MODELING AND SIMULATION OF TAPERED GRINDERS

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ANNOTATION

The general structure of the dynamic models of conical grinders the distribution of time and particles partially bring the appearance of a differential equation. Achieving energy efficiency, the cone crushing crushing equipment is modeled as a single well-mixed crushing zone, and the material is distributed to a limited number of size classes.

Keywords:. Bowl, rude stone, inner cone, outer cone, crushing chamber, mathematical model, simulation.

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INTRODUCTION

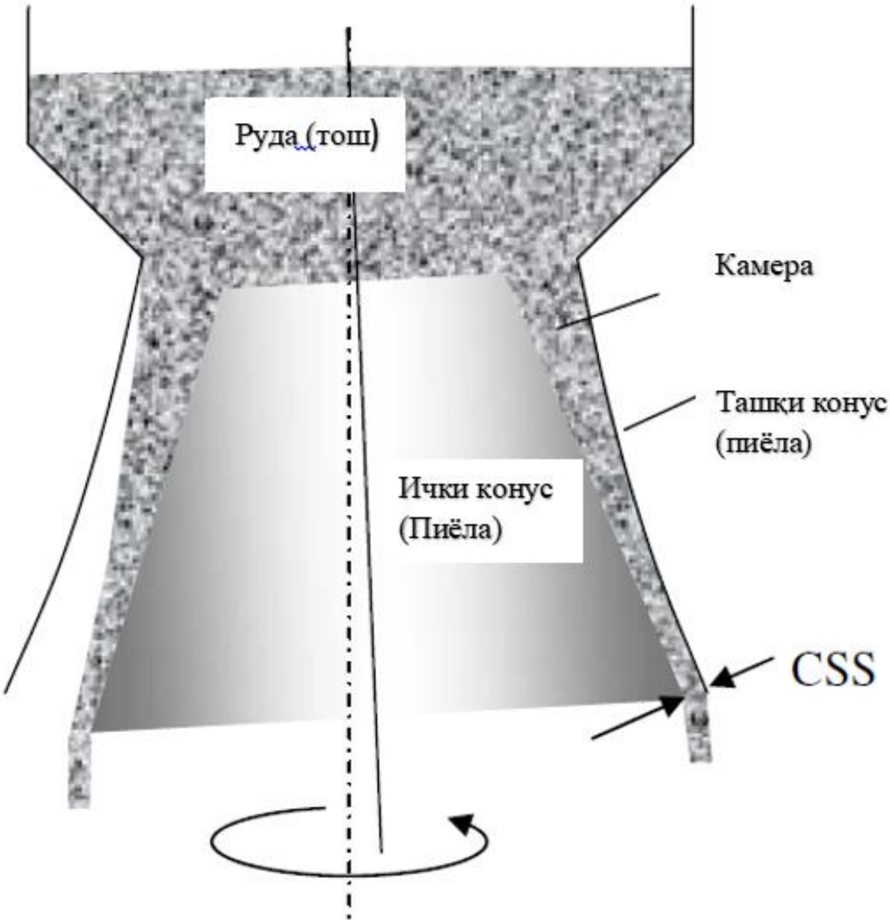
The general structure of Dynamic models of tapered grinders is presented in the form of a partial differential equation, depending on the distribution of time and particle size. The classification of the flow through the grinder and the assumptions about the speed of the atomizer make it possible to model the effect of the main controllable variables. It also shows how to discretize and zoom a model using a simple differential equation. The simulation process shows that the model demonstrates the Real action of a cone grinder. The effect of changing the speed of rotation is significant, which indicates that this variable is potentially useful for improving the control of the grinder. [1., 16-p.].

The cone crushing crushing equipment has attracted attention for several decades for at least two reasons. First, it consumes a lot of electricity when crushing, like all crushing-crushing methods. Secondly, even the quality of the crushed product is important, whether it will be the final product of the plant or will go to further processing. In the second case, changes in the product of the grinder can lead to problems, for example, in the crushing stage [1., 257-264p.].

In recent years, changes in the two directions of technology have opened up new opportunities for the management of cone crushing and crushing equipment. One of them is the application in which the frequency is controlled, which makes it possible to use the rotational speed as a controlled variable. [6., 156-p].

The models of static cone crushing crushing equipment are standard in scientific research, for example, the cone crushing crushing equipment is modeled as a single well-mixed crushing zone, and the material is distributed to a limited number of size classes. In dynamics, however, the analysis of models with the result of consideration of multiple spacing zones is presented [5., 15-16-41-p.].

A similar approach is used in the same way that we put it in the case, although we formulate the model as a distributed variable process with zones of infinite number of spacing, as well as a constant size distribution. The cone crushing crushing equipment consists mainly of a cone-shaped bowl (Figure 1), which characterizes the movement of the cone inside the cone-shaped bowl. When the pawl is spinning, a stream of fresh rocks falls from the loader to the chamber, which is crushed in a compress between the pawl and the pawl. In each shot, the stones rub down and eventually leave the grinder below. The closed side parameter (yotp) is the shortest distance between the pedestrian and the pedestrian at the exit, along with the speed of rotation of the cover are the main control variables. [4., 31-39-p.].



1-figure. The appearance of the cone grinder vertically

One of the important goals of these models is closed-loop control, so we will focus on modeling the impact of variables on the control, as well as the dynamic movement of the size distribution [5., 15-16-41-p.].

MATERIALS AND METHODS

Multi-parameter model of cone crushing and crushing equipment. Like the thermodynamic processes, we set the material balance of the C control volume of the grinder.This control volume is not a physical volume, but a small level in the grinder camera*Y=(y,y+dy)*range and small range of particle size*D=(D,D+dD)*determined as. In this case, due to the limited size of this control volume, dy and dD can be zero.

We use the function of particle taqsimlash in modeling the processes of processing minerals. In this case, P (D) denotes the mass fraction of particles whose sieve size is smaller than D. Particle density function variation is p=dP/dD, so

$$\int_{D2}^{D1} p(\delta)d\delta = P\,(D1) - P\,(D2)$$

D2 and *D1*represents the ratio of particles of the size between them. In practice, almost always discrete versions of taqsimlash and density functions are used.

Discrete particle density function- $p_i=P(D_{i-1}^*)-P(D_i^*)$

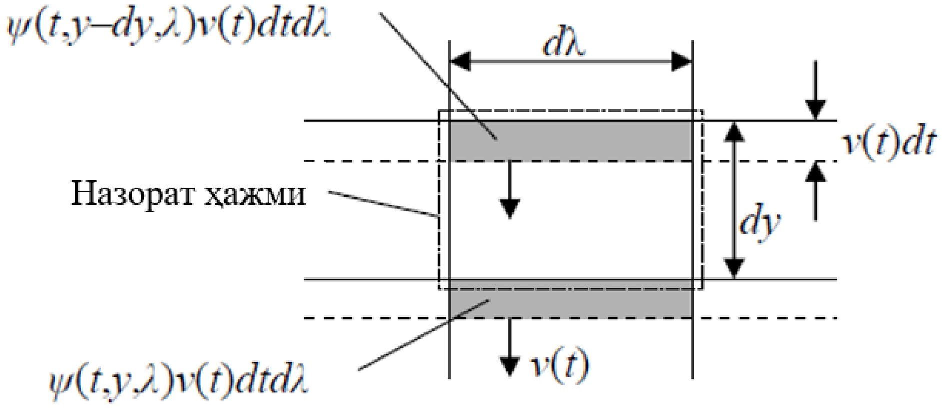
In here(D_i*)specifies solid discrete size classes.

In this work, we will install a continuous model of the tapered grinder, and then it will look natural to use the P(D) distribution density function. The drawback is that p(D) can be infinite for a small D, this happens when simulating a cone grinder. Instead, we define the scale of logarithmic dimensions with the basis of λ≥0, so that the physical size corresponding to λ$D=D_0e^{-\lambda}\chi(\lambda)=D_0e^{-\lambda}p(D_0e^{-\lambda})$we define as. The Interval λ D is defined as the fraction corresponding to the size range□=(λ,λ-dλ)

бу ерда$D=D_0e^{d\lambda-\lambda}$и$D+dD=D_0e^{d\lambda-\lambda}$.

$D$the share of the material in the table can be calculated as follows

$$p_D = \int_{D}^{D+dD} p(\delta)d\delta = \int_{D_0e^{-\lambda}}^{D_0e^{d\lambda-\lambda}} p(\delta)\, d\delta =$$
$$-\int_{\lambda}^{\lambda-d\lambda} p\left(D_0e^{-\lambda}\right) D_0e^{-\lambda}d\lambda = \int_{\lambda-d\lambda}^{\lambda} \chi(\lambda)d\lambda$$



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2-fig. Volume control

Physical size the mass of the material in a certain size range in the dV element dλ χ(λ) is obtained as pdVdλ, where ρ is the density of the material.

For Cone crushing-crushing equipment, it is convenient to use a horizontal cut with a hoop as a volume element. Its volume can be described as dV=Ady, where A(y, t) is the cross-sectional area of the current at the level of y, and T is the time.

To simplify the formation of the model, we determine the density of the mass

$$x(t,y,\lambda)=\rho A(y,t)\chi(t,y,\lambda) \quad (2)$$

This control volume is the same as the mass of the material C

$$x(t,y,\lambda)dyd\lambda \quad (3)$$

For a current with a velocity v(t), we define the density of the mass flow as x(t,y, λ)v(t), so the mass flow of the particles in the measurement range Λ will be equal to x(t,y, λ)v(t)dλ.

The classification function c (t, y, λ) denotes the percentage of the mass that does not go down, since it has a very large size for the downward slope. Thus, 1-c (t,y,λ) is the ratio of the controlled volume of material to be transported downwards. If the average speed of this transport is determined by v(t), then in the dt time interval, the material V(t)dt moves to the meter and the mass in the control volume decreases. [7., 1-16-p.].

$$\psi(t,y\ \lambda)v(t)dtd\lambda \quad (4)$$

in here $\psi(t,y,\lambda)=(1-c(t,y,\lambda))x(t,y,\lambda)$ (2-расм).

A similar feedback about the range of degrees above the control volume indicates an increase in the volume of the mass in the control

$$\psi(t,y-dy,\lambda)\vartheta(t)dtd\lambda \approx \left(\psi(t,y,\lambda)-\frac{d\psi}{dy}(t,y,\lambda)\right)v(t)dtd\lambda. \quad (5)$$

Thus, by taking the difference between (4) and (5) expression and dividing by dydl, a decrease in the mass density in the control volume is achieved due to the downward displacement of the material, resulting in

$$\left(\frac{d\psi}{dy}(t,y,\lambda)\right)v(t)dt \quad (6)$$

Cone crushing-crushing equipment the s(λ) percentage of particles of λ size in each cavity of the crushing chamber is crushed to smaller sizes. D_1=(D1,D1+dD1) the ratio of the crushed particles falling into the size range D=(D,D+dD) after one crushing is equal to B(D+dD,d1)−B(D,d1), where B (Cumulative) is the crushing function, D1 is the reproducentative measure of the size range d1. The use of a logarithmic scale with Λ1=(λ1,λ1−dλ1) corresponds to D1, which means that

$$B\left(D_0e^{d\lambda-\lambda},d_1\right)-B\left(D_0e^{-\lambda},d_1\right)\approx B\left(D_0e^{d\lambda-\lambda},D_0e^{-\lambda_1}\right)-B\left(D_0e^{-\lambda},D_0e^{-\lambda_1}\right)$$
$$\approx B^{ъ}\left(D_0e^{-\lambda},D_0e^{-\lambda_1}\right)D_0e^{-\lambda}d\lambda$$

*$b(\lambda, \lambda_1) = B' (D_0e^{-\lambda}, D_0e^{-\lambda}{}_1)D_0e^{-\lambda}$*by definition, the mass of Y particles divided by the size of the mass*D*and*D_1*

$$b(\lambda,\lambda_1)s(\lambda_1)x(\lambda_1)d\lambda d\lambda_1 dy \quad (7)$$

Y the total mass (7) of particles in the expression can be obtained by integrating over all dimensions from λ1 to λ, that is

$$\int_0^{\lambda} b(\lambda,\lambda_1)s(\lambda_1)x(\lambda_1)d\lambda d\lambda_1 dy$$

The increase in the mass density of C in the control volume ф(λ) ((3) according to the expression) dλdy can be obtained by dividing the interval by the volume, that is, ф(λ)=(Bsx)(λ) linear operator B is determined as follows

$$(Bz)(\lambda)=\int_0^{\lambda} b(\lambda,\lambda_1)z(\lambda_1)d\lambda_1$$

In addition, crushing decreases the volume of control due to S(λ)X(λ)dλdy mass crushing, IE. the density of the mass decreases to s(λ)x(λ). Rotational speed w gives the number of crushing-crushing events per second rotations. Thus, the increase in mass density in the control volume in the dt time interval

$$w(t)\left(\phi(\lambda)\right)-s(\lambda)x(\lambda)dt(8)$$

It is often assumed that the distribution of the particle size after crushing does not depend on the initial size, that is,the crushing-crushing function B(d1, d2) is actually a function of the parameter D1/d2 without dimensions. Thisβ*$(d_1/d_2)=B(d_1,d_2)$*we mark, and then*$B'(d_1,d_2)=\beta'(d_1/d_2)/d_2$*, in here*β'*гим*β*indicates the yield of. And so on

$$b(\lambda,\lambda_1)=B^{ъ}\left(D_0e^{-\lambda},D_0e^{-\lambda_1}\right) = \beta'\left(D_0e^{-\lambda}/D_0e^{-\lambda_1}\right)D_0e^{-\lambda}/D_0e^{-\lambda_1}$$
$$=\beta^{ъ}\left(e^{\lambda_1-\lambda}\right)e^{\lambda_1-\lambda}$$

Thereforeb*$(\lambda)=\beta'(e^{-\lambda})e^{-\lambda}$*when B crushing-crushing operator can be expressed as follows

$$(Bz)(\lambda)=\int_0^{\lambda} b(\lambda-\lambda_1)z(\lambda_1)d\lambda_1.$$

(8) and (6) if we combine the expressions t+dt in time, the mass of the particles of the control volume will be as follows

$$x(t+dt,y,\lambda)=x(t,y,\lambda)-v(t)\frac{d\psi}{dy}(t,y,\lambda)dt+w(t)\left(\phi(t,y,\lambda)\right)-s(t,y,\lambda)x(t,y,\lambda)dt$$

If we lose arguments taking into account dt → 0

$$\frac{dx}{dt}=w(\phi-sx)-v\frac{d\psi}{dy}$$

Or *ϕ*and*ψ*the last expression is formed if we substitute

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$$\frac{dx}{dt} = w(B(sx) - sx) - \upsilon \frac{d}{dy}(1 - c)x) \quad (9)$$

The condition under which the limit value must be met is X(t,0,) relative to the mass density of raw materials. (2) according to the expression it can be expressed as follows

$$x(t,0,\lambda)=\rho A(0,t)\chi_0(t,\lambda) \quad (10)$$

In here $\chi_0(t,\lambda)=\chi(t,0,\lambda)$ - the function of the density of crushed raw materials.

(9) (10) the boundary conditions of the equation together with the equation is a common model structure for Cone crushing crushing equipment. To obtain the developed model, there must be accurate data on crushing, crushing, selection, classification and particle speed.[7., 1-16-p.8., 613-617-p.].

Density of mass flow of raw materials and products

$$q_{in}(t,\lambda) = x(t,0,\lambda)\upsilon(t)\big(1 - c(t,0,\lambda)\big)$$
$$q_{out}(t,\lambda) = x(t,Y,\lambda)\,\upsilon(t)(1 - c(t,Y,\lambda))$$

and$\lambda \geq 0$ in the case, the total mass is obtained by integrating the currents.

3. Results of scientific research and mathematical models.

Multi-parameter model of cone crushing and crushing equipment.

Models of the process of processing minerals are often formed in a discretionary way. The advantage of forming a model in the form of distributed parameters, for example (9) as a differential equation in expression, modeling and simulation functions are distinguished. This means that it can be easy to check the values obtained on the basis of different modeling, and also the simulation with built-in mathematical equations and software is carried out in a convenient way. 2200

To carry out the simulation, we use the Matlab Simulink software tool, which processes differential equations. [3.,257-264 p.].

(9) the structure of the model can be as follows

$$\dot{x} = w(B(sx) - sx) - \upsilon(1 - c)x_y^{ь} - c_y^{ь}x \quad (11)$$

Let's assume that the mesh of rectangular points is marked

$0=y_0<y_1< \ldots <y_N<Y$ ва $0=\lambda_0<\lambda_1< \ldots <\lambda_M$.

So on$x$, $x'_y$and so we determine the values by the value functions of the Matrix. This matrix is on the grid grid

$$X(t) = \begin{bmatrix} x(t,y_1,\lambda_1)\cdots\cdots x(t,y_1,\lambda_M) \\ \vdots \quad \ddots \quad \vdots \\ x(t,y_N,\lambda_1)\cdots\cdots x_y^{ь}(t,y_N,\lambda_M) \end{bmatrix}$$

$$X_y(t) = \begin{bmatrix} x_y^{ь}(t,y_1,\lambda_1)\ldots\ldots\ldots x_y^{ь}(t,y_1,\lambda_M) \\ \vdots \quad \ddots \quad \vdots \\ x_y^{ь}(t,y_N,\lambda_1)\ldots\ldots\ldots x_y^{ь}(t,y_N,\lambda_M) \end{bmatrix}$$

$\dot{x}(t, y, \lambda)$, $c(t, y, \lambda)$, $c'_y(t, y, \lambda)$, $s(y, \lambda)$using values$X_t(t)$, $C(t)$, $C_y(t)$, S and$\Phi(t)$we determine the matrices. Now we can represent the PDE (11) in the grid as follows

$$X_t(t) = w(t)\Phi(t) - S\,X(t) - \vartheta(t)((1 - C(t))^{\circ}X_y(t) - C_y(t)^{\circ}X(t) \quad (12)$$

$x'y(t,y_i,\lambda_j)$the first difference, for example, from derivatives$x'_y(t,y_i,\lambda_j)\approx(x(t,y_i,\lambda_j)-x(t,y_{i-1},\lambda_j))/(y_i-y_{i-1})$can approach. In it we can write the expression as follows

$$\begin{bmatrix} x_y^{ь}(t,y_j,\lambda_j) \\ x_y^{ь}(t,y_2,\lambda_j) \\ \vdots \\ x_y^{ь}(t,y_N,\lambda_j) \end{bmatrix} \approx L^y \begin{bmatrix} x(t,y_j,\lambda_j) \\ x(t,y_2,\lambda_j) \\ \vdots \\ x(t,y_N,\lambda_j) \end{bmatrix} + L_0^y x x(t,y_0,\lambda_j)$$

for some matricesL^yandL^y_0.

So on $X_y(t) = L^yX(t) + L^y_0\,x_0(t)^T$, In here $x_0(t)^T=[x(t,0,\lambda_1)\ x(t,0,\lambda_2)\cdots x(t,0,\lambda_M)]$.

Based on vectorization

$$\text{вес}(X_y(t)) = (I\otimes L^y)\text{вес}(X_y(t)) + (I\otimes L_0^y)x_0(t)$$

As a crushing- operator

$$\emptyset(t,y,\lambda_j) = \int_0^{\lambda_j} b(\lambda_j,\lambda)\, s(t,y.\lambda)x(t,y,\lambda)d\lambda \approx \sum_{k=0}^{j-1} b(\lambda_j,\lambda_k)\, s(t,y,\lambda_k)x(t,y,\lambda_k)(\lambda_{k+1}-\lambda_k)$$

In vector form

$$\begin{bmatrix}\phi(t,y_i,\lambda_0)\\ \phi(t,y_i,\lambda_1)\\ \vdots\\ \phi(t,y_i,\lambda_M)\end{bmatrix} \approx \Gamma \begin{bmatrix}s(t,y_i,\lambda_0)x(t,y_i,\lambda_0)\\ s(t,y_i,\lambda_1)x(t,y_i,\lambda_1)\\ \vdots\\ s(t,y_i,\lambda_M)x(t,y_i,\lambda_M)\end{bmatrix}$$

In here

$$\Gamma = \begin{bmatrix} O & & & \\ \Gamma_{10} & O & & \\ \vdots & & \ddots & \\ \Gamma_{M0}\Gamma_{M-1,0} & \cdots & \Gamma_{M,M-1} & O \end{bmatrix}$$

and $\Gamma_{ij} = b(\lambda_i, \lambda_j)(\lambda_i - \lambda_{i-1})$.

And so on, $vec(\Phi(t))=vec((S\circ X(t))\Gamma^T)=(\Gamma\otimes I)vec(S)\circ vec(X(t))$ $\Phi(t)^T=\Gamma(S\circ X(t))^T$ we will have an expression.

(12) on the basis of expression vectorization $vec(X_t(t)) = w(t)(vec(\Phi(t)) - vec(S)\circ vec(X(t))) - v(t)(vec(1 - C(t))\circ X_y(t) - vec(C_y(t))\circ vec(X(t)))$ 2201

we will have and finally determine the following

$z(t)=vec(X(t)$ $\qquad \bar{C}(t) = diag(vec(C(t)))$

$\bar{S}=diag(vec(S))$ $\qquad \bar{C}_y(t) = diag(vec(C_y(t)))$

substitutions lead to the appearance of the following

$$\dot{z}(t)=w(t)((\Gamma\otimes I)-I)\bar{s}z(t)$$

$$\dot{z}(t) = w(t)((\Gamma \otimes I) - I)\bar{S}z(t) - v(t)((I - \bar{C}(t))(I \otimes L^y) - \bar{C}_y(t))z(t) - v(t)(I-\bar{C}(t))(I\otimes L^y{}_0)\, x_0(t),$$

MATLAB A linear, time-varying limited-scale system that is easily implemented in Simulink. [3., 257-264 p]

Cone crushing-crushing equipment model simulation

Typical form of classification function

$$c^d(d) = \begin{cases} 1-\left(\dfrac{d-d_2}{d_1-d_2}\right)^n, & d_1 \le d < d_2 \\ 0, & d < d_1 \\ 1, & d \ge d_2 \end{cases}$$

In here $d_1=\alpha_1 U$ and $d_2=\alpha_1 U+d^*$

U - closed side Settings

$n, \alpha_1, \alpha_2, d^*$- parametrs

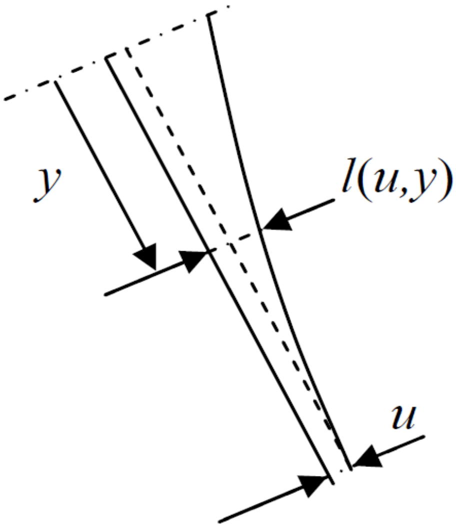
Here, the thickness of the camera depends on the installation of the closed side (it is determined by u and L(u, y) (Figure 3))). Accordingly

$$c(t,y,\lambda) = \begin{cases} c_0(t,y,\lambda), d_1(t,y) \le D_0 e^{-\lambda} < d_2(t,y) \\ 0, \quad D_0 e^{-\lambda} < d_1(t,y) \\ 1, \quad D_0 e^{-\lambda} < d_1(t,y) \end{cases}$$

In here

$$c_0(t,y,\lambda) = 1 - \left(\frac{D_0 e^{-\lambda} - d_2(t,y)}{d_1(t,y) - d_2(t,y)}\right)^n$$
$$d_1(t,y) = \alpha_1 l(u(t),y)$$
$$d_2(t,y) = \alpha_2 l(u(t),y) + d^*$$

*l(u, y)*the thickness of the hollow chamber is linear$l(u,y)=l_0(y)+u$ - depends on the closed-side settings, where the closed-side settings are when y=0$l_0(y)$- camera profile defined as the thickness of the camera



3-figure. Camera thickness in compression phase l(u, y)
The dotted line defines the camera profile, that is, the thickness of the camera in u=0.

In modeling, we assume that the time of the phase of obtaining motion of particles and the effect of their free falling motion affect the movement of shock particles.T_0 time to the particles for each pulse, which is required for free fall$T= \eta T_0$ it takes time, the particles in it $gT^2/2=g\eta^2T_0^2/2$[2., 7-p.].

Thus, the average falling speed is equal to$v=gT^2/2T_0=g\eta^2T_0/2$, because if it isT_0 $1/wv(t)=g\eta^2/2w(t)$ function of Granules by raw material size

$$P(D) = \begin{cases} 1 - e^{-(\eta/\eta_{63})^{\alpha}}, & D \le D_0 \\ 1, & D > D_0 \end{cases}$$

In here$\eta=/(D_0-D)$

$\eta_{63}=D_{63}/(D_0-D_{63})$

D_{63}andαas parameters, can also be considered as a function of time. Corresponding variable particle density function $\chi_0(t,\lambda)=D_0e^{-\lambda}p(D_0e^{-\lambda})$

In here$p(D)=dP(D)/dD$.

In our simulations, we use expressions of Eyler convergence. Thus

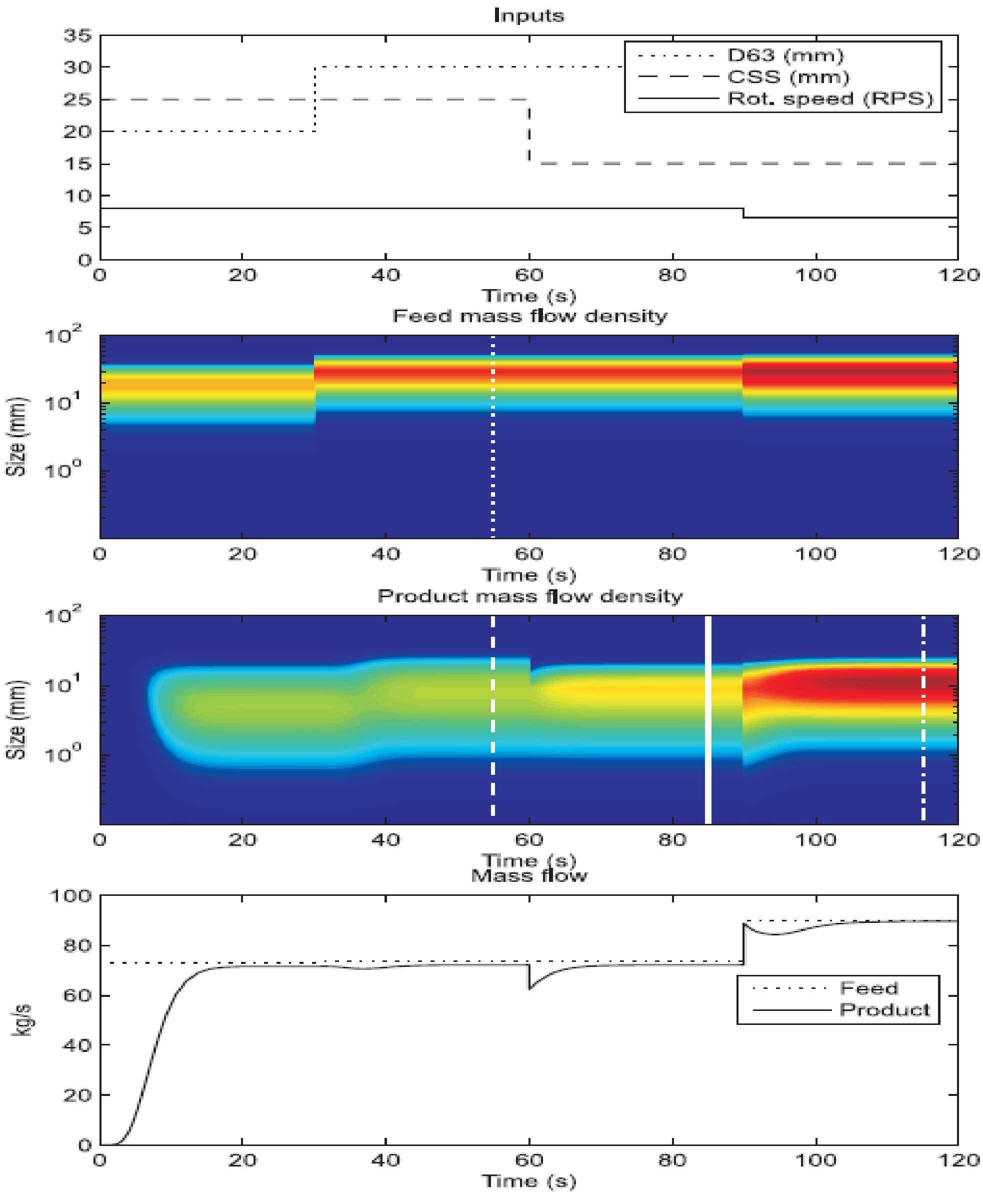
$$L_y = \begin{bmatrix} \frac{1}{y_1 - y_0} & 0 & \cdots & 0 & 0 \\ \frac{1}{y_1 - y_2} & \frac{1}{y_2 - y_1} & & 0 & 0 \\ & \ddots & \ddots & & \vdots \\ 0 & 0 & & \frac{1}{y_{N-1} - y_{N-2}} & 0 \\ 0 & 0 & & \frac{1}{y_{N-1} - y_N} & \frac{1}{y_N - y_{N-1}} \end{bmatrix}$$

and$L_0^y = \left[\frac{1}{y_0 - y_1} \quad 0 \cdots 0\right]^T$. *N=6, M=3*, and$\lambda_M$*=6,9*here is how it is selected$y_i = \frac{iY}{N}$and$\lambda_i = i\lambda_M / M$.

The Model includes several parameters. The values used for them are considered valid even if they are not taken from existing crushing equipment. For the physical dimensions of the cone crushing-crushing equipment, we selected the following values, the length is Y=1,2 m, the camera profile should be l_0 (y)=(1-y/Y)l_0 (0) linear, the bunda l_0 (0)=0.15 m. The area of the cross section at the entrance is chosen a(0,t)=0,3m2, and the density is equal to r= 600 kg/m2. [3., 254-257-bet. 9., 259-268p.].

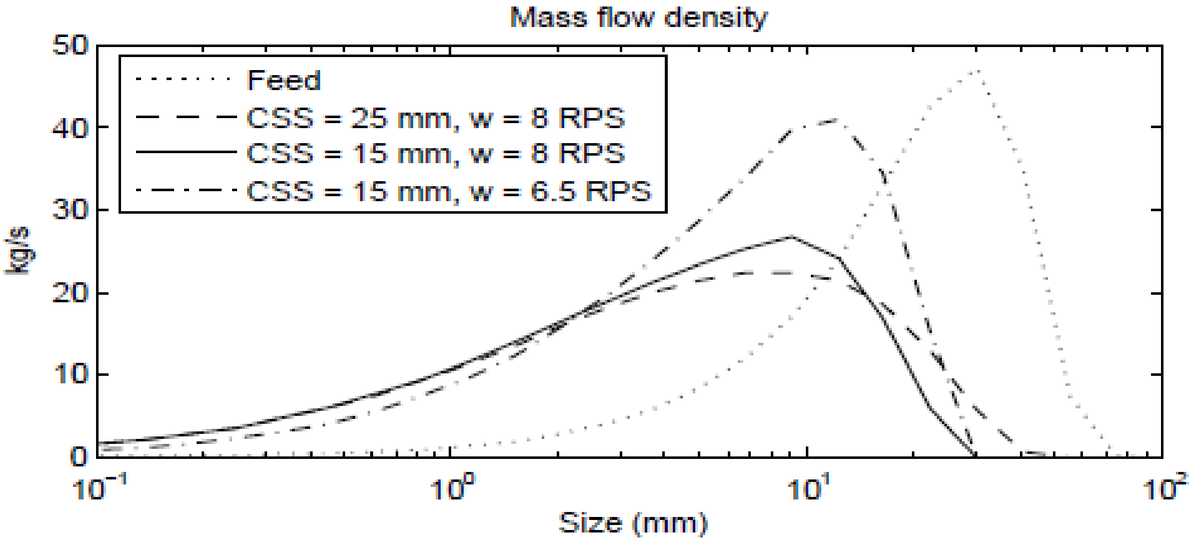
sonn_1*=0,45*, n_2*=3,2*, α_1*=0,6*, α_2*=2*, *n=2*and*d*=0*, *K=0*, c_0 *=0,1* and*a=0,1*. The free fall time in our simulations was chosen as η percentage 0,5. Input parameter α constant 1,2 selected.

Input parameter to see how the model reacts to changes in input, output volume distribution and controlD_{63}, the speed of rotation w and the closed side setting it was changed step by step according to the shape (4-figure). Density of mass flow in the middle parts of the figureq_{in}andq_{out}it is shown respectively, and at the bottom it shows the total input and output.[3., 254-257-p. 9., 259-268-p.].



4-figure. Cone crushing-the results of simulation of the Model (9) with the help of the parameter values of the crushing equipment

Figure 5 shows the distribution of raw materials and product volumes in times when the flow is stable (Figure 4 (in the middle) is marked by vertical axis lines). As expected, reducing the closed-side settings will result in the size distribution shrinking to smaller dimensions. Interestingly, the increase in the speed of rotation leads to a decrease in the flow of material, as well as the spread of the dimensions of the distribution to the smaller side.



5-figure. D_{63}=30 мм and 6c^{-1}mass flow density of rock mass for speed

As can be seen from the graphs, when the flow of material is maximum, it leads to a further decrease in the speed of rotation, as well as a decrease in the flow due to the constant material blockage of the tapered grinder. To reduce the load flow, it will be necessary to simulate drosselation, which can be achieved by changing the classification function in such a way that less material is transported downwards at a higher mass density.

Conducted simulations show that using the rotation speed and closed-side settings, a multi-dimensional management strategy can improve the management of dimensions and reduce power consumption, since the speed of rotation significantly affects the power consumption .

The developed cone crushing-crushing equipment model is very convenient for modeling tapered grinders. This model allows for a theoretical and exponential analysis of the expected behavior.[3.,257-264 p.].

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