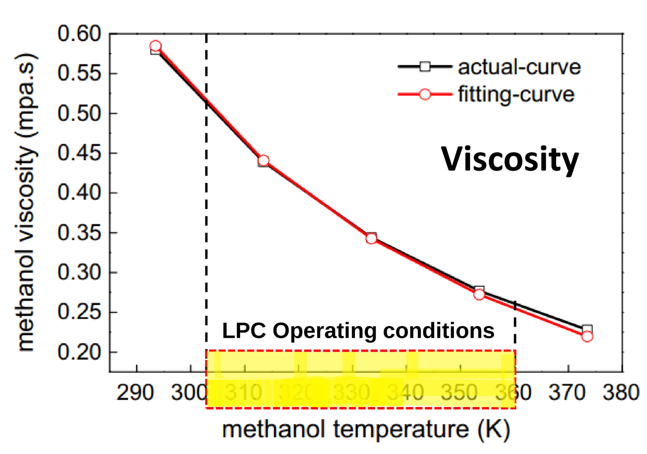
Methodology & Test conditions

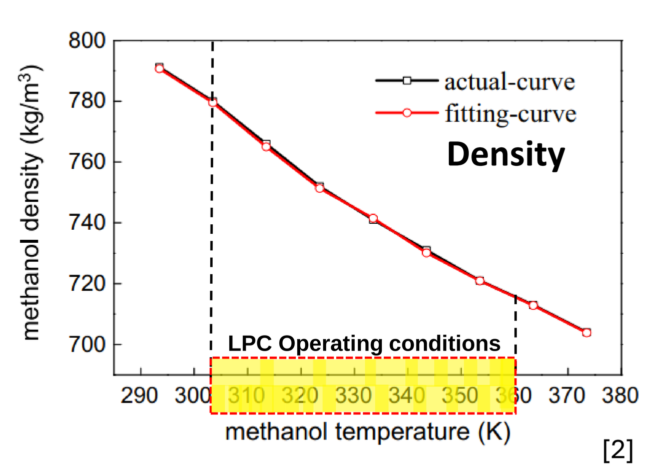
- Injector mounted in-house injector holder.
- 3 mm copper heater set tip temperature



<u>Methanol spray Test Conditions</u>
G2 : 0.5 bar chamber pressure
G3 : 1 atm chamber pressure
<u>Cold conditions</u>
Chamber gas temp: Ambient
Injector Tip Temperature : ambient
<u>Hot conditions</u>
Chamber gas temp: 60 °C
Injector Tip Temperature : 90 °C
Fuel Injection Pressure : 50. 100, 150, 200 bar

Variation in Methanol Properties with temperature





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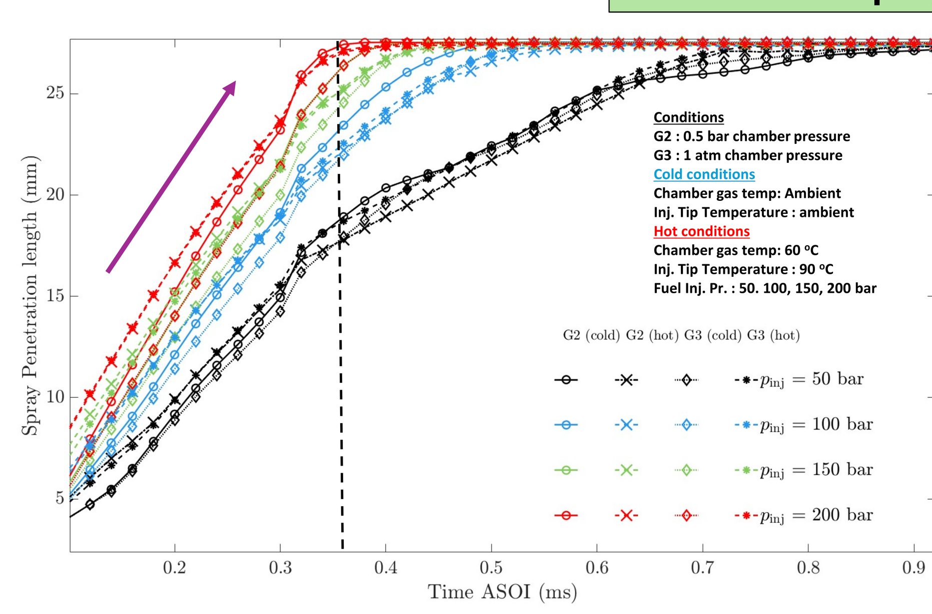
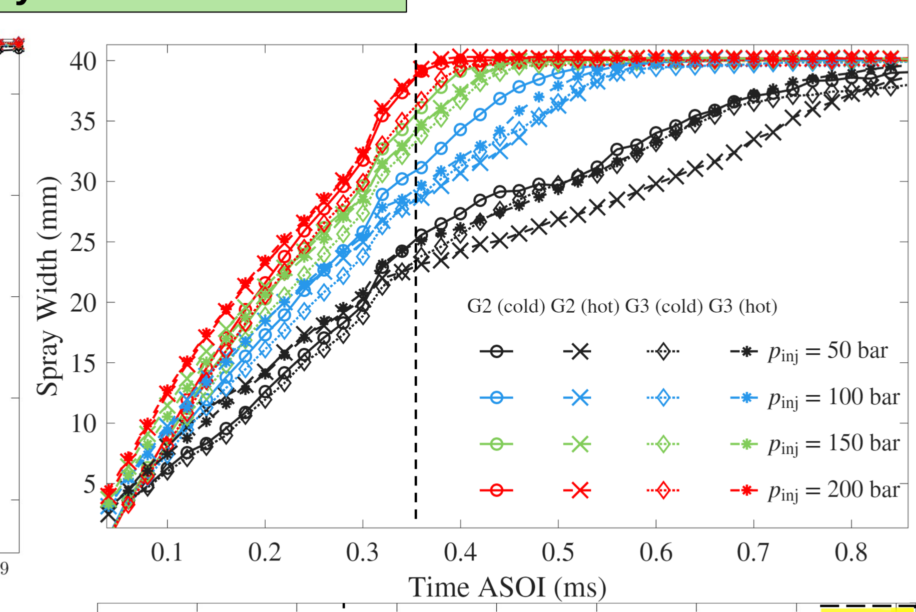
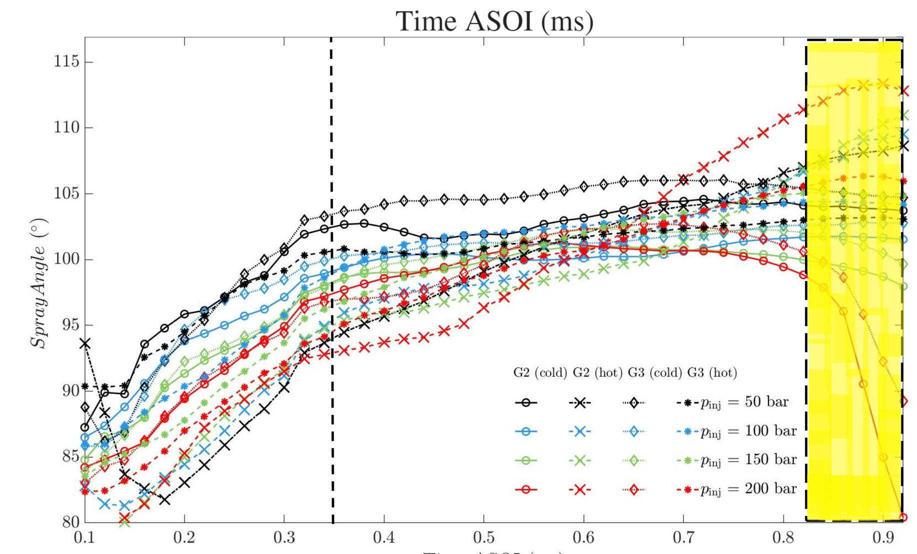
Methanol Spray Characterisation

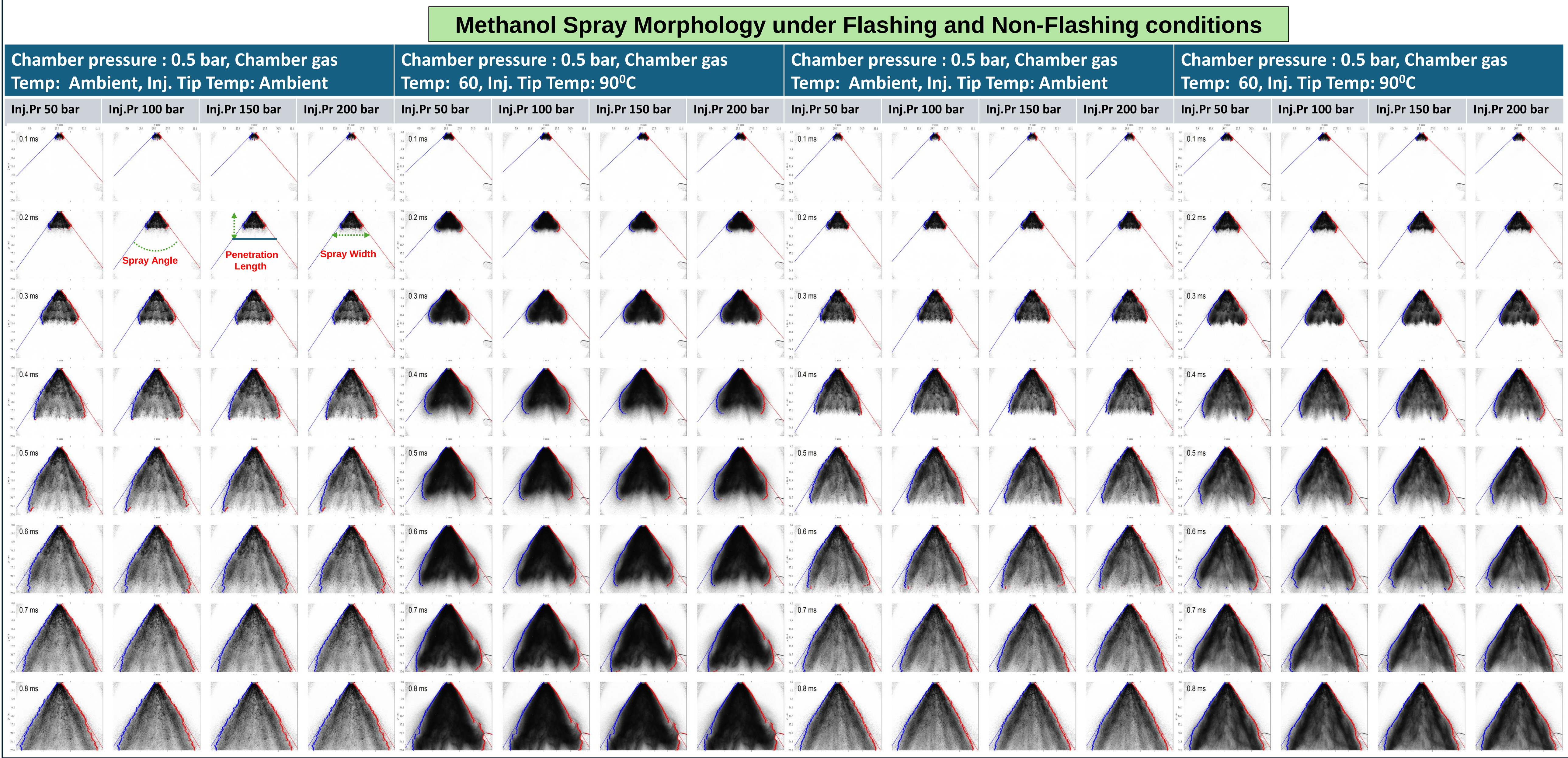




- Under hot gas and tip conditions (G2, G3), spray penetration was reduced compared to cold conditions by up to ~2 % at ~ 0.35 ms ASOI.
- Spray maximum width for G2 showed similar trends at ~2% reduction at 0.35 ms ASOI and an injection pressure of 200 bar.
- Spray cone angle decreased by ~3 % with increasing injection pressure under hot conditions (G2, G3) at ~0.35 ms ASOI. From ~0.65 ASOI there is a marked increase in cone angle for hot G2 conditions compared to cold.



Methanol Spray Morphology under Flashing and Non-Flashing conditions



Conclusion

- The rate of spray penetration and maximum width increased with fuel injection pressure for all cases (G2 and G3) whilst spray angle decreased.
- Spray penetration in hot cases was reduced compared to cold conditions due to reduced evaporation, viscosity and density at elevated temperatures.
- At injection pressures above 100 bar, both G2 and G3 hot conditions exhibited similar spray behaviours, G2 showed greater penetration, due to negative chamber pressure.
- Under G2 hot conditions at 200 bar fuel pressure, the spray angle widened from 0.65 ms ASOI due to flash atomisation effects.
- Spray width was observed to be greater in cold conditions compared to hot conditions, which can be attributed to slower evaporation rates in the cold environment.
- Methanol port fuel or direct injection could be beneficial for marine engines at flash boiling conditions due to reduced penetration rates, cone angle, spray width (reduced wall wetting).
- Further studies are however required to determine droplet size and velocity distributions.

The partnership
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[1] Alex Peter Gander PhD thesis 2024
[2] Chen et al. / Applied Thermal Engineering 114 (2017) 673–684

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