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Theory and practice of complex processing of technogenic fibrous materials

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Abstract. The article presents the results of analytical studies of the mechanism for processing materials by pressure from the forming rolls and the development of energy efficient equipment for mixing and granulation the technogenic fibrous materials.

1. Introduction

One of the most important tasks of the development of modern industrial society is the rational use of material resources through the complex processing of various technogenic materials with the modern solution of urgent environmental problems and protecting the environment from pollution [1-4].

At the same time, one of the urgent and unresolved problems is the development of technological conditions and effective technical devices for processing technogenic fibrous materials (TFM): various basalt waste (for example, isovol), waste wood processing and pulp-and-paper industries, a wide range of fibrous materials of the agro-industrial complex, wastes of vermiculite production and other materials of anisotropic structure [5-7].

One of the effective ways of processing TFM is the method of their compacting into molded bodies of a predetermined geometric shape and dimensions: rolled pellets, extruded materials, pressed briquettes, etc. [8-10]. Thus extruding of TFM provides a wide range of use of technogenic materials for various technological purposes: as molded porous fillers of composite mixtures, production of organic-mineral fertilizers of prolonged action, granular stabilizing additives from pulp-and-paper wastes for high-quality stone-mastic asphalt concrete, highly concentrated microfibre fillers for modern innovative 3D-technologies, etc.

However, the implementation of the above technologies is hampered by a number of unsolved problems that depend on the specific physico-mechanical characteristics of the TFM: small initial bulk density of materials and their low flowability, increased moisture demand and adhesion, etc. This significantly complicates the process of uniform distribution of the binder in the composite mixture and the production of homogeneous charges, which reduces the quality of the formed products and the productivity of the forming aggregates.

The aim of the present studies was to eliminate the above-mentioned disadvantages, to developmore efficient technological conditions and technical devices for organizing the process of TFM extruding in a flat-matrix granulator.

2. Equipment for TFM mixing

To obtain homogeneous composite mixtures using TFM, the authors developed patent-protected design of a recirculating mixer of the combined action [11], Fig.1.

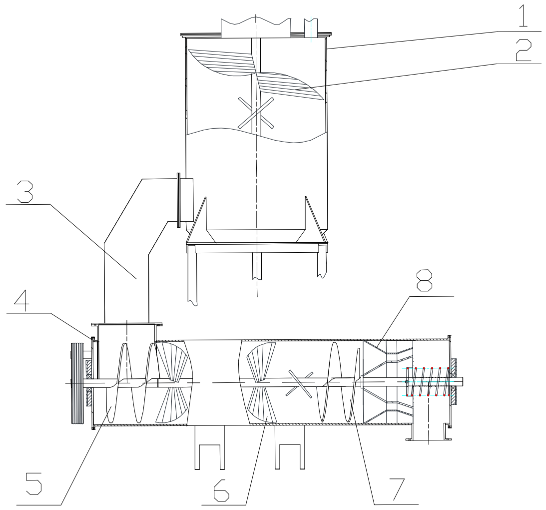

Figure1. A recirculating mixer of the combined action. 1-vertical mixer; 2, 6-double-threaded helical mixer arms; 3-pipe branch; 4-horizontal mixer; 5, 7-single-threaded helical mixer arms; 8- block for mechanical pre-compaction of the mixture

The realization of the process of TFM mixing with various physical and mechanical characteristics is carried out due to the serial high-speed mixing of the mixture with the organization of internal recycling of the material at each stage and the consequent increase in its density through mechanical pre-compacting and microgranulation. Due to the successively installed vertical and horizontal mixers with mixer arms, mixing takes place in two stages. The first stage is turbulent-gyration mixing. The second stage is recirculation with steam humidification.

3. Research of the extruding process of composite mixtures with TFM

To improve the extruding process of composite mixtures with TFM and to improve the quality of granules formed in a flat-matrix granulator, let us consider the mechanism of processing materials by pressure from the forming rolls.

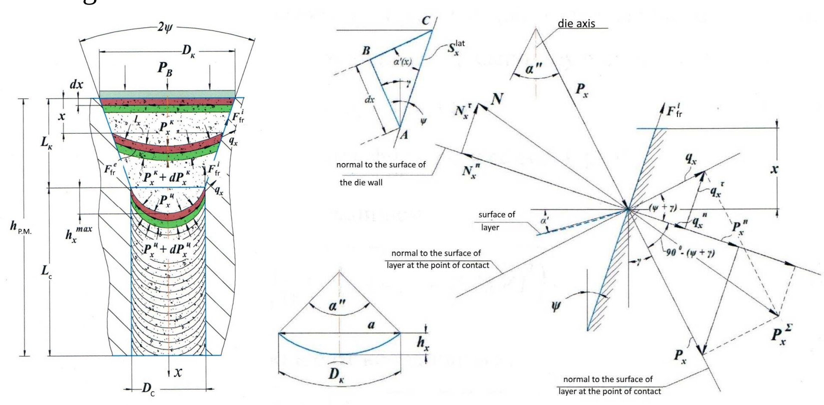

Figure2. A scheme for the calculation of the extruding process of TFM in a die with a variable cross-section a-geometric profile of the die; b-diagram of the allocation of forces on the lateral surface of a conical part of the die

Let us consider the motion of a TFM along a channel of a die of a variable cross section. The diagram of the allocation of forces on the lateral surface of a conical part of the die (Fig. 2-b) is represented by forces and parameters: h_x-value of charge layer bending, m; D_k-outer diameter of conical die, m; D_c-diameter of cylindrical part of die, m; ψ-the angle of inclination of the walls of the die to its axis, deg.; $L_к$, L_c-the length of the conical and cylindrical parts of the die accordingly; L_{px}-perimeter of the channel cross-section with a lateral surface (m^2) at a depth of x, m; $P_B = P_X, P_X^n, P_X^\tau$-pressure and its constituents (P_X^n, P_X^τ) from the side of the forming roll accordingly, MPa; q_x-a lateral stress on the conical part of the die from the side of the compacted material and its constituents q_X^n, q_X^τ, MPa; N, N^n, N^τ- the reaction of the die wall and its constituents (N^n, N^τ) to the joint action of the lateral stress and the redistributed pressure accordingly, N; F_{fr}-the frictional force of the material on the surface of the die, N; f, ξ-coefficients of external friction and lateralstress of the material on the surface of the die accordingly.

The equilibrium equationof the deformed layer at a depth x from the input cross-section in the projection to the axis of the die (Fig. 2-b) will have the form:

$$P_X S_X - (P_X + dP_X)S_X - F_{fr}\cos\psi - N^\tau \cos\psi - N^n \sin\psi = 0 \qquad (1)$$

After that appropriate transformations provided: $S_X = \frac{l_X d_X}{\cos\psi}$; $F_{fr} = N^n f$; $N^n = P_X l_X tg(\psi + \gamma)d_X + q_X l_X d_X$; $N^\tau = P_X l_X d_X - q_X l_X tg(\psi+\gamma)d_X$,get

$$dP_X = -P_X tg\left[\psi + 2\mathrm{arctg}\left\{\sqrt{\frac{3}{4}\left(\frac{D_K^2}{(D_K - 2x\cdot tg\psi)} - 1\right)}\right\}\cdot \frac{4(D_K - 2x\cdot tg\psi)}{D_K^2}\cdot(f cos\psi - \sin\psi)d_X - (\xi P_X + q_X)\cdot\frac{4(D_K - 2x\cdot tg\psi)}{D_K^2}\cdot(f cos\psi - \sin\psi)d_X - P_X\cdot\frac{4(D_K - 2x\cdot tg\psi)}{D_K^2}\cdot cos\psi\cdot d_X + (\xi P_X + q_O)\cdot tg\left[\psi + 2\mathrm{arctg}\left\{\sqrt{\frac{3}{4}\left(\frac{D_K^2}{(D_K - 2x\cdot tg\psi)^2} - 1\right)}\right\}\right]\cdot\frac{4(D_K - 2x\cdot tg\psi)}{D_K^2}\cdot cos\psi\cdot d_X\right] \qquad (2)$$

The numerical solution of equation (2) using the Runge-Kutta method is presented as a graphical dependence (Fig. 3).

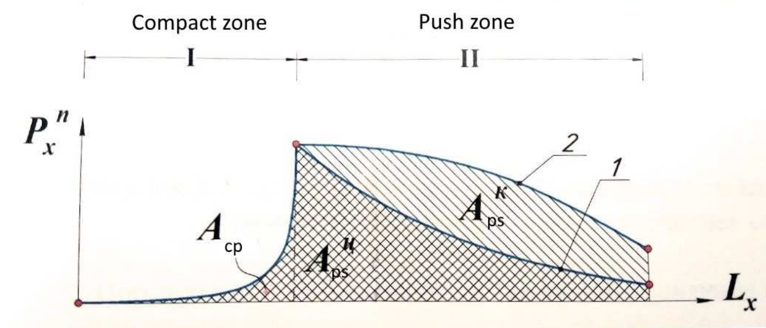

Figure 3. The nature of the change in axial pressure along the length of the die at a constant (1) and variable (2) cross-section

A similar analysis of the process of material movement along the cylindrical part of the die of length L_c allowed us to establish a complete backpressure on the side of the die:

$$P_F = \frac{q_O}{\xi}\cdot\left[exp 4\xi f\cdot\frac{L_F - L_К}{D_c}\cdot\left(\frac{D_К}{D_c}\right)\frac{2f cos\psi}{tg\psi}\cdot\xi - 1\right] \qquad (3)$$

The equation for determining length L_F of the die has the form:

$$L_F = \frac{D_c}{(1-n)4f\xi}\cdot\ln\left\{\left[\frac{c\cdot\xi}{q_O}\cdot(exp\cdot a(\rho - \rho_O) - 1) + 1\right]\left(\frac{D_К}{D_c}\right)\frac{2f cos\psi}{tg\psi}\cdot\xi\right\} \qquad (4)$$

where $n = \frac{L_К}{L_F}$; c, a - constants characterizing the structural and mechanical properties of the material, the resistance of the material to compression; ρ, ρ_O - density of the initial and compacted (granules) materialaccordingly, kg/m^3.

Analysis of the obtained expressions and plotted plot $P_X^n = f(L_X)$ in Fig. 3 shows that the work required to push the compacted fibrous materials through the die is much greater than the work required to compact the material.

All this confirms the advisability of qualitative homogenization of the composite mixture prior to its formation with uniform distribution of the binder reducing the friction coefficient, by volume of the mixture. In addition, in order to reduce power inputs for pellet molding, it is expedient to pre-compact the charge in special devices, which increases the efficiency of the process of pumping the material into the die and subsequent granulation.

In view of the above-mentioned, the authors have developed a device for pre-compaction of fibrous materials with the supply of a liquid or vaporous binder, which reduces the coefficient of friction [12].

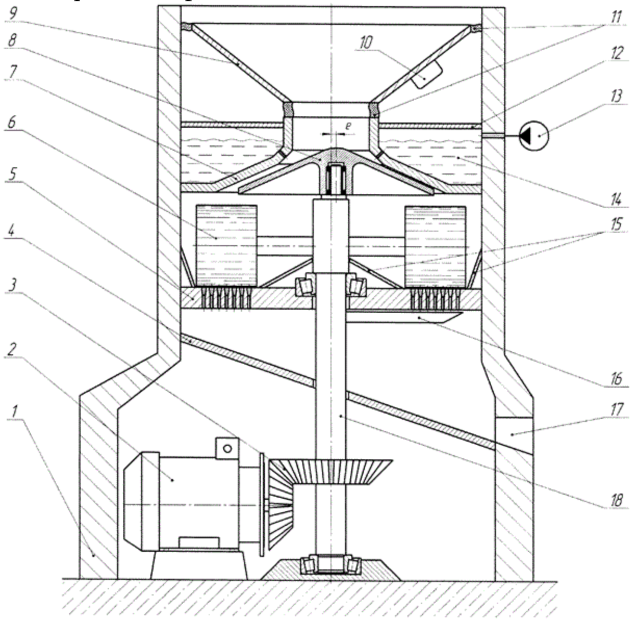

Figure 4. Device for preliminary compaction of fibrous materials. 1-body; 2-motor; 3-mechanical transmission; 4-inclined table; 5-disk array; 6-rollers; 7-outer fixed cone; 8-internal movable cone; 9-hopper; 10-high-frequency generator; 11-elastic element; 12-encapsulate id; 13-feeding pump; 14-tank; 15-inclined bead; 16-knife; 17-discharge port; 18-shaft.

4. Conclusion

As a result of the conducted studies, it was established that for effective complex processing of technogenic fibrous materials it is necessary to develop equipment that takes into account the physico-mechanical features of such materials. The application of the developed devices allows one to reduce the power inputs for molding and to obtain granules from a composite mixture based on technogenic fibrous materials that have high consumer properties.

5. Acknowledgments

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