CONTINUOUS GRANULATION PROCESS FOR SMALL AND SPHERICAL GRANULES BY SIMULTANEOUS OPERATION OF AGGLOMERATION, GRINDING AND SEPARATION USING A SINGLE ROTATING CONICAL VESSEL

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Introduction

In the new granulation technology, one of the purposes of granulating a material is to give it greater added value by reducing fine powder to smaller and more nearly spherical granules. In a granulation process, it can be expected to be useful if two or more operations can be simultaneously performed by a single unit of equipment.

In our previous papers, development of a simultaneous operation system of granulation and separation using a single horizontal rotating conical vessel was described.

In the present work, a continuous granulation process for forming fine powder into small spherical granules is investigated by a simultaneous operation of agglomeration and separation with grinding, using a single rotating conical vessel.

1. Experimental

1.1 Experimental apparatus and procedure

Figure 1 shows the experimental apparatus (A) and the flowsheet (B). A conical vessel made of a thin sheet of steel was fixed in a rotating cylinder. The vessel was inclined slightly toward the narrower end by tilting the rotation axis of the cylinder at 2° to the horizontal. An acrylic circular weir was attached to the narrower end. The wider end of the vessel was closed by an acrylic plate. A scraper was used to prevent powder from sticking to the wall of the vessel.

An equal-weight mixture of ceramic balls of 3 × 10⁻² m and 1.6 × 10⁻² m in diameter was charged into the vessel as grinding media to grind larger granules. Calcium carbonate powder of average size 6 × 10⁻⁶ m was used as solid material and water as binder.

The rotating speed of the vessel was varied in the range of n = 17–60 min⁻¹ (Nc = 0.2–0.7) and the balls charged were in the range of B = 0.2–0.8 kg in weight (Vc = 0.018–0.072). To maintain a constant feed ratio W (= G/F) = 0.1, the powder was continuously fed into the center of the vessel at a constant rate F = 1.7 × 10⁻² kg·min⁻¹ by a table feeder and an electric vibratory conveyor, and the water as binder

Fig. 1. Experimental apparatus (A) and flowsheet (B)

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was continuously poured onto the cascading surface of powder at the center through a nozzle at a constant rate of $G = 1.7 \times 10^{-3} \text{kg} \cdot \text{min}^{-1}$ by a pump. The granules were sampled at the outlet. The size distributions were measured by screening. The shape characterization of a granule was determined by a projective picture analyzer.

2. Experimental Results and Discussion

2.1 Granulation phenomena and results with grinding

By observation of granulation phenomena in the conical vessel, the granulation process might be performed in the three axially divided sections of the vessel shown in Fig. 2. Powder (average size; $\bar{x}_p$) fed into the center of a rotating conical vessel with binder is granulated near the feeding point (Granulation zone B) with cascading flow. The smaller-size particles ($\bar{x}_p$) among the granules move toward the narrower end (Rounding zone C) of the vessel and the larger ones ($\bar{x}_g$) segregate to the wider end (Grinding zone A) by the segregation effect on the particles in the conical vessel. The former granules are made spherical by cascading flow in zone C and are discharged from the outlet at the narrower end. The latter granules are ground selectively into small ones ($\bar{x}_g$) at the wider end by grinding media. The small granules ($\bar{x}_g$) after being ground move from the wider end to the narrower one by the size segregation effect and are discharged from the outlet with the other small spherical granules ($\bar{x}_g$). All granules are collected at the outlet as the final product ($\bar{x}$).

Figure 3 shows photographs of typical granules, differing in size and shape index.

Figure 4 shows some granule size distributions obtained by the simultaneous operations under various grinding conditions, compared with that by an open-circuit granulation without grinding media. The sizes and size distribution of granules obtained by the simultaneous operation with grinding are much smaller than those of granules processed without grinding media.

2.2 Effect of grinding conditions on granule size

Figure 5 shows the effect of a grinding condition $[B \cdot n]$ on the median size of the final product $\bar{x}$. The $[B \cdot n]$ was adopted as a measure of grinding intensity in the present work. The experimental results show a considerably good correlation between $\bar{x}$ and $[B \cdot n]$ regardless of $B$ or $n$. The size of the final product decreases as grinding intensity $[B \cdot n]$ increases. The results might be caused by the fact that the small granule size ($\bar{x}_g$) decreases by grinding of the larger granules ($\bar{x}_p$) in zone A as $[B \cdot n]$ increased.

2.3 Effect of grinding conditions on granule shape

To examine the effect of the grinding conditions on the shapes of the granules, 50 particles were chosen at random from among same-size granules that were graded by screening of a sample. The shape index of each granule $\delta$ was defined by Eq. (1) and calculated by measuring the dimensions of the granule projection:

$$\delta = \frac{\text{Heywood diameter of a granule projection}}{\text{Maximum length of a granule projection}}$$

where the closer the value of $\delta$ to unity, the more nearly circular is the granule projection. By photographs and stereo-microscope, it was found that the projection of a granule having $\delta \geq 0.90$ was close to circularity and that the granule was close to being spherical.

Figure 6 shows typical experimental relationships between shape index $\delta$ and size $x$ of granules obtained under various grinding conditions. From Figs. 3 and 6 it can be seen that the relationships between $\delta$ and $x$ change at about $x = 5 \times 10^{-4} \text{m}$. At $x < 5 \times 10^{-4} \text{m},$
δ increases with granule size regardless of grinding conditions, while at \( x > 5 \times 10^{-4} \) m, δ is approximately constant regardless of granule size \( x \), depending on the grinding conditions. It might be difficult to make more nearly spherical granules of \( x < 5 \times 10^{-4} \) m under the present conditions, although smaller granules could be obtained.

Figure 7 shows the effect of grinding conditions on the shapes of the final granules. The average size of the final product \( \bar{x} \) decreases as the speed of rotation \( n \) increases. The average shape index \( \bar{\delta} \) increases with \( n \) up to \( n = 50 \text{ min}^{-1} \), although \( \delta \) decreases at \( n = 60 \text{ min}^{-1} \). However, \( \bar{x} \) and \( \bar{\delta} \) decrease as the weight of balls charged \( B \) increases.

As shown in Fig. 7, the granules become smaller and more spherical as \( n \) increases up to \( 50 \text{ min}^{-1} \) (\( N_c = 0.6 \)), while most of the granules become smaller but non-spherical as \( B \) increases. It can be seen that the granule size is given by the grinding intensity [\( B \cdot n \)] but that the granule shape is affected by the grinding treatments, i.e. surface grinding or body crushing.

**Conclusion**

It is possible to make fine powder continuously into smaller and more nearly spherical granules by simultaneous operation of agglomeration, grinding and separation in a single rotating conical vessel.

**Nomenclature**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Unit</th>
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<tbody>
<tr>
<td>( B )</td>
<td>weight of balls charged</td>
<td>[kg]</td>
</tr>
<tr>
<td>( F )</td>
<td>feed rate of powder</td>
<td>[kg \cdot \text{min}^{-1}]</td>
</tr>
<tr>
<td>( G )</td>
<td>feed rate of binder</td>
<td>[kg \cdot \text{min}^{-1}]</td>
</tr>
<tr>
<td>( n )</td>
<td>speed of rotation</td>
<td>[\text{min}^{-1}]</td>
</tr>
<tr>
<td>( N_c )</td>
<td>critical speed ratio at wider end</td>
<td>[ ]</td>
</tr>
<tr>
<td>( R )</td>
<td>cumulative percent of residue</td>
<td>[%]</td>
</tr>
<tr>
<td>( V_b )</td>
<td>volume ratio of balls to vessel</td>
<td>[ ]</td>
</tr>
<tr>
<td>( W )</td>
<td>feed ratio of binder to power ( (=G/F) )</td>
<td>[ ]</td>
</tr>
<tr>
<td>( \bar{x} )</td>
<td>average (median) size of granules</td>
<td>[m]</td>
</tr>
<tr>
<td>( \bar{\delta} )</td>
<td>shape index defined by Eq. (1)</td>
<td>[ ]</td>
</tr>
<tr>
<td>( \bar{\delta} )</td>
<td>average shape index of granules</td>
<td>[ ]</td>
</tr>
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**Literature Cited**