Design of a Fluidized Drum Granulator for Ammonium Nitrate Production

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Abstract: There are various difficulties with theoretical modeling of a fluidized drum granulator owing to the mathematical modeling of the movement of fluidized solid particles. Many models are available for the movement of fluidized drums such as rotary drum dryers. This study examined the manufacturing process of dried ammonium nitrate. The process was assumed to have two phases in the drum and during transfer of the obtained granules in the drum granulator, and the retention time was calculated. Data reported in the literature were used to design a fluidized drum granulator for ammonium nitrate production. For the design, the dimensions of the drum in the granulator, slope, rotation speed, lifter number, geometry, dimensions of the fluidized bed table, and location were described. In addition, the retention time of the ammonium nitrate particles was calculated according to the production capacity.

Keywords: fluidized drum granulator; airborne phase; dense phase; axial flow

1. Introduction

Granulation is an industrial process for improving the features of particles. The granulation process is used to create a bond between particles or between phases and particles. This process works to grow and stabilize granules.
The granulation process can be carried out using various kinds of equipment: a rotary drum, fluidized bed, and high shear units. The fluidized drum granulator is the most recent technology and combines the use of a fluidized bed table and a drum[1]. The rotary drum and inclined fluidized bed dryer contain lifters high up within them.

The fluidized drum granulator system is a complex structure. The main problem with this system is mathematical modeling of the particle behavior. Granules in the granulator are raised by lifters in the drum toward the top of the fluidized bed table and rolled to the bottom of the drum. On the surface of the fluidized bed, particles drop down the inclined surface as they cool. Lifters move the granules out of the granulator. The same cycle continues until particles of the desired size are obtained [2].

Although fluidized drum granulators have been successfully implemented at the industrial scale, no papers have been published on this granulation process [3]. Therefore, a good mathematical model of granulation is needed to improve the operating conditions. The aim of this study was to obtain the desired granules by choosing suitable operating conditions of a fluidized drum granulator.

Ammonium nitrate has no chloride and is water soluble; it is a fertilizer with variable properties. It is used widely in agricultural areas. Today, fertilizer is applied to the soil directly or sprayed onto it. The crushing strength of ammonium nitrate pills is higher than that of ammonium nitrate granules. Thus, the granules form a physical mixture with other fertilizers[4]. This work developed a design for ammonium nitrate because it has different allotropic features during granulation.

Momentum, mass, and energy balance should be calculated simultaneously in the design of a fluidized drum granulator for manufacture of ammonium nitrate. The actual retention time should be calculated to determine the relationship between crystallization and solid–solid phase transformation for the energy balance. In this calculation, determining the axial flow rate is important owing to the transfer of solid particles.

The production capacity (100 ton/h) and desired granule size were the first target parameters for the design of the fluidized drum granulator. In this design, the drum dimensions, drum inclination, rotation speed, geometry, number of lifters, and dimensions and location of the fluidized bed table should be calculated first. The retention of solids in the granulator can then be calculated.

2. Materials and Methods

2.1. Mathematical Modeling

For the mathematical model, two phases of solids were assumed to move in the rotating drum [5]: the airborne phase and the dense phase. The airborne phase consists of particles falling down from
the lifters. The dense phase moves on the fluidized bed and falls down the drum. Sherritt et al.’s [6] model describes the movement of solids in a fluidized bed. The same model can be used to describe the movement in a fluidized drum granulator.

2.2. Retention Time of Solids

The retention times of solids in the drum, the total mass that moves in the fluidized bed, and the axial flow rate are calculated as follows[7]:

\[
T = \frac{ML}{F} \tag{1}
\]

where L is the drum length.

\[
F = F_1 + F_2 + F_{\text{melt}} \tag{2}
\]

\[
M = M_1 + M_2 + (F_{\text{melt}}/L) \tau \tag{3}
\]

The subscripts 1 and 2 denote the airborne and dense phases, respectively. \( F_{\text{melt}} \) is the flow rate of the ammonium nitrate solution through the drum.

2.3. Axial Flow

Figures 1(a) and 1(b) show the cross-sectional area of the fluidized drum granulator. Three areas in the granulator define granule movement in the airborne phase. Areas I and II are related to solid particles that fall on the fluidized bed via lifters and then fall down to the drum. Area III defines the movement of particles on the fluidized bed.

\[\text{Figure 1. Cross-sectional views of fluidized drum granulator.}\]
Assuming that the particles are in the airborne phase, all lifters can be thought of as having similar axial flow rates. According to Sheritt et al.’s [6] mathematical model, the total axial flow rate of airborne solids is

\[ F_1 = \frac{N \rho_b n}{2} \left[ 2 \pi \int_{l}^{0} \frac{z}{l} d\theta + \int_{0}^{\theta_1} \frac{z}{l} d\theta + \int_{0}^{\theta_{in}} \frac{z}{l} d\theta \right] \]

where \( \rho_b \) is the density on the fluidized bed, \( \theta_1 \) is the position at which solids fall down on the fluidized bed (figure 1b), \( \theta_{in} \) is the initial releasing angle, \( n \) is the rotation speed, \( N \) is the number of lifters, \( l \) is the length of lifters at the release points, and \( d_{z}^{m} \) is the position at which granules fall down in areas I and III (figure 1a). The angular position is measured in the rotation direction (figure 1b).

Because of axial movement and difficulties during this time, the retention of particles, \( z \), can be calculated by a force equation that can be created for an airborne particle. For every region \( m \), the axial movement is [7]

\[ \left( \frac{\pi}{6} d_{p} \right)^{3} \rho_{p} \frac{dv_{z}}{dt} = \left( \frac{\pi}{6} d_{p} \right)^{3} \rho_{p} g \sin(\alpha) \]

where \( d_{p} \) is the particle diameter, \( \rho_{p} \) is the particle density, and \( \alpha \) is the drum inclination. As the initial velocity is zero, Equation 5 is then integrated for each region \( m \) to determine the axial movement[7].

\[ d_{z}^{m} = g \sin(\alpha) \left( t^{m} \right)^{2} \]

Here, \( t^{m} \) is the time at which particles fall in a particular area.

To calculate \( t^{1} \), the force balance equation for the force of air in the fluidized bed is written as follows[7]:

\[ \frac{dv_{y}}{dt} = -g \cos(\alpha) + \frac{3 \rho_{air} C_{D}}{4 d_{p} \rho_{p}} \left( v_{air,y} - v_{y} \right)^{2} \]

\[ \frac{dv_{x}}{dt} = -\frac{3 \rho_{air} C_{D}}{4 d_{p} \rho_{p}} \left( v_{air,x} - v_{x} \right)^{2} \]

where \( C_{D} \) is the friction coefficient and \( \rho_{air} \) is the air density. \( t^{1} \) is the falling time and is a movement function that is calculated according to the fluidized bed’s location, using Equations 7 and 8 [8].
To calculate $t^I$, the friction force is neglected in Equations 7 and 8. $t^I$ is calculated by the equation for the relationship between the drum movement and the height, which is calculated by Equation 7 [6]. In modeling of the fluidized drum granulator, the solid axial flow rate is assumed to be minimum in area II.

The $t^m$ and $t^II$ values are calculated similarly. However, some additions are performed based on $t^I$. During these calculations, the rolling time of solids on the surface of the fluidized bed is neglected. Phase 2, which is another object for the mathematical modeling of a fluidized drum granulator design, can be calculated as suggested by Sheritt et al. [6].

According to Sheritt et al. [6], the particle movement in region II in the airborne phase is formulated by using the falling down speed from the fluidized bed surface and the falling time. If a formula is developed that includes regions I and III for particle movement in the airborne phase, a related formula is given as follows [7]:

$$M_1 = \frac{N \rho b n}{2} \left[ \frac{2\pi}{\theta_1} t^I d\theta + \frac{\theta}{\theta_{in}} t^{II} d\theta + \frac{2\pi}{\theta_1} t^{III} d\theta \right]$$

(9)

In the case of movement of the dense phase, a similar method is used.

### 3. Results and Discussion

Drum properties can vary widely [9]. For this study, the capacity of the fluidized drum granulator was assumed to be 100 ton/h; its diameter was 5 m, and the L/D ratio was 2. Thus, the drum’s height was 10 m [10]. The lifters used in the drum were 0.08 m in height. The lifter angle was 145°. There is limited information in the literature on the location of the drum relative to the fluidized bed table for the design of a fluidized drum granulator; thus, parameters such as the wideness and inclination of the drum were measured in this study and found to be 1.5 and 0.45 m, respectively.

For a granulator with a production capacity of 26-30 ton/h and particle growth rate of 20–30%, the fluidized drum productivity and axial flow capacity should be calculated to determine the movement width of particles that move from the lifters in the drum to the surface of the fluidized bed, the drum inclination, and the number of particles that fall down to the surface of the fluidized bed table depending on the number of lifters and rotation speed [10].

For spherical particles characterized by the number/volume ratio of granules, the granule growth is expressed as follows [7]:

$$\frac{d_D}{d_D^0} = \left[1 + 1/R \right]^{1/3}$$

(10)
where $d_p_0$ is the average diameter and $R$ is the feedback ratio.

The flow width $w$ of particles lifted onto the surface of the fluidized bed from the lifters was 0.24 m; the number of lifters was 20; the drum inclination was 5°; and the drum’s rotating speed was 5 rpm. These were specific parameters that described the movement mechanism of the granulator. Figures 2–5 show plots of the retention time versus the granule growth ratio, flow width, drum inclination, and rotating speed, respectively. As seen in the figures, increasing any of the four factors either increased the axial flow or decreased the retention time and granule dimensions.

A production capacity of 14–16 kg/s was considered to examine the increase in the granule dimensions ($dp/dp_0 = 1.2–1.3$). Independent factors related to $dp/dp_0$ or to the specific capacity at the two points shown on the abscissa were calculated. These independent factors are $W$, $N$, $a$, and $n$ and can be measured graphically[7].

![Figure 2](image-url)  
**Figure 2.** $F$, $\tau$, and $dp/dp_0$ as functions of $W$.

A granule growth rate of 20–30%, as shown in Figures 2 and 3, caused variations in production capacity. For the fluidized drum granulator used under these specific production conditions, the drum diameter was determined to be 5 m, the drum length was 10 m, and the number of lifters was between 15 and 20. The height of these lifters was 0.08 m, the width was 0.20–0.27 m, the drum inclination was 5°, and the rotation speed was 5.0 rpm. The retention time was measured to be 20 min.
Figure 3. $F$, $\tau$, and $dp/dp_0$ as functions of $N$.

Figure 4. $F$, $\tau$, and $dp/dp_0$ as functions of $\alpha$. 
4. Conclusions

The aim of this work was to design a fluidized drum granulator with a production capacity of 100 ton/h. Through the use of the available literature and mathematical modeling, the drum dimensions, inclination, rotation speed, number of lifters, and dimensions and location of the fluidized bed table were determined. Then, the retention time of granules in the granulator was measured.

Several studies have been conducted on particle movement in the airborne phase in a system, as discussed by Wang et al. [11]. According to the models in these studies, the momentum, mass, and energy should be balanced simultaneously. In each case, the relation between the crystallization and phase transition ensures granulator design.

Potential Conflicts of Interest

The authors declare no conflict of interest

References


