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Modeling of Peat Mass Process Formation Based on 3D Analysis of the Screw Machine by the Code YADE

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Abstract In the article authors investigate extrusion press for forming of peat furnace charge in order to produce fuel pellets. For modeling the behavior of pellets, we used discrete elements method in YADE framework.

Keywords: *screw extruders, form of the forming and calibrating part of matrix dies, discrete elements method, press energy output*

1. Introduction

Currently, in the regions of the Russian Federation there is a growing demand for energy resources, and for this reason the extraction of peat as a local fuel type increases [1].

The formation of peat mass is conducted at its natural humidity of 78 – 82%, and then drying of the agglomerate peat fuel takes place with significant power consumption. Preliminary drying of the peat material to the humidity of 60-65% in the field and further formation decreases total period of drying. While forming peat of decreased humidity, costs for drying of the produced agglomerate peat fuel decreases, but power consumption increases while forming peat materials on screw extruders (Figure 1) having traditional geometrical parameters in matrix dies – cone and cylindrical transitions. In order to develop improved methods of forming with screw extruders, we need scientific justification of geometric parameters of matrix dies.

Formation of peat mass is an integral part of the peat extraction process and obtaining of agglomerate peat fuel with screw extruders MTK– 16 (Russia), KTD-1, ANB-704 (Belarus), PK-1SL (Finland), Figure 1.

Operating element of the peat-forming machine is screw 3 (Figure 1) that takes peat materials from cutter 5 that cuts deposit and supplying the material to dies 2 attached to the bushing plate 3 called a die.

A distinguishing feature of screw extruders is a possibility of quick replacement of dies in case of transition to different unit sizes of peat materials and creation of great pressure on the material formed.

Transition of mass flow from large screw diameter to small diameter of matrix die (Figure 3) creates additional resistance for the material movement due to its cross-deformation and contraction of the material. It will unavoidably affect the amount of power costs due to material friction with the surface of die channel and its wear resisting property. Calibrating part of a die is needed for relieving stress in the material that has been obtained at the entrance to the forming part.

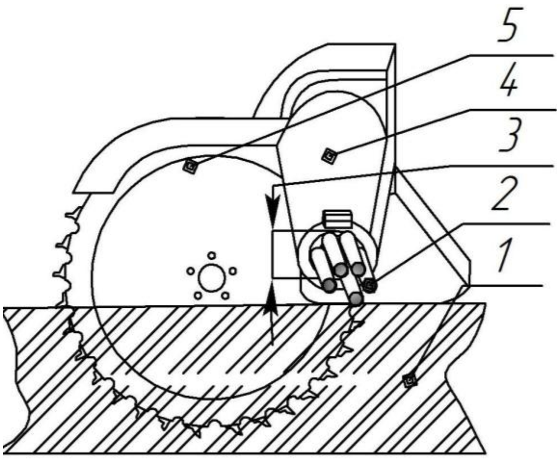

Figure 1. Extraction of peat materials and production of agglomerate peat fuel with screw extruders PK-1SL: 1 – peat deposit; 2 – dies; 3 – bushing plate; 4 – processing screw in a housing; 5 – cutter

2. Computer Model

On the basis of peat briquetting investigations of Russian scientists [2,3], as well as on the basis of investigations of foreign authors on flow of slip bodies [4], we propose to make the entrance part of the die (bookel) in the way of a catenary line. Profile calculation is performed upon the following formula:

$$y = \frac{b_1}{2}\left[\exp\left(\frac{x}{h_1 c}\right) + \exp\left(-\frac{x}{h_1 c}\right)\right], \quad (1)$$

$$c = \frac{1}{\ln\left[1 + \frac{b}{b_1} + \sqrt{\frac{b}{b_1}\left(\frac{b}{b_1} + 2\right)}\right]}, \quad (2)$$

where h_1 – distance between symmetry axis of the curved part of the die profile and entrance end of the channel; b –

height of the curved part of the channel profile; b_1 – half of channel height along the symmetry axis of cambered die (Figure 3).

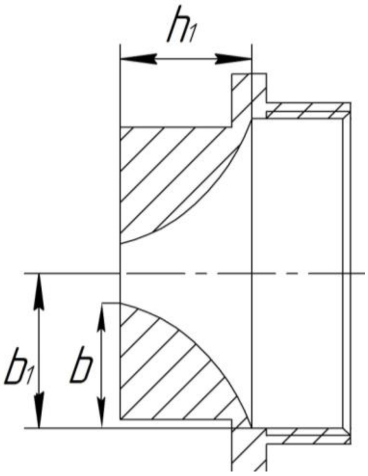

Figure 2. A die which entrance part is made in the way of a catenary line

According to theoretical calculations of the Russian scientist Professor B.A. Bogatov [2] perform narrowing inlet nozzle portion by a chain line can significantly decrease the costs for the extruder while forming peat as compared with straight cone of narrowing and cylindrical transition. In order to check the data of theoretical investigations, we've conducted virtual tests of the model created in the open-source software YADE for modeling particle movement with discrete elements method and using ParaView visualization program based on the laboratory of 3D-modelling of the Institute of mineral dressing in the TU Freiberg Bergakademie, Germany [5]. YADE software has been created for the calculation with discrete elements method on the basis of developments of scientists from Université de Grenoble, France, and scientists from other leading universities of Europe. YADE has proved its applicability in many fields: processing and destruction of rocky materials, analysis of module unit operation and separate machines on extruding free-flowing substances.

3. Numerical Results

While conducting calculation, we've considered three forms of narrowing of the die entrance part (Figure 3).

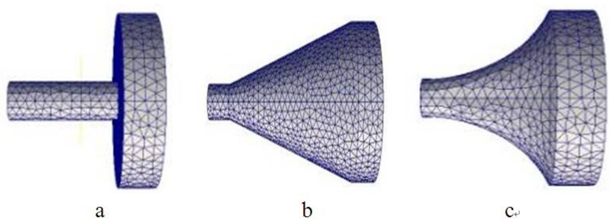

Figure 3. Form of narrowing of the die entrance part: a – cylindrical transition; b – conical; c- in the way of a catenary line

Calculation modules of YADE software (Figure 4) allowed obtaining data about such values as: particle angular velocity ω, rad/s; particle linear speed ν, m/s; normal stress in material particles in case of the interaction with processing screw Q stand, Pa; torque on screw shaft M, Nm; resultant of forces applied to the flight screw F cut, N.

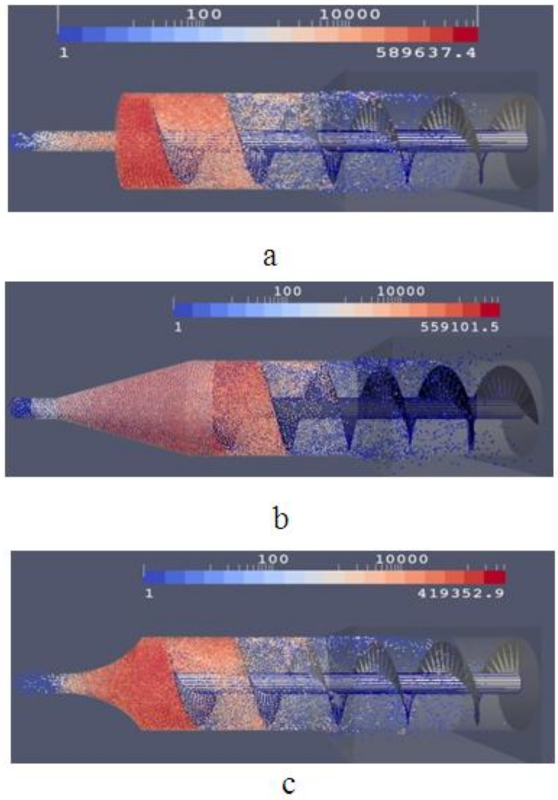

Figure 4. Modeling scheme: a) cylindrical passage; b) narrowing in the way of a catenary line; c) conical narrowing

Angular and linear velocity of the particles are determined by the average of the readings recorded by the analysis YADE all particles, being in the case of screw machine. Tension on normal Q different standards (Figure 4 a, b, c) depending on the proximity of the particles to the die, and it shows different color particles corresponding scale.

Table 1 shows the results of an experiment in the virtual software module YADE. Productivity in even feed process is 3 tons of pellets/hour.

Table 1. Results of tests of different narrowing forms of dies

narrowing form	ω, rad/s	ν, m/c	Q stand, kPa	M, Nm	F cut, N
cylindrical	1,43	6,55	589,6	7,6	574
conical (17,5°)	1,33	6,6	559,1	6,2	423
in the way of a catenary line	1,32	6,4	419,4	5,1	349

Peat mass compressed in the forming part is protruded into its calibrating part, which length defines the time of relaxation of inner stresses and calibrates the piece surface. In order to determine the ratio of these parameters we used a semi-empiric model of Benbow-Bridgwater [6]. The scientists who have developed this model used the conclusion that total pressure during formation is a sum of pressure in the pressure area P1 and extrusion area pressure P2 (Figure 5). Model Benbow-Bridgewater - is the sum of the pressures (P1 + P2), changing in the transition from one particle diameter in the other. This expression has been expanded and refined for each diameter die.

Pressure P1 reflects the effect of the shape at the entrance to dies, σ 0, α are evaluated as material constants featuring material resistance, and as supposed, they are not dependent from the die geometry. A mass flow goes in the die as a solid plug surrounded by the shallow moisture layer, which separates it from the wall. Thus, shearing stress is a function of mass speed, and β is a material constant featuring speed effect while decreasing pressure P2 along the die length. When evaluating indicators of stress decrease in the material during the tests of a die with narrowing in the way of a catenary line, the equation (3) gets shape ratio sr = 0,72 (standard stress decrease by 18%) for the die entrance part made in the way of a catenary line.

$$P = P_1 + P_2 = \left(\sigma_0 + \alpha \nu_{CP}\right) \ln\left(\frac{S_o}{\Sigma S}\right) \cdot k_\phi + 4\left(\tau_0 + \beta \nu_{CP}\right) \cdot \left(\frac{L}{d}\right) \quad (3)$$

Here P1is a pressure in the pressure area, Pa; P2 is an extrusion area pressure, Pa; σ0 is one-axis stress of fluctuation at the entrance to the die, Pa; average rate of mass flow in the forming part, m/s; α is a rate development factor at the entrance to the die; S0 is a cross-sectional area of the screw housing, m; ΣS is the total area of section of die forming and calibrating parts, m; τ0 is a shear stress at the forming part wall, Pa; β–a share of near-wall sliding from the average mass flow rate; L is the length of the die forming part, m; d is the diameter of the die forming part, m; kf is an experimental ratio considering the influence of the die entrance part form.

It should be mentioned that in order to determine the interaction forces between the particles, a linear contract model was used. Rigidity of particles imitating peat particles has been selected without considering their physical parameters.

The obtained absolute values of torques and stresses can be used only for illustration of quality picture of screw extruder operation. In order to determine the geometrical parameters of the calibrating part of the matrix die, the ratio of length of forming part h 1 and calibrating part h 2 of the die, experiments were conducted on 8 dies with different parameters (Figure 5) on the extruder «Autograph - Shimadzu». While manufacturing agglomerate peat fuel on the machine with set geometrical parameters at the stage of peat material preparation, it's necessary to conduct botanical analysis, decomposition level, ash-content, dispersity and degree of contamination.

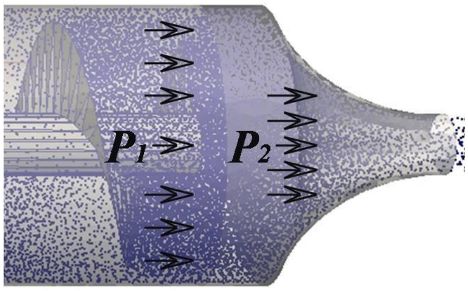

Figure 5. Pressure in the pressure area and extrusion area in the die

The obtained results can be taken into account while updating matrix dies of MTK-16 machine, as well as during designing stationary machines for the production of fuel pellets while processing dumps of mining enterprises [7].

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