Comparative Analysis of Low-Pressure Injection Dynamics Across Alternative Gaseous Fuels.

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MariNH3 — Clean, green ammonia engines for maritime

This study investigated the low-pressure injection characteristics of helium, hydrogen, methane, ammonia, and propane under laboratory conditions. The research focused on comparing key injection characteristics when delivered through a commercially available automotive injector. A Background Oriented Schlieren (BOS) technique provided high-resolution visualisation of gas dispersion and mixture formation, generating essential empirical data for potential use in computational fluid dynamics (CFD) model validation. A notable aspect of this research was the comparison of helium as an experimental surrogate for hydrogen, and propane as a surrogate for ammonia.

Key Innovations

Background Oriented Schlieren (BOS)

Enables the visualisation of the jet using the distortion of a background pattern due to changes in the refractive index

Experimental Surrogate Comparison

Helium ↔ Hydrogen

No flammability risk

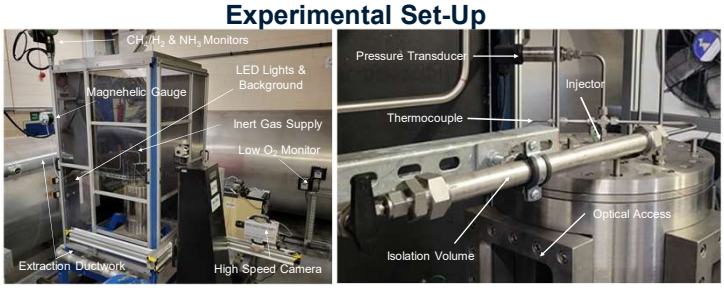
Propane ↔ Ammonia

No toxicity hazard.

Observed Air Entrainment Fraction Method

The observed plume volume and calculated volumetric flow per injection was used to infer the Equivalence Ratio

Experimental Set-Up



Methodology

Automotive Injector

Bosch EV-1/3A Pintle injector, 0.54mm nozzle, Injection Pressure 2- 6 Barg Duration 5-20ms

Safety

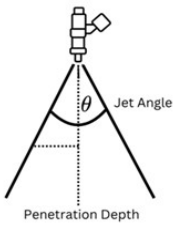
Injected into an Inert N_2 atmosphere, <2% O_2 by molar concentration. Fixed & personal gas monitors were used

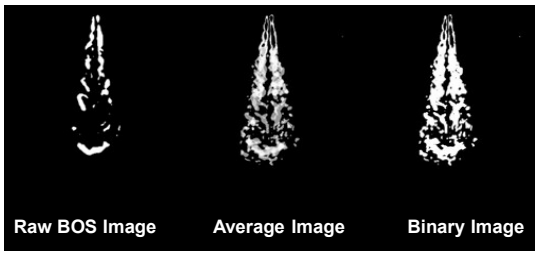
Data Analysis

Used WOFA software, MATLAB processing & ImageJ for the manual measurements

Plume Volume

The jet angle and penetration depth were used to infer the volume of the injection plume (*Vp*).





Volumetric Flow

The volume flow per injection was calculated from the thermocouple and pressure transducer data using

$$PV = nRT$$

Air Fuel Ratio (AFR)

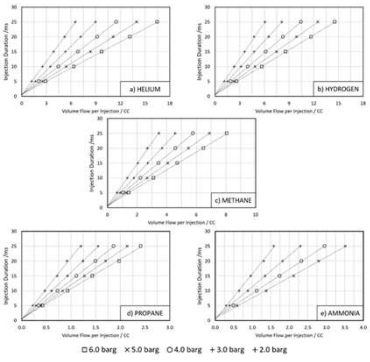
Knowing the volume injected (*Vi*) and the Volume of the Plume (*Vp*) it is possible to calculate the Volumetric AFR

$$AFR_{(Vol)} = \left(\frac{Vp - Vi}{Vi}\right)$$

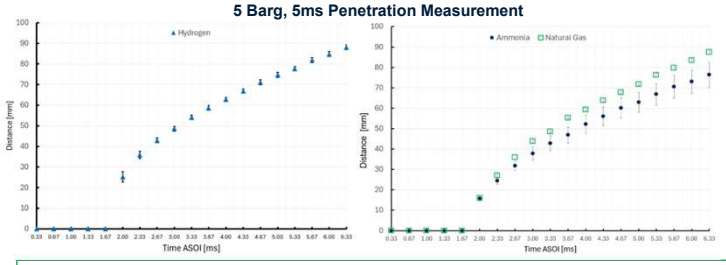
Equivalence Ratio (ϕ)

Using the $AFR_{(vol)}$ the equivalence ratio is determined from the stoichiometric $AFR_{(vol)}$

$$\phi = \frac{AFR_{Vol}}{AFR_{Stoichiometric}}$$



Jet Analysis Results Summary



Significant penetration depth variation with NH_3 possibly due to Joule-Thompson effect

Linear scaling

Penetration ∝ injection duration

Pressure Effects

He, H_2, CH_4 show consistent trends.

Pressure Anomalies

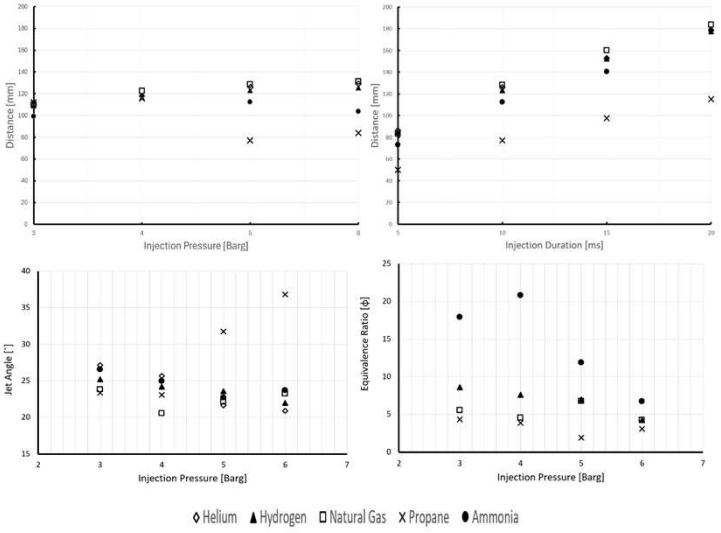
C_3H_8 & NH_3 show non-linear behaviour >4 Barg

Jet Angle

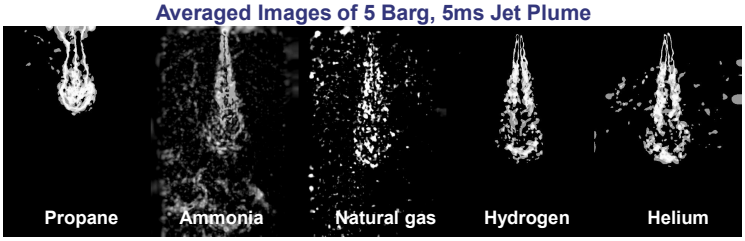
C_3H_8 shows non-linear behaviour >4 Barg

Equivalence Ratio

NH_3 shows non-linear behaviour between 3-4 Barg



Averaged Images of 5 Barg, 5ms Jet Plume



Impact & Applications

Validated Approach

H_e confirmed as excellent H_2 surrogate for safe laboratory testing of port fuel injection systems

CFD Validation Data

Comprehensive dataset enables accurate computational model development for zero-carbon fuel systems

Future Work

Enhanced BOS technique needed for NH_3 to reduce noise;

Joule-Thompson effect requires further investigation.

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