MariNH$_3$

Clean, green ammonia
engines for maritime

Sponsored by: CIMAC International Council Power | Drives | Propulsion

Commissioning of the Cardiff University counter-flow burner; and initial model validation for ammonia fuel blends

Anthony Giles – Cardiff University

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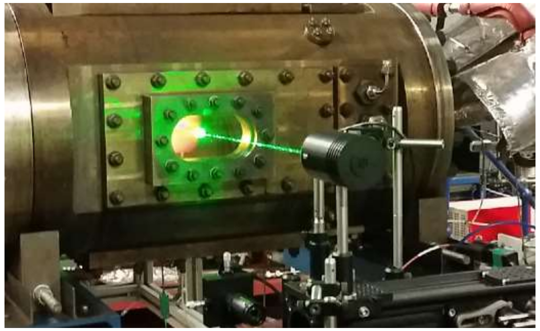

GTRC Combustion Facility, Cardiff University

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GTRC Project Activities

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WP5 Fuel Storage, Handling and Lubrication

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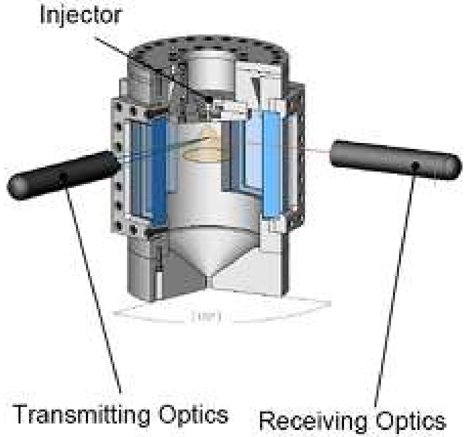
- To characterise and optimise fuel injection methods and operating strategies
- To quantify the interactions of the fuelling with the gas flow, combustion and emissions



Automotive Injector Rig

Utilising previously developed vessel to evaluate comparative behaviour of ammonia both as liquid and vapour.

Initial benchmarking of OEM injector undertaken to develop analytical techniques.

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WP5 Fuel Storage, Handling and Lubrication

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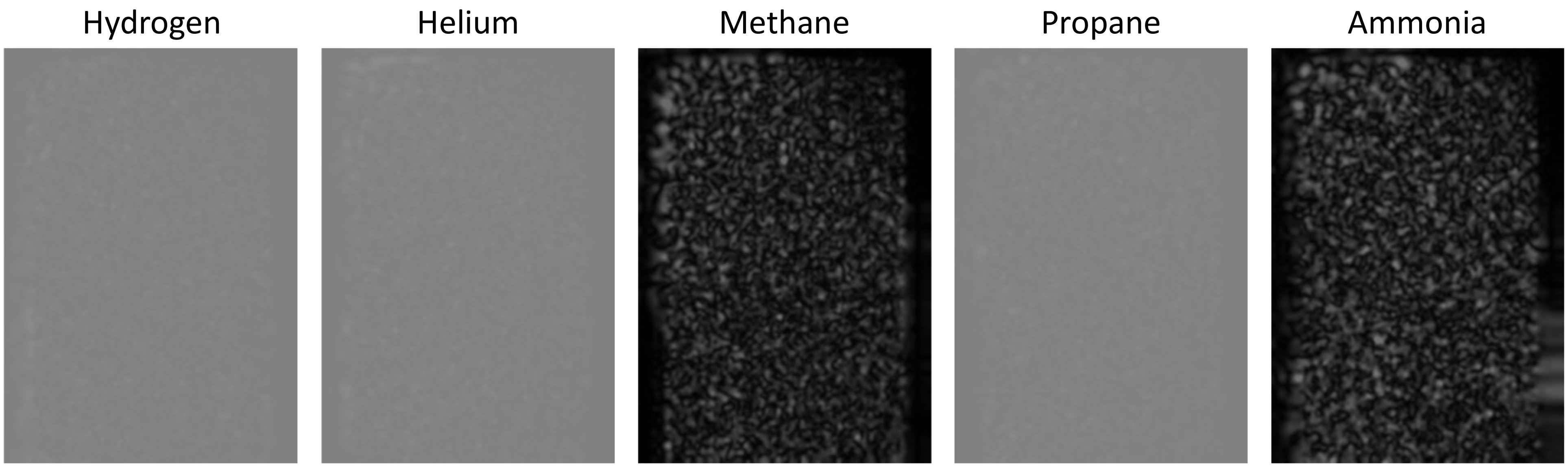
- Example comparison of 6barg results



- Andrew Crook poster presentation

WP6 Combustion Mode Fundamentals

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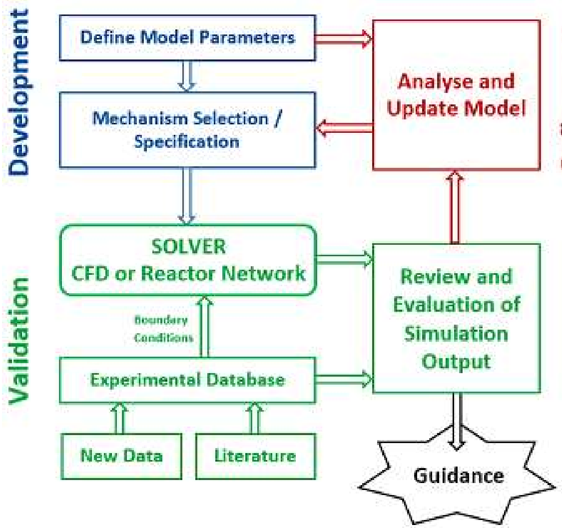
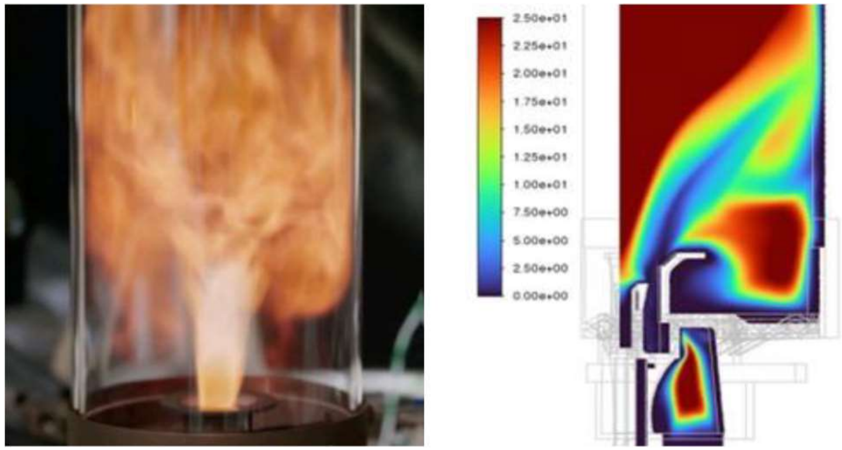
- To quantify characteristics of key fuel blends for use in future combustion simulation codes
- To improve understanding of the combustion and after-treatment chemistry to produce new simulation tools and aid future engine development



Methodology for Mechanism Development



Validation of CFD Simulations

GTRC Counter Flow Burner Development

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Overview

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- In order to develop an understanding of the fundamental characteristics of Ammonia flames and Ammonia blends, it was decided that the GTRC would commission its pressurized counter flow burner (only a few currently operational).
- A counterflow burner setup is used to primarily determine laminar flame speed and extinction strain rate of fuel oxidizer mixtures.
- Potentially, coherent anti-Stokes Raman Spectroscopy (CARS), Rayleigh scattering and laser-induced fluorescence (LIF) can be applied to determine local temperature and species concentrations.

HD image top, High-Speed chemiluminescence (OH*, 4000fps Gn1, Gt 10µs) bottom
GTRC counter flow burner (HPCFB) apparatus

Overview

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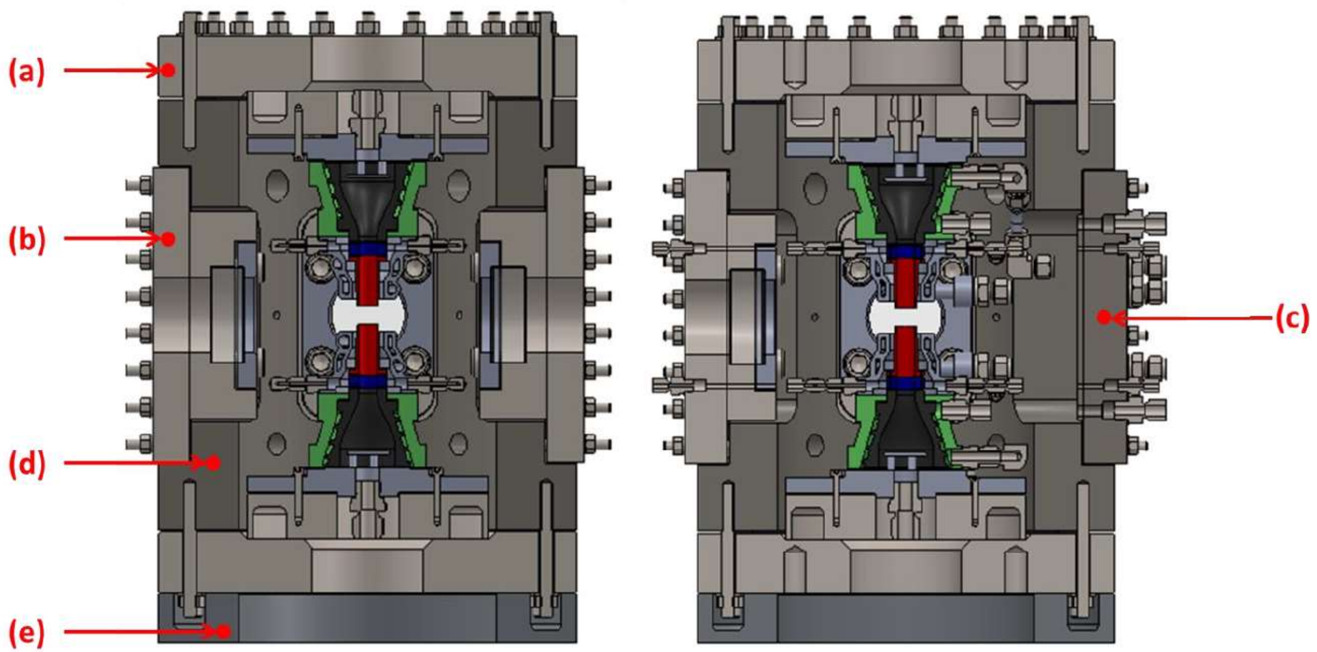
A counter flow burner consists of two opposed nozzles through which air, fuel, inert gases can be introduced. The HPCFB has two such burners mounted within a pressure casing, to allow for operation at elevated pressure and temperature.

a - Water cooled flanges
b - Window plates
c - Instrumentation plate
d - Pressure casing
e - Casing support ring



Sectional view of HPCFB

Chemical Kinetic Simulations

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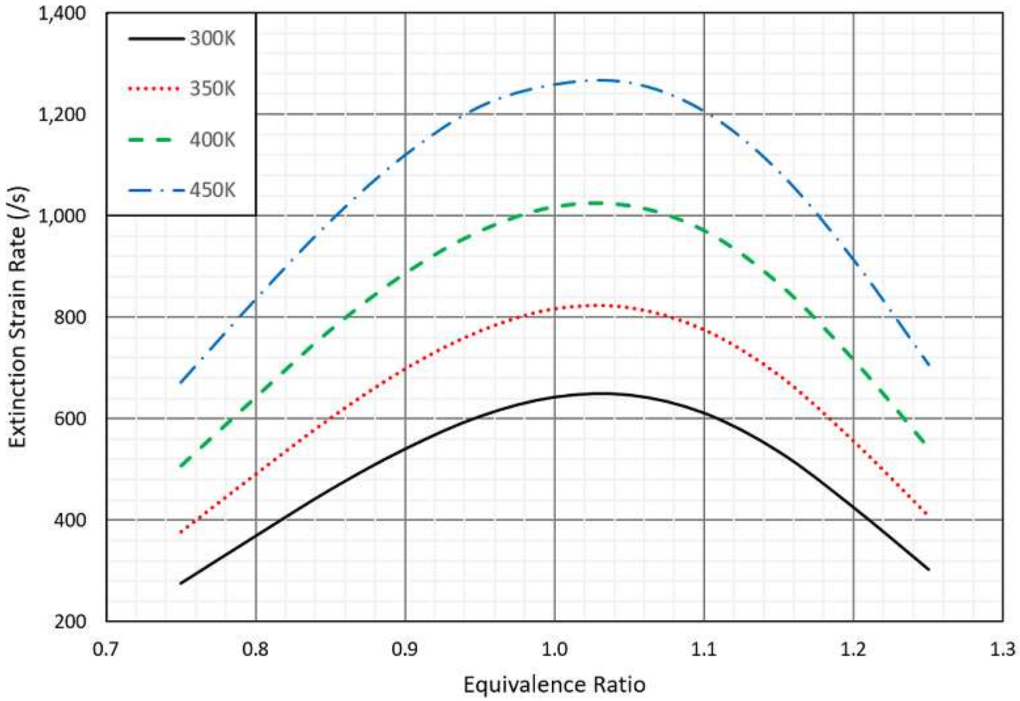

Calculated Extinction Strain Rate – Premix Methane, 25mm BSD, Gri-Mech 3.0 kinetic mechanism

- Majority of benchmarking for the HPCFB will be undertaken using single flame premix methane combustion.
- Well established GRI-Mech 3.0 mechanism chosen for comparison with experimental data.
- Utilises 53 species (including argon) and 325 reaction pathways.

http://www.me.berkeley.edu/gri_mech/

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Chemical Kinetic Simulations

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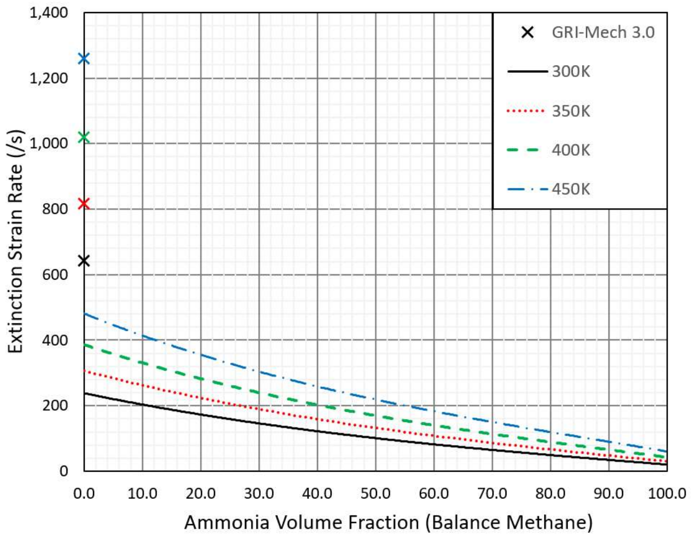
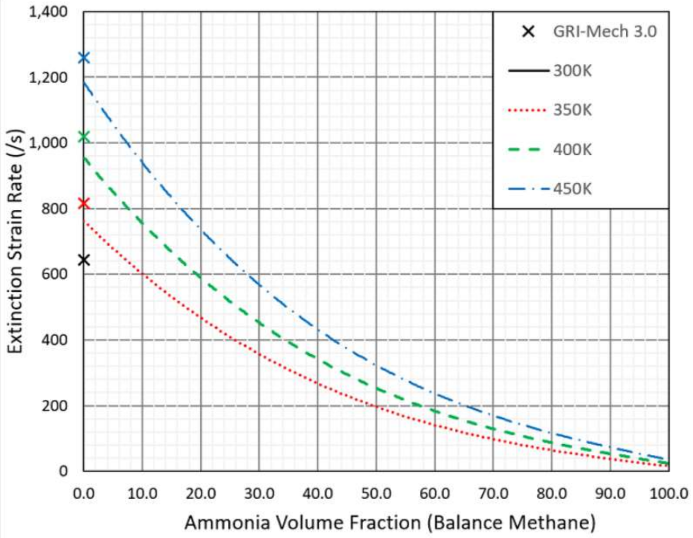
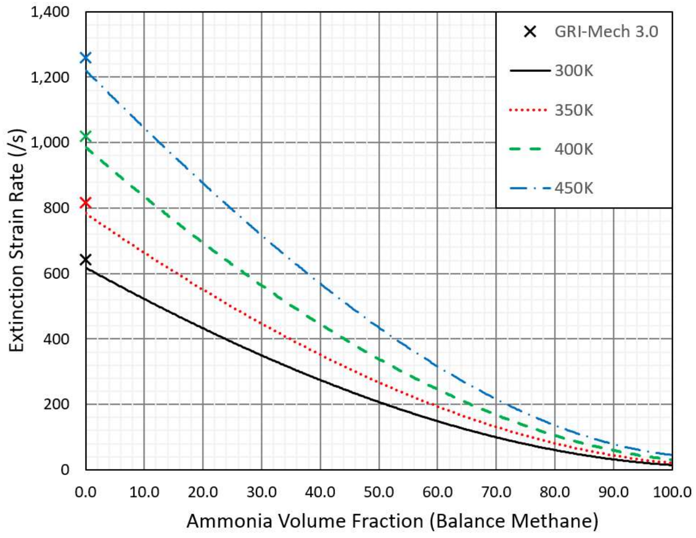
- Chemical kinetic mechanisms for ammonia/methane blends have evolved over time



Tian Z. et al (2009)
- 84 species and 703 reaction pathways
- doi:10.1016/j.combustflame.2009.03.005



Okafor EC. et al (2019)
- 42 species and 130 reaction pathways
- doi.org/10.1016/j.combustflame.2019.03.008



Arunthanayothin S. et al (2020)
- 157 species and 2444 reaction pathways
- doi.org/10.1016/j.proci.2020.07.061

Chemical Kinetic Simulations

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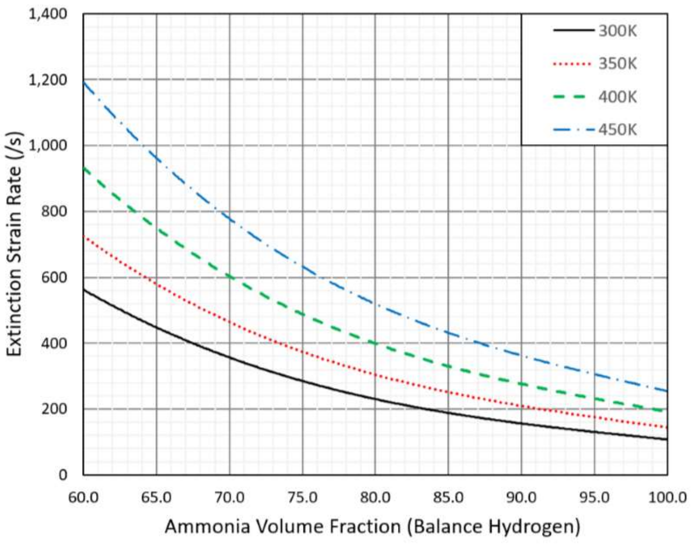
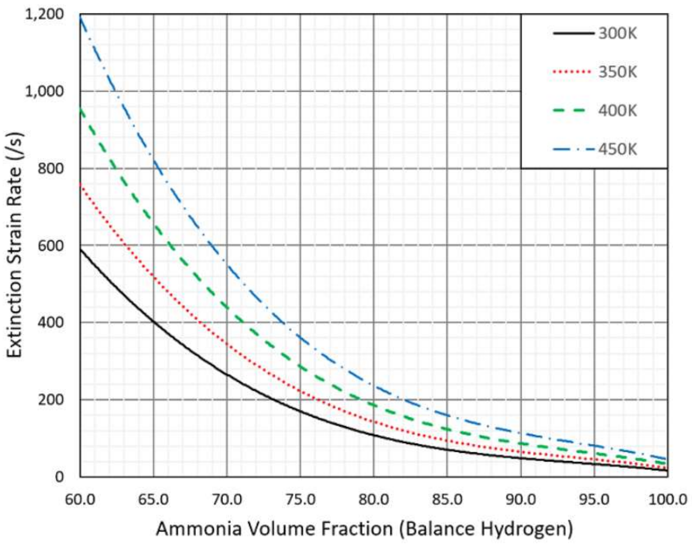
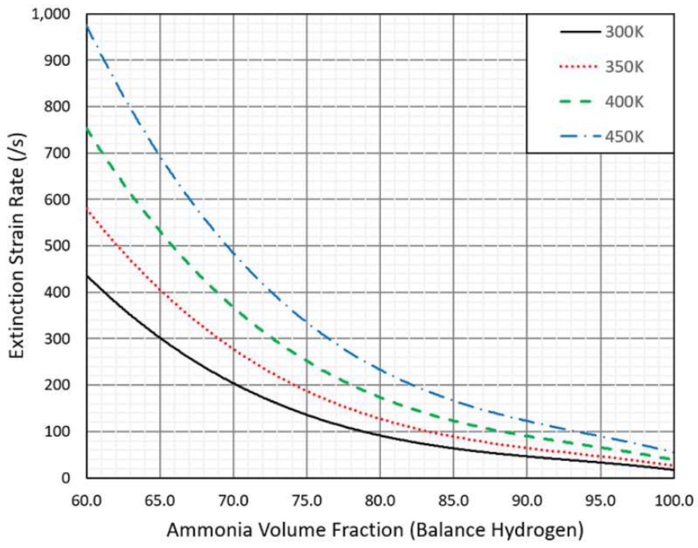
- Likewise for blends of ammonia and hydrogen



Duynslaegher C. et al (2012)
- 19 species and 80 reaction pathways
- doi.org/10.1016/j.combustflame.2012.06.003



Nakamura H. et al (2017)
- 33 species and 232 reactions
- doi.org/10.1016/j.combustflame.2017.06.021



Gotama GJ. et al (2021)
- 26 species and 119 reaction pathways
- doi.org/10.1016/j.combustflame.2021.111753

Chemical Kinetic Simulations

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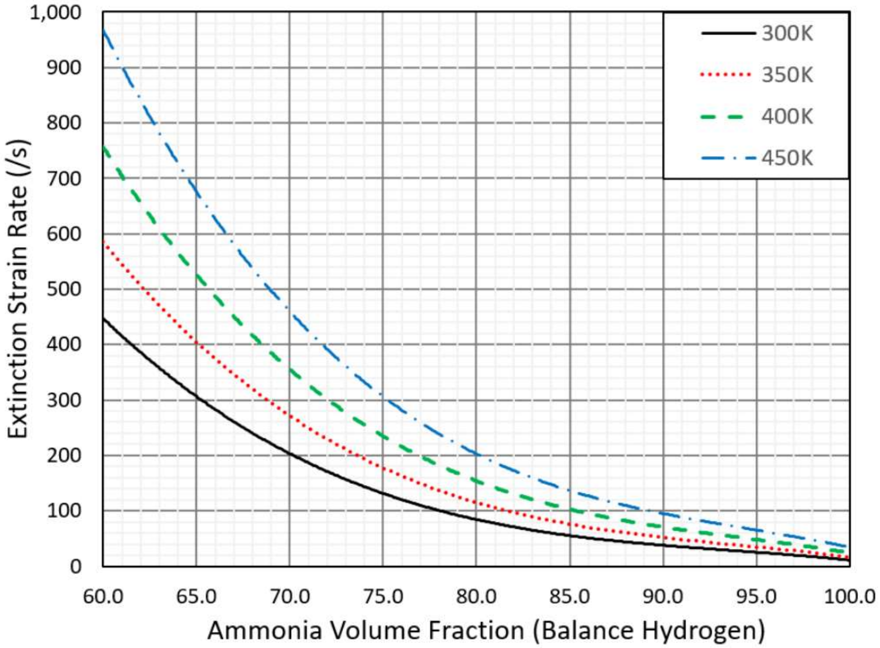
- Refined kinetic mechanisms for ammonia / hydrogen blends developed



Alnasif A. et al (2025)

- 21 species and 64 reaction pathways
- doi.org/10.18573/jae.46

- Reduced mechanism more efficient for use in CFD. Proven performance in evaluation studies.

- Ali Alnasif poster presentation

Recent Experimental Results

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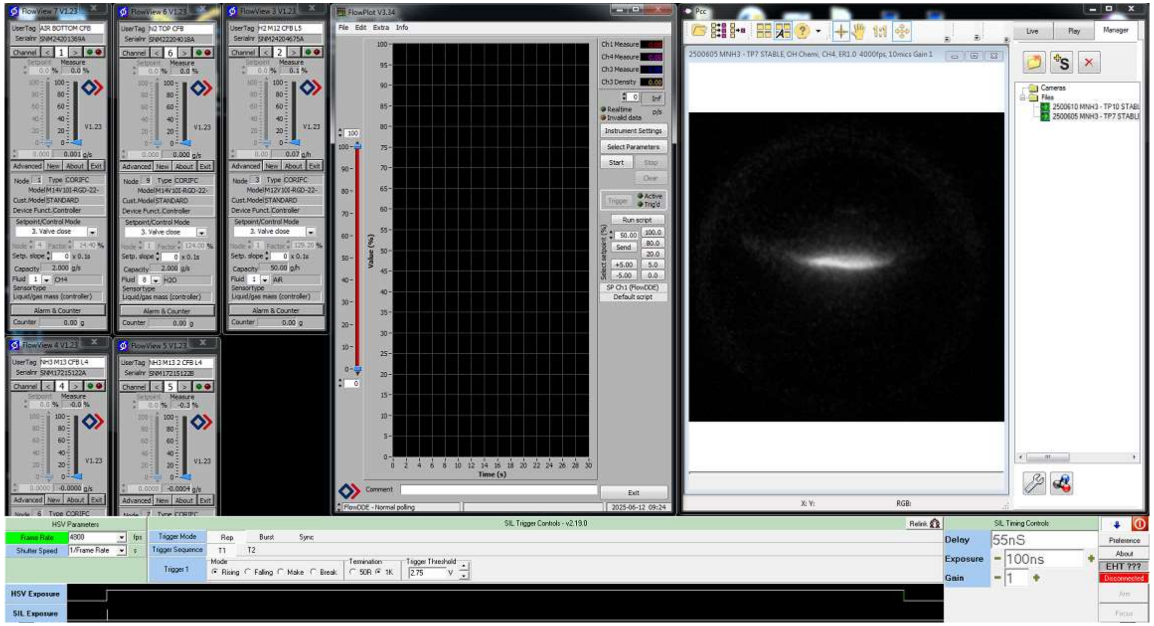
- Upgrades made to counter flow rig to improve temperature control and monitoring.
- Temperature monitoring of internal vessel and diluted exhaust gas temperature key in selection of PSV and pressure control valve.
- Rig control involves complex balancing of multiple gas flows; ongoing improvements planned.



CountCurrent Flow monitoring assembly

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Recent Experimental Results

Methane Benchmarking

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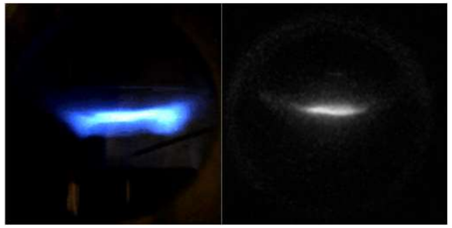
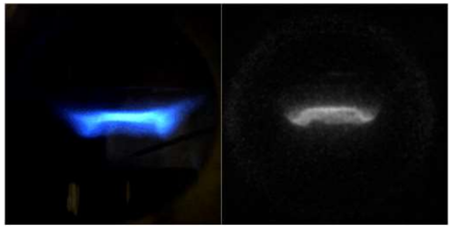
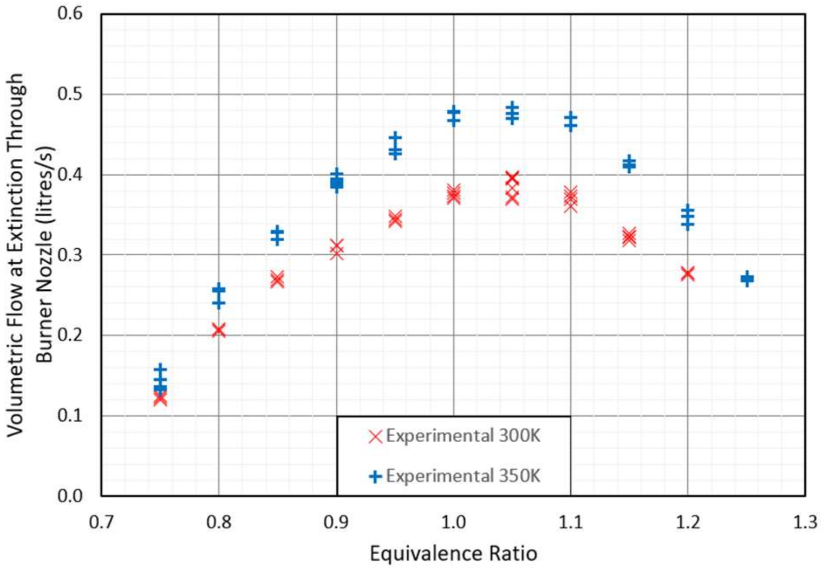


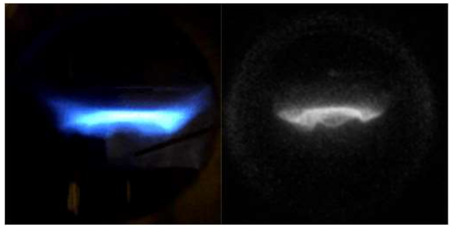
Methane 350K ER 1.0



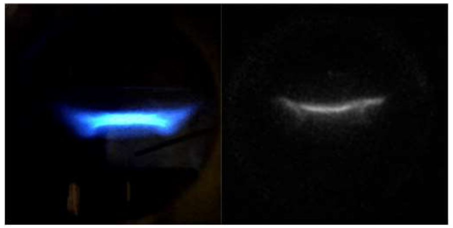
Methane 350K ER 0.9

Methane 350K ER 0.8





Methane 350K ER 1.1



Methane 350K ER 1.2

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Recent Experimental Results

Methane Benchmarking

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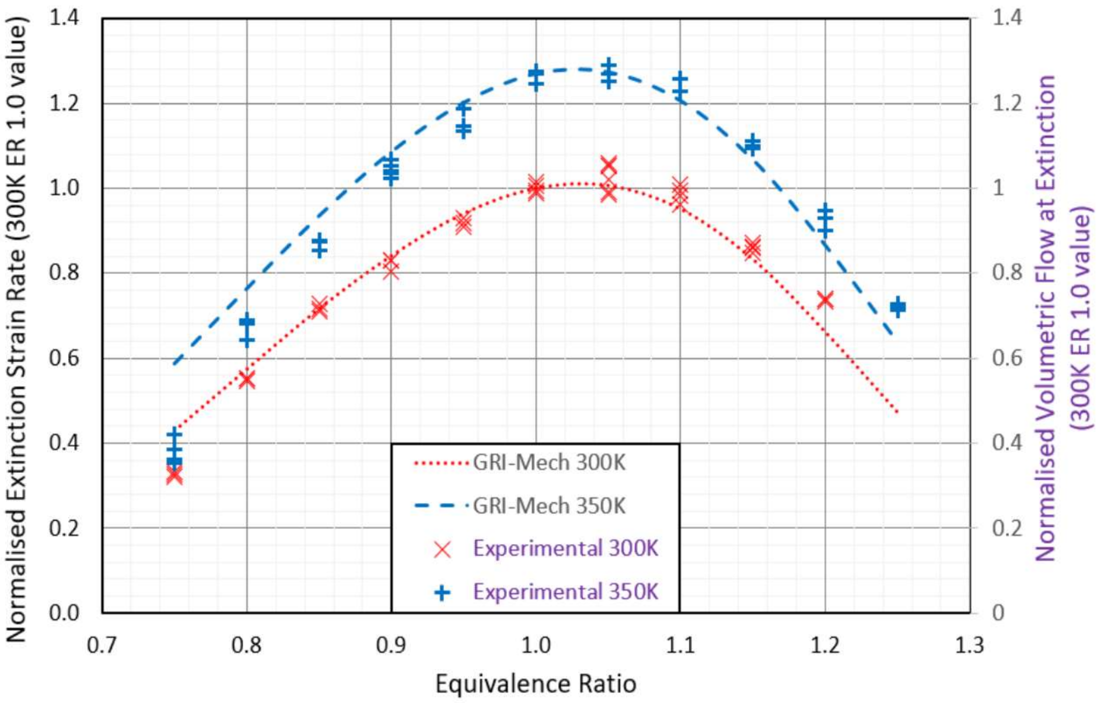

- Normalising both experimental and Chemkin results to 300K ER1.0 point allows for a direct comparison of trends.
- Work underway to assign extinction strain rate values to experimental results.
- Initial observations are that there is a good agreement between experimental work and modelling.

Recent Experimental Results

Ammonia Methane Results

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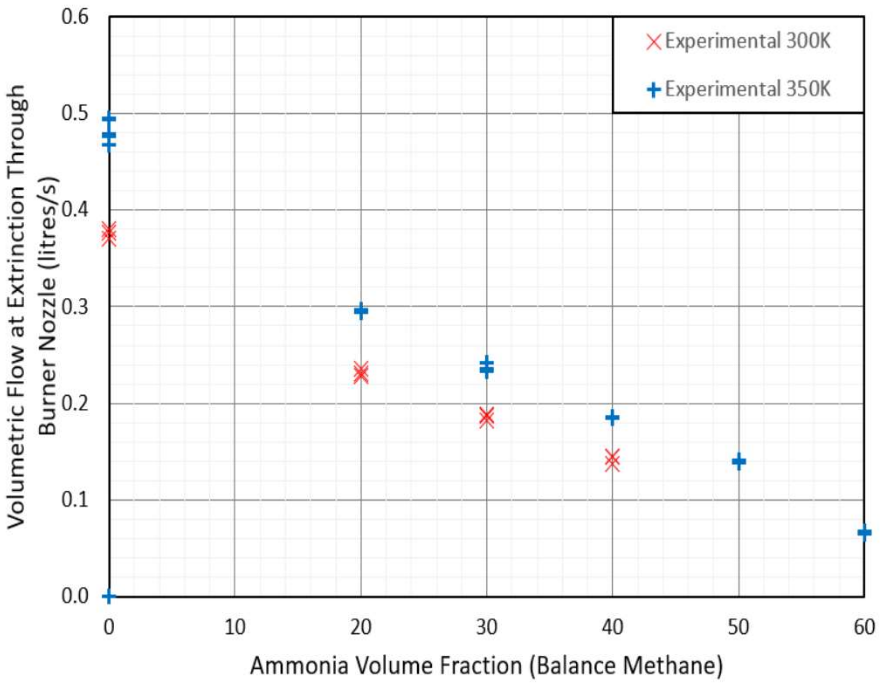

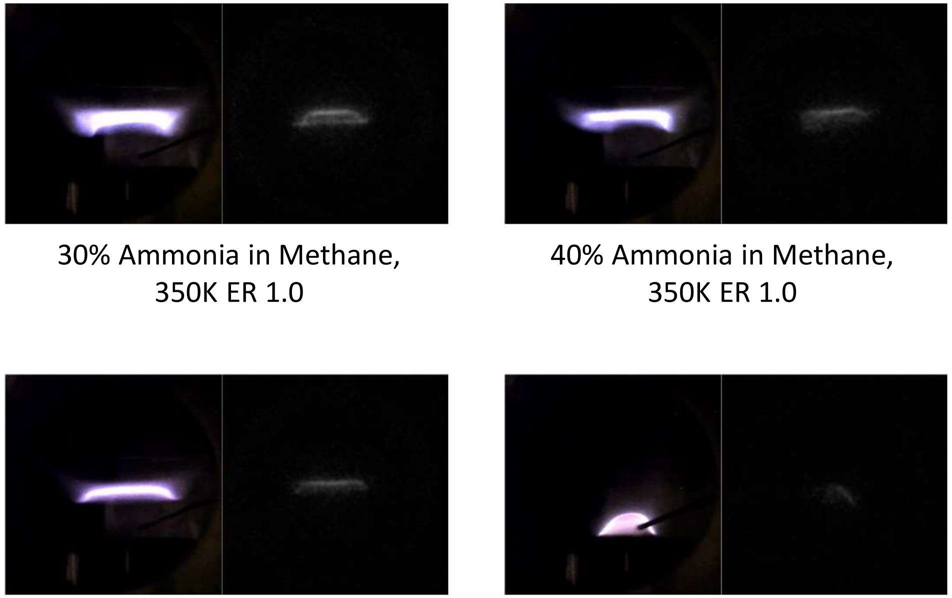

30% Ammonia in Methane, 350K ER 1.0

40% Ammonia in Methane, 350K ER 1.0

50% Ammonia in Methane, 350K ER 1.0

60% Ammonia in Methane, 350K ER 1.0

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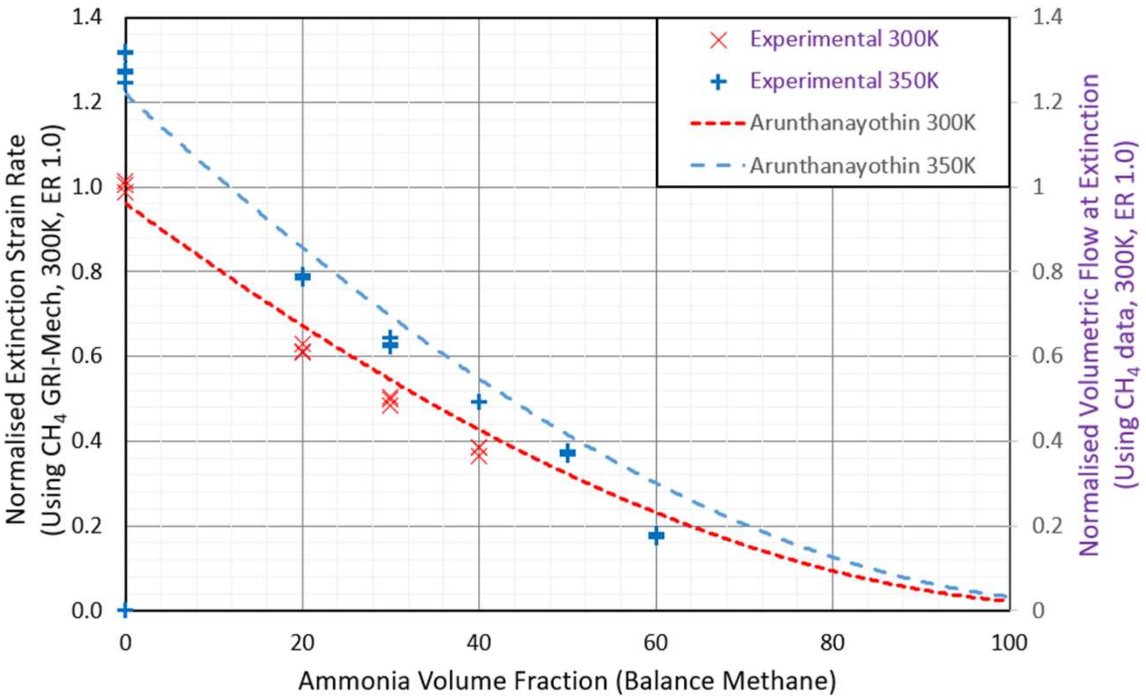
Recent Experimental Results

Ammonia Methane Results



- Again, results currently presented in normalised fashion for comparison.
- Okafor mechanism appears to under predict when compared to experimental results.
- By comparison Arunthanayothin mechanism slightly over predicts at intermediate methane percentages.

Recent Experimental Results

Ammonia Hydrogen Results

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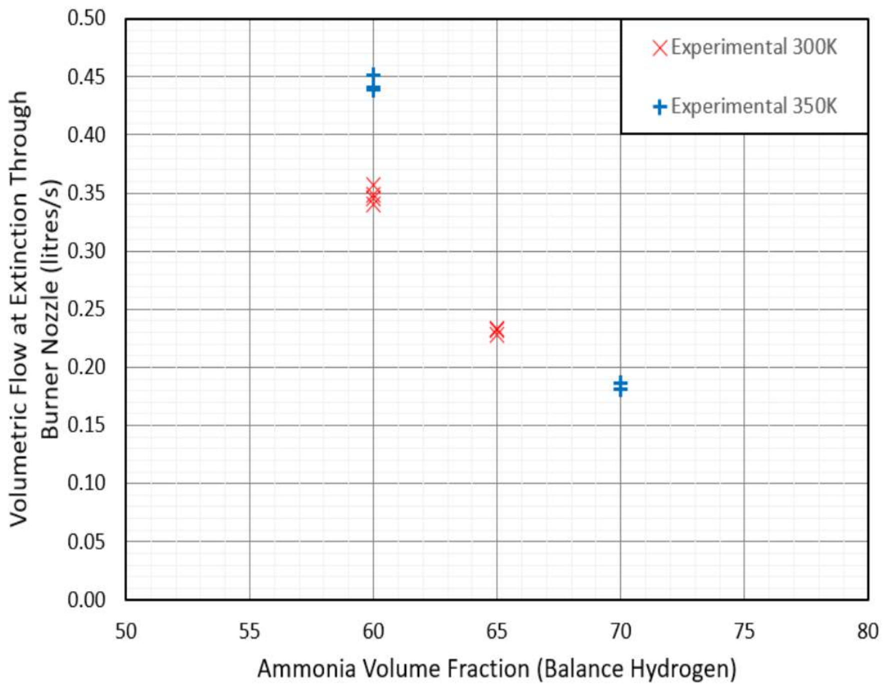
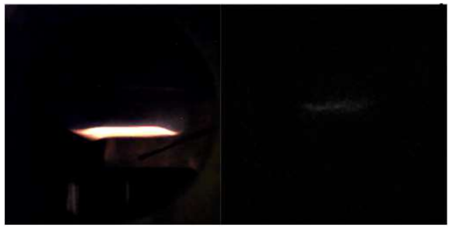


60% Ammonia in Hydrogen, 350K ER 1.0



70% Ammonia in Hydrogen, 350K ER 1.0

- Operational range of burner limited by current configuration (nozzle gap, flow meters etc).

Recent Experimental Results

Ammonia Hydrogen Results

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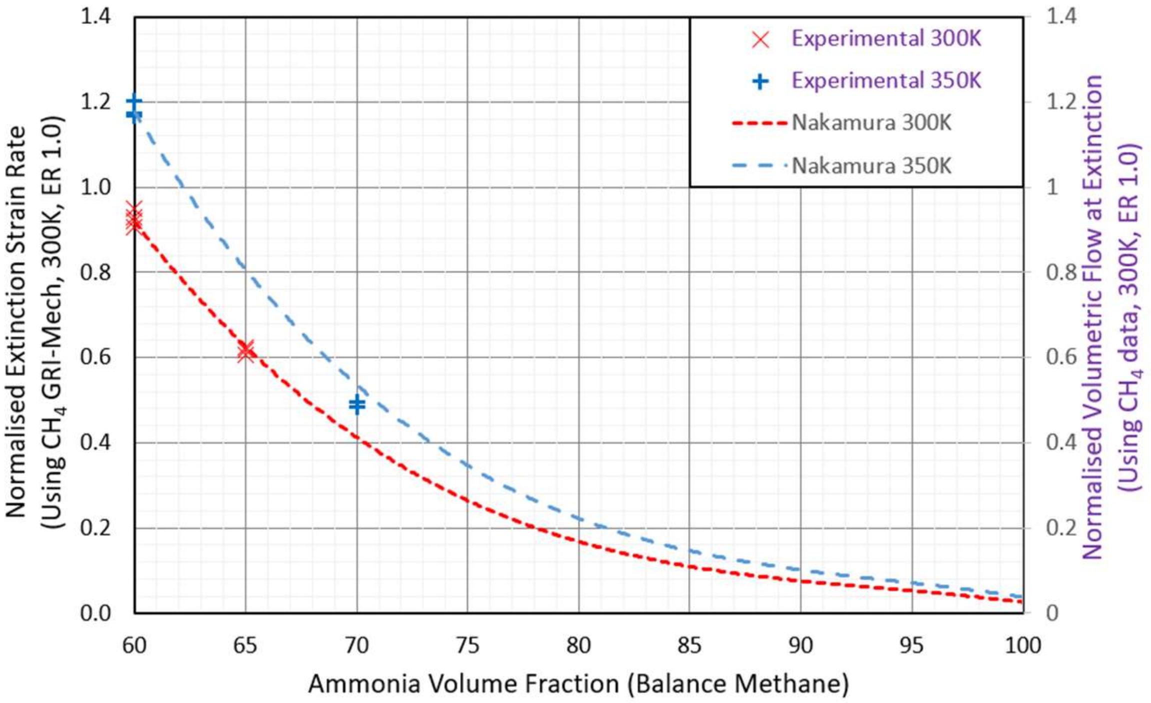

- Limited ammonia hydrogen results, again presented in normalised fashion.
- Quite good agreement to the Nakamura mechanism.
- More data required, with determination of the extinction strain needed for accurate model comparison.

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Current Work, Future Plans

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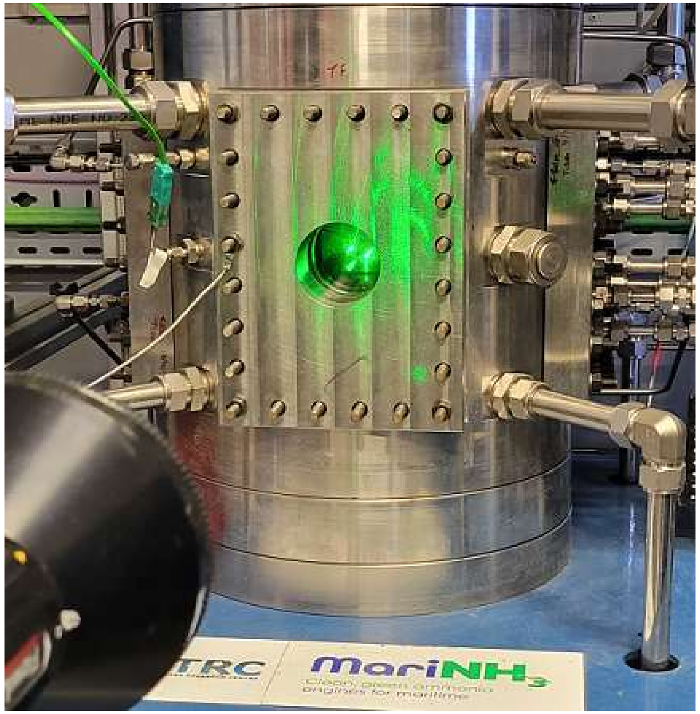
- In process of taking velocity measurements to allow for the determination of relationship between volume flux and strain rate.
- Repeating, expanding data sets for blends of ammonia with both methane and hydrogen. Additional fuels to be include.
- Evaluating additional kinetic mechanisms
- Ordering valve etc. to facilitate pressurisation of counter flow vessel.



LDA system

Summary

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- The MariNH3 project has facilitated the commissioning of a pressurised counter flow burner at the GTRC facility operated by Cardiff University.
- Initial benchmarking trials undertaken. Validation measurements are underway to assign extinction strain rate values to the data generated.
- Ready to now move on to pressurised and higher temperature operation, providing unique data for future chemical kinetic model development and validation of ammonia fuel blends.

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Laser Doppler Anemometry (Velocimetry)

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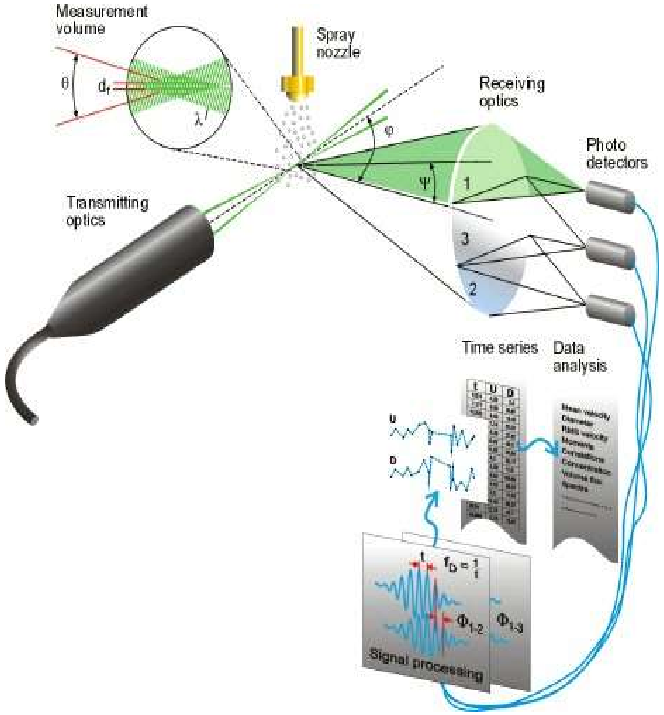
- Laser Doppler Anemometry or Velocimetry (LDA or LDV) is a non-intrusive optical technique used to measure the velocity of fluid flows or the velocity of moving objects. It works by shining a laser beam onto a moving object and measuring the Doppler shift of the scattered light. This shift in frequency is directly proportional to the velocity of the object
- The measurement point is defined by the intersection of two focused laser beams and the measurements are performed on single particles as they move through the sample volume.



LDA Apparatus

WP6 Combustion Mode Fundamentals - Chemical Kinetic simulations

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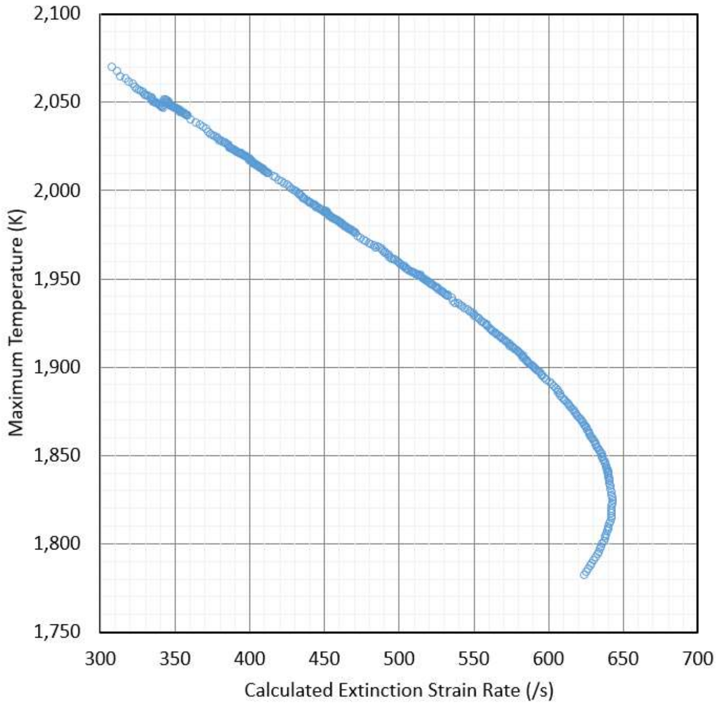
- To assist with the benchmarking of the HPCFB, a range of simulations have been carried out using the opposed flow flame reactor within Ansys Chemkin.
- Like experimental data, the results of simulations are dependent on several factors.
- Several reaction mechanisms have been chosen for methane, ammonia/methane and ammonia/hydrogen studies. Additional mechanisms will continue to be evaluated.



Individual simulations passing through Strain maxima

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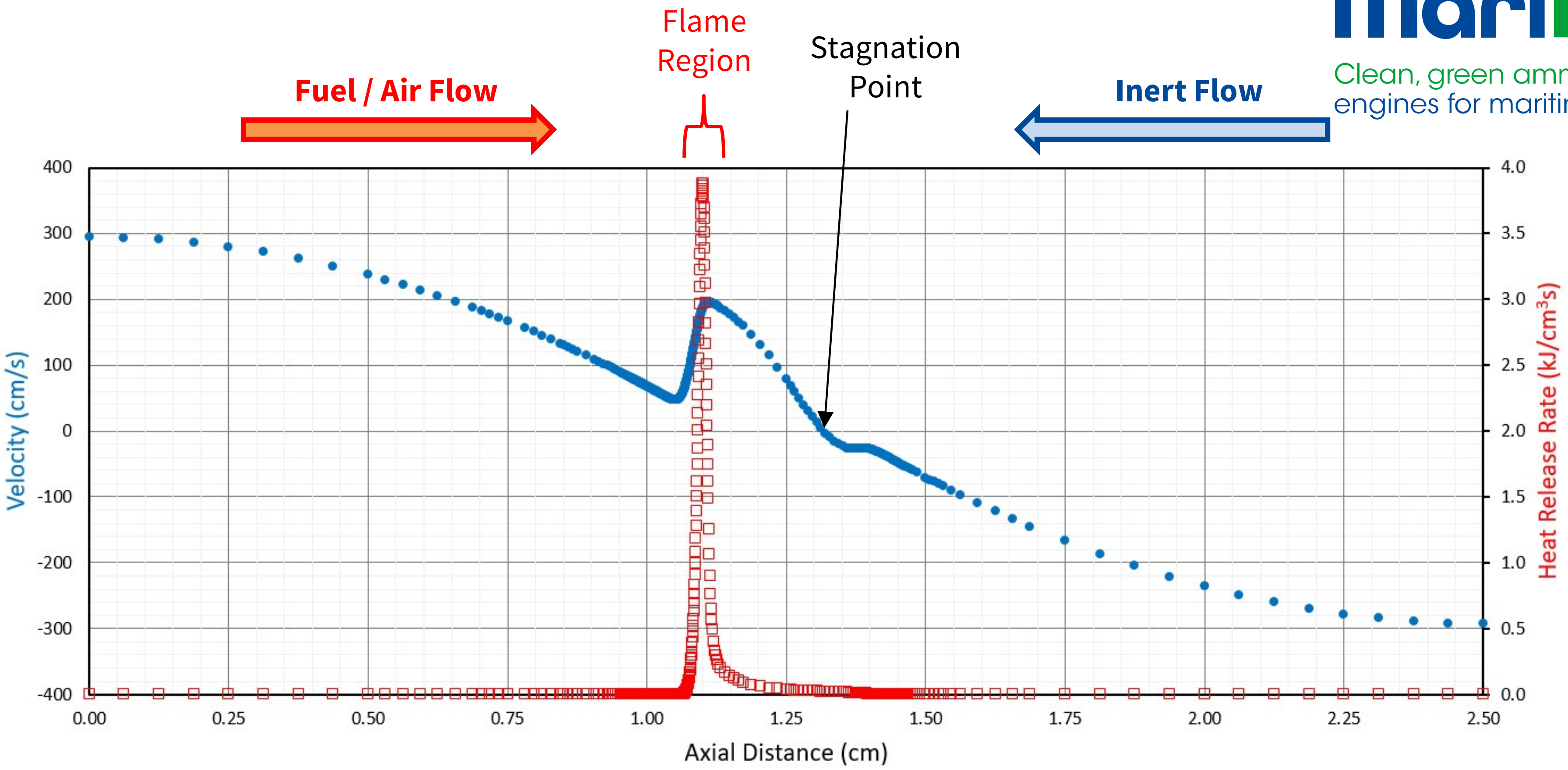

Chemkin simulation of a stable, stoichiometric premixed (single) methane flame – 25mm BSD, 300K Preheat, Gri-Mech 3.0 kinetic mechanism

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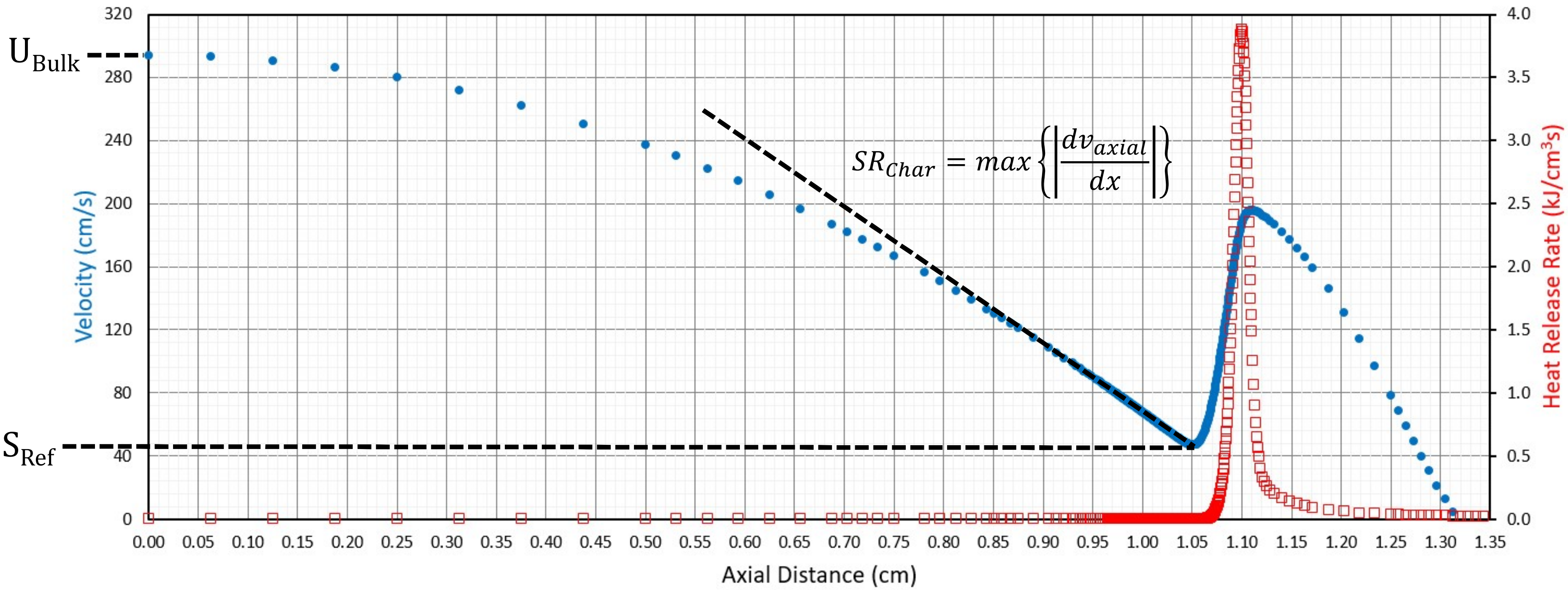

Determination of Characteristic Strain and Reference Flame Speed from counterflow burner velocity profile

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