PROPOSITION DE SUJET DE THESE

Reactive Flow Dynamics in Porous Media: Numerical and Experimental Analysis for Advanced Combustion Systems

Reference : **MFE-DMPE-2025-19**
(recall in every communication)

Thesis start : October 2025	**Application deadline : July 2025**

Key words

Porous Media Combustion, Reactive Flows, Experimental and Numerical Analysis, Lean Combustion, Fluid Mechanics, **based in Germany (KIT)**.

Candidate profile

We are seeking a PhD candidate with a strong background in fluid mechanics and a solid understanding of reactive flows. Candidates with experience across experimental, theoretical, and numerical methods will be given preference, as this project requires an interdisciplinary approach. Proficiency in English is essential.

Project context

Combustion in porous media, see Figure 1, is at the forefront of modern energy solutions, offering promising advancements for high-efficiency, low-emission systems. This PhD project at the Karlsruhe Institute of Technology (KIT) in Germany provides an opportunity to investigate the intricate physics of reactive flows in porous structures. By understanding the dynamics of flame stabilization, heat transfer, and turbulence within these media, we aim to contribute to the development of sustainable, high-performance combustion technologies.

Why study porous media combustion?

Porous media combustion enables higher energy efficiency, enhanced flame stabilization, and reduced emissions compared to conventional combustion systems. The potential applications include radiant burners, boiler systems, chemical reactors and sustainable energy systems. Despite its advantages, key aspects—such as the effects of pore topology on flame stability and pollutant reduction—remain underexplored.

This PhD project will examine these interactions, offering insights to improve the design and performance of combustion systems.

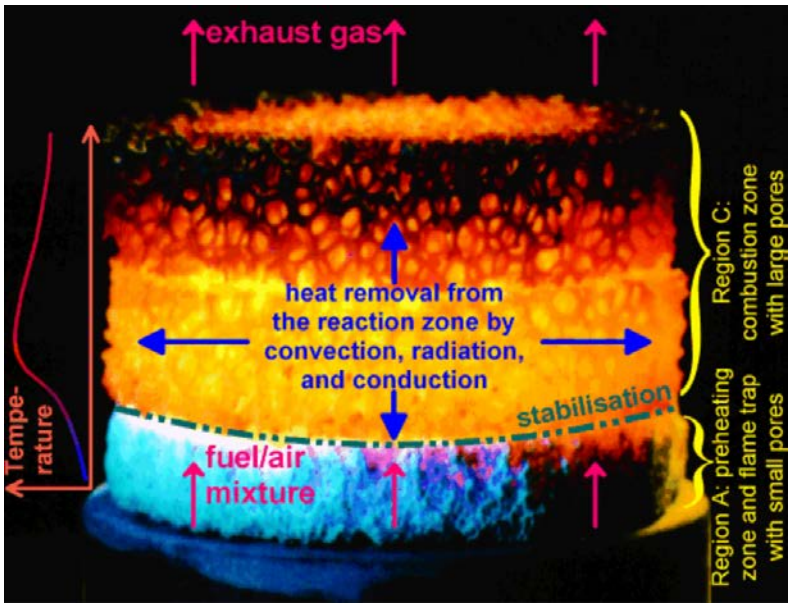

Figure 1 : Principal processes in porous media combustion

Primary Objectives

The PhD project will focus on three physics-oriented objectives:

The first focus of this project is to investigate **traveling wave phenomena in porous inert media**. This involves analyzing how flames propagate downstream or upstream within the material, and the relationship

between these propagation characteristics and the pore topology and heat exchange between the flame and the porous structure. Stabilized flames will also be studied, particularly in lean fuel mixtures, with an emphasis on extending flammability limits for low-calorific fuels, which are increasingly relevant in sustainable energy applications.

The second aspect involves exploring **enhanced flame dynamics through semi-turbulent effects**. By leveraging structural features in PIM, such as wake effects behind struts, it is possible to induce pseudo-turbulence within porous media. This turbulence increases the flame surface area, enhancing the effective flame speed and enabling higher inflow rates. Such improvements allow for greater power density without compromising stability.

Lastly, the project aims to develop **optimized porous material designs for high performance** by integrating the insights gained from traveling wave phenomena and semi-turbulence effects. A particular focus will be on designing layered and graded porous structures that stabilize flames effectively, reducing the risk of flashback and blow off. These designs will target higher power densities, offering practical solutions for advanced combustion systems.

Methodology

To accomplish the previous objectives, the PhD candidate will employ a comprehensive approach, integrating numerical simulations with experimental validation to achieve data-driven insights and models.

- **Numerical analysis**: Using state-of-the-art computational fluid dynamics (CFD) software, specifically EBIdnsFoam (developed at KIT), you will simulate reactive flow behavior within various porous media geometries.
- **Experimental validation**: Design porous media samples through advanced additive manufacturing methods, followed by combustion tests to measure flame characteristics and emissions.
- **Flow-chemistry coupling and modeling**: Leveraging insights from both simulations and experiments, you will develop models to capture the interactions between pore-scale structure, flow and thermal properties. A special focus will be placed on identifying transitions within flow-chemistry regimes, drawing parallels between turbulent and laminar flow behaviors as they impact chemical reaction fronts.

Expected Outcomes

During this PhD project, you will:

- Gain a thorough understanding of reactive flows within porous media, developing both theoretical insights and practical applications.
- Generate knowledge applicable to the design of porous structures optimized for combustion stability and high power density.
- Contribute to the global drive toward cleaner energy solutions through advancements that reduce harmful emissions.

Unique research environment and collaborations

This PhD position is hosted by the Karlsruhe Institute of Technology (KIT), a leading research institution in Germany. The project will be supervised by Professors Stein and Trimis at KIT, with additional guidance from Dr Roncen at ONERA–Toulouse (France). This collaborative structure enables annual exchanges with ONERA, fostering synergies with other PhD candidates working on related topics. You will benefit from access to KIT's state-of-the-art combustion laboratories and interdisciplinary research networks, positioning you at the cutting edge of combustion science.

Why join this program?

Joining this PhD program means engaging in innovative research with tangible, real-world impact. As you delve into the complex dynamics of porous flow-chemistry, your work will have broad applications across critical fields, from energy systems to environmental technology. The research environment offers access to world-class facilities, including KIT's Porous Media Combustion Lab, where advanced testing tools support experimentation. You'll also benefit from powerful computational resources, such as the specialized CFD software EBIdnsFoam, developed to model complex reactive flows in porous media. This program fosters international collaboration through annual exchanges with ONERA-Toulouse, providing you with invaluable opportunities to work alongside leading experts, connect with peers, and build a strong academic and professional network across Europe.

Application process

We welcome applications from candidates with diverse academic backgrounds and international experience. In your application, please include:

- A detailed CV
- All certificates to document your relevant expertise
- A cover letter expressing your motivation
- Contact information for two academic references, and one industrial reference if you are currently engaged in an internship within the industry sector.

We encourage early applications as selections will be made on a rolling basis.

Collaborations

This PhD thesis will be held at Karlsruhe Institute of Technology (Germany), under the supervision of Pr Stein and Pr Trimis, while being supervised by R. Roncen from ONERA-Toulouse (France). Trips to ONERA will be held annually to exchange with PhD students working on the same topic.

ONERA's supervision	**Thesis directors**
Department : Multi-Physique pour l'Energétique	Lab : KIT (Karlsruhe, Germany)
Lab: DMPE/STAT, (Toulouse , France)	**Directors** : Pr. O. Stein and Pr. D. Trimis
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