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Particle surface moisture content estimation using population balance modelling in fluidised bed agglomeration

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ABSTRACT

The objective of this study was to investigate the effect of particle surface moisture content on growth rate during fluidised bed agglomeration. In order to establish the relationship between process conditions and particle surface moisture content, the combined population balance and thermodynamic model, as described by Ronsse et al. (2007a,b), was used but was modified to include the degree of wetting and surface moisture content as variables in the population balance. Growth kinetics were experimentally verified by fluidised bed agglomeration tests using 100 μm glass beads and maltodextrin based aqueous binder solutions, under varying process conditions. Studied process variables included binder concentration, fluidisation air temperature, liquid binder feed rate and liquid binder atomisation pressure. With the exception of varying binder concentrations, it was observed that a clear correlation existed between the model-predicted surface moisture content and the experimentally obtained growth rates. This work clearly demonstrates that, in population balance modelling of fluidised bed agglomeration, constant rate agglomeration kernels are insufficient and need to be sensitised to surface moisture content and binder concentration.

1. Introduction

Fluidised bed agglomeration is a widely used unit operation in the agrochemical, food and pharmaceutical industries with the aim of modifying the physical properties of individual particles not only with respect to increasing the particle size, but also to alter shape, density, porosity and particle morphology (Saleh et al., 2003). Consequently, handling properties of powders (including wettability, flowability, dust formation, compaction behaviour, etc.) can be improved by agglomeration. In the fluidised bed agglomeration process, the binder, in the form of an aqueous or organic solution of a polymer, is continuously atomised or sprayed onto the fluidised particles (Link and Schlünder, 1997; Zank et al., 2001). Particle growth is realised by means of interparticle liquid bridge formation during the collision of wetted particles (Link and Schlünder, 1997; Saleh et al., 1999). In order to consolidate the interparticle liquid bridges, the bed is supplied with fluidisation air having a high evaporative capacity (Depypere et al., 2003). The continuous repetition of particle wetting, collision, liquid bridge formation and drying occurring in the fluidised bed will result in a progressive growth of particle agglomerates (Turchiuli et al., 2011).

As the fluidised bed agglomeration process involves a series of complex thermodynamic interactions between the different phases (gas, solids and sprayed liquid) involved, the agglomeration process is prone to yield-reducing or quality-degrading side-effects, i.e. uncontrollable particle growth and bed quenching (Guignon et al., 2002; Teunou and Poncelet, 2002). Although controlled agglomeration is the objective in many fluidised bed unit operations, in some applications agglomeration is considered as a negative side-effect (Dewettinck and Huyghebaert, 1998; Kage et al., 1998; Nakano and Yuasa, 2001). For instance, in aqueous film coating, the preferred particle growth mechanism is layering, i.e. the binder is deposited on the particle surface without stable interparticle bridge formation. Whether growth by layering or growth by agglomeration is promoted, depends on process conditions including the fluidised bed's evaporative capacity (as a function of fluidisation air supplied to the bed) and the spraying rate of the dissolved binder, as is exemplified in Fig. 1 (Gouin, 2005). If layering is desired (i.e. in film coating), then the fluidised bed is supplied with a higher evaporative capacity than commonly used in agglomeration. As a result, the solvent (water) fully evaporates on the particle surface prior to interparticle collision and thus, the formation of liquid bridges is inhibited. However, increasing the evaporative capacity of the bed is also accompanied with undesired additional losses of binder due to premature droplet evaporation, i.e. to so-called spray drying losses (Ronsse et al., 2008).

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Nomenclature

A	surface (m^2)
d	diameter (m)
DM	binder dry matter content (kg/kg)
J	mass flow rate, liquid binder (kg/s)
G	mass flow rate, gas phase (kg/s)
$n(\,)$	number density function
N	number of particles
n	number of control volumes or compartments
Re	dimensionless Reynolds number
S	control volume or compartment
T	temperature (°C)
t	time (s)
u	particle diameter (m)
v	velocity (m/s)
W	surface moisture content (kg/m^2 or mg/m^2)
Y	surface binder content (kg/m^2 or mg/m^2)
We	dimensionless Weber number
Z	growth rate (µm/min)
β	agglomeration kernel
ϕ	degree of wetting
φ	relative humidity
μ	dynamic viscosity (Pa s)
θ	contact angle (°)
ρ	density (kg/m^3)
σ	surface tension (N/m)

Subscripts

at	atomisation air
crit	critical
g	glass transition
in	inlet air
out	outlet air
p	particle
sol	solution (binder)

The mechanism of particle growth (i.e. growth by layering or growth by agglomeration) and the actual particle growth kinetics in liquid-sprayed fluidised beds are mainly determined by the amount of free liquid binder available on the particle surface (Abberger, 2001), as the latter determines the ability to form liquid bridges during particle–particle collisions. In turn, the freely available liquid depends on the spraying rate, the evaporative capacity (i.e. drying rate) in the bed and the size of the impacting droplets (Abberger et al., 2002; Schaafsma et al., 2006; Hede et al., 2008; Laksmana et al., 2009). With respect to droplet size, its distribution is a key parameter as larger droplets tend to contribute to uneven distribution of freely available liquid binder over the particle population, hence contributing to agglomeration (Schaafsma et al., 2000).

Adequate control of the agglomeration process and of the resulting characteristics of the agglomerated powder, as well as scale-up and process optimisation in terms of reactor design, requires understanding of how the different involved microprocesses interact – which include fluidisation, atomisation, drying, droplet impingement and droplet adherence (Werner et al., 2007). Physically based process models, which incorporate the fundamentals of these processes on a micro level scale, could prove to be useful tools in understanding or clarifying the impact of the different input variables on the agglomeration process. Because experimental results are limited to a specific combination of process equipment, coating and core materials, the use of comprehensive physically based process models – whose scope of application is more broad than existing empirical data – can therefore substantially reduce the research and design work required for any new combination of binder, core material, fluidised bed reactor type and process scale (Turton, 2008; Fries et al., 2011).

In modelling the agglomeration process in a fluidised bed, different approaches were adopted. Recent advancements in multiphase modelling have resulted in the study of the use of highly

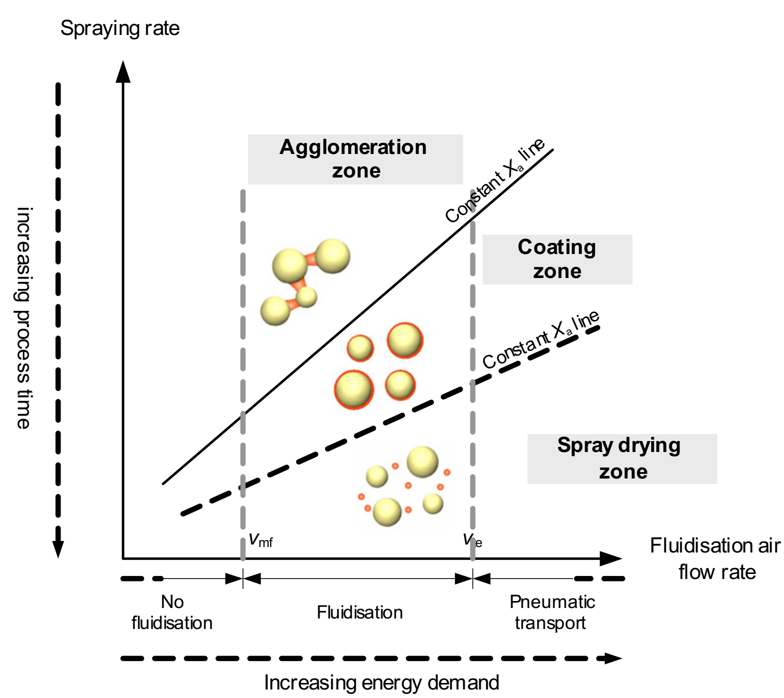

Fig. 1. Relationship between type of particle growth encountered in liquid sprayed fluidised beds and the spraying rate and fluidisation air flow rate as process variables (after Gouin, 2005).