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Modernization of the Drying drum Design for Organic Fertilizers

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Abstract

Sapropel is an organic fertilizer extracted from the bottom of water bodies. In order to introduce it to the fields, it is necessary to dry it to a humidity content of 45...55%, for which drum-type dryers are used. The most effective drying process occurs at the moment of the flight of sapropel from the lifters to the bottom of the drum. The present paper mathematically describes the process of sapropel particle movement along the entire length of the lifter and provides equations describing the moment of flight. The values of the coefficients and angles of friction of sapropel on steel at various humidity levels are experimentally established. The obtained values were used to calculate the particle movement parameters using the MathCAD program. As a result of the solution, the optimal angles of inclination of the lifter to the radius of the drum were obtained, which provide the maximum flight range of sapropel depending on its humidity.

Keywords: sapropel, humidity, drying, cylinder, friction angle, flight time, lifting blade.

I. INTRODUCTION

To maintain soil fertility, various types of fertilizers are used, including organic ones [1]. A natural organic fertilizer, which contributes to an increase in humus content in arable layers, is sapropel [2,3]. The composition of sapropel includes nitrogen, phosphorus, potassium, calcium and other chemical elements that contribute to the growth and development of plants [3,4,5].

Sapropel is a silt deposit of lakes and lagoons, consisting mainly of organic substances from the remains of aquatic organisms mixed with mineral sediments. The main problem when creating fertilizers is the high humidity of the extracted sapropel, which reaches 99%. With such humidity, sapropel can hardly be used as fertilizer, therefore, various technologies and devices are used to dewater sapropel and other agricultural objects [6,7,8,9]. GEOTUBE, modern technology for dewatering bottom sludge from industrial and agricultural waste, is widely used in the world, especially in the USA. The main disadvantage of this technology is the long drying time, which depends on weather conditions.

Direct-flow drum-type dryers are the most common for drying sapropel, since when the material moves in the drum, mechanical mixing of layers of material with different humidity and mechanical destruction of lumps of material occur [10].

When drying sapropel in a drum dryer, the raw material rises to a certain height and is poured down. It is during the flight that the greatest evaporation of moisture from sapropel occurs. Accordingly, the longer the flight of particles lasts, the longer its path, the more efficient the drying process. In this regard, the **research goal** was formed: reducing the drying time of organic sapropel by justifying the design parameters of the lifters of the drying drum.

To achieve this goal, **research objectives** were formulated:

1. Compose a mathematical model of particle movement in the drum.
2. Empirically determine the angle of friction of sapropel on steel.
3. Justify the design parameters of the lifters in the drying drum.

II. MATERIALS AND METHODS

To study the drying process of sapropel using a drum dryer, a block diagram was drawn up (Fig. 1).

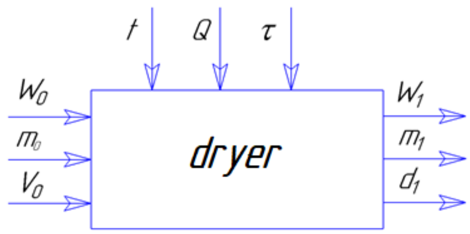

Figure 1. Block diagram of a drum dryer.

The input parameters are:

W_0 – initial humidity, %;

m_0 - mass of feedstock, kg;

V_0 – feed rate (conveyor belt speed), m/s.

The main indicators of the product that has undergone technological drying will be:

W_1 – final humidity, %;

m_1 - mass of dried material, kg;

d_1 – particle size of dry material, mm.

The characteristics that influence the drying process are the following indicators:

t – average heating temperature, □ C;

Q - amount of heat of one drying cycle, J;

τ – time of one drying cycle, s.

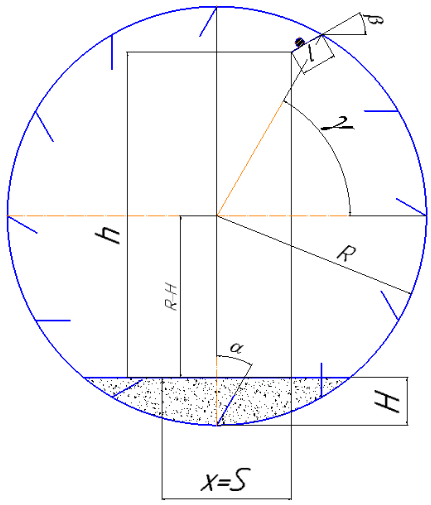

Figure 2. The movement pattern of a sapropel particle in a drum.

To raise the sapropel to the required height, the drum is provided with lifters installed at an angle α to the radius of the drum. Part of the material from the lower layer of height H is captured and lifted during the drum rotation. At a certain point in time, the force of gravity overcomes the friction force of sapropel on the surface of the lifter and the process of pouring begins. We denote the beginning of this process through the angle γ (Fig. 2). Let us consider the movement of sapropel in a first approximation, representing the sapropel located on the lifter as a material point of mass m.

The rotation of the drum occurs at a constant angular velocity, so the rotational movement of the point at the moment of pouring can be considered uniform. A gravitational force, a friction force, a support reaction force, and a centrifugal inertia force act on a material point of mass m (fig. 3).

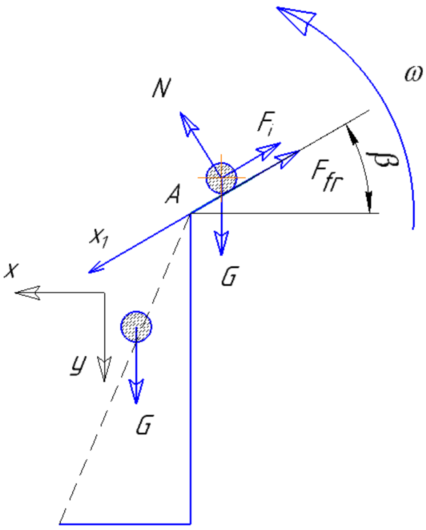

Figure 3. The design scheme of the material point movement.

We write the equilibrium equation in the form of projections of all forces on the axis OX_1:

$$\sum F_{kx_1} = -G \cdot \sin\beta + F_{\text{тр}} + F_{\text{и}} = 0, \tag{1}$$

where β – angle between the horizontal and lifter.

When the drum rotates, the angle β will change according to the condition:

$$\beta = \gamma - \alpha + \omega t, \tag{2}$$

where ω – drum angular velocity, s^{-1}.

Then, the condition for the beginning of the sapropel movement on the lifter surface has the form:

$$G \cdot \sin\beta_0 > F_{fr} + F_i. \tag{3}$$

We will transform all the forces acting on the material point, taking into account the parameters of the particle and the kinematics of movement in the first section:

$$m \cdot g \cdot \sin\beta_0 > f \cdot m \cdot g \cdot \cos\varphi + m \cdot \omega^2 \cdot R, \tag{4}$$

where m – particle mass, kg;

f – sapropel friction coefficient on steel;

φ – friction angle;

R – drum radius, m;

g – acceleration of gravity, m/s^2.

We transform expression (4) with respect to angle β:

$$\beta_0 > \arcsin(\sin\varphi + \frac{\omega^2 \cdot R}{g}) \tag{5}$$

Based on the expression, for the sapropel to start moving, the angle between the horizontal and the lifter should be greater than the friction angle φ, taking into account the action of the inertia force.

To determine the trajectory of movement and the width of the dispersion section, we write the equation of movement along the lifter (section to point A):

$$m\ddot{x}_1 = \sum F_{kx_1} = G \cdot \sin\beta - F_{fr} - F_i \tag{6}$$

We will write down all the forces and simplify the expression:

$$\ddot{x}_1 = g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R. \tag{7}$$

We integrate the differential equation twice and, using the boundary conditions, determine the integration constants:

$$\begin{cases} \dot{x}_1 = g \cdot (\sin\beta - f \cdot \cos\beta) \cdot t - \omega^2 \cdot R \cdot t; \\ x_1 = g \cdot (\sin\beta - f \cdot \cos\beta) \cdot {t^2}/{2} - \omega^2 \cdot R \cdot {t^2}/{2}. \end{cases} \tag{8}$$

In the expressions obtained, $\dot{x}_1$ is the equation of the particle velocity along the lifter, and x_1 is the path, i.e. lifter length.

Structurally, the lifter length was 100mm. Based on this, we determine the time of particle movement from the beginning of the lifter until the moment the particle leaves it:

$$t = \sqrt{\frac{2 \cdot l}{g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R}}. \tag{9}$$

We substitute the value of time t in the equation $\dot{x}_1$ and determine the particle velocity at the moment of descent from the lifter:

$$\dot{x}_1 = \vartheta_\text{A} = [g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R] \cdot \sqrt{\frac{2 \cdot l}{g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R}}. \tag{10}$$

In the second section, the particle moves due to gravity and initial velocity. We compose the differential equations of movement in xy coordinates, taking into account the initial conditions: at t=0 $x_0 = 0, \dot{x}_0 = \vartheta_\text{A} \cdot \cos\beta$, $y_0 = 0$, $\dot{y}_0 = \vartheta_\text{A} \cdot \sin\beta$.

$$\begin{cases} m \cdot \ddot{x} = 0; \\ \ddot{y} = mg. \end{cases} \tag{11}$$

We integrate the differential equations twice and using the boundary conditions we determine the integration constants:

$$\begin{cases} \dot{x} = \vartheta_\text{A} \cdot \cos\beta; \\ x = \vartheta_\text{A} \cdot \cos\beta \cdot t; \\ \dot{y} = g \cdot t + \vartheta_\text{A} \cdot \sin\beta; \\ y = g \cdot {t^2}/{2} + \vartheta_\text{A} \cdot \sin\beta \cdot t. \end{cases} \tag{12}$$

To determine the particle's flight range, it is necessary to exclude the time parameter t, expressing it from the equation of movement along the x axis and substituting y in equation (12):

$$y = g \cdot {x^2}/{2(\vartheta_\text{A} \cdot \cos\beta)^2} + x \cdot \tan\beta. \tag{13}$$

At the moment of falling y=h, and x=S (see fig.2). Solving expressions (13) together, taking into account the value of the rate of descent of the particle from the lifter (10), we obtain the dependence of the flight range of the particles on the position of the lifter in the drum relative to the horizontal:

$$x = \frac{1}{g} \cdot \left(-\tan\beta \pm \sqrt{\tan^2\beta + \frac{2gh}{\left\{\cos\beta [g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R] \cdot \sqrt{\frac{2 \cdot l}{g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R}}\right\}^2}} \right) \cdot \left\{[g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R] \cdot \sqrt{\frac{2 \cdot l}{g \cdot (\sin\beta - f \cdot \cos\beta) - \omega^2 \cdot R}} \cdot \cos\beta\right\}^2. \tag{14}$$

If we take into account that the rolling of sapropel does not occur instantaneously, but over a certain period of time, then expression (14) should be time-dependent. When the drum rotates, the angle of inclination of the lifter to the horizon will change according to:

$$\beta(t) = \omega \cdot t + \arcsin(\sin\varphi + \frac{\omega^2 \cdot R}{g}) \tag{15}$$

In expression (14), the flight height h varies depending on where the particle was on the lifter. That is, sapropel, which is located on the edge of the lifter, begins to pour off immediately at $\beta = \beta_0$, and the part that is closer to the drum pours off after some time t (10). We express the dependence of h on t:

$$h = R - H + R \cdot \sin(\beta(t) + \alpha) - l \cdot \sin\beta(t) \tag{16}$$

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To solve the obtained equations, it is necessary to know the value of the coefficient (and angle) of friction of sapropel on steel at different humidity.

To determine the angle of friction of sapropel when moving along a steel lifter blade, an installation was developed, shown in Figure 4.

Figure 4. A laboratory installation for determining the angle of friction.

The experimental technique was as follows:

The installation was located on a flat surface so that the base was in a horizontal position.

Sapropel was placed on a steel plate hinged on one side.

By means of a flexible connection, the loose end of the plate was raised and the angle at which the sapropel began to roll down and the angle at which the bulk began to move was recorded.

For the experiment, samples with a humidity of 80, 70, 60, 50, and 40% were prepared. The experiment at each humidity value had threefold repetition and the obtained results were processed according to the rules of mathematical statistics.

III. RESULTS AND DISCUSSIONS

Figure 5 shows the obtained dependences of the angle of friction of sapropel on humidity.

Analyzing the obtained dependences, we can draw the following conclusions:

1. As sapropel humidity increases, the angle of friction against steel increases, changing in a nonlinear dependence;

2. The pouring angle of individual particles is virtually independent of humidity. This is due to the fact that small lumps and particles of sapropel have a shape close to the ball, therefore this angle characterizes the movement at which rolling occurs, which means that there is rolling friction;

3. To ensure maximum flight time in the drum, the angle of inclination of the lifting blades α along the length of the drum should be changed. At the beginning of the drum, where the humidity is high, the angle should be less than at the end of the drum, where the humidity of sapropel is lower than the initial one. It is this position of the lifting blades that will ensure a uniform position of the beginning of movement of sapropel particles, taking into account humidity.

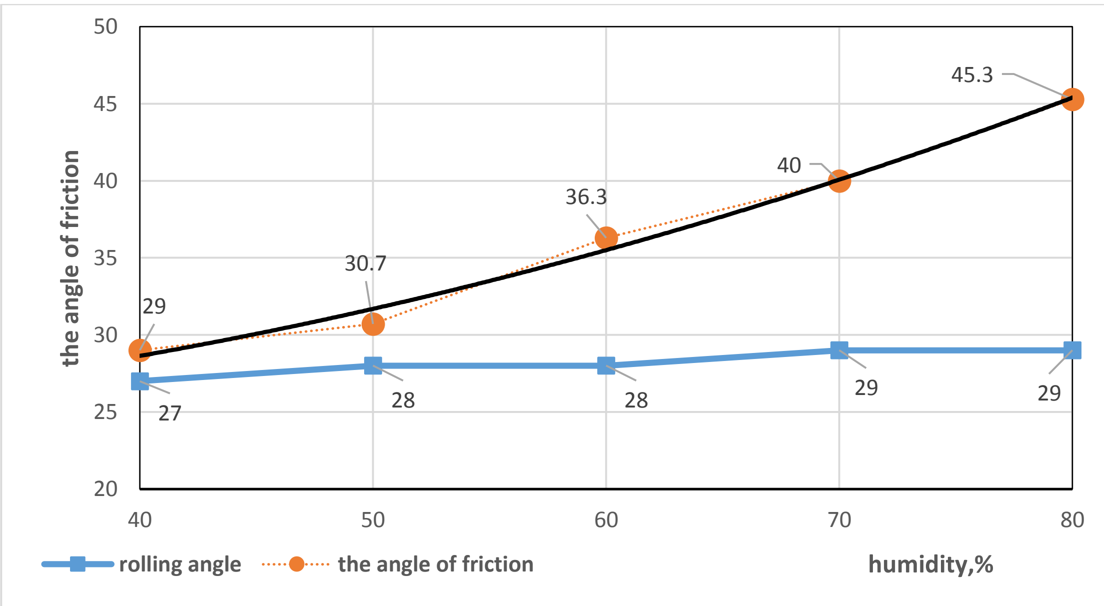

Figure 5. Dependences of the angle of friction of sapropel on humidity.

To solve the equations using the obtained coefficients of friction of sapropel on steel and the kinematic parameters of rotation of the drum, an algorithm was compiled in the mathematical editor MathCAD. In the calculations and the presented dependences, the indices 1 ... 4 were used, which correspond to the humidity of sapropel according to Table 1.

Table 1. Correspondence of the index to sapropel humidity.

index	1	2	3	4
the angle of friction, grad	45	40	35	30
humidity %	80..85	70	60	40…50

Solving equation 9, taking into account the rotation of the drum by the angle β (t), we obtain the values of time t necessary to overcome the length of the blade (Fig. 6). Taking into account the length of the blade of 100 mm, we have the time values depending on humidity.

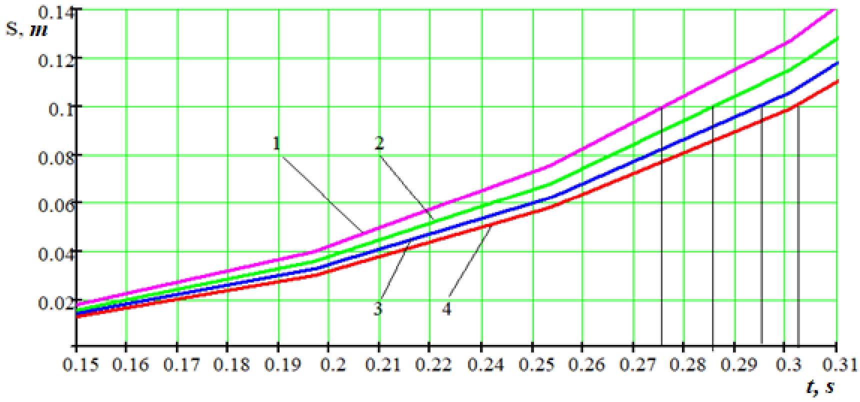

Figure 6. Dependence of the time in which the sapropel leaves the blade on humidity.

According to the diagrams, a wetter sapropel leaves the lifting blade faster than a drier one. This is because the angle of friction at a humidity of 85% is greater than at lower values of humidity, which means that the effect of gravity is most effective.

Solving equation 10, taking into account the known time, we determine the rate of descent of the sapropel particles from the edge of the blade. Given the rotation of the drum, it should be noted that the velocity vector will also change, which will subsequently affect the flight length. Figure 7 shows the obtained dependences of the rate of sapropel particles fly-off from the blade at various humidity levels.

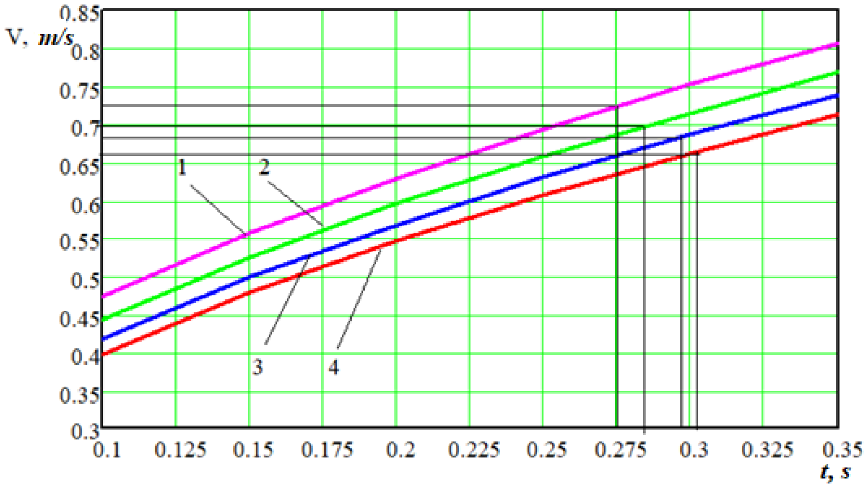

Figure 7. Velocity of the sapropel particles fly-off from the blade.

Depending on humidity, particles closer to the surface of the drum come off the blade at velocities of 0.66 ... 0.73 m/s. These values are the result of solving equation 10.

Solving 14, 15, 16 together relative to the indicator S (range of flight of particles), taking into account the rates of descent of the last particles from the blade, we obtain the dependence of the flight range on the initial angle of inclination of the blade to the radius (Fig. 8).

The optimal values of the angles α are those at which the flight range is maximum, and therefore the drying time of a thin layer of sapropel is the longest. We present all the results obtained in the form of a table.

Table 2. Characteristics of sapropel movement depending on humidity.

sapropel humidity, %	angle of friction, deg	travel time on the lifter, s	range of flight, m	blade inclination angle, deg.
80..85	45	0,275	0,153	30…33
70	40	0,285	0,169	35…37
60	35	0,296	0,184	40..45
40..50	30	0,303	0,198	46…50

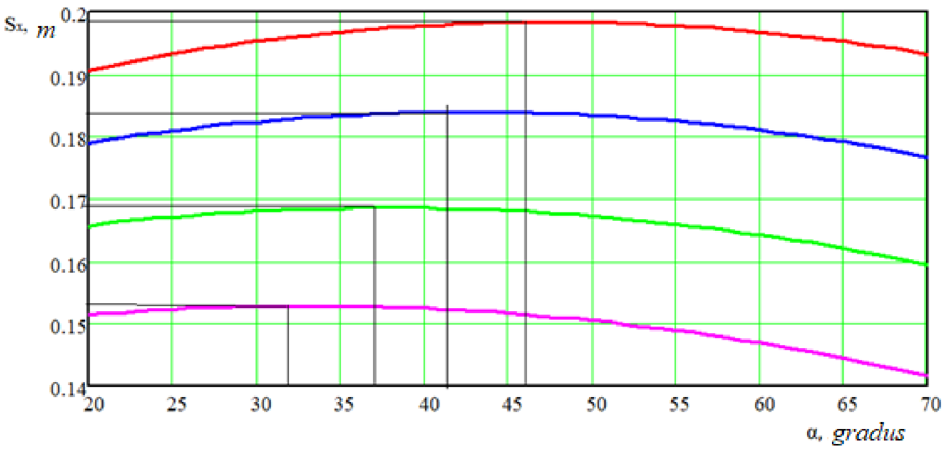

Figure 8. Dependence of the flight range of a sapropel particle on the initial angle of inclination of the blades.

IV. CONCLUSION

Drum dryers are the most effective for drying sapropel, since, in the drying process, the material acquires a homogeneous finely crumbly structure. The compiled equations describe the process of movement of sapropel in the drum, allowing the time of the most effective drying process to be determined. To identify the dependences of the beginning of the rolling of sapropel from lifting blades, the friction angles of sapropel on steel were experimentally determined depending on humidity. The results were used in mathematical modeling of the process of movement of sapropel in a drying drum using the MathCAD program. Dependences of the sapropel flight range on humidity show that at the beginning of the drum, where the sapropel humidity is 80...85%, the angle of inclination of the lifting blades should be 30 degrees to the radius of the drum, and closer to the end of the drum - 46...50. Such a constructive solution will allow lifting sapropel of various humidity levels to a height at which the flight of particles has the greatest trajectory, which means that the drying process has maximum efficiency.

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