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On two-compartment population balance modeling of spray fluidized bed agglomeration

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ABSTRACT

The present work focuses on the modeling and analysis of a spray fluidized bed granulation (SFBG) process based upon the concept that particles are communicating between the two compartments at some steady state mass flow rate. A numerical technique for solving the proposed two-compartment model (2CM) is developed and validated against some newly derived analytical solutions. Moreover, the inverse technique for extracting the rate constant of one-compartment model (1CM) is extended to 2CM. A correlation of aggregation rate constant of 2CM with the rate constant of conventional 1CM under some restrictions is investigated and it is found that the 1CM cannot be used, in general, to predict results of 2CM. Furthermore, it is observed that the existence of two zones in SFBG is responsible to certain extent for time dependent behaviour of aggregation rate constant. Finally, influence of compartment sizes and particles residence times on particle size distribution is investigated.

1. Introduction

Agglomeration process is used in many industries such as food, pharmaceutical and chemical to enhance the physical properties of the granules. Many of such agglomeration processes are carried out in a spray fluidized bed granulator. Spray fluidized bed granulation (SFBG) offers an optimal choice to enhance the size of the particles by providing a compact design of the apparatus, intensive mixing, high heat and mass transfer rate and simultaneous wetting and drying of particles. In the spray fluidized bed agglomeration process, particles are set in motion by pumping hot air from the bottom of the granulator. Meanwhile, the binder liquid is sprayed on the fluidized particles in the form of small droplets. During the motion, particles come in contact with other particles at wet spots and a liquid bridge forms between colliding particles. The hot and dry air passing through the granulator converts the liquid bridge into solid bridge by transforming the water mass into the gas phase.

Mathematically, the size distribution of particles in the granulator is tracked down by the population balance equation (PBE). The pure agglomeration one dimensional (1D) population balance equation (PBE), also called Smoluchowski equation (Smoluchowski, 1917), for batch system with homogeneous distribution of particles in the external coordinate region and using volume of the particle as an internal coordinate is given by Hulbert and Katz (1964) as

$$\frac{\partial n(v,t)}{\partial t} = \frac{1}{2}\int_0^v \beta(t, v-u, u)n(t, v-u)n(t,u)du - \int_0^\infty \beta(t,v,u)n(t,v)n(t,u)du, \tag{1}$$

where n is the number density distribution at time t, u and v are volumes of colliding particles, and $\beta(t, u, v)$ is the aggregation kernel.

Analytical solutions of the PBE (1) are possible only for some simple aggregation kernels. Scott (1968) derived analytical solutions for constant, sum and product kernel. It is often convenient to define some integral properties, also called moments, of the number density distribution. The jth moment of the number density distribution n is defined as

$$\mu_j(t) = \int_0^\infty v^j n(t,v)dv.$$

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Nomenclature

Latin symbols

i, j	integer index
dv	volume element
F_{sd}	particles flux from spray to drying zone
F_{ds}	particles flux from drying to spray zone
I	total number of discretized intervals of the size range of particles
$n(t, v)$	number density distribution of particles
$\hat{n}(t, v)$	number density distribution of particles of 'experiment'
$n_\alpha(t, v)$	particles number density in spray zone at time t
$n_{1-\alpha}(t, v)$	particles number density in drying zone at time t
N_i	number of particles in the ith
$N_{\alpha,k}$	number of particles in the kth interval of spray zone
$N_{1-\alpha,k}$	number of particles in the kth interval of drying zone
$\hat{N}_{2C}$	total number of particles from 'experiment'
t	time
u, v	volume size
x_k	volume of the kth interval

Greek symbols

α	spray zone ratio $\in(0, 1)$
$1-\alpha$	drying zone ratio
$\beta(t, u, v)$	aggregation kernel of one compartment mode
$\beta_{2C}(t, u, v)$	aggregation kernel of two compartment mode
$\beta^*(u, v)$	size dependent part of the aggregation kernel
$\beta_0(t)$	rate constant for one compartment model
$\beta_{0,2C}(t)$	rate constant for two compartment model
τ_α	residence time of particles in sparing zone
$\tau_{1-\alpha}$	residence time of particles in drying zone
τ_{circ}	time required for one circulation of particles in 2C model
μ_j	jth moment of the distribution about zero
$\mu_{0,\alpha}$	0th moment of the spray zone distribution
$\mu_{0,1-\alpha}$	0th moment of the drying zone distribution
$\dot{\mu}_0$	rate of change of the 0th moment
δ	Dirac-Delta function
λ_k	splitting operator

Abbreviations

1C	one compartment
1D	one dimensional
2C	two compartment
CAT	cell average technique
CFD	computational fluid dynamics
DEM	discrete element modeling
DPB	discrete population balance
EKE	equi kinetic energy kernel
EKM	equi-partition of momentum
Num	numerical
ODE	ordinary differential equation
PSD	particle size distribution
PBE	population balance equation
SFBG	spray fluidized bed granulation

The zeroth and first moments are proportional to the total number and total mass of the system, respectively. Analytical solutions of some integral quantities are rather easy to obtain and therefore they may be used for verifying accuracy of numerical approximations. Kumar, Kumar, and Warnecke (2013) has provided analytical solutions of first two moments for various combinations of combined aggregation, breakage, growth and nucleation.

Agglomeration, especially in spray fluidized bed, is usually modeled by 1D and 1C PBE (1). Pure agglomeration is not only considered for simplicity but also justified for spray fluidized bed because, when aiming at agglomeration, materials and operating conditions are, in practice, chosen as to avoid other mechanisms like breakage, growth and nucleation. A considerable amount of literature has been published on one-dimensional population balances. Besides its extensive application to fluidized bed granulation, Peglow, Kumar, Heinrich, et al. (2006); Liu and Litster (2002); Tan et al. (2004), it has also been used, for example, in modeling of drum granulation, Adetayo, Litster,