Physicochem. Probl. Miner. Process. 51(1), 2015, 15−22

www.minproc.pwr.wroc.pl/journal/

Physicochemical Problems of Mineral Processing

ISSN 1643-1049 (print)
ISSN 2084-4735 (online)

Received January 29, 2014; reviewed; accepted May 18, 2014

A METHOD FOR DETERMINING SIEVE HOLES BLOCKING DEGREE

Katarzyna Ewa LAWINSKA, Piotr WODZINSKI, Remigiusz MODRZEWSKI

Lodz University of Technology, Department of Process Equipment, Division of Granular Material Classification, Lodz, Poland; k_lawinska@interia.pl

Abstract: The aim of this paper is to describe the process of sieve holes blocking. A series of tests and their results revealed a dependence describing the value of an average screen blocking coefficient as a function of two main factors affecting the process. These parameters are the toss indicator and the content of difficult-to-screen particles in the feed. The experiments presented in the paper showed that description in mathematical terms of the sieve holes blocking process is complex and difficult. A third degree polynomial function with two variables enables determination of the value of an average screen blocking coefficient in the processes of screening for specific arrangements: screen–particle–toss indicator–content of difficult-to-screen particles.

Keywords: *screen, sieving, screen blocking coefficient, granular materials*

Introduction

Screening of particulate materials is a process which has been performed in various branches of industry. There is a large number of publications describing this process and characteristics of screening machines (Akhmadiev and Gizzjatov, 2013, Beeckmans et al., 1985). The unfavourable process of sieve holes blocking and the screen blocking coefficient, however, are neither well-known nor widely discussed. As yet, this phenomenon has not been described quantitatively for minerals processing applications. During the screening of particulate materials under industrial conditions, sieve holes are often considerably clogged, which in turn significantly decreases screening performance. The mechanism of the sieve holes blocking process is largely random.

It was reported by Feller (1980) that both partial passage and clogging of the screen should be considered in order to evaluate screen performance. A screen rate function, defined as the sum of the passage and clogging rate factors versus relative particle size, was developed to characterize screen performance. It is independent of screening

http://dx.doi.org/10.5277/ppmp150102

duration, and is not limited to a particular size distribution of the material or one screening duration. The issue of sieve holes blocking is not the only problem of this kind encountered in engineering processes used in broadly defined minerals processing. In all processes of filtrating mixtures containing post-manufacturing contaminated water, originating from water and sludge circuits, there is also clogging of holes in the filtration mesh and the clogging of the filtration deposit pores (Piecuch et al., 2013).

The sieve clearance coefficient, A_0, defined as the ratio of the holes surface area to the total screen surface area, provides information on the screening capacity of a particular screen (Sztaba, 1993). The probability of particles passing through the holes of the screen increases with the increase of this coefficient. The screen blocking coefficient f is applied for a quantitative description of screen blocking. It is defined as the ratio of the number of free holes to the total number of sieve holes. If coefficient f is combined with A_0, one obtains an effective surface area F_{ef} of the screen, i.e. the surface area through which the stream of material is passing through the sieve as seen in Eq. 1 (Wodzinski, 1997)

$$F_{ef} = f \cdot F \cdot A_0 \tag{1}$$

where F is the screen surface area. Disregarding the screen blocking coefficient may lead to significant inaccuracies in design calculations that cause a major reduction in the screen active surface area. Particles which size is similar to the sieve holes clog those holes and considerably decrease the actual clearance coefficient p (Fraczak and Wodzinski, 1999), which is one of the most important characteristics of sieves (Eq. 2)

$$p = \frac{F_{ef}}{F}\,. \tag{2}$$

A series of laboratory experiments was carried out to determine the factors which significantly affect the process of screening of fine-particulate materials (d < 1.0 mm) and very fine-particulate materials (d < 0.1 mm) (Lawinska and Wodzinski, 2012; Fraczak and Wodzinski, 1999). The tests also provided information on the parameters affecting the sieve holes blocking process. They proved that the toss indicator and the content of hard-to-screen particles have the greatest impact on the value and course in time of the blocking coefficient for various shapes of particulate materials. The toss indicator has a major effect on the screening efficiency and, consequently, on the value of the sieve holes blocking coefficient. It is defined as the ratio of the maximum inertial force to the maximum gravity force, i.e. the ratio of the maximum screen acceleration to the gravitational acceleration. Proper selection of this parameter is of great importance to the process of screening. The blocking process also occurs when there are particles in the feed which size is similar to the size of the sieve holes. Such particles are called hard-to-screen particles and they include particles that are slightly smaller, equal to or slightly larger than the sieve holes. The particles are blocked between holes edges. The blocked particles, that partially protrude from the surface of the sieve, make it more difficult for the material to move around the sieve and accelerate its impairment. Furthermore, particles that remain in the upper fraction increase the thickness of the material layer on the screen, thus reducing the probability of the rest of the material passing through the holes.

Properties of particles may be divided into chemical, energy-related and physical ones. The latter, which include particle shape, particle surface toughness, abrasion susceptibility and hardness, are determining the sieve holes blocking probability (Baic, 2013). Three model shapes of particulate materials are known: round-like particles (spherical particles), particles with sharp edges (sharp-edged particles) and particles of an irregular shape (irregular particles). Particulate materials that are used in industry may be divided between the model groups according to their shape. The conducted tests prove that the shape of particles has a significant impact on the sieve holes blocking process. For this reason, this parameter is also considered in a further analysis.

Experimental

Materials

The screening process began with the preparation of mixtures of particulate materials of various particle-size compositions. The principal tests were preceded with the separation of the material into fractions (range of 0.1 mm to 2.5 mm). This enabled the determination of the content of particles in fractions, including the hard-to-screen particles. Particles of the dimensions of $0.8 \cdot l \leq \overline{d} \leq 1.2 \cdot l$ ($\overline{d}$ – average particle size, l – sieve hole size) were assumed as the hard-to-screen particles. Weighing individual fractions and mixing them together led to the production of 10 mixtures, which content of the hard-to-screen particles amounted to x = 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%. This in turn enabled the determination of the impact of the hard-to-screen particles in the feed on the value of the blocking coefficient. Each mixture prepared in such a way weighed 1 kg. The material used for the tests was free of moisture and contamination. Because of the varying shapes of the particulate material, the tests were conducted separately for each group. Agalite particles (spherical particles), quartz sand (irregular particles) and marble aggregate (sharp-edged particles) were used for the experiments.

Methods

The mixtures were screened using a set of laboratory screens with square holes made of metal wire. The tests were conducted for five screens which hole sizes were 0.5, 0.63, 0.8, 1.0, 1.2 mm. The experiments involved a laboratory vibrator that is distinguished by linear vibrations and flexural vibrations. Regulated toss indicator provided for the assessment of the impact of this parameter on the sieve holes blocking process. The toss indicator of the laboratory vibrator used in the experiment was calculated using Eq. 3:

$$K = \frac{A \cdot \omega^2 \cdot \sin(\alpha + \beta)}{g \cdot \cos\beta} \tag{3}$$

where A is the amplitude of the vibration, ω is the vibrations frequency, β is the angle of the sieve inclination to the horizontal line, α is the angle of vibrations inclination to the horizontal line, g is the gravitational acceleration. In the experiments angles α and $\beta = 0$. The series of experiments were conducted at the value of $K = 0.62$, 1.98, 3.5 and 4.9. Such values of the toss indicator are applied when classifying materials which level of screening difficulty is "easy" or "medium". Higher values of the toss indicator are only necessary in the case of hard-to-screen materials, i.e. moist materials and those easily adhering to an open grid plate.

A control screen with the mixture was placed in the vibrator. Prior to the start of the vibrator, the blocking coefficient f_0 (for time t=0) was calculated in relation to the given particulate material at the moment of being fed onto the screen. Next, the vibrator was started and the material was screened through the sieve in time t. After the mixture was screened, the number of clogged sieve holes in five areas of the screen was counted. For this purpose, a template with cut-out frames, each covering 100 sieve holes, was used (each screen had its own template). The blocking coefficient was calculated using the ratio of free holes to the total number of sieve holes. The values of coefficient f obtained from five different areas of the screen were averaged and treated as the blocking coefficient for the given screen in the given time. Blocked particles were removed from the holes and returned to the tested mixture. Screening continued until steady state t_∞ was reached (the number of clogged holes in the screen is constant, f_∞). Such a time span was selected to ensure that the measurement is as precise as possible and that the different stages of the vibrator start did not affect the test.

Results and discussions

The tests described above provided information on the value of the screen blocking coefficient and its fluctuation in time (for mixtures of different content of hard-to-screen particles and of different toss indicators). On the basis of the obtained data a series of diagrams $f = f(t)$ was prepared (Fig. 1). The course of this dependence is similar to the exponential function model known from literature (Blasinski and Wodzinski, 1973, 1976).

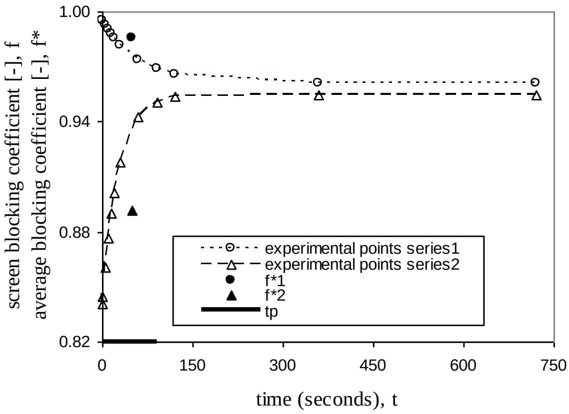

Fig. 1. Experimental screen blocking coefficient vs. time

A steady state was reached after the screening time of t=720 s. Considering the fact that the time of contact between the material and the screen is shorter in industrial processes, the obtained values of the screen blocking coefficient were averaged for each measurement series.

Time t_p is the process duration, i.e. residence time for an industrial sieve. The material residence time on an industrial sieve, in general, is from several to 90 s. The arithmetic mean from the range of $<f_0, f_{tp}>$ was assumed to be (Eq. 4):

$$f^* = \frac{\sum_{t=o}^{t=t_p} f_t}{t}. \tag{4}$$

An average value of the screen blocking coefficient f^* was obtained for each of the tested arrangements (f^*_1, f^*_2). The value of coefficient f^*, constant in time, enabled a comparison of the obtained results and drawing of diagrams f^* = f(K, x) for three model shapes of particulate materials (Figs. 2-4).

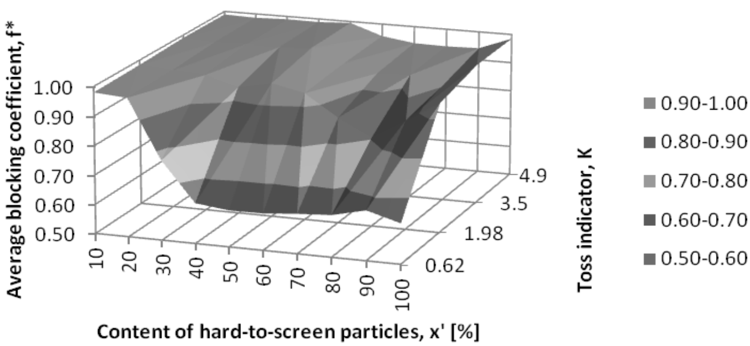

Fig. 2. Average screen blocking coefficient – spherical particles

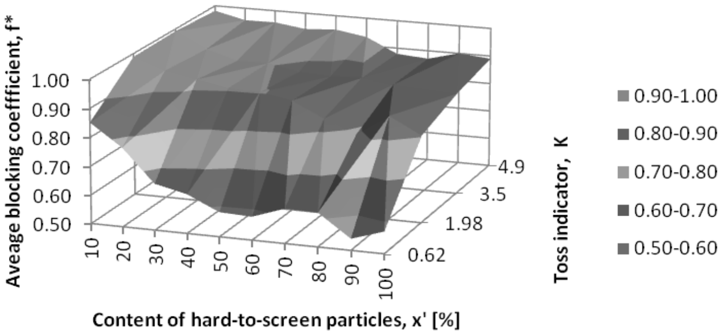

Fig. 3. Average screen blocking coefficient – irregular particles

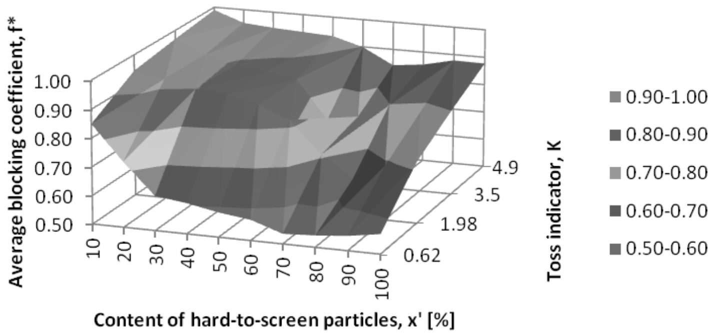

Fig. 4. Average screen blocking coefficient – sharp-edged particles

The diagrams (Figs. 2-4) confirm that the sieve holes blocking process is complex, random to a large degree and difficult to describe in mathematical terms. A significant impact of the toss indicator and the content of hard-to-screen particles on the value of the average blocking coefficient can be observed. A difference in the values of coefficient f^* for different model shapes of particles is also visible. For a sharp-edged material the value of coefficient f^* is the lowest, i.e. the greatest number of sieve holes are clogged. For this reason, the attempt to provide a quantitative description of the screen blocking process without dividing the material into various shapes is erroneous. The course of diagrams (Figs. 2-4) rules out a simple form of a typical dependence.

Mathcad13 software functions were used in order to determine dependence $f^* = \mathrm{f}(K, x)$. Mathcad is equipped with a series of commands that make it possible to perform complicated operations in a simple manner, e.g. in order to define complex functions. A program in Mathcad is a special expression comprising a series of instructions generated using program operators (Gajewski, 2011). When defining the algorithm for determining the power matrix and the values of coefficients, a model of an n-degree polynomial of a function of two variables (K, x) was analysed. The determination coefficient R^2 was also calculated in order to verify the goodness of fit of the proposed model. Coefficients R^2 for a first- and second-degree polynomial amounted to ≈0.7 and ≈0.8 respectively, which shows only a satisfactory fit. Much higher values of R^2 were obtained for a third-degree polynomial. The obtained forms of a third-degree polynomial and the values of coefficients R^2 with a division into shapes of the particulate material are listed in Table 1.

Table 1. A list of coefficients and powers of a third degree polynomial model of an average screen blocking coefficient as a function of the toss indicator and the content of hard-to-screen particles

Shape of the material	Form of a third-degree polynomial $f^* = \mathrm{f}(K, x)$	R^2
spherical shape	$f^* = -0.211K^1x^2 + 0.58K^0x^3 - 0.033K^0x^3 - 1.04K^0x^1 + 0.439K^1x^1$ $-0.025K^2x^1 + 0.945K^0x^0 + 0.192K^1xx^0 - 0.082K^2x^0 + 0.009K^3xx^0$	0.921
irregular shape	$f^* = -0.1K^1x^2 - 0.284K^0x^3 + 0.972K^0x^2 + 1.087K^0 + 0.192K^1xx^1$ $-0.00804K^2xx^1 + 0.709K^0x^0 + 0.415K^1x^0 - 0.144K^2x^0 + 0.015K^3x^0$	0.969
sharp-edged shape	$f^* = -0.086K^1x^2 + 0.57K^0x^3 - 0.0373K^0x^2 - 0.438K^0x^1 + 0.031K^1x^1$ $+0.018K^2x^1 + 0.633K^0x^0 + 0.4K^1x^0 - 0.13K^2x^0 + 0.013K^3x^0$	0.943

Table 1 provides a method for quantitative determination of an average screen blocking coefficient, considering two main factors affecting its value. The values of determination coefficient R^2 prove the goodness of fit of the discussed model. By reducing the equations given in Table 1, one can obtain three dependences for an average value of the screen blocking coefficient f^* for:

- mixtures with spherical particles

$$\begin{aligned} f^* = {} & -0.211K^1x^2 + 0.58x^3 - 0.033x^2 - 1.04x^1 + 0.439K^1x^1 \\ & -0.025K^2x^1 + 0.945 + 0.192K^1 - 0.082K^2 + 0.009K^3 \end{aligned} \tag{5}$$

- mixtures with irregular particles

$$\begin{aligned} f^* = {} & -0.1K^1x^2 - 0.284x^3 + 0.972x^2 - 1.087x^1 + 0.192K^1x^1 \\ & -0.00804K^2x^1 + 0.709 + 0.415K^1 - 0.144K^2 + 0.015K^3 \end{aligned} \tag{6}$$

- mixtures with sharp-edged particles

$$\begin{aligned} f^* = {} & -0.086K^1x^2 + 0.57x^3 - 0.0373x^2 - 0.438x^1 + 0.031K^1x^1 \\ & +0.018K^2x^1 + 0.633 + 0.4K^1 - 0.13K^2 + 0.013K^3 \end{aligned} . \tag{7}$$

On the basis of Eqs. 5–7, one can calculate the value of an average screen blocking coefficient and determine the active surface area of the screen, as well as the clearance coefficient, at the stage of planning the screening process and screening machine.

Conclusions

The screen blocking coefficient is an important parameter of each screen and the machine in which the screen is installed. The toss indicator and the content of hard-to-screen particles in the feed are the factors that have the greatest impact on the sieve holes blocking process.

Dependences given in this paper provide an evaluation of the extent of this negative phenomenon in the screening of fine-particulate materials. This information may be used for designing and optimizing industrial screening processes.

Acknowledgments

This study was performed as part of a chartered assignment W-10/1/2014 Dz.St.

References

AKHMADIEV F.G., GIZZJATOV R.F., 2013, *Separation Processes of Granular Materials by Sizes at the Sieve Classifiers*, J. Chem. Chem. Eng., 7, 56-63.

BAIC I., 2013, *Analysis of the chemical, physical and energetic parameters of coal sludge deposits inventoried in the Silesian Province*, Annual Set The Environment Protection, 15, 1525–1548.

BEECKMANS J.M., HU E., GERMAIN R., MCINTYRE A., 1985, *Performance characteristics of a probability screening machine*, Powder Technology, 43(3), 249-256.

BLASINSKI H., WODZINSKI P., 1973, *Sieve holes blocking*, Zeszyty Naukowe PŁ, Inż.Chem., Volume 2.

BLASINSKI H., WODZINSKI P., 1976, *Research process of sieve holes blocking*, Zeszyty Naukowe PŁ, Inż.Chem., Volume 6.

FELLER, R., 1980, *Screening analysis considering both passage and clogging*, Trans. ASAE, 23(4), 1054 - 1056.

FRACZAK S., WODZINSKI P., 1999, *The effect of hard-to-screen grains content in the feed on sieve blocking*, Physicochemical Problems of Mineral Processing, XXXVI Symposium, 33-47.

GAJEWSKI R.R., 2011, *MathCAD- engineering calculations and programming*, Oficyna Wydawnicza Politechniki Warszawskiej, 51-60.

LAWINSKA K., WODZINSKI P., 2012, *Determination of the effective sieve blocking coefficient*, Physicochemical Problems of Mineral Processing 48(1), 247-252.

PIECUCH T., PIEKARSKI J., MALATYŃSKA G., 2013, *The equation describing the filtration process with compressible sediment accumulation on a filter mesh*, Archives of Environmental Protection, 39(1), 93-104.

SZTABA K., 1993, *Screening*, Śląskie Wydawnictwo Techniczne.

WODZINSKI P., 1997, *Screening and screening machines*, Wydawnictwo Politechniki Łódzkiej, 20-36.