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Study on the reproducibility of the "fish-hook" phenomenon at Gayco M-92 air classifier

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Abstract. In the '80-'90s the presence of the so-called "fish-hook" effect was under discussion at hydrocyclones because according to several researchers it was a random mistake in the examination. This phenomenon exists in the air classification also, but there is no accessible information about such systematic experiments which deal with the reproducibility of this effect. In frame of a doctoral research work experiments were made with laboratory Gayco M-92 centrifugal air classifier to observe the reproducibility of the separation at given operating parameters. In this paper the results of these experiments are presented related to the standard deviation of the separation functions and the shape of the "fish-hook" at air classification. During the experiments were adjusted optimal ranges of operating parameters based on earlier laboratory examinations and semi-industrial researches which made by the Institute of Raw Materials Preparations and Environmental Processing, University of Miskolc, Hungary. According to the results of the experiments can be concluded, that the reproducibility of the separation was very well in case of each measurement, and the "fish-hook" is not a sporadic phenomenon as several researches claimed.

Key Words: air classification, separation function, "fish-hook"-effect, reproducibility, standard deviation.

Introduction. The separation is a method in mineral processing which is based on the different properties of the material such as particle size, density, electric, magnetic, optical or other properties. The mechanical separation which based on the particle size is called classification.

Air classifiers are the equipments of the dry separation of fine ground materials which are widely used in the industrial practice (Gombkötő 2009). The separating properties as sharpness, efficiency and performance of the separation, namely the adequate work of the separators depends on the setting parameters.

In case of centrifugal air classifiers the sharpness of the separation is influenced significantly by the operating parameters such as the feed rate, the speed of the rotor and the air flow, the inclining angle of the turbine blades and the design of the separator, etc. The optimal classification can be reached by the combination of these parameters.

Generally, the reproducibility of the laboratory measurements is sensitive point of the research work. At air classification if the control of an operating factor is not definiable due to the construction of the device or it is not permanent during the experiments: the reliability and comparability of the original and reproduced data decrease strongly.

Since 2010, in a frame work of doctoral studies at the Institute of Raw Materials Preparation and Environmental Processing, University of Miskolc, experiments were made with a Gayco M-92 laboratory centrifugal air classifier to examine how working parameters influence the sharpness of the separation curves, mainly the shape of the so-called "fish-hook" phenomenon.

The selection functions, namely the Tromp curves are special functions for qualification of the separation. The shape and the sharpness of the Tromp curve and their special metrics describe the efficiency of the separation. Tromp curves are definable from the measured yields of the mass rate in each particle size fraction. The "conventional" metrics such as metric of Terra (E_p), Imperfection (I) and Kappa (K) characterize the sharpness of the separation and can be calculated with knowing the values of x_{25}, x_{50} and x_{75}. However, there are the metrics of Pethő which characterize the separation by the location of the center of error area (Bőhm et al 1984; Pethő 1986).

On average the separation functions of almost all separators are monotonic bounded and start from origin of coordinates and end at T=1 value (Figure 1). The Tromp curves of hydrocyclones and air classifiers are different (Figure 2), because there are no starts from the origin due to the so-called bypass. The bypass is the migration of a part of fine particles into the coarse product.

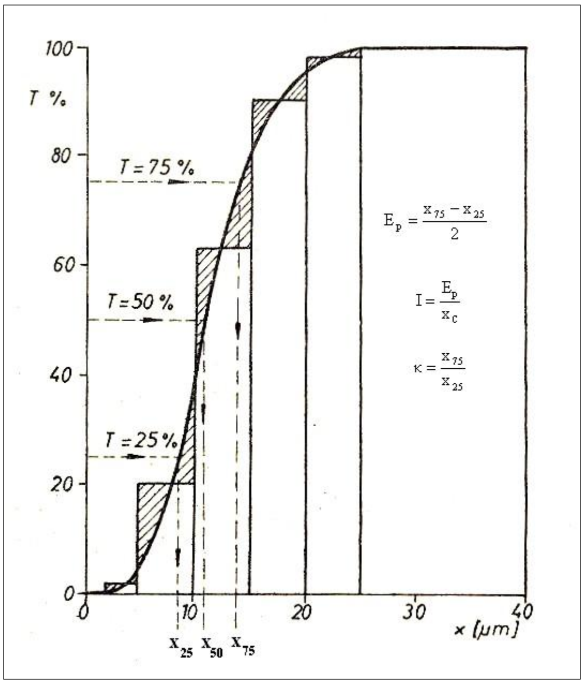

Figure 1. „Regular” Tromp curve of the coarse product of separation.

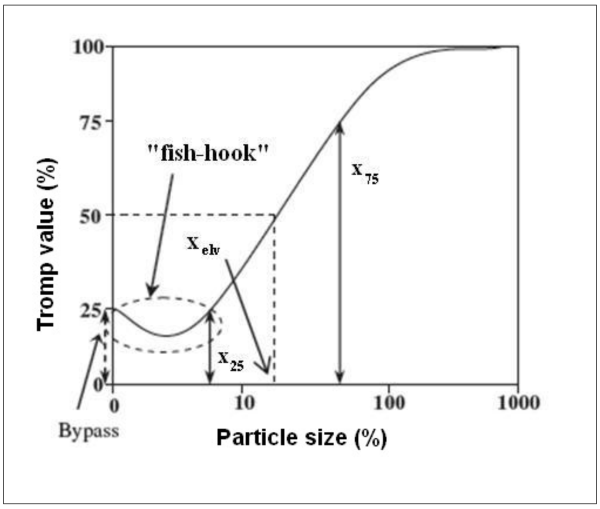

Figure 2. Tromp curve with „fish-hook”.

Published articles which made by the Institute until today (Mucsi et al 2011; Faitli et al 2011, 2012; Kaliczné 2011, 2012; Kaliczné & Gombkötő 2012) were reported the results of laboratory and semi-industrial experiments where were examined the impact of several controllable parameters on the efficiency of the separation. Most of these researches focused mainly the effect of the rotor speed, feed rate and the speed of the air flow in case of given plant operating conditions.

Now, the aim of this paper is presenting the importance of the precise dosage of feeding in other words the permanent feed rate to reach reproducible experimental data at a laboratory air classifier.

Background of the investigation of "fish-hook" effect. The separation curves of most separators are „regular" monotonic bounded functions between 0 and 1 Tromp values (Csőke, manuscript; Pethő 1986), however the curves of some separators are different.

The early publications have already reported a special "anomaly" in some ten microns particle range on the separation function of hydrocyclones which looked like a "fish-hook" (Pethő 1986; Luckie & Austin 1975). Figure 3 shows the main parameters of the "hook". This phenomenon depends on the interactions of the fine and coarse particles and it seems that it causes the degradation of the efficiency of the separation (Finch & Matwijenko 1977; Finch 1983).

Approximately in the end of the '90s, when the dry fine grinding-classifying technology and the particle size analyzing started to develop significantly, researchers also found this phenomenon at the air-classifiers (Finch & Matwijenko 1983; Del Villar & Finch 1992; Wang et al 1999; Majumder et al 2003, 2007; Aydoğan et al 2006; Benzer et al 2011; Dueck et al 2007; Irannajad et al 2009; Eswaraiah et al 2012).

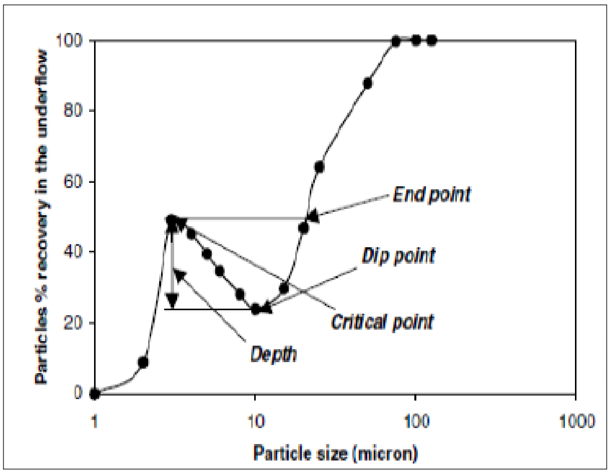

Figure 3. Special parts of the „fish-hook" (Majumder et al 2003).

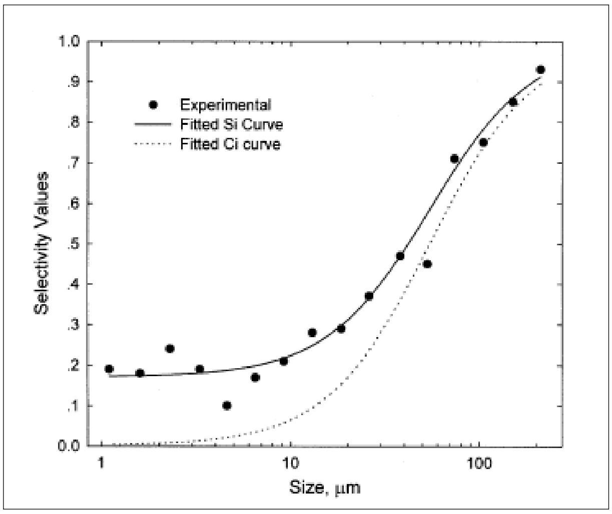

Figure 4a. Experimental and fitted Tromp values at Cho & Kim (1999).

In the first times several researchers thought that it was just a random mistake in the examinations, therefore the phenomenon was ignored in the calculation for many years (Roldan-Villasana et al 1993; Nageswararao 2000).

After, in 2000, Nageswararao (2000) reported to the discussions which had been formed around the "fish-hook"-effect related to the efficiency of the hydrocyclones. Numerous scientist such as Finch & Matwijenko (1983), Luckie & Austin (1975), Kavetsky (1979), Kelly (1991) and others confirmed the definite presence of the "hook" by their experiments, but in contrast with these results the experiments made by Brookes et al (1994) and Rouse et al (1997) showed random occurrence of the phenomenon.

Also in Nageswararao's summary the "fish-hook" is sporadic and irreproducible phenomenon at hydrocyclones.

Even today there are several research groups who work with fine feeds, but they are not reports to the "fish-hook"-effect, they ignore these data points from the evaluation (Cho & Kim 1999; Kim et al 2001) (Figure 4a).

Since there are several similarity between the design and the operation of wet and dry fine classifiers, the results and models of hydrocycolnes can be improved for air-classifiers.

Unfortunately, there are just a few accessible publications in this theme all over the world, and mainly in connection to the separation characteristics of hydrocyclones (Wang et al 1999; Irannajad et al 2009; Eswaraiah et al 2012; Wang & Yu 2010). Hence, there is necessary to know how the "fish-hook" phenomenon behaves at the air-classifiers, mainly in aspect of the reproducibility.

Experimental procedure. The experiments of reproducibility have been made by a Gayco M-92 laboratory centrifugal air classifier with 200 g Al_2O_3/measurement (x_{50} = 50μm). The operating parameters such as angle of the shutters, i.e. the speed of the air flow and the variable rotor speed and feed rate have been adjusted to optimal value ranges based on earlier systematic researches (Kaliczné 2011, 2012).

The fine size material was fed by a vibratory feeder at three different feed rate. Table 1 shows the operating parameters and the number of parallel measurements.

Table 1

Used operating parameters of the measurements

Angle of the shutters adjustment : α=0° (constant)			
Feed rate [kg/h]	Speed of the rotor [m/s]		
	11.05	14.74	17.91
22	3 x	3 x	2x
52	2 x	2 x	-
61	-	-	2x

At given operating parameters two or three parallel measurements have been made to determine the reliability, namely the value of standard deviation of particle size distributions and Tromp values at each examination.

After the measurements the quantities of the separated products were measured by KERN laboratory balance, and then their particle size distribution was measured by HORIBA Practica LA-950V2 laser diffraction particle size distribution analyzer. The Tromp curves of the separation were calculated from the received distribution results. Conclusions were deducted from compared characteristics of the separated products made by different operating parameters during the evaluation.

To calculate of the standard deviation the next equation was used:

$$\sigma = \sqrt{\frac{\Sigma(y_{ij} - y_{iave})^2}{n-1}} \qquad (1)$$

where

- y_i is the value of particle size distribution, $F_i(x)$ or the Tromp, T_i at the i^{th} fraction,
- j is the number of the parallel measurement,
- y_{iave} is the average value of parallel measurements at the i^{th} fraction.

To calculate of the relative standard deviation:

$$S = \frac{\sigma * 100}{\bar{y}_{ave}} \qquad \text{where} \qquad \bar{y}_{ave} = \frac{\Sigma y_{iave}}{n} \qquad (2)$$

Results of the research

Reproducibility of the separation at constant flow rate. Figure 4b show the Tromp curves of the separation at 22 kg/h feed rate and increasing rotor speed (11.07; 14.74; and 17.96 m/s).

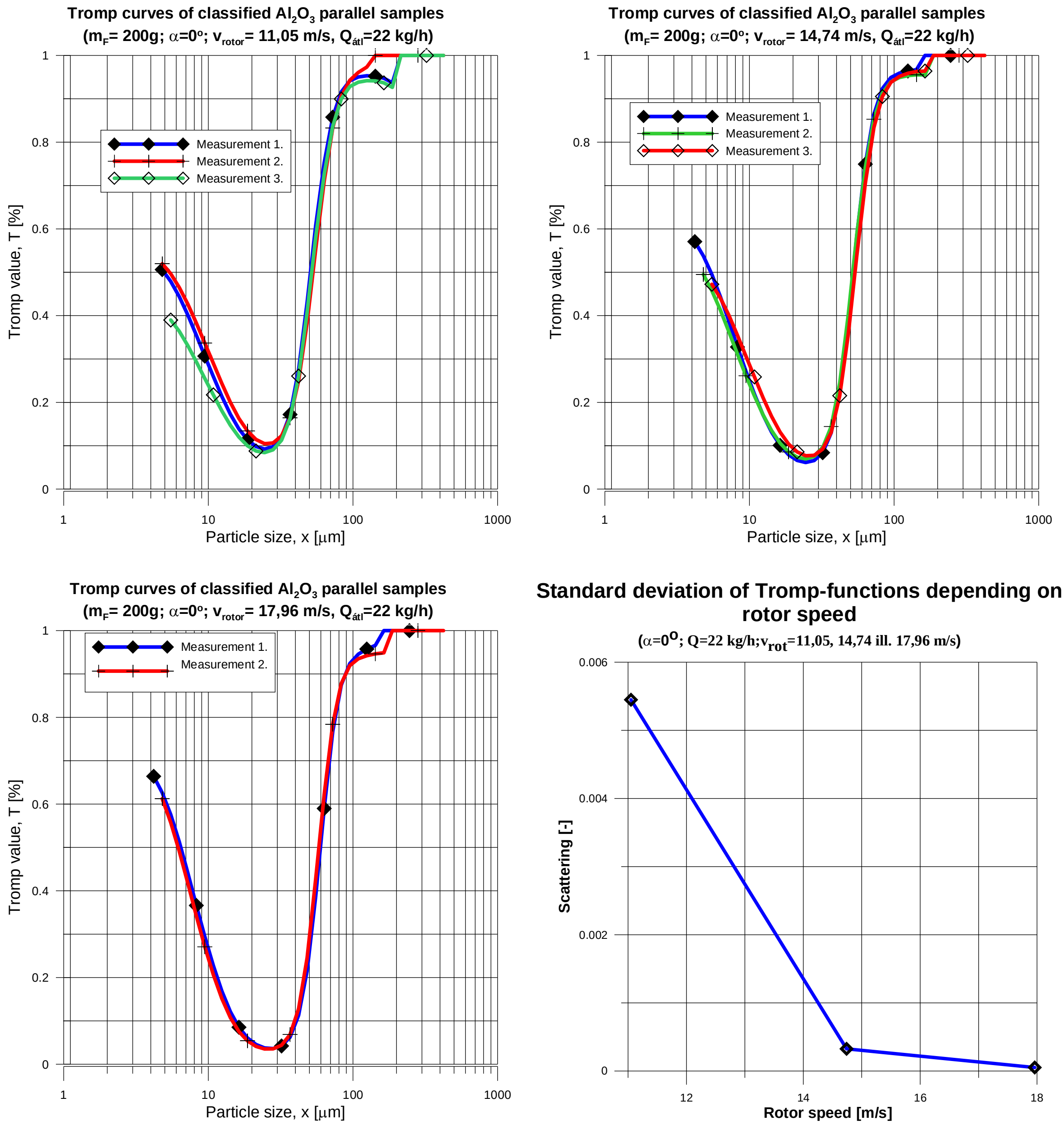

Figure 4b. Tromp functions and standard deviations of parallel samples at 11.07, 14.74 and 17.96 m/s rotor speed in Gayco centrifugal air-classifier.

It can be seen from the diagrams that the difference between the Tromp values of parallel samples are not more significant. However, before the dip point of the “fish-hook” (Majumder et al 2003) the value of standard deviation increases towards the fine particle size range. If the rotor speed increases the differences decrease. This correlation is valid for the whole function.

Furthermore, it can be also observed, that if the feed rate and the angle of the shutters are constant, the dip point is located in same particle size fraction even if the rotor speed is increased. The “fish-hook” will be deeper and wider, i.e. the quantity of the most finer particles (bypass) increases in the coarse product. However the quantity of this “worse” particles decreases significantly towards the coarser particle ranges.

Reproducibility of the separation at constant rotor speed. Figure 5 shows the diagrams at optimal 14.74 m/s rotor speed and increasing feed rate (22, 52 and 61 kg/h).

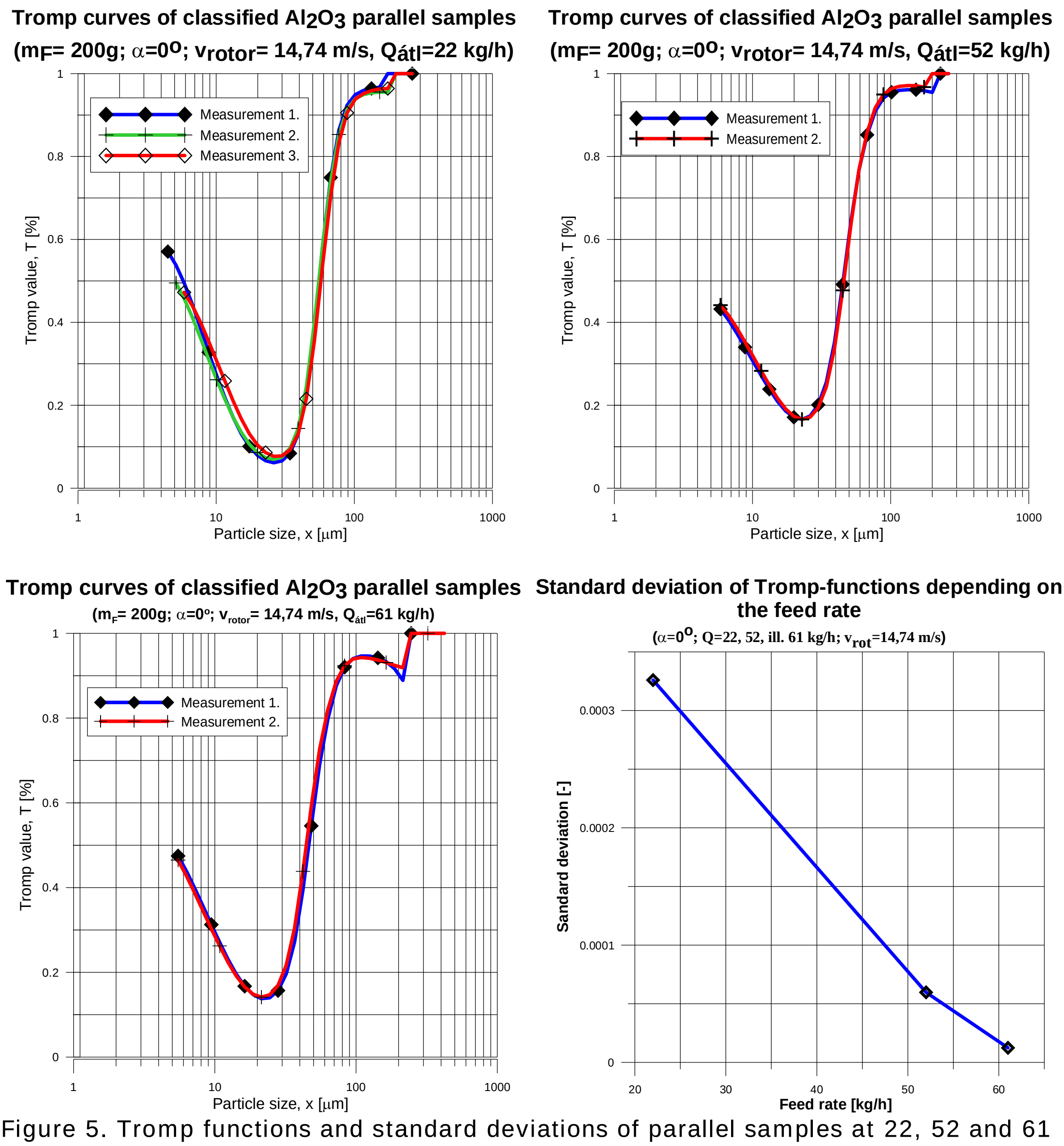

Figure 5. Tromp functions and standard deviations of parallel samples at 22, 52 and 61 kg/h feed rate in Gayco centrifugal air-classifier.

With increasing the feed rate the standard deviation of the Tromp values of parallel measurements decreases, consequently the measurement will be more accurate with increasing of the load. More significant values of deviation can be also observed before the dip point of the "hook" which decreases towards the coarser size ranges.

Conclusions. Compared to the Tromp-curves and the particle size distribution diagrams it can be concluded the following.

At the centrifugal classification of dry fine ground materials the presence of the "fish-hook" is not a sporadic phenomenon. It is a regular event which can be reproduced well in case of all measurements. At given operating parameters the shape of the "fish-hook" is fixed. This is confirmed by the parallel examinations. However, the shape and size of the "hook" depends on the particle size distribution of the feed material.

The reproducibility of the separations get better with increasing of the rotor speed at constant feed rate, and with increasing the feed rate at constant rotor speed.

The standard deviation in both case increases towards the finer particle size ranges if the value of a given parameter is lower. However, the efficiency of the separation decreases with increasing the feed rate.

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