On-Line Image Analysis to Control the Fertilizer Manufacturing Process

Microtrac Online Image Analysis Application Note

Background

Many different types of compounds containing nitrogen (N), phosphorous (P) and potassium (K) are found as major ingredients in synthetically manufactured fertilizers, used to supply nutrients for about half the world’s food consumption.

A couple of examples of the many synthetic fertilizers are DAP (di-ammonium phosphate) and KCl (potassium chloride). Almost all fertilizer manufacturing processes produce solid “round” granules in the 1 to 6-mm range, many in the 2 to 4 range. However, the initial feedstock to the process is in liquid form, referred to as the Melt. The diagram on page two (Figure 1.) shows a commonly used Drum Granulation process.
The Process

Drum Granulation: The Melt enters the front end of the drum granulator, which is rotating and contains lifters along the inside to gently throw the granules as they grow. The exit stream contains granules ranging in size from 0.1 to 10 mm. That stream is then screened at 4 mm, with the + 4-mm granules going to an oversize silo, and from there through a roll crushe

The - 4-mm stream is screened at 2 mm, with the - 2-mm stream going to an undersize silo and from there back to the granulator. The product is the 4 x 2-mm stream which makes up about 1/3 of the entire process stream at any one time.

Pan Granulation substitutes a pan (saucer-shaped) granulator for the drum granulator.

Prilling adds a liquid mixer into which the undersize silo stream goes for dissolution prior to return to the granulation process, in this case a prilling tower. The prilling tower is a tall vertical tower which is fed by a rotating funnel-shaped container with holes in it. The Melt and the dissolved undersize stream are fed to the funnel. A column of air rises up through the prilling tower while the droplets fall to the bottom arriving there as near dry granules, being fed then to the 4-mm screen. The + 4-mm stream goes directly to the roll crushe and then to the undersize silo.

Figure 1: Flow diagram of typical drum granulation fertilizer manufacture. Optional sampling points to bring sample to an online Microtrac PartAn for measuring particle sizes and shapes are shown. There are several variations of this basic process for synthetic compound fertilizers. Some descriptions follow: Move to main text, below.
Nozzle Spraying involves recycling both the +4-mm and the -2-mm streams to a mixer for dissolution in oil. These dissolved streams are fed with the liquid Melt to sets of nozzles near the top of a tall tower which spray the combined feed streams upward after which the droplets begin to fall through a column of air coming up through the tower as in the prilling process.

Fluid Bed processing involves using a fluid bed unit operation in place of the drum granulator for producing the granules that are then screened.

Pug Milling, Crystallization and Sheroidization are lesser used processes, but they also basically replace the drum granulator and produce a narrowly sized stream of “round” granules.

The Problem

A very important finishing step in all of these processes is coating the granules with a thin wax layer which controls the leaching rate after the fertilizer is applied to crop fields. This is the reason that in addition to the need for a narrow size distribution, the granules should be as round and consistently smooth as possible. Irregularly shaped particles that are more like fused globules than round granules tend to break at the narrower points exposing surfaces with no coating, and are more difficult to coat evenly over the entire surface.

The Solution

Image Analysis is a particle characterization technique which is becoming more and more desired and used over traditional methods, because of all the additional information it provides. Traditionally, only one particle size is measured, either the particle volume distribution (electrical sensing zone, ESZ) or the equivalent spherical diameter, ESD, distribution (laser diffraction, sedimentation, and sieve analysis). Image Analysis, on the other hand, provides up to some 24 different size and shape morphological parameters for each particle measured. For an application like optimizing control of fertilizer manufacturing, this technology can provide size, roundness, and surface roughness information about the product, so that all of these properties can measured and controlled with one analyzer.
On-Line Analysis: On-line Image Analyzers have been operating in fertilizer plants around the world since the first installation in 1988. Below is a predecessor of the Microtrac PartAn analyzer, a long time in operation without failure.

The graphs below show some of the advantages of on-line control of a process versus lab control. The top graph is illustrative of the typically long times between sampling and analysis using lab control. Here about 2 hours pass within one process fluctuation, based on a change in some control set point (average value) from data of the last analysis. In this example, the set point is shown at 80%. For a fertilizer process, one set point might be the % of product within 2.5 and 3.5 mm, the narrower the distribution the better. Or, one set point could also be the % of product with a “roundness” factor greater than 0.88 (1.0 being a perfect sphere), or a Convexity value (surface roughness (1.0 being perfectly smooth) greater than 0.92.

With on-line control, sampling and measurement are automatically nearly continuous. This means the process variables that might need to be changed to bring it back under control (moving back toward set point) are adjusted much more often than in lab control, and the set point can be raised to achieve more product within specification, 90 vs 80% in this example, and therefore optimizing the performance of the fertilizer in the field. In fact, the turn-around time for sending new on-line control signals automatically back to the process in fertilizer production is on the order of about only 5 minutes.
1. Lab sampling frequency of every 2 hours does not detect the fluctuations.
2. On-line sampling frequency of PartAn does detect the fluctuations.

Figure 3: Graphs of process fluctuations illustrating the advantages of on-line control over lab control.
Figure 4: An example of the PartAn Trend (fluctuations over time) presentation. Parameters for presentation are user-selectable in the PartAn software. These parameter results can be used by the operator to make the proper process adjustments when necessary to bring the process under tighter control, or they can be acted on automatically by a computer equipped with PID and Programmable Logic control algorithms for adjusting the process variables in a feedback loop.
Process equipment is designed to handle the large fluctuations. A result of less fluctuation can be increased production, because the Melt feed rate is one of the adjustable process variables, and the higher it can be run, due to lower fluctuations and faster control response, the higher the production rate will become. (1)

With the PartAn one will also reduce the unforeseen down-time in the process (longer up-time), because on-line control will bring the process from start-up to steady state operation much faster than lab control can. (2)

From the increased revenue resulting from each of these production increases, the payback period for the equipment investment can be calculated. (3)

Research and Development

The PartAn is also available as a lab instrument for R&D. As new and better fertilizers are developed, from new compounds and/or processes, the ability to generate the same information about the product that would later be controlled on line makes good sense. All of the many morphological parameters measured during the development phase would be available in a history of how the product performed relative to these parameters. That information could then be directed to the control actions to take as on-line analysis would indicate in the process.

The Technology

Image Analysis is one of the newer technologies being used for particle characterization. It’s simple, logical and easy, and it provides about 24 more morphological (sizes and shapes) parameters than traditional particle size analyzers do. A combination of a strobe light, optics and digital camera records images of passing particles. The pixel size is known, and from the number and relative locations of the pixels, all of the parameters are easily calculated. Various equivalent diameters, length, width, maximum and minimum distance are a few of the size parameters measured. Some of the shape parameters include aspect ratio, and various surface roughness and roundness parameters. Summary data and both number and volume distributions are some of the data forms available for each parameter. A file of images of all particles measured is provided, seen below, and both the 2-D and 3-D parameters are listed at the upper right for any particle selected. The full 3-D results, based on a patented particle tracking technique, can be calculated by only the PartAn, of all image analyzers.
Figure 4: Particle images. Each row contains different orientations of one particle, which allows the 3-D calculations.

A Scatter Diagram, shown below in blue, allows a view of where each particle resides relative to the two distribution parameters in the red graphs. In this case the two most important to fertilizer are plotted, diameter (size) in the top graph and roundness (shape) to the right of the Scatter Diagram.
Figure 5: Scatter Diagram giving the relative location of each particle for size and roundness, and distributions of those parameters along with their Summary data. Any two of the 24 parameters can be plotted here.

Typical distribution graphs can also be displayed, along with the tabular data, in up to six overlays of different parameters for one analysis or the same parameter for six different historical samples, as shown below.
Figure 6: Overlays of six different parameters and as differential and cumulative distributions for one sample.

Summary

Size and shape are important parameters for good fertilizer quality. Narrow size distributions and round and smooth particles are important for even leaching rate of the nutrients to crops. These two parameters, and many more, are easily measured by image analyzers.

On-line image analyzers are being used, since 1988, in fertilizer plants around the world, to provide rapid and tight automatic control of these parameters. Lab image analyzers can provide the historical size and shape data through the development process for new and better fertilizers. This information can be used to plan the production control schemes for the new products. Pay-back time for the on-line installation is short, and can easily reduce unforeseen down-time. The Microtrac PartAn is the only image analyzer that gives full 3-D size and shape information.
Footnotes

1 Benefit: Increased production -
If one can increase production 1% for a 50-ton/hour production facility, and up-time in the process is 90%, then that increase in production is 0.5ton/hour * 24 * 365 * 0.9 = 3942 tons/ year, or $1,971,000 / yr.

2 Benefit: Increased production time (up-time) -
Let us assume a conservative increase of 1% that will result in about 90 hours longer production time per year. At 50-ton/hour that will give 50 ton/hour * 90 hours * $500/ton = $2,250,000 / yr. Combined, these two benefits of on-line analysis represent about a 2% increase in production and revenue.

3 Payback time for PartAn On-line installation:
Based on the 2% incremental revenue, if the price of the PartAn on-line installation with sampler is $ 150,000 and the price of 1 ton of fertilizer is $500, then the payback period will be about 14 days.(3)