A model is proposed for the process of screening of a surface by expelled and reflected particles in a dust flow together with a method for evaluating the screening effect in the vicinity of the body's critical point.

When a dust flow occurs over a body reflected particles and particles of body material eroded from the surface may collide with other particles moving toward the surface. A portion of their kinetic energy is then absorbed and changes the direction of particle motion changes, producing the so-called screening effect, which leads to a decrease in intensity of material removal as compared to its value in the absence of particle collisions.

The phenomenon almost always occurs to some degree when a flow holding solid particles acts on a body. For example, formation of a screening layer is possible in dusty flows in various energy generation devices which use solid fuel, in gas supply equipment channels, in air- gas-dynamic tubes carrying two-phase flows, in incidence of a two-phase jet on an obstacle, in motion of a body in a dusty atmosphere [1-3], etc.

The screening effect affects the service life of components in various pieces of equipment, so that its study is a problem of practical importance.

This question was examined some time ago in experimental studies [1-3] and theoretical investigations [4, 5]. However those studies offered no concrete recommendations for quantitative evaluation of the changes in intensity of material removal $G$ when the screening effect is considered. Such estimates are possible on the basis of the model of this process proposed by the present author in [6].

It should be noted that consideration of the effect of body surface screening by reflected particles on erosion removal of material in the general case is a remarkable complex multiparameter problem. Therefore, in developing a mathematical model it is desirable to limit consideration to the most significant parameters in the vicinity of the body's critical point. Other limitations and assumptions will be noted in the course of developing the model.

We will consider Fig. 1a, which schematically depicts a model of the screening layer. Here $x_i$ is the mean radius of some $i$-th annular section of the surface with width $\Delta$; $x_n$ is the radius of the circle on the surface of the body for which the intensity of $G$ is calculated with consideration of screening.

Upon collision with the body the dust particles rebound from the surface with some velocity $v_2$, and remaining within the confines of a layer of thickness $h$, are set in motion by the gas and removed from the surface with a velocity $W_p$, together with fragments of abraded surface material. Since in the vicinity of the critical point (above the body surface) within the limits of the layer $W_p << v_p$, it is obvious that accumulation of particles is possible here, with increase in particle concentration, as follows from the equation of conservation of particle flow

$$2\pi \rho_m \left( \rho_p v_p + \rho_m v_m \right) \sum_{i=0}^{n} x_i = \frac{2\pi n \rho_m}{6} \sum_{i=0}^{n} \lambda_{0} \rho_{c} \sum_{i=0}^{n} w_{pni},$$

where $\rho_m$ is the density of the mechanical mixture of particles, assuming (arbitrarily) along the surface of the continuous layer; $n = x_n / \Delta$ is the number of divisions of the radius $x_n$ into segments of width $\Delta$; $\lambda$ is the number of particle centers ($1/m^2$) in the screening layer (of thickness $h$) in a projection on a plane perpendicular to the velocity vector $v_p$. 

According to the rule of mixtures, for \( \rho_m \) we find the expression

\[
\rho_c = \rho_p \left( \frac{G + 1}{G_0 \rho_p + 1} \right),
\]

where \( G = \left( \rho_w u_w \right)/\rho_0 v_p \). Then from Eq. (1), using Eq. (2), we have

\[
\frac{6}{\pi} \frac{\rho_p v_p \left( G_0 \rho_p + 1 \right) R_N}{\rho_p v_p d_p^n} = \sum_{i=0}^{n} \frac{x_i}{w_{pi}},
\]

where

\[
\bar{w}_{pi} = \frac{w_{pi}}{v_p}; \quad \lambda = \sum_{i=0}^{n} \lambda_i; \quad \bar{x}_i = \frac{\lambda}{R_N} \left( \frac{1}{2} + i \right), \quad i = 0, 1, 2, \ldots, n
\]

(at \( i = 0 \), \( \bar{x}_i \) corresponds to the mean relative radius of a circle, and at \( i = 1, 2, \ldots, n \), to a ring).

Equation (3) will allow us to evaluate the effect of various parameters on the increase in density of the layer above the surface by reflected and abraded particles.

In view of the possibility of intercollision of particles upon their approach to the surface the intensity of mass removal \( G \) must be considered in a probability formulation as the sum

\[
G = G_0 p_0 + G_{11} p_1 + \cdots + G_{mn} p_m,
\]

where \( G_0, p_0 \) are the intensity of mass removal and the probability of its existence for free (collisionless) particle flight; \( G_{mn} p_m \) is the mathematical expectancy of the intensity and its corresponding probability for repeated collisions. Then, for example,

\[
G_{11} = G_1 + G_2,
\]

which indicates the sum of the intensities of removal created by primary (unperturbed) particles \( G_1 \) and secondary particles \( G_2 \) which have experienced collision with primary particles.

To calculate the probabilities \( p_0, p_1, \ldots, p_m \) we use Poisson's law

\[
p_m = \frac{\alpha^m}{m!} \exp(-\alpha),
\]

where \( m = 0, 1, 2, \ldots \) are possible values of events; \( \alpha = \pi R^2 \lambda \) is the mathematical expectancy of the number of particle centers within the limits of some elementary circular area of radius \( R \) (see Fig. 1b), incidence into which can lead to collision of particles.

To determine \( p_m \) with Eq. (6) it is necessary to know the value of \( \sum_{i=0}^{n} x_i / w_{pi} \) in Eq. (3), which can be obtained by solution of the equation of particle motion in the screening layer, which we write in the following form:

\[
\frac{dw}{dx} = A \left[ \left( \bar{w} - \bar{w}_p \right) + 0.167 \text{Re}_w^{0.67} \left( \bar{w} - \bar{w}_p \right)^{1.67} \right],
\]