The Evolution of Screening Systems for Optimum Granular Fertilizer Product Quality

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Abstract

Until around the 1980’s, the accepted typical size distribution standards for granular fertilizer was Tyler 6 to 16 (1.18-3.35 mm) in the U.S. and 1-4 mm in many other parts of the world. However, in order to avoid caking dust problems during handling operations and to improve the evenness of fertilizer distribution from mechanical spreaders, fertilizer product quality expectations in the marketplace have changed. Attention has been focused on eliminating small granules, moving towards a much more closely sized product and generally increasing the median size of granular products.

Keywords: Granular fertilizer: size guide number: uniformity index

Nomenclature

SGN size guide number
UI uniformity index
d granule diameter, mm
F rate of granule growth
R recycle ratio

1. Definition

The new sizing expectations are defined by two important criteria; Size Guide Number (commonly referred to as SGN) and Uniformity Index (commonly referred to as UI). The definitions of these terms are:

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1.1. Size Guide Number (SGN)

The median granule diameter multiplied by one hundred. In other words, the size at which 50% of the product is retained expressed in millimetres multiplied by one hundred.

\[
SGN = d_{50} \times 100
\]  

1.2. Uniformity Index

The ratio of the small granules (particles retained at 95%) to large granules (particles retained at 10%) multiplied by one hundred.

\[
UI = \frac{d_5}{d_{90}} \times 100
\]

or

\[
UI = \frac{[95\% \text{ retained}]}{[10\% \text{ retained}]} \times 100
\]

Where a UI of 100 means all granules are the same size.

2. Market Expectations

Product is now expected to be essentially between 2 and 4 mm. Furthermore, while 90% of 2-4 mm was once considered good, the expectation is now 93-95% or even 98% in range. In addition, the trend has moved towards larger sized product and the expectation for SGN has increased from around 225 to approximately 300. In some markets, even larger SGN is sought. A more closely sized product is also highly desirable and the expectation for UI has increased from around 50 to 60 or greater.

This paper will discuss the evolution of screening system arrangements designed to meet these new expectations.

3. Stage 1 – Double Deck Screens

Many older plants were designed with double deck screens located downstream of the dryer. In fact, until rather recently some new plants (not designed by Jacobs) continued to use this arrangement. The advantage was that the arrangement was compact, saved space and was relatively inexpensive. The disadvantage is the product size distribution was typically poor, particularly by today’s standards.

In a double deck screen, the upper deck separates oversize granules and the lower deck separates fines. Product sized granules pass through the upper deck but are retained on the lower deck. For almost all MAP/DAP plants it is necessary to recycle some on-size granules along with crushed oversize and fines in order to control granulation at the optimum point. For a plant that is granulating “well”, a typical size distribution of the feed to the screens is as follows:

| + 4mm | 20% |
| + 3mm | 22% |
| + 2mm | 33% |
| - 2mm | 25% |

The typical recycle ratio requirements in a DAP plant is 4:1. Therefore approximately 60% of the on-size material generated has to be recycled. A typical arrangement using double deck screen is shown in Figure 1 below.
330

From Dryer Elevator

Scenes

From Dryer Elevator

Product to Cooler

Oversize Pulverizers

To Recycle Elevator

Figure 1

The product is collected in a hopper where a portion of the product is fed to the cooler via a variable speed conveyor which extracts the material from the hopper. The balance of the product overflows from the hopper to the recycle conveyor to maintain the required recycle ratio.

The problem with a double deck screen arrangement is that all material exiting the dyer is screened even though most of the product will be subsequently re-combined with the fines and crushed oversize. Since separation of the fines required more area than oversize separation, the overall size of the screens is determined by the lower deck. A good rule of thumb for fines separation is a maximum of 9.8 mtph per m² of screen area. Therefore, a plant designed for a throughput of say 450 mtph would require four 1.5 m x 6.1 m (5 ft x 20 ft) double deck screens.

Older plants equipped in this manner would typically yield a product with an approximate SGN of 225 and an UI of 50.

4. Stage 2 – The Addition of Polishing Screens

The next stage in the evolution of screening systems is the introduction of “polishing” screens. These screens were installed to act as a second screening stage to remove oversize and fines that were not removed in the first stage of screening. This was in response to market pressure to maximize the percentage of 2-4 mm product. Typically these screens were installed downstream of the cooler. For a plant with a dryer throughput of 450 mtph (production rate of 90 mtph), one 1.5 m x 6.1 m (5 ft x 20 ft) double deck screen would be required.

A plant equipped with double deck screens followed by “polishing” screens would typically yield a product with an approximate SGN of 255 and a UI of 51.

5. Stage 3 – Single Deck Screens

A technique, pioneered by Jacobs, to improve the performance of the screening system is to screen oversize and fines on separate single deck screens. With this arrangement, only the required amount of product to control the recycle is screened. This significantly reduces the load on the fines screens. A typical arrangement is shown in Figure 2 below:
A good rule of thumb for oversize separation is 16.6 mtph per m$^2$ of screen area. For the same size plant as described above, three 1.5 m x 6.1 m (5 ft x 20 ft) single deck oversize screens would easily be adequate. Because product and associated fines have been diverted to recycle ahead of the fines screens, the load on those screens has been reduced to about 180 t/h. In this case, three 1.5 m x 4.6 m (5 ft x 15 ft) single deck fines screens are easily adequate. The polishing screen requirements remain the same.

Table 2

<table>
<thead>
<tr>
<th>Stage</th>
<th>Primary Screens Upper Deck Area, m$^2$</th>
<th>Primary Screens Lower Deck Area, m$^2$</th>
<th>Polishing Screens Upper Deck Area, m$^2$</th>
<th>Polishing Screens Lower Deck Area, m$^2$</th>
<th>Total Screen Area, m$^2$</th>
<th>2-4 mm, %</th>
<th>SGN</th>
<th>UI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>37 (400 ft$^2$)</td>
<td>37 (400 ft$^2$)</td>
<td>0</td>
<td>0</td>
<td>74 (800 ft$^2$)</td>
<td>85</td>
<td>225</td>
<td>50</td>
</tr>
<tr>
<td>Stage 2</td>
<td>37 (400 ft$^2$)</td>
<td>37 (400 ft$^2$)</td>
<td>9</td>
<td>9</td>
<td>92 (1000 ft$^2$)</td>
<td>90</td>
<td>255</td>
<td>51</td>
</tr>
<tr>
<td>Stage 3</td>
<td>28 (300 ft$^2$)</td>
<td>21 (225 ft$^2$)</td>
<td>9</td>
<td>9</td>
<td>67 (725 ft$^2$)</td>
<td>95</td>
<td>285</td>
<td>61</td>
</tr>
</tbody>
</table>

In conclusion, the move to single deck screens reduces the overall screening area by more than 25% while at the same time improving product quality significantly.
6. Stage 4 – The Jacobs Standard

Jacobs identified two problems with the system described above that required attention.

6.1. The Product Hopper

In principle the product hopper with a controlled rate of extraction is an appropriate design; in practice it resulted in problems which affected the ability to control the recycle. Firstly, the hopper collects and stores not just product, but also fines. Secondly, the material has just exited the dryer and is therefore hot. Fine, hot fertilizer inevitably leads to caking problems.

We found that the hopper would “rathole” and at times the outlet would block completely. It proved impossible to prevent build up on the sides, front and back walls of the hopper. The feed to the hopper from most of the screens simply landed on top of the build up and immediately overflowed to the recycle conveyor. Even when granulation was excellent, we found that we could not extract sufficient product from the hopper to maintain recycle rate at the desired point. The higher than desired recycle resulted in dry conditions in the granulator and an increase in fines production – a vicious cycle. We concluded that we needed to eliminate the hopper.

The current Jacobs standard uses electrically controlled flaps underneath each of the oversize screens. The position of these flaps is controlled automatically in response to the demand for recycle from the recycle weigher.

6.2. Recycle of “Small” Product

It occurred to us that recycling product sized material was inherently flawed since it includes recycling of material that is already close to 4 mm and some even a little larger than 4 mm. We reasoned that since there was always ample amount of product sized material available to maintain the plant in balance; we had the opportunity to recycle only the “small” sized product. This may be defined, for example, as granules smaller than 3 mm. The arrangement is shown in Figure 3 below.

![Figure 3](image-url)
Double deck screens are used to separate oversize on the upper deck and “large” product (say +3 mm) on the lower deck. Flaps are installed in the “unders” chutes from the double deck screens. The position of these flaps are controlled automatically in response to the demand from the recycle weigher. Single deck screens are then used to separate fines.

Our expectation was that this change would have the following benefits:

1. Reduction in recycle ratio required by the process. Since the size distribution of the recycle would decrease, there would be an increase in recycle surface area per tonne of recycle and therefore a reduction in recycle ratio.
2. An increase in SGN. Since all of the “large” product would exit the plant as product, there would be a reduction in the percentage of “small” product exiting the plant.
3. An increase in UI. Since the percentage of “small” product in the final product exiting the plant is reduced, the product would be more closely sized.
4. An increase in the percentage of product in the 2-4 mm range. Since there is a lower percentage of “small” product, the amount of fines (-2 mm) in the final product would be reduced.

7. Computer Simulation of New System

In order to quantify our expectations we carried out a computer simulation. We used actual data from a previous generation Jacobs’ designed plant to establish the parameters to be used in our simulation.

In simple terms, granules can be formed by two different mechanisms:

1. Layering (sometimes known as “onion skin” or accretion).
2. Agglomeration

7.1. Layering

In this process, a fluid (in this case ammonium phosphate slurry) is sprayed onto the surface of the recycle or “seed” particles to form an additional layer. Each time a seed particle is recycled, an additional layer is added and the granule grows accordingly. This mechanism is typical of high recycle processes where a granule makes many passes through the granulator before being extracted from the plant as product. Product formed in this fashion is typically very hard and quite spherical.

Figure 4 below, courtesy of IFDC, demonstrates the principle.

![Figure 4. Source: UNIDO / IFDC Fertilizer Manual](image-url)
7.2. Agglomeration

In this process, recycle particles are cemented together by the fertilizer solution forming salt bridges between individual particles. This mechanism is typical of low recycle processes.

Product formed in this fashion is typically much less spherical in appearance, more difficult to dry since the moisture is deep within the granule, and more prone to breakage as the bonds are not strong. Figure 5 below, courtesy of IFDC, demonstrates the principle.

![Figure 5](image)

If the mechanism for granule formation were purely layering, we would expect the following equation (4) to predict the rate of granule growth:

\[
F = \left( \frac{R + 1}{R} \right)^{0.333}
\]

Where:

- \( F \) = exit dryer size fraction / recycle size fraction
- \( R \) = recycle ratio

Detailed particle size fractions data was available from our reference plant for exit dryer, recycle and product streams (+4, +3.4, +2.8, +2.4, +2.0, +1.7, +1.4, +1.0, -1.0).

The data was measured during steady state operation with the process running at a 4:1 recycle ratio. The data demonstrated that granule formation and growth could not be modelled as a one-dimensional population. Clearly growth was due to the agglomeration of some particles, as well as predominant layering. We adjusted our granule growth formula accordingly.
The result of our simulation is shown in Table 3 below:

<table>
<thead>
<tr>
<th></th>
<th>Normal Product Recycle</th>
<th>Small Product Recycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product SGN</td>
<td>284</td>
<td>295</td>
</tr>
<tr>
<td>Product UI</td>
<td>61.3</td>
<td>62.5</td>
</tr>
<tr>
<td>Product % 2 – 4 mm</td>
<td>95.1</td>
<td>98.3</td>
</tr>
<tr>
<td>Recycle Ratio</td>
<td>4.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>

8. Summary

The demands of the marketplace have changed significantly since the 1980’s. There has been a trend towards larger and more uniformly size granules.

The older screening arrangement of double deck screen was not capable of meeting the new product quality requirements. Reaction to market demands initiated the use of single deck screens for oversize and fines separation. And now allows for screening only as much product as required to maintain the plant in balance. Taking the load off the product screens and in conjunction with the use of polishing screens, resulted in the leap forward for product sizing performance.

The latest generation of Jacobs designed plants have taken screening performance to the next level by enabling only small sized product to be recycled to maintain the plant in balance. In addition to product quality improvements the new arrangement allows for a reduction in recycle ratio.

References