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Clean, green ammonia
engines for maritime

Fundamental Combustion Tests on Ammonia Sprays and Fuel Blends

Anthony Giles – Cardiff University

Ask questions online

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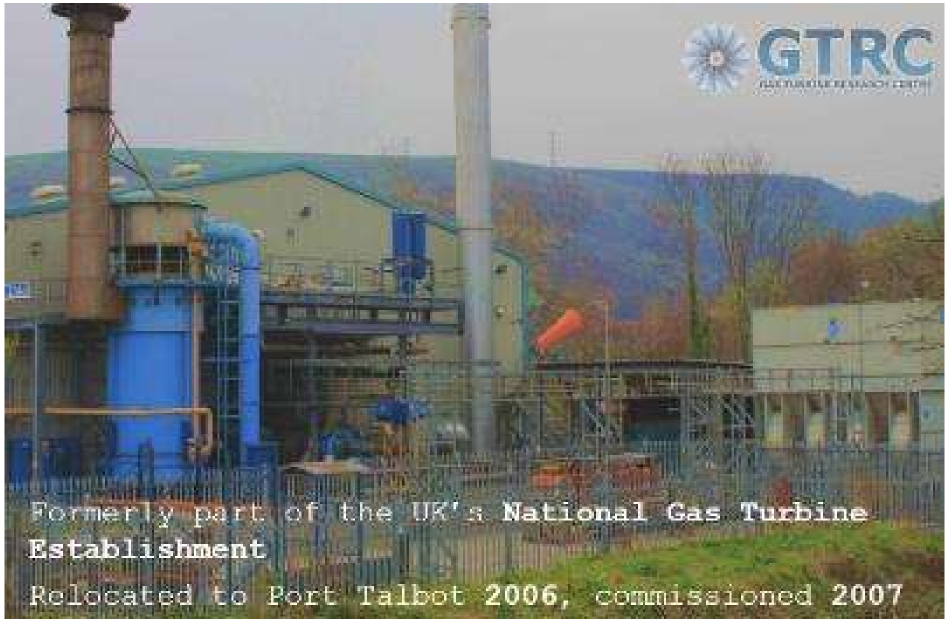

GTRC Facility, Cardiff University

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GTRC Project Activities

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GTRC Project Activities

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- WP6 Combustion Mode Fundamentals

To quantify the laminar and turbulent burning velocities 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

- WP5 Fuel Storage, Handling and Lubrication

To characterise and optimise fuel injection methods and operating strategies

To quantify the interactions of the fuelling with the gas flow, combustion and emissions

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WP6 Combustion Mode Fundamentals

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WP6 Combustion Mode Fundamentals - 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 counterflow burner.
- 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.

GTRC counterflow burner (HPCFB) apparatus

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A counterflow 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.

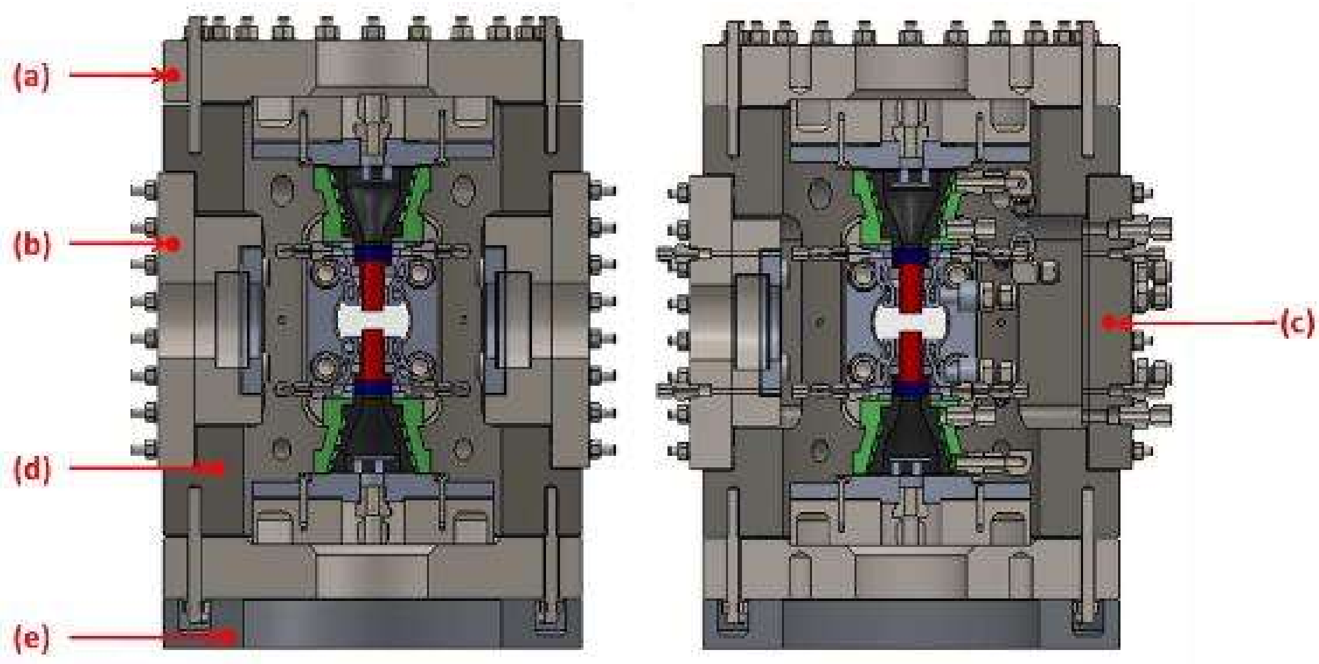
a - Water cooled flanges

b - Window plates

c - Instrumentation plate

d - Pressure casing

e - Casing support ring



Sectional view of HPCFB

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WP6 Combustion Mode Fundamentals - Principles of a Counterflow burner

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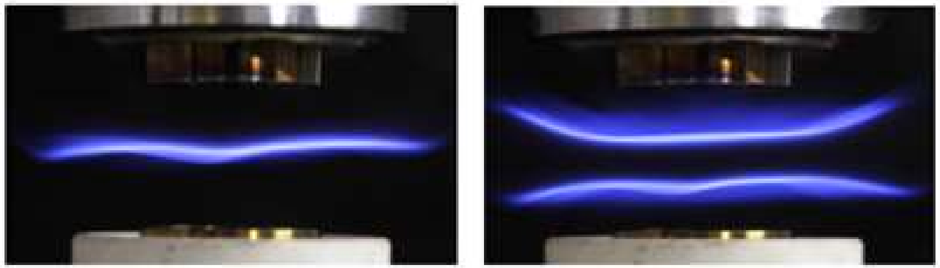
- Counter flow burners can operate in three main configurations, with the flows from each nozzle balanced on a velocity or momentum basis:

Diffusion	- Fuel flow is balanced against an oxidizer flow.
Premix single flame	- A fuel air mixture is balanced against an inert (nitrogen) flow.
Premix twin flame	- Fuel air mixtures are balanced from each of the nozzles.



Images of a single (left) and twin (right) counterflow burner flames

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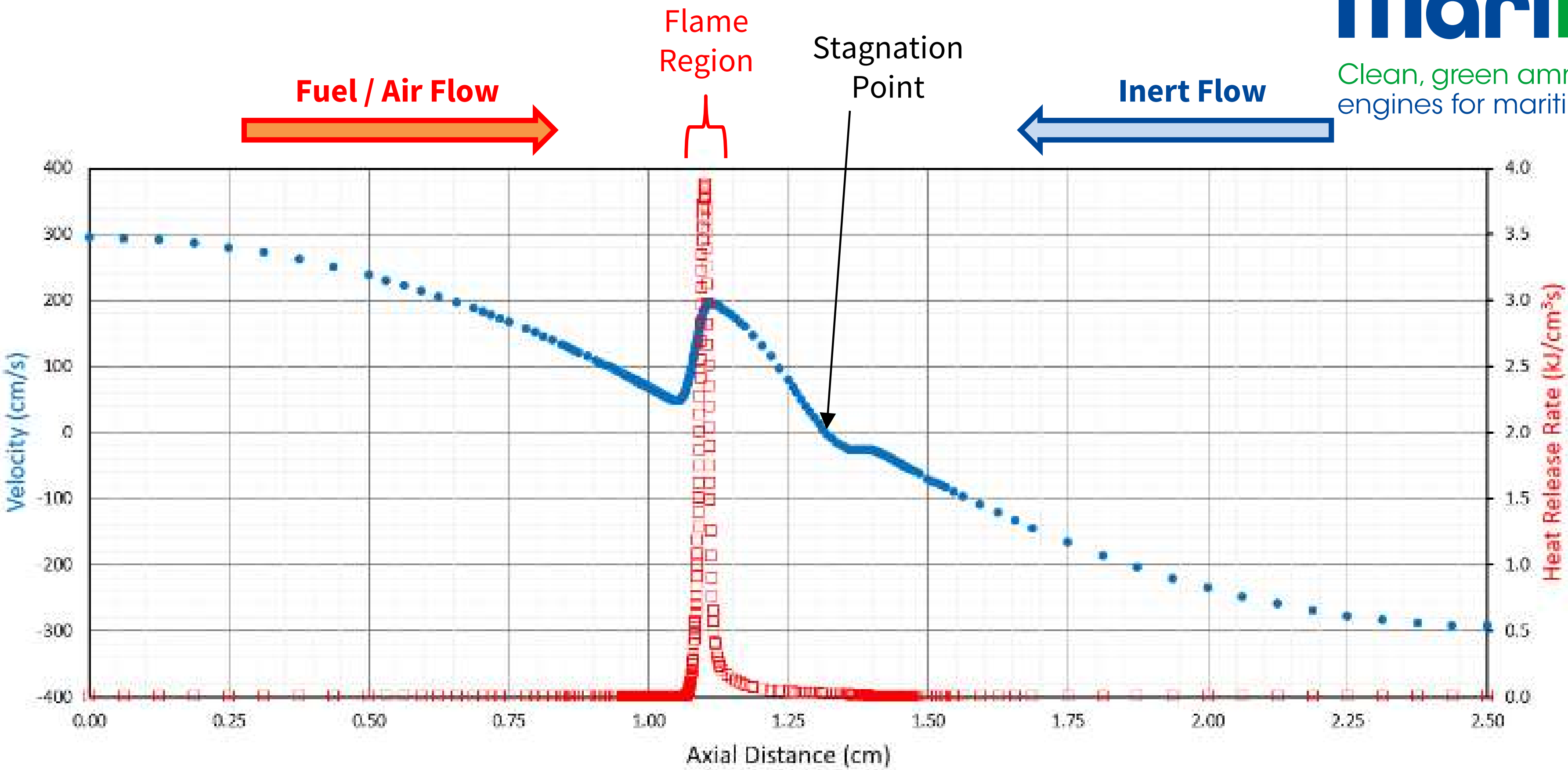

Chemkin simulation of a stable, stoichiometric premixed (single) methane flame – 25mm BSD, 300K Preheat, Gri-Mech 3.0 kinetic mechanism

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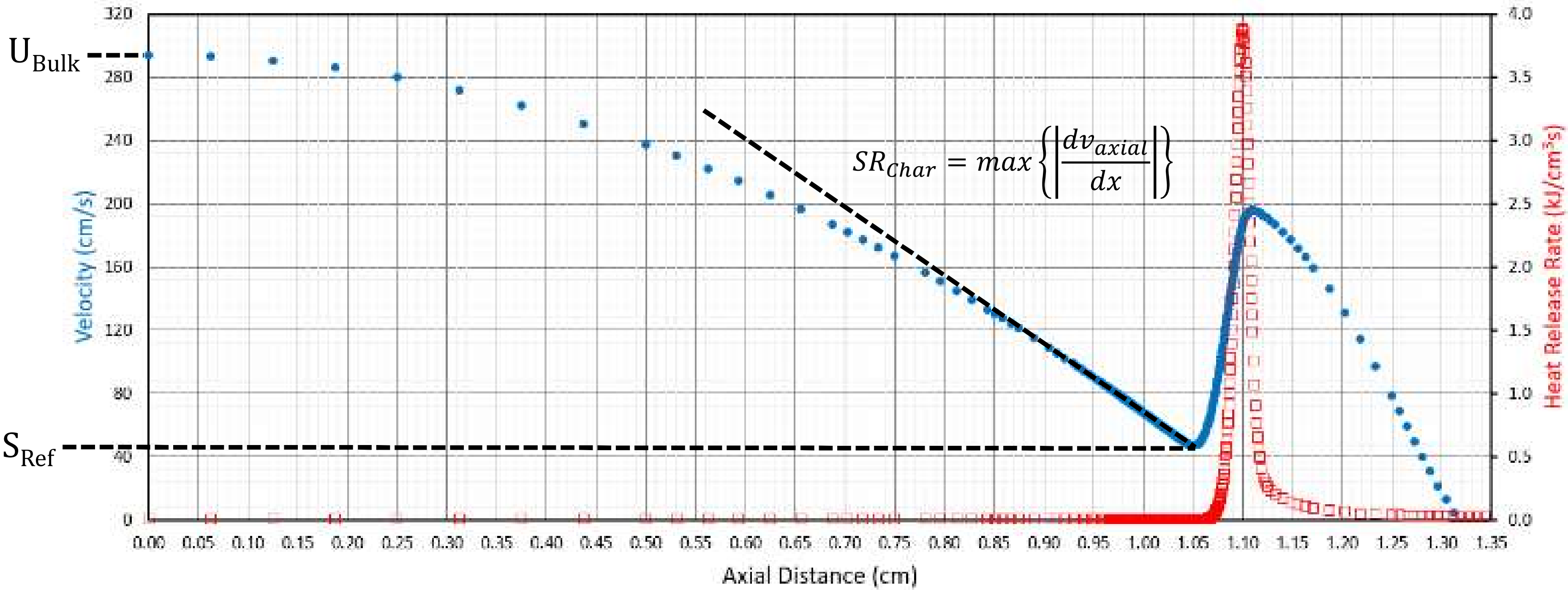

Determination of Characteristic Strain and Reference Flame Speed from counterflow burner velocity profile

WP6 Combustion Mode Fundamentals - Chemical Kinetic simulations

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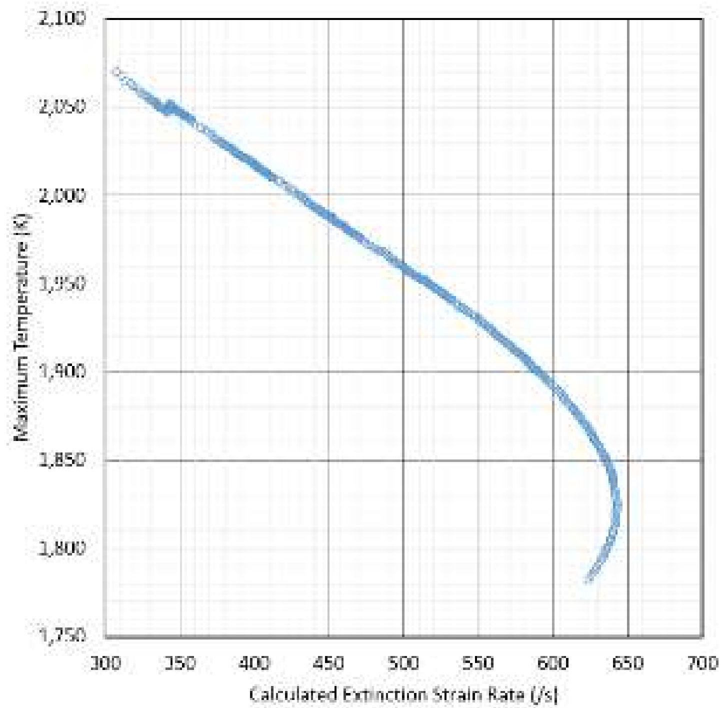
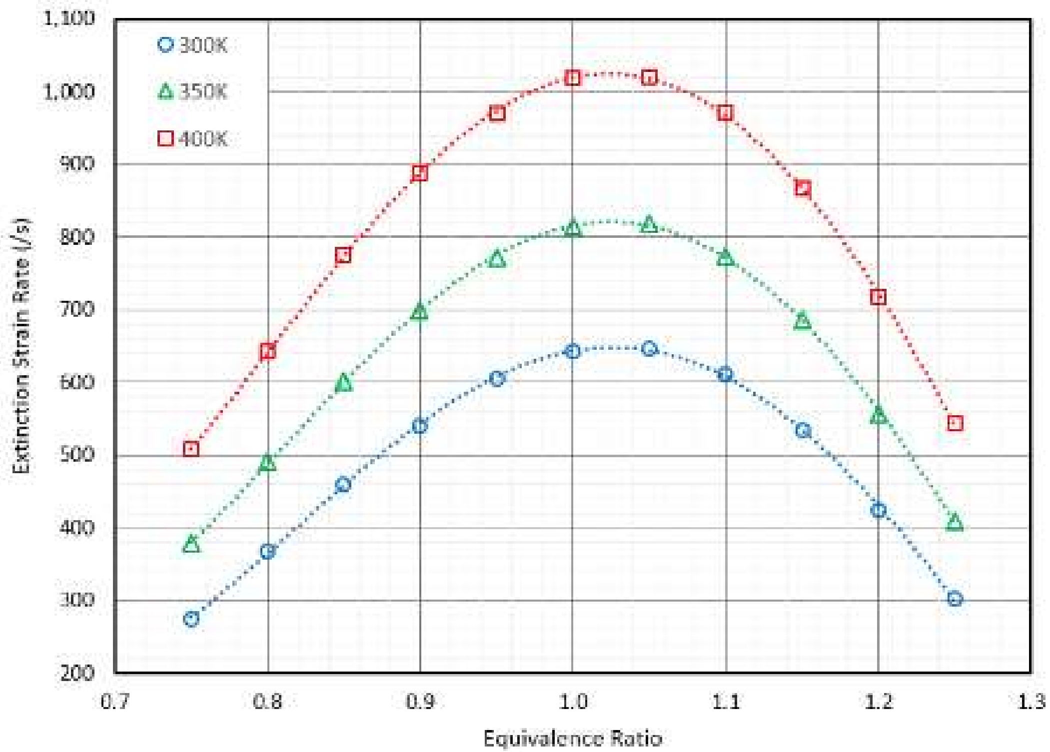
- To assist with the benchmarking of the HPCFB, a range of simulations have been carried out using the opposed flow flame reactor within Ansys Chemkin.
- Like experimental data, the results of simulations are dependent on several factors.
- Different reaction mechanisms have been chosen for initial methane,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



Individual simulations passing through Strain maxima



Calculated Extinction Strain Rate – Premix Methane and Air vs Nitrogen, 25mm BSD, 300K Preheat, Gri-Mech 3.0 kinetic mechanism

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- 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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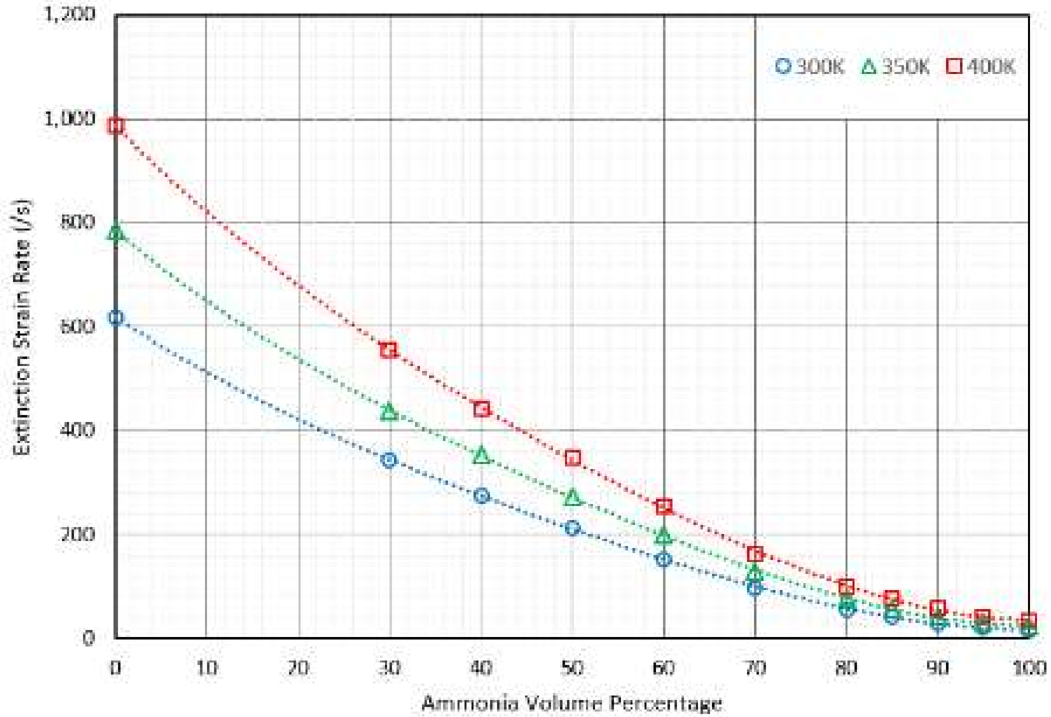
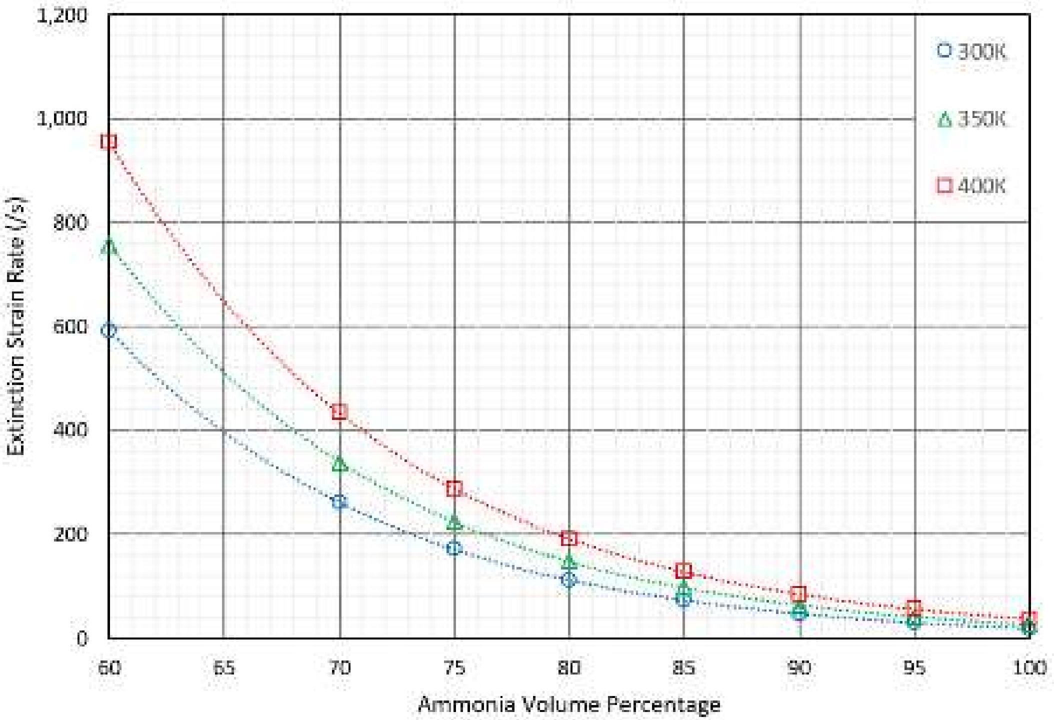
- Evaluation of the behavior of ammonia/methane blends has been provisionally undertaken using a single chemical kinetics mechanism

- Mechanism chosen is that of Arunthanayothin S. et al, utilising 157 species and 2444 reaction pathways.
  doi.org/10.1016/j.proci.2020.07.061



Calculated Extinction Strain Rate – Ammonia/Methane blend with Air vs Nitrogen, 25mm BSD, 300K Preheat, Arunthanayothin kinetic mechanism



Calculated Extinction Strain Rate – Ammonia/Hydrogen blend with Air vs Nitrogen, 25mm BSD, 300K Preheat, Nakamura kinetic mechanism

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- Blends of ammonia/hydrogen have also been examined for a single chemical kinetic mechanism
- The mechanism of Nakamura H. et al was chosen, which utilises 33 species and 232 reactions.
  doi.org/10.1016/j.combustflame.2017.06.021

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WP6 Combustion Mode Fundamentals - Initial experimental results

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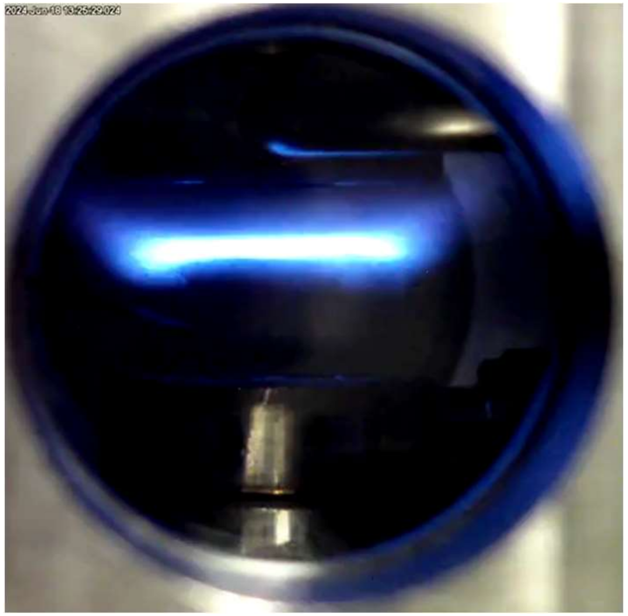
- Development of HPCFB is nearing final stage.
- All experiments are run remotely from GTRC control room. Flows to experiments controlled using Coriolis MFC's. Flame and apparatus is monitored using HD cameras.
- Flame is ignited using ignition electrode. Depending on initial flow conditions, stabilization occurs as an "anvil" or "flat" flame.
- Once stable, all flows are progressively increased until flame is driven to extinction.



Example of counterflow flame extinction - Premix methane/air vs nitrogen, ER 1.05, 350K

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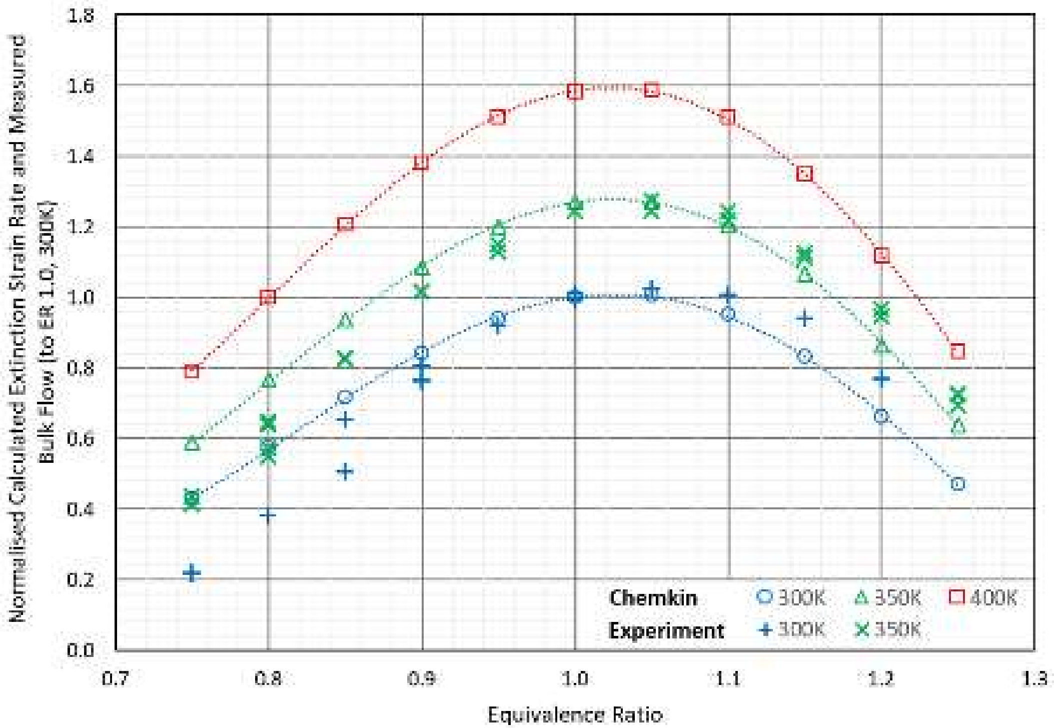

Calculated and Experimental Extinction Values
Premix Methane and Air vs Nitrogen.

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- Experimental data for methane obtained for preheat of 300K and 350K, for a range of equivalence ratios.
- Data presented normalized to value for ER 1.0 at 300K, both for experimental and Chemkin simulation.
- Experimental data presented based on nozzle exit velocities. Proportional relationship to Extinction Strain Rate currently being determined.

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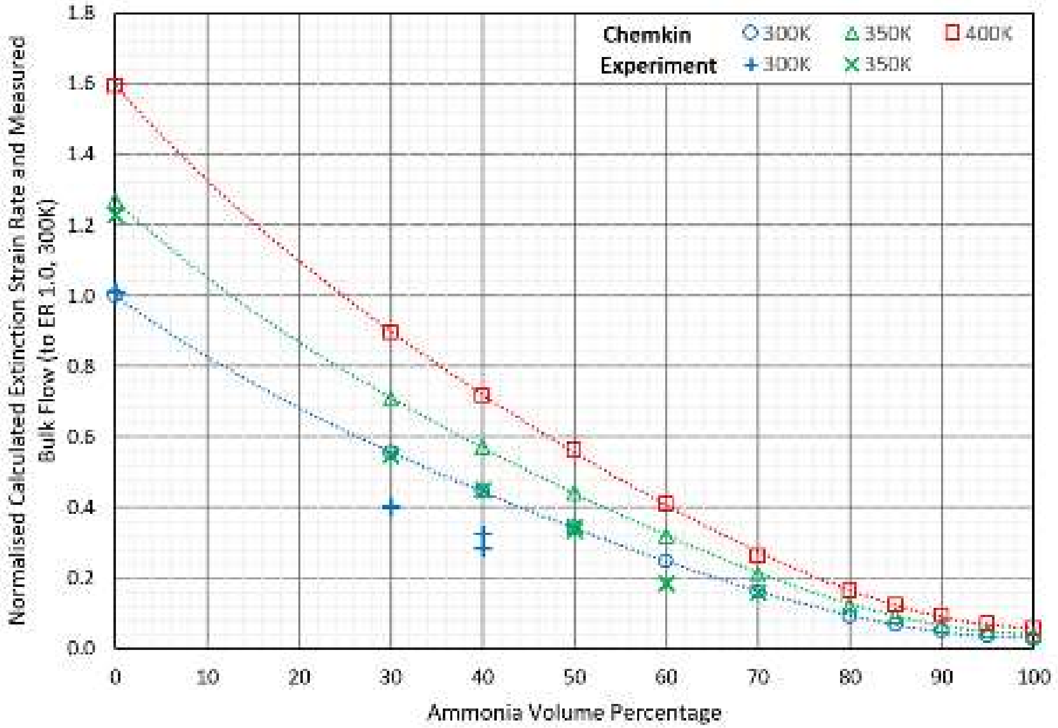
- Experimental data for ammonia / methane blends obtained for preheat of 300K and 350K.
- Data presented normalized to value for 100% methane, ER 1.0 at 300K, both for experimental and Chemkin simulation.

- Again , experimental data presented based on nozzle exit velocities.



Calculated and Experimental Extinction Values
Premix Ammonia/Methane and Air vs Nitrogen.

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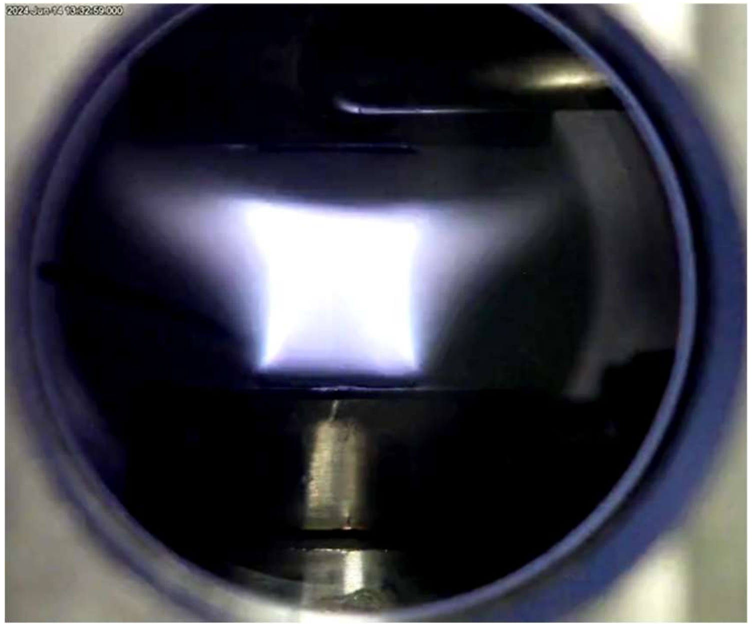

Weak flame extinction -
Premix ammonia/methane (30/70) and air vs nitrogen, 350K

Condensation issue with low preheat temperature –
Premix ammonia/hydrogen (60/40) and air vs nitrogen, 300K

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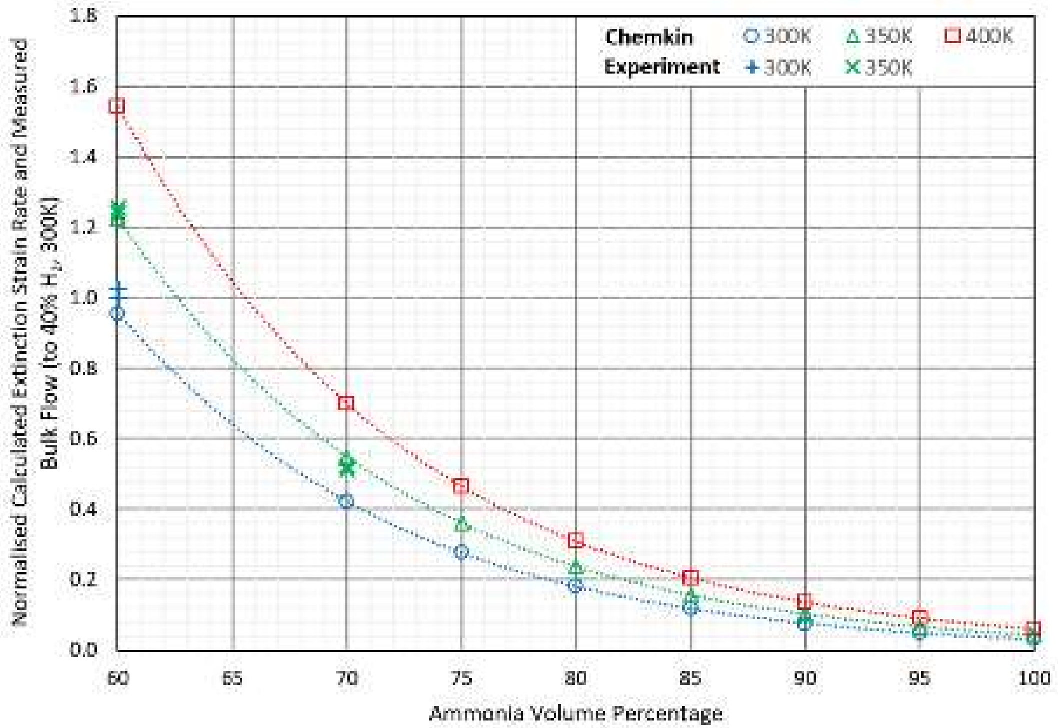

Calculated and Experimental Extinction Values
Premix Ammonia/Hydrogen and Air vs Nitrogen.

- Experimental data for ammonia hydrogen blends obtained for preheat of 300K and 350K.
- Data presented normalized to value for 50:50 blend of ammonia / hydrogen, ER 1.0 at 300K, both for experimental and Chemkin simulation.
- Again experimental data presented based on nozzle exit velocities.

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WP6 Combustion Mode Fundamentals - Current work, future plans

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- Currently working through benchmarking process, understanding operation of burner.
- New inline heaters to be installed, will allow for improved control and increased preheat of air / nitrogen streams. Maximum preheat temperature expected to be around 500K.

- Further testing required to increase, refine datasets.
- Velocity profiles and turbulence measurements to be obtained in coming weeks. Will allow for confirmation of Extinction Strain Rate values for experiments taken to date.

- Approval been given for mounting of PSV directly onto vessel for pressurised operation.
- Back pressure valve selection at final stage, final measurements required of outlet temp.
- Consideration being given to mechanism for rotation of ignition probe outside of flame zone.

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WP5 Fuel Storage, Handling and Lubrication

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WP5 Fuel Storage, Handling and Lubrication - Overview

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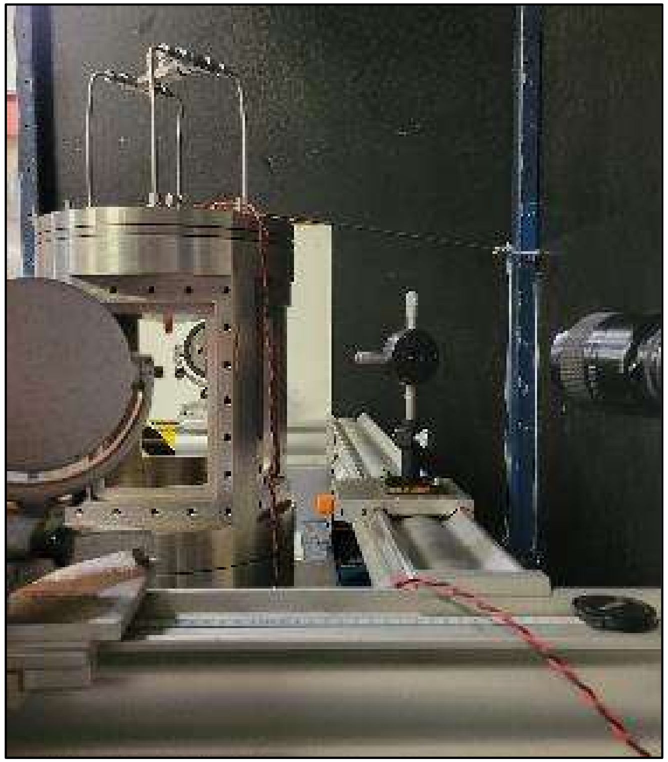
- An "Automotive Injector Pressure Vessel", previously used on collaborative research projects with Ricardo PLC is to be used for the characterization of Ammonia sprays from automotive injectors.
- The vessel is being recommissioned with the aim of having it rated again for operation at 10barg.
- In order to ensure that consistent injector operating conditions are used by all project partners. Similar injector hardware and control systems are being specified



Automotive Injector Test Vessel.

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WP5 Fuel Storage, Handling and Lubrication – Overview

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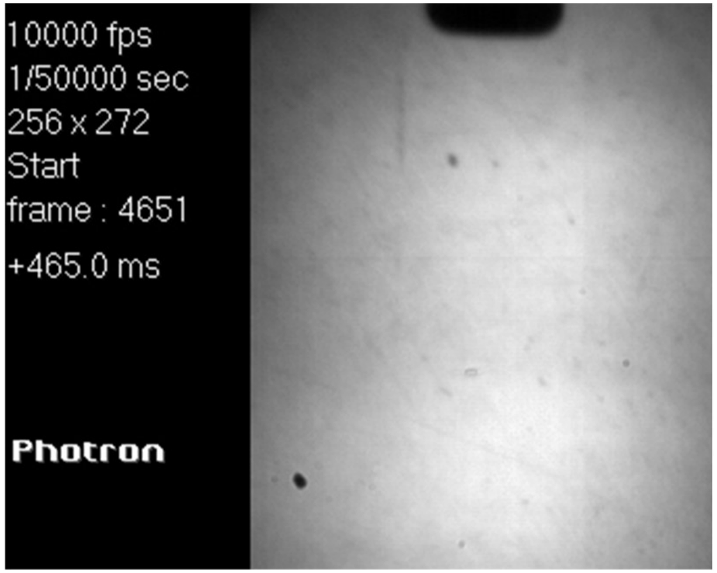

Schlieren Imaging, 5 Barg Helium Injection, Bosch EV-1/3A

- The automotive spray vessel has been incorporated into a larger test rig, which was previously developed for investigating large scale hazardous releases.
- Injector test program underway, initially benchmarking with standard Bosch PFI / DI units.
- Background Oriented Schlieren being compared to conventional Schlieren imaging for gaseous phase work.

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WP5 Fuel Storage, Handling and Lubrication – Current Work, Future Plans

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- Currently transitioning to analysis of conventional injectors for gaseous fuels. Low pressure ammonia. Low and high pressure hydrogen.
- Preparing for fundamental spray study (plain orifice) once GTRC combustion test rig is available.

- Liquid ammonia testing to commence using OEM automotive injectors. Once available and specified, project injector will be studied.
- In parallel to ammonia testing - Benchmarking datasets for injectors on liquid fuels, methanol and octane. Working with Brighton to ensure comparable test conditions.

Questions

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