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The effect of binder concentration in fluidized-bed granulation: Transition between wet and melt granulation

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ABSTRACT

According to the binder nature, fluidized-bed granulation (FBG) is usually classified as wet or melt granulation. In particular, the industrial urea granulation performed in fluidized beds, is often called "melt granulation" because a highly concentrated urea solution is used as binder (between 95–97 wt%) (Cotabarren et al., 2012). However, plant disturbances can cause changes in binder urea concentration and thus granulation can shift from melt to wet granulation and vice versa.

In a previous investigation, the granulation system urea (seeds)–urea (binder) was extensively studied in a pilot-scale batch fluidized-bed granulator (Veliz Moraga et al., 2015). Besides, the effect of seed size, bed temperature, binder flowrate and fluidization and atomization air flowrates on process variables as well as on product properties were studied. The aim of this work is to analyze the effect of the binder urea concentration on the urea granulation performance and product properties. This concentration was varied from 87.5 wt% to 98 wt%, while the fluidization air velocity, urea melt flowrate, bed temperature set-point and atomization air flowrate were kept constant. The product properties (percentage of agglomerates and coated particles, crushing strength and moisture content) and granulation efficiency are discussed in terms of the transition from wet to melt granulation. The critical urea content was experimentally found; indeed, urea concentrations lower than the critical one dramatically affect the product quality. Finally, the criterion proposed by Villa et al. (2016) for predicting agglomerates formation is used to determine the minimum allowable binder urea concentration. The prediction is consistent with the trends experimentally observed, indicating the good capacity of the criterion to identify the boundary for agglomeration occurrence.

1. Introduction

Granulation includes a sequence of events to increase the particle size of granular material (Wang et al., 2017). Several technologies are used for particle size enlargement with different aims such as improving handling and flowability, obtaining a certain size, enhancing product appearance, controlling particle moisture content, reducing dusting or material losses, producing structural useful forms, etc. (Barrasso and Ramachandran, 2015; Schmidt et al., 2015).

Granules can be obtained in different equipment, among others, rotary drums, high shear mixers and fluidized beds (Litster et al., 2004; Osborne et al., 2011; Snow et al., 1999). These units basically differ in the way they favor particles mixing. The advantages of a fluidized bed with respect to other granulation systems include coupling of spraying,

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Nomenclature

A	Agglomerated product mass fraction (–)
C	Pure coated product mass fraction (–)
cp_u	Urea mass heat capacity (J/kg K)
$d_{n,g}$	Gas nozzle orifice diameter (m)
$d_{n,l}$	Liquid nozzle orifice diameter (m)
d_{nv}	Mean number-volume diameter (m)
$d_{nv,calc}$	Calculated mean surface-number diameter (m)
d_0	Seed arithmetic mean diameter (m)
DAP	Dimensionless Agglomeration Parameter (–)
F_f	Filter-bags fines mass fraction (–)
F_p	Product fines mass fraction (–)
F_w	Wall fines mass fraction (–)
k_p	Particles thermal conductivity (W/m K)
K	Parameter defined in Eq. (7) (–)
L	Fluidized-bed height (m)
$\dot{M}_{binder}$	Binder mass flowrate (kg/s)
M_f	Filter-bags fines mass (kg)
M_{uf}	Final urea mass in the bed (kg)
M_{us}	Maximum sprayed urea mass (kg)
M_{u0}	Initial urea mass in the bed (kg)
M_w	Wall fines mass (kg)
$\dot{M}_a$	Atomization air flowrate (kg/s)
t	Time (s)
T_{fus}	Fusion temperature (°C)
T_{bed}	Bed temperature set-point (°C)
v_{mf}	Seed minimum fluidization velocity (m/s)
v_f	Superficial fluidization air velocity (m/s)
X_u	Urea mass concentration ($kg_{urea}/kg_{solution}$)

Greek symbols

ΔH_{fus}	Urea fusion latent heat (J/kg)
μ_a	Air viscosity (Pa s)
η	Granulation efficiency (–)
ρ_L	Binder density (kg/m^3)
θ	Contact angle (–)

granulation, drying and cooling stages in one single unit as well as control, within certain limits, of the granules physical properties by manipulation of some operating variables (Heinrich et al., 2005).

When the binder used in granulation is a liquid material, the process is classified into wet or melt granulation. In wet granulation, the liquid binder is distributed on the seeds and, subsequently, the granules are dried to evaporate the solvent. In melt granulation, powders are enlarged by using meltable materials. These last binders are added to the system either as: 1) powders that melt during the granulation process or 2) atomized molten liquids (Zhai et al., 2010). The first melt granulation technique is usually called co-melt or in situ melt granulation (Zhai et al., 2010), while the second method could be referred as spray-on melt granulation (Osborne et al., 2011).

The effects of process variables and material properties of the solid and the liquid on particle size enlargement in fluidized beds were reported by quite a large number of articles (Ennis et al., 1991; Hemati et al., 2003; Iveson et al., 2001; Pont et al., 2001; Smith and Nienow, 1983; Tan et al., 2005, among others). These contributions are valuable for understanding and quantifying the mechanisms that control granule attributes (Suresh et al., 2017).

Melt granulation presents some advantages with respect to wet granulation: a) the use of solvents is avoided, eliminating the disadvantages associated with solvent recovery and final disposal and minimizing the energy cost related to solvent evaporation (Abberger et al., 2002; Mielke et al., 2016; Walker et al., 2006); b) the amount of liquid added during granulation is better controlled since uncontrolled solvent evaporation will not occur (Parikh, 2010) and c) for moisture-sensitive materials, granulation can be carried out without organic solvents (Parikh, 2010).

The industrial urea granulation process is considered one of the most significant breakthroughs in the fertilizer manufacture and, thus, of great interest (Cotabarren et al., 2012; Heffer and Prud'homme, 2016). Urea is the most widely consumed nitrogen-based fertilizer, being critical in the modern agriculture scenario. Industrial urea granulation is performed in fluidized beds, by spraying from the bottom a highly concentrated urea solution. Urea seeds are quite large (about 2 mm) and, for some technologies, the binder droplets are significantly smaller than the initial nuclei (about 40 times smaller than the urea seeds). In the industrial practice, short granulation times are used and coating is preferred over agglomeration for size enlargement.

In this context, and taking into account that it is difficult to establish the differences between wet and melt granulation because these processes are usually carried out with different solid cores (seeds), urea is an attractive system to study both types of granulation. The aim of this paper is to explore the effects of the binder concentration on process performance and product quality. Particularly, the influence of the binder urea concentration (from 98% to 87.5%) on the fraction of agglomerated granules is evaluated. Besides, the impact of binder concentration on granulation efficiency as well as on granule moisture content, size, morphology and crushing strength is studied.

2. Materials and methods

2.1. Equipment

A schematic diagram of the experimental device is shown in Fig. 1. The experiments were carried out in a batch fluidized-bed granulator (see geometrical parameters in Fig. 1) constituted by a stainless steel bottom conical vessel (1), and a cylindrical column (6) on top of it. The air distributor is a stainless steel perforated plate (2). The fluidization air was supplied by a centrifugal blower (3). Before entering the bed, the fluidization air flowrate was measured by an orifice flow-meter (4) and preheated by an electrical heater (5) to maintain the bed temperature at the desired level. The bed and grid pressure drops were manually measured by water U-tube manometers. The elutriated fine particles were collected by a set of three filter bags located at the top of the fluidized-bed freeboard (6). These filters were periodically blown back by air pulses to disengage the particulate matter. The feed (urea melt) was prepared in an oil-heated tank (7) by typically adding 1 kg of urea, the required small volume of water to reach the desired urea concentration and a tiny amount of food dye to easily monitor the fluidized-bed granulation through the unit observation window. The urea melt tank (of about 0.002 m^3) was placed on a scale and kept at constant temperature (≈130 °C) by means of an oil reservoir (operating at 140 °C). The urea melt was delivered to an internal mixing two-fluid spray nozzle (8), which was located just above the air distributor, by means of a given compressed air flowrate (atomization air) that was preheated up to 130 °C before entering into the urea solution tank (9). The atomization air was also preheated and its flowrate was controlled and measured by a valve and a rotameter, respectively. The external tube-skin temperature of the urea line (from the hot container to the spray nozzle) was controlled through an electric heat tracing system. A Programmable Logic Control system (PLC) was used to register and control process variables (Veliz Moraga et al., 2015).

2.2. Experimental procedure

For each run, a batch of approximately 2 kg of urea seeds was initially charged into the bed chamber. The seeds had diame-