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SORTING AS A PROCEDURE OF EVALUATING AND COMPARING SEPARATION RESULTS

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Results of separation of the same feed into products can be evaluated by different procedures. Relatively well known are product-separation, upgrading, and classification. The procedure of product separation relies on determination of the mass or yield of products, upgrading is based on determination of mass or concentration of a feed component (chemical component, particle, fraction) in products while classification relies on analytical determination of content of various fractions present in the feed and products and takes into account the value of the feature responsible for separation. In this paper another approach is described, which was named sorting. This procedure utilizes the results of analysis of the quality of separation products and the feed based on the determination of the value of the property utilized for separation (or related feature) of individual particles (or a group of particles) and assigning it to different sorting groups of similar properties. The sorting curves are plotted as a selected separation parameter versus the group number. There are many sorting-separation parameters including contents, yields, and their combinations. The simplest parameter of sorting is probably the recovery of a group of particles, which provides sorting curves similar to the Tromp curve used in classification. The separation results can be plotted either in a form of two lines, one line, or a point. However, a meaningful comparison of the separation results by means of sorting curves is possible when the separation tests are performed for a given feed quality and given magnitude of ordering forces while the position of the splitting forces changes. A family of sorting curves can be obtained for tests performed at different levels of the ordering forces.

key words: separation, splitting, upgrading, classification, sorting

INTRODUCTION

Separation relies on physical or virtual splitting of a starting material into real or virtual products that differ in quantity, quality or both. The separation takes place after exposure the feed to the separating forces. The separating forces are ordering, disordering and splitting forces (Fig.1). These forces significantly influence the results of separation. To evaluate the degree of separation, the products of the process have to be analyzed. The determination of quantity of the products of separation is performed

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using such analytical procedures as weighing, counting, volume measurement, etc. They provide the yield of the products. If the quality of the products is identical or we are not interested in the quality the separation products, the process can be characterized by the yield of the products or dependent parameters such as recovery of a component only. This procedure can be called the product-separation (Drzymała, 2001a).

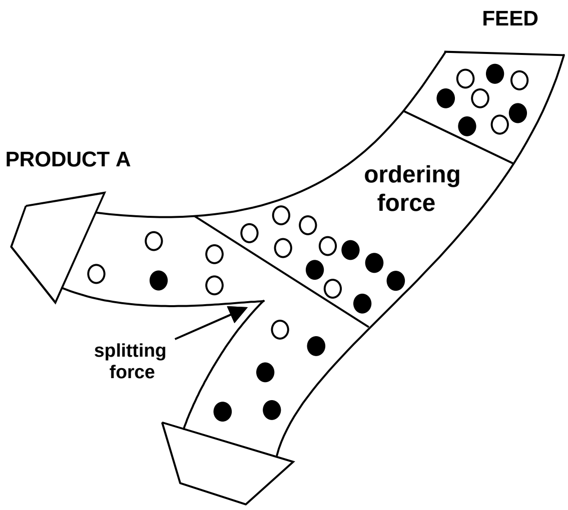

Fig.1. For a given property of the feed the result of separation depend on separating forces including ordering, splitting and other, for instance disordering, forces

The quality of the products can be established by different analytical methods (chemical, optical, screening, etc.). Presently two approaches, called upgrading and classification, are commonly applied for qualitative analyses of materials and samples, and next for characterization of separation. The upgrading relies on mass or content of a component in another components of the feed while classification on the value of the main feature used for separation (Drzymała, 2001a). Mentioned above product-separation procedure is based on the mass of the products of separation.

It seems obvious that other properties of the main feature used for separation may provide additional means of evaluation of the separation results. In this paper a property of the main feature that is belonging to a certain group of particles of similar properties will be used as an analytical procedure for determination of the quality of the products. It will be called sorting, because assignment of particles to a certain group is based on similarity of individual particles. In same cases the sorting into groups can be accomplished according to similarity of feature of a group, instead of individual, particles. The methods which can be used for evaluation and characterizing results of separation are briefly described in Table 1.

Table 1. List of methods of evaluation and characterizing results of separation

Parameter	Aspect of separation
mass of products	product-separation
mass of a component of feed and products of separation determined analytically in representative samples. Typical components: chemical components (elements, minerals, etc.), particles, fractions, etc.	upgrading (enrichment)
real or mean **value of feature** utilized for analytical separation of samples of feed and separation products into portion of matter (fractions also called classes, individual particles , etc.). The feature of analytical separation is the same (or related) as the feature of separation of feed into products	classification
consecutive **number** of a component (individual particle or group of particles) of feed and separation products assigned to the component during analytical procedure of sorting of particles according to the value of feature utilized for separation into products or related features	sorting

EVALUATION OF RESULTS OF SEPARATION BY SORTING

A hypothetical process will be considered here in which the feed was split into two products, that is, concentrate (product A) and tailing (product B). The samples of the feed and products of separation were sent to a mineralogical laboratory. The particles in the samples were observed under optical microscope and assigned to 10 different groups containing visually 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of a black mineral. The black mineral was the useful mineral and the separation of the feed into products A and B took place due to the value of a property (let us assume that it was magnetic susceptibility) proportional to the content of the black mineral in the particle. The groups were named 1, 2, ..., and 10, respectively. The mass and content of each group in the feed and products of separation was determined by counting the particles and then taking into account their density and volume. The mass can also be determined directly by weighing. The results of the mineralogical sorting analysis are given in Table 2. The numerical values were further used for calculation of other separation parameters including recovery of each group, and Hancock's parameter (Tarjan, 1986) for each group (Table 3). The separation parameters can be used for plotting different sorting curves. Two of them are shown in Figs 2a and 2b. Since there are infinitive number of sorting parameters, which can be generated (Drzymala, 2001b) from the content of a group in the feed (α), content of a group in product (λ), and yield of the product (γ), the number of sorting curves is also unlimited (Drzymala, 2002). In addition to that, each sorting curves can be plotted either in cumulative or non-cumulative form on normal, logarithmic or multi-logarithmic scale.

Table 2. Results of separation based on mineralogical sorting analysis. Yield of product A (γ_A) was 32.1% and product B γ_B = 67.9%

Group of particles No.	Feed		Product A		Product B	
	content	cumulative content	content	cumulative content	content	cumulative content
n_i	α_i %	$\Sigma\alpha_i$ %	$\lambda_{i, A}$ %	$\Sigma\lambda_{i, A}$ %	$\lambda_{i, B}$ %	$\Sigma\lambda_{i, B}$ %
1	0.01	0.01	0	0	0.015	0.010
2	2.45	2.46	0	0	3.61	3.62
3	12.32	14.78	2.51	2.51	16.96	20.58
4	24.05	38.83	8.39	10.90	31.45	52.03
5	21.16	59.99	16.21	27.11	23.50	75.53
6	13.12	73.11	16.02	43.13	11.75	87.28
7	11.45	84.56	19.66	62.79	7.57	94.85
8	7.78	92.34	16.54	79.33	3.64	98.49
9	3.86	96.20	9.42	88.75	1.23	99.72
10	3.80	100.00	11.25	100.00	0.28	100.00

Table 3. Calculated parameters of separation based on mineralogical (sorting) analysis. Yield of product A (γ_A) was 32.1% and product B γ_B = 67.9%. Recovery is calculated according to Eq. 1

Group of particles n_i (No.)	Selected separation parameters			Pairs of parameters of sorting curve			
	Recovery of group n_i of particles in product A, ε_i, %	Hancock parameter H=$\varepsilon_{i,A}$ - $\varepsilon_{i,B}$ %	others	recovery sorting curve	recovery sorting curve	Hancock sorting curve $(H_{75}-H_{-75})/2$	Hancock sorting curve
1	0	-100.00	....				
2	0	-100.00	....				
3	6.54	-86.92	....				
4	11.20	-77.6	....	$n_{\varepsilon 50}$ = 6.7	$n_{\varepsilon 50}$ = 6.7	$n_{\varepsilon 50}$ = 6.7	$n_{\varepsilon 50}$ = 6.7
5	24.59	-50.82	....				
6	39.20	-21.6	....	E_n = 1.6	O_s = 15.4	H_n = 2.5	O_s = 10.0
7	55.11	10.22	....				
8	68.24	36.48	....				
9	78.34	56.68	....				
10	95	90.00	....				

TYPES OF SORTING CURVES

The simplest sorting curve represents the results of separation in the form of content of various groups of particles as a function of the group number (Fig. 2a). To show adequately the separation results using the group content as separation parameter, two sorting curves have to be plotted. One curve can be drawn for the feed and the other for separation products or the two curves can be for the products of separation. In Fig. 2a one line was plotted as a dashed line to emphasize that it provides an excess information and it can be omitted. The sorting curves from Fig. 2a are not particularly convenient because there are two lines. It is more convenient to combine the two curves into one. It can be accomplished by choosing an appropriate separation parameter, which used alone would provide full information about the separation. Recovery, for instance, is such a parameter (Barski, and Rubinstein, 1970). In our case the recovery is defined as:

recovery of a group of particles in product A ($\varepsilon_{i,A}$) = content of a group in product A ($\lambda_{i,A}$) x yield of product A (γ_A) / content of a group in feed (α_i) (1)

The sorting curve ($\varepsilon_{i,A}$) = f($n_{i,A}$), where n_i is the group number, used alone characterizes well the results of separation because the sorting curve for product B is a mirror image of curve for product A, because:

$$\varepsilon_{i,B} = 100\% - \varepsilon_{i,A} \tag{2}$$

The recovery-sorting curve is plotted in Fig. 2b, and the sorting curve for product B, as a line which can be omitted, was plotted as a dashed line. It should be noted that the recovery-sorting curve is similar to the Tromp or separation curve (Kelly and Spottiswood, 1982) used for delineation of separation as a classification. The difference between the recovery-sorting and recovery-classification curves is that the former is plotted as a function of the number of a group of particle, not as a function of the numerical values of the feature of the fraction.

The recovery-sorting curve can be further reduced to a point by replacing the curve with its shape parameters. For the Tromp plot the most frequently used are such shape parameters as $n_{\varepsilon 50}$ and E_n. We will use here the same approach. The $n_{\varepsilon 50}$ and E_n parameters are defined as follows:

$n_{\varepsilon 50}$ = number of group of particles of similar feature used for separation (or related) for which the recovery of the group in a product is equal to 50% (3)

$$E_n = (n_{\varepsilon=75\%} - n_{\varepsilon=25\%})/2 \tag{4}$$

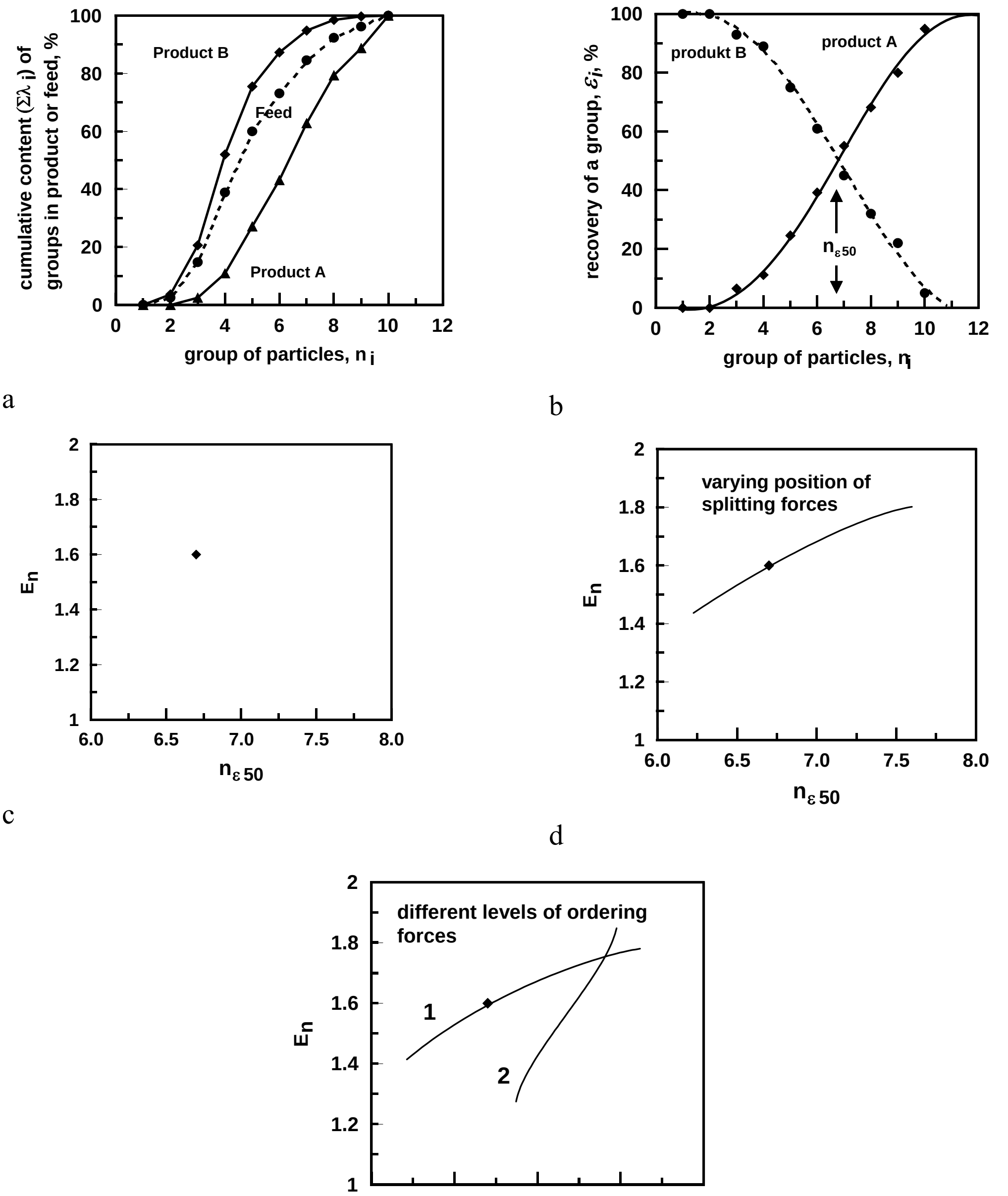

Fig. 2. Sorting curves: a) cumulative content vs. group number, b) recovery of a group vs. group number, c) E_n vs. $n_{\varepsilon 50}$, d) E_n vs. $n_{\varepsilon 50}$ for varying positions of splitting force, e) E_n vs. $n_{\varepsilon 50}$ for varying positions of splitting force and at two different levels (1 and 2) of ordering forces

It should be noticed that any pair of parameters, which are capable to characterize more or less accurately the recovery curve could be used. Another pair could be $n_{\varepsilon 50}$ and the sharpness of separation O_s, which is the slope of the recovery-sorting curve near $n_{\varepsilon 50}$ (Barski and Rubinstein, 1970; Wills, 1970). The plot of E_n vs. $n_{\varepsilon 50}$ is shown in Fig. 2c. For one separation test carried out for the same feed at a constant position of the ordering and splitting forces the plot of E_n vs. $n_{\varepsilon 50}$ (or O_s vs. $n_{\varepsilon 50}$) contains only one experimental point. To create a sorting curve containing more experimental points we have to run more separation tests at different positions of the splitting force. This procedure, after mineralogical (sorting) analysis of the products of separation, provides additional points on the sorting curve (Fig. 2d). Another sorting curve can be plotted for another level of the ordering force (Fig. 2e). Having two sorting curves it becomes possible to compare the results of different separation tests with the same feed.

CONCLUSIONS

It was shown in this paper that sorting could be used as another procedure of characterizing separation. It is different from the product-separation, upgrading, and classification procedures, which are frequently used for characterization and comparing separation results. The sorting method relies on sorting individual particles into groups according to their similarity of the property used for separation or related properties. There are many sorting parameters. The sorting parameters can be used for plotting sorting curves. Depending on the sorting parameters the result of one separation can provide two sorting lines, one line, or a point. A meaningful comparison of separation results by sorting is possible provided that separation tests for a given feed are performed at a given magnitude of the ordering forces and at varying position of the splitting forces. Further test can be carried out at different levels of the ordering forces.

Very likely there are other methods of evaluation of separation results but they should not be much different from those already presented in this paper.

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Oceny wyników rozdziału separacji na produkty nadawy o tym samym składzie można dokonać w oparciu o różne procedury. Dobrze znane są metody polegające na opisie separacji jako rozdział na produktu, wzbogacanie, czy też klasyfikacja. Opis separacji polegającej na rozdziale na produkty polega na ilościowym określeniu wychodu produktów (np. masy), podczas gdy wzbogacanie jest oparte na określeniu ilości (np. masy) i jakości produktów w oparciu o zawartość składników (chemicznych, ziarn, frakcji) w nadawie i produktach. Z kolei klasyfikacja polega na analitycznym określeniu zawartości pewnych frakcji obecnych w nadawie i produktach separacji biorąc pod uwagę cechę, dzięki której nastąpiła separacja. W tej pracy opisano jeszcze inną procedurę, którą nazwano sortowaniem. Metoda ta wykorzystuje wyniki analizy jakości produktów separacji i nadawy oparte na określaniu wartości cechy, która została użyta do separacji, lub cechy od niej zależnej, dla indywidualnych ziarn lub grupy ziarn i przypisanie jej do różnych grup o podobnych właściwościach. Wyniki charakteryzowania procesu pod kątem sortowania mogą być wykreślane w postaci: wybrany parametr separacji względem numeru grupy. Istnieje wiele parametrów procesu separacji opisywanego jako sortowanie i są one oparte o zawartość i wychód oraz ich kombinacje. Najprostszym parametrem sortownia opartym o zawartość i wychód jest prawdopodobnie uzysk grupy ziarn, który dostarcza danych do wykreślenia krzywej sortowania podobnej do krzywej Trompa stosowanej przy opisie separacji jako klasyfikacji. Wyniki separacji jako sortowanie mogą być wykreślane w postaci dwóch linii, jednej linii lub punktu. Pełne porównanie wyników separacji za pomocą krzywych sortowania jest możliwe wtedy, gdy wyniki separacji dotyczą stałej jakości nadawy i danego poziomu sił porządkujących zastosowanych do separacji, podczas gdy położenie sił rozdzielających ulega zmianie. Z kolei rodzinę krzywych separacji można uzyskać prowadząc separacje przy różnych wartościach sił porządkujących.