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Experimental investigation of process stability of continuous spray fluidized bed layering with internal separation

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ABSTRACT

The present work investigates spray fluidized bed layering to continuously generate sodium benzoate granules from a solution. Product granules are discharged from the process through a classifying tube installed centrally in the distributor plate of the fluidized bed. To ensure a constant product quality, such as particle size, process conditions realizing a stable stationary operation are vital. At the same time process stability strongly depends on the size and amount of new seed particles for the layering process. In all presented experiments seed particles are solely produced internally by overspray. Thus process stability is investigated according to a variation of separation and drying parameters, namely classifying gas velocity, spray mass flow rate, fluidizing gas inlet temperature and fluidizing gas mass flow rate. Different classifying gas velocities yield different bed hold-ups. Small and high hold-ups lead to a stationary particle size distribution in the fluidized bed for long process times and thus to a stable continuous layering growth process. Moderate hold-up yields sustained oscillations of the particle size distribution of the granules in the bed and thus a marginally stable process. Changing drying conditions also influence the stability of continuous layering processes due to their influence on overspray generation. Intense drying conditions lead to an emptying of the fluidized bed and thus an unstable process. Moderate drying conditions lead to damped oscillations of the particle size and thus a nearly stationary process behavior for long process times. Drying conditions in between yield sustained oscillations of the particle size distribution of the granules in the bed, turning the process marginally stable again.

1. Introduction

Production of free-flowing, dust-less granules from solid-containing liquids, for example solutions or suspensions, by spraying onto a bed of initial core particles is one of the main applications of fluidized bed technology (Kunii & Levenspiel, 1991; Mörl et al., 2007). This task is mainly achieved by two macroscopic size enlargement processes: Aggregation (or synonymously, agglomeration) which describes the formation of larger assemblies out of at least two particles. Here, the sprayed solid-containing liquid often acts as a binder which provides the necessary connection between the particles. In other instances, the sprayed liquid modifies the surface properties of the particles in such a way that they assemble to larger structures without a binding agent, see for example, Palzer (2007) for an application in food processing. This process, also named spray fluidized bed granulation (SFBG) in the literature, has been studied in recent years by many researchers, for instance Antonyuk et al. (2011), Boerefijn and Hounslow (2005), Iveson et al. (2001), Pietsch (2002), Smith and Litster (2012), Tan et al. (2006), and among others, in terms of the aggregation kinetics, binding mechanisms and resulting product properties.

The second size enlargement process which is connected to the production of free-flowing granules is called layering and describes the increase in particle size (or volume) by subsequently forming new layers of solid material on the core particles. If the sprayed material differs from the core material, this process is called coating. Spray fluidized bed layering and coating processes find wide-spread application, for example, in pharmaceutical, food, fertilizer and detergent industry, and have also been studied in terms of process kinetics and product quality, see, for example, Heinrich et al. (2002), Hemati et al. (2003), Karlsson et al. (2011), and Kulah and Kaya (2011).

By a right choice of process parameters, see for example, Ennis et al. (1991) and Iveson et al. (2001), either layering or granulation (in the sense of aggregation) can be realized in a process. In this work, layering growth of particles is considered as the dominant size enlargement process. Size reduction processes, for example, attrition or breakage, are assumed to be negligible or in equilibrium with aggregation processes.

Another process that takes place and which runs on a much smaller size scale is nucleation. It describes in general the formation

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of solids out of the liquid, that is, the phase transition, and is an important underlying mechanism necessary to realize the continuous operation of spray fluidized bed layering.

To obtain high product throughput with constant product properties, continuous spray fluidized bed layering processes working in a stable steady state are desired. Internal separation with classifying air and external separation with sieves can be used to realize product discharge during the continuous process. Only few workgroups investigate the continuous layering process in general and even less the continuous layering process with internal separation. The existing literature often deals with the simulation of this process based only on few experimental data (see Heinrich et al., 2002; Vreman et al., 2009). Others utilize these modeling approaches to develop theoretical process control methods (e.g. Bück et al., 2014; Palis and Kienle, 2012). All these studies describe the possibility of occurrence of oscillations of the particle size, leading to an unstable process. Also, methods that could theoretically be used to eliminate these instabilities are presented. Eliminating these oscillations to realize a stable process is crucial to ensure constant product properties and product output. But there is a lack of experimental data published describing these instabilities. The present work will fill this gap.

The starting point of the presented experiments will be the work of Vreman et al. (2009). They describe oscillations of the particle size in an industrial continuous fluidized bed spray granulator with internal separation and are able to simulate these oscillations. Vreman et al. (2009) link these oscillations of the particle size to the production of new seed particles for the layering growth by overspray. Overspray denotes the fraction of spray droplets drying and generating new particles before impinging on existing particles. They do not offer detailed experimental data and only consider the overspray rate to be dependent on the bed height and thus the bed hold-up. In the following work we will present two series of continuous spray fluidized bed layering experiments with internal separation and internal nucleation (overspray generation). In the first series the theoretical findings of Vreman et al. (2009) will be proven experimentally. In a second series of experiments the influence of the drying parameters on the overspray generation and thus on the process stability will be investigated. Besides the particle size, product quality can also be defined by a specific particle structure. Varying drying conditions strongly influence the particle structure (see Tsotsas, 2012), which also has to be consequently investigated.

2. Process description

In spray fluidized bed layering growth processes solid-containing liquids are sprayed onto seed or core particles. Droplets hit the particle surface and spread according to their material properties and the process parameters, building up a wet film (Kariuki et al., 2013). The particle bed is fluidized by heated gas, often air, which yields evaporation of the liquid. The solid phase remains on the particles and by repetition of wetting and drying a solid layer is formed (see Zank et al., 2001). This growth mechanism is illustrated in Fig. 1.

In the presented continuous spray fluidized bed layering process, the granules are discharged from the granulation chamber through a classifying tube installed centrally in the distributor plate (see Fig. 2A). During the growth process also the sinking velocity of the granules increases. When the sinking velocity of granules equals the velocity of the classifying air, the granules have the chance to leave the fluidized bed. According to the separation function of the classifying tube, also smaller and bigger particles can be discharged, which means, the classification is non-ideal.

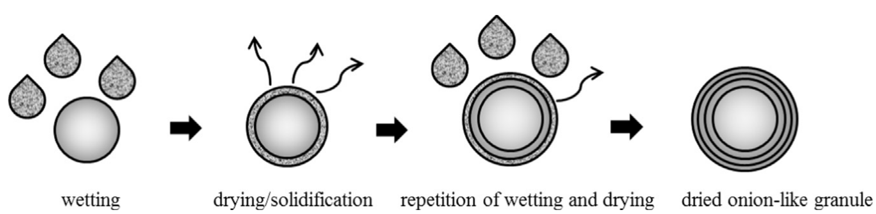

Fig. 1. Mechanism of layering growth.

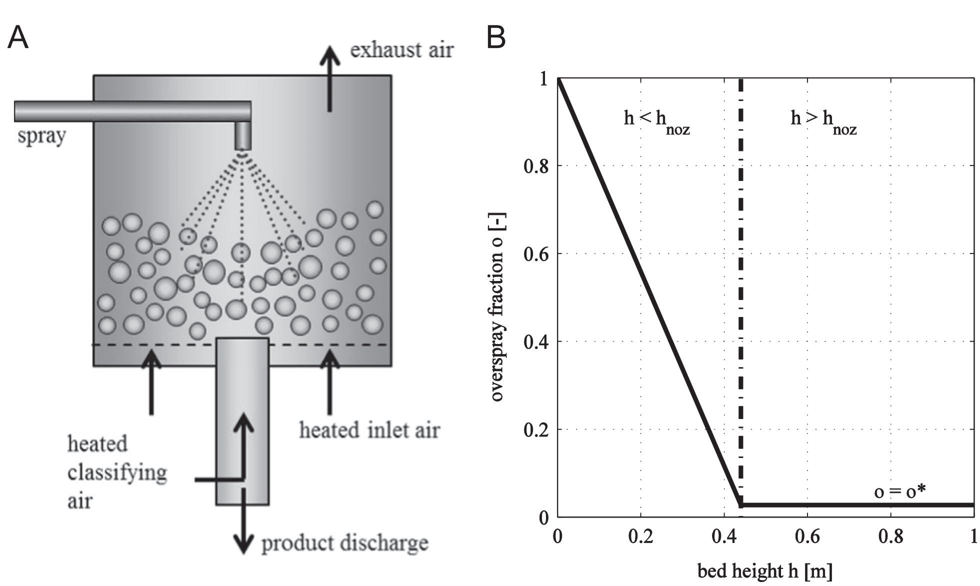

Fig. 2. A: granulation chamber, B: estimated dependency of overspray fraction on bed height (see Vreman et al., 2009), $o*$ denotes constant overspray fraction depending on process conditions.