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ASSUMPTIONS FOR MODELLING OF SEPARATION IN COIL CLASSIFIERS

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The coil classifiers are flow classifiers in which the process of separation of grains into fractions differentiated by their grain size occurs in the stream of the medium and the separation feature is a characteristic velocity of grains movement in relation to the medium which is the function of their size. The multi-parameter capacity of the system of conditions of the classification process course makes up for serious difficulties in constructing of this model. The paper presents an attempt of identification of significant conditions out of these in which the process takes place. The authors separated groups of factors affecting the course and results of classification and described their role in forming the technological indicators and separation characteristics. Also a scheme of construction of a phenomenological model of classification which can be considered to be sufficient for practical purposes, especially for the tasks connected with the regulation and controlling of the operation of coil classifiers in industrial conditions.

Key words: flow classification, coil classifier, conditions of the classification process, process modelling

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FLOW CLASSIFICATION

Essentials of flow classification

The coil (spiral) classifiers constitute a separate group of flow classifiers in which the characteristic velocity of grains (v_c) in the liquid medium, formed under certain conditions, constitutes the feature of grains separation. The extreme value of this velocity is constituted by the limit velocity (v_0) with which the grain moves when the forces acting on it are at equilibrium. The formulas for the characteristic velocity, especially the limit one, are widely discussed in the literature (Barskij et al. 1974; Budryk 1937; Höffl 1985; Ljaščenko 1935; Sztaba 1992, 1993, 1997; Tumidajski 1993; Collective work 1976, 1972, and others) though this problem has not been sufficiently worked out for the general case of characteristic velocity (Ljaščenko 1935). There are, however, many formulas and calculating methods which enable the values of limit velocity for certain ranges of basic conditions of the process course to be calculated (i.e. to evaluate more precisely with the practical accuracy). This velocity is also generally applied for technological calculations.

The characteristic (limit) velocity v_c depends on:

properties of the grains - classified solid phase (e.g. mineral grains):

- grain density - ρ_s, kg/m^3,
- grain size – d, m,
- grain shape (considered numerically in calculations),
- other less important factors ,

properties of the liquid phase – classification medium:

- density of the medium, ρ_c, kg/m^3,
- viscosity of the medium (e.g. determined by the dynamic viscosity rate) - μ, Pa.s,

basic characteristics of the external force field in which the system grain-liquid occurs:

- the acceleration of gravity force (g) or (and) centrifugal acceleration (Ω) – m/s^2.

There are many formulas for calculating the limit velocity having theoretically an unlimited range of applications. This is Budryk's formula (Budryk 1937; Collective work 1976):

$$v_0 = \frac{a}{d \cdot \rho_c}\left(\sqrt{1 + d^3 \cdot b \cdot \rho_c \cdot (\rho_s - \rho_c)} - 1\right) \text{ m/s} \quad (1)$$

where: $a = 18 \cdot \mu$, $b = g/(162 \cdot \mu^2)$.

This formula can be applied for spherical grains.

A modified form (Sztaba 1992) of Budryk's formula was derived for non-spherical grains. The shapes of grains can be characterised the following coefficients:

- spherical coefficient, introduced by Wadell (Andreev et al. 1959; Sysło 1964) -

$C_k = \frac{F_k}{F_z}$ and

- coefficient introduced by A. Nowak (1979; 1981) - $C_{AN} = \frac{d_z^2}{d_r^2} \approx \frac{d_z^2}{d_p^2}$,

where: F_z, F_k – external surfaces: grains and a sphere of the volume equal to the volume of a grain, m^2, d_z, d_r, d_p – grain size: substitute, view, projection, respectively, m, (Sztaba 1964). This formula has the form:

$$v_0 = 18 \cdot \frac{C_{AN}}{\sqrt{C_k}} \cdot \frac{\mu}{d_z \cdot \rho_c} \cdot \left(\sqrt{1 + \frac{g}{162} \cdot \frac{C_k}{C_{AN}} \cdot \frac{(\rho_s - \rho_c) \cdot \rho_c}{\mu^2} \cdot d_z^3} - 1 \right), \text{ m/s} \tag{2}$$

and contains all the above mentioned factors affecting the value of the limit velocity v_0. Substituting in the quoted and other formulas the acceleration due to gravity (g) and centrifugal force (Ω) allows, with certain simplifications, to apply these formulas for the calculations of grain movement under the influence of centrifugal force (Nowak 1981).

The application of flow classification

The operations of flow classification occur commonly in technological processes of processing and transforming solid materials that are medium and especially fine-grained. They are characterised by high efficiencies with a simultaneously lower precision of separation in comparison with the screen classification ("mechanical" – sieving). As far as the latter one is concerned, they are much cheaper, both from the point of view of machinery costs and exploitation expenditure. The finer material is separated, the larger are the differences. When the very fine grains are classified, the application of screen classification is economically nonviable, and in case of extremely fine grains, technologically impossible, except for some rare cases, occurring mostly in chemical technology, production of special abrasive materials, semi-products for electronic or medical ceramics and a few others.

Flow classifiers

The equipment for flow classification, i.e. flow (stream) classifiers, reveals extreme diversity of construction solutions, depending on numerous factors and also on technological assumptions (Barskij et al. 1974; Grzelak 1975; Hőffl 1985; Ljaščenko 1935; Nowak 1981; Razumov et al. 1982; Collective work 1976, 1972 and many others). Usually the attempts of detailed systematic classifications of these machines are given up in favour for determining of their certain classes, differentiated by certain groups of conditions of operation courses and certain types of construction solutions (Collective work 1976, 1972). The subject-matter of this paper comprises exclusively the classification operations, performed in coil classifiers.

COIL CLASSIFIERS

Figure 1 presents the schematic diagram of construction of the coil classifier.

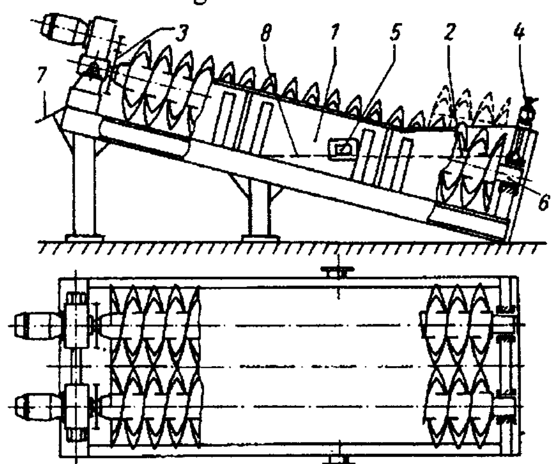

Fig. 1. Two-coil spiral classifier (according to Hőffl, 1985)
1 – chute, 2 – worm, 3 – drive, 4 – worm shaft lifting mechanism, 5 – suspension inflow, 6 – worm shaft bearing, 7 – underflow intake chute, 8 – suspension level

The spiral classifiers belong to the group of classifiers (Barskij et al. 1974):
- with the liquid medium of classification (hydraulic),
- gravitational,
- horizontal-current,
- with lateral intake of feed,
- with mechanical underflow (coarse-grained product).

The mechanical outtake of the underflow occurs by means of the worm (spiral, coil) conveyor, the presence of which makes the coil classifiers distinct among other flow "mechanical" classifiers (having mechanical parts for taking the underflow out). In high-efficiency classifiers two parallel conveyors are installed (spirals) (Fig. 1). Three-coil classifiers are almost exceptional.

The operation of the coil classifier is generally known and described in the literature, including the reference quoted in the introduction, therefore it is not discussed in this paper. To supplement the previous remarks about the range of applications of such classifiers, it should be mentioned that the occurrence of the zone of free water run-off from the underflow product (between the left edge – Fig. 1. – of the suspension surface (8) and the threshold of underflow intake (7), enables the use of spiral classifiers not only for the grain classification but also for dewatering of coarse-grained suspensions. The effect of dewatering occurs always as accompanying the classification in flow machines. In case of classifying the materials of heterogeneous mineral composition, especially density-like, there is also a side effect of enrichment, which, however, is a characteristic feature of all flow operations. These problems are not discussed in this work (Sztaba 1988).

IDENTIFICATION OF CONDITIONS OF THE SEPARATION PROCESS IN THE COIL CLASSIFIER

The above mentioned multi-parameter characteristics of the system in the course of the classification process is especially visible in case of mechanical classifiers (including the coil ones) which reveal a specific configuration of construction elements, including these which have movable elements, distinctly affecting the course and results of the process. The works of Sztaba (1992; 1993) and Sztaba et al. (1996, 1998) indicate difficulties which occur during the attempts of considering the values characterising the construction elements, in the construction of model descriptions of classification processes. The main reasons are the lack, in many cases, of technological justifications of direct assumption of numerical characteristics of values of construction elements in models, as opposed to the influence (most often indirect, in many cases confounding or even not fully univocal) of these values upon the technological effects of the process and also the lack, so far, an unanimous concept of considering, in such descriptions, the influence of the classifier on the process of construction configuration. The quoted works contain an attempt of systematic approach of such a configuration, yet the effects of their influence are not univocal, not mentioning even the joint effect of the set of these elements.

In this situation an attempt of identification of significant conditions was made in which the process occurs by means of the phenomenological description. The groups of factors affecting the course and results of the process were differentiated (groups: 1. – construction characteristics of the classifier and 2. – movement characteristics of the process) and their role in shaping the process technological conditions of the process was described (group 3.). A similar influence on the separation characteristics is a separate problem (group 4.).

Factors describing the conditions of the separation process and the evaluation of its results

The title conditions of the process course and the parameters of description and evaluation of its results (Tichonov 1973; Sztaba 1988; Sztaba et al. 1990) can be grouped as follows. The list presents, respectively, the factor's name, denotation and dimension:

1. construction characteristics of the classifier
1.1. length of the classifier chute - L, m
1.2. width of the classifier chute – B, m
1.3. length of the overflow edge – b, m
1.4. diameter of the spiral – D, m
1.5. pitch of the spiral thread – S, m
1.6. number of spiral threads – Z,
1.7. number of worms (underflow conveyors) – N,
2. movement characteristics of the process
2.1. depending on the classifier construction parameters
2.1.1. number of spiral revolutions – n, min^{-1}
2.1.2. inclination angle of the classifier chute - φ, rad
2.1.3. height of the overflow edge – H, m
2.1.4. distance between the feed inlet and the overflow edge – l, m
2.1.5. area of the suspension level – P, m^2
2.2. depending on the feed properties
2.2.1. frequency function (distribution function of grain sizes of the feed) - $f_0(d)$
2.2.2. density of the solid phase - ρ_s, kg/m^3
2.2.3. coefficients of grain shapes – C_k, C_{AN},
2.2.4. density of the liquid phase - ρ_c, kg/m^3
2.2.5. viscosity of the liquid phase - μ_c, Pa.s
2.2.6. volume concentration of the solid phase in the feed - Θ_0, (%), or as a fraction
2.2.7. feed density - ρ_0, kg/m^3
2.2.8. suspension (feed) viscosity - μ_0, Pa.s
2.2.9. efficiency of the solid phase in the feed – Q_0, kg/h
2.2.10. efficiency of the inflow of additional water – Q_{wd}, kg/h
3. technological results of the process
3.1. efficiency of the solid phase in the overflow – - Q_p, kg/h
3.2. efficiency of the solid phase in the underflow – Q_w, kg/h

3.3. yield of the solid phase of the overflow - γ_p, (%), or as fraction
3.4. yield of the solid phase of the underflow - γ_w, (%)
3.5. volume concentration of the solid phase in the overflow - Θ_p, (%)
3.6. volume concentration of the solid phase in the underflow - Θ_w, (%)
3.7. overflow density - ρ_p, kg/m^3
3.8. underflow density - ρ_w, kg/m^3
3.9. frequency function (distribution function of grain sizes of the overflow) - $f_p(d)$
3.10. frequency function (distribution function of grain sizes of the underflow) - $f_w(d)$
4. characteristics of grain separation
4.1. separation boundary (division grain, cut size) – d_{50}, mm
4.2. probable deviation (quarter deviation) of separation – E_p, mm
4.3. absolute indicator of separation accuracy – r (dimensionless).

The values of groups 1 and 2 determine the course and results of separation. Further on, they are treated as *determining (variable) values.* The values of group 3 (first of all) and group 4 are *determined (variable) values.* In practice, their values (most often, only some of them) are assumed according to technological needs, resulting from the place and function of the described operation in the technological system (process).

The above listed determining values (groups 1 and 2) maintain this role in all aspects of evaluation of results of action of the classifier (functions: classification, dewatering, enrichment). The values of group 1 are connected with invariable elements of construction of the classifier and are not subject to regulations. Their possible changes would require appropriate changes in the construction of the machine, i.e. a construction of a new device. The values of subgroup 2.1 are as a rule also fixed by the construction features of the device but can, when needed, be changed with any significant construction alterations. This, however, happens only exceptionally. It then concerns first of all item 2.1.3 (H) and 2.1.4. (1). The change of the value of position 2.1.2 (φ) and (or) 2.1.3 (H) changes the values of the suspension mirror area (2.1.5 – P), connected with them and with appropriate values from group 1. (1.2 – B and 1.3 – b) a simple geometric dependence.[2] Among the values of subgroup 2.2 all these which characterise the material of the solid phase of the feed and the liquid phase of the suspension [2.2.1 - $f_0(d)$,[3] 2.2.2 - ρ_s, 2.2.3 – C_k and C_{AN}, 2.2.4 - ρ_c, 2.2.5 - μ], depend on the natural properties of these materials and are not subject to regulation, from the point of view of the process they are *disturbing (variable) values.* Out of the remaining values of this group, any assumption of values is possible in case of 2.2.6 - Θ_0, 2.2.9 – Q_0 and 2.2.10 – Q_{wd}. The others are connected with other values in the way presented roughly in the following part of this chapter. The value Θ - volume concentration of the solid phase in the suspension

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[2] in classifiers provided for giving out an overflow of fairly fine grain sizes or (and) of fairly high efficiency of this product, B = b, as on Fig. 1.

[3] size of grains, d, a general feature, basic variable for the description of granulometric properties of grained materials

(occurring in the paper as Θ_0, Θ_p, Θ_w respectively, in relation to the feed, overflow and underflow) is a very important value characterising the suspension and allowing many its properties to be calculated, including these which directly affect the separation process in the classifier. It is described as a quotient of the volume of the solid phase (V_s, m^3) and the volume of the entire suspension ($V = V_s + V_c$, m^3; V_c, m^3 - the volume of the liquid phase in this suspension):

$$\Theta = \frac{V_S}{V_S + V_C} \tag{3}$$

For the sake of order, it should be mentioned that in industrial conditions often a similar value is applied, called the suspension *concentration* (α) and determined as a quotient of the solid phase (Q_s, kg) to the mass of the suspension ($Q = Q_s + Q_c$, kg; Q_c, kg – mass of the liquid phase of this suspension):

$$\alpha = \frac{Q_S}{Q_S + Q_C} \tag{4}$$

Both these important values are connected by dependencies

$$\alpha = \frac{\Theta \cdot \rho_S}{\Theta \cdot \rho_S + (1-\Theta)\cdot \rho_C}, \qquad \Theta = \frac{(1-\alpha)\cdot \rho_C}{(1-\alpha)\cdot \rho_C + \alpha \cdot \rho_S} \tag{5}$$

When the value Θ is known, it is possible to calculate the suspension density (ρ), its apparent viscosity (μ‘) and capacities of suspension (Q^z) and water in the suspension (Q^w). The role of these values in the flow classification process is described by Barskij et al. (1974), Ljaščenko (1935), Nowak (1981), Sysło (1964), Sztaba (1993, 1994, 1997), Tichonow (1973), Collective work (1972, 1976) and others.The density of the mixture of k components (in general case) is calculated by the formula:

$$\rho = \sum_{i=1}^{k} \rho_i \cdot \Theta_i \quad \Bigg| \quad \sum_i \Theta_i = 1 \tag{6}$$

where:
– ρ - mixture density, kg/m^3
– ρ_i - density of the i-th component of the mixture, kg/m^3
– Θ_i - concentration by volume of the i-th component in the mixture, (%).

For the two-component mixtures, e.g. suspensions which are, among others, the feed and classifier products (in case of classification of density-homogenous products, especially the monomineral ones, or in the conditions of omitting the occurrence of various components – "apparent homogeneity"), formula (6) is simplified to the form:

$$\rho = \rho_S \cdot \Theta_S + \rho_C \cdot (1 - \Theta_S) \tag{7}$$

where (as given before)
– ρ_s, ρ_c - density of the solid, liquid phase, kg/m^3
– Θ_s - volume concentration of the solid phase, (%),
(1 - $\Theta_s = \Theta_c$ - volume concentration of the liquid phase of the mixture, in practice only the concentration of the solid phase is used – in the feed and classifier products Θ_0, Θ_w, Θ_p, respectively).

If, as in the case of hydraulic classification, water is the liquid phase (ρ_c= 1000 kg/m^3), then

$$\rho = \Theta \cdot (\rho_S - 1000) + 1000 \tag{8}$$

Apparent viscosity is calculated (formula given by Baczynski):

$$\mu' = \mu_C \cdot \left(1 + 4{,}5 \cdot \frac{\Theta}{1 - \Theta}\right) \tag{9}$$

where μ_c - coefficient of dynamic viscosity of pure liquid, Pa.s.

One of the most important applications of value Θ can be found in calculating the limit velocity in the conditions of *constrained settling*. The quoted formulas (1) and (2) concern the so-called *free settling* under the conditions of the lack of additional actions which are caused by the co-settling grains (and also, to some extend, geometry of the area in which the separation takes place) (e.g. Collective work 1972, 1976 and others). Formally, in a simplified way, the velocity of constrained settling (v_s, m/s) can be calculated substituting in Eqs (1), (2) and others, not quoted here, the value ρ instead of ρ_c and the value μ' instead of μ (μ_0 for the feed, analogically for the products, although calculating the apparent viscosity for them is not well-grounded.

Knowing the expenditure of the solid phase in the suspension stream (also in the tank, etc.) – Q_x, kg/h (x = 0, p,w), the capacity of the stream of the entire suspension can be calculated:

$$Q^Z = \frac{Q_X}{\alpha} = \frac{Q_X \cdot \Theta \cdot \rho_S}{\Theta \cdot \rho_S + (1-\Theta) \cdot \rho_C} \tag{10}$$

and the expenditure of the stream of water in the suspension

$$Q^W = Q^Z - Q_X. \tag{11}$$

It should be noted that: formulas (3) to (11) are general and some denotations do not form a self-consistant system with the system of denotations assumed before.

The values determined from the technological group (3) allow the process to be evaluated due to the implementation of both the function of classification and dewatering. A possible evaluation of effects of enrichment in the process of classification require first of all some additional data about the contents of the feed components which can be the subject of the evaluation.

Out of the values belonging to this group only the values of product density are obtained from direct measurements (ρ_p - 3.7. and ρ_w - 3.8.) and in a very limited range (only to the values of function $f(d)$[4] for single values of d) data about the grain composition ($f_p(d)$ – 3.9, $f_w(d)$ – 3.10, similarly as occurring in group 2, function $f_0(d)$ – 2.2.1). Also the measurements of the capacity of the suspension stream (Q^Z) of both products (though, practically, only the overflow). The other, technologically important, values are obtained in an indirect way or as a result of laboratory tests of samples taken from the streams of products (($f_p(d)$ and $f_w(d)$). The values of the yields of products:

$$\gamma_P = \frac{Q_P}{Q_0}, \qquad \gamma_W = \frac{Q_W}{Q_0} \tag{12}$$

expressed usually in percentage values, in industrial conditions practically impossible to be calculated directly from formulas (12), are computed most often from the balance of components (Stępiński 1964; Collective work 1976 and others) of the solid and liquid phases with the application of the measured values of ρ (ρ_0, ρ_p, ρ_w), or the grain classes with the application of functions $f(d)$ ($f_0(d)$, $f_p(d)$ and $f_w(d)$) and an appropriate calculation procedure, using usually the least square method – e.g. the formula given by Grumbrecht

[4)] Here the frequency function $f(d)$ is used as the function of grain characteristics (Sztaba 1964, Collective work 1976); in practical applications almost always other functions are used, integer ones, of much higher utility advantages whereas the frequency function is more convenient in theoretical and general considerations.

(Tumidajski 1993) or others, for which the calculating programs have already been worked out.

The important value Θ (here $\Theta \equiv \Theta_s$ of the concentration of the solid phase) is calculated from the formula being the transformation of formula (7):

$$\Theta_S = \frac{\rho - \rho_C}{\rho_S - \rho_C} \tag{13}$$

The values Q_p and Q_w can be calculated knowing the given value Q_0 and the previously discussed values of yields of products (γ_p and γ_w or the feed density and products and Q^z at least for one product – transforming, among others, formulas (10) and (11)).

The listed values of the group of characteristics of grain separation (4) concern only the function of classification (separation of the feed into products of different grain size distribution, i.e. coarser *underflow* and finer *overflow*). These characteristics do not concern the function of dewatering or the effects of enrichment.

The characteristics 4.1 – d_{50}, mm and 4.2 – E_p, mm are taken off from the *separation curve* (Sztaba 1956; Mayer 1971), calculated and applied (the values of the *numbers of separation* - τ(d) for the overflow and T(d) for the underflow are calculated) in the way described (Sztaba 1956). The value 4.3, $r = E_p/d_{50}$. It is characteristic for a given classifier (Sztaba 1956). These values serve to estimate the process of classification as a random process. The value of d_{50}, the size of a grain of the same probability of transmitting into the overflow and underflow, determines the boundary between these products and E_p characterises the dispersion of values of these probabilities; thus characterising the separation accuracy (the higher the smaller the value of E_p).

In practice, it is not enough to obtain the separation of limit grains on the level of 50%. For example, one of the methods of calculation of sizes of coil classifiers (Razumov et al. 1982; Collective work 1976) uses the maximum overflow grain, determined as the grain of such a size that there are 95% of grains in the overflow which are under this size (the so-called 95%-grain). In such cases the separation curve has to be used (τ or T) together with the grain size distribution characteristics of the feed (f_0(d)) (Sztaba 1956).

For practical reasons the calculations of coil classifiers are mainly performed because of the sizes of: cut size (d_{50}), efficiency of the solid phase in the feed (Q_0) and in the underflow (Q_w), or (in case of the assumption of the use of the dewatering function) the overflow (ρ_p) and underflow (ρ_w) densities. For the sake of comparison mainly the values characterising the accuracy of separation (e.g. E_p, r) are evaluated (more seldom used).

The influence of conditions of the process course on its technological results and estimation

The formerly discussed relations between the values applied for the description of course conditions and results of classification as well as limitations to the values practically useful in industrial conditions contribute to significant reduction of the number of values which should be taken under consideration when describing the mutual relations between them. According to the general rule assumed for the present paper, the values affecting the underflow characteristics are not differentiated.

The determining values to be considered are as follows:

1) area of the suspension level – P; P = P(B, b, φ, H),

2) distance of the feed inlet from the overflow edge – 1,

3) frequency function of the feed solid phase – $f_0(d)$[5],

4) efficiency of the solid phase in the feed - Q_0,

5) volume concentration of the solid phase in the feed, determining the conditions of grain constrained settling - Θ_0, (in general regulated by the expenditures of the solid phase and water, or calculated by formula (13),

6) joint efficiency of water in the feed - $\Sigma Q^w = Q^w_0 + Q_{wd}$; Q^w_0 - efficiency of water introduced together with the feed.

The remaining values of groups 1 and 2:

- the values of constant values for a certain group of processes: density of the solid phase (ρ_s) and the liquid (water) (ρ_c) and its viscosity; their influence on the classification conditions results clearly from formulas (1), (2), (5), (7), (10), (13); The coefficients of grain shapes of the solid phase (C_k, C_{AN}) are rarely significant for determining the limit velocity,

- the values influencing the characteristics and expenditure of underflow can be neglected (being important mainly for the function of dewatering): the length of the classifier chute (L), characteristics of the spiral and its movement (D, S, Z, N, n) – in case of evaluation of the grain characteristics of this product it is possible to use the relations between the grain size distributions of the feed, overflow, underflow and yields of the latter:

$$a_{wi} = \left. \frac{a_{0i} - a_{pi} \cdot \gamma_p}{\gamma_w} \right|_{\gamma_p + \gamma_w = 1} \tag{14}$$

[5] It is impossible to use such an entire function; the range of this work exemplifies it as a symbol of the feed grain size distribution; in case of the flow classification its most important feature is constituted by the content of extremely fine grains and, especially, the so-called primary muds (Razumov et al. 1982, collective 1976) whose presence significantly affects the rheological properties of the suspension, first of all increasing its apparent viscosity (over the value calculated, e.g., from formula (9) and thus decreasing the limit (characteristic) velocities of grains sedimentation.

where a_{0i}, a_{pi}, a_{wi} – contents of the i-th grain class in the feed, overflow, underflow, dimensionless.

It is enough to take into consideration the following values:

1) yield of the underflow solid phase – γ_p,
2) volume concentration of the solid phase in the overflow – Θ_p,
3) separation boundary (cut size) – d_{50},
4) probable deviation of the separation – E_p.

Additionally, it should be observed that the grain composition of the overflow ($f_p(d)$, a_{pi}) can be calculated, if necessary, applying the transformed formula (14) and the parameters of the separation curve (d_{50} and E_p). The qualitatively determined relations between the conditions of the process course and its results are listed in Table 1 in the cells of which there are symbols determining the character of the relation. These symbols determine the changes of the value denoted at growth of the variable determining value: + - determined value increases, - - determined value decreases. Moreover, it was assumed that apart from a few cases of clear strong non-linear dependence, denoted as ^+ or ^-, (increase or decrease, respectively), in case of the remaining relations the accurate character of the relation is not determined. It is also assumed that with the change of the value of a concrete determining value, the remaining values are not changed.

Dependencies of selected values determined from the basic determining values

$Z_{determining}$		$Z_{determined}$			
j	Symbol	γ_p	Θ_p	d_{50}	E_p
1	P	-	-	^-	-
2	I	+	+	+	+
3	$f_0(d)$[6]	+	+	+	+
4	Q_0	+	+	+	+
5	Θ_0	-	-	-	-
6	ΣQ^*	+	+	^+	+

[6] in fact, this is the formerly discussed (5) content of super-fine grains

Diagram of construction of the model of classification

In the simplest case of construction of the phenomenological model of the process it can be written, separately for each determined value, as:

$$Z_{\text{determined}} = \sum_{j} \pm b_j \cdot Z_{\text{determining},\, j} \qquad (15)$$

where

– $Z_{\text{determining}}$, $Z_{\text{determined}}$ – input and output variables (values), (determining and determined), considered in Table 1,

– b – empirical coefficient with the symbol corresponding to the symbol in the Table 1.

Also other procedures of construction of such models can be applied. System (15) can serve also as an introductory scheme to determinist models, e.g. constructed with the application of principles of the dimensional analysis. Regardless of the presented dependencies, it should be reminded that two basic types of coil classifiers can be differentiated for which a distinguishing feature is constituted by the position of the lower end of the spiral in relation to the overflow edge (Razumov et al. 1982; Collective work 1976).

Numerically, this feature is determined by the difference D – H:

1) *classifiers with the non-immersed spiral* – (D – H) > 0 – are use for classification at larger values of d_{50} (size of 95% overflow grain usually > ~ 0.074 mm), obtained value of E_p is usually larger than in other constructions,

2) *classifiers with the immersed spiral* – (D – H) < 0 – are used for classification at lower values d_{50} (size of 95% overflow grain usually <~ 0.2), obtained value of E_p is usually smaller than in other constructions.

This variety of constructions should be taken into consideration when formulating conclusions which generalise the results of investigations carried out on the separation process in classifiers of differentiated construction features. The dependencies of Table 1 will be of the same character but in the model record the values of numerical coefficients will be different at respective values.The presented scheme of construction of models can be sufficient for practical purposes, particularly for the tasks connected with regulation and control of coil classifiers in industrial conditions. Having such models at disposal would make precise the principles of selection in comparison to the mentioned methods of designing of these machines, which, as a rule, do not consider the qualitative technological parameters of the process products (Razumov et al. 1982; Collective work 1972, 1976).

Such models cannot be considered satisfactory from the cognitive point of view. Maintaining only for selected determined values there are no grounds for determining a univocal model record, taking into account all these values. These difficulties will be enlarged by broadening their list. There are, however, some premises for a theoretical proof, empirically stating an almost linear dependence (according the existing investigation results) between d_{50} and E_p which contributed to the introduction of the value r, approximately constant for a given classifier (Sztaba 1956), yet there are not enough data to state univocally this constancy for various items of machines of this type. The problem consists of large sampling of relatively numerous machines, apart from the execution of such samplings. The performed considerations and investigations allowed the results to be presented and confirmed a formerly formulated thesis (Sztaba 1993) about a significant effect of construction parameters on the operation of classifiers with numerous mechanical elements. Therefore, no possibilities of constructing the generalised models can be expected before a significant progress is reached in descriptions and quantifications of roles of mechanical elements in flow technological devices, including coil classifiers. On the other hand, the work on modelling of flow processes classification, carried out in other machines, without such strong participation of influences of mechanical elements on technological results (chamber and other simpler hydraulic and air classifiers, and also centrifugal devices of free vortex eg. hydrocyclones), can explain many details, important for flow classification processes and even the entire class of flow processes, necessary for solving the discussed problems. Strict determinist description of separation processes in machines of forced vortex (classifying sedimenting centrifuges), in spite of significant progress in modelling (Nowak 1981), must be confronted with problems, analogical to coil classifiers, with the description of the influence of mechanical elements on their operation and results. Nevertheless, no progress in solving them can be expected without such investigations which broaden the initial positions of further modelling of the process occurring in such complex conditions as coil machines.

The presented scheme of fraction modelling, sufficient for practical purposes, should be applied by means of using the collected industrial data and constructing phenomenological models for certain applications and simultaneously aiming at their gradual generalisation.

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REFERENCES

ANDREEV, S.E., TOVAROV, V.V., PEROV, V.A., (1959), *Zakonomernosti izmel'čenija i isčislenie charakteristik granulometričeskogo sostava* (*Essentials of Grinding and Numerical Characteristics of Granulometric Composition*) - Metallurgizdat, Moskva (in Russian).

BARSKIJ, L.A., RUBINŠTEJN, J.B., (1970), *Kibernetičeskie metody v obogaščenii poleznych iskopaemych* (*Cybernetic Methods in Mineral Enrichment*) - Izdatel'stvo „Nedra", Moskva (in Russian).

BARSKIJ, M.D., REVNIVCEV, V.I., SOKOLKIN, J.V., (1974), *Gravitacionnaja klassifikacija zernistych materialov* (*Gravitational Classification of Minerals*) - Izdatel'stvo „Nedra", Moskva (in Russian).

BUDRYK, W., (1937), *Przyczynek do teorii wzbogacania w ośrodku płynnym* (*Some Approach to the Theory of Enrichment in Liquid Medium*) - Przegląd Górniczo-Hutniczy nr 3 (in Polish).

COLLECTIVE WORK, (1972), *Sprawočnik po obogaščeniju rud*, (Handbook of Mineral Processing) vol. 1.- Izdatel'stvo „Nedra", Moskva (in Russian).

COLLECTIVE WORK,(1976), *Poradnik Górnika*, (*Miner's Guidebook*) vol 5 - edition 2., Wydawnictwo „Śląsk", Katowice (in Polish).

GRZELAK, E., (1975), *Maszyny i urządzenia do przeróbki mechanicznej surowców mineralnych – (Machinery and Equipment for Mechanical Enrichment of Minerals)* Wydawnictwa Naukowo-techniczne, Warszawa (in Polish).

HŐFFL, K., (1985), *Zerkleinerungs- und Klassiermaschinen* (*Crushers and Classifiers*) - VEB Deutscher Verlag für Grundstoffindustrie, Leipzig (in German).

LJAŠČENKO, P.V., (1935), *Gravitacionnye metody obogaščenija* (*Gravitational Methods of Enrichment*) - Gosudarstvennoe Ob'edinennoe Naučno-Techničeskoe Izdatel'stvo, Moskva – Leningrad (in Russian).

MAYER, F.W., (1971), *Berechnung des neuen Trennungschärfe-Kennwertes* (*Trennfehlermoment*) aus den Teilunszahlen, 1. und 2. Teil – (*The Evaluation of New Distribution Numbers*) Aufbereitungs-Technik nr 2 i 4 (in Germany).

NOWAK, A., (1979), *Kornformfaktor für die Bewegung in einem flüssigen Medium* (*The Shape Coefficient for the Application in the Wet Classification Processes*) - XXX Berg- und Hüttenmännischer Tag, Freiberg (in Germany).

NOWAK, A., (1981), *Charakterystyki rozdziału jednorodnych ziarn mineralnych w wirówkach klasyfikujących* (*Characteristics of Separation of Homogenous Mineral Grains in Classifying Centrifuges*) - PWN Warszawa – Kraków (in Polish).

RAZUMOV, K.A., PEROV, V.A., (1982), *Proektirovanie obogatitel'nych fabrik* – (*Designing of Processing Plants*) - Izdatel'stvo „Nedra", Moskva (in Russian).

STĘPIŃSKI, W., (1964), *Wzbogacanie grawitacyjne* (*Gravitational Enrichment*)- PWN Łódź - Warszawa – Kraków (in Polish).

SYSŁO, M., (1964), *Uogólnione prawo Stokesa dla brył spójnych* (*Generalised Stokes' Law for Compact Solids*) - Zeszyty Naukowe Akademii Górniczo-Hutniczej nr 94, Rozprawy z.33, Kraków (in Polish).

SZTABA, K., (1956), *Metoda statystyczna badania procesu klasyfikacji mokrej* (*Statistical Method for Investigating the Wet Classification*) - Archiwum Górnictwa, t.I., z.1 (in Polish).

SZTABA, K., (1956), *Krzywe rozdziału w procesie klasyfikacji mokrej* (*Separation Curves in Wet Classification*) - Archiwum Górnictwa, t.I., z.2 (in Polish).

SZTABA, K.S., (1964), *Niektóre własności geometryczne zbiorów ziarn mineralnych* (*Some Geometrical Properties of Mineral Grains Sets*) - Zeszyty Naukowe Akademii Górniczo-Hutniczej nr 85, Rozprawy z.25, Kraków (in Polish).

SZTABA, K., (1988), *Współwystępowanie efektów klasyfikacji i wzbogacania w procesach przepływowych* (*Co-occurrence of Effects of Classification and Enrichment in Flow Processes*) - Fizykochemiczne Problemy Mineralurgii z.20 (in Polish).

SZTABA, K., NOWAK, A., MAKARY, B., (1990), *Rozwój rozwiązań technologicz(nych i metod modelowania procesów klasyfikacji przepływowej* (*Development of Technological Solutions and Modelling Methods of Flow Classification*)- Zeszyty Naukowe Politechniki Śląskiej nr 1088, seria Górnictwo z. 190, Gliwice (in Polish).

SZTABA, K., (1992), *Problems of Taking into Account Shapes of Mineral Grains in Flow Classification* - The First International Conference on Modern Process Mineralogy and Mineral Processing, Beijing.

SZTABA, K., (1992), *Warunki i możliwości rozbudowy i ujednolicenia opisów modelowych procesów klasyfikacji przepływowej (Conditions and Possibilities of Development and Unification of Model Descriptions of Flow Classification Processes)*- Fizykochemiczne Problemy Mineralurgii z. 26 (in Polish).

SZTABA, K., (1993), *Directions and Development Trends of Model Descriptions of Flow Processes - Archives of Mining Sciences* (Archiwum Górnictwa) PAN, t.38, z.2.

SZTABA, K., (1994), *The Problems of Modeling of Technological Processes of the Mineral Processing* - IV Meeting of the Southern Hemisphere on Mineral Technology & III Latin American Congress on Froth Flotation, Concepcion (Chile), 20-23 November 1994.

SZTABA, K., (1994), *The Problems of Flow Classification of Very Fine Grained Materials* - IV Meeting of the Southern Hemisphere on Mineral Technology & III Latin American Congress on Froth Flotation, Concepcion (Chile), 20-23 November 1994.

SZTABA, K., TORA, B., TUMIDAJSKI, T., (1996), *Modelling of Processes of the Mineral Processing* - System Analysis, Modelling, Simulation (*SAMS*) 1996, Vol.24.

SZTABA, K., (1996), *The Problems of Modelling of Technological Processes of Mineral Processing* - International Conference Minerals & Materials '96, Somerset West, South Africa, 31 July - 2 August 1996, Volume I: Minerals.

SZTABA, K.St., (1997), *Możliwości uściślania opisów ruchu ziarn w ośrodkach płynnych (Possibilities of Precise Descriptions of Grain Movements in Liquid Media)* - Zeszyty Naukowe Politechniki Łódzkiej nr 780, Inżynieria Chemiczna i Procesowa z. 22, Łódź (in Polish).

SZTABA, K., TORA, B., TUMIDAJSKI, T., (1998), *Modelling of Mineral Processing Based on the Law of Mass Conservation* - 9[th] International Symposium on „System - Modelling - Control", Zakopane.

SZTABA, K., (1998), *Założenia metodyczne budowy wielostadialnych układów klasyfikacji przepływowej (Methodological Assumptions of Construction of Multi-stage Systems of Flow Classification)* - in *Kompleksowe wykorzystanie surowców a ochrona środowiska,* AGH - Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków (in Polish).

TUMIDAJSKI, T., (1993), *Zastosowanie metod statystycznych w analizie procesów przeróbki surowców mineralnych (Application of Statisical Methods in Mineral Processing)* - Śląskie Wydawnictwo Techniczne, Katowice (in Polish).

TICHONOV, O.N., (1973), *Vvedenie v dinamiku massoperenosa processov obogatitel'noj technologii (Introduction in Dynamics of Enrichment Processes)* - Izdatel'stvo „Nedra", Moskva (in Russian).

Kazimierz St. SZTABA, Alicja NOWAK, Założenia do modelowania separacji w klasyfikatorach zwojowych, Fizykochemiczne Problemy Mineralurgii 34, 77–94 (w jęz. angielskim)

Klasyfikatory zwojowe (spiralne) są urządzeniami służącymi do rozdziału średnio- i drobnouziarnionych zawiesin fazy stałej w cieczach (z reguły w wodzie) na produkty o zróżnicowanym uziarnieniu fazy stałej. Cechą ziarn decydującą o zachowaniu się ziarna w procesach przepływowych jest ich prędkość charakterystyczna – w praktyce tzw. prędkość graniczna. Oprócz podstawowego efektu klasyfikacji ziarnowej, w każdym jej procesie występują efekty różnicowania w poszczególnych produktach, stosunku fazy stałej do ciekłej, a w przypadkach klasyfikacji materiałów niejednorodnych pod względem składu mineralnego, występują ponadto uboczne efekty wzbogacania. Klasyfikatory zwojowe nadają się szczególnie do stosowania również w charakterze urządzeń odwadniających. Zespół cech konstrukcyjnych, ruchowych i eksploatacyjnych klasyfikatorów zwojowych obejmuje w związku z możliwościami różnorodnych zastosowań, kilkadziesiąt czynników wpływających na przebieg procesu i jego wyniki

technologiczne oraz wartości wskaźników służących do opisu procesu rozdziału. Wpływ większości owych cech na wyniki procesu nie jest w pełni rozpoznany. Uniemożliwia to budowę modelu deterministycznego procesu, a budowa modeli fenomenologicznych wymaga bardzo licznych badań, wykonywanych przy zmiennych wartościach wielu warunków. Ich realizacja, zwłaszcza w warunkach przemysłowych jest niezwykle trudna. W opracowaniu przedstawiono dyskusję wpływu warunków procesu na jego wyniki w odniesieniu do efektu klasyfikacji, a także w ograniczonym stopniu do efektów odwadniania. Przedstawiono propozycję sposobu postępowania w przypadku poszukiwania opisów modelowych o ograniczonej szczegółowości.