Features of fibrous materials agglomeration in flat-matrix granulators

E A Shkarpetkin *, A V Osokin

Belgorod State Technological University named after V.G. Shukhov (BSTU n.a. V.G. Shukhov), 46 Kostyukov str., Belgorod, 308012, Russia

E-mail: jonick86@inbox.ru

Abstract. From the standpoint of ensuring the receipt of the recycled bodies for various technological purposes with standard and improved properties applicable in construction, petrochemistry, metallurgy and other areas of material production, recycling in the field of agglomeration of fibrous man-made materials is relevant. The article is devoted to the theoretical studies of the fibrous materials agglomeration characteristics in flat-matrix granulators-extruders with the channels of variable circular cross-section. Taking into account the analysis of the well-known calculation methods and as a result of the theoretical studies, the general regularities have been revealed and the equations have been proposed for determining the equilibrium conditions of a deformable material layer and changes in pressure in the channel, taking into account the effect of the operating device and fiber properties. Analytical dependences and changes in the axial pressure along the channel are obtained reflecting the regularities of the fibrous material movement.

Introduction

The processes of agglomeration are widely used in various industries in the manufacture of final products or semi-finished products for the convenience of their transportation, storage and further application in molded form. The implementation of the process of agglomeration of technogenic fibrous materials of different origin, which can be used as the basis for the production of bricks, cement modifiers, crushed stone-mastic asphalt concrete, insulating aggregates, absorbents for collecting oil products, etc. is of particular interest. [1-4].

The choice of technological equipment for agglomeration is closely related to the physical, mechanical and rheological properties (viscosity, elasticity, strength, plasticity, etc.) of the processed materials, which determine their ability to resist deformation under the action of external forces. At the same time, the materials that are anisotropic three-phase medium with a complex capillary-porous structure with the ability to swell and shrink during the sorption of water vapor, significantly impede the implementation of their agglomeration processes [5-7].

Methodology

Obtaining agglomerates with the given geometric and physical and mechanical characteristics can be achieved by the method of all-round compression when passing the processed material through the channels of a certain profile. The most common continuous machines implementing this method are granulator-extruders and roller presses with open molding channels [8]. The conditions for the formation
of granules are created directly in these channels - the required axial pressure arising from the action of the working body on one hand and from the resistance to pushing the material (back pressure) on the other hand is achieved.

The back pressure arises as a result of the material’s friction against the channel walls and is created by a movable stop, which is a previously pressed portions of the material in it. This determines the density of the resulting granules. The higher the channel resistance, the more pressure must be achieved to push the material along its axis, then the density of the granules will be higher.

It is known that as the material moves through the molding channel, the effect of axial pressure on it from the side of the operating device decreases.

To determine the law of axial pressure change in a variable cross-section channel, a common method is used. It consists in compiling and solving the equilibrium equation of a selected layer of thickness $dx$ at a certain depth $x$ from the input cross section. In particular, the channels of variable circular cross section and the square cross section [9, 10] are considered.

**Theoretical studies**

On the basis of the analysis and generalization of the known approaches to the description of the material movement (mixtures of fine powders with viscous-plastic properties), the design scheme was compiled using a variable circular cross section channel (Figure 1).

**Figure 1.** Scheme for calculating the movement of material through a channel of the variable circular cross section

Axial pressures act on the selected layer above the $P_x$ layer and under the layer - $(P_x + dP_x)$. In addition, lateral pressure (lateral thrust) $q_x$ and the external force of the material friction on the molding channel surface caused by it, acts in the cross section along the layer perimeter.

The equilibrium equation of the selected layer (for the presented scheme) will look like:

$$P_x S_x - (P_x + dP_x) S_x = f_x \cdot q_x \cdot l_x \cdot \cos \psi \cdot dx -$$

$$q_x \cdot l_x \cdot \sin \psi \cdot dx + q_x \cdot l_x \cdot \tan \psi \cdot \cos \psi \cdot dx = 0;$$

where $S_x$ is the cross-sectional area of the channel at a depth $x$, m$^2$; $f_x$ is the coefficient of the material external friction against the channel walls; $l_x$ is the perimeter of the cross section of the channel at a depth $x$, m; $\psi$ is the angle of the channel walls inclination to its axis, in degrees.

Separating the variables and integrating we get:
where $D_k$ is the diameter of the inlet section of the spinneret channel, m; $\xi$ is the lateral thrust coefficient (lateral pressure), (determined experimentally).

Here $P$ is the normal component of pressure from the side of the working body (stamp, press roll), at which the next compressed portion of material is pressed in and the entire material in the channel is pushed.

Thus, the obtained equation (2) allows to determine the pressure drop along the length of the channel of the variable cross-section of a circular shape.

Solving the equation (2) with respect to $P$ at $x = L_k$ and $P_x = 0$ (since there is no back pressure at the channel output) we get an expression for determining the resistance of the channel with a long $L_k$:

$$P_x = \left( P + \frac{q_0}{\xi} \right) \left( \frac{D_x - 2x \cdot \tan \psi}{D_x} \right)^{\frac{2f_i \cos \psi}{\tan \psi} - \frac{q_0}{\xi}}$$

(2)

The channel resistance, determined by equation (3), is the back pressure, which, in order to obtain granules of a given density, must ensure the maximum pressure $P$ of the operating device (its normal component). Equating the right-hand sides of the equations and deciding on $L_k$, we get the channel length providing this backpressure:

$$L_k = \frac{D_x}{2 \cdot \tan \psi} \left[ 1 - \left( \frac{C \cdot \xi}{q_0} \left( e^{\psi (\rho - \rho_0)} - 1 \right) + 1 \right)^{\frac{\psi}{2f_i \cos \psi} - \frac{q_0}{\xi}} \right]$$

(3)

where $C$ is the parameters of the fibrous material characterizing its physical and mechanical properties during granulation, Pa, (determined experimentally); $\rho$ is the density of the molded granules, kg / m$^3$; $\rho_0$ is the bulk density of the mixture (material) before its granulation, kg / m$^3$; $q_0$ – is residual lateral pressure due to the elastic expansion of the compacted material, Pa.

The equations show that the resistance of the forming channel with a conical part varies exponentially and depends on the geometric parameters of the forming channel ($D_k$, $\psi$, $L_k$) and the physical and mechanical properties ($f_i$ and $\xi$) of the granulated medium.

Considering a number of features of the fibrous materials properties (large ratio of length to diameter of fiber $L / D$, high internal friction $f_i$, low relative mobility of fibers during molding, high degree of compaction $\lambda_{upl}$) when developing a mathematical description of the movement of the fibrous material at the variable cross-section channel to the output section. It was assumed that the material is pressed into the channel, moves in it by layers of finite thickness and takes the meniscus form during deformation. This is due to the fact that in flat-spinneret granulators-extruders, during one pressing cycle (rolling a press roll on a layer of material), a portion of the layer of material is pressed in due to its separation (cutting) along the perimeter of the inlet section at the moment of passage of the press roll on it, further movement occurs after repeating the cycle. In addition, as the portions move to the exit under the friction forces action at the channel walls, a bend arises along the arc (Figure 2).
Figure 2. Scheme for calculating the movement of a fibrous material through a spinneret channel of the variable cross section

Taking into account the accepted assumptions, the equation (1) of the equilibrium of the deformed layer at a depth $x$ from the input section in the projection on the spinneret axis (Figure 2) can be written in the following form:

$$P_x S_x - (P_x + dP_x) S_x - F_{mp}^i \cdot \cos \psi - N^z \cdot \cos \psi - N^n \cdot \sin \psi = 0$$

(5)

where $F_{mp}^i$ is the force of external friction of the material on the walls of the spinneret (due to lateral thrust), $H$; $N^z, N^n$ are the normal and tangential (to the spinneret wall) components of the reaction force $N$, respectively $H$.

After the transformations of the given expression, the separation of variables and subsequent integration, we reduce the expression to the form $dy = F(x, y) dx$

Then we get:

$$dP_x = -P_x \cdot \tan \psi + 2 \arctg \left\{ \frac{3}{4} \left( \frac{D_x^2}{(D_x - 2 \cdot x \cdot \tan \psi)^2} - 1 \right) \right\} \times$$

$$\times \frac{4(D_x - 2x \cdot \tan \psi)}{D_x^3} (f \cos \psi - \sin \psi) dx -$$

$$-(\xi \cdot P_x + q_0) \cdot \frac{4(D_x - 2x \cdot \tan \psi)}{D_x^3} (f \cos \psi - \sin \psi) dx -$$

$$- P_x \cdot \frac{4(D_x - 2x \cdot \tan \psi)}{D_x^3} \cos \psi dx +$$

$$+(\xi \cdot P_x + q_0) \cdot \tan \psi + 2 \arctg \left\{ \frac{3}{4} \left( \frac{D_x^2}{(D_x - 2 \cdot x \cdot \tan \psi)^2} - 1 \right) \right\} \times$$

$$\times \frac{4(D_x - 2x \cdot \tan \psi)}{D_x^3} \cos \psi dx.$$

(6)

The obtained differential equation (6) describes the pressure change over the depth of the molding channel of the variable cross section.
Analysis of the equations’ solutions (2) and (6) allows to assume that the process of sintering fibrous materials in flat-matrix granulators-extruders with the channels of variable circular cross section requires $k_f$ times more energy at the same pressure value of the $P_B$ molding based on fine powders with viscous-plastic properties. This is determined by the ratio of the areas $S_{pr1}$ and $S_{pr2}$ of the figures according to the graphs (Figure 3), constructed in proportion to the work of $A_{pr}$ forces acting from the press roll to push the material through the channel.

**Figure 3.** The change in axial pressure during agglomeration:

1 - powders with viscous-plastic properties, 2 - fibrous material

Thus, the results obtained do not contradict the physical meaning occurring during the processes agglomeration and confirm the correctness of the mathematical transformations.

**Summary**

As a result of the theoretical studies, it was found that the formation of fibrous materials in the channels of variable circular cross-section requires an increased energy consumption in comparison with the formation of granules of the same density from the elastically viscous plastic materials. The equations and analytical dependencies are obtained to determine the equilibrium conditions of a deformable material layer, the change in axial pressure in a channel of variable circular cross section along its length, taking into account the impact of the operating device and fiber properties. The equations allow a more reasonable approach to the calculation and selection of extruder granulators’ parameters, for example, with a flat matrix.

**References**

[1] Nefedova I N, Krasheninnikova N S, Garber E G 2011 *Waste from the production of mineral wool as a technogenic raw material, Chemistry and chemical technology of inorganic substances and materials* (materials of the 3rd Scientific Conference, Tomsk Polytechnic Publishing House. University) 33–34.

[2] Palgunov P P, Sumarokov M V 1990 *Recycling industrial waste* (Stroiizdat. Moscow).

[3] Romanovich A A, Orekhova T N, Meshcheryakov S A, Prokopenko V S 2014 *Technology of receiving mineral additives* (Bulletin of BSTU named after V G Shoukhov) 5 181-192.

[4] Chertov E D, Vasechkin M A, Nosov O A, Vardanyan G R 2014 *Contactless method of forming elements of transport structures from organomineral composite materials* (Bulletin of VSUET) 2 71-76

[5] Dornyak O R, Sviridov L T 2006 *Structural-mechanical properties and stress-strain state of wood in pressing processes. Rheological equation of state* (Bulletin of Moscow State Forest University - Forest Bulletin) 1 50–57.
[6] Shkarpetkin E A, Osokin A V and Sabaev V G 2018 *Investigation of the composition of composite mixtures during their granulation* (IOP Conf. Series Material Science Engineering) **327** 042118.

[7] Sevostyanov M V, Ilyina T N, Sevostyanov V S, Emelyanov D A 2015 *About the Role of Surface Phenomena in the Processes of Dispersed Materials* (Research Journal of Applied Sciences) **10** (10) 684-689.

[8] Dubinin N N, Evtushenko E I, Nemets I I, Nosov O A, Osokin A V 2014 *Rotary Machines for Ceramic Wall Materials. Research Journal of Pharmaceutical (Biological and Chemical Sciences)* **5** (5) 1710-1718

[9] Melnikov S V 1978 *Mechanization and automation of livestock farms* (Proc. allowance higher. studies. Institutions, Leningrad).

[10] Kuchinskas Z M, Osobov Yu L 1988 *Equipment for drying, granulating and briquetting feed* (Freger, Moscow, Agropromizdat).

**Acknowledgements**

The work is realized in the framework of the Program of flagship university development on the base of the Belgorod State Technological University named after V.G. Shukhov, using equipment of High Technology Center at BSTU named after V.G. Shukhov