GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2018 Volume 34 Issue 1 Pages 83–96

DOI 10.24425/118638

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The phenomenon of screen blocking for mixtures of varying blocking grain content

Introduction

A particle is an element of a permanent disintegrated medium, restricted by an enclosed surface of any shape. The basis for a sieve process is to let all the particles come into contact with a fixed surface (the sieve), with holes of a specific shape and size. Sieving is a process that particulate mixtures are often subjected to. The main aim of sieving as a method for size classification is to separate a group of particles, the dimensions of which fall within the specified limits, from the given material. For this purpose sieves equipped with one or several sieves are used. Therefore, sieves are an essential element of a sieving process. A large number of sieve designs is available. The selection of a correct sieve for a given particulate material determines the course of a sieving process. The variety of designs makes it difficult to determine the unequivocal systematics of sieves. Material directed for sieving is called the feed. The feed consists of two fractions of particles: upper and lower size fractions. Particles that pass through the sieve give rise to a product called the lower size product, while the particles that remain on the sieve – the upper size product. Other terms are also used, such as mesh fraction versus minus mesh, etc. Sieving is a very common method of separation, used on its own or combined with other processes (Drzymala 2009). Two phenomena take

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place while a material moves around a sieve: layer segregation and the passage of small particles (the size of which classifies them as the lower size fraction) through the sieve holes. The flow behavior of granular material is governed by forces exerted at the many points of contact between the different particles (Bek et al. 2016). Particle-size composition curves and distribution curves are established for the purpose of evaluating the classification process. References state that the yield of a particles class in a product is also called the distribution number, sieving efficiency (Malewski 2013) and distribution function. Material balance and mathematical equations are used for analysis and evaluation of separation results (Duchnowska and Drzymala 2011). During the sieving process we deal with a number of parameters, which need both monitoring and controlling (Foszcz et al. 2016). The impact of individual process parameters and factors on the course of a sieving process formed the basis for research presented in the publications (Allen 2003; Fitzpatrick 2007; Liu 2009; Igathinathane et al. 2012; Liu et al. 2015; Guerreiro et al. 2016). Particles properties may be divided into chemical, energy related and physical ones (Baic 2013). There are also many articles describing the impact of the shape and size of particles (Obraniak and Gluba 2011; Obraniak and Gluba 2012; Otunniyi et al. 2013; Yuexin et al. 2014; Duchnowska and Bakalarz 2015; Haselhuhn and Kawatra 2015; Mucha et.al. 2016; Uliasz-Bocheńczyk et. al. 2016) on the course of processes and operations as well as concerning the optimization of the separation process (Zhou 2015) and sieving machines (Hong 1999; Baragetti and Villa 2014). A reliable measurement of particle size and particle size distribution (PSD) is central to the characterization of particulate minerals (Rhodes 2008). There are many models describing the sieving process (Alkhaldi and Eberhard 2007; Tumidajski 2010; Akhmadiev and Gizzjatov 2013; Chirone et al. 2016). The most well-known is the discrete element method (DEM), involving the integration of ordinary differential equations of motion of a free arrangement of material solids (Li et al. 2003; Pérez-Alonso and Delgadillo 2013; Jafari and Saljooghinezhad 2016). Both particle size distribution and particle density distribution for feed and concentrate were approximated by several classical distribution functions (Niedoba 2016). Sieving is an important process, above all: in mining, metallurgy, coal processing, civil engineering, environmental protection, as well as in food, chemical, pharmaceutical and leather industries. The scale of the process is so large as a teragram of products are being sieved every single day.

Holes are often blocked during the sieving of granular materials in industrial sieve. When sieve holes are blocked by particles, they are excluded from the active surface of the sieve, thus reducing the sieving surface area. The process of sieve holes blocking is an unfavorable phenomenon, as it reduces the surface area of the lower size fraction flow through the analyzed sieve. Consequently the sieving process capacity decreases significantly. Literature on the subject provides only a few examples of sieve holes blocking during the sieving of particulate materials. It was reported by Feller (Feller 1980) that both the partial passage and clogging of the sieve should be considered in order to evaluate sieve performance. The sieve blocking coefficient f is applied for the quantitative description of sieve blocking. It is defined as a ratio of number of free holes (n_{free}) to the total number of holes in the sieve (n_{total}) (Eq. 1):

$$f = \frac{n_{free}}{n_{total}} \tag{1}$$

The phenomenon of blocking the holes of the sieve is a process resulting from two processes, occurring simultaneously: the clogging and declogging of sieves. An exponential (Eq. 2) (Lawinska et al. 2014) or logistic function (Eq. 4) (Lawinska et al. 2015) model may be used for describing sieve holes blocking:

$$f = f_\infty + (f_0 - f_\infty)e^{-k_0 \cdot t} \tag{2}$$

where k_0 is the blocking constant. The phenomenon of blocking the holes of the sieve is a process resulting from two processes occurring simultaneously at the time of the clogging and declogging of sieves $k_0 = k_1 + k_2$, where k_1 is the sieve blocking constant and k_2 is the sieve unblocking coefficient.

$$k_0 = \frac{1}{t_n} \cdot \ln \left| \frac{f_0 - f_\infty}{f_n - f_\infty} \right| \tag{3}$$

$$f = \frac{f_0}{1 + (f_0 - f_\infty)e^{-c \cdot t}} \tag{4}$$

The value of coefficient c may be estimated using time t_∞, after which the value of coefficient f does not change:

$$c \approx \frac{11.8}{t_\infty} \tag{5}$$

The value of the sieve blocking coefficient varies in time. It changes from the value of $f = f_0$ to the value of $f = f_\infty$ (for time $t = t_\infty$ the dynamic equilibrium of sieve holes blocking and unblocking processes is set; from that moment on the value of the sieve blocking coefficient does not change any more). At the moment of the material being fed to the sieve $t = 0$, the sieve blocking coefficient equals f_0. This means that the sieve has not performed a vibration yet, however, there are already sieve holes that are blocked. Disregarding the sieve blocking coefficient may lead to significant inaccuracies in design calculations that practically mean a major reduction of the active surface area of the sieve.

If coefficient f is combined with A_0, one obtains an effective surface area F^* of the sieve, i.e. the surface area through which the stream of material is passing through the sieve as seen in (Eq. 6):

$$F^* = A_0 \cdot f \cdot F \tag{6}$$

where F is the sieve surface area. Particles in which size is similar to the sieve holes, clog those holes and considerably decrease the actual clearance coefficient φ, which is one of the most important characteristics of sieves (Eq. 7):

$$\varphi = \frac{F^*}{F} \tag{7}$$

The particle relative size factor is the fundamental parameter conditioning the sieving process and the motion of the material layer along the sieve. It is a dimensionless size that determines the flow of particles through the sieve holes. The size of those particles is similar to the size of the sieve holes and they are the ones blocking those holes. Hard-to-sieve particles have the following dimensions:

$$0.8l \leq d \leq 1.2l \tag{8}$$

↳ d – average particle size,
l – sieve hole size.

Hard-to-sieve particles may be divided into undersized and blocking particles. Undersized particles are the ones whose dimensions are smaller than or equal to the size of the sieve hole, and that take the most time to pass through the sieve holes. Blocking particles are the ones whose dimensions are equal to or slightly greater, than the size of the sieve hole (Eq. 9):

$$l \leq d \leq 1.2l \tag{9}$$

Those particles do not pass through the sieve holes, remain over the sieve and may clog (block) the sieve holes, thus reducing the sieve clearance coefficient (Lawinska et al. 2016; Lawinska and Modrzewski 2017).

The aim of this article is to provide a new definition of the sieve blocking coefficient and conduct an analysis concerning the impact of the content of blocking particles in particulate materials mixtures on sieve holes blocking during their sieving.

1. Materials and method

The experiments were done using a laboratory vibrator with a regulated toss indicator. Linear vibrations and flexural vibrations are characteristic of this vibrator. Measurement series were performed for toss indicator $K = 1.5$, 1.98. Woven sieves of square holes, whose diameters are: 0.5 mm, 0.8 mm and 1 mm were used. The principal tests were preceded with the division of material into fractions. The main part of the tests involved the sieving of each mixture, one by one, through the tested sieve. The tests were done for model mixtures varying in their particle-size composition, including the content of blocking particles ($x_b = 0-60\%$), as well as the content of the lower-size fraction K_l and the upper-size fraction K_u. The model mixtures were selected in such a way, that their composition resembles the real mixtures. The same amount of the particulate material was sieved each time. The number of blocked sieve holes was counted at certain intervals on the entire surface of the control sieve.

Such time interval was selected to ensure that the measurement was as precise as possible and that the different stages of the vibrator start-up did not affect the test. The times of the subsequent measurements were determined used the criterion:

$$t = 2^{m-1} \tag{10}$$

while m is the next natural number, different from zero, constituting the number of the next measurement. Measurements were also taken for time $t = 0$ (prior to the start-up of the laboratory vibrator). Tests were done until time $t = t_\infty$, after which the number of blocked sieve holes was constant or fluctuated within the measuring error. Granular material of the fraction of 0.1–2.5 mm was sieved for the purpose of this article. Dry and contamination-free material was used. The tests were done in accordance with applicable standards (above all: PN-ISO 565:2000).

2. Results

The authors of this paper propose an innovative description of sieve holes blocking, replacing sieve blocking coefficient f mentioned in the references. Instead, they suggest the $F_{blocking}$ coefficient expressed as:

$$F_{blocking} = \frac{number\ of\ blocked\ sieve\ holes}{total\ number\ of\ sieve\ holes} \cdot 100\% \tag{11}$$

The $F_{blocking}$ coefficient specifies the percentage number of blocked sieve holes in relation to the total number of sieve holes. According to the authors, the assumption of the $F_{blocking}$ coefficient facilitates the analysis of sieve holes blocking and is a reliable value. Characteristic courses of the sieve blocking coefficient which describes the dependence $F_{blocking}$ (Eq. 11 no percentages) and f (Eq. 1) as a function of time are symmetrical with respect to straight line $y = b$ for both cases, i.e. when $f_0 > f_\infty$ and when $f_0 < f_\infty$ (Fig. 1).

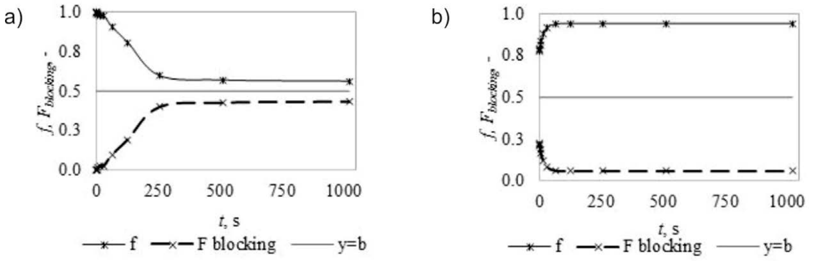

Fig. 1. Sieve blocking coefficient f and $F_{blocking}$ in the function of time for a case:
a) where $f_0 > f_\infty$ (mixture with spherical particles – agalite, 1 mm sieve, toss indicator 1.98);
b) where $f_0 > f_\infty$ (mixture with irregular particles – quartz sand, 0.5 mm sieve, toss indicator 1.5)

Rys. 1. Współczynnik zablokowania otworów sitowych f oraz $F_{blocking}$ w funkcji czasu dla przypadku:
a) kiedy $f_0 > f_\infty$ (mieszanina o okrągłym kształcie ziaren – agalit, sito 1 mm, wskaźnik podrzutu 1,98);
b) kiedy $f_0 > f_\infty$ (mieszanina o nieregularnym kształcie ziaren – piasek kwarcowy, sito 0,5 mm, wskaźnik podrzutu 1,5)

In the tests, the value of the $F_{blocking}$ coefficient for the material and sieve arrangements, as well as mixtures of varying content of blocking particles in the feed was determined. The sizes of blocking particles were assumed in accordance with dependence (Eq. 9). Next, charts for the dependence of the $F_{blocking}$ coefficient in the function of time were made (Fig. 2).

The analysis of the charts (Fig. 2) shows that the content of blocking particles does indeed have a major impact on the percentage number of blocked sieve holes for the tested arrangements (mixtures of varying content of blocking particles). Furthermore, an increase in the number of blocked sieve holes combined with an increasing content of hard-to-sieve particles may be observed. In case of a mixture with the content of blocking particles of x_b = 0%, sieve holes blocking is negligible, therefore it is justified to exclude this arrangement from further discussion. In order to precisely analyze the impact of the content of

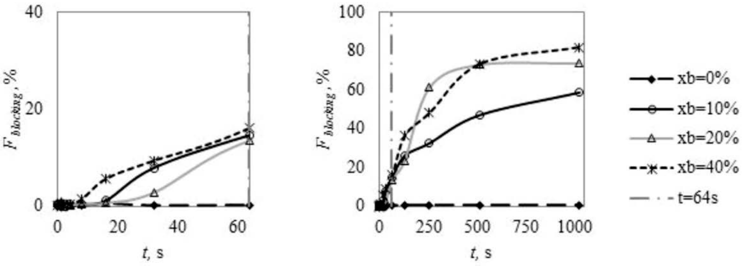

Fig. 2. The course of the sieve blocking coefficient $F_{blocking}$ in time for mixtures of varying blocking particles content x_b for time interval [0–64 s and 0–1024 s]

Rys. 2. Wykres współczynnika zablokowania $F_{blocking}$ w funkcji czasu dla mieszanin o różnej zawartości ziaren blokujących x_b w nadawie dla przedziału czasu [0–64 s i 0–1024 s] blocking particles in the feed, the duration of the sieving process was divided into two periods, i.e. [0–2^6 s] and [2^7–2^{10} s]. The division into these periods was also maintained when searching for a correlation that would make it possible to determine $F_{blocking}$ in the function of the content of blocking particles. An average value of the $F_{blockig}$ coefficient for the individual time intervals was assumed for further analysis. The assumption of an average value is justified by the division of the time interval into two periods, as a result of which an error generated by the use of an average value is not accumulated.

For time interval [0–2^6 s] a slight, linear increase in the value of $F_{blocking}$ in the function of x_b may be observed (Eq. 12):

$$F_{blocking} = 0.1105 \cdot x_b - 0.8875 \tag{12}$$

For time interval [2^7–2^{10} s] dependence $F_{blocking} = f(x_b)$ becomes a third degree polynomial (Eq. 13):

$$F_{blocking} = 0.0018x_b^3 - 0.2065x_b^2 + 7.895x_b - 57.907 \tag{13}$$

The values of determination coefficient R^2 prove the goodness of fit of the discussed models (Fig. 3).

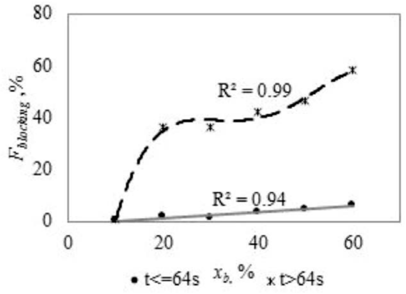

Fig. 3. The dependence of the $F_{blocking}$ in the function of varying blocking particles content x_b

Rys. 3. Zależność współczynnika $F_{blocking}$ w funkcji różnej zawartości ziaren blokujących x_b

This article also investigates the impact of the content of the lower-size fraction K_l and the upper-size fraction K_u in the feed on the value of coefficient $F_{blocking}$. For this purpose, tests results for mixtures of the same content of blocking particles and different content of the individual fractions were compared. For time interval [0–2^6 s] the sieve blocking coefficient reaches low values, while those values are higher for mixtures with a majority of the lower-size fraction diversified in terms of the content of the lower- and upper-size fractions with the same content of blocking particles x_b (2.97 maximum, Fig. 4). In time interval [2^7–2^{10} s] the values of $F_{blocking}$ are significantly higher (approx. 60% maximum) (Fig. 5). The greatest intensity of sieve holes blocking occurs for a mixture with the content of blocking particles of x_b = 40% and a majority of the lower-size fraction. Higher values of coefficient $F_{blockig}$ correspond to higher values of the differences between the individual mixtures. The obtained results of tests on mixtures of varying content of blocking particles (with a specific particle-size composition) are highly correlated with each other. An analysis of the individual dependences of the tested arrangements was performed using the Pearson's correlation coefficient with a two-tailed confidence interval in order to verify the assumptions.

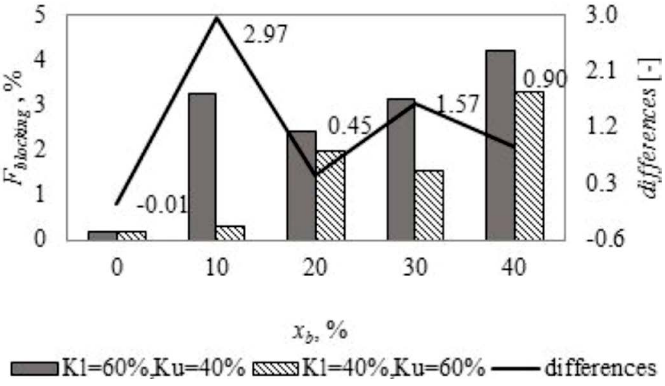

Fig. 4. Coefficient $F_{blocking}$ in the function of the content of blocking particles x_b for mixtures of varying content of the upper- and lower-size fractions for time interval [0–2^6 s]

Rys. 4. Współczynnik $F_{blocking}$ w funkcji zawartości ziaren blokujących x_b dla mieszanin o różnej zawartości klasy dolnej i górnej dla przedziału czasu [0–2^6 s]

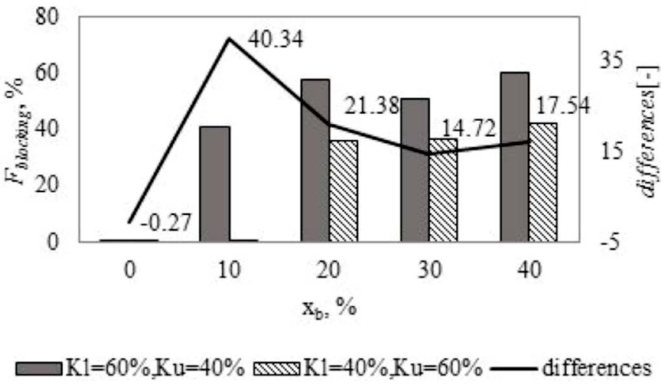

Fig. 5. Coefficient $F_{blocking}$ in the function of the content of blocking particles x_b for mixtures of varying content of the upper- and lower-size fractions for time interval [2^7–2^{10} s]

Rys. 5. Współczynnik $F_{blocking}$ w funkcji zawartości ziaren blokujących x_b dla mieszanin o różnej zawartości klasy dolnej i górnej dla przedziału czasu [2^7–2^{10} s]

The Pearson's correlation coefficient is a quantity, which describes the quality of a fitting to the original data. The values of the correlation coefficient vary from –1 to +1 (Kirch 2008; Barlow et al. 2010), where −1 indicates a perfect negative correlation, 0 – no correlation and +1 shows a perfect positive correlation. For the definition of this coefficient, let's consider the two continuous variables $\{x, y\}$ represented by the set of n data points $\{(x_i, y_i), i = 1, \ldots, n\}$ and their means: $\bar{x}, \bar{y}$ respectively. As a result of the correlation analysis, those mixtures were characterized by a high degree of correlation at the first stage, i.e. (0.8–1.0) (Evans 1996) (with the content of hard-to-sieve particles of 20, 30 and 40%, respectively). The same tendency in time interval [2^7–2^{10} s] was observed. On the other hand significant differences were characteristic of those cases of mixtures where: x_b = 0% and x_b = 10%. Furthermore, for x_b = 0% there was a conversion from a poor dependence (–0.28) in time interval [0–2^6 s] to a moderate one. In the case of the content of blocking particles of x_b = 10%, with the passage of the measurement time, there was a strengthening of the dependence – from a moderate one (0.42) for time interval [0–2^6 s] to a strong one (0.73) for [2^7–2^{10} s] (Table 1).

Table 1. Degree of correlation between mixtures of a specific content of blocking particles x_b and varying content of the individual fractions: time range [0–2^6 s] and [2^7–2^{10} s]

Tabela 1. Poziom skorelowania między mieszaninami o określonej zawartości ziaren blokujących x_b oraz różnej zawartości poszczególnych klas: zakres czasu [0–2^6 s] i [2^7–2^{10} s]

Pearson's correlation coefficient r	Content of blocking particles x_b [%]				
	0	10	20	30	40
[0–2^6 s]	–0.28	0.42	0.97	0.98	0.96
[2^7–2^{10} s]	0.54	0.73	0.99	0.86	0.96

The degree of very strong correlation was reached with the relevance of the test expressed using probability value $p < 0.05$ The observed differences in correlation, generated through the variable content of blocking particles for the mixtures (of varying particle-size composition) make it possible to conclude that this factor has a statistically significant impact on sieve holes blocking expressed using coefficient $F_{blocking}$.

Conclusions

Sieve holes blocking is inevitable and results in a reduced effective surface area of a sieve, which provides grounds for research on this topic. The blocking fraction that includes particles that are equal to or slightly larger than the sieve holes affects the number of blocked sieve holes. Accounting for coefficient $F_{blocking}$ in research on sieve holes blocking facilitates the analysis of the obtained results and seems more logical and unambiguous in comparison to coefficient f defined in previous works (Lawinska et al. 2014, 2015, 2016; Lawinska and Modrzewski 2017).

An increase in the content of blocking particles in the feed results in an increase in the percentage number of blocked sieve holes. At the initial stage of a sieving process this dependence is linear, while later on the tested dependence becomes a third degree polynomial. The content of the upper- and lower-size fractions in the feed significantly affects sieve holes blocking and, consequently- the capacity and efficiency of a sieving process. The conclusions regarding the sieve blocking coefficient drawn from the small-scale tests (using laboratory vibrators and control sieves for the purpose of covering the widest possible scope of parameters variability) could be used in industrial applications.

The research work has been carried out within: "The phenomenon of sieve holes blocking during the screening of fine-grained materials" project financed by Faculty of Process and Environmental Engineering, Lodz University of Technology (Grant 2014/501/10-34-2-1044) and this study was performed as a part of chartered assignment 501/10-34-1-7015.

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ZJAWISKO BLOKOWANIA OTWORÓW SITOWYCH DLA MIESZANIN O RÓŻNEJ ZAWARTOŚCI ZIAREN BLOKUJĄCYCH

Słowa kluczowe

sito, materiał ziarnisty, ziarna blokujące, nadawa, frakcja

Streszczenie

Artykuł dotyczy analizy zjawiska blokowania otworów sitowych przesiewaczy oraz określa wpływ zawartości ziaren blokujących w nadawie na to zjawisko. Proces blokowania polega na grzęźnięciu ziaren różnych wielkości w otworach sitowych. Jest to zjawisko znacznie obniżające wydajność procesu przesiewania. Mechanizm blokowania otworów sitowych jest w dużym stopniu przypadkowy. Do opisu blokowania oczek w sicie stosowany jest współczynnik zablokowania otworów sitowych. Ziarna blokujące to klasa ziaren równych, bądź nieco większych od wymiaru otworu sitowego. Ziarna te nie przejdą przez oczka w sicie, pozostając w produkcie nadsitowym mogą zatykać (blokować) otwory sitowe zmniejszając współczynnik prześwitu tego sita. Badania przeprowadzono na wstrząsarce laboratoryjnej i sitach kontrolnych, przesiewając kolejno mieszaniny materiałów ziarnistych o różnej zawartości ziaren blokujących oraz różnych procentowych udziałach klasy dolnej i górnej. Użyto materiałów ziarnistych o trzech modelowych kształtach ziaren: agalit (kształt kulisty), kruszywo (kształt ostrokrawędziowy) i piasek kwarcowy (nieregularny kształt ziaren). W ramach niniejszej pracy przeprowadzono również statystyczną analizę wyników uzyskanych na drodze doświadczalnej oraz przedstawiono nowy sposób opisu zjawiska blokowania otworów sitowych. Proponowany współczynnik zablokowania określa procentową ilość zablokowanych otworów w sicie w odniesieniu do liczby jego wszystkich otworów. Wymiar ziarna jest parametrem, który determinuje wartość współczynnika zablokowania otworów sita w czasie. Wzrost zawartości ziaren blokujących w nadawie skutkuje wzrostem procentowej ilości otworów zablokowanych. Zawartość poszczególnych frakcji w mieszaninie ma znaczący wpływ na przebieg procesu blokowania. Przesiewanie jest bardzo rozpowszechnionym procesem przemysłowym, a na rynku dostępne są różne warianty konstrukcyjne przesiewaczy i rodzaje sit. Fakt ten tłumaczy celowość podjęcia tej tematyki w prezentowanej pracy.

THE PHENOMENON OF SCREEN BLOCKING FOR MIXTURES OF VARYING BLOCKING GRAIN CONTENT

Keywords

sieve, granular material, blocking grains, feed

Abstract

Article is devoted to sieve holes blocking and describes the impact of the content of blocking grains in the feed on this phenomenon. The process of screen blocking involves grains of varying size being blocked in sieve holes. This is a phenomenon that significantly decreases the screening process capacity. The screen blocking coefficient f is applied for a description of screen blocking. Blocking grains are the ones which is equal to or slightly larger than the sieve holes. Those grains do not pass through the sieve holes, remain over the sieve and may clog (block) the sieve holes, thus reducing the screen clearance coefficient. The tests were done using a laboratory vibrator and control sieves, by subsequently screening mixtures of particulate materials with a different content of blocking grains and different percentage share of the upper- and lower-size fractions. Particulate materials of three model grain shapes were used for the tests: spherical, sharp-edged and irregular. The paper also includes a statistical analysis of the results obtained through experiments and an innovative method for describing sieve holes blocking. The new blocking coefficient specifies the percentage number of blocked sieve holes in relation to the total number of sieve holes. Grain size is a parameter that determines the value of the screen blocking coefficient in time. An increase in the content of blocking grains in the mixtures results in an increase in the percentage number of blocked sieve holes. The content of individual fractions in the mixture also has a significant impact on the course of sieve holes blocking. Screening is a very common industrial practice, and various designs of screens and types of sieves are available. That is why the subject of this paper is so important.