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Editorial

Recent Advances in Fluidized Bed Hydrodynamics and Transport Phenomena—Progress and Understanding

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Fluidization technology has found widespread applications for a variety of chemical and physical transformations since its introduction in the first half of the 1900s. Today, some commercial bubbling and circulating fluidized beds are among the largest chemical reactors in the world. Typical physical operations include solid heating, drying, coating, granulation, filtering, mixing, or separation; chemical reactions are carried out in the refining, petrochemical, energy, chemical synthesis, pharmaceutical, food, biochemical and biotechnological, cement, and mineral industries. Due to their intrinsic operational flexibility and efficiency, they act as ideal technological platforms for multifunctional transformations that realize clean processes, sustainable energy production/conversion, well-controlled transformations, and low-footprint syntheses.

The advantages of fluidized beds over other fluid–solid contactors are linked to the efficiency and contact conditions at the fluid–particle level. On top of the limited pressure drop across the bed compared to fixed beds, the hydrodynamics and heat and mass transfer of fluidized beds benefit from the continuous agitation of the particulate phase and higher transfer coefficients. Dead zones, hot spots, inhomogeneities, and variability in the quality of the products are significantly mitigated, if not completely avoided. On the other hand, the complex interplay between the fluid and solid flow fields, solid segregation, abrasion, and erosion on walls and immersed surfaces, high-amplitude pressure oscillations, structural vibrations, and other issues still prevent full exploitation of the potential of this fluid–solid processing technology. Although its introduction dates back several decades ago, intense research efforts are still dedicated to gaining new insight at the fundamental level and to improving fluidized bed scale-up and optimization.

The present Special Issue collects contributions from different research groups active in the field and covers a broad variety of recently proposed computational tools, advanced experimental measurements and characterization methods, new operational configurations, and novel applications. The papers published provide a thorough discussion of recent results on gas- and liquid-fluidized beds under very different conditions and regimes, including bubbling, circulating, spouted, confined, pulsating, swirling, vibrated, and jet configurations. A short summary is provided below.

Pressure fluctuations in the riser of a dual-interconnected circulating fluidized bed were investigated in [1]. A cold-flow model of a chemical looping combustion (CLC) system was investigated using a monocomponent and a binary mixture of glass beds and polyethylene with different sizes and densities. The introduction of a second particulate solid phase determined significant differences in the pressure fluctuation intensity compared to the single-component case both in the riser and in the air reactor. The effects of changing mixture composition, solid inventory, and fluidization velocity were thoroughly characterized, providing useful insight for CLC applications.

Pressure fluctuations were used in [2] as a monitoring method for detecting issues in the bubbling fluidization quality of oxygen carrier beds as a part of a chemical looping gasification process. The aim was to apply pretreatment on biogenic residues adopted as feedstock for liquid biofuel production, thereby limiting the detrimental formation of ashes responsible for progressive agglomeration and defluidization. The proposed pretreatment solutions effectively improved the hydrodynamics of a fluidized bed of wheat straw.

Three manuscripts addressed liquid fluidization. In [3], the behavior of fluidized binary mixtures exhibiting layer inversion was systematically investigated and compared with the predictions of the corresponding critical voidage by the particle segregation model (PSM). The effects of different size and density ratios and mixture compositions covered all observed patterns, i.e., size segregating only, density segregating only, and layer inversion with velocity, for most of which, the model's predicted values were quantitatively in agreement.

Progress in understanding the fundamentals of microprocess and microfluidic technology was proposed in [4], in which a microcirculating liquid-fluidized bed was experimentally characterized in terms of hydrodynamics and solid circulating velocity. By applying particle image velocimetry (PIV), the critical transition velocity was found to be similar to the particle terminal velocity, and the effect of the solid inventory, particle size, and density was quantified.

The interaction of gas bubbles, liquid flow, and solid particles was investigated in [5] with reference to bubble formation and oxygen mass transfer parameters. The addition of ring and cylinder-shape media in the system induced a significant increase in the mass transfer coefficient (K_L a) in both bubble column and air-lift reactor configurations.

The development and applications of computational tools were discussed in various papers [6–12]. Fluidized bed hydrodynamics and heat transfer were computationally investigated in [6] by a Computational Fluid Dynamics-Discrete Element Method (CFD-DEM) model. The effects of fluidization velocity, bed height, and heat source distributions were quantified in order to examine the potential outcome of exothermic gas–solid reactions. A significant impact was reported for the fluidization velocity and bed aspect ratio on the hydrodynamics and temperature distributions, proving the effective role of multiphase flow in promoting heat transfer processes.

The motion of solids inside a fluidized bed rotor granulator was simulated using a CFD-DEM approach in [7] to assess how the presence of the liquid phase determined the particle dynamics and contact time. The particle coating was investigated, including particle growth and drying with a new model including capillary and viscous forces, demonstrating the effect of liquid injection and binder solution on the unit's performance.

With reference to the DEM-based simulations of fluidized beds, the fundamentals of a coarse graining technique have been reviewed in [8]. The technique is shown to be a promising solution to the huge thirst of computational resources required by DEM simulations of pilot- and industrial-scale fluidization units. Basic aspects of the coarse graining strategy and the effect of its degree on the computational savings were detailed, analyzed, and discussed in relation to the current and future trends.

In [9], computational fluid dynamics coupled with Lagrangian tracking was used to investigate gas–solid flow at elevated temperatures with the aim of intensifying heat and mass transfer processes. Particle dynamics, particle residence times, and the resulting transfer processes were characterized as a function of the pulsating conditions.

Validated Eulerian–Eulerian simulations were utilized to systematically investigate the gas–solid flow in a fluidized bed opposed jet mill in [10], in terms of time-averaged volume fraction, velocity, and two-phase flow fields. The influence of the particle-flow dynamics as resulting from different combinations of solid hold-up and nozzle air velocity were assessed with reference to the aspects pertaining to the milling performances.

A commercial software was used by [11] to investigate the gas–solid flow in the riser and downer of a cold-flow model of a circulating fluidized bed (CFB). Solids' residence time, hold-up, and radial velocity profiles were examined to assess the propensity to exhibit backmixing and flow nonuniformity.

Macroscopic modeling was used in [12] to predict the performances of vibrated fluidized bed dryers under a broad set of different conditions, demonstrating the significant progress of flowsheeting simulators in representing complex fluidized bed process units. In particular, a continuous dryer model was implemented and tested within the open-source framework Dyssol, accounting for the fluidization hydrodynamics of particles of all Geldart's groups, including the effect of vibration.

Confined fluidization, i.e., the fluidization of fine particles in the voids of a packed bed of coarser particles, was experimentally investigated in [13] as a novel technology to enhance the CO_2 adsorption capacity of amine-modified silica particles. Together with a specifically tuned high-performance sorbent, the improved contact efficiency of the confined fluidization environment was shown to ensure high performance, good stability, and effective control of the thermal effects.

Fine particle coating using a combination of a Wurster-type fluidized bed and aerosol atomizer was experimentally demonstrated in [14]. The effect of different core materials, coating solutions, and other operating conditions were characterized in detail with respect to the coating layer quality and overall process yield. In the Wurster fluidized bed, the use of very small aerosol droplets was shown to enable the coating of fine particles without severe agglomeration.

Hydrodynamics of Geldart's group B particles in bubbling and turbulent gas-fluidized beds were investigated in [15] with particular reference to the bubble dynamics. Starting from the relatively well-characterized bubble size and velocity for low-velocity bubbling beds, higher-velocity fluidized beds of diameter ranging from 0.1 to 1 m were considered, at superficial velocities in the range 0.18 to 1.6 m/s. Correlations for the bubble phase hold-up, bubble velocity, and vertical length were developed. In addition, the shape of the bubbles was characterized across the transition into the turbulent regime.

In recent years, solar receivers based on the fluidized bed concept have attracted considerable interest. The effect of the bed particle size was characterized in [16] for SiC particles. After quantifying the outlet gas temperature, heat absorption, and thermal efficiency as a function of the particle size and gas superficial velocity, the authors proposed novel design considerations.

Pulsed fluidized beds were employed in [17] to examine the hydrodynamics of fluidized ultrafine nanosilica powders. The peculiar pulsating regime ensured full collapse of the fluidized bed. The experimental characterization aimed at measuring the transients in the upper, central, and lower regions of the fluidized bed, whose varying dynamics contributed to the overall bed hydrodynamics. The resulting combination was shown to provide a promising reduction of the minimum fluidization velocity and an increase in bed homogeneity.

By using a miniaturized spouted bed, the manufacture of highly filled polymer–iron oxide composites was successfully demonstrated in [18]. The quality of the polymer-coated fine metal powders led to interesting properties of the final product, thanks to the suitability of the spouted bed design and its special fluidized gap design combined with a bottom spray nozzle.

Bed hydrodynamics under swirling fluidization was experimentally investigated in [19] by using particle image velocimetry (PIV) methodology. A bladed annular distributor provided the inlet flow characteristics, and the tangential solid velocity field was obtained for blade angles ranging from 30° to 75° with respect to the horizontal plane and for different solid inventories.

Finally, in [20], characterization of the bulk flow properties of industrial powders was proposed based on a computational tool developed to efficiently perform data regression while accounting for nonlinearity in the yield loci. Successful application was demonstrated for powders typically employed in fluidization units, such as ceramic, rutile, calcium carbonate, and dolomitic lime powders.

Applications of the fluidization technology in research and industrial processes are known to be widespread but far from being exhausted. As discussed above, the breadth of the topics covered and the quality of the contributions in this Special Issue of *Processes* are remarkable. They summarize the current progress and understanding in the hydrodynamics and transport phenomena of fluidized beds. It is our hope that this collection of articles will stimulate readers in new developments of methods, models and tools, novel schemes, and ideas for further research efforts, allowing the next generation of fluidized beds to be developed in the near future.

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