INVESTIGATION OF GRANULATION PROCESS INFLUENCE TO GRANULATED ORGANIC COMPOST FERTILIZER PROPERTIES

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Abstract. Granulation application in organic compost fertilizer production allows making better use of nutrients, it also significantly reduces the amount of fertilizers needed to be poured in the soil and reduces the cost of their storing, transportation and spreading in the soil. Granulation process parameters and factors affecting the cattle manure-based compost of organic granular fertilizer physical-mechanical properties were investigated. Theoretical and experimental studies have shown that the produced pressed fertilizer qualitative traits and physical-mechanical properties of the pelleting process were influenced by the technological parameters of granule production. It was determined that the kinetic friction force occurs when granules slide against metal and plastic friction surfaces, which depend on the material properties, friction surface condition and sliding velocity. The granule pourability was influenced by the fractional composition of the pellets which determined the natural slope angle (43º-47.6º) and inrush failure angle (26º-22.7º).

Key words: granulation, granulated compost fertilizer, physical-mechanical properties.

Introduction

Secondary raw materials of agricultural production process such as cattle and bird manure, feed wastes are still the main source of organic fertilizers. It is really hard to store high amounts of manure, and there is almost no way to spread it over the soil evenly. Secondly, the process of fertilizing the soil using organic fertilizers is seasonal; while production of manure continues throughout the year. The solution of all the problems mentioned above would be recycling cattle and bird manure by granulating it. Using high pressure, water would be extracted, and, due to increased density (capacity) of the material, it would require ten times less space [1; 2].

Granulated organic fertilizers are manure of cattle and birds, chopped and dried in high heat and then compressed into granules. The mass of granulated fertilizer is greatly smaller and can be spread using pouring machines of mineral fertilizers or simply applying them during the sowing. Density of the compressed granulated material is expressed by [3]:

$$\gamma = \frac{H_0}{H_1} \cdot \gamma_0 , \quad (1)$$

where H_0 –height of granulated material layer before the compressing roller, m;
H_1 –height of granulated material layer after the compressing roller, m;
γ_0 –density of initial material (compost), kg·m^{-3}.

During the compression, the height of the roller granulating material layer before it was pressed. H_0 is expressed by [3]:

$$H = R - \frac{r}{\sqrt{1+f_k^2}} - \sqrt{\frac{(R-r)^2 + f_k^{\,2} \cdot R(R-2r)}{1+f_k^2}} , \quad (2)$$

where R – radius of the cylinder matrix, m;
r – radius of the roller, m;
f_k – coefficient of compressed material friction into the wall of the matrix channel.

The effectiveness of the granulating process depends on the mechanic process of granule formation, which has direct impact on the granulating methods, such as technical and technological settings of the granulator efficiency Q [3]:

$$Q = \pi(2R - H_0)H_0 \cdot b \cdot \gamma \cdot z \cdot n \quad (3)$$

where Q – efficiency of the granulator, kg·s^{-1};
b – width of the matrix, m;

γ_k – density of pressed material, kg·m^{-3};
z – count of compress rolls;
n – matrix spinning rate, s^{-1}.

Compressing is a mechanical process of recycling dispersive materials into granules or briquettes using high pressure. Compressed material should be imagined as a system made of three phases: solid, liquid and gas [4-6].

Gas phase consists of air, which fills in the gaps between the particles, which are inside the spores or on the surface of the material. During compressing of dispersive material, majority of air is removed.

The solid and liquid phases have the highest influence, their physical – mechanical and chemical properties [6; 8]. The first densification of the compressed material happens during relative throughout movement of particles. At the start of compression, the surface contact area of particle contact is small. During the rise of pressure, the particles of the material deform and while the gaps between them shrink the surface contact area expands.

Pressure of compressing goes throughout the particles via their contact points, spreading it all over the mass of the compressed material. During pressing, energy is being wasted to overcome internal friction between the material particles by thickening them and for matters that are in motion, also for external friction that occurs between the material and the walls of the channel matrix and to defeat elastic and residual deformation [3; 6; 8].

At the end of the primary densification of the material it deforms: reversible or elastic and irreversible or residual. Residual and irreversible deformations of the material consist of fragile and plastic. During fragile deformations due to high pressure the capacity and shape of the particles in the material change. To accomplish that, particles of the material must be grinded into each other under high pressure during relative movement among them. The change of capacity and shape of the particles during densification characterizes plastic deformation.

The process of densification consists of removal of empty space in the particles and macromolecules depending on high pressure. Strength of granular structure relies on plastic deformations, while the character of the last mentioned depends on high pressure [5; 8].

At the beginning of compressing, the material gets its initial granular structure during dispersive densification of the material structure. Physical and chemical processes of particles interacting each other relate to elastic deformation of material when the compressed material resists to the impact of high pressure. Elastic deformations tend to vanish in transition to residual and, by removing the pressure, they manifest as a result of elastic expansion of granule. Formation of granule is a result of two consistent processes: densification and elastic expansion. Elastic expansion in granule causes change in its granular structure and strength.

Physical and mechanical properties of material have high impact on the character of deformation, especially fragility, humidity and temperature. The analysis of dispersive compressing of material shows that inner and outer friction is of extra importance [3; 6].

Inner friction is opposite to relative shift of object particles. Inner friction relies on the physical – mechanical properties of the material, especially humidity and temperature [4; 5]. Outer friction of dispersive material has high impact to the indicators and work of the granulator, such as loss of energy and wane of the work surface [3; 6].

Power of friction arises due to the pressure of the side channel in the matrix. Granular material is a phenomenon of inequality. The unequal distribution of material phenomenon occurs due to the influence of friction power during densification of friable material without its free expansion. As a result, the layer of the material only partly absorbs the pressure. Due to the friction power, the pressure in the material cross-section differs [3; 8].

Organic cattle manure compost pellet strength can be expressed as a function:

$$\sigma = f(p, \delta, w, t, k, \tau, v), \tag{4}$$

where p – pressing comparative pressure, Pa;
δ – compost crushing rate, %;

w – granulated material moisture content, %;
t – granulated material and the matrix channel temperature, ºC;
k –type of the granulated material;
τ – time to pressing into pallets, s;
v – pressing velocity, $m \cdot s^{-1}$.

When using a cylindrical matrix, greater strength is obtained when traction forces occur between the material particles in the pressing process, and compression time in the matrix channel is higher than the pellet relaxation time [3; 6; 8].

Firstly, densification of the material inside the granulator starts between the compressing rollers and the inner surface of the matrix. The amount of the obtainable material of rollers depends on the granulating substance inner friction and the coefficient between the material and roller friction. When the rollers are pressing the material towards surpasses, the compressed power of the material in the matrix channel starts to move through it. The amount of the compressed material depends on many factors. Accordingly, the amount of the material can be expressed as ratio between the radius of the matrix and roller, granulated substance inner coefficient and friction power function. Due to increase of the friction coefficient among the material and the roller, the width of the compressed material layer for the matrix radius increases.

The aim of this work is to investigate the granulation process influence on the granulated organic compost fertilizer properties, to evaluate technological-technical means of organic compost preparation for fertilizer, to assess the quality indicators and physical-mechanical properties of the produced granules.

Materials and methods

A high-quality organic fertilizer pellets production technological process consists of the following stages: production of compost, compost milling and drying, and granulation. The key technology of this cycle becomes a continuous pressing operation, where the granulated material having an initial bulk γ^o is compacted to γ. During this operation in the channel matrix there is constant compaction of dry substances, characterized by the relative density of the granulated material (γ/γ^o).

When compressing powdery substance and when its expansion in the transverse direction is eliminated, then any pressure of the powdery material increase in one direction inevitably leads to a proportional increase in the bulk material pressure in the direction perpendicular to the channel wall. It is observed that at the same pressure the granulated material volume mass located in the matrix channel is greater than the extruded matrix channel material (pellet) volume mass. When the pellets exit the matrix channel, the residual internal stresses within the channel for cross-linking direction between the extruded material particles decrease and radial stress in the lateral surface of the granule layer decreases, too. Based on this reason, it can be stated that when pressing organic materials it is needed to create such conditions for the conduct of deformation, which would reduce the pressure on the side walls of the matrix channel. Granule strength is determined by the granule stay time in the matrix channel, which depends on the length of the channel and the channel side surface configuration.

Static friction is influenced by the force at which relative movement of one body against another under different conditions takes place: comparative load, surface shape, material and so on. During the investigation, the friction force was not measured in respect of time and was considered as the frictional force necessary for maintenance of two bodies' movement under certain given velocity: 0.02; 0.04; 0.06 and 0.08 $m \cdot s^{-1}$.

During the experiment, dependence of kinetic friction from the sliding velocity and load was determined at a constant granule humidity of 24.2 %.

Pellet pourability is described by natural slope angle determined by freely falling pellets on horizontal plane. The inrush failure angle defines the coefficient of friction. Higher angle results are of smaller granule pourability. The friction characteristics were determined by evaluating the flow angles (natural slope and inrush failure), using a special laboratory stand [9]. All investigations are repeated 5 times; the average values and tolerances are calculated.

Results and discussion

To sum it up, in order to set up optimal settings of the granulator work elements (rollers and matrix), such as rollers outer surface forms, also the inner friction coefficient of the material as well as the static and dynamic friction coefficients of colliding materials(substances) should be known.

Plastic deformation properties and the size inside the material and in the upper layer have an impact on the friction power at the process of granulation. Friction force F_f or the friction coefficient depends on the surface area of the contact, and when it increases the adhesion area on the surface and friction also increase. When the friction force reaches the maximum value ($F_{f\ max}$), sliding between two bodies occurs.

The force which moves the body out of static equilibrium is determined under static friction. Whilst an effective into one of the bodies, when the force increases on the initial places of the contact surface, elastic deformation appears, and later on plastic deformation can be spotted, which increases over the time.

Outer kinetic friction is a complicated phenomenon that needs to be examined as energy which is consumed under friction. When plastic deformation takes place at the granulation time, all the energy must be used for plastic deformation without losing it in the heat form. In case of only elastic deformations friction work moves on to separating heat.

The test results show that the static friction force depends on the workload; while under low load, it can be expressed by *Amontono's Law* with just enough accuracy. Kinetic friction force occurs when granules slide against metal and plastic friction surfaces which, as shown by the test results, depend on the material properties, friction surface condition and the sliding velocity (Fig.1 and Fig. 2).

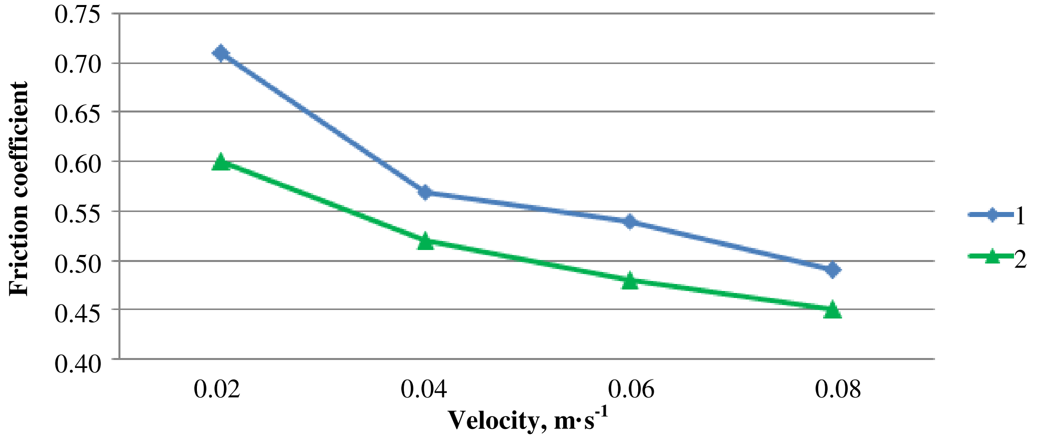

Fig. 1. **Granule kinetic friction coefficient dependency on sliding velocity on metal surface:** 1-4 mm diameter granules; 2-6 mm diameter granules

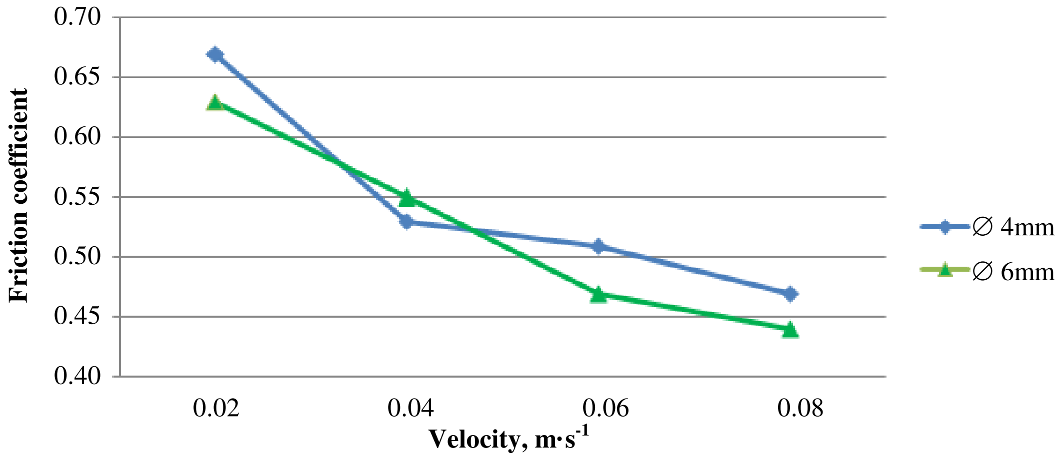

Fig. 2. **Granulekinetic friction coefficient dependency on sliding velocity on plastic surface**

As it may be seen from the graphs, the kinetic friction coefficient is the highest at the lowest speed, and when the velocity increases, the coefficient decreases. The friction coefficient has the highest value (0.71) on the metal surface when the sliding velocity is 0.02 $m \cdot s^{-1}$, and it has the lowest value (0.44) on the plastic surface when the sliding velocity is 0.08 $m \cdot s^{-1}$.

This is explained by the idea that in sliding processes compost organic fertilizer granule properties change on the surface of the contact areas. Increasing the sliding speed and load also the temperature of the substance increases; thus, plasticity also gets higher. All this influences the reduction of the kinetic friction coefficient.

The relaxation process of granules after their production was investigated. It was established that incomplete relaxation process in granules influences elastic deformation. About 52 % of pellets produced mass quantities do not meet the design matrix channel diameter, which influences granule pourability.

The determined granulenatural slope angle and the inrush failure angle dependency on granule fractions (3.15-4.0 mm; 4.0-5.0 mm; 5.0-7.1 mm) is shown in Fig. 3.

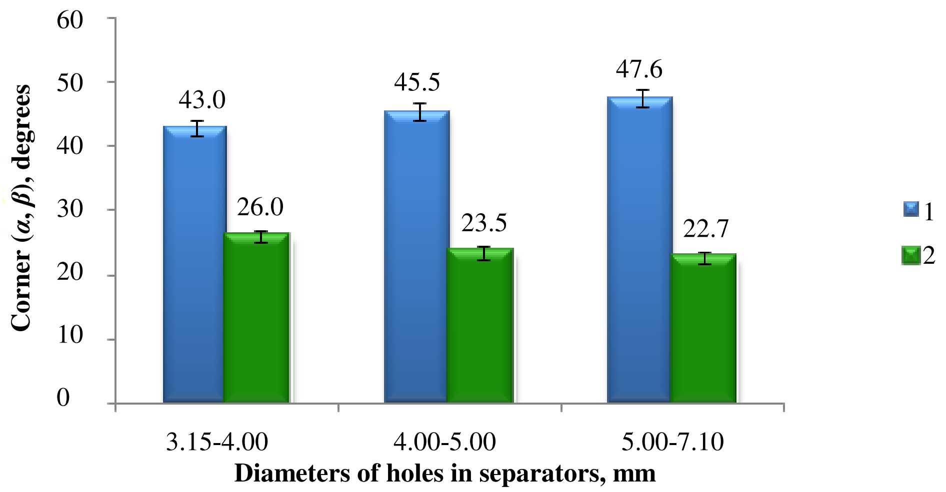

Fig. 3. **Natural slope and inrush failure angle dependency on granule diameter:**
1 – natural slope angle (α); 2 – inrush failure angle (β)

The results show that, when the diameter of the granules increases, the natural slope angle also increases from 43.0 ± 2.8º to 47.6 ± 3.2º, while the inrush failure angle decreases from 26.0 ± 0.9º to 22.7 ± 0.8º. It can be concluded that increasing the diameter of the bead results in reduced contact surface area.

Conclusions

1. The research results of the granulation process investigations showed that the technological, physical – mechanical and rheological granulation material properties have the main influence on the granulator operating mode. The granulator main operational parameters are the pressure and speed modes; they determine the pelleting process energy consumption and the product quality.
2. It was determined that the kinetic friction force occurs when granules slide against metal and plastic friction surfaces, which depend on the material properties, friction surface condition and sliding velocity. The kinetic friction coefficient is highest at the lowest speed; when the pressing velocity increases, the coefficient decreases. The friction coefficient has the highest value (0.71) on the metal surface when the sliding velocity is 0.02 $m \cdot s^{-1}$, and has the lowest value (0.44) on the plastic surface when the sliding velocity is 0.08 $m \cdot s^{-1}$.
3. It was established that the incomplete relaxation process in granules influences elastic deformation. As a result, about 52 % of pellets produced mass quantities do not meet the design matrix channel diameter, which influences granule pourability.

4. It was found that when the velocity and load increase, the kinetic friction coefficient decreases. The friction coefficient decreases from 0.67 to 0.44 when increasing the velocity from 0.02 $m \cdot s^{-1}$ to 0.08 $m \cdot s^{-1}$ on the plastic surface, and the friction coefficient falls from 0.71 to 0.45 on the steel surface.
5. It was determined that when the diameter of the granules increases, the natural slope angle also increases from 43.0 ± 2.8º to 47.6 ± 3.2º, while the inrush failure angle decreases from 26.0 ± 0.9º to 22.7 ± 0.8º.

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