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Hydrodynamics of compartmented fluidized beds under uneven fluidization conditions

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ABSTRACT

Fluidized beds may be conveniently applied to demanding thermal and thermochemical processes thanks to their inherently good thermal performances: bed-to-surface heat transfer coefficients, effective thermal diffusivities. Collection and thermal storage of solar radiation in Concentrated Solar Power (CSP) systems is one challenging example of this application. Thermal properties may be further enhanced by non-conventional design and operation of fluidized beds based on uneven or unsteady (pulsed) fluidization. A novel concept of solar receiver for CHP (combined heat and power) generation consisting of a compartmented dense gas fluidized bed has been proposed to effectively accomplish collection of incident solar radiation, heat transfer to the working fluid of the thermodynamic cycle and thermal energy storage. This application, like others of the same kind, poses the objective of achieving controlled compartmentation of a large scale fluidized bed by selectively promoting fluidization in some regions while keeping others in a fixed state. This task may be accomplished by means of a compartmented windbox, without physical partitioning or internals immersed in the bed. This study addresses this problem by investigating the hydrodynamics of a near-2D dense gas-fluidized bed operated at ambient conditions and equipped with a compartmented fluidizing gas distributor. The hydrodynamics was characterized by pressure measurement at different locations in the bed to mark the onset of local fluidization and to map the extension and location of fluidized and de-fluidized regions in the bed for different choices of operating conditions. An important follow-up of the study is the analysis of the dynamics of the bubble and emulsion phase in an unevenly fluidized bed. Dynamical patterns of bubble and emulsion phases have been scrutinized by analysis of space- and time-resolved void fraction profiles obtained by electrical capacitance measurements.
Altogether results indicate that a perfectly compartmented fluidized bed cannot be obtained simply using a compartmented windbox. However a proper choice of fluidizing gas partitioning between the compartments enables good control of the local fluidization conditions, of gas cross-flow between the compartments, of large-scale solids circulation.

1. Introduction

The development of solid particle receivers in Concentrated Solar Power (CSP) applications is gaining much interest [1–4]. Among particle receivers, dense gas-solid fluidized suspensions have been recently proposed as heat transfer fluid (HTF) and thermal energy storage media [3–8] thanks to their excellent thermal properties, namely bed-to-wall heat transfer coefficient (several hundreds of W/m^2K) and effective thermal diffusivities ($0.001–0.1 m^2/s$) associated with convective transfer due to bubble-induced and gross bed solids circulation [9–11]. Both these features may be optimized by proper selection of fluidized solids type and size and fluidization regime. Non-conventional design and operation of fluidized beds based on uneven or unsteady (pulsed) fluidization may further enhance their thermal performances for CSP and thermal energy storage applications [8]. The use of fluidized solids as alternative to other storage/exchange media, like molten salts, entails the possibility to overcome issues associated with the use of corrosive or environmentally unfriendly fluids and to operate the receiver at much higher temperature under direct irradiation of solid particles [12–15]. Furthermore, the potential of solar-irradiated gas–solid fluidized beds is related to the possibility to perform solar-driven thermo-chemical processes [16–17] for production of solar fuels and chemicals [18–23].

Dense gas-solid fluidized beds have the potential to effectively accomplish three basic complementary tasks: a) collection of incident solar radiation; b) transfer of the incident power to heat exchange surfaces and henceforth to high-efficiency power cycles; c) thermal energy storage, aimed at equalizing the inherent time-variability of the incident radiation for stationary combined heat and power (CHP) generation. All these features have been exploited in a novel concept of solar receiver

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for CHP generation with inherent thermal energy storage. The concept is based on a novel design of the solar collector, based on a compartmented dense gas fluidized bed optimized so as to accomplish the three complementary tasks [7]. Application of this concept poses a challenging task: how can compartmented fluidization of a large scale bed be achieved? By compartmented fluidization we mean the ability to achieve controlled fluidization of selected sections of a large scale bed while others are kept in the fixed or in a different fluidized state. To preserve the very favourable thermal and flow properties of the bed, this objective must be pursued without physical confinement of the bed or use of internals, but just by partitioning of the fluidizing gas to a compartmented gas distributor.

The hydrodynamics of a near-2D dense gas-fluidized bed operated at ambient conditions and equipped with a compartmented gas distributor will hereby be analyzed. Bed hydrodynamics was characterized by pressure measurements at multiple locations in the bed to mark the onset of local fluidization. Pressure maps are worked out to assess the location and extension of fluidized and defluidized regions in the bed, under a range of operating conditions. Dynamical patterns of the bubble and of the emulsion phases are further investigated by analysis of space- and time-resolved void fraction profiles obtained by electrical capacitance measurements.

2. Experimental

2.1. Experimental apparatus and materials

Fig. 1 shows the picture and the schematic representation of the experimental apparatus with its ancillary equipment. The experimental apparatus consists of a near-2D fluidized bed (2850 × 1860 × 200mm) equipped with an array of pressure taps at different locations in the bed. The fluidized bed can be considered as "nearly two-dimensional" because it is characterized by a thickness much smaller than the other dimensions, but at the same time large enough to prevent extensive wall effects for bubbles smaller than 120 mm. Accordingly, the test facility can be used to investigate bed hydrodynamical patterns along the width and the height of the bed as they would develop in full-scale 3D compartmented fluidized beds.

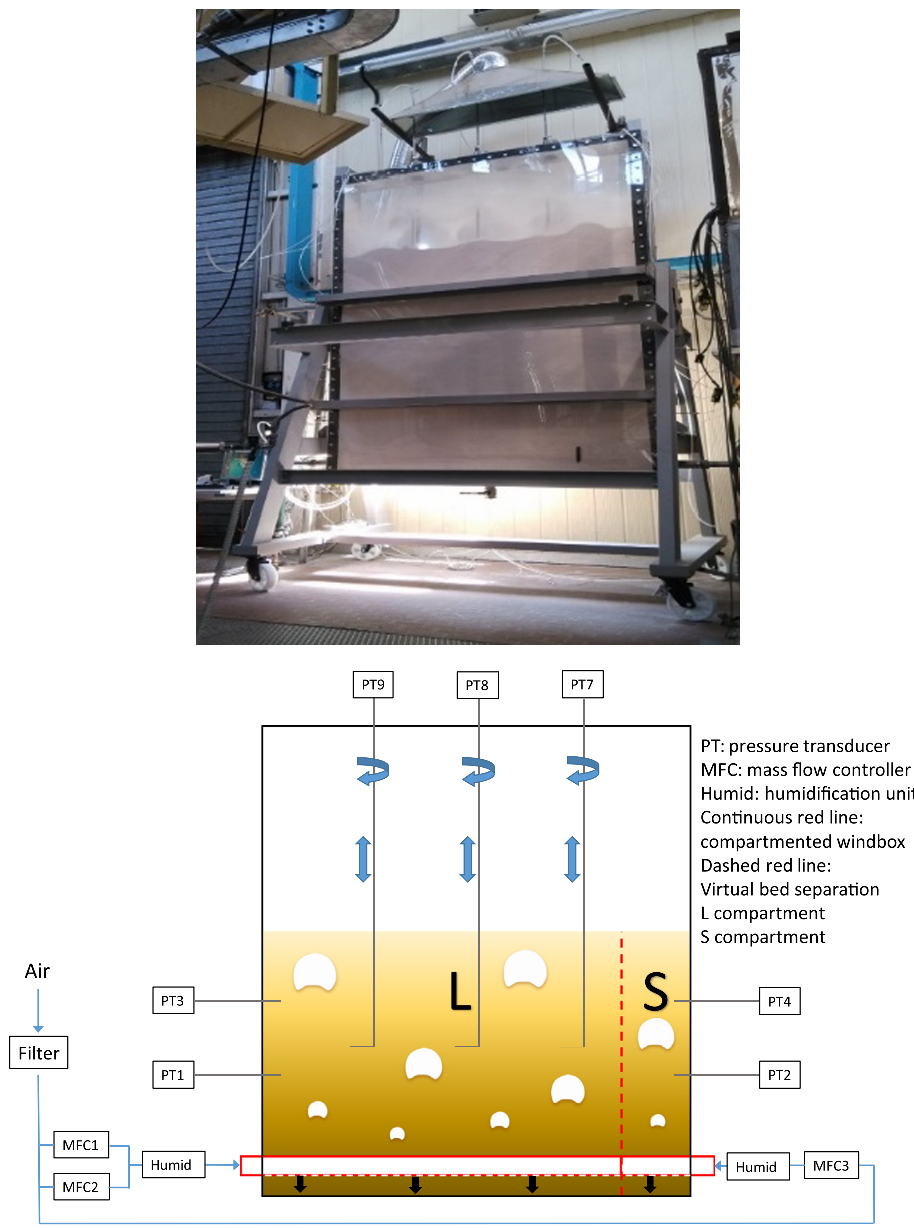

Fig. 1. The experimental apparatus.