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Influence The Structural And Mechanical Properties Of A Solid Fraction Of The Fermented Bird' Dung Onto Wet Granulation Process.

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ABSTRACT

A scheme of step-by-step wet granulation of the solid fraction of fermented bird dung (SF FBD) in auger granulator is presented. The process of pressing the material at each stage of granulation is considered. Structural and mechanical properties of the pressed material are studied. It has been revealed that SF FBD refers to pseudoplastic bodies, which, when subjected to pressure, exhibit the properties of an anomalous medium. A rheological model of the behavior of the pressed material in a screw granulator is proposed. A mechanical model of the behavior of SF FBD is modeled. It was revealed that the material being pressed at pressure values generated in a screw granulator in the zone of plasticization, behaves like an anomalous liquid medium. It obeys the laws of flow of Newtonian fluid.
Keywords: Wet granulation, rheological model, the zone of kneading, paddle knife, matrix, bird dung.

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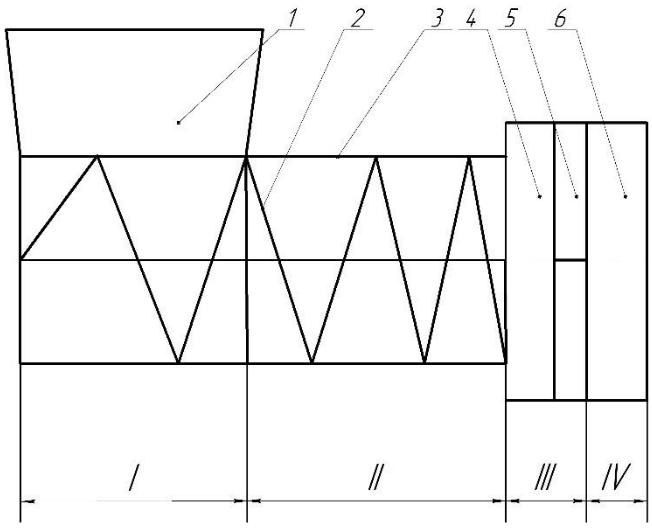
INTRODUCTION

Researches of specialists [1, 2, 3, 4, 5] show that a promising direction for the development of the processing of poultry manure is the creation of low-waste or completely waste-free resource-saving production. An example of such a technology is a resource-saving technology for processing poultry manure, developed by the staff of the Department of Machinery and Technology of the Agro-Industrial Complex, Stavropol State Agrarian University [6]. It is based on the biological decomposition of organic matter in bird dung in the absence of oxygen - anaerobic digestion. One of the unresolved issues in the process line is the stage of obtaining granular organic fertilizers. This stage solves a very important task - the further use of the nutritional and energy potential of the solid fraction of fermented bird dung (SF FBD), which is currently in demand in the fertilizer market.

MATERIALS AND METHODS

To accomplish the task, we propose the design of a screw granulator, presented in Figure 1 [7]. In the screw granulator it is necessary to distinguish four stages of material processing (Figure 1): I - material loading stage; it serves to take the incoming material, its capture and advance into the body; II - the stage of compression, compaction of the material; III - the stage of changing the structural and mechanical properties of the material (the material acquires a viscoplastic state); IV - the stage of formation of the material (the movement of material through the die die).



1 - boot window; 2 - auger; 3 - housing; 4 - zone of plasticization;5 - blade knife; 6 - matrix

Figure 1: Scheme of auger granulator with distribution the stages of pressing

The principle of operation of the screw granulator can be described as follows. The extruded material (SF FBD) enters the screw granulator through the loading window (stage I). At the second stage (II), the material is gradually deformed, its compaction occurs and the destruction of interparticle bonds begins. At the stage of changing the structural-mechanical properties of the material (III) under the action of pressure in it, the interparticle bonds are completely destroyed. In this case, the formation of new structures with the predominance of the forces of attraction of particles of the dispersed phase. The smallest organic particles enter phase contacts with liquid molecules, and they are “spliced” under the action of stress as a result of diffusion processes. At this stage, the material acquires the properties of a viscoplastic body and begins to flow. Next, the extruded material enters the die, where it is molded into pellets (stage IV).

The substantiation of the design parameters of a screw granulator and the determination of the optimal technological conditions of the pressing process of the SF FBD should be based on its general regularities, which implies the obligatory knowledge of the structural and mechanical properties of the SF FBD, as well as its bulk deformation properties that characterize the behavior of the material under all-round compression. The analysis of the fractional composition of the SF FBD showed the following. The size of its particles vary over a wide range. Particles ranging in size from 2 to 3 mm and above make up 12%. They are represented by fibers of plant origin. Particles ranging in size from 1 to 2 mm in SF FBD make up 19%. They are represented by particles of feed and small mineral impurities - sand. Particles ranging in size from 0.1 to 1 mm make up the largest amount - 36.8%. They contain the smallest organic impurities. The rest of the TF compositional parameter with sizes less than 0.1 mm is 32.2% and is represented by bacteria of the methanogenic association and the smallest organic impurities [8]. Moreover, particles with sizes less than 1 mm makeup 69%, which characterizes it according to the classification of B. Ostwald 9], as a solid-like fine system.

RESULTS AND DISCUSSION

In the granulator, SF FBD is in conditions of increasing compression, and when approaching the matrix - in conditions of all-round compression. The combination of the elastic, viscous and plastic characteristics of the TF PPS will give an opportunity to determine the rheological model adopted for it. To this end, we consider the dependence of the shear rate of the pressed material on the shear stress. The curve has a complex nature (Figure 2, a).

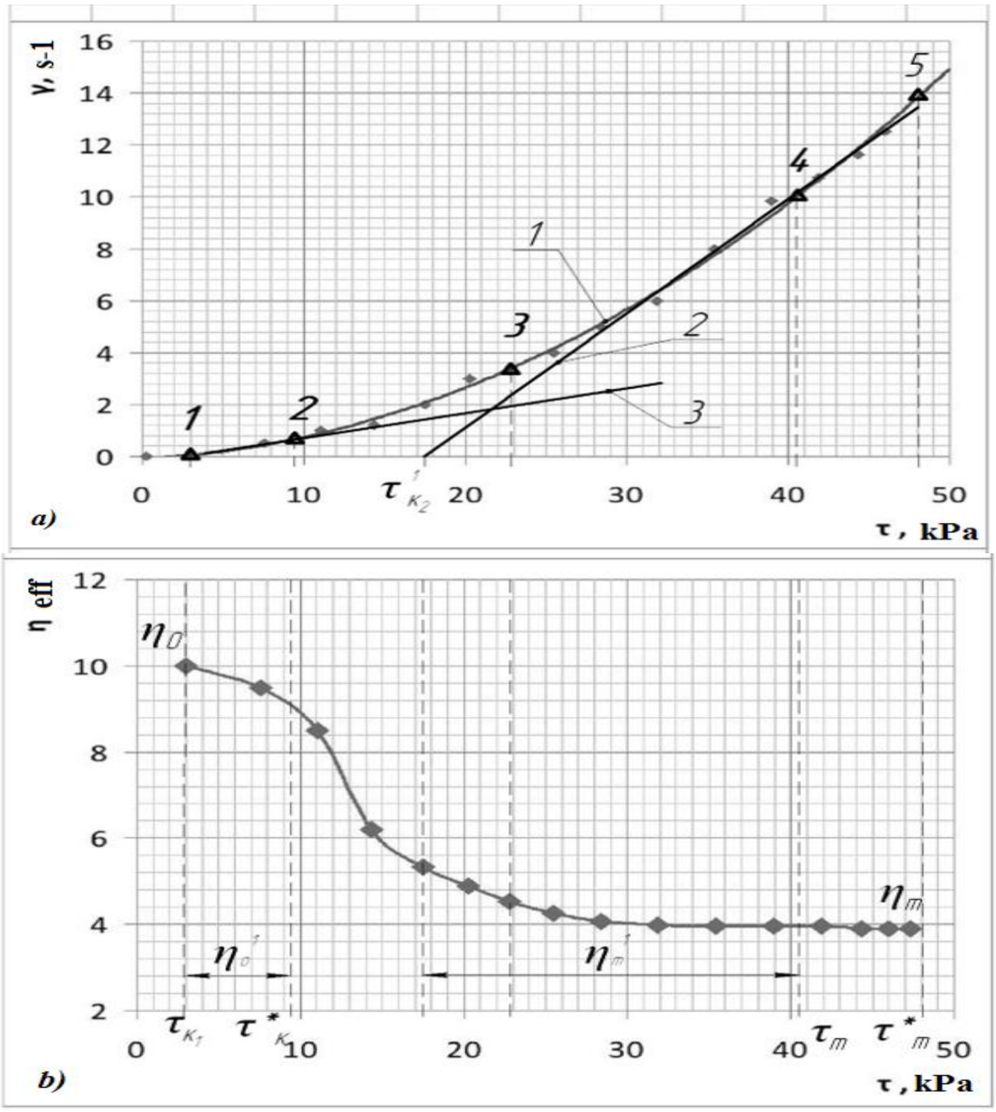


Figure 2: Dependence of the shear rate γ and the logarithm of the effective viscosity η_{eff} on the shear stress τ SF FBD

It reflects the influence of the rheological properties of the material in the process of its deformation. As can be seen from the dependence, at a constant shear stress τ greater than the value of the ultimate shear stress τк1, there is an instantaneous elastic deformation of the TF PSC (points 0-1). External impact on the material does not violate the strength of its structure. In this period of action of the shear stress, the material being pressed is subject to Hooke's law. This can be described as the action of a coil spring. The shear stress increases from 0 to 3 kPa, the shear rate is 0, the effective viscosity has a maximum value of 10.0 kPa · s (Figure 2, b).

Section 1-2 corresponds to the first stage of pressing (Figure 2, a). Then comes the limiting value of the shear stress and begins the elastic (elastic) deformation of the SF FBD (points 1-3). This stage can be divided into two sections. The first - points 1-2 is characterized by a gradual destruction of the structure of the material, a violation of interfacial bonds in it. The stage is characterized by the beginning of the flow of the material with the manifestation of the highest effective and plastic viscosity η_{eff}. The behavior of the material can be modeled by the Kelvin-Vogt element [10]. The value of shear rate with increasing shear stress from 3 to 9.3 kPa gradually increases to 0.7 s^{-1}. The effective viscosity of the TF PPP within the site decreases from the maximum value of 10.0 to 9.1 kPa · s (Figure 2, b).

At section 2-3, the structure of the material begins to collapse avalanche. In this case, the shear stress increases to a value of 22.8 kPa, the shear rate is 3.5 s^{-1}, and the value of the effective viscosity decreases almost twofold and reaches a value of 4.7 kPa · s. The material on this site begins to have other structural and mechanical properties - it begins to flow. Stage II corresponds to the pressing process (Figure 1).

Next, consider the area 3-4. The avalanche destruction of its structure continues in the material; the material flows with the lowest effective viscosity. The material acquires the properties of a pseudoplastic body. With a sharply increasing shear stress of up to 40.5 kPa, the shear rate also increases by a factor of 2.9 and reaches a value of 10.0 s^{-1}. The effective viscosity decreases slightly to a minimum of 4 kPa · s. This section corresponds to stage III pressing SF FBD in a screw granulator (Figure 1), which passes in front of the matrix, where the zone of plasticization and the injection blade is located [7].

Section 4-5 is characterized by the Newtonian flow of a material with constant viscosity. It slightly increases the shear stress to 48 kPa, and the shear rate reaches 13.8 s^{-1}, while the effective viscosity of the material remains almost at the same level and is 3.8 kPa · s. Patterns of material movement in the zone of plasticization of a screw granulator and further in matrix die can be considered as the motion of a Newtonian fluid in a stationary mode [10]. This section corresponds to the fourth stage of the extrusion of the material - molding from the material of granules (Figure 1).

The revealed regularity of the strain kinetics of SF FBD consists of series-connected elements of mechanical models: Hooke's element with elastic modulus G, Newton's element with viscosity η_{eff} and Saint-Venant plastic element (Figure 3).

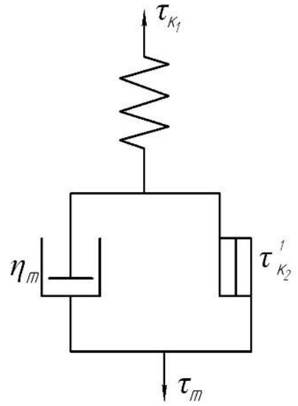


Figure 3: Combined mechanical model the flow of the solid fraction of fermented bird dung

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Applying stress τ to a combined model that exceeds the ultimate shear stress $\tau_{\kappa 1}$, will lead to the deformation of the elastic element by a certain amount of deformation and shear modulus (*G*)calculated by the formula:

$$G = \frac{\tau}{\dot{\gamma}_0}, \qquad (1)$$

τ – applied shear stress, kPa;

$\dot{\gamma}_0$ – the relative magnitude of the instantaneous elastic deformation.

At the same time, a slow flow in a viscous element begins in the auger granulator η'_0compressible material. This section of the slow course of the TF PPS is represented by curve 1-2 in Figure 2, a. The viscosity of the elastic after effect was determined by the formula:

$$\eta'_0 = \frac{\tau}{\Delta\dot{\gamma}_1}, \qquad (2)$$

$\Delta\dot{\gamma}_1$ – change in the rate of elastic deformation in section 1-2, characterized by a change in the tangent of the angle α of inclination of the tangent to this area, s^{-1}.

By the time point corresponding to point 3, the development of elastic deformation is completely completed, and then a viscous flow is observed, which is expressed by an approximated straight line 2 (Figure 2, a). The flow rate in this region is proportional to the voltage. ($\tau<\tau^1_{k2}$)and inversely proportional to the highest plastic viscosity according to Shvedov, which was determined by the formula:

$$\eta_m = \frac{\tau - \tau^1_{k_2}}{\dot{\gamma}_m}, \qquad (3)$$

$\dot{\gamma}_m$ – the rate of increase of the deformation of the flow of material, s^{-1}.

The compiled mechanical model presented in Figure 3 is a Herschel-Bulkley model and practically coincides with the Bingham mechanical model, since it reflects the physical essence of the process occurring in the auger granulator [11]. This model is described by the rheological equation.

$$\dot{\gamma} = \frac{\tau}{G} + \frac{\tau - \tau^{1}_{k_2}}{\eta_m}. \quad (4)$$

By the nature of the flow curve $\dot{\gamma} = f(\tau)$, depicted in Figure 4, the TF PPS can be attributed to viscoplastic solid-dispersed systems, and its formation can be considered as plastic deformation and flow of a pseudo-plastic material.

As confirmation of the above, we have constructed three rheological curves for the flow of SF FBD (Figures 4-6).

Figures 4-6

They were compared using the Herschel-Balkley power equation.

$$\tau - \tau_0 = B_1 \cdot \dot{\gamma}^n, \quad (5)$$

τ_0 – ultimate shear stress, kPa;
B_1 – the coefficient of proportionality of viscosity with a velocity gradient equal to unity, Pa · s;

n – material flow index.
By$\tau_0=0$equation 5 takes the form of the Ostwald de Ville power equation:

$$\tau = B^*_1 \cdot \dot{\gamma}^n, \quad (6)$$

by$n=1$ – Shvedova Bingam, and$B^*_1$is the proportionality coefficient for the velocity gradient $\dot{\gamma}_1 = 1c^{-1}$.

To give the coefficient of proportionality of a certain physical meaning - the effective viscosity η_{eff} we write:

$$\tau - \tau_0 = B^*_0 \dot{\gamma}^n \dot{\gamma}_1^{1-n} = B^* \left(\frac{\dot{\gamma}}{\dot{\gamma}_1}\right)^n \cdot \dot{\gamma}_1 = B^*_0 \left(\frac{\dot{\gamma}}{\dot{\gamma}_1}\right)^{n-1} \cdot \left(\frac{\dot{\gamma}}{\dot{\gamma}_1}\right) \dot{\gamma}_1. \quad (7)$$

Denoting by$m=1-n$the rate of destruction of the structure, and through $\dot{\gamma}/\dot{\gamma}_1 = \gamma_*$ dimensionless velocity gradient, we get

$$\tau - \tau_0 = B^*_0 \dot{\gamma}_*^{-m} \dot{\gamma} = \eta_{eff} \dot{\gamma}, \quad (8)$$

from where

$$\eta_{eff} = B \dot{\gamma}_*^{-m}, \quad (9)$$

η_{eff} – effective viscosity, Pa · s.

According to the classification [11], the behavior of the curves (Figures 4-6) correspond to a pseudoplastic solid-like body. Also, from the regression equation of the curve in Figure 6, where the value -m = -0,2989, after using the formula $m=1-n$ got n equal 0,7, which is less than one. Such a value of the flow index of the pressed material in a screw granulator characterizes it as a pseudoplastic solid-like system.

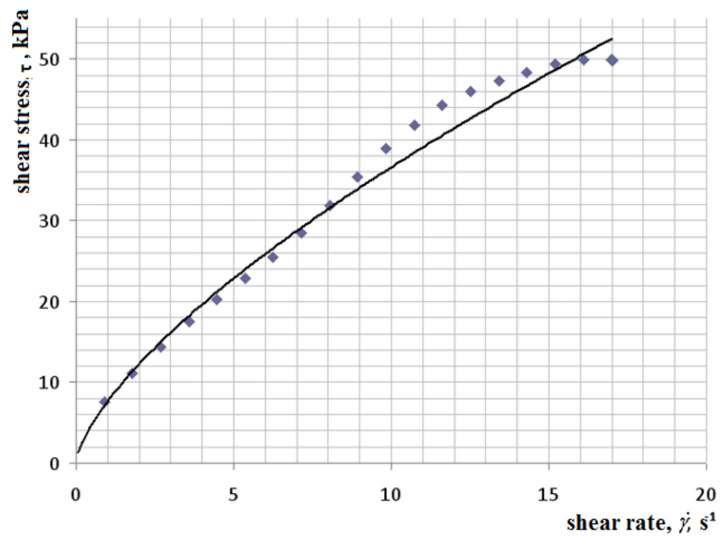

Figure 4: Dependence of shear stress τ on shear rate $\dot{\gamma}$ SF FBD in uniform scales

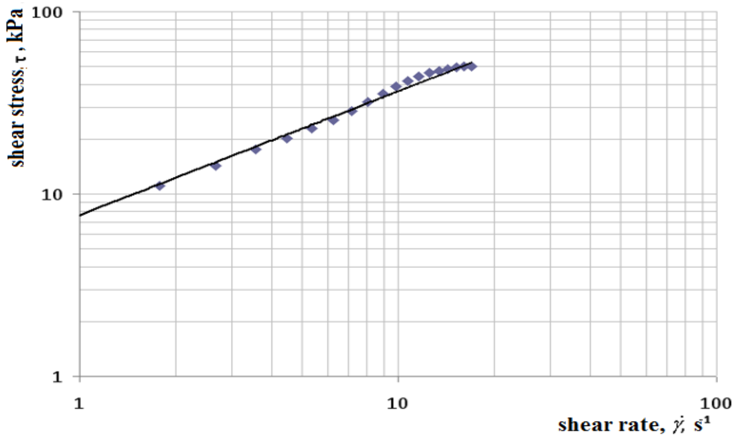

Figure 5: Dependence of the shear stress τ on the shear rate of the $\dot{\gamma}$ SF FBD in logarithmic scales

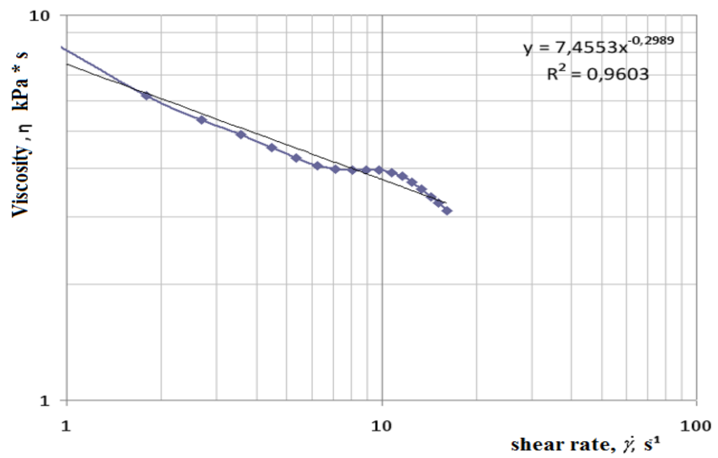

Figure 6: Dependence of the effective viscosity η_{eff} on the shear rate of the $\dot{\gamma}$ SF FBD in the log scale

CONCLUSION

The study of the rheological properties of the pressed material - SF FBD showed that the material is a solid pseudoplastic body and has all its properties. The abnormal behavior of the viscosity of the material is due to the structuring of the system and the change in the structure during its deformation. When shear stress exceeds 20 kPa, material begins to flow. The viscosity becomes independent of shear rate and presses a minimum value of 4 kPa · s. Thus, in this range SF FBD behaves like Newtonian fluid. Extrapolation of section 4-5 to the intersection with the abscissa axis allowed us to determine the yield strength of the SF FBD according to Bingham, which is equal to 17.5 kPa, and characterizes the number and strength of interparticle contacts, as well as the strength of its structure. Wide yield area (difference $\eta_{max} - \eta_{min}$) viscosity limit SF FBD determines its important technological property - formability (granulation).

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