

## Evaluating screening performance

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Screening is the process of separating dry material based on particle size. The performance of a screening machine has a significant impact on the quality and quantity of product produced in a given process. Optimizing screening performance will lead to maximization of profitability. The performance of any screener is a function of such variables as:

- Screen motion, whether vibrating, gyratory, linear or stationary;
- Screen loading, which is expressed in feed rate/unit area;
- Screen slope and corresponding effective aperture;
- Material characteristics, such as particle size distribution, particle shape, bulk density, moisture, friability and static charge.

To evaluate screening performance, one must first know the objective of the operation. Often, it is to produce a single product through the removal of oversize, fines, or both. Sometimes, a single, multiple-deck screener produces several products in a process known as grading.

The evaluation of screening performance generally involves answering two questions:

1. Does the screener deliver an acceptable product; that is, what is the product quality?
2. How much of the product in the feed was actually recovered as good product; that is, what is the efficiency?

### Product quality

Product quality can be expressed in many ways, most of which is based on measurements of particle size. For dry granular or powder-like materials in the 40-micron to 10-mm range, sieve analysis is the accepted standard.

In sieve analysis, a small sample of material is introduced to a stack of test sieves, with the coarsest sieve on top and a collection pan on the bottom of the stack. Each sieve consists of a precisely woven wire screen with a standard opening. The sieves are identified by a number and a standard, such as "#10 U.S." or "#35 Tyler" (Table 1). Sieve numbers are based on the number of opening/inch. So the larger the sieve number, the smaller the opening.

The analysis is conducted by exposing the sieve stack to a circular motion in a mechanical sieve shaker. This circular motion, along with a separate tapping motion from above, causes the material to segregate through the sieves. After a set time period, the stack is disassembled, and the amount of material retained on each sieve and in the pan is weighed. Those weights retained on sieve trays are expressed as a percentage of the total.

Product quality is usually expressed by a product size specification that identifies

**TABLE 1. TEST SIEVE OPENINGS.**

U.S. sieve #	Tyler sieve #	Openings	
		In	Microns
3 <sup>1</sup> / <sub>2</sub>	3 <sup>1</sup> / <sub>2</sub>	.2230	5,600
4	4	.1870	4,750
5	5	.1570	4,000
6	6	.1320	3,350
7	7	.1100	2,800
8	8	.0937	2,360
10	9	.0787	2,000
12	10	.0661	1,700
14	12	.0555	1,400
16	14	.0469	1,180
18	16	.0394	1,000
20	20	.0331	850
25	24	.0280	710
30	28	.0236	600
35	32	.0197	500
40	35	.0167	425
45	42	.0140	355
50	48	.0118	300
60	60	.0098	250
70	65	.0083	212
80	80	.0071	180
100	100	.0059	150
120	115	.0049	125
140	150	.0042	106
170	170	.0035	90
200	200	.0030	75
230	250	.0025	63
270	270	.0021	53
325	325	.0017	45
400	400	.0015	38

the nominal particle size range (in terms of sieve number), along with acceptable tolerances at the limits of the range.

For example, a grade of citric acid crystals that has a nominal particle size range of -16/+30 U.S. (finer than a #16 U.S. test sieve, larger than a #30 U.S. test sieve), might have a specification that could be expressed in any of the following ways: -16/+30 U.S., <5% oversize, <10% fines; 5% maximum +16, 10% maximum -30; and 95% minimum through #16 U.S., 90% minimum on #30 U.S.

Specification of a tolerance is necessary because producing absolute separations with production screeners is impractical. A reasonable tolerance on the coarse end, or "top side," of the range will generally result in higher product yields. Imposition of a 0% specification will necessitate using a screen that has an opening smaller than that of the test sieve, a condition that typically leads to excessive carryover of good product to the "overs" fraction.

There must always be a tolerance on the fine end, or "bottom side," of the product size range because no screener can remove 100% of the fines.

Sometimes multiple sieves are used to better define the desired particle size distribution. For example, the S.A.E. specification for S230 steel shot is: 0% retained on #16 U.S. sieve; 5% maximum retained on #20 U.S.; 85% minimum retained on #30 U.S.; and 97% minimum retained on #35 U.S.

Specifying nominal size and tolerance limits is by far the most common method of representing product quality. Other methods of defining product quality have been developed, usually for specific industries. Several methods are described as follows:

**Average particle size.** Also known as mean particle size, or D50 size, average particle size represents the sample's median particle size in terms of weight as opposed to particle count. Half the weight of a sample consists of particles that are larger than the average particle size, while the other 50% by weight are smaller.

Average particle size can be determined graphically by plotting the sieve openings in millimeters on the horizontal axis and the cumulative weight of material passing the sieve opening on the vertical axis (Fig. 1).

**TABLE 2. GRAIN FINENESS NUMBER.**

U.S. sieve #	Percent retained	Factor	Product
6	0.0	0.03	0.00
12	0.0	0.05	0.00
20	0.0	0.10	0.00
30	0.2	0.20	0.04
40	2.2	0.30	0.66
50	14.7	0.40	5.88
70	34.6	0.50	17.30
100	33.3	0.70	23.31
140	13.5	1.00	13.50
200	1.5	1.40	2.10
270	0.0	2.00	0.00
Pan	0.0	3.00	0.00
	100.0		62.79

AFS GFN = 62.79

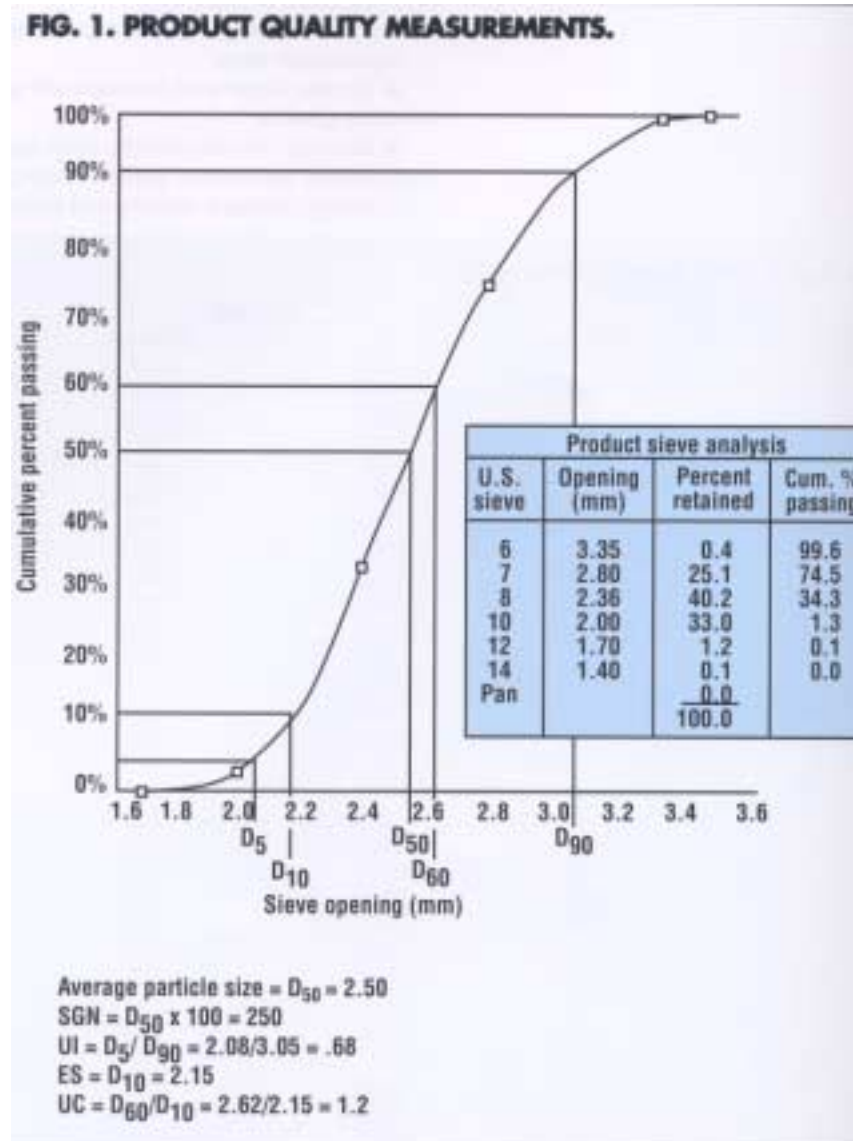


TABLE 3. MATERIAL BALANCE CALCULATION.

A	B	C	Overs							
Fraction:	Fines	Product	Overs	15.0% x A	+	56.2% x B	+	28.8% x C	=	Feed by material balance
Yield:	15.0%	56.2%	28.8%							
6	0.0	0.4	83.4	0.00	+	0.22	+	24.02	=	24.2
7	0.0	25.1	16.5	0.00	+	14.11	+	4.75	=	18.9
8	0.0	40.2	0.1	0.00	+	22.59	+	0.03	=	22.6
10	20.5	33.0	0.0	3.08	+	18.55	+	0.00	=	21.6
12	49.9	1.2	0.0	7.49	+	0.67	+	0.00	=	8.2
14	21.8	0.1	0.0	3.27	+	0.06	+	0.00	=	3.3
Pan	7.8	0.0	0.0	1.17	+	0.00	+	0.00	=	1.2
	100.0	100.0	100.0	15.0%		56.2%		28.8%		100.0

FIG. 2. LABORATORY TEST DATA.

Feed distribution				
U.S. sieve	Opening		Percent retained	
	in	mm	Test	Mat'l bal.
6	.132	3.35	24.0	24.2
7	.110	2.80	20.3	18.9
8	.0937	2.36	22.5	22.6
10	.0787	2.00	21.5	21.6
12	.0661	1.70	7.2	8.2
14	.0555	1.40	3.3	3.3
Pan	---	---	1.2	1.2
			100.0	100.0

Product specification:

- 1% Max. +6 U.S.
- 3% Max. -10 U.S.
- 80% Min. efficiency

A line is dropped from the 50% point to the horizontal axis.

The average particle size can also be calculated mathematically by interpolation, but assuming linearity between data points in this approach can lead to error.

An alternative is to perform a cubic spline curve fit to produce an equation for the curves connecting each data point. Then, through an iterative solution, find the opening that results in a percent retained value of 50%. This process is best performed on a computer.

**m Size guide number (SIGN) and uniformity index (UI).** The fertilizer industry has adopted SGN, which is the accepted measurement of product quality developed by the Canadian Fertilizer Institute. To calculate SIGN, the opening in millimeters that would retain or pass 50% by weight is determined, then multiplied by 100. Like average particle size, SIGN is determined graphically, by interpolation, or through computer-aided curve fitting. Fertilizer components typically have SGNs in the range of 160 to 280.

The UI is closely related to SGN, albeit less commonly used. Loosely defined, UI is the ratio of the size of the small particles to the large particles.

To calculate the UI, first determine the opening size that would retain 95% (or pass 5%) of the sample. Then, divide this by the opening that would retain 10% (or pass 90%), and multiply by 100. The 95% and 10% points are also best determined through graphical solution (Fig. 1).

Typical components of blended fertilizer have a UI of about 50. A lower UI indicates a broad particle size distribution and a higher UI indicates a narrow distribution (i.e., a UI of 100 would mean

1,000 pph/ft<sup>3</sup>

6 mesh, .035 in diameter  
.132 in opening  
9 mesh, .023 in diameter  
.088 in opening

-10 Fines		-6/+10 Product		+6 Overs	
U.S.	% Ret.	U.S.	% Ret.	U.S.	% Ret.
6	0.0	6	0.4	6	83.4
7	0.0	7	25.1	7	16.5
8	0.0	8	40.2	8	0.1
10	20.5	10	33.0	10	0.0
12	49.9	12	1.2	12	0.0
14	21.8	14	0.1	14	0.0
Pan	7.8	Pan	0.0	Pan	0.0
	100.0		100.0		100.0

that all particles are the same size).

• **Effective size/uniformity coefficient (ES/UC).** The filter media manufacturers use their own measurement to grade carbon and sand granules used in filtration. The effective size is the opening (in millimeters) that passes 10% (retains 90%) of the sample by weight.

Filter media is also graded by a UC that quantifies the bandwidth of the particle size distribution. To calculate the UC, the opening size that would pass 60% (retain 40%) of the sample is determined and divided by the ES (the opening that passes 10%).

As with SGN and UI, the ES and UC are best determined by graphical means or computer-aided curve fitting (Fig. 1). The UC is inverse to UI. Thus, the higher the UC, the broader the particle distribution. For example, carbon filter media typically has a UC around 1.5.

• **Grain fineness number (GFN).**

The American Foundrymen's Society (AFS) developed GFN as a way of characterizing the particle size of a sample of sand. As illustrated in Table 2, a sample's GFN is calculated by multiplying the weight retained on each sieve by that sieve's "Factor," and then summing these products.

While these methods of definition allow the evaluation of product quality, this alone does not quantify screening performance. Practically any screener can be set up to deliver the acceptable product quality. However, this same setup may cause an unacceptable amount of good product to be lost to the rejected fractions.

How much of the available product the screener recovers from the material fed to it must also be evaluated.

**Screening efficiency**

Efficiency is often incorrectly used to describe product quality. Screening efficiency or, more specifically, product recovery efficiency, is the ratio represented by the amount of on-size product separated by the screener divided by the amount of on-size material present in the feed.

Screening efficiency determines process yield, which in turn determines production rates. Yield is the amount of material separated as product, and is expressed as a percentage of the rate of material fed to the screener (Fig. 2).

Efficiency is most often calculated as follows:

Efficiency (product recovery) =  $\frac{\% \text{ on-size in product} \times \% \text{ product yield}}{\% \text{ on-size available in feed}}$  (1)

Or, for the example in Fig. 2:  
$$\frac{(25.1\% + 40.2\% + 33.0\%) \times 56.2\%}{18.9\% + 22.6\% + 21.6\%} = 87.6\%$$

When analyzing a laboratory screening test, one should be cautious that the feed distribution be determined by a material balance. One takes the sieve analyses for each fraction, multiplies the percent on each sieve by the yield for that particular fraction, and sums the products for each sieve (Table 3).

This will minimize the effect of sampling error. If this is not done, the efficiency calculation can actually produce efficiencies of greater than 100%.

Determining the variables in these equations is relatively easy in a laboratory setting. In the field, it is sometimes difficult to measure mass flowrates of the reject fractions, but sampling of the various fractions is usually possible.

Armed with these, an approximation of efficiency for a single-deck separation can be calculated:

Efficiency (undersize recovery) =  $\frac{(\% \text{ undersize in feed} - \% \text{ undersize in overs})}{[\% \text{ undersize in feed} \times (100\% - \% \text{ undersize in overs})]}$  (2)

Screening efficiency is usually inversely proportional to the amount of near-size present in the feed. For simple scalping applications where little nearsize is present, 100% screening efficiencies are achievable.

For extremely difficult grading applications, efficiencies as low as 50% might be considered good. Generally, screening efficiencies of 80% to 100% are common in chemical processing.

As with product quality, screening efficiency must never be used as the sole measure of screening performance. To illustrate, one can easily make any screener 100% efficient by removing the screen from the top deck and putting a blank plate on the bottom deck.

Recovering every bit of product available

in the feed will be assured, but product quality will be suspect.

In addition to product recovery efficiency, other measures of efficiency are sometimes employed. Some applications lend themselves to analysis of overs removal efficiency or fines removal efficiency. The calculation is essentially the same.

Efficiency overs removal) =  $\frac{\% \text{ oversize in overs} \times \% \text{ overs yield}}{\% \text{ oversize available in feed}}$  (3)

Or, from Fig. 2:

$$\frac{83.4\% \times 28.8\%}{24.2\%} = 99.3\%$$

Efficiency (fines removal) =  $\frac{\% \text{ undersize in fines} \times \% \text{ fines yield}}{\% \text{ undersize available in feed}}$  (4)

Or, from Fig. 2:

$$\frac{(49.9\% + 21.8\% + 7.8\%) \times 15.0\%}{8.2\% + 3.3\% + 1.2\%} = 93.9\%$$

In reality, these efficiencies are another measure of product quality. For example, a screener operating with 100% overs removal efficiency is, by definition, producing a product that contains 0% oversize.

**Capacity and efficiency**

Through laboratory testing, it is possible for manufacturers to predict the product quality and screening efficiency that will be delivered by a screening machine in a given application.

It is important to realize that these predictions are valid only within a specific capacity range. Exceeding the stated capacity can lead to flooding the screen deck, which will result in good product tailing over the screen and reduce efficiency.

Overloading the fines removal screen will cause fines to tail over the screen, contaminate the good product and reduce product quality.

A screener's capacity can be expressed as an absolute, that is, a feed rate to a given size machine. Sometimes, it will be expressed as an allowable screen loading, stated in terms of feed rate/unit screen area.

The data shown in Fig. 2 were obtained at a screen loading of 1,000

pph/sq ft of screen area. The capacity of a 50-sq-ft screener in this application is:

$$\text{Capacity} = \text{loading} \times \text{screen area} \quad (5)$$

Or:  
 $1,000 \text{ pph/ft}^2 \times 50 \text{ ft}^2 = 50,000 \text{ pph}$   
capacity

Conversely, if the desired feed rate is known, the amount of screen area required can be calculated:

$$\text{Screen area required} = \text{feed rate}/\text{loading} \quad (6)$$

Or:  
 $75,000 \text{ pph}/1,000 \text{ pph/ft}^2 = 75 \text{ ft}^2$   
screen area required

The rated capacity of a screening machine always refers to the feed rate, not the product output rate. Production rates will be a function of the particle size distribution of the feed and the screening efficiency, both of which can vary in a production environment. Production rates can also be predicted through laboratory testing.

For example, in the application represented in Fig. 2, a feed rate of 50,000 pph is assumed. The mass flowrates of the various output streams are calculated as follows:

Product rate:  $50,000 \text{ pph} \times 56.2\% = 28,100 \text{ pph}$

Fines stream:  $50,000 \text{ pph} \times 15.0\% = 7,500 \text{ pph}$

Overs stream:  $50,000 \text{ pph} \times 28.8\% = 14,400 \text{ pph}$

In situations where efficiency is relatively low, it is important to determine why and where the product is being lost.

This is done by examining the sieve analyses of the reject fractions. In the example in Fig. 2, 16.6% (16.5% + 0.1%) of the overs fraction is actually good product and 20.5% of the fines is good product. How much actual product loss these percentages represent is determined as follows:

Product loss to overs fraction = % product in overs x % overs yield x feed rate (7)

Or:  
 $(16.5\% + 0.1\%) \times 28.8\% \times 50,000 \text{ pph} = 2,390 \text{ pph}$

Product loss to fines fraction = % product in fines x % fines yield x feed rate (8)

Or:  
 $20.5\% \times 15.0\% \times 50,000 \text{ pph} = 1,540 \text{ pph}$

The effects of this product loss must be considered when comparing screeners of varying efficiencies.

A less-efficient screener will require a higher feed rate to produce the same amount of product. It will also result in higher costs due to the additional amount of reject material that must be either reprocessed, sold as off-spec product, or scrapped and thrown away.

In conclusion, proper evaluation of a screening test or process must include measurements of both product quality and screening efficiency. Such an analysis will make it possible to determine the optimum balance of product quality and yield.

### **Bibliography**

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"Procedure 106-87-S, calculation of grain fineness number of whole grain aggregate," American Foundrymen's Society, Des Plaines, IL, 1989.

- To receive a free 14-page "How to take the guesswork out of screening" booklet-Rotex Inc., Cincinnati, OH.