Detailed investigation of granulation processes using a fibre-optical probe and discrete element simulations

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Spout fluidized beds are frequently used for the production of granules or particles through granulation, which are widely applied for example in the production of detergents, pharmaceuticals, food and fertilizers. Spout fluidized beds have a number of advantageous properties, such as high mobility of the particles preventing undesired agglomeration and enabling excellent heat transfer control. The particle growth mechanism in a spout fluidized bed as function of the particle-droplet interaction has a profound influence on the particle morphology and thus on the product quality. Nevertheless, little is known about the details of the granulation process. This is mainly due to the fact that it is not visually accessible. In this work we use fundamental, deterministic models to enable the detailed investigation of granulation behavior in a spout fluidized bed.

A discrete element model is used, which describes the dynamics of the continuous gas-phase and the discrete droplets and particles. For each element momentum balances are solved. The momentum transfer among each of the three phases is described in detail at the level of individual elements. The discrete particle model used in this work is based on the hard-sphere model developed by Hoomans et al. (1996) and Link et al. (2007). The discrete element model is further developed by improving the description of both the particle-droplet and particle-particle interactions. The motion and drag force of droplets are defined in more detail, and the effect of the moisture content on the particle-particle collisions is studied. Results of the particle-particle and particle-droplet collision simulations are compared with measured local particle volume fractions as well as particle velocities by using a novel fibre optical infrared light probe in a cylindrical pilot-plant scale fluidized bed with an inner diameter of 400 mm. The probe consists of an array of optical fibres. In the center of the probe there is one row of optical fibres emitting infrared light into the fluidized bed. The light reflected by the particles passing the probe is detected by two rows of optical fibres. The intensity of the light reflected by the particles passing the probe is a quantity for the porosity. The reflected light is transmitted to IR- light detectors which create a corresponding voltage signal. The calibration procedure was carried out in the same way as proposed by Hartge et al. (1989).

In order to measure the particle velocities the signals of the two detecting fibre optical rows are measured with two different IR detectors. Thus, it is possible to measure the velocity of a particle

moving perpendicular to the detecting fibre optical rows by evaluating the time difference between the two signals and the distance between the two detecting fibre optical rows. The time difference is calculated by a cross correlation of the two signals. In order to measure the porosity and vertical particle velocity components at different radial positions and different heights from the bottom plate the fibre optical probe can be inserted into the fluidized bed through 10 different probe tubes positioned at the circumference of the fluidized bed. With this technique also injected liquid droplets can be detected. Therefore, simulations and experiments were carried out for three different cases using Geldart B type porous aluminium oxide particles: a freely bubbling fluidized bed without any injection and a spout fluidized bed with injection of either only gas or gas and water, that means under additional presence of droplets. For the injection a bottom sprayed pneumatic externally mixing two-fluid nozzle was used.

The results show that at higher distances from the air distributor plate the porosity in the centre of the fluidized bed increases because of the bubble coalescence and thus bubble growth in the upper region of bubbling fluidized beds. The jet, especially the atomization air flow rate, strongly affects the local porosities and the particle velocities in the injection zone, which is characterized by high porosities which decrease at the borders of the injection zone due to particle entrainment into the jet and the particle acceleration. The atomization air momentum decreases with distance from the air distributor plate. At the wall of the fluidized bed a significant decrease of the porosity occurs due to the downward movement of the particles and the particle circulation in fluidized beds (Figure 1).

Furthermore it can be seen that the area of influence of the spout is rather limited (Figure 2). The results depict that for certain conditions the droplets do not entirely penetrate the bed (Figure 3), which is good, since breakthrough is not desirable in the operation of spout fluid beds. The penetration depth of the jet with additional injection of liquid is much larger than under pure atomization air conditions. Figure 4 show additional results obtained from the discrete particle model simulations, i.e. instantaneous particle positions indicating the flow structures including bubble size and shape, particle-particle collision rates and porosity distributions. The droplet deposition (indicated in black in Figure 4a) is also in region of high particle concentrations even where the atomization air has no influence. With the experimental and theoretical investigations it is possible to estimate the size of dry and wet zones in liquid sprayed fluidized beds, which is important for the scale up. Depending on the time scales of moisture absorption and circulation of the particles in the bed, changes to the geometry and/or the operating conditions may be considered. It is demonstrated how the discrete element model can be used to obtain information about the interaction of the discrete phases, i.e. the growth zone in a spout fluidized bed.

References
Hartge, E.-U., Rensner, D., and J. Werther (1989). Faseroptisches Messsystem zur Erfassung lokaler Feststoffkonzentrationen und -geschwindigkeiten in höher konzentrierten Gas-/ Feststoffströmungen, Chem.-Ing.-Tech., MS 1781/89.
Link, J.M., Godlieb, W., Deen, N.G., and J.A.M. Kuipers (2007). Discrete element study of granulation in a spout-fluidized bed, Chem. Eng. Sci. 62, 195-207.
Hoomans, B.P.B., Kuipers, J.A.M., Briels, W.J., and W.P.M. van Swaaij (1996). Discrete particle simulation of bubble and slug formation in a two-dimensional gas-fluidised bed: A hard-sphere approach, Chem. Eng. Sci. 51, 99-118.
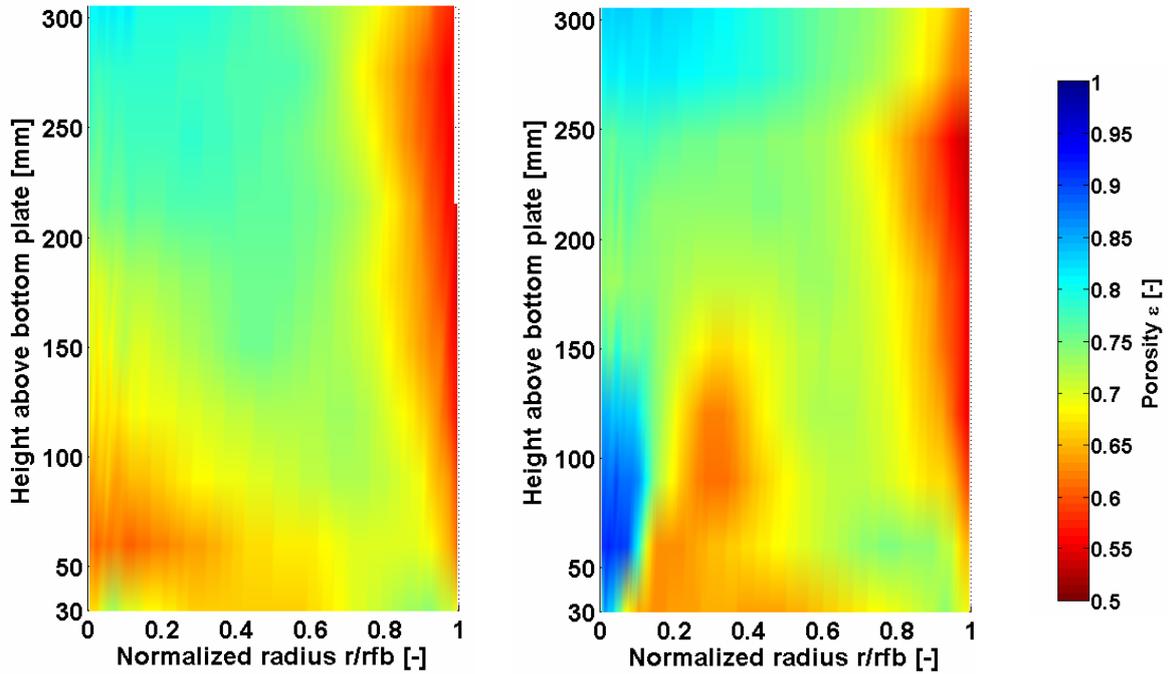
Figure 1: Measured time averaged porosities without (left) and with bottom injection of pure atomization air.
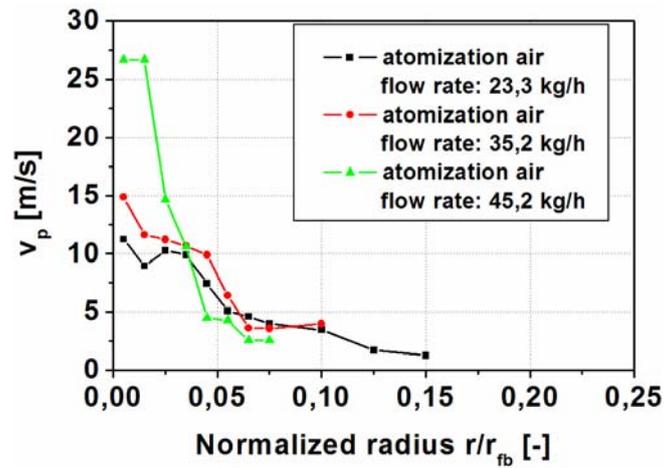

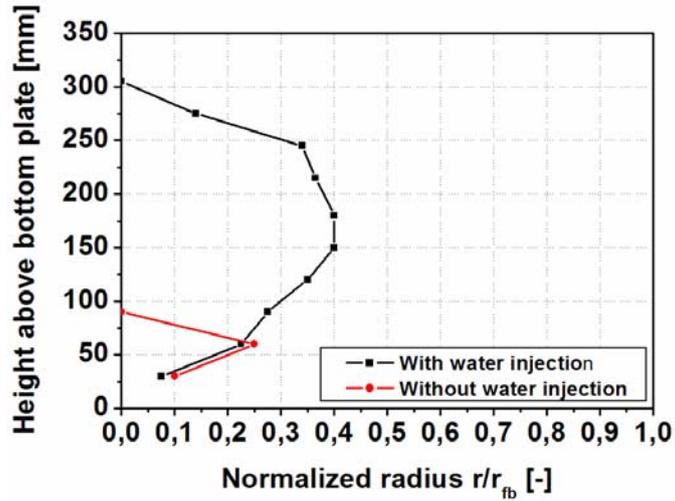Figure 2: Measured particle velocities at a height of 30 mm with injection of only gas.

Figure 3: Comparison of measured penetration depths for $\dot{M}_{gas,jet} = 23.3 \, \text{kg/h}$ and $\dot{M}_{water} = 35 \, \text{kg/h}$ with injection of only gas (red curve) and gas and water (black curve).
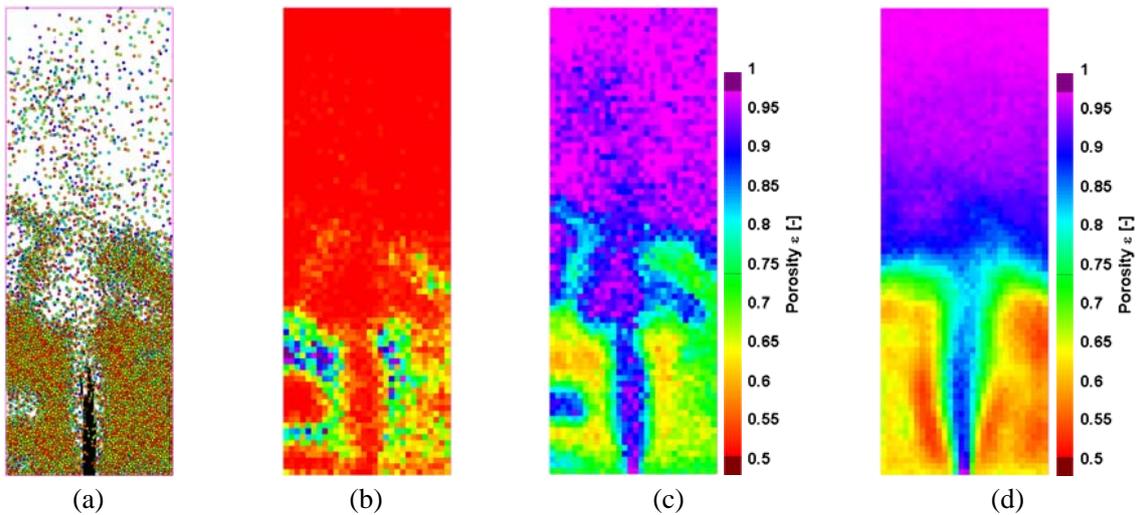

(a)   (b)   (c)   (d)

Figure 4: Calculated instantaneous particle and droplet positions (a), particle-particle collision rate with the colour blue indicating a collision rate of $4 \cdot 10^9$ collisions / $(\text{m}^3 \, \text{s})$ (b), instantaneous porosity (c) and time averaged porosity (d) without injection of atomization air in a 0.01 m thick slab with a width of 0.3 m and a height of 1.0 m positioned at $y/D = 0.5$