# Evaluation of classifiers with the Bettersizer S3 Plus and the 3P Tromp analysis software

3P INSTRUMENTS

Characterization of
particles · powders · pores

## Introduction

Centrifugal separators or classifiers are used in many fields of application (e.g. building materials) to classify or separate powder size fractions. To determine the efficiency of such a separator, the so-called **separation curve (tromp curve)** is used [1].

Separators operate according to the following operating scheme:

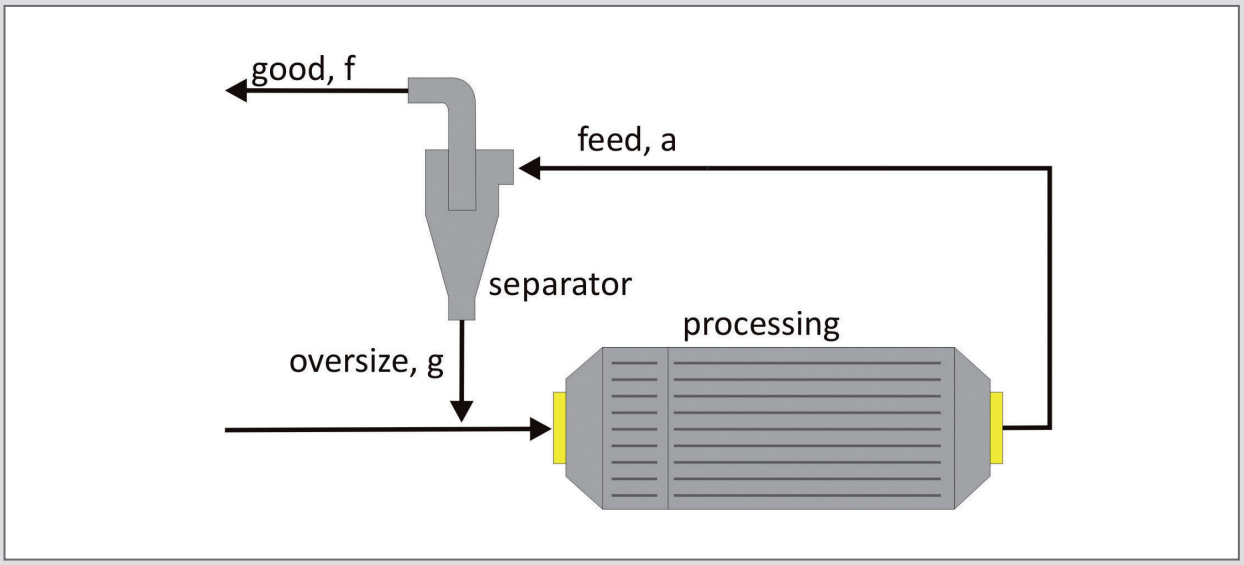


***Figure 1 :*** *Operating scheme of a separator*

Thereby is
f… mass fraction of the good fraction after separation
g… mass fraction of the oversize fraction after separation

$$f = \frac{\dot{m}_F}{\dot{m}_A} = 1 - g \qquad (1)$$

$$g = \frac{\dot{m}_G}{\dot{m}_A} = 1 - f \qquad (2)$$

$\dot{m}_A$… Mass flow feed [t/h]
$\dot{m}_F$… Mass flow good [t/h]
$\dot{m}_G$… Mass flow oversize [t/h]

Another important variable is the **circulation c**. It is defined as the ratio of mass of feedstock to fines:

$$c = \frac{1}{f} = \frac{\dot{m}_A}{\dot{m}_F} \qquad (3)$$

The **separation curve** (or Tromp curve, separation efficiency curve, split curve) T(x) is a very effective tool for assessing the performance of the separators. It represents the probability that a particle of a certain size „ends up" in the coarse material. This probability is determined for each size fraction x of the sample:

$$T(x) = \frac{\dot{m}_G}{\dot{m}_A} \cdot \frac{q_G(x)}{q_A(x)} = g \cdot \frac{q_G(x)}{q_A(x)} \qquad (4)$$

$q_G(x)$… Density function oversize
$q_A(x)$… Density function feed

# Evaluation of classifiers with the Bettersizer S3 Plus and the 3P Tromp analysis software

In practice, there are various error influences which mean that corrections have to be introduced to obtain a meaningful separation curve.

**Random errors** are errors in the measurement of the particle size distribution, which result in the total powder balance being different after separation (oversize and good) and before separation (feed). The three measurement curves are corrected mathematically so that the balance is correct and are then used for classifier evaluation instead of the original measurement curves.

$$T(x) = \frac{\dot{m}_G}{\dot{m}_A} \cdot \frac{q_{korr,G}(x)}{q_{korr,A}(x)} = g \cdot \frac{q_{korr,G}(x)}{q_{korr,A}(x)} \quad (5)$$

Systematic errors are errors in the operation of the classifier. For example, if the feed material is fed in too quickly, a certain amount of material τ is not separated, i.e. it passes the classifier without any change in the particle size distribution. The degree of separation (i.e. the minimum percentage value that is returned to the oversize) at this point is called the bypass τ, the corresponding diameter value is called the Dlimit.

$$\tau = T(\mathrm{Dlimit}) \quad (6)$$

In the zone below the Dlimit, however, no separation takes place. To eliminate this so-called „flow splitting effect", the separation degree curve is modified as follows:

$$T_r(x) = \frac{T(x)-\tau}{(1-\tau)} \quad (7)$$

This is referred to as reduced **separation curve $T_r(x)$.**

The selectivity κ of the classifier, which is the indicator for the quality of the separation / classification, is defined as the ratio of the diameter values at 25 and 75 % (in µm) of the separation curve. It thus reflects the slope of the curve; κ = 1 would be an ideal classification.

$$\kappa = \frac{D25}{D75} \quad (8)$$

An ideal centrifugal separator would have a separation efficiency of 1.

The imperfection I is a measure for the quality of the classifier. It is defined as:

$$I = \frac{D75-D25}{2 \cdot D50} \quad (9)$$

**The following classification applies:**

| | |
|---|---|
| I < 0.4: | good classifier |
| 0.4 < I < 0.6: | medium classifier |
| 0.6 < I < 0.8: | poor classifier |
| I > 0.8: | very poor classifier |

The Bettersizer S3 Plus is particularly suitable for the comprehensive assessment of centrifugal separators or classifiers due to its unique combination of technologies and software equipment.

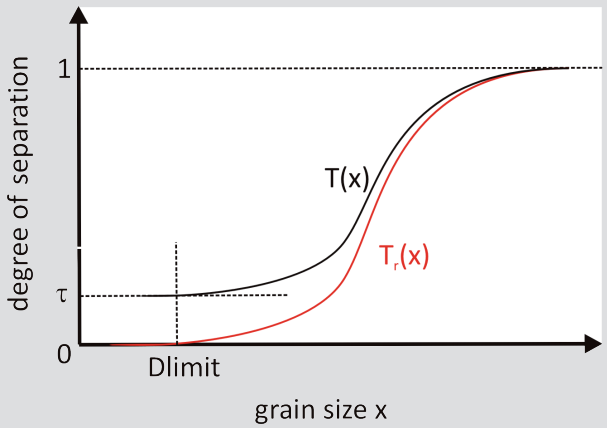


***Figure 2 :***
*Separation degree curve T(x) of classification with systematic error (non-separation of a certain fraction)*

# Evaluation of classifiers with the Bettersizer S3 Plus and the 3P Tromp analysis software



## Technology of the Bettersizer S3 Plus

The Bettersizer S3 Plus is a combined particle size analyzer of the latest generation, consisting of the two measuring methods „static light scattering" and „dynamic image analysis". Due to the advantages of this combination, this system offers a comprehensive and exact characterization of powders and dispersions regarding particle size and shape from the nano- to the millimeter range (measuring range 0.01 – 3,500 µm).

**Figure 3** shows the DLOIOS technology (Dual Lens & Oblique Incidence Optical System) on which the Bettersizer S3 Plus is based:

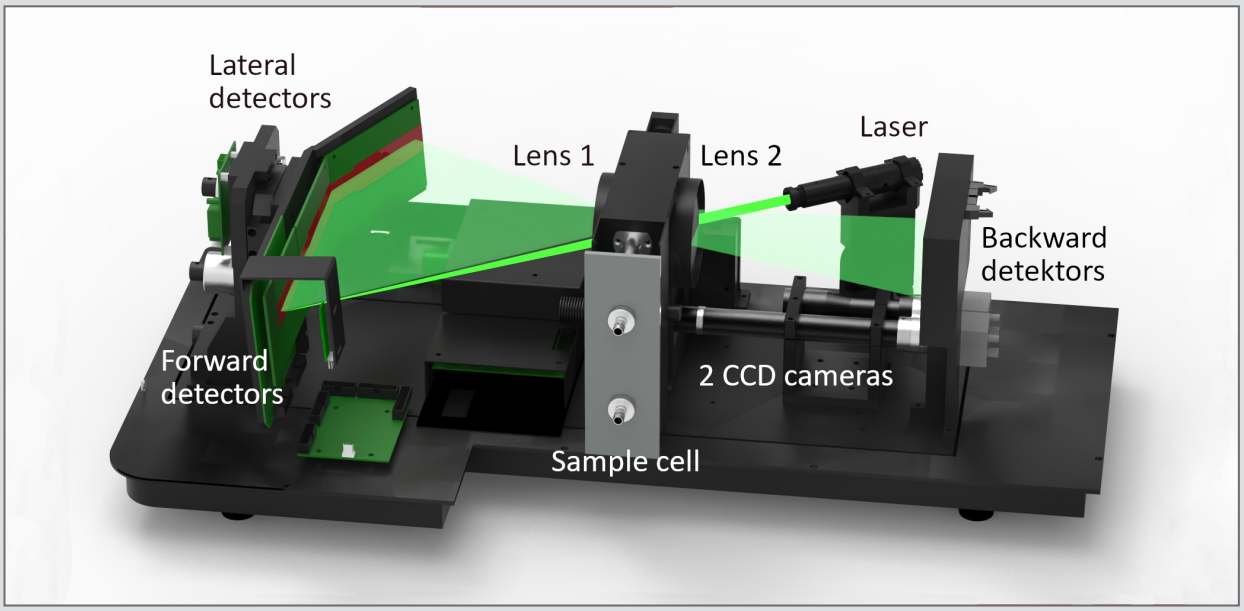


***Figure 3 :*** *Schematic representation of the DLOIOS technology of the Bettersizer S3 Plus*

The particles to be measured are pumped through the double measuring cuvette system in a solvent of choice. In the first cuvette, short-wave parallel laser light (532 nm) hits the particles and is scattered characteristically depending on the particle size distribution. This scattered light is reliably detected by the fixed detector system over an angular range of 0.02 – 165°. This extremely large measuring range is realized using the DLOIOS system, a patented single-laser technique with double lens system and oblique light incidence.

In the second cuvette, the particles are continuously photographed, evaluated and statistically classified by the image analysis system, consisting of two high-speed CCD cameras and high-precision telecentric lenses, at a rate of up to 10,000 particles/minute in real time. The cameras are equipped with a 0.5X lens (15-fold magnification) and a 10X lens (300-fold magnification), and can be used individually or combined and cover a particle size range of 2–3,500 µm.

In summary, the Bettersizer S3 Plus with its unique design allows

- the exact particle size measurement of very small particles from 10 nm (DLOIOS technique)
- the calulation of real number and volume distributions with suitable equivalent size diameters (CCD camera technology)
- a higher accuracy for coarse material than conventional static light scattering devices (combination method DLOIOS and CCD camera technology)
- the detection of individual oversized grains, agglomerates, air bubbles (CCD camera technology)
- a shape analysis with more than 20 specific shape parameters

# Evaluation of classifiers with the Bettersizer S3 Plus and the 3P Tromp analysis software

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## Evaluation of classifiers with the Bettersizer S3 Plus and the software „3P Tromp“ analysis software

3P Tromp is a very easy to use analysis software customized for classifier evaluation. It is based on the measurements of particle size distributions of feed, good and oversize of a separated sample with the Bettersizer S3 Plus. These are selected directly in the input window of 3P Tromp (**Figure 4**). As an example, a sand separated at 500 µm is used here.

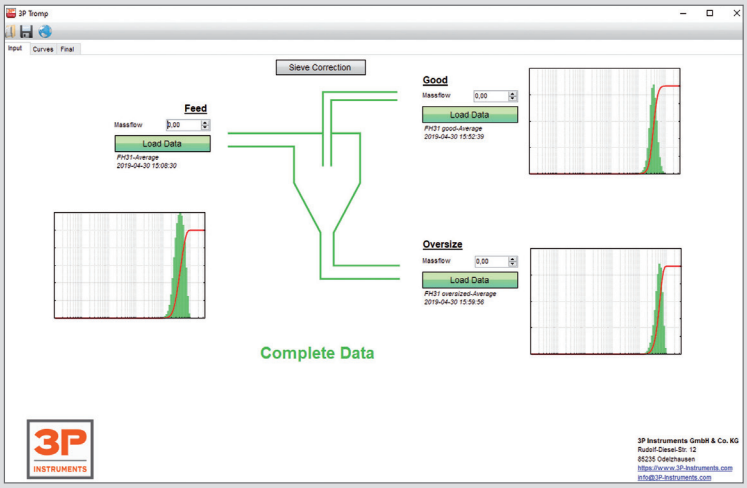


***Figure 4 :*** *Input window of 3P Tromp*

**Figure 5** shows the original and corrected cumulative curve (cumulative distribution) for all three measurements (feed, good, oversize). As described above, the software uses the corrected measurement curves for the calculation of the separating curve to avoid random errors.

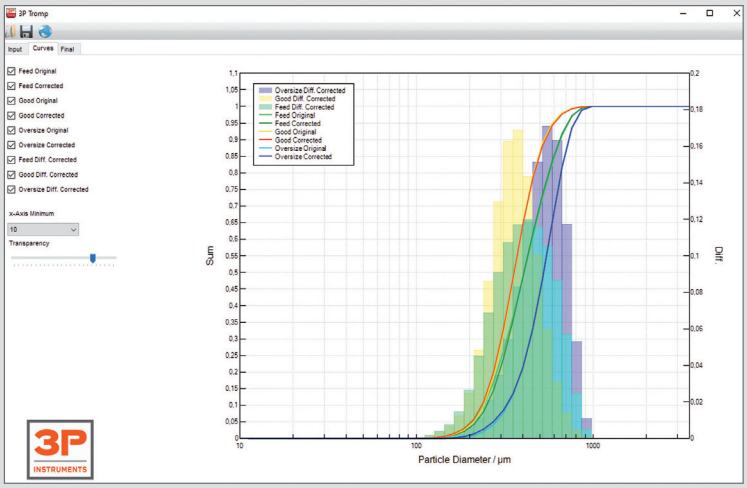


***Figure 5 :*** *Cumulative distribution of feed, good and oversize of the separated sand - original (according to equation 4) and corrected measurement (according to equation 5)*

**Figure 6** shows in each case the separation curve and reduced separation curve of the separated sand on the basis of the corrected distribution curves according to equations 5 and 7. Table 1 shows all important data of the classifier evaluation (see equations 1 - 9) in an overview.

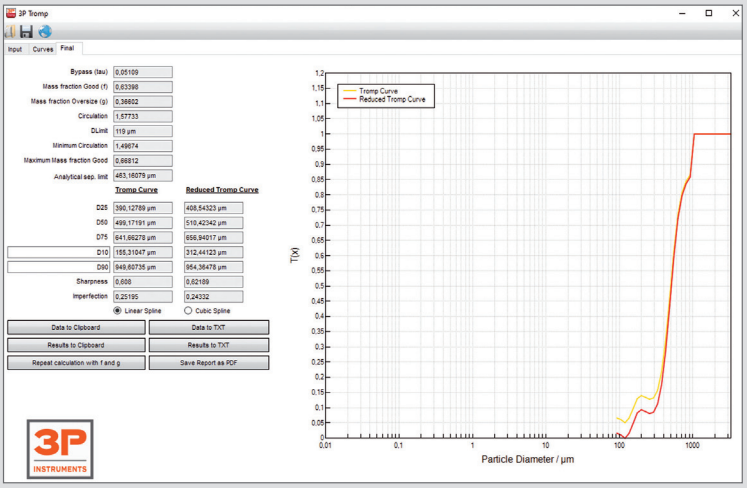


***Figure 6 :*** *Separation curve and reduced separation curve of the sand separated at 500 µm*

# Evaluation of classifiers with the Bettersizer S3 Plus and the 3P Tromp analysis software

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***Table 1:*** *Summary of the classifier evaluation - separation of sand at 500 µm*

| **Input** | | | |
|---|---|---|---|
| Feed | Sand Feed | | |
| Good | Sand Good | | |
| Oversize | Sand Oversize | | |
| Sieve correction | | | |
| Interpolation | Linear Spline | | |
| **General Results** | | | |
| Bypass (t) | 0.05109 | Analytical separation limit xA | 463.16079 µm |
| Mass fraction good (f) | 0.63398 | Mass fraction oversize (g) | 0.36602 |
| Circulation | 1.57733 | Minimum Circulation | 1.49674 |
| Dlimit | 119 µm | Maximum mass fraction good | 0.66812 |
| **Tromp Curve** | | Reduced Tromp Curve | |
| D25 | 390.13 µm | D25 | 408.54 µm |
| D50 | 499.17 µm | D50 | 510.42 µm |
| D75 | 641.66 µm | D75 | 656.94 µm |
| D10 | 155.31 µm | D10 | 312.44 µm |
| D90 | 949.61 µm | D90 | 954.36 µm |
| Sharpness | 0.608 | Sharpness | 0.62189 |
| Imperfection | 0.25195 | Imperfection | 0.24332 |

**Summary of the separation:**

The corrected cumulative curves of feed, good and oversize hardly differ, so random errors in particle size measurement are of little importance. When considering the reduced separation curve, the bypass is about 0.05, i.e. this fraction passed through the classification without being separated. The D50 value of the reduced separation curve is about 510 µm, very close to the real separation value of 500 µm. The imperfection is calculated at 0.24332, which corresponds to a good classifier according to equation 9 and the subsequent classification.

## Summary

The Bettersizer S3 Plus, together with the new 3P Tromp software, provides an easy to use and accurate assessment of a classifier. The innovative and unique combination technology of the instrument allows an accurate particle size analysis especially in the critical range of large particle sizes. The 3P Tromp software offers all the essential features to correct random and systematic measurement errors and to achieve an absolutely reliable and robust result.

## Literature

[1] M. Stieß; Mechanische Verfahrenstechnik – Partikeltechnologie 1; Springer-Verlag, Berlin, 1995/2008, ISBN 978-3-540-32551-2

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