

# SOLID MIXING AND HEAT EXCHANGE IN DENSE FLUIDIZED BEDS



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The target of carbon neutrality by mid-21st century has strongly encouraged the use of bio-based energy. Nevertheless, projections about the industrial scene show that fossil fuels will still dominate in the coming years. Therefore, their proper exploitation, together with the efforts toward energy transition, is required. In this context, chemical looping combustion (CLC) has recently gained broad interest by accomplishing combustion of both fossil and renewable solid fuels, with inherent CO<sub>2</sub> capture. The associated energy production goes from zero to negative carbon emissions. CLC involves indirect fuel combustion as any direct contact of the fuel with air is avoided. Oxygen carrying particles are used to supply oxygen for the reaction through redox cycles and circulation between an oxidizing zone (air reactor) and a reducing zone (fuel reactor). Based on energy penalty criteria, CLC is now considered as one of the most promising routes for carbon capture and storage.

Gas-fluidized beds represent a valid technological option to perform thermochemical processes including CLC. Indeed, they offer several advantages if compared to competing technologies such as fixed beds, grate reactors, rotary kilns: temperature uniformity and control, excellent bed-to-surface heat transfer coefficients, scalability to large sizes, fuel flexibility, ability to add and remove particles continuously, relatively low pressure drops, high heat and mass transfer rates between gas and particles, capability to vary the gas flow rate over a wide range. The mentioned features outweigh the disadvantages, such as gas “backmixing” resulting in deviations from plug flow, gas bypassing through bubbles, entrainment, attrition, erosion/wastage of fixed surfaces and complexity, when the fluidized bed is properly designed.

One key aspect for an optimal design of new units and an optimal operation of existing fluidized bed units is the control of solids mixing. This concerns fuel axial and lateral dispersion in the bulk material and self-dispersion of the bulk material itself. The former affects fuel conversion, the latter governs the variations of the temperature field across the bed. Gas bubbles are responsible for solids mixing according to three mechanisms: lifting in the wake of a rising bubble, sinking in the emulsion around a rising bubble, splashing at the surface of the bed when a bubble erupts. These mechanisms determine material exchange between the so-called “mixing cells”. A common approach is to quantify mixing using a dispersion coefficient. Values published in literature are scattered over several orders of magnitude. This is because vertical and lateral mixing are not comparable and the same applies to the mechanisms of self and mutual dispersion. Moreover, many results are obtained in small units or at cold conditions, which are not representative for industrial scale fluidized beds. This leads to a lack of complete understanding and quantification of solids mixing.

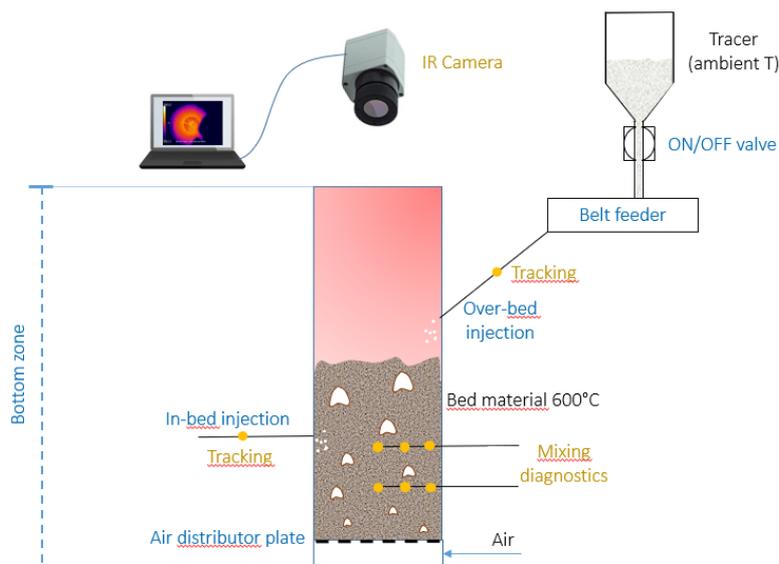
The aim of the present PhD is to advance in the study of solids mixing in dense fluidized beds, to investigate on how it is affected by the fuel injection system and on how it affects the heat exchange. A consistent part of the PhD concerns the work to perform an experimental campaign on a pilot-scale dense fluidized bed, where typical combustion conditions are simulated. It is followed by a final modelling/CFD work.

During the first year, a complete literature review has been performed to identify the best diagnostics to be used in the experimental campaign. The techniques for direct and indirect particle tracking that can be adopted in fluidized systems are numerous: solid sampling, gas sampling, thermal tracing, image analysis, tomographic methods, magnetic tracing, acoustic method, radioactive tracing, pressure drop method, fluorescence technique... However, although the non-reactive conditions, not all of them are suitable for performing measurements in large-scale fluidized beds operated at high temperatures. Capacitance probes have been selected as tracking tool for tracer particles, while non-contact infrared measurement has been chosen for temperature detection. Tracking by capacitance probes is based on the different dielectric constants between bed and tracer material. Therefore, some effort has been spent to find the suited solids, with the tracer being also representative of a fuel like pet-coke or

biomass. High-temperature resistant capacitance probes have been constructed *ad hoc* for the experiments, and first calibration tests at ambient and high temperature conditions have been performed in a lab-scale unit.

During the second year, literature study has been shifted towards the phenomenology of solid mixing in dense fluidized beds. In addition, an in-bed pneumatic injection system has been designed for the pilot-scale unit. This system allows a fast batch injection of the tracer in the fluidizing medium at 600°C, with the solid mass flow being monitored visually and by a Doppler-effect based sensor. The in-bed injection will be compared with an over-bed free falling feeding of the tracer. Other materials have been selected as tracer candidates and need to be tested. The pilot-scale experimental campaign is expected to start by the end of the second year, once the final technical issues have been finalized.

The third year is devoted to the completion of the experimental campaign and to the modelling/CFD work.



### References:

Molignano, L., Troiano, M., Solimene, R., Tebianian, S., Salatino, P., Joly, J.F., 2021. Diagnostics of solid mixing by capacitance probes in dense fluidized beds for thermochemical conversion of solid fuels. Proceedings of 10<sup>th</sup> European Combustion Meeting, 1398 -1403.