CLASSIFYING SUCCESS

Thomas Holzinger, Holzinger Consulting, discusses the role of classifiers in assessing the quality of cement.

Introduction

A process diagram showing the production line of a grinding system (Figure 1) was discussed earlier this year in *World Cement*.[1] Following comminution, it is of utmost importance to remove the fines – according to the respective product fineness specification out of the mill – as efficiently as possible. This process requires the use of classifiers, which will be the topic of this article.

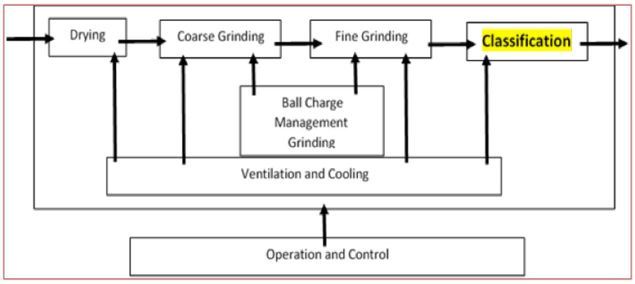


Figure 1. Production process chain.

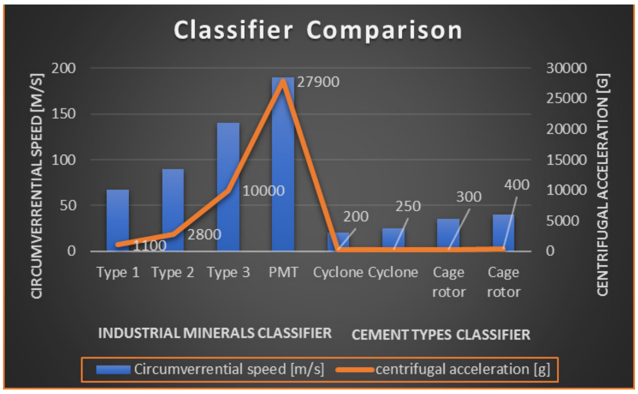


Figure 2. Centrifugal acceleration comparison for different classifiers.

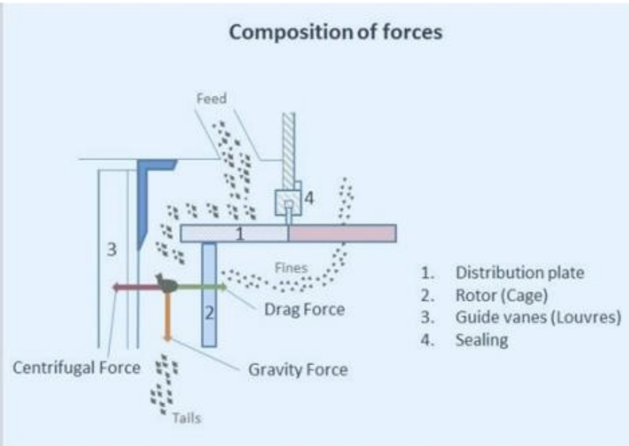


Figure 3: Particle forces during air classification.

F_d	$\sim d^2 \cdot v_{air}^2$	↑↑	-	↑↑	-
F_g	$\sim d^3 \cdot \rho \cdot g$	↑↑↑	↑	-	-
F_c	$\sim d^3 \cdot \rho \cdot \frac{v_t^2}{r}$	↑↑↑	↑	-	↑↑
		rejects	rejects	product	rejects

Figure 4. Particle forces influencing the fines recovery.

But let's start from the beginning with definitions. What is classification and what is the difference between separation and classification from a nomenclature perspective?

Material and particle characteristics are defined by size, phase, density, magnetic susceptibility, electric chargeability, conductivity, and surface wettability, etc. While classification of particles defines them according to their size classes, separating them according to their other characteristics, is technically defined as a process called separation.

In a grinding process, where a certain defined product is requested, with a defined top cut, cut-point, or maximum particle size, mechanical or dynamic classifiers are required. Mechanical classifiers for particle sizes above several hundred microns are called screens. These machines work generally only by gravity and hence have their limitation in top cut fineness, as, for high industrial capacities, they would become too large for practical installation. Technically, screening, depending on the throughput, is limited to no less than 100 μm, where ultrasonic screens might be used. To classify or to separate larger particles from a fine powder, a different type of energy to gravity is applied, namely, centrifugal force. In Figure 2, different types of classifiers are compared in terms of the centrifugal acceleration forces necessary for classification of fine particles.

Static classifiers such as cyclones, are in the range of 200 g-forces on the particles, while for third generation cage-rotor type classifiers for the cement industry, up to 400 g-forces are sufficient for common products. For fine classification, for example in the mineral industry, much finer powders are produced and hence the forces are much stronger, reaching up to 28 000 g-forces for products with a top cut d_{97} < 5 μm.

Figure 3 shows the forces on a particle passing the classification zone and is affected by three types of forces:

- Gravity force: $\sim d^3 \cdot \rho \cdot g$
- Drag force (as applied by the fan): $\sim d^2 \cdot v^2_{air}$
- Centrifugal force (classifier rotor speed): $\sim d^3 \cdot \rho \cdot vt^2 r$

Where:

- d = particle diameter.
- ρ = particle material density (kg/m³).
- υair = air velocity (m/sec.).
- v_t = particle tangential velocity (m/sec.)
- r = particle trajectory radius (m)
- g = gravity constrant (m/sec.²)
- vt²/r = angular acceleration (~ x * g (1- <x> 20 000).

When a particle enters the type of classifier illustrated, it falls down under gravity. The open process flow area of the classifier cage rotor has a certain height and hence the particle has a limited time to enter the fines stream before it passes by and enters the rejects stream. This is proportional to its mass and hence proportional to its density and diameter cubed.

The drag force, applied by the suction of the fan through the classifier cage rotor, tries to pull the particle into the fines stream. This force is therefore proportional to the particle diameter squared and the air velocity squared. The higher the air volume, and hence the air velocity into the classifier rotor, the more

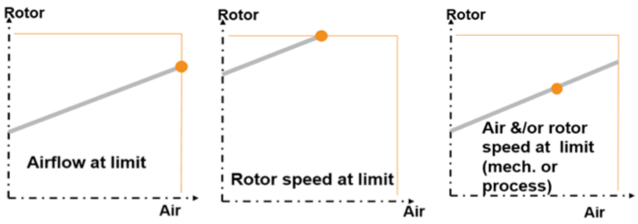


Figure 5. Classifier and fan limitations for a certain product fineness.

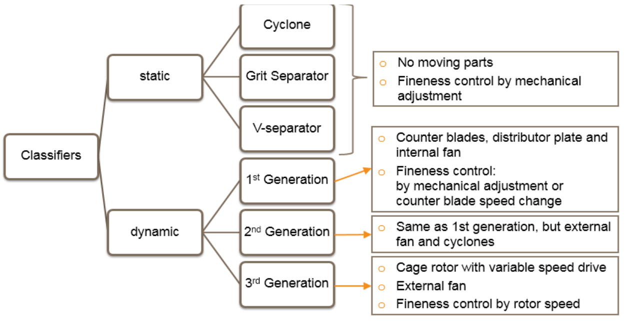


Figure 6. Air classifier categorisation.

particles get pulled through to be collected in the fines or final product.

To make the transition through the cage rotor into the fines stream, any given particle must first be accelerated to the velocity of the rotor. If both the particle and rotor have a similar velocity and the particle is fine enough (a small enough in mass) and if the drag force is higher than the centrifugal force, it will be collected in the fine product. The centrifugal force is proportional to the mass of the particle (~d^3). As a result, the more mass the particle has, the higher the probability that it will not achieve the transition boundary speed and will be rejected into the classifier rejects coarse material stream.

Figure 4 gives a summary of the forces and their influence on the probability of whether a particle will be found either in the fines or in the rejects of a classifier.

The smaller and lighter a particle is, the more likely it is to end up in the fines or final product. It is also apparent that it depends very much on the air velocity induced by the fan, for a particle to be recovered in the fines. Therefore, it is important to have the fan operated at the highest possible speed, unless there is a mechanical limitation to adjust to a higher classifier rotor speed for a finer target product top cut. These limitations might be the following:

- Mechanical deficiencies and vibration of the classifier rotor.
- Maximum speed of the classifier rotor already reached.

Such that the target fineness can only be adjusted finer by reducing the airflow (Figure 5).

A simple relationship, according to the Stokes' law on calculating the cut-point of a classifier, also shows the influences of drag-force (v_r), or air volume, and the classifier speed, as well as particle densities and the viscosity of the fluid (air temperature).

1. $$cut\ point\ T(x) = \sqrt{\frac{\eta * v_r * r}{\varphi_P * u_P^2}}$$

Where:

- η = dynamic fluid viscosity.
- v_r = Particle radial velocity entering the classifier wheel.
- r = radius classifier wheel.
- φ = apparent particle density.
- u = peripheral velocity classifier wheel.

The higher the radial velocity (airflow), the coarser the cut-point (final product), and the bigger the wheel, the coarser the cut-point at the same peripheral velocity. Meanwhile, on the inverse, there is the apparent particle density, which for denser materials makes for finer classification under the same air and classifier speed conditions, and the peripheral velocity of the classifier wheel, which makes the cut-point finer as it increases.

Figure 5 shows possible limitations on classifier operation. The first frame shows that the classifier still has potential to increase speed, but the fan is on its limit. The second shows that both classifier speed and airflow have potential to be increased, but mechanical deficiencies – either on the classifier rotor or on the fan – do not allow a speed increase, hence no production increase. The third frame shows the classifier speed as the limitation to further increase, while the fan would still have reserves to increase the airflow.

Air classifier types

In general, air classifiers can be differentiated into two types (Figure 6): static classifier and dynamic classifier.

Static classifiers do not have any moving parts but can have static vanes, changing the internal vortex direction in order to control the product fineness like in a grit classifier.

Dynamic classifiers have rotating parts for material and air flow distribution to control the product fineness, either by changing their speed or by changing the airflow of the fan.

Static classifiers: cyclones

Cyclones are mainly used to reduce the dust load in the following ways:

- Air classifier loop for the main fan operating in combination with an air separator (Figure 13).
- In combination with air-swept ball mills.
- In hammer-crusher dryer loops.
- Flash dryers.

The dedusting efficiency is in the range of 75 – 80% at common pressure drops of 10 – 15 mbar. High-efficiency cyclones also achieve efficiencies >90% but at high-pressure drops > 30 mbar.

Grit separators

In Figure 8, the scheme of a grit classifier is shown. The dust-laden air enters the classifier from below and flows through a large number of adjustable blades.
The fineness adjustment is done by altering the angle of the blades. The more tangential, the finer the product. The product top cut can also be made finer by lengthening the immersion tube, similar to a cyclone. Its applications are as following:

- In air swept mills.
- In ball mill dedusting loops.
- As static classifiers in vertical roller mills.
- In hammer crusher loops.

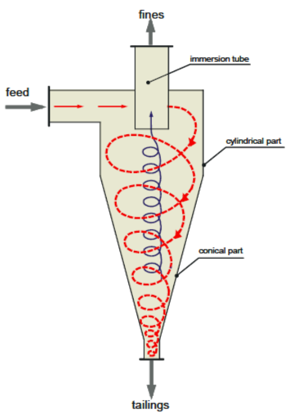


Figure 7. Scheme cyclone.

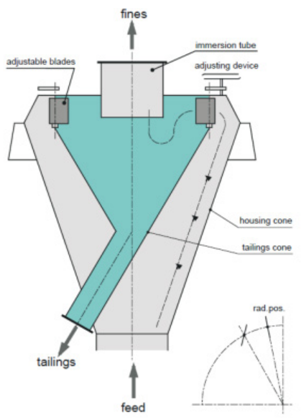


Figure 8. Grit separator scheme.

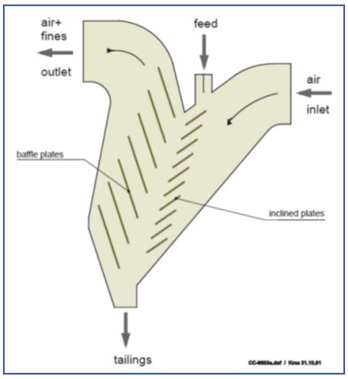


Figure 9. Scheme V-Classifier.

***Table 1.* First-generation classifier spec. classifier loads (tph,m²).**	
Cement fineness acc. to Blaine (cm²/g)	**Spec. classifier load (tph,m²)**
~2500	2.2 – 3.6
~4500	1.0 – 1.5
Note: Spec. classifier load = production (tph) nominal cross secrion (m²). Nominal cross section refers to the outer classifier dimension.	

As shown in Figure 9, the feed material enters from above the classifier and falls through the classifying zone over inclined plates. Classifying air is introduced transversely to the raw material flow. The classification zone is located between the inclined plates, where the coarse material falls through into the tailings and the fines are drawn through the space between the baffle plates and discharged at the air exit opening.

Applications: high-pressure comminution circuits with roller presses for raw material and clinker.

Dynamic classifiers

Dynamic classifiers have an internal rotating section for classification with the airflow provided by an internal or external fan.

The first-generation types created their own internal airflows with fan blades and counter-blades. By altering them accordingly, the efficiency and product recovery of the classifier could be adjusted. These classifiers were used for a wide range of cements and their typical operation is shown in Table 1.

$$\text{Spec. Classifier Load} = \frac{production\,[\frac{t}{h}]}{nominal\ cross\ section\,[m^2]} \quad (2)$$

Second-generation classifiers are fed from the top through feed spouts and the material is dispersed on the rotating distributor plate. Fine particles are carried to external cyclones and recovered, while reject coarse particles move downwards to the rejects cone. The air is produced by an external fan and recirculated to the classifier via air vanes. Inleaking false air is removed via a dedusting filter to keep the classifier at negative pressure. Typical operating loads for different cement finenesses are shown in Table 2.

Third-generation classifiers (Table 3), or high-efficiency classifiers, are the latest development and different types are available. The central part is a rotating cage comprising a top distribution plate and a ring of vertical blades or rods as rejectors.

Figure 10 provide options of how a classifier can be installed in an air loop. Both options have advantages and disadvantages depending on the process it is utilised for.

The purpose of having a dedusting fan and filter installed in the air cyclone classifier arrangement is to:

- Keep the classifier at a negative pressure (3 – 5 mbar).

***Table 2.* Second generation classifier spec. classifier loads (tph,m²).**	
Cement fineness acc. to Blaine (cm²/g)	**Spec. classifier load (tph,m²)**
2500	11
3000	8
4000	5
4500	4

- Material cooling – depending on the system design (10 – 30% of classifying air volume).
- Removing fines from the loop.

Classifier efficiency

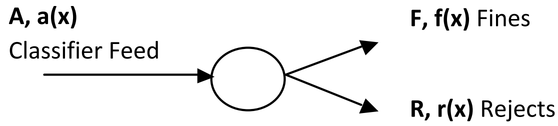
What is the classifier efficiency and how can it be calculated? There are various options to do so. The first is the ratio between the final production rate and the amount fed to the classifier at a certain product fineness.

3. $$\eta_{class} = \frac{m_{fines}}{m_{feed}} * 100\% \ @ \ d_{97} \text{ of } xy\ \mu m$$

This calculation does not consider the mass recovery of a certain feed size depending on how much of this certain feed size was presented to the classifier.

Table 3. **Third generation classifier design values.**	
Specific Feed to air load (kg/m³)	< 2.5
Circumferential speeds (m/sec.) raw meal and coal	< 25
Circumferential speeds (m/sec.) cement and petcoke	< 35
Air velocity through rotor (m/sec.) cement	< 4
Air velocity through rotor (m/sec.) raw meal	< 5
Specific Rotor Loads [tph,m²]	10 - 12

Therefore, a calculation considering the mass and the content balance is as follows:



Where:

- Mass balance: A = F+R.
- Content balance: A*a(xi) = F*f(xi)+R*r(xi) ... for all size fractions x_i.

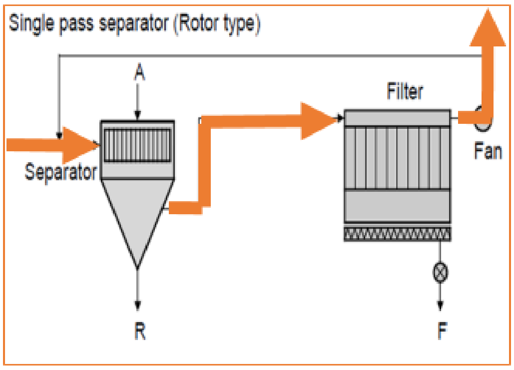
4. $$\eta(x_i) = \frac{F * f(xi)}{A * a(xi)} * 100\%$$

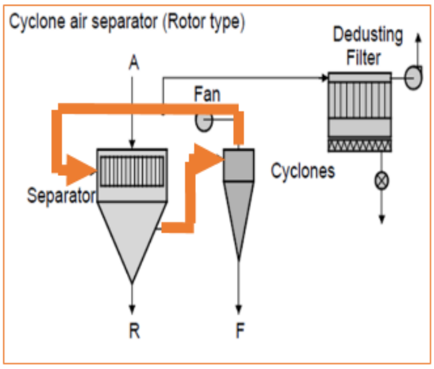
Where

- F = mass flow of fines (tph).
- A = mass flow of feed (tph).
- R = mass flow of rejects (tph).
- f = fines: %-passing at x µm.
- a = feed: %-passing at x µm.
- r = rejects: %-passing at x µm.

An even more detailed analysis method is the calculation of the classifier efficiency curve, also called separation curve, selectivity curve or more familiarly, Tromp curve.

The Tromp curve (Figure 11) describes for each particle size (x-axis) the probability for it to be





Classifier arrangement	Specifications	Advantages	Disadvantages
Single pass	Amount of fresh air in relation to classifier air: 10 – 30% Cooling potential: 5 – 10°C	• Higher drying and cooling capacity. • Lower system pressure drop. • Less installed equipment.	• Big filters required.
Cyclone Air	Amount of fresh air in relation to classifier air: 100% Cooling potential: 30 – 40°C	• Lower investment. • Smaller footprint.	• Limited drying and cooling capacity.

Figure 10. Single pass classifier layout (top; right) and cyclone air classifier layout (top; left) with advantages and disadvantages (bottom).

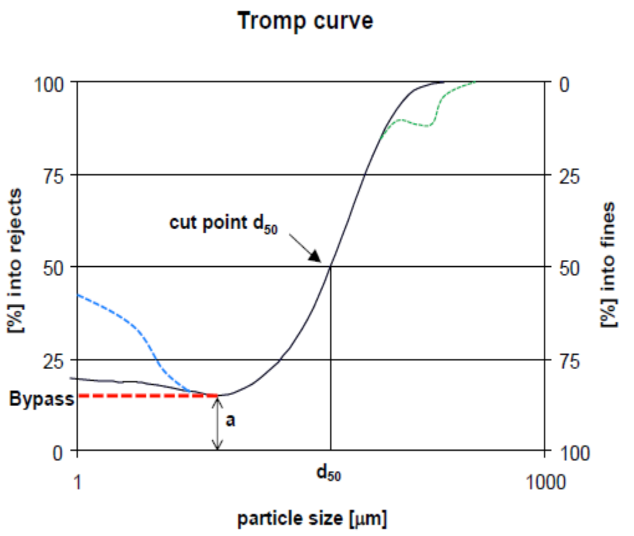


Figure 11. Tromp curve.

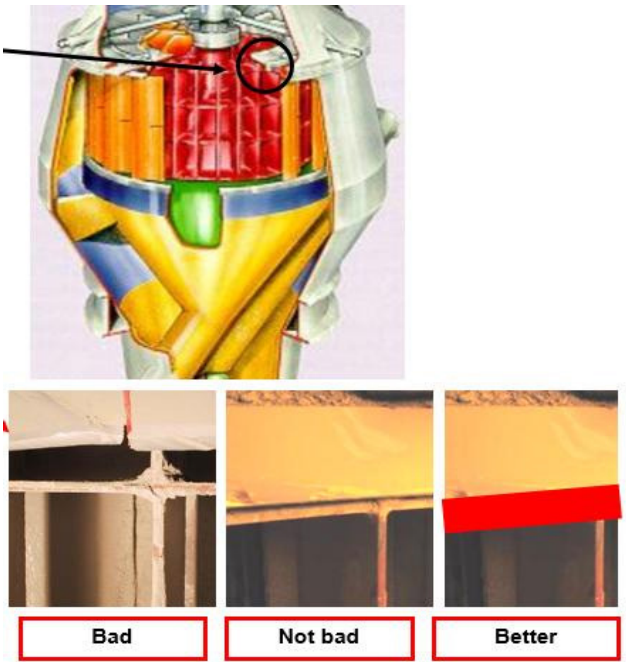


Figure 12. Classifier dynamic seal deficiency.

recovered in the coarse product or rejects. It is

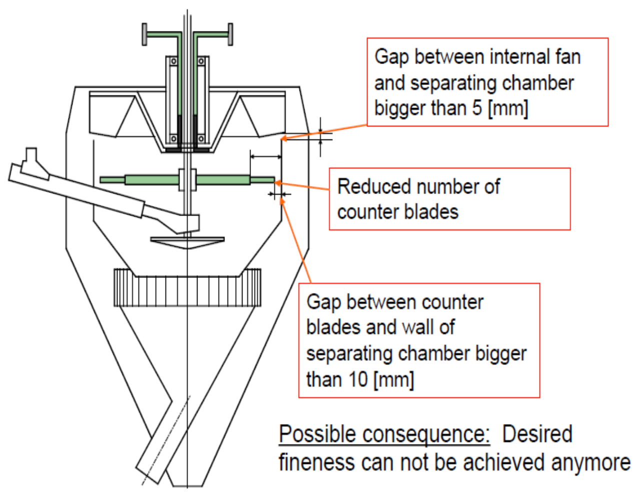


Figure 13. 1st generation classifier.

defined as the recovery of a feed size class x1 to x2 µm (x1>0) into the coarse (reject) stream.

5. $$T_R(x_i) = \frac{R * \Delta r_{(xi)}}{A * \Delta a_{(xi)}} * 100\%$$

The d_{50} value is called the 'cut-point'. Dynamic classification, as previously defined, is not as precise as mechanical classification or screening, with a proportion of the fines always found in the coarse rejects as well as some coarser particles also found in the fines. The amount of these coarser particles is further defined by the steepness of the curve, which is called the 'sharpness of separation' (k).

6. $$k = \frac{d_{75}}{d_{25}} \text{... Sharpness of Separation}$$

A k value between ~1.3 and 1.1 indicates a sharp laboratory classification; a k value between ~1.7 and 1.3 indicated a share technical classification; and a k value between ~3.3 and 1.7 indicated a classical technical classification.

In Figure 11, the lowest point of the curve is called bypass. This point, together with the specific classifier feed air load, describes the efficiency of the classifier. The lower the bypass, at a reasonable feed air load, the better the efficiency of the classifier.

Typically, third generation classifier for products >100 µm, can be loaded with about 2.5 kg/m^3.

7. $$\frac{Feed\ [\frac{kg}{h}]}{Air\ volume\ [\frac{m^3}{h}]} \leq 2.5\ [\frac{kg}{m^3}]$$

The finer the products become, the lower the feed-to-air load is, and for products <10 µm, it can be only 0.5 kg/m^3.

If the Tromp curve shows some irregularities on the coarse end, (Figure 11: green dotted line), it is mainly due to mechanical deficiencies at the classifier dynamic seal (Figure 12).

Figure 12 shows the example deficiencies of a dynamic seal. The best way to improve the seal is by covering the seal gap with a metal sheet ring and to having an overlap of a minimum of 50 mm, as shown in the right example.

On the other hand, if the bypass is low but afterwards the curve increases again (Figure 11: blue dotted line), with high values, it indicates that the super-fines have re-agglomerated again after the mill, due to high electrostatic forces. This also leads to a production loss and can be solved by using a dispersing agent (grinding aid) or increasing the dosage, if one is already used.

Some reasons or root causes for higher bypass values or poor 'sharpness of separation' values can be as follows:

- High bypass:
  - Classifier overloaded by feed material: too high feed-to air-ratio for the product fineness.
  - Poor feed dispersing (moisture, agglomeration) or distribution in classifying area.
  - Poor air distribution across the classifier rotor height.
- Sharpness of separation:
  - Poor air distribution across the rotor height.
  - Uneven air velocity profile.

In a grinding circuit, it is highly important that the classifier is running at high efficiency. Any reduction leads immediately to the following:

- Reduced mill production.
- Increased electrical energy consumption (mill, fan).
- Deterioration of product quality.

For first and second generation classifiers, a reduced efficiency can be influenced by considerations shown in Figure 13.

Summary

The role of classifiers in the quality assurance of powder products or intermediates in the cement industry is paramount. It has been demonstrated in this article, in the various methods of assessment and correction of classifier performance – and therefore efficiency – that a well selected, well-maintained classifier unit is the key to both product quality and the overall energy efficiency of any process. This can be in a grinding/milling circuit or as a stand-alone unit for the production of special products, e.g. superfine cements, for spraying. Whatever the role of the classifier, understanding its influence over the successful operation of processes in cement production is the path to both product enhancement and future product development.

Reference

1. HOLZINGER, T., "Optimum Grinding", *World Cement* (May 2018), pp. 98 – 104.

About the author

Thomas Holzinger is a consultant to the cement and minerals industry in grinding and classification, as well as an experienced staff educator and trainer for troubleshooting, maintenance and wear part management.