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Effects of pulsating air flow in fluid bed agglomeration of starch particles

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ABSTRACT

Fluid bed agglomeration is commonly used to improve the instant properties and flowability of cohesive food powders. However, fluidization of cohesive particles is characterized by cracks and channeling, but air pulsation systems can be attached to the fluid bed in order to improve bed homogeneity. The aim of this study was to investigate the influence of air pulsation frequencies, at (0, 5, 10 and 15) Hz, in fluid bed agglomeration of cassava starch and cornstarch particles. The particles size increased with agglomeration, resulting in the decreasing of wetting time and higher flowability. The solving of Population Balance Equations achieved the experimental aggregation kernel constants. The pulsation of (5 and 10) Hz resulted in the higher agglomeration rates, for both cassava and cornstarch study, respectively. The evaluation of the experimental PBE kernel constants were useful to measure the aggregation rate and to compare the performance of a fluid bed granulator.

1. Introduction

One of the main desirable characteristics of food powders are the porous and irregular shape of the particles, with improved instant properties, such as short wetting time and higher dispersibility when sprayed over a liquid surface (Hogekamp and Schubert, 2003). These kinds of products are named “instant products” (Schubert, 1987), and are commonly produced by agglomeration processes that provide high aeration and result in lower compaction of granules, such in the recycling of fines in a spray dryer or binder atomization in a fluid bed.

The fluidized bed agglomeration can transform food powders into granules with good instant properties. However, food powders are generally produced by spray drying or milling and the fluid dynamics behavior of these particles may be classified as cohesive, with cracks and channels, and its fluidization become a challenge.

Pulsed-fluid bed is the fluidization of particles by an intermittent inlet air stream, in a pulsation frequency. The pulsed-fluid beds can improve the bed homogeneity and decrease the cohesive effects on fluidization of fine particles (Reyes et al., 2007a,b; Senadeera et al., 2000). Additionally, when in conventional fluidized bed processes, the foodstuff particles with sizes smaller than 50 μm or finer are easily elutriated to the cyclone, but the use of air pulsation causes a reduction in the minimum fluidization air velocity required to achieve the fluidized state (Gawrzynski et al., 1999; Kudra and Mujumdar, 2004; Prachayawarakorn et al., 2005).

The agglomeration of cohesive food powders has been analyzed in some previous studies, and was successfully done using a pulsed-fluid bed (Dacanal and Menegalli, 2010, 2009; Dacanal et al., 2013; Hirata et al., 2013; Machado et al., 2014). Particle agglomeration in a pulsed-fluid bed was obtained by spraying liquid over solid particles fluidized by a hot air stream, in a pulsation frequency. Granules produced by this equipment had increased size, changing the bulk properties of particulate solids. The growth mechanism depends on the conditions of operation, properties of the raw material, drying conditions, and fluid dynamics of the bed (Dacanal and Menegalli, 2010, 2009).

Most experimental studies related to fluidized bed agglomeration consider relatively large particles, which are easily fluidized, and inert particles agglomerated with model binders (Hemati et al., 2003). Some research papers that used fluidized beds for agglomeration, coating or drying of cohesive powders reported problems about their fluid dynamics behavior, which were characterized by their strong inter-particle cohesive force (Chen et al., 2009a, 2009b; de Souza et al., 2010). Other experimental studies investigated the

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hydrodynamics of fluidized bed and spouted bed with pulsation systems, and confirmed that these devices can improve bed homogeneity and reduce the cohesive behavior (Khosravi Bizhaem and Basirat Tabrizi, 2013; Niamnuy et al., 2011). The fluidization of nano-powders was also experimentally achieved in a pulsed-fluidized bed, showing the useful applications of these systems (Ali and Asif, 2012). Another studies investigated the flow behavior of pulsed-fluidized beds using the computational fluid dynamics (Li et al., 2009) and discrete element method simulation (Wang and Rhodes, 2005), and reported that pulsation frequencies improved fluidization quality due to gas velocity fluctuations. There are few reports in the literature about the fluidization and agglomeration of starch particles, but a study of starch particle fluidization using a vibration system showed that the vibration system resulted in lower rates of fines elutriation (Tasirin and Anuar, 2001). In another study, the agglomeration of cornstarch particles was carried out in a conventional fluidized bed and resulted in granules with the desired properties (Chen et al., 2009a).

In a previous study (Dacanal and Menegalli, 2010), the authors achieved optimal process conditions in the agglomeration of a soy protein isolate. Additionally, other previous study investigated the effects of pulsation frequencies in the fluid dynamics behavior of a soy protein isolate (Dacanal et al., 2013), and showed that air pulsation frequency can slightly affect the enlargement rate, but there were substantial changes in the fluidization profile. The optimum operating conditions for those trials were achieved at frequencies of 300 and 600 rpm using a rotating sphere valve.

In general, there are few reports in the literature about the agglomeration of cohesive food powders in fluid bed systems, and this study aimed at providing better understanding of the profiles of fluid dynamics of cassava starch and cornstarch particles when the air pulsation frequencies are used in a top-spray agglomeration process. The measurements on physical properties of the granules and aggregation kernel constants, from Hounslow's population balance equation, evaluated the performance of the pulsed-fluid bed granulator.

2. Experimental method

2.1. Materials used

Cassava study: The raw material used in the agglomeration experiments were samples containing 0.40 kg of native cassava starch (Company: Yoki Alimentos S.A., Brazil).

Cornstarch study: Samples containing 0.40 kg of native cornstarch were used as raw material in agglomeration experiments (Company: Ingredion Brasil, Ingredientes Industriais Ltda Brazil S.A., Brazil).

In the both cases studies, aqueous solution of 50% w/w containing maltodextrin (20%DE, MOR-REX® 1920, Corn Products, Brazil) at 27 °C was used as a liquid binder in top-spraying.

2.2. Fluid bed equipment and accessories

The equipment used was a batch-fluidized bed based on a previous prototype design (Dacanal and Menegalli, 2010), and equipped with a rotating spherical valve installed below the air distribution plate, which promotes fluidizing air pulsation at valve rotation frequencies of (0, 300, 600, and 900) rpm. An electrical motor with variable speed drive adjusts the rotation of the spherical valve. The fluid bed chamber has a cylindrical base (4 in diameter and 0.15 m height), above which there is a conical expansion of 0.35 m height and a cylindrical body (10 in diameter and 0.40 m height), as shown in Fig. 1. The fluid bed chamber was built from 304 stainless steel. An on/off electrical heater controlled the fluidizing air temperature. The fluidizing airflow was monitored by a rotameter and an orifice plate flowmeter. The liquid binder and the compressed air were pumped into the two-fluid nozzle (model 1/8JN-SS+SU11-SS, Spraying Systems, Brazil), atomizing the liquid binder.

2.3. Description of the air pulsation system and fluid dynamics characterization

The bed aerodynamic behavior was determined by measuring the bed pressure drop as a function of air velocity and pulsation frequency for the raw material without atomization of the binder. The air pulsation frequencies were fixed at (0, 5, 10 and 15) Hz, which corresponds to the spherical valve rotation frequencies of (0, 300, 600, and 900) rpm. Fig. 2 shows the fluidizing air velocity profiles obtained for these pulsation frequencies. In the case of no air pulsation, the valve was kept completely opened, and the air velocity was maintained at a maximum (v_{max}) of 0.35 m/s. When applied the air pulsation system, the air velocity (v) followed the absolute value of a sine function (Eq. (1)). Where: f is the valve rotation frequency, and t is the time of process. For each spherical valve revolve, the air velocity achieved the maximum value twice. In other words, the effective frequency of air pulsation is 2 times the frequency of the valve rotation.

$$v = v_{max} \cdot |Sin(2\pi \cdot f \cdot t)| \tag{1}$$

2.4. Description of agglomeration process in pulsed-fluid bed

The fluidizing air temperature and velocity were fixed at 95 °C and 0.35 m/s, respectively. Elutriated particles were collected by a cyclone. Atomization was performed countercurrent to the fluidizing airflow, consisting of a jet sprayed with conical geometry and a circular projection area. The nozzle height was fixed at 0.30 m inside the fluid bed. The maximum process time or period of liquid atomization was fixed at 50 min (3000 s). However, before the liquid was injected, the process variables were fixed at the selected operational conditions. Subsequently, the amount of native starch (raw powder) was introduced into the fluid bed, starting the process. Atomizing air pressure and the concentration of the binder and feed flow rate were fixed at 0.5 bar (50 kPa), 50% w/w and 3.0 g/min, respectively. The binder temperature was 27 °C. The agglomeration processes were carried out in the pulsation frequencies of (300, 600, and 900) rpm. The agglomeration trials at 0 rpm were not possible, because the fluidized bed collapsed under this condition and resulted in the over-wetting of the sample. In the end of the process, the granulated particles were collected from the bottom of the fluid bed and packed into polypropylene bags until they were analyzed. The physical properties of the native starch particles were then compared with the granules in both case studies.

2.5. Physical properties and product characterization

The physical properties of native particles and agglomerated particles of cassava starch and cornstarch were evaluated by analysis of particle size distribution, moisture content, flowability, cohesiveness, and morphology.

2.5.1. Moisture content

The raw and agglomerated product moisture contents were determined by drying at 70 °C under vacuum, according the AOAC Official Method 920.151.