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INFLUENCE OF SELECTED WORK PARAMETERS OF THE ROLLING SCREEN OPERATION ON SCREENING EFFECTS

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Abstract: The paper deals with effectiveness of particle size separation. The investigations of limestone screening were run on a laboratory scale using a rolling screen. Batch tests were run for various batch outputs as well as different angles of deviation of motovibrators. Quantitative and qualitative effectiveness indices were calculated as well as the imperfection and probable error, which depend on the sieve mesh. A model of determining the screening effectiveness as a function of four independent variables: the amplitude of vertical vibrations of sieve decks (described by means of the angle of deviation of motovibrators), screening time, batch output and the mesh sizes of respective sieves was proposed. The results presented in the paper and the applied approach to stochastic modeling can be used under industrial conditions for rolling screens with variable dynamic parameters at different screening parameters.

Keywords: *screen, screening, effectiveness, separation sharpness*

Introduction

The size separation of particles below 3 mm in size and size separation of fine particles of about 0.1 mm in size creates numerous problems in industrial comminution circuits. It is especially connected with technological crushing and screening circuits either preparing the material for downstream beneficiation processes or producing the final fine-particle products for building industry (Gawenda 2013a, Saramak 2012, Saramak et al., 2010). The key works on mineral processing (Banaszewski 1990, Battaglia and Banaszewski 1972, Dietrych 1962, Sztaba 1993,Wodzinski 1988, Modrzewski and Wodzinski 2013, Lawinska and Wodzinski 2012, Gawenda 2013b) show many aspects of problems of screening fine particles.

Technological screening processes depend on three basic characteristic factors: technical parameters of the screen, physico-mechanical properties of screened materials and the method of conducting the screening. These factors interact, determining the

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quality and efficiency of screening. Therefore, designing and modernizing screening is important to recognize and consider all the factors of screening.

Investigations of the screening process on the rolling screen

The investigations of screening of fine 0–2 mm particles of limestone were performed with a rolling screen located in the Department of Technology and Apparatuses of Chemical and Food Industry of University of Technology and Life Sciences in Bydgoszcz (Pocwiardowski et al., 2012, Pocwiardowski and Wodzinski 2011, Pocwiardowski 2011). They aimed at analyzing a hypothesis stating that the application of vertical vibrations (vertical amplitude) at an optimum selection of remaining parameters of screening would increase significantly the effectiveness of the screening process. The investigations were carried out with a rotational screen, designed for sieving of fine particles. This machine performs a complex spatial rotational motion and the main resistance of the screening is caused by the layer of particles, not by the sieve. As known, the problem of such machines is blocking of the sieve meshes, resulting from the movement of the material on the sieve surface and adhesive susceptibility of fine particles which results in lower effectiveness of screening and separation sharpness. Therefore, to increase screening effectiveness, additional vertical vibrations (vertical amplitude) were introduced by means of the drive of two rotating motovibrators operating with mutual self-synchronization. In this way the screen obtained torsional vibrations and additional vertical ones. It was possible to install five screen decks with different sieve meshes in the screen and to change the angle of motovibrators i.e. the alternation of amplitude values of vertical vibrations, as presented in in Table 1. In this way the screen has become an important experimental base, enabling to evaluate both the effects and dynamic parameters of the screening process and the parameters of declassified fractions of fine-particle material.

Table 1 lists the selected (optimum) parameters of screen operation used during laboratory tests (Pocwiardowski et al., 2012, Pocwiardowski and Wodzinski 2011, Pocwiardowski 2011). The frequency of vibrations was constant an equal to 1500 s^{-1}. For registration the amplitude volume a PULSE system of Bruel and Kjaer was

Table 1. Values of amplitudes for respective angles of deviation of motovibrators and for the data of screen decks in mm. Data were taken from Pocwiardowski et al., 2012, Pocwiardowski and Wodzinski 2011, Pocwiardowski 2011

Sieve mesh [mm]	Angle of motovibrators [^{o}]			
	20	30	45	50
0.1	0.22	0.34	0.49	0.54
0.2	0.31	0.41	0.53	0.59
0.4	0.29	0.40	0.54	0.60
0.8	0.31	0.46	0.58	0.62
1.6	0.30	0.43	0.58	0.62

applied. The sensor in this set measures the amplitude of vibration in three dimensions of XYZ axes. The sieve meshes were 0.1, 0.2, 0.4, 0.8 and 1.6 mm. Material moisture was 0.14%. In order to investigate the accurate screen work and its efficiency the authors provided analyses according to the sampling of the performed screening process of different screen capacities, i.e. 12, 19 and 26 kg/h.

The results obtained in the screening experiments were used to evaluate indices of the screening process such as screening effectiveness, imperfection and probable dissipation. Applying these indices the authors analyzed the correlations of screen work and screening effects as well as determined the model of screen work.

Analysis of effects of rolling screen performance

Evaluation of screening effectiveness

Qualitative and quantitative effectiveness values were taken into account to estimate technological criteria of effectiveness of the screening process. When evaluating effectiveness, as a rule the recovery of the finest size fraction, denoted either as S_i or ε_d in the undersize product is taken into consideration, determining quantitative effectiveness (Sztaba 1993):

$$S_i = \gamma_d \frac{a_{dd}}{a_{nd}} = \varepsilon_d \ [\%] \qquad (1)$$

where: γ_d –yield of the lower (undersize) product [%], a_{nd} –content of fine particles in the feed [%], a_{dd} –content of fine particles in the lower product [%], which should be equal to 100%.

Table 2. Average quantitative effectiveness S_i for different angles of deviation of motovibrators and average batch screening outputs Q_1=12, Q_2=19 and Q_3=26 [kg/h]

Capacity	Q_1				Q_2				Q_3			
Sieving time [h]	0.5	1.0	1.5	2	0.5	1.0	1.5	2	0.5	1.0	1.5	2
motovibrators angle, [°]												
20°	99.0	90.8	85.8	81.7	99.4	87.3	81.1	77.1	89.0	77.4	71.4	65.5
30°	99.2	96.6	92.4	91.0	98.9	93.8	88.8	84.6	97.4	93.6	89.9	87.0
45°	99.0	98.9	98.1	97.7	98.8	98.5	98.5	98.2	98.5	98.2	97.3	95.1
50°	98.4	98.3	98.2	97.9	97.6	97.6	97.4	94.0	99.0	98.7	96.1	91.3

The effectiveness values were calculated for each sieve in the set, for each angle of deviation of motovibrators and for every output Q, according to the assumptions of experiments (Table 1). Table 2 presents average effectiveness for the whole set of the sieves.

While analyzing the data it can be observed that the most favourable screening results, regardless of the time of execution of the experiment, were obtained for the 45^0 angle of deviation of motovibrators (amplitude of vertical vibrations equal to 0.49-0.58 mm) at average output of $Q_1 = 12$ and $Q_2 = 19$ kg/h. The obtained effectiveness was over 98%. For the output of $Q_3 = 26$ kg/h the most favourable results were also obtained in relation to the remaining values of angles of deviation of motovibrators but slightly worse than those at the output of Q_1 and Q_2. It proves that Q_3 value was too high for the machine due to which a part of the material could not be sieved properly because of the too thick layer of material on the sieves, i.e. too high screen overload.

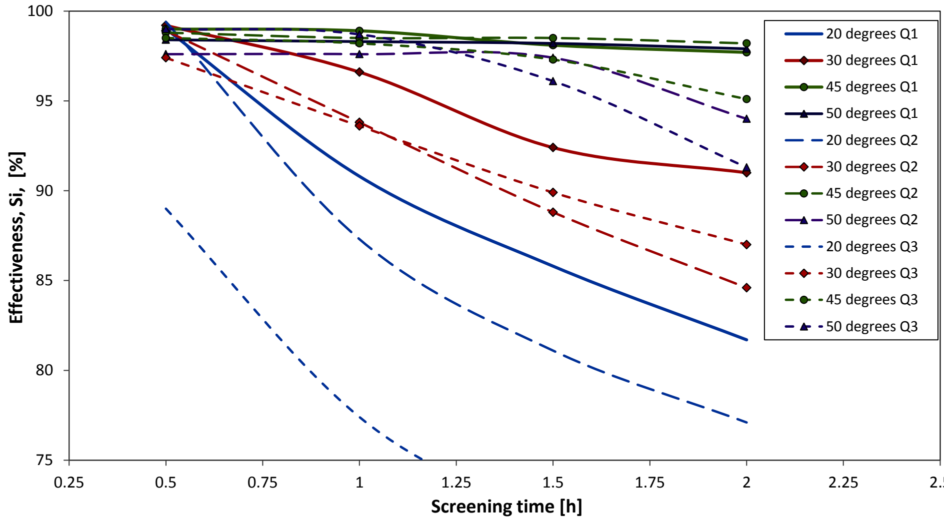

Fig. 1. Relationship between screening time and the results of quantitative effectiveness

The decrease of sieving effectiveness with time of the experiment was also observed, especially for angles equal to 20° and 30°. It was caused by blocking of sieves, especially those of finer meshes, and the fine particles, instead of passing through the sieves, were transported together with the upper product, forming the so-called subparticle. It is confirmed by the results of analysis of dependence between the time of screening and quantitative effectiveness, presented in Fig. 1. It can be easily observed that for the angles of 45° and 50° the best average effectiveness values were obtained, regardless of experiment duration, because the increase of the amplitude of vertical vibrations prevented the sieves from blocking by the so-called difficult and fine particles as well as from gluing by means of adhesive forces.

Screening effectiveness is significantly connected and directly proportionally with the dimension of sieves in the screen which was shown more precisely when analyzing correlative relations further on. Qualitative effectiveness was calculated according to formula:

$$Sj_2 = 100 - a_{gd} \ [\%] \qquad (2)$$

where: a_{gd} – content of fine particles in the oversize product [%]. Sj_2 was calculated for each angle of deviation of motovibrators and for each sieving output Q.

Table 3 presents the results in the form of average effectiveness values for the whole range of sieves for different angles of deviation of motovibrators and average batching efficiencies.

Table 3. List of values of average qualitative effectiveness for different angles of deviation of motovibrators and average batch screening outputs $Q_1 = 2$, $Q_2 = 19$ and $Q_3 = 26$ kg/h

Capacity	Q_1				Q_2				Q_3			
Sieving time [h]	0.5	1.0	1.5	2	0.5	1.0	1.5	2	0.5	1.0	1.5	2
motovibrators angle, [°]												
20°	99.0	97.2	95.6	93.3	99.4	92.9	88.9	85.3	94.1	88.5	82.9	76.9
30°	99.0	98.5	97.3	97.0	99.0	97.7	95.7	93.8	98.1	97.1	95.9	94.7
45°	96.8	97.3	97.3	96.9	97.6	98.3	98.6	98.5	97.3	97.9	97.8	95.7
50°	95.0	96.1	96.9	96.9	96.0	97.2	97.2	94.0	98.3	98.1	95.8	93.3

According to the collected results it can be easily observed that, similarly as in the case of quantitative effectiveness, regardless of the duration of the experiment, the most favourable screening results were obtained for 45^0 angle of deviation of motovibrators (amplitude of vertical vibrations 0.49-0.58 mm). The results for the remaining angles are characterized by much larger scatter, which indicates an inappropriate selection of process dynamic parameters, which affects sieve blocking, improper distribution of material on the sieve, lack of mixing of the material layer and prevention of contact of fine particles with the sieve surface.

Evaluation of imperfection and separation sharpness

The work of a screen can be characterized by such indices as productivity and efficiency, connected with effectiveness and separation sharpness. The authors applied the method of determining the cut size d_{50}, imperfection index I and separation sharpness in the form of probably error E_p for analytical investigations of the screening results according to the performed sampling and analyses. Separation sharpness, i.e. probable error E_p, was calculated from the formula (Kelly and Spottiswood 1989, Drzymala 2007):

$$E_p = \frac{d_{75} - d_{25}}{2} \ [\text{mm}] \qquad (3)$$

where: d_{75} – 75 percentage particle size, d_{25} – 25 percentage particle size.

Imperfection index I was calculated from the formula (3):

$$I = \frac{E_p}{d_{50}} \tag{4}$$

Table 4. The values of imperfection and probable error for 45° angles of deviation of motovibrators and average batch screening outputs $Q_1 = 12$, $Q_2 = 19$ and $Q_3 = 26$ kg/h

Sieving time [h]		0.5	1.0	1.5	2
		Q_1			
Sieve mesh [mm]					
0.4	I	0.1681	0.1682	0.1685	0.1685
	Ep [mm]	0.1518	0.1519	0.1521	0.1519
0.8	I	0.1700	0.1703	0.1698	0.1691
	Ep [mm]	0.0767	0.0768	0.0766	0.0763
1.6	I	0.0264	0.0222	0.0219	0.0217
	Ep [mm]	0.0329	0.0278	0.0274	0.0272
		Q_2			
0.4	I	0.1692	0.1691	0.1689	0.1688
	Ep [mm]	0.1527	0.1526	0.1524	0.1523
0.8	I	0.1714	0.1732	0.1729	0.1716
	Ep [mm]	0.0772	0.0780	0.0779	0.0773
1.6	I	0.0214	0.0206	0.0203	0.0202
	Ep [mm]	0.0268	0.0257	0.0254	0.0253
		Q_3			
0.4	I	0.1690	0.1689	0.1688	0.1686
	Ep [mm]	0.1525	0.1525	0.1523	0.1521
0.8	I	0.1718	0.1718	0.1705	0.1699
	Ep [mm]	0.0771	0.0772	0.0766	0.0763
1.6	I	0.0217	0.0206	0.0204	0.0203
	Ep [mm]	0.0272	0.0258	0.0255	0.0253

The smaller values for these indices (close to 0) are obtained, the more accurate is the process. In this way the values of imperfection and probable errors were determined for different angles of deviation of motovibrators. The values of indices I and E_p, calculated for sieves of 0.4, 0.8 and 1.6 mm for 45° angles of deviation of motovibrators are shown in Table 4.

Analyzing the results it can be observed that both the screening time and process productivity do not influence significantly the values of imperfection and probable error whereas both indices decrease with the increase of sieve dimensions.

For the sake of comparison, Fig. 2 presents the values of indices of imperfection and probable error for the angles of 20, 40 and 50^0 of deviation of motovibrators. It can be observed, for the angle of 20^0 the values of I and E_p are higher than for 45 or

50^0. This confirms that less accurate separation of material occurs at lower amplitudes. For 45 and 50^0 the values I and E_p are close to each other. It means that both amplitudes have been chosen properly for the process.

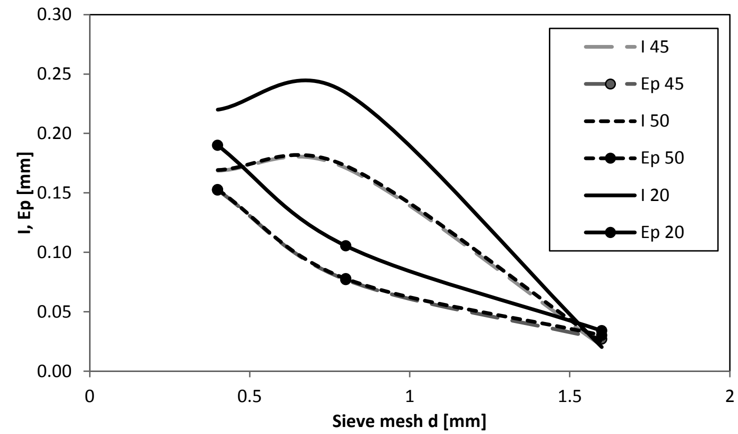

Fig. 2. Dependences of imperfection (I) and probable error (E_p) for the angles of 20, 45 and 50° for the sieves of 0.4, 0.8 and 1.6 mm (curves I_{50} and I_{45}, similarly as E_{p50} and E_{p45}, overlap)

To make the screening process run optimally in industrial conditions, the set of dynamic parameters of the rolling screen should be selected properly. Here the most important role is played by the amplitude since with its increase the screening accuracy is greater.

Analysis of correlations of parameters of the screen work and screening effects

Table 5 presents correlations between the effectiveness (S_i) and analyzed independent variables, like the amplitude of vertical vibrations of sieve decks (described by means of the angle of deviation of motovibrators), screening time, efficiency/productivity understood as a batch screening output and the mesh sizes of respective sieves. The frequency of rotations was constant and was 1500 rotations/minute.

Table 5. Correlation coefficient values between screening effectiveness (S_i) and selected process parameters

Independent variable	Correlation coefficient, R
Screening output	–0.148
Amplitude	0.484
Screening time	–0.260
Sieve mesh	0.410

All the correlation coefficients are significant at the 95% confidence level. Screening effectiveness S_i, according to Table 5, is the most strongly connected with the value of amplitude of vertical vibrations (which increases with the growth of the angle of deviation of motovibrators). The size of the sieve mesh reveals a slightly lower correlation with S_i value. Both variables are positively correlated with screening effectiveness S_i which means that it grows with the increase of amplitude of vertical vibrations and mesh size.

The screening time and output are negatively correlated with the S_i which means that quantitative effectiveness decreases with the growth of screening time or the output. Screening efficiency is the lowest variable correlated with the effectiveness. The negative correlation between quantitative effectiveness and screening time can be explained by the fact that sieves were blocked, especially for low values of amplitudes of vertical vibrations. This is important because when the working parameters of the screen are properly selected, the sieve should not be blocked and it is logical that the longer is the process of screening, the more accurately the material is sieved. That means that effectiveness S_i should grow but, on the other hand, the longer the process, the more material passes on the sieve deck and more probably the sieves could be blocked. Disregarding the type of materials used for the production of sieves, they should clean easily as a result of vertical vibrations whereas at too high amplitudes the sieves (wire bridges) can throw fine particles, preventing them from passing the meshes.

Model of work of the rolling screen

The determination of the model of work of the screen was carried out with the application of multiple regression. The general functional model of screen work effectiveness, i.e. screening effectiveness, can be represented by means of the following equation:

Quantitative effectiveness $S_i = f(\text{amplitude, time, output, sieve mesh})$ (5a)

According to the performed calculations the following model of screening effectiveness was obtained for the analyzed screen:

Quantitative effectiveness $S_i = 76.56 + 56.12A - 0.44B - 7.88C + 19.86D$ (5b)

where: A – amplitude of vertical vibrations (angle of deviation of motovibrators, B – the output, C – screening time, D – sieve mesh.

All model indices are significant, therefore all independent variables affect significantly the change of screening effectiveness S_i. The amplitude of vertical vibrations reveals the highest influence upon effectiveness of screening, i.e. effectiveness increases by 5.6% on the average with the growth of amplitude by 0.1 mm. The mesh size is another variable; effectiveness increases by 1.9 % with the growth of mesh size by 0.1 mm. The process efficiency, in turn, has reasonably low influence upon effectiveness. The model accuracy reaches an average level and is equal to $R^2 = 0.418$ which means that about 42% of effectiveness is explained by this model. The remaining 58% of the unexplained effectiveness is caused by other factors, not included in the discussed considerations, which may have some influence (e.g. frequency of vibrations and moisture, already accepted as constants and errors connected with averaging of samples).

When the work effectiveness of the screen is evaluated, attention should be drawn to the problem of decrease of screening effectiveness with increasing duration of screening. When the time of screening is prolonged, its efficiency is limited and it should increase its effectiveness. The decrease of screening effectiveness with the growth of its duration, as observed during the tests, cannot be accepted. This phenomenon can be explained by filling the sieve meshes with the passage of time. This problem is strictly connected with the value of toss index. The index affects not only the conditions of segregation of the material layer but also promotes the sieve opening to be free of particles (Banaszewski 1990, Battaglia and Banaszewski 1972, Dietrych 1962, Sztaba 1993).

The toss index can be calculated from the formula:

$$u = \frac{A\omega^2}{g}\frac{\sin\gamma}{\cos\beta} \tag{6}$$

where: A – amplitude of vibrations in mm, ω – frequency of vibrations in rad./s, β – angle of deviation of sieve deck, γ – angle of deviation of forced force, g – acceleration of gravity m/s^2.

The condition of motion of the screen with the particle toss is: $u > 1{,}2$. It can be observed in Table 6 that this condition is fulfilled at the rotations n = 1500 s^{-1} only for the amplitude of about 0.5–0.6 mm. The above calculation is in agreement with the experimental results for which at the amplitude <0.5 mm the decrease of screening effectiveness occurred with lengthening of time. The condition of proper work of the tested screen consists in, apart from obtaining a spatial motion of the screen, maintaining the toss index at $1.2 < u < 1.5$. This condition is especially significant for the sieves with the smallest meshes.

Table 6. The calculated toss indices for different values of vibration amplitudes

n [s^{-1}]	u		
	A = 0.4 mm	A = 0.5 mm	A = 0.6 mm
1500	1.00	1.26	1.51

Summary

According to the analyses of quantitative and qualitative effectiveness the most favourable screening results, regardless the time of the experiment execution, were obtained for torsional and vertical vibrations for the angles of 45^0 of motovibrators (the amplitude of vertical vibrations was 0.49-0.58 mm). A too low amplitude will cause blocking of sieve openings, lack of mixing of the material layer and preventing the fine particles from contacting the sieve surface and thus the decrease of effectiveness of the screening process.

The best indices of the particle size classification by screening (high effectiveness of about 98% and good separation sharpness in the form of probable error under 0.17 mm were achieved in the laboratory conditions in the rolling screen at vibration frequency 1500 s^{-1}, amplitude 0.49-0.58 mm and toss index 1.2-1.5 of value g, at the screen load from 8 kg/m^2h for the 0.1 mm sieve up to 16 kg/m^2h for the 0.8 mm sieve.

The obtained results involving a laboratory screen and the applied approach to stochastic modeling can be used in industrial screening using rolling screens with variable dynamic parameters for different screening conditions.

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