HOSTED BY
ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Resource-Efficient Technologies ■■ (2016) ■■–■■

RESOURCE EFFICIENT TECHNOLOGIES

www.elsevier.com/locate/reffit

Research paper

Experimental and modeling study of fluidized bed granulation: Effect of binder flow rate and fluidizing air velocity

U. Vengateson *, Ratan Mohan

Department of Chemical Engineering, Indian Institute of Technology, New Delhi 110016, India

Received 27 June 2016; received in revised form 29 September 2016; accepted 5 October 2016

Available online

Abstract

Fluidized bed granulation is a widely used technique of producing granules in pharmaceutical, food, detergent, and fertilizer industries. In this study, fluidized bed granulation of two powders – wheat flour and rice powder – with water as binder is studied experimentally and by modeling. The effects of two process parameters – binder flow rate, fluidizing air velocity – are determined. Experimental results show that increasing the binder flow rate favors the formation of bigger granules while increasing fluidizing air velocity leads to a decrease in average granule diameter. Population balance model with suitable form of coalescence kernel (β) has been used to describe the granule growth. Later, this kernel is linked with process parameters – binder flow rate and fluidizing air velocity.

Keywords: Granulation; Fluidized bed; Population balance; Coalescence kernel

1. Introduction

Granulation is a process of converting small diameter particles into larger diameter agglomerates made up of initial particles. Fluidized bed granulation is one among many methods such as high shear granulation, drum granulation, etc. to produce coarse particles. This method is preferred over other techniques because it provides good mixing, high heat and mass transfer rates, and maintains the bed more or less at uniform temperature [1]. In fluidized bed operation, fine droplets of binder are sprayed on the surface of fluidizing particles. When the wetted particles collide, liquid bridges are formed among particles. The liquid bridges are later converted into solid bridges when they receive sufficient heat from the fluidizing air, to drive off the solvent present. Thus the particles are cemented together to form granule.

Growth of particles in fluidized bed depends on many operating conditions and nature of the feed particle and binder. The particle size range, initially with narrow cut, becomes wider and wider as the granulation process continues and hence particle size distribution (PSD) and average granule diameter changes. These changes are strongly influenced by the process parameters – fluidizing air velocity (FAV), binder flow rate (BFR), bed temperature, bed load, spray characteristics etc., – and physicochemical properties of the binder and feed material. As with all engineering processes, knowledge of the phenomenon and the effect of various parameters are important for the proper design, operation and control of the equipment to get the desired product [2]. Both experimental and modeling/simulation studies on fluidized bed granulation are seen in literature, with an increased interest in the subject in the past twenty years. In general, experimental studies examine the effect of physico-chemical parameters, such as the feed particle characteristics, binder properties (viscosity, surface tension, etc.) and operating variables such as fluidizing air velocity, binder flow rate, inlet air temperature, and bed load, on the product granule size distribution (GSD) and morphology. Modeling studies aim to compute the evolution of the PSD with granulation time, from the initial feed to the final product stage. Most of the models involve population balance approach, in form or another.

In the present work, an experimental and modeling study of fluidized bed granulation of two powders – wheat flour, rice

---

U. Vengateson is currently working at National Petrochemical Company, Yanbu, Saudi Arabia.

* Corresponding author. Department of Chemical Engineering, Indian Institute of Technology, New Delhi 110016, India. Fax: +966 143252341.

E-mail address: drvengateson@gmail.com; u.vengateson@natpetpp.com (U. Vengateson).

http://dx.doi.org/10.1016/j.reffit.2016.10.003

Please cite this article in press as: U. Vengateson, Ratan Mohan, Experimental and modeling study of fluidized bed granulation: Effect of binder flow rate and fluidizing air velocity, Resource-Efficient Technologies (2016), doi: 10.1016/j.reffit.2016.10.003

Nomenclature

A	Constant in time dependent β_o, i.e. $\beta_o = At^B$
B	Constant in time dependent β_o, i.e. $\beta_o = At^B$
D_{sv}	Sauter mean diameter, µm
d_i	Average size of particles in ith cut
L_i	Lower limit of particle size in ith bin (µm)
L_{av}	Average particle size in ith bin (µm)
m	Total number of bins
N_i	Number of particles in ith bin
‘q_b	Binder flow rate, kg/sec
t_{df}	Granulation time when defluidization starts, min
u_e	Excess gas velocity, m/sec
U_{mf}	Minimum fluidization velocity, m/sec
u	Volume of colliding granule, m^3
u_s	Superficial fluidizing air velocity, m/sec
v_i	Volume of single particle in ith bin, μm^3
V_i	Total volume of particles in ith bin, μm^3
w_i	Weight of particles staying in ith cut
x_i	Mass fraction of particles in ith cut

Greek letters

β	Coalescence kernel, min^{-1}
β_o	A factor in size dependent coalescence kernel, $\beta = \beta_o(u + v)$
ρ_p	Particle density, kg/m^3

powder – is undertaken. The aim is to experimentally obtain specific granulation data for these powders. These powders were chosen out of interest in fluidized bed granulation of food powders. Wheat flour belongs to more or less Geldart C category whereas rice powder belongs to Geldart A category of powder classification. They are only representative of the food materials and the choice is more from the viewpoint of their being inexpensive and easily available and not for actual use of their granules in food industry. Effect of operating parameters – binder flow rate, fluidizing air velocity – has been studied experimentally in the granulation of the above powders. Modeling of the granulation process has been done using the population balance model with suitably determined form of β. Adjustable constants in β are linked to some of the process parameters.

2. Literature survey

2.1. Binder flow rate (BFR)

The rate at which binder is added to the fluidized bed affects growth rate of particles significantly and it has been studied by many researchers since early 1970s. Davies et al. [3] investigated the effect of binder flow rate (BFR) on the granule characteristics such as avg. diameter, friability, bulk density, and flowability. In their study, 10 kg of powder mix containing lactose and corn starch was granulated using 9.1% aqueous gelatin. The solvent (water) flow rate varied from 85 to 145 g/min till the total quantity of 2200 g of solution was added. The result indicated that increasing binder flow rate caused the formation of bigger granules with more flowability, and decreased bulk density and friability. In the study of Mehta et al. [4] for the granulation of pharmaceutical powder mix – 17.5% sucrose, 69.9% lactose USP, 12.2% starch USP and 0.4% pregelatinized starch – with water as binder, effect of different binder flow rate in the range of 23 ml/min–33 ml/min was investigated. In this study, 500 g of powder mix was granulated with 5 min binder addition, followed by 8 min drying period. It was found that ensuing particle sizes were log-normal and the mean granule diameter was approximately proportional to the liquid flow rate squared and standard deviation was independent of this parameter. Hemati et al. [5] studied the influence of binder flow rate on growth of sand particle. They used two different binders, aqueous NaCl and 1% aqueous CMC solution. When sand was granulated with aqueous NaCl, it was shown that increase in binder flow rate (7.6e-5–16.6e-5 kg/sec) had very little effect on growth rate for a given ratio of NaCl introduced to initial particle mass. On the other hand, for the case of CMC 1%, binder flow rate (145–420 g/hr) had significant effect on growth rate, especially for value greater than 200 g/hr. Boerefijn et al. [6] conducted experiments to study the growth of four particles – hollow glass beads, anhydrous lactose, sodium carbonate, glass ballotini – using PEG 4000 as binder and varied flow rate from 4.8 to 12 kg/hr. It was observed that increase in spray rate increased granule growth for fixed ratio of feed to binder. Tan et al. [7] conducted granulation experiments for glass ballotini – PEG 1500 system – to study the influence of binder flow rate in the range of 3.6 g/min–10 g/min. Though volumetric mean diameter of granules increased with increasing binder flow rate for fixed granulation time, granule size did not significantly change with binder flow rate for a given quantity of binder added to the bed. Jimenez et al. [8] carried out granulation experiments for glass beads and soluble maltodextrin particles agglomerated respectively, with an acacia gum solution and water. They measured both droplet size and liquid jet angle for acacia gum solution. When binder flow rate was increased from 2.65 to 7.75 ml/min, the liquid jet angle increased (33°–40°) as well as the diameter of the liquid droplets (35–45 µm). As a result, the fraction of the bed occupied by the wetting – active zone – increased from 14% to 29% and the penetration depth of the liquid jet increased from 14 to 17 cm [9]. α-lactose monohydrate was granulated in miniaturized fluidized bed by spraying polyvinylpyrrolidone of different concentrations (6%, 8%, 10% w/w) using electrostatic nozzle. D10, D50, and D90 of granules after 3 min of operation for different binder flow rates (16–18, 30–36, 48, 66–68, 94–96 g/hr) were reported in 3D plot and growth was observed significant when flow rate exceeds 36 g/hr. Different methods of binder addition, wet and dry, were studied to produce pharmaceutical granule of size 150–300 µm by Osborne et al. [10]. Granola breakfast cereal was produced in fluidized bed granulation by Pathare et al. [11] and the effect of binder flow rate on granule size was studied. By spraying aqueous solution of ammonium sulfate on core particles of size 0.9–1.6 mm, large spherical granules were produced by Wang et al. [12] and also

Please cite this article in press as: U. Vengateson, Ratan Mohan, Experimental and modeling study of fluidized bed granulation: Effect of binder flow rate and fluidizing air velocity, Resource-Efficient Technologies (2016), doi: 10.1016/j.reffit.2016.10.003