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Quantifying Voidage Distributions in Fluidised Bed Reactors Using CFD-DEM Simulations

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In drinking water purification operations, liquid-solid fluidised (LSF) bed reactors are often used, for example in seeded crystallization softening processes (1). Fluidised beds can be considered as dynamic porous media with fascinating spatio-temporal behaviours (1). Usually, LSF systems are considered to be homogeneous under moderate superficial fluid velocities. However, recent fluidisation experiments using calcite grains have demonstrated the appearance of discrete water "pockets or parvoids" at low superficial liquid velocities, evolving into more complex structures at higher velocities (1). It remains unclear however, whether such heterogeneous behaviour benefits or hinders the chemical crystallization efficiency (2,3).
Based on the results presented in (1), we extend the Computational Fluid Dynamics - Discrete Element Method (CFD-DEM) simulations to obtain more detailed information about the observed heterogeneous behaviour (2,3). Simulations are performed using different water inlet velocities and different calcite grain size fractions obtained from full-scale reactors. We analyse our results in terms of voidage and particle distribution functions. Images of the experiments and simulations are visually compared for the formation of voids, see Fig.1. The simulations show clear differences in void fraction for different flow rates in the cross-section of the column. The heterogeneity and onset of fluidisation behaviour obtained from the simulations and experimental observations are found to be in statistically significant agreement. Finally, for particle sizes smaller than reported in (1), we find that the range of observed voidages is much narrower compared to using larger particles.
This clearly demonstrates that voidage must not be assumed as a single constant value. Instead, LSF beds shows significant spatial and temporal variations with distinct regions of higher and lower voidage, forming dynamic structures throughout the bed. This finding is critical as it underscores the need to move beyond simplified homogeneous models when analysing and designing fluidised bed systems. Accounting for these distributions offers a more accurate representation of the system's behaviour, which could lead to improved predictions of hydrodynamic performance and enhanced optimisation of processes such as crystallisation in water softening reactors.

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