October 28 & 29

COMBURA NVV 2025

Book of Abstracts

NVV
Nederlandse Vereniging
voor Vlamonderzoek

THE COMBUSTION INSTITUTE 1954

October 28 & 29, 2025
Domusdela, Eindhoven, The Netherlands

BOOK OF ABSTRACTS

Table of contents

GENERAL INFORMATION

The COMBURA symposium is the main annual event on combustion research and applications in the Netherlands. This year it will be held for the 23rd time. Combura is organized by the Nederlandse Vereniging voor Vlamonderzoek NVV (Netherlands Association for Flame Research), with active involvement of the Dutch Section of the Combustion Institute.

Practical information about the symposium as well as an outline of the program are provided on the main website, www.combura.nl. The full program is also detailed below.

CONTACT
For questions regarding the program contact Anna Felden at a.m.j.felden@tudelft.nl

Program and organizing Committee

- Francesca De Domenico, Delft University of Technology
- Anna Felden, Delft University of Technology
- Conrad Hessels, TU Eindhoven
- Xiaocheng Mi, TU Eindhoven
- Dirk Roekaerts, Delft University of Technology

Program information

Day 1: October 28

17:00-19:00 NVV meeting (room: August)
From 16:30 Poster session (room: Jos)
From 19:00 Dinner (restaurant)

Day 2: October 29

9:00 *Symposium opening*
9:15-10:45 Keynote Lectures (room: De Kapel)

Ewa Marek

University of Cambridge, UK
https://www.ceb.cam.ac.uk/research/groups/erc
Active and Inactive Metal Oxides for Low-Temperature Combustion and Selective Oxidation

Andrea Giusti

Imperial College, London, UK
https://profiles.imperial.ac.uk/a.giusti
Electromagnetic interactions and engineered fuels to deliver flames on demand: towards a new paradigm for sustainable energy and propulsion systems

10:45-11:00 *Coffee break*
11:00-12:15 Poster Session (room: De Kapel)
12:15-13:00 *Lunch*
13:00-13:50 Plenary session (room: De Kapel)

Marcel Cremers

DNV
https://www.linkedin.com/in/marcel-cremers-8846954/
Industrial combustion problems related to the energy transition

13:50-14:00 *Break*
14:00-16:20 Parallel sessions: Oral presentations of the selected contributed papers will be taking place in two parallel sessions (rom Session 1: De Kapel; room session 2: Jos)
16:20-16:30 *Coffee break*
16:30-17:00 Plenary session (room: De Kapel)
The winner of the **NVV Combustion Award 2024** will be announced. This award is given to the young expert with the **best MSc thesis** (obtained from a University in the Netherlands) **in the field of combustion technology**. The evaluation is done by a jury composed by the board of NVV.
The three **best posters** presented at the symposium will receive an **award** from the Dutch Section of the Combustion Institute (DSCI). The evaluation will be done by a jury composed by the board of DSCI.
17:00 *Symposium closing followed by drinks*

ABSTRACTS OF KEYNOTE LECTURES

Keynote lecture 1

By **Ewa J. Marek,**
Department of Chemical Engineering and Biotechnology, University of Cambridge, UK

Active and Inactive Metal Oxides for Low-Temperature Combustion and Selective Oxidation

The combustion community considers how solids can affect combustion mainly in the context of wall-flame interactions. However, a pronounced presence of solids is characteristic of packed and fluidized beds, commonly used by the chemical industry, with stationary or moving particles of metal oxides, in size from microns to millimeters, that constitute the bed. In these conditions, solids define the void space for reaction while the solid-gas interactions promote or quench radical pathways. Additionally, the solids can actively provide species to react with the fuel, leading to heterogeneous oxidation, known as chemical looping. Altogether, the presence of solid particles presents a range of opportunities that enable us to control oxidation towards selective or complete oxidation, depending on needs.

This talk will present our work using inert (SiO2 and Al2O3) and active metal oxides (Fe2O3, SrFeO3) when combusting hydrogen and ethylene in packed and fluidized bed arrangements. I will discuss the benefits and problems of using fluidized beds with pre-mixed and separated gas feeds. Then, besides chemical looping for combustion, I will shortly expand on the concept, presenting our flagship chemical looping epoxidation (CL-E) and chemical looping oxidative dehydrogenation (CL-ODH) reactions.

Bio

Dr Ewa Marek is an associate professor at the Department of Chemical Engineering and Biotechnology, University of Cambridge and a fellow of Jesus College. She leads the Energy Reactions and Carriers Group, working on the production of value-added chemicals from intermittently available renewable feedstock and electricity, incorporating non-thermal plasma, ultrasounds and chemical looping to drive efficient, transient processes. This work led to 2021 Hinshelwood Prize and 2023 Energy&Fuels Rising Star Award for early-career academics. Before setting up her group, she was a post-doctoral associate in the Engineering Department, Cambridge, and earlier, she worked for six years on industrial R&D and advanced measurement methods in the UK, Netherlands and Poland. She studied energy and chemical processing (BEng, MSc) in Cracow and carbon capture (PhD) in Katowice (both in Poland).

Links

https://www.ceb.cam.ac.uk/staff/dr-ewa-marek
https://www.jesus.cam.ac.uk/people/ewa-marek

Keynote lecture 2

By **Andrea Giusti,**
Associate Professor, Department of Mechanical Engineering – Faculty of Engineering, Imperial College London, UK

Electromagnetic interactions and engineered fuels to deliver flames on demand: towards a new paradigm for sustainable energy and propulsion systems

The use of electromagnetic fields to achieve full control of the reaction process is proposed as a new paradigm for next generation hybrid thermal-electric propulsion systems. The vision is first presented in the context of electrification of transportation and sustainability of hard-to-decarbonize sectors, such as aviation. Electric modulation of charged droplet trajectories is then introduced as a novel technology for the control of mixing. Systems with different level of complexity are presented, ranging from single-component droplets to nanofuel droplets. Non-reacting high-fidelity simulations are discussed to analyze the competing effects of drag and electrical forces on the trajectory of evaporating droplets and the resulting vapor-air mixing. The use of magnetic forces to control the mixing of gaseous fuels is eventually presented, together with the concept of engineered carriers. Concluding remarks on challenges and open questions close the seminar.

Bio

Dr Andrea Giusti is Associate Professor in Thermofluids at Imperial, in the Department of Mechanical Engineering. He obtained his PhD in 2014 at the University of Florence and then he joined the Engineering Department at the University of Cambridge as Rolls-Royce Research Associate. He became a Lecturer at Imperial in October 2018. Andrea leads a research group in multi-physics combustion and engineered fluids, to propose sustainable solutions for the energy and transportation sectors. Andrea is currently Editor-in-Chief of the International Journal of Spray and Combustion Dynamics; committee member of the International Workshop on Turbulent Combustion of Sprays, committee member of the British Section of the Combustion Institute, and Bye-Fellow of Fitzwilliam College in Cambridge.

Keynote lecture 3

By **Marcel Cremers,**
Principal consultant at DNV, NL

Industrial combustion problems related to the energy transition

DNV publishes its Energy Transition Outlook yearly. The outlook provides insights into how the energy system will evolve. It is based on DNV's independent model on the world's energy system. It covers the period through 2050 and forecasts the energy transition globally and in 10 world regions. In this speech Marcel will provide the key results of DNV's Energy Transition Outlook. In addition to this, Marcel will provide specific information on how DNV sees the energy system evolve, the changes in the industry, and the role of dispatchable fuel-fired energy plants in the energy system will have. It will be covering both fossil and low carbon fuels. Specifically, Marcel will indicate typical combustion challenges of power plants when converted to hydrogen. Finally, Marcel will present an example of a case study showing how green hydrogen-fired gas turbines in industrial cogeneration application can provide zero-carbon dispatchable generation in power systems with high shares of variable renewable energy.

Bio

Dr Marcel Cremers is principal consultant at DNV. He has been working as consultant for the company since 2006 and has been technical expert and/or project manager in technology reviews, (pre)-feasibility studies, tendering procedures, investor/vendor technical due diligences, market & policy reviews, and technical and business (risk) assessments. Marcel has worked for many project developers, financial institutions and banks, asset owners and policy makers. His main expertise is in bioenergy, thermal energy systems, heating appliances, low carbon fuels and small-scale hydroelectric power.
Marcel is also business lead emerging energy technologies for DNV on the topics of low carbon fuels (hydrogen, PtX, biofuels), thermal generation, hydro power, and emerging technologies.
Marcel holds an MSc in Mechanical Engineering, Thermo-Fluids Engineering from Eindhoven University of Technology, and a PhD in Combustion from the same university.

COMBURA 2025: PROGRAM OF CONTRIBUTED ORAL PRESENTATIONS

October 29	SESSION I Room: De Kapel	SESSION II Room: Jos
14:00-14:20	Wenjiang **Tian**	Teja **Donepudi**
14:20-14:40	Sobhan **Azizianamiri**	Anirban **Ghosh**
14:40-15:00	Stan **Latten**	MohammadReza **Kohansal**
15:00-15:20 Break		
15:20-1540	S.S. **Hemamalini**	Berksu **Erkal**
15:40-16:00	Georgios A. **Kelesidis**	Tom **Siebelt**
16:00-16:20	Boyan **Xu**	Jappe **Hoeben**

Parallel Session I

Spatiotemporal temperature distribution and spectral emissivity during the initial combustion of millimeter-sized liquid iron particles
W. Tian*, Y. Shoshin*, V. Kornilov*, X.C. Mi*,**
*Eindhoven University of Technology, **Eindhoven Institute of Renewable Energy Systems (EIRES)

Impact of Air-Based Dilution on Combustion and Efficiency in a Turbocharged Hydrogen Internal Combustion Engine
S. Azizianamiri, X. Tauzia, A. Maiboom and N. Perrot
Nantes Université, École Centrale Nantes, CNRS, LHEEA, France

Influence of skip-firing on engine combustion behavior and emissions
S. Latten*, F. Akbulut**, M.C.M. Cuijpers*, L.M.T. Somers*, and N.C.J. Maes*
*Eindhoven University of Technology, ** Hitit University, Turkey

Effects of preferential concentration on the combustion of iron particles. A numerical study with homogeneous isotropic turbulence
S.S. Hemamalini*,**, B. Cuenot* and X.C. Mi*,**
*Eindhoven University of Technology, **Eindhoven Institute of Renewable Energy Systems (EIRES)

Multi-scale modeling of soot nucleation
G.A. Kelesidis*, A. Fakharnezhad**, D.M. Saad***, J.D. Berry* and E. Goudeli**
*Delft University of Technology, **The University of Melbourne, Australia, ***Stanford University, USA

Near extinction flame behaviors under different ammonia cracking ratios
B. Xu* and R.J.M. Bastiaans*
* Eindhoven University of Technology

Parallel Session II

Insights from large-eddy simulations of variable density round jets
Teja Donepudi, Jurriaan W.R. Peeters, Rene Pecnik, and Sikke Klein
Delft University of Technology

Python-wrapper based implementation of the turbulent flame speed closure (TFC) model in SU2 for turbulent premixed combustion
Anirban Ghosh*, Nijso Beishuizen** and Jan Withag*
* University of Twente, **Bosch Thermotechniek B.V., Deventer

Ignition Delay Time of NH3/H2 mixtures: RCM measurement and simulations
MohammadReza Kohansal*, Anatoli Mokhov**, Sander Gersen***, Rob Bastiaans*
* Eindhoven University of Technology, ** University of Groningen, *** DNV GL Oil & Gas, Groningen

Self-excited dynamics of hydrogen methane blends in laboratory and industrial scale combustors
Berksu Erkal and Jim Kok
University of Twente

Experimental study on iron pellet steam oxidation for hydrogen storage
T. Siebelt*, Y. Ma**, and X.C. Mi*,***
*Eindhoven University of Technology, **Delft University of Technology
***Eindhoven Institute of Renewable Energy Systems (EIRES)

RWE light house project case study: Moerdijk high hydrogen conversion
James Bain*, Jappe Hoeben*, Rachel Skudder*, Laurent Cretegny**, Frederic Delaval**, Peter Feher**, and Fabien Codron**
*RWE, Swindon, UK, **General Electric Vernova, Cambridge, Massachusetts, USA

COMBURA 2025: CONTRIBUTED POSTER PRESENTATIONS [alphabetical on first author] Sessions: October 28, 16:30-19:00 (Room Jos); October 29, 11:00-12:15 (room De Kapel)

Heat-Sink Effect of Solid Particles on Laminar Burning Velocity in CH_4–Air Mixtures: Measurements with a Hybrid Heat-Flux Burner (HHFB)
Olivia Ahlborn, Xinlu Han, Mark Hulsbos, XiaoCheng Mi, Roy Hermanns

DNS-Informed Modeling of Hydrogen–Oxygen Detonation Waves for RDCs
Andrea Bari, Jeroen van Oijen, and XiaoCheng Mi

ICE combustion inefficiencies in a lean air-fuel mixture
Shubham Bawkar, Rob Bastiaans

Analysis of turbulent premixed spherical combustion kernels
Rob Bastiaans

Lime based DAC starts with zero carbon lime production
C. Bertrand, Origen's Team

Ignition Characteristic of Single Spherical iron particle: FeO and Fe melting time
Liulin Cen, Yong Qian, Xingcai Lv

Emission characterization of fuel-flexible kerosene-H2 combustor
K. Dave, A. Garcidueñas Correa, A. Gangoli Rao, F. De Domenico

Brief information about the scope of the departments of the Gas Institute and some widely implemented developments by the Department of Air Pollution Protection
E.P. Dombrowska, A.V. Smikhula, I.Ya. Sigal, O.V. Marasin

Fuel Staging and Burner Designs for Hydrogen-Powered Gas Turbines
Berksu Erkal, Jim Kok

Laminar Burning Velocities of Hybrid Iron–Methane Flames at 1 atm: Numerical and Experimental Insights
Xinlu Han, Xiangao Ma, Roy Hermanns, Xiaocheng Mi

Development and CFD Simulation of a Tar Cracking Reactor for Cleaner Syngas Production
Umer Hayyat, Amir Mahmoudi, David Garcia Llamas, Artur Pozarlik

Assessment of Flamelet Generated Manifold for Predicting Quenching Distances in Laminar Hydrogen-Air Flames
Tahsin Berk Kiymaz, Nijso Beishuizen, Jeroen van Oijen

Threshold?! Behavior of NH3/H2 Ignition Delay Time
MohammadReza Kohansal, Anatoli Mokhov, Sander Gersen, Rob Bastiaans

LES simulations for NOx determination H2 micromix mGT's
Materusz Lasica, Cedric Devriese, Rob Bastiaans

Direct Observation of H2-Air Flame Quenching in a Converging Channel
Dongliang Liu, Yuriy Shoshin, Nijso Beishuizen, Jeroen van Oijen

Turbulent jet ignition for heavy-duty hydrogen internal combustion engines
Ralph Maas, Bart Somers, Noud Maes

The prediction of extinction for bluff-body stabilized NH3/H2/N2 premixed flames
Roel Maas, Boyan Xu, Rob Bastiaans

Physicochemical Characterization of Soot Emissions from Combustion of Jet Fuel Blended with Pentanol
Constantinos Moularas, Una Trivanovic, Irini Tsiodra, Kalliopi Tavernaraki, Nikolaos Mihalopoulos, Georgios A. Kelesidis.

Supercritical combustion: detailed (FFCM-1) and global chemistry mechanism with gravity considerations
Sylwia Oleś, Jakub Mularski, Halina Pawlak-Kruczek, Abhishek K. Singh, Artur Pozarlik

Pulsed DBD plasma-driven multipoint ignitor to enhance deflagration to detonation transition
Ravi Patel, Xiaocheng Mi, Jeroen van Oijen

Where do hydrogen flames ignite? (Part 2)
Diego A. Quan Reyes, Dirk Roekaerts, Jeroen van Oijen

CFD Study on Primary Air Distribution in an Industrial Biomass Furnace
Anne Rikhof, Amir Mahmoudi, Huub Ratering, Artur Pozarlikaes

Large Eddy Simulation of Premixed Hydrogen Combustion using PeleLMeX
H Sabharwal, A.M.J. Felden, Sikke Klein

Design of a combustion chamber for a hydrogen SOFC-GT hybrid engine.
Rishikesh Sampat, Francesca de Domenico, Arvind Gangoli Rao

Microwave Driven Plasma Intensified Gasification: An Experimental Investigation
N. Sharma, A.M.J. Felden and W. de Jong

Hydrogen flame-driven flash reduction of millimeter-sized iron oxide particles
Wenjiang Tian, Atanu Dolai, Calvin Wong, Giulia Finotello, XiaoCheng Mi

Iron flame diagnostics: revealing the obscured
Giliam van der Wielen, Nico Dam, Niels Deen, Conrad Hessels

Gas temperature measurements in iron flames using O2 LIF
Calvin Wong, Giliam van der Wielen, Humaid Qasem, Nico Dam, Conrad Hessels

Effect of Particle Porosity on the Ignition Temperature of micron-sized Iron Powder
Kaining Zhang, Shrikant Paliakara, Willie Prasidha, Wenjiang Tian, Nicole Stevens, Giulia Finotello, and XiaoCheng Mi

D. FIRST AUTHOR OF ALL CONTRIBUTED PAPERS

ORALS (alphabetical on first author)

1. **Azizianamiri**
2. **Bain**
3. **Donepudi**
4. **Erkal**
5. **Ghosh**
6. **Hemamalini**
7. **Kelesidis**
8. **Kohansal**
9. **Latten**
10. **Siebelt**
11. **Tian**
12. **Xu**

POSTERS (alphabetical on first author)

(abstract available only for 2,7,25,26,29)

1. **Ahlborn**
2. **Bari**
3. **Bawkar**
4. **Bastiaans**
5. **Bertrand**
6. **Cen**
7. **Dave**
8. **Dombrovska**
9. **Erkal**
10. **Han**
11. **Hayyat**
12. **Kiymaz**
13. **Kohansal**
14. **Lasica**
15. **Liu**
16. **Maas Ralph**
17. **Maas Roel**
18. **Moularas**
19. **Oleś**
20. **Patel**
21. **Quan Reyes**
22. **Rikhof**
23. **Sabharwal**
24. **Sampat**
25. **Sharma**
26. **Tian**
27. **van der Wielen**
28. **Wong**
29. **Zhang**

Recommended format for naming of poster-files uploaded to drive using QR code:
Number-name, for example: 1-Ahlborn.pdf

Impact of Air-Based Dilution on Combustion and Efficiency in a Turbocharged Hydrogen Internal Combustion Engine

S. Azizianamiri, X. Tauzia, A. Maiboom and N. Perrot
sobhan.azizianamiri@ec-nantes.fr
Nantes Université, École Centrale Nantes, CNRS, LHEEA

Introduction

The transport sector faces strict decarbonization targets, with hydrogen internal combustion engines (H_2ICE) emerging as a promising near-zero CO_2 solution. However, hydrogen combustion at high load can generate significant NOx emissions due to high flame temperatures. Lean combustion enables high efficiency with low NOx emissions, nevertheless, operating a commercial engine at ultra-lean conditions and high load remains challenging due to limits in volumetric efficiency, power density, and combustion stability.

The study investigates the potential of air-based dilution (lambda variation) in a turbocharged, direct-injection hydrogen engine equipped with a variable geometry turbine (VGT). The engine was developed within the HyMot project, which targets decarburization of the light commercial vehicle sector. By keeping fuel mass constant and adjusting intake airflow, the study isolates the effects of λ, intake pressure, and spark timing on combustion, NOx emissions, and efficiency. The goal is to clarify the trade-offs and feasibility of ultra-lean, high-load H_2 operation under realistic engine conditions.

Methodology

The study was carried out on a four-cylinder, spark-ignition in-house hydrogen engine with direct injection. The engine is turbocharged with a variable geometry turbine (VGT) and was operated at a fixed speed of 2500 rpm under high-load conditions (8–12 bar BMEP). Fuel mass was held constant at each load point, while intake airflow was varied to adjust the excess air ratio ($\lambda = 2.2–3.6$). This approach allowed the isolated study of air-based dilution at ultra-lean conditions.

In parallel, a 0D/1D numerical model was developed in GT-SUITE and validated against experimental data using the three-pressure analysis (TPA) method. The combined approach enabled detailed evaluation of in-cylinder pressure, combustion phasing, and loss mechanisms.

Results and Discussion

Figure 1 presents the variation of indicated thermal efficiency (ITE) and NOx emissions with λ at 8 bar BMEP under MBT spark timing. Increasing λ from 2.2 to 3.6 caused a sharp reduction in NOx, reaching near-zero levels above $\lambda \approx 3.4$. ITE peaked at about 44% near $\lambda \approx 3.0$, mainly due to reduced wall and exhaust heat losses. At very lean conditions, however, efficiency declined slightly as unburned fuel and pumping losses increased, despite the continued reduction in thermal losses.

Figure 2 compares in-cylinder pressure traces at different λ values for fixed spark timing (12° bTDC). Increasing λ both slowed combustion and raised intake pressure, leading to higher in-cylinder pressure at ignition. At intermediate λ, this pressure rise compensated for slower flame propagation, maintaining or even increasing peak pressure. Beyond $\lambda \approx 3.0$, delayed combustion phasing became dominant, reducing peak pressure and extending burn duration. These

observations emphasize the dual role of λ and intake pressure in governing in-cylinder thermodynamics.

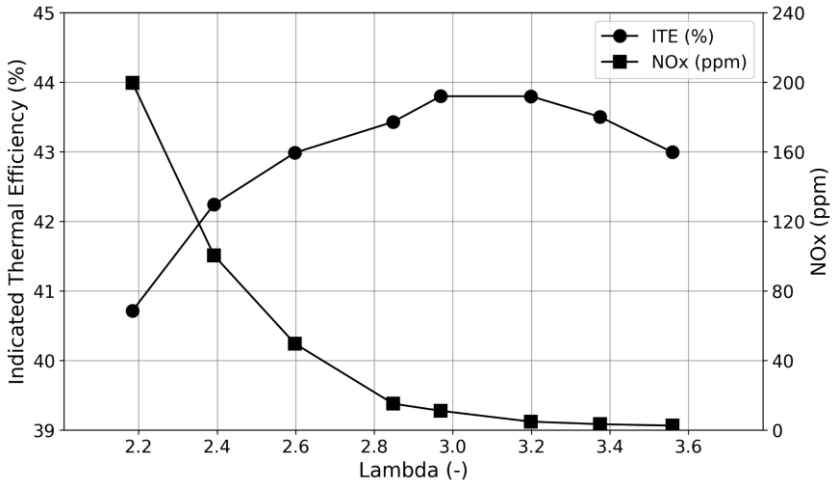


Figure 1. Effect of lambda on indicated thermal efficiency and NOx emission at 8 bar BMEP.

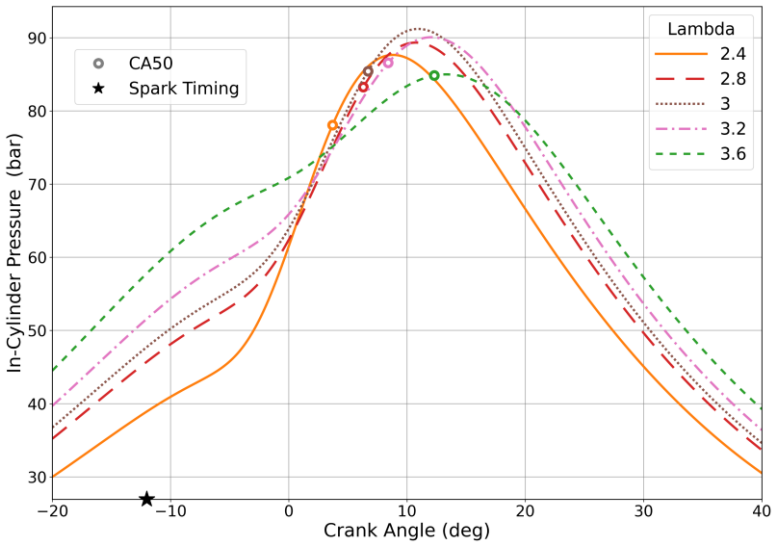


Figure 2. Effect of lambda on in-cylinder pressure trace of cylinder four at 8 bar BMEP.

Conclusion

Ultra-lean, high-load operation of a turbocharged DI hydrogen engine was demonstrated up to λ = 3.6 at 8–12 bar BMEP. NOx emissions decreased to near-zero levels above λ ≈ 3.2, while efficiency peaked around 44% at λ ≈ 3.0. At very lean mixtures, rising unburned fuel and pumping losses limited further gains, despite reduced thermal losses. Intake pressure proved critical for maintaining peak pressure and favorable combustion phasing under diluted conditions. The validated GT-SUITE three-pressure analysis supported these findings and clarified the role of different loss mechanisms. Future work will extend this approach to exhaust gas recirculation and combined dilution strategies to further enhance efficiency while ensuring ultra-low emissions.

This paper has been presented first at the ETN 12th 12th International Gas Turbine Conference Advancing turbomachinery innovations and strategies for net-zero pathways,14-15 October 2025, Bruxelles. Paper ID number 45-IGTC25 and next at Combura 2025, Eindhoven, 28-29 October 2025.

RWE light house project case study: Moerdijk high hydrogen conversion

James Bain*, Jappe Hoeben*, Rachel Skudder*, Laurent Cretegny**, Frederic Delaval**, Peter Feher**, and Fabien Codron**

*RWE, Trigonos Building, Windmill Hill Business Park, Swindon, SN5 6PB, UK.

**General Electric Vernova, 58 Charles Street, Cambridge, Massachusetts, USA

Abstract

Hydrogen is considered a key technological solution to decarbonise many heavy industries, including in the power sector to fuel Gas turbines (GT). Typically, GTs operate on carbonaceous fuels such as natural gas, which produce CO2 emissions. To avoid further emission of CO2 into the atmosphere and avoid stranded assets, conversion of in-the-field assets is a key aspect for the low-cost attainment of lowcarbon operation. This paper highlights the feasibility work on-going at RWE's Moerdijk GE Vernova 9F.04 (9F.02) F-class 420 Mwe CCGT Power Station, located in the Netherlands. It presents a case study of the hydrogen conversion to 80+ vol-% outlining the technical, operational and environmental considerations involved. This study outlines the fuel supply chain integration undertaken to ensure a secure supply of hydrogen can be delivered to site through either leveraging existing or new infrastructure and an overview of the technical developments to convert the asset (GE 9F.04) to operate on hydrogen containing fuels, involving retrofitting with the latest OEM combustion technology. An overview of the lifecycle emissions reduction and operational cost implications are also included.

COMBURA Symposium

Insights from large-eddy simulations of variable density round jets

Teja Donepudi[1], Jurriaan W.R. Peeters[1], Rene Pecnik[1], and Sikke Klein[1]
[1]Process & Energy Department, Delft University of Technology, Delft, The Netherlands

Abstract

Variable-density mixing in jet configurations is common in engineering applications, ranging from chemical processing to combustion systems. This is particularly relevant in gas turbine combustors with H_2-enriched fuels, where density gradients strongly affect fuel – oxidizer mixing, making accurate CFD predictions essential for combustor design optimization. In our earlier cold-flow study on the OP16 DLE combustor[1] operating with 100% H_2, significant differences were observed between RANS and LES predictions of the underlying flow field, in particular the scalar concentration field. Subsequent experiments confirmed that LES provided a more accurate description of the mixing dynamics. These findings motivate a detailed analysis of variable-density turbulent jets to improve understanding of the physical mechanisms governing their evolution and to provide a foundation for more reliable turbulence modelling.

This study focuses on a turbulent round jet, a simplified yet representative flow configuration encountered in (partially) premixed, swirl-stabilized combustors. LES with the dynamic Smagorinsky SGS model were carried out in a cubic domain of side length $20D$ (D is the nozzle diameter) at $Re_D = 3000$. Four density ratios (s) between 0.07 and 1 were considered, with $s = 0.07$ for an H_2–air jet and $s = 1$ for an air–air jet. LES results were validated against literature data. This study investigates both the mean jet structure and turbulent statistics. Mean flow characteristics include the streamwise variation of effective density, potential core length, the onset of the self-similar region, and jet spreading rates based on velocity and scalar fields. Variable-density effects on turbulent statistics are investigated using radial profiles of Favre stresses and turbulent kinetic energy (TKE) budget terms in the self-similar region. In addition, time-averaged contributions to the resolved-scale enstrophy transport equation are analyzed to assess the role of baroclinic torque, arising from misaligned pressure and density gradients, in jet evolution and mixing.

References

[1] Donepudi, T., Pecnik, R., Peeters, J. W., Klein, S., Bouten, T., and Axelsson, L.-U., "Shear-Driven Hydrogen-Air Mixing in OP16 DLE Combustor: A Comparative Study Between URANS and LES," *Turbo Expo: Power for Land, Sea, and Air*, Vol. 87936, American Society of Mechanical Engineers, 2024, p. V002T03A011.

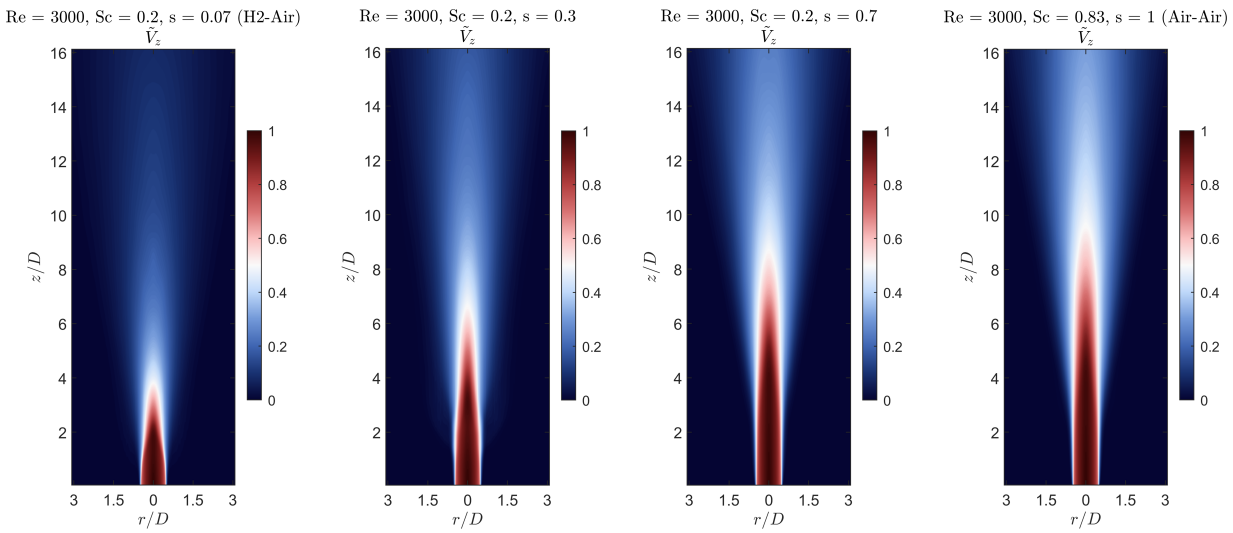
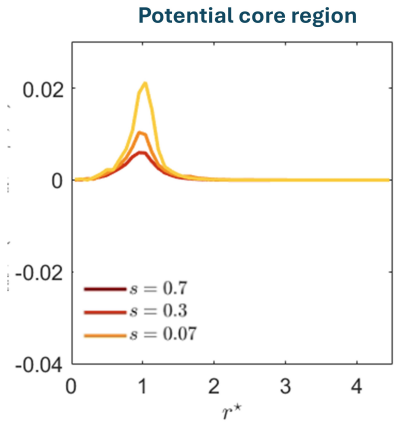
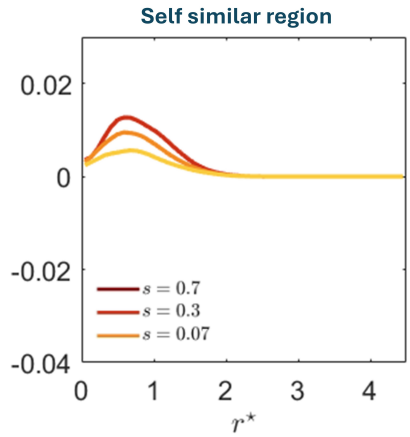


Figure 1: Normalized mean Favre axial velocity profile for different density ratios.

$$P^{\tilde{k}} = -\bar{\rho}\tilde{R}_{ij}\frac{\partial \tilde{u}_i}{\partial x_j} + a_i\frac{\partial \bar{P}}{\partial x_i}$$



Lighter jets produce more TKE near the shear layer in the potential core due to steeper exit gradients.



Lighter jets produce less TKE due to weaker shear gradients.

Figure 2: Normalized TKE production term for different density ratios.

SELF-EXCITED DYNAMICS OF HYDROGENMETHANE BLENDS IN LABORATOR AND INDUSTRIAL SCALE COMBUSTORS

Berksu Erkal* and Jim Kok**
*b.erkal@utwente.nl
**j.b.w.kok@utwente.nl

Abstract

Meeting the growing global energy demand through low-carbon and sustainable solutions has become a priority, particularly in sectors such as industrial furnaces and boilers. Among the available options, replacing methane – the most common fuel in industrial energy generation – with hydrogen is considered a crucial step toward reducing greenhouse gas emissions. Yet, the retrofitting and reliable operation of existing combustion systems with hydrogen remain open challenges. One of the main issues is maintaining stable operation without triggering thermoacoustic instabilities, either by using current burner designs or with only limited modifications.

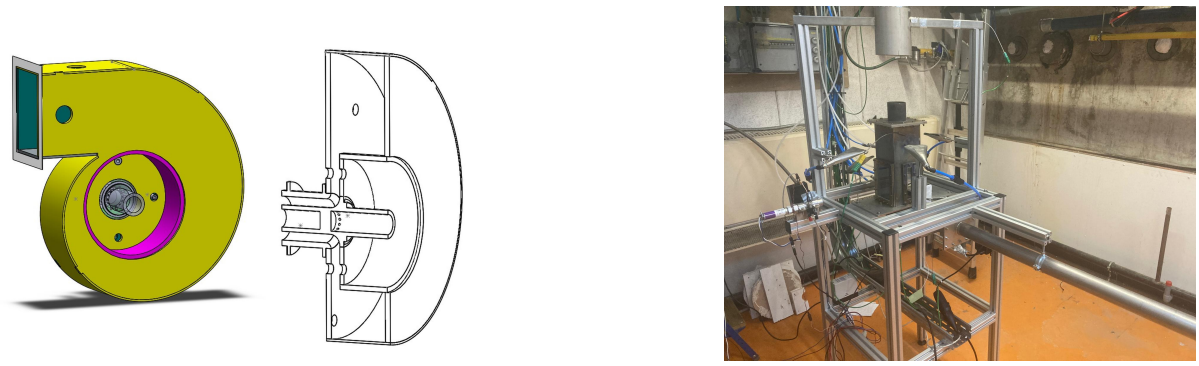
Within the DYNAF project, a 50 kW laboratory-scale combustor equipped with a cyclone burner has been developed to investigate the behavior of hydrogen–methane blends. The setup also includes a variable-length upstream tube, allowing detailed analysis of acoustic feedback and instability mechanisms. Complementing these laboratory experiments, full-scale trials at 1.2 MW thermal capacity have been performed at Duiker Clean Technologies to assess industrial feasibility. In parallel, in collaboration with Bosch, a dedicated facility was established at the Kleinhorst laboratory, where flame transfer functions can be systematically measured and validated.

Introduction

Industrial furnaces are prone to structural vibrations arising from various sources, which in some cases may result in component failures. Since variations in fuel composition have a direct influence on combustion dynamics, a laboratory-scale combustor was designed to study low-frequency instabilities that may emerge during the transition toward hydrogen-based fuels. As illustrated in Figure 1, an upstream tube was employed to create the self-excitation behavior of the incoming airflow. This flow then enters a cyclone burner, where it acquires a swirling motion before mixing with the fuel in the annular section. The fuel is injected through twelve 2 mm-diameter holes oriented perpendicularly to the main stream.

Inside the annular region, the swirling airflow mixes with the injected fuel, forming a premixed charge that combusts within the chamber and exits through a chimney, which is reduced to one-quarter of its original cross-sectional area. Pressure fluctuations were recorded at four locations: one at the cyclone burner inlet and three along the combustion chamber wall, positioned 50 mm, 100 mm, and 200 mm from the chamber base. In addition, as depicted in Figure 1, optical access windows enabled both high-speed imaging and photomultiplier-based measurements.

Beyond these controlled laboratory experiments, large-scale validation was also pursued. Combustion trials with a thermal power of 1.2 MW were performed at Duiker Clean Technologies to replicate industrial operating conditions. In parallel, a specialized facility was set up in collaboration with Bosch at the Kleinhorst site, allowing systematic assessment of flame transfer functions under well-controlled conditions.



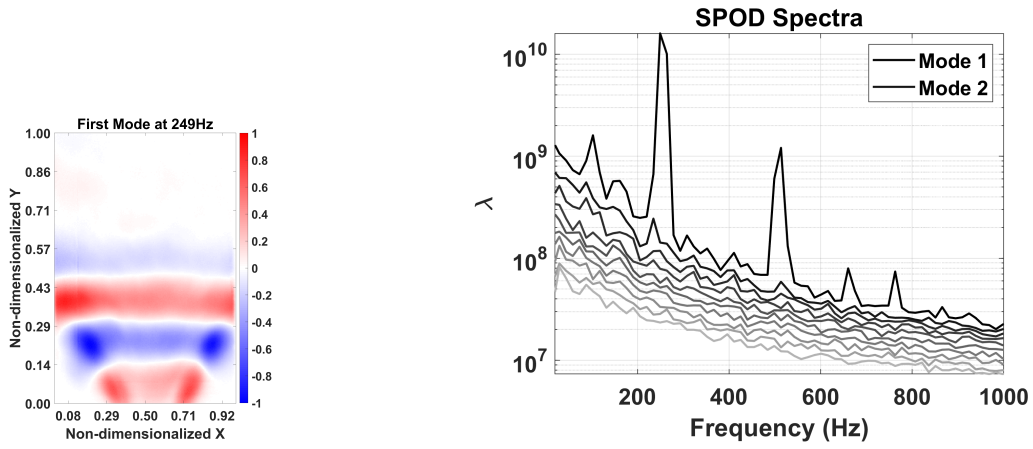
(a) Cyclone Burner **(b)** Experimental Setup

Figure 1. Dynaf Combustor and Setup

Results

Due to space limitations, only a subset of the results could be presented here. All experiments were performed at 30 kW thermal load, covering both pure methane operation and hydrogen/methane blends with hydrogen fractions ranging from 20% to 100%. Additional measurements were also carried out with an elongated combustion chamber to assess the effect of chamber geometry on thermoacoustic responses. During the tests, heat release fluctuations were monitored with a photomultiplier tube and compared against pressure data collected at multiple locations. High-speed imaging at 7500 fps was further analyzed using spectral proper orthogonal decomposition (SPOD)[1],[2]. With a frequency resolution of 14 Hz, the FFT of the SPOD energy distribution was calculated and evaluated alongside pressure and heat release spectra.

The overlap in dominant frequencies across these datasets shows that even a single camera can provide reliable insights into thermoacoustic instabilities without requiring highly dense data acquisition. Consistently, hydrogen enrichment was found to intensify instability levels. An illustrative SPOD result is given in Figure 2. Because of the page limit, detailed FFT mode results are omitted but will be presented during the conference. In addition, large-scale trials conducted at Duiker Clean Technologies will be discussed in the presentation, highlighting their connection with the laboratory-scale observations.



(a) 80% Hydrogen Test **(b)** 80% Hydrogen Test

Figure 2. Experimental Results

References

[1] O. T. Schmidt, "Spectral proper orthogonal decomposition using multitaper estimates," *Theoretical and Computational Fluid Dynamics*, vol. 36, no. 5, pp. 741–754, 2022.

[2] O. T. Schmidt and T. Colonius, "Guide to spectral proper orthogonal decomposition," *AIAA Journal*, vol. 58, no. 3, pp. 1023–1033, 2020.

PYTHON-WRAPPER BASED IMPLEMENTATION OF THE TURBULENT FLAME SPEED CLOSURE (TFC) MODEL IN SU2 FOR TURBULENT PREMIXED COMBUSTION

Anirban Ghosh*, Nijso Beishuizen and Jan Withag***
anirban3195@outlook.com
*Department of Thermal and Fluid Engineering, University of Twente, 7522 NB Enschede, The Netherlands
**Bosch Thermotechniek B.V., P.O.Box 3, 7400 AA Deventer, THE NETHERLANDS

Abstract

The deflagration-to-detonation transition (DDT) in hydrogen-enriched premixed flames is a critical process in combustion science. Detailed chemistry models can accurately capture the underlying physics of DDT, but their high computational cost limits their feasibility for large-scale simulations. To address this challenge, reduced-order combustion models offer a practical alternative.

In this work, we develop a reduced-order model for turbulent premixed flames in the incompressible regime (deflagration stage), implemented within the SU2 framework using the Turbulent Flame Speed Closure (TFC) approach. The model incorporates two key features. First, turbulent flame speed is evaluated using the closure proposed by Dinkelacker et al., which captures preferential diffusion effects and extends the applicability of the model to hydrogen-enriched flames. Second, pressure dependence of flame properties is explicitly included. The model was validated against high-pressure turbulent flame experiments conducted at the Paul Scherrer Institute for methane flames with up to 40% hydrogen enrichment. SU2–TFC simulations reproduced flame speed and temperature profiles with an accuracy of up to 90% relative to experimental measurements (Fig 1).

The framework was subsequently extended to account for heat-loss effects during combustion. In contrast to conventional TFC models, which rely on empirical correlations, the present approach calculates heat-loss enthalpy directly from the reaction progress variable and the local wall temperature. This enthalpy is imposed as a boundary condition in the total enthalpy equation, establishing a direct link between local heat loss and laminar flame speed. The modified laminar flame speed is then incorporated into the source term of the reaction progress variable equation, allowing non-adiabatic effects to be captured without empirical input. Application of this method to a 60% methane–40% hydrogen flame (Fig 2) revealed an increased flame height relative to the adiabatic case, consistent with heat losses in the recirculation region of a dump combustor. By eliminating reliance on empirical heat-loss correlations, this work broadens the predictive capability and generalizability of reduced-order combustion models for hydrogen-enriched premixed flames under realistic operating conditions.

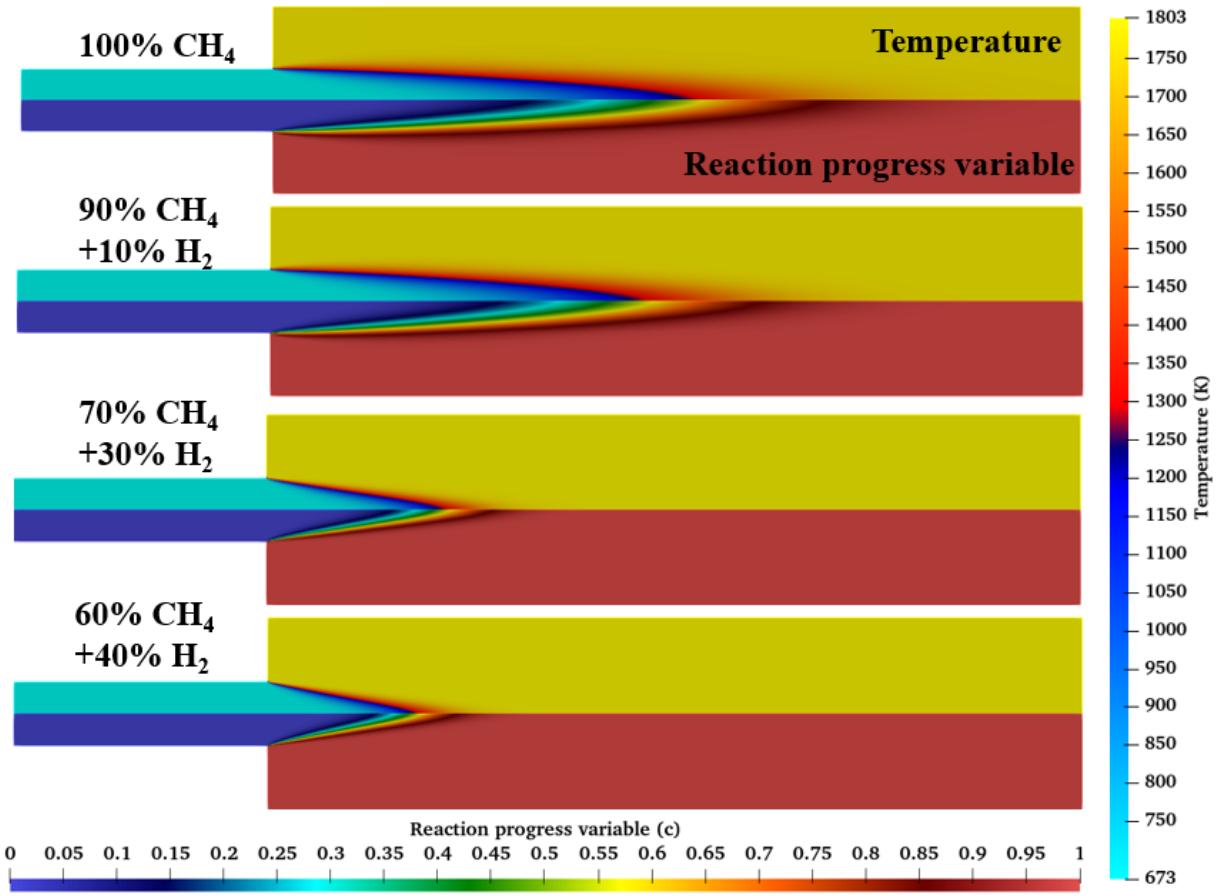


Figure 1. Plot of reaction progress variable and temperature for varying % of hydrogen

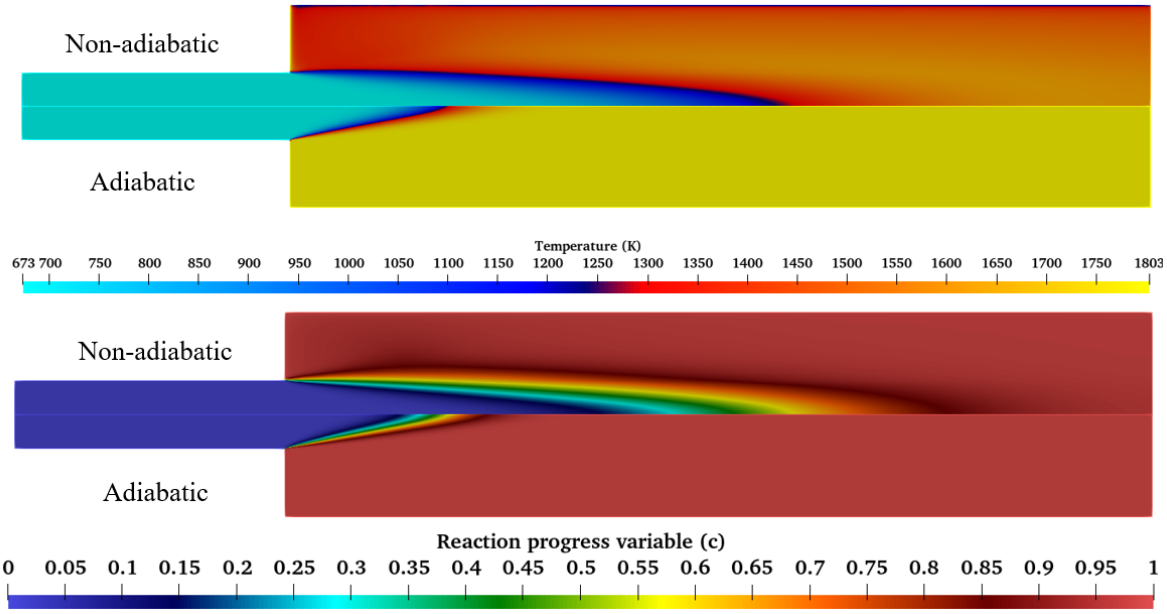


Figure 2. A comparison of temperature and reaction progress variable for adiabatic and non-adiabatic case

EFFECTS OF PREFERENTIAL CONCENTRATION ON THE COMBUSTION OF IRON PARTICLES

A NUMERICAL STUDY WITH HOMOGENEOUS ISOTROPIC TURBULENCE

S.S. Hemamalini[a,b], B. Cuenot[a] and X.C. Mi[a,b]
s.s.hemamalini@tue.nl
[a]Eindhoven University of Technology, P.O. Box 513, 5600MB, Eindhoven, The Netherlands
[b]Eindhoven Institute of Renewable Energy Systems, P.O. Box 513, 5600MB, Eindhoven, The Netherlands

Abstract

Iron particles, with their non-volatile combustion mode, remain in the dispersed phase through the combustion process, causing the flow in a typical iron powder combustor to be particle-laden and turbulent. Preferential concentration is a phenomenon prevalent in such turbulent flows that causes particle clustering and may be detrimental to the combustion process.

To estimate the effects of clustering on the combustion process–the most significant of which is the extension of the combustion time, direct-numerical-simulations (DNS) are performed on a cubical domain with enforced homogeneous isotropic turbulence. Three sets of simulations pertaining to Kolmogorov Stokes number $\mathrm{St} = (1, 10, 50)$, turbulent Reynolds number $\mathrm{Re}_\lambda = (5, 10, 20)$ and global equivalence ratio (considering FeO as the oxidation product) $\phi = (0.25, 0.5, 0.75)$ are executed.

The prevalence of clustering was found to be strongly sensitive to St, as reported in the literature. The magnitude of clustering is estimated through mean minimum spacing $\bar{\delta}_{\mathrm{min}}$ and a clustering index $\sigma(V)/\bar{V}$ where V is the Voronoï volumes of the particles obtained through Voronoï decomposition. Increasing Re_λ enhances the magnitude of clustering, but retains the timescales of cluster formation (Fig. a). Increasing ϕ significantly extends the completion time of combustion owing to the depletion of O_2 in particle-rich regions (Fig. b).

The particle combustion times are estimated for combustion of a fully clustered distribution, a Poisson (random) distribution, and a particle-gas coupled 0D suspension model and compared. Poisson distribution of particles burns faster with a higher peak mean temperature possibly due to collective heating effects. The evolution of the mean temperature in the combustion of the clustered distribution is smooth and results in a smaller peak value (Fig. c).

However, the total combustion time τ_{b}^* (normalized with the combustion time from the 0D suspension) of a clustered distribution is significantly extended, up to eight times at $\mathrm{Re}_\lambda = 20$ and $\phi = 0.75$ (Fig. d).

Analysis of the normalized Voronoï volumes V_{norm} (normalized with the mean Voronoï volume $\bar{V}$) at the start of combustion shows that particles in highly dense regions burn longer as seen before in literature. Furthermore, the combustion time τ_{b}^* exhibits a strong exponential dependence on V_{norm} in the "cluster" regions (Fig. e), and an asymptotic behavior in the "void" regions (Fig. f). However, significant spread is seen in the correlation. Time-averaging V_{norm} does not minimize this variation considerably (Fig. g). Analysis of the macroscale O_2 depletion zone indicates the importance of the macrostructure–proximity of multiple clusters– on the extension of the combustion time τ_{b}^* (Fig. h), with particles inside such depletion zones having prolonged combustion with a weaker dependence on their local clusters.

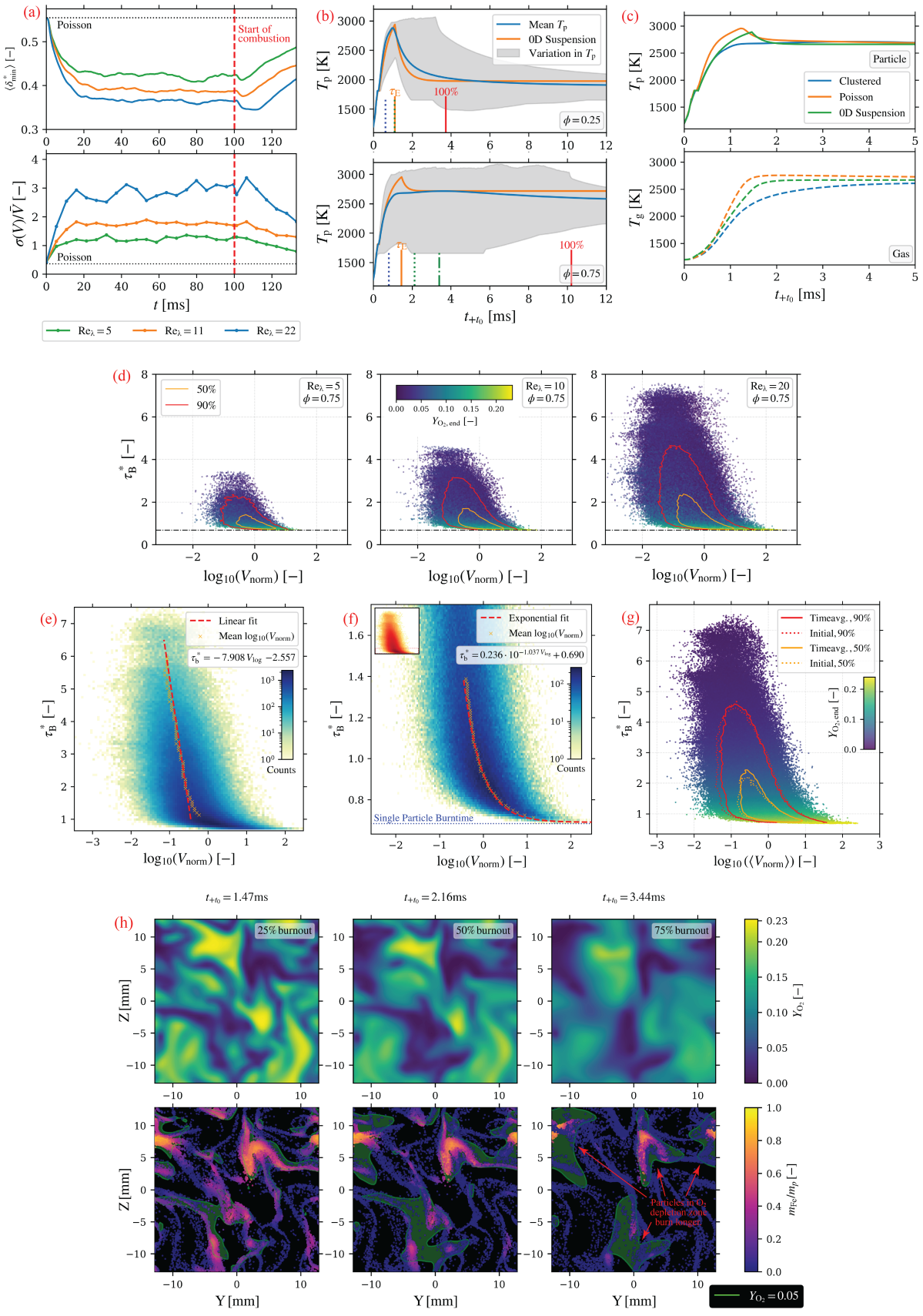


Figure 1. Graphical Abstract

Multi-scale modeling of soot nucleation

G.A. Kelesidis[1], A. Fakharnezhad[2], D.M. Saad[3], J.D. Berry[1] and E. Goudeli[2]

[1]*Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands*

[2]*Department of Chemical Engineering, The University of Melbourne, Melbourne, Australia*

[3]*Department of Energy Science and Engineering, Stanford University, Stanford, California, USA*

Abstract

Soot has long been central to combustion science because of its adverse health impacts [1] and contribution to global warming [2]. Advancing combustion chemistry and developing a systematic understanding of soot nanoparticle formation are therefore critical for cleaner combustion technologies. Modeling soot formation remains highly complex though, particularly during nucleation. Although nucleation contributes less to soot mass than surface growth, it strongly influences particle size distribution and chemical composition, both crucial for meeting emission standards. Detailed nucleation mechanisms, which describe collisions and reactions of polycyclic aromatic hydrocarbons (PAHs) and radicals [3], offer valuable insights but are computationally prohibitive for engine-scale simulations. As a result, semi-empirical nucleation rates [4] based solely on acetylene concentration are often employed. However, such simplifications substantially may overestimate the soot volume fraction even in simple laminar flames [5]. Hence, there is a pressing need for robust yet computationally efficient soot nucleation models to improve emission predictions and guide soot mitigation strategies.

Here, a multi-scale modeling approach is presented for describing soot nucleation dynamics, interfacing reactive Molecular Dynamics (MD) [6] with a monodisperse particle dynamics model [7]. Reactive MD is employed to investigate nucleation of soot nanoparticles during isothermal acetylene pyrolysis at 1200-1800 K (Fig. 1). Initially, acetylene molecules are pyrolyzed isothermally, leading to the formation of reactive species (Fig. 1a) that grow into larger PAHs and eventually to incipient soot (Fig. 1f). A "lumped", acetylene-based nucleation rate is derived by tracking the rate of formation of soot clusters at various fuel concentrations, following a power law dependency with the initial acetylene concentration. The MD-obtained soot nucleation rate is incorporated in a monodisperse particle dynamics model to describe soot formation in a laminar premixed methane flame (equivalence ratio, φ = 1.95 [8]). The soot volume fraction predicted by the particle dynamics model with the MD-derived nucleation rate is in good agreement with measurements, showing significant improvement (3 orders of magnitude) compared to the volume fraction estimated using a semi-empirical relation [4]. Therefore, the proposed MD-informed particle dynamics model can be directly integrated into computational fluid dynamics simulations without relying on complex chemical reaction pathways for

soot nucleation. This approach allows for connecting operating conditions with soot yield predictions for the design of cleaner combustion systems.

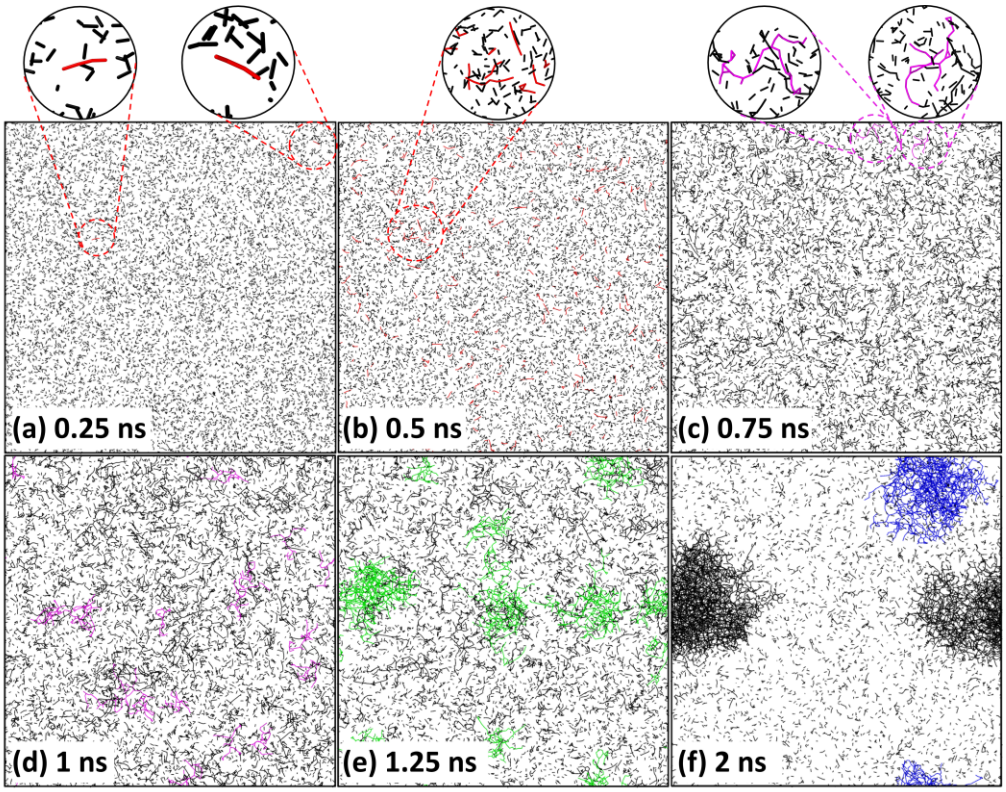


Fig. 1. Snapshots of hydrocarbon molecules and soot clusters formed during acetylene pyrolysis by reactive MD simulations at 1600 K and residence times of (a) 0.25, (b) 0.5, (c) 0.75, (d) 1, (e) 1.25, and (f) 2 ns.

References

[1] D. Lizonova, A. Nagarkar, P. Demokritou, G.A. Kelesidis, Effective density of inhaled environmental and engineered nanoparticles and its impact on the lung deposition and dosimetry, Part Fibre Toxicol 21 (2024) 7.

[2] G.A. Kelesidis, D. Neubauer, L.S. Fan, U. Lohmann, S.E. Pratsinis, Enhanced Light Absorption and Radiative Forcing by Black Carbon Agglomerates, Environ Sci Technol 56 (2022) 8610-8618.

[3] M.R. Kholghy, G.A. Kelesidis, S.E. Pratsinis, Reactive polycyclic aromatic hydrocarbon dimerization drives soot nucleation, Phys Chem Chem Phys 20 (2018) 10926-10938.

[4] S.J. Brookes, J.B. Moss, Predictions of soot and thermal radiation properties in confined turbulent jet diffusion flames, Combust Flame 116 (1999) 486-503.

[5] G.A. Kelesidis, S.E. Pratsinis, Determination of the volume fraction of soot accounting for its composition and morphology, Proc Combust Inst 38 (2021) 1189-1196.

[6] A. Fakharnezhad, D.M. Saad, G.A. Kelesidis, E. Goudeli, Nucleation rate of carbonaceous nanoparticles by n-heptane pyrolysis at high pressure and temperature via molecular dynamics simulations, Aerosol Sci Technol 59 (2025) 1137-1150.

[7] M.R. Kholghy, G.A. Kelesidis, Surface growth, coagulation and oxidation of soot by a monodisperse population balance model, Combust Flame 227 (2021) 456-463.

[8] P. Desgroux, A. Faccinetto, X. Mercier, T. Mouton, D.A. Karkar, A. El Bakali, Comparative study of the soot formation process in a "nucleation" and a "sooting" low pressure premixed methane flame, Combust Flame 184 (2017) 153-166.

Ignition Delay Time of NH3/H2 mixtures: RCM measurement and simulations

MohammadReza Kohansal*, Anatoli Mokhov, Sander Gersen***, Rob Bastiaans***

m.kohansal@tue.nl

* Eindhoven University of Technology, Eindhoven, The Netherlands

** University of Groningen, Groningen, The Netherlands

*** DNV GL Oil & Gas, Groningen, The Netherlands

Abstract

In this research, the Ignition Delay Time (IDT) of NH3/H2 is studied to understand the ignition behavior and the performance of existing chemical mechanisms. Ignition Delay Time measurement is performed using a Rapid Compression Machine (RCM) [1] and for numerical analysis, a homogeneous zero-dimensional reactor from the Cantera package [2] is implemented to model the Ignition Delay Time in the RCM.

Results show that hydrogen addition has a significant decreasing effect on both the IDT and the ignition temperature of NH3. Considering an IDT~4 ms, the combustion temperatures of pure NH3 and H2 are 1160 K and 950 K, respectively—a 210 K difference. Interesting, adding just 10% hydrogen leads to a 170 K reduction in the combustion temperature of NH3. In other words, with only 10% hydrogen addition, the ignition temperature shifts 81% of the way toward that of pure hydrogen. This highlights the threshold-like behavior of NH3/H2 ignition delay time (IDT), meaning that beyond a certain hydrogen content, the ignition characteristics of the NH3/H2 mixture no longer change significantly and resemble those of pure H2. For example, this trend is evident in the isothermal measurements at 930 K: while there is a noticeable difference between 90NH3/10H2 and 80NH3/20H2, the IDTs of 80NH3/20H2 and 70NH3/30H2 are roughly the same and much close to that of pure hydrogen. Based on this, the threshold appears to lie somewhere between 10% and 20% H2 for this case (Pc = 70 bar, φ = 1.0).

Regarding the equivalence ratio effect, ignition delay times of NH3/H2 are measured at equivalence ratios of 0.5, 1.0, 2.0, and 4.0. Results showed that increasing the equivalence ratio from 0.5 to 2.0, and further to 4.0, results in reduction in IDT. The effect of equivalence ratio on the 80NH3/20H2 mixture is less pronounced, but the IDT still decreases with equivalence ratio up to 2.0. Beyond this point, from 2.0 to 4.0, the decreasing trend levels off. Although no clear trend is observed in this range, there appears to be a slight, negligible increase in IDT as the equivalence ratio rises from 2.0 to 4.0.

Regarding the comparison between simulation and measurements, four mechanisms are selected for comparison: Dai, DTU, Zhu, Liao. For various H2 concentration, comparison of measurements and simulations are summarized below: **100%H2**: Dai, Zhu, and Liao mechanisms show good agreement with experiments, but Liao has the lowest deviation, **20%H2 & 30%H2**: Liao has the closest prediction and Dai deviates drastically. **5%H2 & 10%H2**: Zhu outperform Liao but still Liao has a good agreement. **100%NH3**: Dai and Zhu have close prediction to measurements, DTU is off, and Liao shows no ignition.

To summarize, Liao has the best performance for pure and high H2 content, and by going to lower H2 contents, Zhu becomes the most accurate mechanism. Dai and Zhu perform well for both extreme cases, pure H2 and NH3. In general, DTU has the lowest accuracy. One thing should be note here that although mentioned mechanisms perform well in the specified conditions, the predictions for lower pressures, e.g., 20 bar and 30 bar, are not accurate in most cases.

References

[1] S. Gersen, A.V. Mokhov, J.H. Darmeveil, H.B. Levinsky, Ignition properties of n-butane and iso-butane in a rapid compression machine, Combust. Flame 157 (2010) 240–245.

[2] D.G. Goodwin, H.K. Moffat, R.L. Speth, Cantera: an object-oriented software toolkit for chemical kinetics, thermodynamics, and transport processes. version 2.3.0, (2017).

INFLUENCE OF SKIP-FIRING ON ENGINE COMBUSTION BEHAVIOR AND EMISSIONS

S. Latten*, F. Akbulut, M.C.M. Cuijpers*, L.M.T. Somers*, and N.C.J. Maes***
s.latten@tue.nl
*Department of Mechanical Engineering – Power and Flow, Eindhoven University of Technology
**Department of Motor Vehicles and Transportation Technologies, Hitit University

Abstract

Introduction

For fundamental research into the mixing- and combustion behavior inside Internal Combustion Engines (ICE), full-metal engines are often converted into optical engines by replacing part of the cylinder liner with transparent windows, and by using a Bowditch piston extension to provide a means to capture light through an optically transparent piston. This directly allows for the visualization of combustion in the cylinder using (high-speed) cameras. However, these modifications result in very different thermal properties of the associated components compared to their metal counterparts, where temperature differences should be kept to a minimum to avoid thermal stress. To this end, skip-firing is often applied, such that the engine is fired and subsequently motored for a number of cycles, allowing the in-cylinder surfaces to remain relatively cool. However, a single fired cycle may not accurately reflect real engine operating conditions. Therefore, to simulate heat transfer and in-cylinder conditions more realistically, multiple consecutive fired cycles are often used, where only the data from the last cycle is recorded. This way, only the cycles with representative in-cylinder temperatures and internal Exhaust Gas Recirculation (EGR) fractions will be considered. In addition, performing meaningful emission analyses on engines operating in skip-firing mode is challenging, since the exhaust gases are diluted by the motored cycles, making it difficult to scale it to the continuously fired case.

Experimental Setup

In this work, experiments for various engine conditions and skip-firing parameters are performed, to investigate the influence of skip-firing on the heat release and engine-out emissions. The experiments are conducted on a full-metal modified PACCAR MX-13 single-cylinder heavy-duty research engine. This engine has no optical components, allowing it to run both in skip-firing and in continuously-firing mode, to perform a better comparison. The engine specfications are listed in Table 1.

Table 1. MX-13 engine specifications

Parameter	Specification
Engine speed [rpm]	800-1700
Displacement [L]	2.15
Bore [mm]	130
Stroke [mm]	162
Compression ratio	17.2
Number of valves	4
Max. injection pressure [bar]	2500

To record the in-cylinder pressure, a Kistler 6125C piezo-electric pressure transducer is used. This allows for the calculation of various properties, such as the apparent Rate of Heat

Release (aRoHR) and Ignition Delay (ID). In addition, a Horiba MEXA 7100 DEGR exhaust gas analyzer and AVL 415s smoke meter are used to measure exhaust CO, CO_2, O_2, NO_x, THC, and PM emissions.

Results

Initial experiments were conducted at an engine speed of 1200 RPM and load of 40%, using B7 diesel as fuel. All engine conditions were kept constant, except for the skip-firing parameters: the total number of cycles was kept at 10, but the ratio of firing to skipped cycles was varied. For these cases, differences in aRoHR and engine-out emissions were studied to see how skip-firing affects combustion.

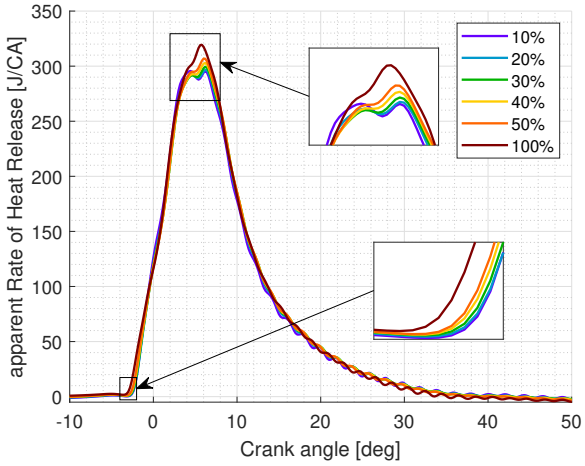


Figure 1. aRoHR over CA for various firing fractions

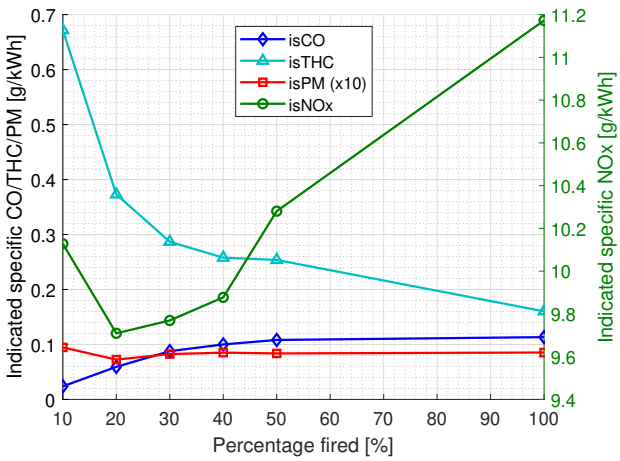


Figure 2. CO, THC, PM, and NO_x emissions over firing fractions

Figure 1 shows the cycle-averaged aRoHR as function of CA, for continuous firing and different skip-firing strategies. From the bottom inset, it can be observed that as the firing mode is shifted from continuous to 10% firing mode, the ignition delay increases. However, the 10% and 20% firing cases have a comparable ignition delay. Now taking a look at the top inset, it can be seen that the peak in aRoHR increases with firing percentage, and that the right-most part the 10% and 20% case again present similar results. However, the initial so-called pre-mixed burn of the 10% firing case is significantly larger compared to the other cases. A lower firing percentage results in more motored cycles, which decreases the in-cylinder temperature and thus leads to a longer ignition delay and a slower heat release. This could explain most of the results described above, except for the behavior of the 10% case. For this case, there is only one consecutive fired cycle, which means that there is little residual exhaust gas present in the cylinder. This increases the oxygen content, which increases reactivity, leading to a shorter ignition delay and faster heat release. It seems that for the 10% and 20% cases, the effects of the reduced in-cylinder temperature and increased oxygen content cancel each other out.

In Figure 2, the CO, THC, PM, and NO_x emissions are shown as function of firing percentage. The PM emissions remain relatively constant, while the CO and NO_x emissions seem to increase with increasing firing percentage, whereas the THC emissions decrease. The NO_x however, shows a sharp decrease going from 10% to 20% firing, possibly because of the absence of residual exhaust gas.

Better understanding of the described phenomena will allow for detailed combustion and emission analysis in future H_2 operation using the optical engine.

EXPERIMENTAL STUDY ON IRON PELLET STEAM OXIDATION FOR HYDROGEN STORAGE

T.T. Siebelt* and Y. Ma and X.C. Mi* *****
t.t.siebelt@student.tue.nl
*Eindhoven University of Technology, Eindhoven, The Netherlands
**Delft University of Technology, Delft, The Netherlands
***Eindhoven Institute of Renewable Energy Systems (EIRES)

Abstract

This is still an ongoing study into the steam oxidation and hydrogen reduction characteristics of iron pellets. Here we want to share our intermediate findings and lay out the principles of iron-based hydrogen storage.

Hydrogen storage is one of the challenges in the future hydrogen economy. Hydrogen is difficult to contain and compress, making transport and long-duration storage inefficient and costly. One solution could be storage by making use of the redox cycle of iron with water, as seen in Equation 1. Iron has the advantage in volumetric energy density and low losses during storage compared to hydrogen. Recently, this reaction has again gotten traction for hydrogen storage. In the Netherlands, student team SOLID is developing systems to perform this reaction [1]. In Germany, the startup AMBARTEC is doing the same [2]. The potential of iron for energy storage is also used in the field of combustion, using iron powder as a fuel [3].

$$3\,Fe + 4\,H_2O \rightleftharpoons Fe_3O_4 + 4\,H_2 \tag{1}$$

The reaction of solid iron with steam is not straightforward and has many design parameters. Iron can be used in powder or pellet form, additives can be added, and the process conditions will all influence the reaction.

One dilemma this research looks into is the temperature of the reaction. For oxidation of iron, the equilibrium conditions of Equation 1 are much better at low temperatures. However, this will also reduce the reaction rate. Therefore, TGA and furnace experiments at 500°C and 600°C will be performed. These temperatures are chosen to be below and above the eutectoid point of wustite to see its effect on the reaction velocity. The pellets will also be analysed using SEM-EDX. A cross-section of the pellets helps to determine what the internal reaction front looks like and gives information on what solid-state reaction mechanism and rate-limiting steps are at play.

Method

For this research, two different types of pellets are used. One is an industrially produced pellet, and one is self-made. Both pellets are made in a disk pelletizer and contain impurities. The self-made pellets were produced using Fe_2O_3 nano powders together with a small amount of binding agent. This is rotated in the pelletizer while water is sprayed on it. The powder agglomerates and forms round pellets, which are afterwards dried and baked at 900°C, so the powders in the pellets sinter together.

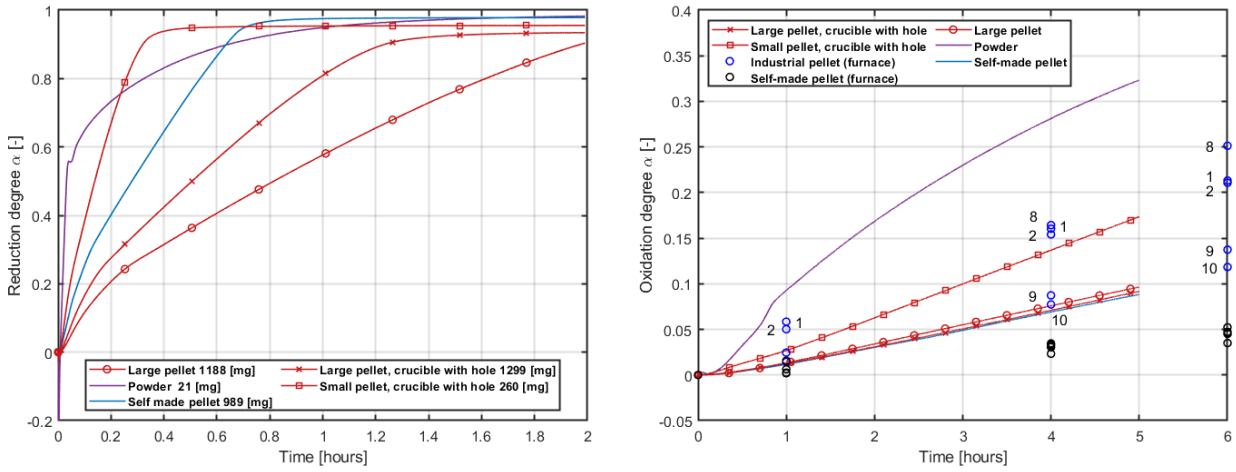
In the experimental phase, the focus will be on steam oxidation of iron pellets at 500°C and 600°C, but most reduction experiments were performed at 800°C. The pellets have been oxidised using a TGA with 2% water vapour and a furnace setup with 25% water vapour to determine the effect of steam concentration on the reaction rate. Lastly, cross-sections of the pellets have been made and analysed using a SEM-EDX.

Results

The research found that oxidation of pellets at 500°C was generally slow and limited by the concentration of water vapour, at least for the TGA with 2% H2O. An increase in water vapour did show an increase in reaction. The limitations of temperature seem to still be at play here, where other research shows much faster reaction velocity for higher temperatures [4]. The limitation could also be in the pellets' morphology, which has to be further researched.

The reduction of self-made pellets was faster than the industrial pellets. During oxidation, this was the other way around. The SEM images showed that the self-made pellets were less porous on the grain scale than the industrial pellets. But they were more uniformly distributed over the pellets' full surface. The industrial pellet had a denser core. Within both pellets, it seemed a denser iron layer formed during reduction that influenced the oxidation capabilities.

In general, the pellets did not show a shrinking core reaction front but grains with a reaction front, indicating a limitation due to solid phase diffusion. The industrial pellets seem to have a higher amount of micro pores, leading to a larger internal surface area, which explains the higher reaction rate.



(a) Reduction degree

(b) Oxidation degree

Figure 1. TGA results of the reduction (a) and TGA and furnace results of the oxidation (b) at 500°C. Depicted masses are original masses before reduction, and the conversion degree assumes the pellet is fully iron(oxide). The scattered data in (b) represent the pellets in the furnace (1 to 10, with 1 receiving the fresh flow in ascending order).

Future work

Oxidation and reduction experiments at 600°C will be performed. This is to see the effect of the wustite phase and reduction temperature on the oxidation kinetics.

References

[1] *Team solid*, https://www.teamsolid.org/, (accessed 20-10-2025).

[2] *Ambartec*, https://www.ambartec.de/en/, (accessed 20-10-2025).

[3] J. Bergthorson et al., "Direct combustion of recyclable metal fuels for zero-carbon heat and power," *Applied Energy*, vol. 160, 368–382, 2015.

[4] B. Gamisch, L. Huber, M. Gaderer, and B. Dawoud, "On the kinetic mechanisms of the reduction and oxidation reactions of iron oxide/iron pellets for a hydrogen storage process," *Energies*, vol. 15, no. 21, p. 8322, 2022.

Spatiotemporal temperature distribution and spectral emissivity during the initial liquid combustion of millimeter-sized iron particle

W. Tian[1], Y. Shoshin[1], V. Kornilov[1], X.C. Mi[1,2]

w.tian2@tue.nl

[1] Power & Flow Section, Department of Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands
[2] Eindhoven Institute of Renewable Energy Systems (EIRES), Eindhoven University of Technology, Eindhoven, The Netherlands

Abstract

Iron powder is a promising recyclable fuel for clean power generation, yet its combustion mechanisms and optical properties during combustion remain unclear. Most studies have focused on micrometer-sized particles due to their practical relevance, but their rapid burning and small size hinder detailed observation of the combustion process. To overcome this limitation, we investigated single millimeter-sized iron particles, which burn longer and allow clearer observation. In our experiments, particles were ignited by a laser and monitored using optical diagnostics to capture the spatiotemporal temperature distribution. The results reveal the coupled evolution of temperature and particle structure, providing new insights into oxidation and reaction processes. Furthermore, to assess the widely adopted graybody assumption in iron combustion, we measured the spectral emissivity of liquid iron and liquid iron oxide under both inert and combustion conditions. This study provides new understanding of iron combustion behavior and the optical characteristics of burning iron.

NEAR EXTINCTION FLAME BEHAVIORS UNDER DIFFERENT AMMONIA CRACKING RATIOS

B. Xu* and R.J.M. Bastiaans*
b.xu1@tue.nl
*Power and Flow, Department of Mechanical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

Abstract

The extinction limits for NH_3/H_2/N_2 bluff body premixed flame under different ammonia cracking ratios show different response to inflow velocity change. To investigate the flame extinction process under different hydrogen percentages, two premixed NH_3/H_2/N_2/O_2 blends with the same unstretched laminar flame velocity under different stoichiometry were chosen and simulated in bluff body stabilized flame using large eddy simulation. The chosen blends contained 70% of NH_3 at phi=0.64 and 40% at phi=0.468 which both resulted in a burning velocity of 5.7 cm/s. With the 70%NH_3 blend, the flame is more compact than with the 40%NH_3 blend. This can be attributed to the different combustion intensity response to the strain rate increasing. One-dimensional simulation provides an evidence for this assumption. These findings provide a deeper understanding about how partially cracked ammonia premixed flame extinction happens.

Keywords: *extinction, partially cracked ammonia, premixed flame*

DNS-Informed Modeling of Hydrogen–Oxygen Detonation Waves for RDCs

Andrea Bari*, Jeroen van Oijen*, and XiaoCheng Mi*,**

*Eindhoven University of Technology, Eindhoven, The Netherlands

**Eindhoven Institute of Renewable Energy Systems (EIRES), Eindhoven, The Netherlands

ABSTRACT

The DNS framework solves the compressible Navier Stokes equations with detailed H_2 and O_2 chemistry in 2D and 3D slab domains representing a finite thickness reactant layer bounded by hot products. Two fueling scenarios are considered: fully premixed layers and stratified layers formed by jet injection to emulate inhomogeneous mixing. Systematic parametric sweeps vary layer thickness, equivalence-ratio gradients, injection timing, and imposed back-pressure to isolate how lateral expansion and mixture inhomogeneity govern irregular-cell structures characteristic of RDC waves. Investigations include wave speed and curvature, detonation cell size statistics, spatio-temporal pressure and heat-release fields, and 3D topology of shock flame interactions. From these datasets, we extract mechanistic links and scaling trends between geometric/mixture controls and the emergence, persistence, and breakdown of irregular cell patterns. These insights are encoded into a DNS validated ROM capable of rapidly predicting wave dynamics across operating envelopes relevant to RDC design. To facilitate cross-scale modeling, we create a benchmark suite enabling consistent validation of large-eddy simulations (LES) for hydrogen oxygen detonations in expanding and stratified configurations. The resulting simulation corpus provides both physical understanding of cell-level dynamics under realistic RDC constraints and practical tools (ROM + LES benchmarks) to accelerate design-space exploration and fidelity assessment of reduced-order and turbulence-resolving models for hydrogen detonation–based propulsion.

EMISSION CHARACTERIZATION OF FUEL-FLEXIBLE KEROSENE-H_2 COMBUSTOR

K. Dave*, A. Garcidueñas Correa, A. Gangoli Rao, F. De Domenico
K.A.DAVE@TUDELFT.NL
FPT Department, Faculty of Aerospace Engineering, TU Delft
Kluyverweg 1, 2629 HS, Delft

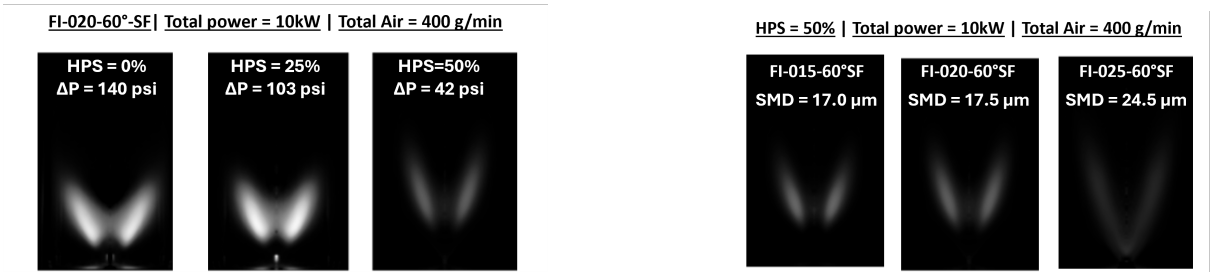
Abstract

Fuel switching in the aviation sector is a critical step to reduce its contribution to climate change. Hydrogen (H_2) is a promising alternative, yet it poses challenges across production, transport, storage, and utilization [1]. Despite these barriers, its potential as a carbon-free energy carrier has motivated ongoing research into its technical viability for aero-engines[2–4].

This work presents results from a novel fuel-agnostic combustor tested with kerosene–H_2 mixtures. The multi-phase combustor was operated with hydrogen power share (HPS) ranging from 0% (pure kerosene) to 50% (energy basis). Flame imaging and emission data were collected, and three different kerosene injectors were employed to assess the influence of atomization quality on performance.

The effect of HPS on flame shape is shown in Figure 1a. With increasing HPS, the flame lift-off height increases, while the opening angle and overall luminosity decrease. The geometric changes are attributed to reduced swirl intensity caused by the axial injection of H_2, whereas the lower luminosity results from diminished production of visible chemiluminescent species (namely CH^*, C_2^* and soot) as the H_2 fraction increases.

Additionally, the experiments also underscored the role of kerosene atomization in flame stability. At HPS = 50%, Figure 1b shows flashback induced by poor atomization. As the Sauter mean diameter (SMD) increases across atomizers, the flame shifts closer to the combustor base-plane while extending in height. This upstream propagation is driven by ligament formation [5] and fuel-rich pockets that enable flame anchoring near the injector. The increased flame height arises because larger droplets evaporate and burn more slowly than smaller, better-atomized ones.



(a) Effect of HPS on flame shape

(b) Effect of kerosene atomization

Figure 1. Comparison of flame shape and flame location under different HPS and kerosene atomization conditions.

Lastly, the influence of HPS on NO and CO emissions is shown in Figure 2. With increasing HPS, NO levels rise slightly before declining, while CO decreases sharply at first and then increases gradually. These trends result from competing effects of H_2 addition, including changes

in swirl intensity and flow field, variations in kerosene atomization and evaporation rates, and differences in premixing.

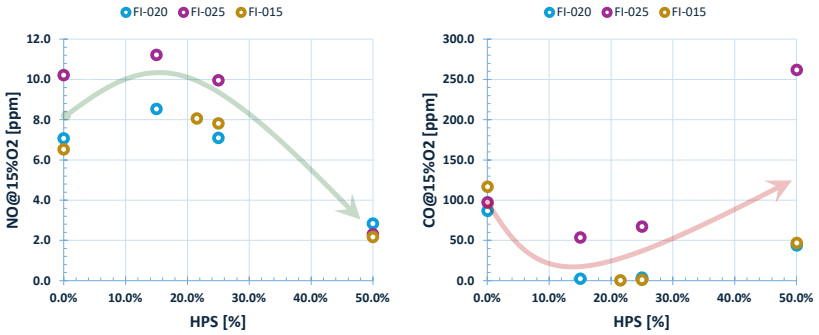


Figure 2. Effect of increasing HPS on NO and CO emissions

Overall, the study demonstrates that kerosene–H_2 mixtures can reduce CO_2 emissions while modifying flame geometry and pollutant formation. The findings provide an initial step toward evaluating kerosene–H_2 blends as a transitional strategy for mitigating aviation's climate impact.

Funding

This work was carried out in the HOPE project co-funded by the European Union under the Horizon Europe Research and Innovation programme Grant Agreement no. 101096275 and UKRI Research and innovation (UKRI) under the UK government's Horizon Europe funding guarantee n° 10068673.

References

[1] A. B. de Vasconcelos Leitão, C. Bringhenti, J. T. Tomita, F. J. dos Santos Silva, C. Xisto, and T. Grönstedt, "A review of hydrogen aircraft propulsion systems: Recent advances and environmental perspectives," *International Journal of Hydrogen Energy*, vol. 176, p. 151 489, 2025.

[2] L. Palanti et al., "CFD-based scouting for the design of a multi-fuel kerosene/hydrogen atmospheric burner," in *ICAS Proceedings*, 2024.

[3] K. Dave, S. Link, F. De Domenico, F. Schrijer, F. Scarano, and A. Gangoli Rao, "Kerosene-H_2blending effects on flame properties in a multi-fuel combustor," *Fuel Communications*, vol. 23, p. 100 139, 2025.

[4] S. Singh, M. Amerighi, N. Scopolini, A. Andreini, S. R. Harth, and D. Trimis, "Effect of $H_2$and Jet-A1 fuel split on flame stability and pollutant emissions from low-swirl burner," *Proceedings of the Combustion Institute*, vol. 41, p. 105 858, 2025.

[5] R. A. Dafsari, H. J. Lee, J. Han, D.-C. Park, and J. Lee, "Viscosity effect on the pressure swirl atomization of an alternative aviation fuel," *Fuel*, vol. 240, pp. 179–191, 2019.

MICROWAVE DRIVEN PLASMA INTENSIFIED GASIFICATION: AN EXPERIMENTAL INVESTIGATION

N. Sharma*, A.M.J. Felden* and W. de Jong*
n.sharma-2@tudelft.nl
*Department of Process & Energy, Delft University of Technology, Leegwaterstraat 39, 2628 CB Delft, The Netherlands

Abstract

Did you know that 87% of the world's energy demand is still met through natural gas or other fossil fuels [1]? This excessive dependence on fossil fuel has pushed us towards irreversible climate and environmental changes. As the world heats up, the call to ditch fossil fuels grows louder [2]. Climate change is no longer a warning, it's our present and we are experiencing it daily! The urgency of the crisis has sparked a global push for greener, cleaner energy solutions [2, 3]. The quest for cleaner energy has long led researchers to explore alternatives of natural gas also known as syngas. Notably, syngas can be produced from waste materials, making it both a renewable and waste-reducing energy source. This has drawn attention to thermochemical conversion technologies, with gasification as one of the promising approaches [4]. Gasification is a partial oxidation process that converts carbon-rich waste into a mixture primarily composed of carbon monoxide and hydrogen (syngas). Beyond serving as a combustible fuel, syngas is a flexible intermediate, enabling the production of electricity, and a wide range of value-added chemicals. Yet, conventional gasification systems still struggle with familiar hurdles: mainly tar formation, incomplete conversion, and fluctuating process stability [5, 6].

To overcome such limitations, researchers are investigating plasma-assisted gasification, particularly microwave-induced plasma. Plasma, an ionized gaseous state, also known as the fourth state of matter, offers a highly reactive medium and high operating temperature which in turn facilitates further breakdown of tars and toxic by-products. Thereby increasing the overall process efficiency [7]. Integrating plasma intensification is a path worth investigating. Plasma, with its unique properties, has the potential to revolutionize gasification [8]. Though the integration of plasma in the process of gasification looks promising, there exists a lack of understanding on the fundamental role of plasma in the process of gasification.

One of the key research gaps in plasma gasification is the limited fundamental understanding of plasma dynamics at play. To address this, the present study intend to integrate advanced diagnostic techniques within a controlled experimental framework, aiming to gather detailed insights into plasma behaviour and its interaction with biomass.

For that purpose, a custom-built $2.45\,\mathrm{GHz}$ microwave plasma reactor has been re- commissioned. The system was originally designed in 2016 as a part of Bill and Melinda Gates Foundation project; Reinvent the Toilet, aimed at transforming human waste into fuel. Within this setup, the influence of key plasma parameters like temperature and densities of the species which influences the syngas composition and process efficiency will be experimentally investigated.

The project is structured into two major themes: First, we characterize the plasma under different monogases, nitrogen and argon. These inert gases offer a controlled environment to understand the fundamental properties of plasma.Here, we explore how varying parameters such microwave power, feedstock characteristics, and residence time affect the outcomes. Plasma will be characterize using optical emission spectroscopy and thermal imaging. Once that foundation is established, we move to the second phase, where the learnings will be translated to

gasify model biomass (cellulose and/or raw lignin). A thorough experimental investigation will be done on the feedstock and the products to track the changes.

The project intends not only to advance the scientific understanding of microwave induced plasma driven gasification but also to support the development and technological maturity of plasma-based waste-to-energy systems.

References

[1] K. Abouemara, M. Shahbaz, G. Mckay, and T. Al-Ansari, "The review of power generation from integrated biomass gasification and solid oxide fuel cells: Current status and future directions," *Fuel*, vol. 360, p. 130 511, 2024.

[2] K. Calvin et al., *IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.* IPCC, 2023, 1–34.

[3] K. R. van Daalen et al., "The 2022 europe report of the lancet countdown on health and climate change: Towards a climate resilient future," *The Lancet Public Health*, vol. 7, no. 11, e942–e965, 2022.

[4] M. Huron, S. Oukala, J. Lardière, N. Giraud, and C. Dupont, "An extensive characterization of various treated waste wood for assessment of suitability with combustion process," *Fuel*, vol. 202, 118–128, 2017.

[5] K.-T. Lee, W.-H. Chen, P. Sarles, Y.-K. Park, and Y. S. Ok, "Recover energy and materials from agricultural waste via thermochemical conversion," *One Earth*, vol. 5, no. 11, 1200–1204, 2022.

[6] A. A. Ahmad, N. A. Zawawi, F. H. Kasim, A. Inayat, and A. Khasri, "Assessing the gasification performance of biomass: A review on biomass gasification process conditions, optimization and economic evaluation," *Renewable and Sustainable Energy Reviews*, vol. 53, 1333–1347, 2016.

[7] M. Hrabovsky, "Thermal plasma gasification of biomass," in *Progress in Biomass and Bioenergy Production*. InTech, 2011.

[8] S. Valizadeh et al., "Valorization of biomass through gasification for green hydrogen generation: A comprehensive review," *Bioresource technology*, vol. 365, p. 128 143, 2022.

HYDROGEN FLAME-DRIVEN FLASH REDUCTION OF MILLIMETER-SIZED IRON OXIDE PARTICLES

Wenjiang Tian*, Atanu Dolai*,, Calvin Wong*, Giulia Finotello*,**, and XiaoCheng Mi*,****

x.c.mi@tue.nl

*Power and Flow Group, Eindhoven University of Technology, Eindhoven, The Netherlands

**Eindhoven Institute of Renewable Energy Systems (EIRES), Eindhoven University of Technology, Eindhoven, The Netherlands

Abstract

Flash reduction provides a rapid and efficient pathway for converting iron oxide to metallic iron, but it requires high temperatures and effective reductants. Fuel-rich hydrogen-air flames offer a simple and scalable approach, as they simultaneously supply both hydrogen and heat. In this work, the flash reduction of millimeter-sized ($\sim$1 mm) iron oxide particles is experimentally investigated using a confined, fuel-rich premixed hydrogen flame. The particles are positioned at the end of the confinement, and the effects of operating conditions are studied by varying the equivalence ratio (Φ = 2.5 and 3) and the confinement length (L = 50 mm and 80 mm), thereby modifying both the product gas temperature and composition. Under all operating conditions, the particle temperature is measured using three-color pyrometry, and the reduction degree (X) is determined from the change in particle mass.

Stable particle temperatures and consistent reduction are observed across all operating conditions. For Φ = 2.5 and L = 50 mm, a reduction degree of 46% is achieved within 3 minutes. Increasing Φ to 3 results in a lower reduction degree of 40%. Although a higher Φ corresponds to a larger hydrogen-to-water ratio in the product gases, the particle temperature decreases with increasing Φ, highlighting the dominant role of temperature over reductant concentration. Extending the confinement length to 80 mm further reduces the particle temperature, leading to a decrease in reduction degree from 40% to 33% as the particle temperature drops from 1390 K to 1110 K at Φ = 3. Finally, the reduction degrees at the same Φ are used to estimate the activation energy (E_a), and Energy-dispersive X-ray spectroscopy (EDX) analysis of the particle cross-sections is performed to further investigate the reduction process.

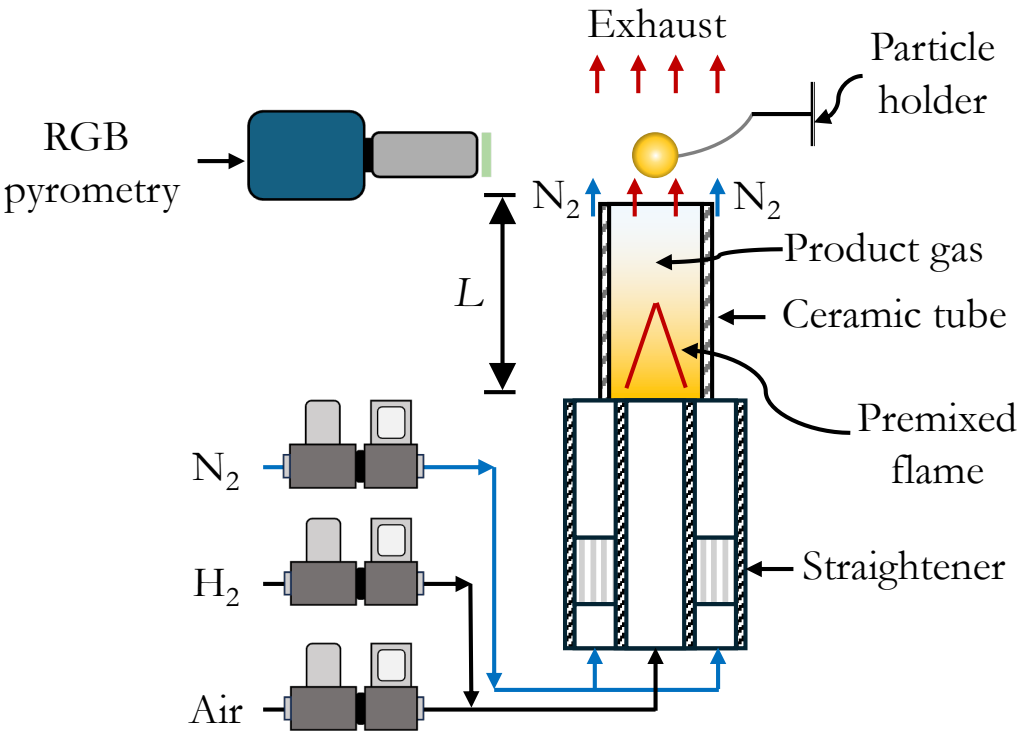


Figure 1. The schematic of the experimental showing the confined fuel-rich hydrogen-air and iron oxide particle. The length of the tube is L.

Effect of Particle Porosity on the Ignition Temperature of micron-sized Iron Powder

Kaining Zhang, Shrikant Paliakara, Nicole Stevens, Willie Prasidha, Wenjian Tian,

Giulia Finotello, and Xiaocheng Mi

k.zhang1@student.tue.nl, x.c.mi@tue.nl

Power and Flow group, Department of Mechanical Engineering, Eindhoven University of Technology, Eindhoven, Netherlands

Abstract

Iron powder is a promising carbon-free energy carrier due to its high energy density and recyclability through combustion and reduction cycles. Combustion efficiency, ignition behavior, and pore formation during reduction are interlinked processes that influence each other during an energy cycle. Ignition temperatures of particles also play a role in the robust operation of practical metal fuel burners. This study examines the impact of pore formation and size on ignition through a combination of bulk powder and single-particle combustion experiments.

Commercial iron oxide is reduced to iron powder at different temperatures (500-800 °C), resulting in different pore sizes and structures. Bulk Powder experimental results reveal that with decreasing pore size, the pre-heating temperature decreases to as low as 200°C resulting in a stable flame. The highest minimum temperature was found to be 680°C for powder reduced at 800°C. Individual particle combustion behavior is also monitored in combination with pyrometric and optical diagnostic techniques. The iron powder used had an average size of 90 µm and was combusted over a wider range of temperatures to validate the minimum ignition temperature obtained through bulk powder experiments. Powder morphology and composition are carried out using scanning electron microscopy (SEM), x-ray diffraction (XRD) and particle size analysis (PSA). Reduction was conducted on a fluidized bed reactor while a metal cyclone burner and single particle burner were used for combustion.