Free movement of mineral fertilizers and their mixtures in air

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Abstract. The object of research is the free movement of mineral fertilizers and their mixtures in the air after discharge from the centrifugal pneumomechanical apparatus, followed by the processes of distribution on the field surface.

The aerodynamic properties of the grains of mineral fertilizers or mixtures are different. Therefore, they are broken down into fractions during free movement in the air after being thrown from the centrifugal apparatus. A new pneumomechanical type equipment scheme was developed, developed and field tests were carried out using the method of assembling structural elements and the rules of classical mechanics, dedicated to the analysis of technological processes of centrifugal devices in existing and patent information materials and quality spraying of fertilizer mixtures. The expression was derived and calculated taking into account the fact that the rate of additional air flow decreases with distance, and the relative velocity of the fertilizer grains relative to it.

The centrifugal pneumomechanical device is designed to perform two functions simultaneously, the first is to throw mineral fertilizers, the second is to create an additional air flow and direct it behind the thrown fertilizer grains. The proposed centrifugal pneumomechanical type apparatus ensures even distribution of component fertilizer mixtures of different sizes, shapes and densities on the field surface.

1. Introduction

The object of research is the process of distribution of mineral fertilizers and their mixtures in the environment after the discharge from the centrifugal pneumomechanical apparatus, ie free movement in the air, and then on the field surface. It is advisable to divide the application of mineral fertilizers on the field surface with centrifugal apparatus into three stages and analyze each of them separately. Of these, the uneven distribution of the free movement of fertilizer grains in the air after discharge from the centrifugal apparatus is more affected. Because wheat grains are divided into fractions based on aerodynamic properties. This means that the quality control of mineral fertilizer application is a factor that does not depend on the technological process of the centrifugal disk apparatus. Therefore, the problem of influencing the free movement of fertilizer grains in the air from the technological processes of the centrifugal disk apparatus, thereby reducing their uneven distribution, represents the relevance of the study.

In world practice, for the mass application of mineral fertilizers on the field surface have been developed disk workpieces of various types of centrifugal type [1,3,4,5,6,7,8,9,10,11,12]. However,
they are designed to sprinkle granular simple or complex fertilizers. It is recognized that this type of workpiece does not meet the agro-technical requirements when spraying mixtures consisting of several simple mineral fertilizers, the granules of which vary in shape, density and size [1,2,3,13].

Based on the above, the purpose of the study is to improve the quality of work by spraying mineral fertilizers and mixtures of different grain sizes with a centrifugal apparatus, affecting their free movement in the air. The task of the study was to improve the technological process of the centrifugal apparatus by creating an additional air flow and to ensure a smooth application of fertilizers on the field surface.

2. Methods.
The research and 40 years of research and analysis of patent-information data on the design and technological process of all types of centrifugal disc apparatus for spraying mineral fertilizers and their mixtures around the world were carried out on the basis of classical mechanics. In this case, the shape of the blades in centrifugal devices for quality spraying of mineral fertilizers and their mixtures of different shapes, sizes and densities and their placement on the disk, the necessary elements for the authors in the design of additional air generating devices were selected and assembled.

3. Results and Discussions

Many years of theoretical and experimental research have shown that the main reason for the uneven application of mineral fertilizers and their mixtures across the field surface, which vary in shape, size and density, is the separation of mineral fertilizer grains into fractions during their movement in air. As a result, fertilizer grains with a low volatility coefficient fall to the ground at a longer distance, while those with a high volatility coefficient fall to the ground at a shorter distance. It can be understood that the unit is spreading small-sized fertilizers in the center and large-sized fertilizers on the outside.

This means that if the mixture contains a large amount of large-scale fertilizer, the amount of fertilizer at the edge of the aggregate working width is denser than at the central part, creating the basis for uneven spraying of the mixture on the components. It follows that it is possible to solve the scientific and technical problem by ensuring that the volatile grains with high volatility coefficients travel longer distances and by this method ensure that the landing distances of different volatile fertilizer grains in the mixture are close or uniform [1,2,3].

According to the results of research conducted by the authors, it is possible to direct the additional air flow behind the fertilizer grains with a high coefficient of volatility (sailing) and ensure that they are thrown over longer distances [2,3]. This requires that the technological work of the centrifugal apparatus is not limited to the application of mineral fertilizers, but also has the ability to generate additional air flow at once, and is theoretically and experimentally based. As a technical solution to these problems, an improved centrifugal apparatus was developed (Fig. 1), [2,3]. The proposed centrifugal pneumomechanical apparatus consists of a flat horizontal disk 1, logarithmic coil-shaped blades 2 mounted on its upper side, and devices 3 which generate additional airflow mounted on the lower side (Fig.1).
The diameter of the flat disc 1 is 600 mm. The height of the paddles is 50 mm. At the bottom of the disc 1 is placed a device that creates one additional air in accordance with each paddle 2 (Fig. 1 a, b, v,). From the moment when the mineral fertilizer grains are thrown from the pneumomechanical apparatus at the initial speed under the influence of centrifugal force, the second phase of their movement, i.e. free movement in the environment, begins. During this period, they begin to be affected by additional airflow.

In the second phase of the study, the following was accepted:
- the force of the additional air flow is directed horizontally;
- the air flow rate does not change along the cross-sectional surface of the outlet;
- The initial velocities and directions of all fertilizer grains thrown from the shovels are the same.

The additional airflow coming out of the outlet of the device expands in proportion to the distance to the hole during its movement, pushing the particles of the medium with it. Given that the additional air flow rate decreases with distance [14] and the relative movement of the fertilizer grains relative to it, as well as the change in velocity, the authors obtained the following expression,

\[
\dot{x} = \pm k \left( \frac{0.48V_x}{ax} \frac{d}{d + 0.145} \right) 2
\]

where: \( \dot{x} \) – the distance traveled by the air stream along the axis, m;
\( x \) – additional airflow velocity along the axis m/s;
\( k \) – air resistance coefficient;
\( V_x \) – initial velocity of additional air flow, m/s;
\( a \) – coefficient of turbulence of the flow, \( a=0.07-0.14 \);
\( x \) – the value of the distance considered from the outlet of the device, m;
\( d \) – the diameter of the outlet hole, \( d=0.043 \) m².

(1) in the expression “+” sign \( V_x > \dot{x} \); “-” the sign is \( V_x < \dot{x} \) used in cases.

(1) expression is a second-order differential equation that was calculated by the Runge-Kutta-Felberg automatic step numerical method. Equation (1) was calculated for the following values:
k=0.184-0.265, \( V_0 = 50.0-110.0 \) m/s; the initial throwing rate of the fertilizer grain \( V_0 = 25 \) m/s, free fall acceleration \( g = 9.8 \) m/s [15].

From the field surface when the centrifugal pneumomechanical apparatus of the mineral fertilizer machine is in working condition \( h = 0.6 \) m The time from the time the fertilizer falls to the surface of the field after it is discarded is given by

\[
t = \sqrt{\frac{2h}{g}}
\]

The second phase is time \( t = 0 \) starting when \( t = t_m \) ends in, in this \( t_m \)-the time it takes for the fertilizer grain to come out of the pneumomechanical apparatus and land on the field surface, s.

Under the influence of additional air flow, the speed of fertilizer grains changes. This is because the value of the additional air flow velocity is on average 3-4 times higher than the velocity at the time of application of mineral fertilizers from the apparatus, and the directions of movement are also parallel. Based on the results of the calculations, Figure 2 shows the change in the velocity of the fertilizer grains under the influence of the additional air flow.

2 \( a, b, v \)-it can be seen from the pictures that the initial velocity of the fertilizer grains is significantly increased under the influence of the additional air flow. For example, if the initial velocity of the fertilizer grain was 25 m/s, its velocity after falling into the additional air stream 42 m/s (2 \( a \)-picture), 53 m/s (2 \( b \)-picture) and 70 m/s (2 \( v \)-picture) rising to. This can be explained by the fact that the force of the additional air flow gives impetus to the fertilizer grains. From the analysis of the graphs, it can be seen that over time the rate of additional air flow decreases rapidly, while that of the fertilizer grain decreases relatively slowly. However, the fertilizer grain had a significantly higher velocity than the initial velocity at the time of discharge from the pneumomechanical apparatus. This is why their throwing distance is large, which allows the machine to increase the working width.

\[ R = mk_nu^2 \]

where \( m \)-mass of fertilizer grain, kg;
\( k_n \)-coefficient of volatility (sail) of the fertilizer grain, 1/m;
\( u \)-relative speed of fertilizer grain, m/s.

The equation of motion of fertilizer grains in the XOU coordinate system in a resistive environment is as follows [17].
where $x$ - fertilizer grains axial traveled along the axis, m;  
$y$ - the distance traveled by the fertilizer grains along the ou axis, m.  
$V_y$ - volatility rate of fertilizer grain, m/s.

(5) solve the equation with respect to time $t$ and put it in equation (2). For this

$$
ch = \frac{e^x + e^{-x}}{2} \quad \text{and} \quad e^x = \exp\{x\}
$$

(6)

Given that the following expression is formed,

$$
e^x = \left\{ \frac{yg}{v_y^2} \right\} = \frac{ch \cdot gt}{v_y}
$$

(7)

(7) perform mathematical operations on expression,

$$
t = \frac{v_y}{g} \ln(e^y \pm \sqrt{e^{2y} - 1})
$$

(8)

(8) Substituting the value of $t$ in the expression (3),

$$
x = \frac{v^2_y}{g} \ln\left\{ \frac{v_0}{v_y} \left[ \ln\left( \frac{yg}{v_y^2} \pm \sqrt{\frac{2yg}{v_y^2} - 1} \right) + 1 \right] \right\}
$$

(9)

where $y=h$ - installation height of the pneumomechanical apparatus relative to the field surface, $h=0.6$ m.

(9) The initial rate of expression fertilizer grains $v_0=18-30$ m/s, $v_y=12$ m/s and $g=9.8$ m/s$^2$ calculated on the values. Based on the calculation results, the connection graphs shown in Figures 3 and 4 below were constructed. Figure 3 shows a graph of the change depending on the critical velocities of the distance traveled by the grain of fertilizer.
As can be seen from Figure 3, the distance traveled increases with the increase in the critical velocity of the fertilizer grain along the bubble curve. This situation can be explained by the fact that the higher the volatility rate of the fertilizer grain, the lower the effect of the environment that resists it. Considering that the volatile velocity of fertilizer grains varies in a large 1.5–15.5 m/s depending on their size, when the volatile velocity is 8–10 m/s, the distance covered by them is in the range of 8.6–11.2 m.

Figure 4 shows a graph of the change in the distance traveled by the fertilizer grain depending on the initial velocity.

It can be seen from Figure 4 that as the rate at which the fertilizer grain enters the resisting medium increases, it is observed that the distance covered by them increases in a view close to the bubble curve. This can be explained by the fact that the large initial velocity of the fertilizer grain can overcome the resistance force exerted on it by the environment at a certain distance.
The additional air flow rate is the angular velocity of the centrifugal apparatus $\omega$, the average radius of the device inlet $R_y$ and the ratio of the inlet surface to the outlet surface $\lambda$ depending on the values. The additional air flow rate was calculated by the following expression

$$V_x = k_m \omega R_y \lambda \tag{10}$$

$$\lambda = \frac{S_k}{S_{ch}} \tag{11}$$

where $S_k$ and $S_{ch}$ – surfaces of the device inlet and outlet holes, respectively, m$^2$

$k$ – the coefficient of loss of its velocity as air moves from the inlet to the outlet, $k=1-\varepsilon$. In theoretical calculations $\varepsilon=0.3-0.6$ values were accepted.

Inlet hole surface $S_k=b_k a_k=0.15 \times 0.10 = 0.015$ m$^2$, while the exit hole $S_{ch}=b_{ch} a_{ch}=0.05 \times 0.03 = 0.0015$ m$^2$. Its surface is changed using a barrier mounted on the entrance hole.

4. Conclusions

Based on the results of the research, the following conclusions were made:

1. The quality of spraying mineral fertilizers and their mixtures with different aerodynamic properties on the field surface is ensured by improving the technological process of the centrifugal apparatus, ie the installation of shovels on the top and additional air flow on the bottom.

2. The radius of application of mineral fertilizers to the device is in the range of 0.100-0.125 m, which ensures that the angle of exit from the device is in the range of 95-110$^0$.

3. The additional air flow rate generated by the device mounted on the centrifugal apparatus is 3.0-4.5 times greater than the outlet speed of mineral fertilizer grains and the direction is parallel, which allows to increase the speed of fertilizer grains by 1.5-3.0 times.

4. Parallel directing of the additional air flow in accordance with the trajectories of the free movement of fertilizer grains in the air ensures that they fall to the same distance, reducing the process of separation into fractions and, consequently, evenly distributed.

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