The screening process can be also be treated as a random process. The probability of particle screening **P**screening depends on many factors and it can be written as: n P

where symbols P1, P2 ..., Pn refer to probability of components of the process. The probabilities of any process can be combined into groups. In our case they can be gathered into three groups, i.e. probability reflecting the size and shape of particle (Pz), probability referring to screen geometry Ps, and probability Pr dealing with the mode of screen movement in which the screen surface is installed, i.e.:

Pscreening= P P P , z s r (4.13)

which was schematically shown in Fig. 4.7.

Various expressions for probability of screening for other cases, especially for different modes of screen movement are offered in the literature. Probability of screening of a free single particle which is ejected during screening (Fig. 4.6 and Fig. 4.8) is expressed by the relation (Sztaba, 1993; Gaudin, 19

$$P_g = \left[\frac{(d_t + a) - (a + d)\cos\alpha_0}{d_T + a}\right]\left[\frac{(d_t + a) - \left(\frac{a + d}{2}\right)\left(\frac{\sin(\theta + \alpha_1) + \sin(\theta - \alpha_1)}{\sin\theta}\right)}{d_t + a}\right] \quad (4.20)$$

where:

θ – angle of particle fall or angle of approach

α_0 – critical angle is determined by the relation:

$$\cos\alpha_0 = \frac{1 + \sqrt{1 + 8m^2}}{4m}, \quad (4.21)$$

θ – angle of particle fall or angle of approach

αo – critical angle is determined by the relation:

and α_1 and α_2 are positive roots of the equation

$$4m^2 (k^2 + 1) \cos^4 \alpha - 4mk (k^2 + 1) \cos^3 \alpha - (4m^2 - 1) (k^2 + 1) \cos^2 \alpha + \\ + 2m (k^2 + 2) \cos \alpha + m^2 k^2 - 1 = 0,$$

in which $k = \mathrm{tg}\ \alpha_u$ and α_u is the angle formed with the screen plane by the line connecting the center of particle gravity with the cross-section centre of a wire forming the screen at the moment of particle touching the wire (screen bridge) ($\alpha_0 \leq 90^0$) and:

$$m = \frac{2d_t + a - d}{a + d}. \qquad (4.22)$$

in which k = tg αu and αu is the angle formed with the screen plane by the line connecting the center of particle gravity with the cross-section centre of a wire forming the screen at the moment of particle touching the wire (screen bridge) (α0

According to Sztaba (1993) there is a considerable difference between the probability formulas and the results of actual screening. Therefore they are seldom used in practice

Usually it is assumed that the kinetics of screening conducted in a periodical way can be described with the first order differential equation: vp i = –dλi /dt = ki λi, (4.23) where vpi determines the speed of passing of certain particles having certain properties through the screen.

Screening involves only the particles smaller than the screen aperture and it will not be a great error to assume that a particle of given properties can be represented by

a narrow size fraction i of the feed. In Eq. (4.23) λi represents the content of fraction i in the product on a screen surface at particular moment of screening time t. For periodical processes at t = 0, fraction i content on the screen is equal to the content of this fraction in the feed, i.e. αi. For a long time of screening λi assumes constant low value, while in the case of ideal screening this value equals zero.

In equation (4.23) ki is the constant of screening rate of particular class of particles. Negative sign in this equation means that the screening rate decreases as the content of particles capable of being screened decreases.

In Eq. (4.23), instead of the content of particular size fraction of particles, one can use particle i mass, the number of particles or their volume, but then constant k value will be different. After solving differential equation (4.23) one obtains general relation describing concentration of the fraction on the screen surface at particular moment of periodical process: $\lambda_{i,t} = \alpha_i \exp(-k_i t)$,

$$\lambda_{i,t} = \alpha_i \exp(-k_i t) \qquad (4.24)$$

where α_i denotes content of i size fraction in the feed. For the description of a continuous screening, Eqs (4.23) and (4.24) should be modified because screening efficiency also depends on location of particle on the screen surface, as well as on the speed of feeding, but not on the time which has passed since the initiation of screening took place. For a continuous screening, when particle movement is not restricted by other particles, the speed of free screening v_s expressed as a change of flow of material mass subjected to screening on a screen surface per unit time and per screen unit width at a particular place at a distance L from the point of feed addition per unit length L change, has the following form (Kelly, Spottiswood, 1982):

$$v_s = -dI_L / dL = k_s I_L, \quad (4.25)$$

$$v_s = -dI_L / dL = k_s I_L, \quad (4.25)$$

where: I_L – specific rate, i.e. the flow of material mass per unit time and screen unit width at a particular place

L – distance between considered place on the screen and the point of material feeding for screening

k_s – rate constant of the process.

The constant of the process rate k_s depends on the kind of particle size fraction i. Therefore, introducing the content of the size fraction λ_i in the feed, leads to the following equation:

$$-d(I_L \lambda_{iL}) / dL = k_s I_L \lambda_{iL}, \quad (4.26)$$

$$-d(I_L \lambda_{iL}) / dL = k_s I_L \lambda_{iL}, \quad (4.26)$$

where λ_{iL} is the size fraction content i on the screen at place L measured as the distance from the front of the screen towards the movement of the screened material. After integrating, one can obtain:

$$I_L \lambda_{iL} / I \lambda_i = \exp(-k_s L). \quad (4.27)$$

$$I_L \lambda_{iL} / I \lambda_i = \exp(-k_s L). \quad (4.27)$$

Since $I_L/I_{L=0} = I_L/I = \lambda_s$, the ratio of the stream of material on the screen at a particular point of screen length and the stream of material at the initial point of the stream, i.e. the feed stream, it is the yield of the material on the screen γ_s. As $\lambda_i = \alpha_i$, i.e. the content of particular size fraction in the feed and since $\gamma_s \lambda_{iL}/\alpha_i = \varepsilon_{-i}$, as well as since the recovery on the screen in the product passing through the screen is $\varepsilon_{+i} = 100\% - \varepsilon_{-i}$, the following relation is obtained (Kelly, Spottiswood, 1982):

$$(100\% - \varepsilon_{+i})/100\% = \exp(-k_{si} L). \quad (4.28)$$

When a large amount of particles is subjected to screening, they can mutually interact, e.g. when the particle layer is very thick, only the particles close to the screen surface undergo screening. The particles which become screened are immediately replaced by similar particles from higher layers. Then, screening can be determined with the use of equation of zero order kinetics (Kelly, Spottiswod, 1982):

–dIL/dL = kc, (4.29)

in which kc is constant of moving particle for a hindered screening. Since, like in the previous case, each size fraction of particle has its own rate constant, therefore:

–d (ILλiL)/dL = kci λiL. (4.30)

To calculate the yield of particular size fraction of particles in the screened product up to a selected location on the screen, the following formula can be applied:

∫ − − + = L L i ci I dL k 0 ln / (100% ε 100%) , (4.31)

which requires integrating expression dL/IL within L ranging vales from zero to the point on the screen length where the screening is hindered. For a continuous screening, very often the initial part of separation can be described using equation for the hindered screening, while in the lower part of the screen with the formula for a nonhindered screening. From the so far presented equations a strong relation between the yield of a particular size fraction and the screening rate is visible. It is also called the output. The output can be expressed as the quantity of screened feed, component or particular fraction. The screening speed can be expressed not only in terms of mass per unit time or per mass unit or even per screen width unit, but also per time and surface. Sztaba (1993) calls it the unit output. According to Malewski (1990), the rate constant for selected size fraction and for non-hindered, periodical screening can be expressed by the relation:

$$k_{si} = k_{0.5}\left[2\left(1-\frac{d_i}{d_t}\right)\right]^{\delta}, \qquad (4.32)$$

where: k0.5 – constant of screening rate for particle size equal half the size of the screen mesh δ – constant. The constant of the screening rate k0.5 depends on many parameters of screening: k0.5 = 3600 VBWφsCds/Qo, (4.33) where: V – speed of material moving on the screen, m/s B – screen width, m W – moisture function effecting screening (for dry material W=1) ϕ – constant dependent on the scale on which screening takes place, also called the scale factor s – clearance factor (s = [di/(di+ ad)]2) c – constant determined empirically, is dependent on screen inclination di – screen opening diameter, m Q0 – intensity of the stream of feed, m3 /h ad – screen wire thickness (size) d – particle diameter. The final formula for the recovery of selected size fraction i of screening as a function of screening time, has the form

εi = 1 – exp[– t ki] = 1 – exp [– t 3600 VBWφsCds [2(1 – d/dt)]δ /Qo] 100%. (4.34)

There are numerous empirical equations describing screening for particular screens and material (Malewski, 1990); Banaszewski, 1990; Sztaba, 1993). For a continuous screening screens most often the equation involves the intensity of the stream in the form of feed stream or stream of selected products or components (fractions) as a function of the recovery of selected particles, also called the screening efficiency. Selected approximate formulas of these relations are shown in Table 4.4

Table 4.4. Selected approximate formulas for mass yields of continuous screening

Author	Formula	Source
Nawrocki	$Q = 900Fn^{0.5}sd_t\rho_u v_m\ C/Sb$ (Mg/h)	Banaszewski, 1990
Kluge	$Q = FQ_jW_gW_d\,SHM$ (Mg/h)	Banaszewski, 1990
Olewski	$Q = 2.23\cdot10^{-4}(100 - \varepsilon)\ d_t\,p_c\,\rho_u$ (Mg/h)	Sztaba, 1993

Q – effective efficiency (mass stream) of the feed at a given recovery.

Q – effective efficiency (mass stream) of the feed at a given recovery.

The Nawrocki formula: n – frequency of vibration, min–1, s – coefficient of openings area, dt – side size of screening material (feed), Mg/m3 , vm– velocity of material on the screen, m/s, C– screening difficulty coefficient, S – screening efficiency coefficient, b – material viscosity coefficient.

The Kluge formula: F – screen surface area, Qj – unit output depending on the screening surface opening and type of screened material, Mg/(h·m2), Wg– coefficient depending on content (in %) of particles greater that the screen openings, Wd – coefficient dependent on the content (in %) of particles smaller than the half size of the screen aperture, S – coefficient depending on requested efficiency of screening; H – coefficient depending on type of screening (wet or dry) and appropriate size of screen openings dt;

M – taking into account number of decks in one riddle, for the first deck M = 1, for a second M = 0.9, while for third M = 0.75. Coefficients Wg, Wd and S can be determined using nomograms available from Banaszewski (1990)

The Olewski formula: pc – surface area of working part of screen, m2 , ε – recovery of undersize product, dt – screen surface opening, ρu– bulk density of the material. The formulas given in Table 4.4 are often complicated, although they represent only approximate versions. According to Banaszewski (1990) a correct determination of the screening output can be done only by experienced specialists who are skillful in estimating the influence of many parameters on the process. Classification of screeners, after Banaszewski (1990) is shown in Fig. 4.9, and after Kelly and Spottiswood (1982) in Fig. 4.10.

4.5. Other parameters of screening

There are many other parameters used for delineation of screening including transport efficiency, screen load, etc. Detailed discussion of these issues are presented in monographs of Sztaba (1993), Banaszewski (1990).

4.6. Analysis and evaluation of screening

Screening is mostly applied as the method for separation of the feed into size fractions. The results of screening of particles is most often analyzed as classification that is the content of size fractions (their quantities) as a function of their name or size numerical value. In order to perform such an analysis, a mass balance of selected size fractions has to be made. A selected size fraction can be treated as a component and its behavior in the screening system can be analyzed from the upgrading perspective. In the upgrading approach the quality and quantity of a selected size fraction is taken into account and balanced. A third approach, splitting, takes into account only the amount of products produced by screening and its name.

4.6

Screening is one of few processes which can be easily described in those three ways. The details of analysis and assessment of screening in the view of division into products (splitting), classification and upgrading have been described in a previous chapter.