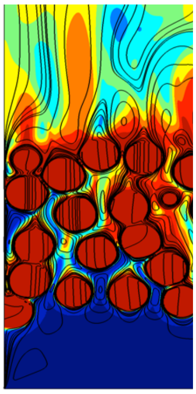
ECOLE DOCTORALE
« Mécanique, Energétique, Génie Civil, Procédés »
ED 468

PhD thesis position (2024-2027)

Starting date: October 1, 2024. Deadline: May 1, 2024

Title	Experimental and numerical modeling of hydrogen combustion in fluidized beds
Supervisors / Contacts	Enrica Masi, Thierry Schuller, Rudy Bazile / enrica.masi@imft.fr, thierry.schuller@imft.fr, rudy.bazile@imft.fr
Laboratory	Institut de Mécanique des Fluides de Toulouse (IMFT), Toulouse, France

Subject / Background



This doctoral research aims to study a fluidized bed process in which hydrogen combustion takes place at sufficiently low temperature in the presence of a partially inert solid medium, in order to face the risks related to the reactivity and wide range of flammability which characterize this fuel. Indeed, the use of hydrogen presents increased risks compared to conventional fuels. The presence of a solid phase allows to control the combustion by thermal and chemical quenching; a fluidization regime promotes mixing and thermal exchanges. Fluidized bed combustion is therefore a promising solution for a safe production of thermal energy from hydrogen.

The first part of the PhD thesis takes an experimental approach to the problem. Hydrogen combustion in a fluidized bed will be reproduced using laboratory experiments. Two types of experiments are considered: a small-scale experiment to perform fundamental studies, and a larger-scale experiment to test the process at a controlled temperature. The small-scale fluidized bed is a device currently under construction, with optical access to the bed. Pressure sensors, thermocouples and sampling probes are also used to characterize the flow. Thanks to the optical access allowed by the quartz walls, several types of diagnostics are possible (including OH* chemiluminescence, shadowgraphy, high speed imaging and laser-induced phosphorescence) to characterize the reactive flow. The goal of these experiments is to characterize hydrogen combustion according to injection conditions, as well as the physical properties of the particles. Special attention will be paid to the characterization of chemical quenching using different solid materials whose reactivity can be modified by surface treatments. Further experiments will be carried out on a second device closer to realistic conditions, but without optical access. It comprises a cylindrical reactor approximately 1 m high and 10 cm in diameter, similar to ref. [1], which serves as a pilot equipped with pressure sensors, thermocouples and sampling probes. A cooling system surrounding the dense bed keeps the pilot at a controlled temperature [2], enabling combustion to be characterized as a function of the mean bed temperature using the material selected during the small-scale experimental campaigns.

The second part of the thesis addresses the problem by the numerical modeling. Initially, a CFD-DEM approach will be considered, using the granular solver of the code YALES2 [3], to reproduce small-scale experiments and investigate locally the gas-particle reactive flow in dense regime. Next, a Euler-Euler approach will be used to reproduce the larger pilot and characterize the process at macroscopic scale using the code neptune_cfd [4]. In the code, models developed for hydrogen combustion in the presence of the particles will be implemented. These models are currently being studied through a DNS-type approach using fully resolved particles, and will also make use of the results obtained at mesoscopic scale by YALES2. The models thus obtained [5] will be integrated into the code netpune_cfd during the thesis, and used to reproduce the experimental pilot. Laboratory experiments will be used to validate the reaction scheme over temperature ranges where conventional reaction schemes are little used, taking into account the effects of surface reactions as well. Experimental data will also be used to validate the numerical modeling. The numerical approach will then be used to investigate the optimum operating point and the limits of the process, subject to safety and efficiency constraints.

Host laboratory

The thesis will be carried out at IMFT, in the reactive-flows group, which has many years' experience in the field of hydrogen combustion and an extensive experimental and numerical expertise in this area [6]. Cross-collaboration was initiated within the group as part of an internship on hydrogen combustion in fluidized beds. This collaboration, which will continue as part of the thesis, draws on the experimental and numerical expertise of the group's researchers in gas-particle flows [7, 8] and H2 combustion [9].

Applicant profile

We are looking for candidates with a master's degree or equivalent (to be obtained before October of the current year), with skills in fluid mechanics. The knowledge of CFD and combustion would be an additional asset. A keen interest in research, both experimental and numerical, is essential.

Gross monthly salary: ~ 2100 €. In addition to the salary received under the doctoral contract, doctoral students may engage in paid teaching activities, up to a limit of 64 hours per school year.

References

[1] J. Baron, E.M. Bulewicz, S. Kandefer, M. Pilawska, W. Zukowski, A.N. Hayhurst, Combustion of hydrogen in a bubbling fluidized bed, Combust. Flame, 156 (5): 975-984, 2009.
[2] S. Dounit, M. Hemati, R. Andreux, Modelling and experimental validation of a fluidized-bed reactor freeboard region: Application to natural gas combustion, Chem. Eng. J., 140 (1-3): 457-465, 2008.
[3] Y. Dufresne, V. Moureau, E. Masi, O. Simonin, J. Horwitz, Simulation of a reactive fluidized bed reactor using CFD/DEM. Center for Turbulence Research Summer Program 2016, Stanford, United States, pp. 35-44, 2016.
[4] Z. Hamidouche, E. Masi, P. Fede, R. Ansart, H. Neau, M. Hemati, O. Simonin, Chapter Two - Numerical Simulation of Multiphase Reactive Flows, Advances in Chemical Engineering, 52: 51-124, 2018.
[5] E.I. Thiam, E. Masi, E. Climent, O. Simonin, S. Vincent, Particle-resolved numerical simulations of the gas-solid heat transfer in arrays of random motionless particles, Acta Mechanica, 230(2): 541-567, 2019.
[6] A. Aniello, D. Laera, S. Marragou, H. Magnes, L. Selle, T. Schuller, T. Poinsot, Experimental and numerical investigation of two flame stabilization regimes observed in a dual swirl H2-air coaxial injector, Combust. Flame, 249: 112595, 2023
[7] M. Elhimer, O. Praud , M. Marchal, S. Cazin, R. Bazile, Simultaneous PIV/PTV velocimetry technique in a turbulent particle-laden flow, Journal of Visualization, 19 (75): 1-16, 2016.
[8] A. Nigmetova, E. Masi, O. Simonin, Y. Dufresne, V. Moureau, Three-dimensional DEM-CFD simulation of a lab-scale fluidized bed to support the development of two-fluid model approach, Int. J. Multiph. Flow, 156: 104189, 2022.
[9] H. Pers, A. Aniello, F. Morisseau, T. Schuller, Autoignition-induced flashback in hydrogen-enriched laminar premixed burners, International Journal of Hydrogen Energy, 48(27): 10235-10249, 2023.