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The influence of vessel geometry on fluidized bed dryer hydrodynamics

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ABSTRACT

The influence of vessel geometry on the hydrodynamic behaviour has been determined by undertaking drying experiments in both cylindrical and conical laboratory-scale batch fluidized bed dryers. Pressure fluctuation analysis shows that during drying in the conical bed, the dominant frequency decreases from 5.0 Hz early in the batch drying process to 2.6 Hz. On the other hand, the dominant frequency increases from 3.9 to 4.7 Hz during drying in the cylindrical bed. The lower bubbling frequency seen with the cylindrical bed during the early stages of drying is attributed to the formation of a defluidized region at the wall immediately above the gas distributor. As the granule became less cohesive due to the loss of surface moisture during drying, bubble coalescence occurred in the conical bed whereas the defluidized region in the cylindrical bed broke apart and higher bubbling frequencies resulted.

1. Introduction

In the production of many solid-dose pharmaceutical products, fluidized bed drying of granule is a required manufacturing step. This granule is cohesive when wet and has a tendency to form agglomerates. The granule will also exhibit channelling when fluidized [1]. To improve the fluidity of cohesive powders, researchers have proposed several techniques including mechanical vibration [2–5,7], bed stirring [4,6,7] and gas pulsation [8,9]. However, the pharmaceutical industry does not employ any of these assisting techniques to aid their granule fluidity during drying. Rather, the industry attempts to rectify these fluidization phenomena using conical, or tapered, bed geometry in their dryer design.

The notion of using a conical geometry for drying is believed to stem from the concept of the spouted bed. In the early 1950's, Gishler and Mathur [10] created the cylindrical spouted bed as a means of drying wheat. To enhance solids motion and eliminate dead spaces in the bottom of these beds, a diverging cone base was used with the air fed to the system through the truncated apex of the cone [11]. In the following years, spouted bed research progressed and purely conical spouted beds were developed [12]. Later, batch conical fluidized beds were proposed by Romankov [13] for spray drying applications.

The hydrodynamic behaviour associated with conical fluidized bed operation is unique. They have some fluidization characteristics that are similar to spouted beds as well as those more typical of conventional fluidization behaviour. Like spouted beds, conical fluidized beds initiate gross circulation of particles due to the tapered geometry. However, intimate gas–solids contacting, which is associated with conventional fluidization, is still maintained. In order to generate this hydrodynamic behaviour in conical beds, certain operating conditions are required. First, conical fluidized beds are operated with distributor plates, whereas the spouted beds use an orifice to introduce gas into the bed. Second, conical fluidized beds typically operated with Geldart A and B powders [14–19]; whereas true spouted bed operation results from the use of Geldart D powders [20–22]. Finally, conical fluidized beds are usually operated at relatively shallow static bed heights as compared to their inlet diameter ($H/D_i \leq 1$). These conditions limit the potential for either slug or spout behaviour.

The earliest description of conical fluidized bed hydrodynamics was by Toyohara and Kawamura [14]. Their study introduced the notion of partially fluidized regimes which exist between the fixed bed and 'perfect mixed-fluidization' regimes in gas–solid systems of binary mixtures. These regimes consist of a partially or completely fluidized core region and a downward moving non-core, or annular region. This distinct circulation pattern is a defining characteristic of conical fluidized beds. Schaafsma et al. [15] used positron emission particle tracking (PEPT) to quantify this circulation pattern in a shallow bed of Geldart B powders. They found that the particles rose quickly through the fluidized core region of the bed and back downward through the slower moving annular region. This is consistent with Toyohara and Kawamura [14]. This same type of circulation pattern has also been reported by our group. Khanna et al. [16] used a radioactive particle tracking (RPT) system to describe conical bed circulation patterns with a bed of dry pharmaceutical

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granule. More importantly however, our group has also demonstrated the circulation patterns generated during the actual drying of pharmaceutical granule. Transient electrical capacitance tomography (ECT) images from a conical fluidized bed dryer reported by Pugsley et al. [17] illustrate that the circulation pattern evolves from a dilute core, dense annulus regime to one where the centralized core region breaks down and a greater extent of the bed is involved in fluidization.

Apart from these circulation patterns, detailed information regarding the bubbling hydrodynamics in conical fluidized beds has also been proposed. Using electrical capacitance tomography (ECT), Wiens and Pugsley [18] studied the hydrodynamics of a conical fluidized bed of pharmaceutical granule over an inlet superficial gas velocity range of 0.5–3.0 m/s. They found that the bubbling behaviour with this powder transitioned from spherical bubbling to splitting bubbles at 2.5 m/s; indicating the onset of turbulent fluidization. Furthermore, the bubbling frequency associated with the bubbling regime decreased from approximately 10 to 5 Hz over the velocity range of 0.5–2.0 m/s. This decrease in frequency indicates bubble coalescence was also prevalent in their system over this velocity range. Finally, the voidage distribution profiles for their mono-dispersed particle size distribution showed that the cross-sectional area of the fluidized core region of the bed increased with gas velocity as well. This same phenomenon was observed by Gernon et al. [19] who studied the fluidized core region in detail using 2-D tapered beds.

The majority of conical bed research documented in the literature has been studied with respect to non-cohesive powders. The most relevant work related to the benefits of the conical geometry operated with cohesive material was done by the group of Chaouki [23]. They improved the fluidity of NiO/Al_2O_3 cryogels, which are Geldart C powders, using a conical bed. Based on the description of the bed hydrodynamics provided in their study, these cryogels did not fluidize well in cylindrical beds. They used visual observations to compare the cylindrical bed hydrodynamics to that of a conical bed and concluded that the hydrodynamics improved significantly when the conical bed was employed.

While conical fluidized bed dryers have been used in the pharmaceutical industry for years, research related to the effect of the conical geometry versus that of a cylindrical bed on fluidized bed drying hydrodynamics has not been quantified in the literature. Furthermore, the impact of the geometry on the hydrodynamics, especially in a process that has changing hydrodynamic conditions such as drying [1,17,24], is unknown. The focus of this work is to investigate the impact of vessel geometry on the hydrodynamic behaviour during the drying of placebo pharmaceutical granule. More specifically, the hydrodynamics resulting from cylindrical and conical laboratory-scale fluidized beds will be compared using pressure fluctuation analysis.

2. Experimental

2.1. Cylindrical bed apparatus

The placebo granule was comprised of the ingredients listed in Table 1. An Eirich Type R02 intensive-action mixer was used for granulation. With this granulator, 1 kg of wet material was produced per batch. The dry ingredients were premixed for 3 min with the impeller and bowl rotational speeds set at low. After pre-mixing, the water was added to the dry excipients over a 5 minute period. Water addition was done using a BETE BJ 001740 low flow flat spray nozzle with a 40° fan angle. The nozzle was connected to a pressure pot operating at 2.5 barg and extended down 14.5 cm from the lid of the granulator to introduce the spray to the granulator bowl. After the water addition phase, post mixing was carried out for an additional 2 min to finalize the granulation process. Sieve analysis was used to characterize the dried granule size distribution. The dry granule was found to have a bimodal size distribution with a mass mean diameter of 235 μm and a particle density of 830 kg/m^3. The size distribution of the granule is shown in Fig. 1.

The cylindrical fluidized bed had a diameter of 15 cm, a height of 45 cm and was constructed of Perspex to allow visual observations to be made. The distributor used in the bed was a 1.5 mm thick aluminum perforated plate. The perforated plate had 2.7 mm orifices that were spaced 7.5 mm apart and drilled on a square pitch. This resulted in a percent open area of 8.9%. Flange-connected to the top of the bed was a conical freeboard which was used to disengage any entrained material from the exhaust gas. The freeboard was covered in

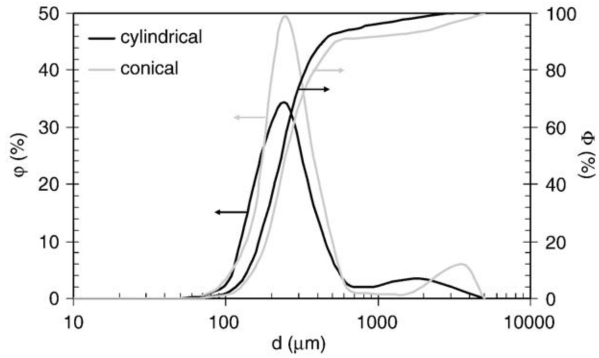

Fig. 1. Frequency and cumulative particle size distributions of the dry granule. Differences in particle size distributions are a result of the different granulation procedures used.

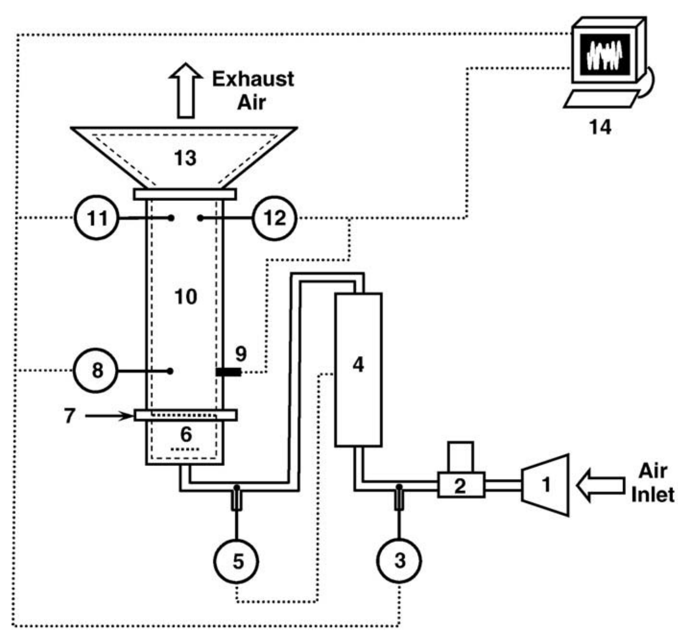

Fig. 2. Schematic of the cylindrical fluidized bed dryer (not to scale): (1) compressor; (2) mass flow controller; (3) inlet humidity sensor; (4) heater; (5) inlet temperature thermocouple; (6) windbox with perforated deflection plate; (7) perforated plate distributor; (8) dense bed thermocouple; (9) pressure transducer; (10) product bowl and freeboard region; (11) exhaust thermocouple; (12) exhaust humidity sensor; (13) disengagement section with cloth filter; (14) data acquisition computer.

Table 1
Placebo pharmaceutical granule formulation.

Component	Percentage by mass (wet basis)
Lactose monohydrate (filler)	35
Microcrystalline cellulose (filler)	31
Hydroxypropyl methylcellulose (binder)	3
Croscarmellose sodium (disintegrant)	1
USP distilled water	30