Modern High Efficiency Air Classification and a Practical Example

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Introduction

Particle size separation or classification can be one of the more challenging unit operations in particle technology. With average particle size distributions greater than 100-micron screening or sieving are most commonly used. Below an average particle size of 100 microns mechanical classification methods are difficult and the use of air classification is required. Modern air classifiers are designed for use in the fine particle separation range (i.e. sub sieve) with particular attention given to the requirements for particle separations in the less than 15 micron range. The keys to good particle separation is the dispersion or separation of particles in the continuous air phase, uniform air flow, and the application of a uniform force opposing the air flow. In essence, effective separation requires the particles to be separated by a uniform energy field which provides a consistent movement of each particle for final separation. Modern classifiers accomplish each of these requirements by optimized feed systems, dispersion zones to separate the particles, and designed particle trajectories that minimize variations within the classifier.

Classification in an air classifier is the result of opposing forces in the system. Typically, the classifier comprises a rotating disk that imparts an outward centrifugal force on the particle. Opposing that force is the inwardly moving air flow that provides an inward force on the particle. Both the outward centrifugal force and the inward air flow will interact with the particle moving the particle in a direction that depends on the particle size, particle density, and the balance of the two forces. Critical to the separation of the particles is the requirement that the particles are dispersed or separated, and the force fields are uniform. Agglomerated particles or random air flows will result in random or poor separation. There are many designs to achieve particle dispersion and uniform force generation. In general, the dispersion zone is created with highly turbulent air that results in particle deagglomeration. The development of the opposing centrifugal force is typically done with rapidly rotating plates with air flow counter to the centrifugal force generation. Spatially, the particles enter a zone with the air flowing toward the middle of the spinning plates and the smaller particles exiting from the center hub of the spinning plates while the larger particles remain on the edge of the rotating plates and exit the classifier at an exit point on the periphery of the rotating plates.

Classification Theory

Most modern classifiers fall under the definition of centrifugal air classifiers, which utilize the opposing forces of centrifugal and drag to achieve a separation. The general theory depicting a single particle within an idealized flow field has been well documented in published literature. The centrifugal air classifier is as follows:

$$D_{50} = \frac{3k}{\pi D_0 N}\sqrt{\frac{\mu Q}{\pi H \rho_p}}$$

Where D_{50} is the "cut size", k is a constant dependent on the flow pattern (determined experimentally). D_o is the diameter of the separation zone, H is the height of the separation zone, μ is fluid viscosity, Q is volumetric airflow rate, N is rotor rotational speed and ρ_p is true particle density.

Based on the definition of a centrifugal classifier, at some point the outwardly directed centrifugal force and the inwardly directed drag force on a particle are equal. This critical particle diameter, which has an equal probability of entering either the coarse or fine fraction, is known as the "cut size" (D_{50}). Determination of the cut size and the classifier performance (sharpness) is best accomplished by using the size selectivity method.
In brief, size selectivity can be expressed as a fraction as follows:

$$\eta_d = \frac{\text{quantity of size D entering coarse fraction}}{\text{quantity of size D in feed}}$$

where η_d is classifier selectivity and D is particle size

The shape of the curve represents the sharpness of separation or, in other words, the spread of misplaced material. An index related to the shape of the selectivity curve is the ratio:

$$\beta = D_{25}/D_{75}$$

where β is the sharpness index, D_{75} the particle size corresponding to the 75% classifier selectivity value and D_{25} to the 25% value. Perfect classification $\beta = 1$, the smaller the β, the poorer the classification.

Practical Example
Air classification can be used on a wide variety of materials such as ceramics, polymers and food products. Proper understanding and control of the process variables will result in a useful and economic product. A simple example of the use of air classification to optimize product yield is the air classification of glass beads as follows where Figure I shows an SEM image of the starting material and Figure II shows the particle size distribution (PSD) of the starting material.

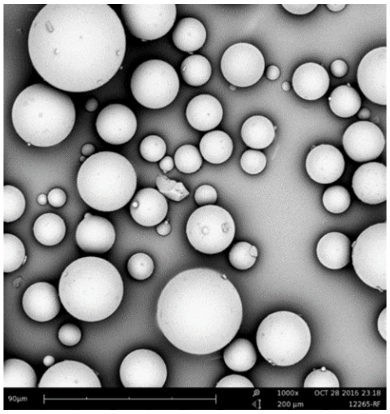

Figure I Starting Glass Beads

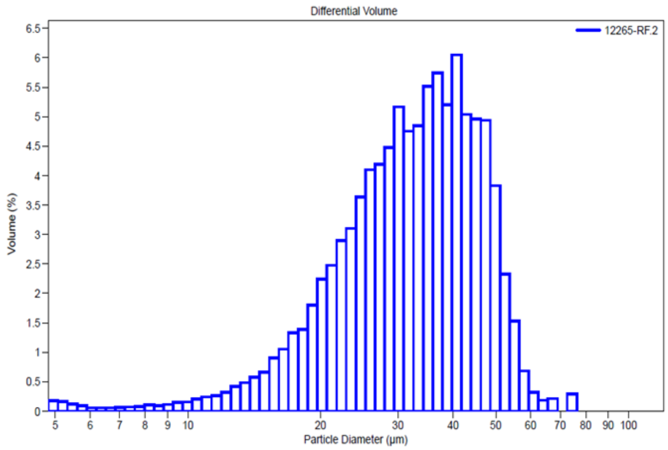

Figure II Starting PSD

In this case, the objective was to produce an air classified final product with the highest yield and an approximate D_{50} of 35 µm by removing, via air classification, the fine particles portion the raw material. Table I shows the distribution of the starting glass beads (D_{10}, D_{25}, D_{50}, D_{75}, and D_{90}) and air classified final product where a tight PSD and broad PSD was obtained.

Sample/D_{xx}	D_{10}	D_{25}	D_{50}	D_{75}	D_{90}
Starting Material	19.01 µm	25.08 µm	33.10 µm	41.56 µm	48.29 µm
Broad PSD (red)	23.95 µm	28.22 µm	35.82 µm	43.94 µm	50.41 µm
Tight PSD (green)	24.95 µm	29.05 µm	34.89 µm	41.96 µm	48.47 µm

Table I Particle Size Distributions of Glass Bead Starting Material and After Air Classification

Figure III shows the PSDs of the two air classified glass bead samples and Figures IV and V are the SEM images of the classified glass bead samples.

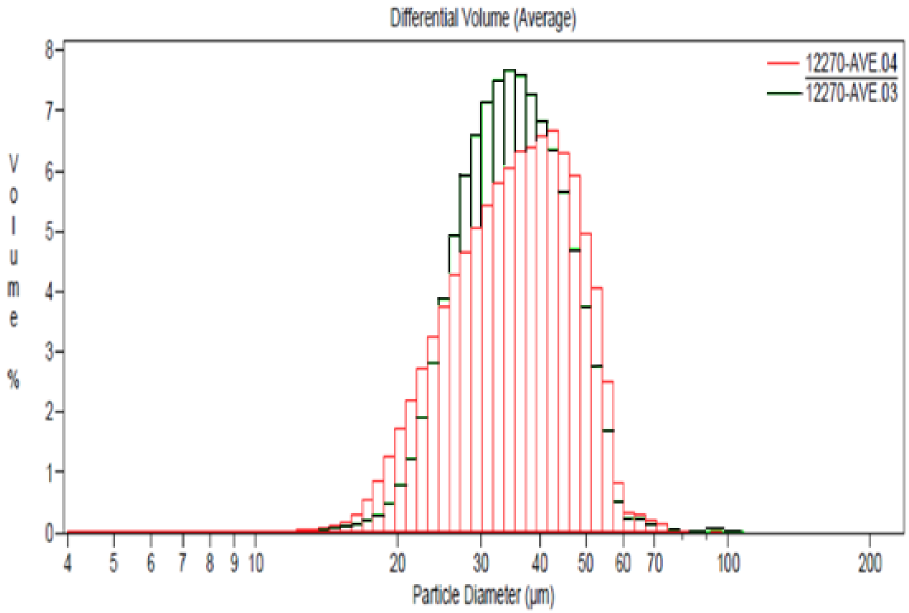

Figure III Particle Size Distrubutions of Tight (green graph) and Broad (red graph) Glass Beads

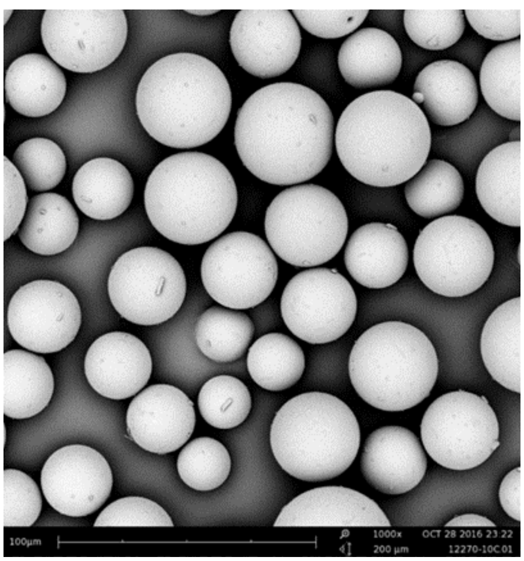

Figure IV Tight Distribution
Glass Beads (25-48 µm)

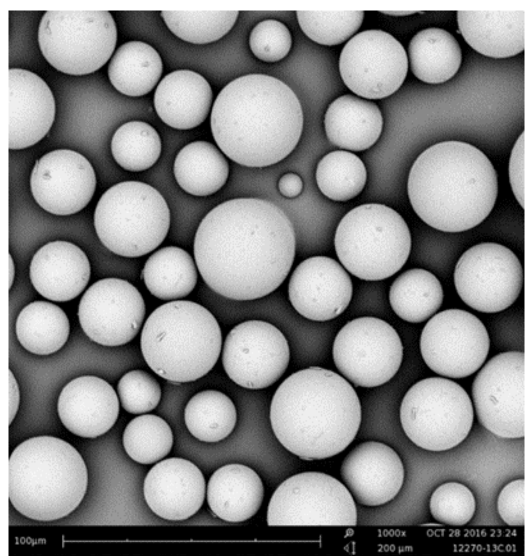

Figure V Broad Distribution
Glass Beads (24-50 µm)

Examining both the PSDs and the SEMs it is readily apparent that there is not an appreciable difference in the two distributions. Both samples have approximately the same D_{50} and both samples show similar SEM images with a few more fine glass beads in the broad distribution. However, from an economic perspective the results are dramatically different. The tight distribution sample had a 43% yield, and the broad distribution sample had a 73% yield. A difference of 3 μm in the D_{10} to D_{90} resulted in almost a doubling of the final yield.

Conclusion

Understanding how an air classification system works and being able to adjust the parameters to obtain the desired distribution is relatively straightforward using the equations lists above in this article. However, fully understanding the practical implications such as yield of changing the breadth of the final distribution cannot be overlooked. In this example the practical success of this classification process depended on both scientific and economic factors.