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Substantiation of the Parameters of a Slit Sprayer for Applying Biological Products when Harvesting Bulky Feeds with High Humidity

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Abstract. The main method of harvesting hay is its pressing, in which a mandatory requirement is to ensure constant conditioned humidity of the material. Compliance with such material parameters in the field is very difficult. Therefore, in order to achieve maximum efficiency when harvesting bulky, it is necessary to use various bioconservants and their uniform distribution over the surface of the selected roll. One of the conditions for the operation of the distribution system is the use of high pressure to crush a drop of a solution of a biological product, which negatively affects the effectiveness of the preservative. In the course of the work, the performance of the sprayer was studied depending on the pressure in the pneumatic system of the spraying device and the diameter of the feeding tube.

1 Overview of the slot sprayer in question

The main directions of agricultural development at present are to increase the storage life of harvested hay, however, this issue is possible only when solving global problems of improving the quality of grain material, as well as reducing energy costs for its production.

To ensure an increase in the quality parameters of harvested feed, increase the storage life of the material and increase the economic efficiency of the technological process of harvesting soft hay, it is recommended to use bioconservants. This method is based on equipping the baler with a device installed in the area of the roll feed into the pressing chamber, which applies the preparation to the harvested material during the hay pressing process [1].

After analyzing information about the design schemes used by balers for hay pressing, it can be concluded that modern balers are mostly not equipped with systems for the distribution of bioconservants, or use distribution systems that operate at high pressure, at which beneficial bacteria simply die. This approach significantly reduces the growth and development of bacteria in the process of hay preservation [2]. Therefore, these balers require improvements to ensure high-quality application of biological products to the processed objects during the selection of rolls.

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The purpose of the study is to ensure an increase in the quality parameters of harvested feed, increase the storage life of the material, and increase the economic efficiency of the technological process of harvesting soft hay.

The device mounted on the baler includes a tank with a solution of working fluid 1 (Figure 1), pipelines 2, an equalizing tank 3 with a crane 4, a compressor unit 5 with a crane 6, an air duct 7 connected to a jet generator 8 (Figure 1) having an air distribution cavity 9 in the housing 10, a fitting for supply 11, a gasket 12 with slit nozzles 13, a lid 14, a liquid collector 15 mounted on the sidewalls 16, with feeders 17.

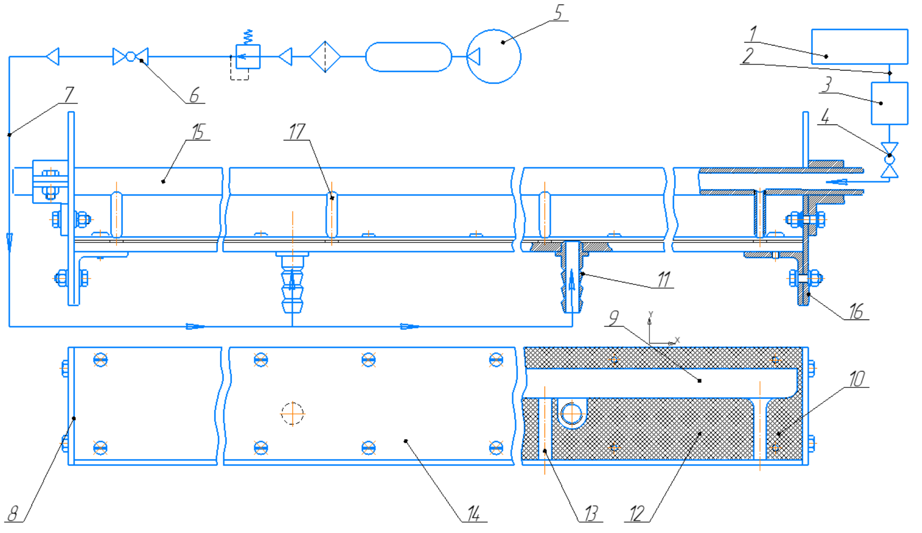

Fig. 1. Device for applying preservative in the process of hay pressing

The number of slot nozzles of the jet generator is selected taking into account the necessary overlap between the airborne jets and can be adjusted by changing the gaskets on the base of the sprayer [1, 2]. The collector with feeders has additional holes for attaching feeders when the number of sprayed airborne jets changes. The feeders are located above the slit nozzles, and their position above the jet is regulated by moving the collector attachment on the sides of the device in height.

The sprayer works as follows. The air from the tractor compressor under pressure enters the water distribution cavity 9 of the jet generator through the nozzle 11, then flows out through the slit nozzles 13 formed by the gasket 12 and the lid 14. Jets of liquid are supplied to the air jets flowing under pressure from the collector of the working fluid 15 through feeders 17, which are dispersed into small droplets and directed to the processing object.

The flow rate of the working fluid is regulated by changing the gasket with slotted nozzles, changing feeders with different outlet diameters, air pressure, a compressor unit gearbox and an equalizing tank.

The formed airborne jet processes the hay fed into the baler's pressing chamber.

Thus, the harvested material is preserved during pressing to increase the shelf life and increase the nutritional qualities of the feed.

1.1 Determination of the air velocity from the slit nozzle

Considering that the jet coming out of the sprayer is located in an environment with the same properties as the full-bodied jet itself [3]. The movement of the free flooded jet occurs at a constant pressure corresponding to the ambient pressure.

There are two sections of the jet: the initial and the main (Figure 2)

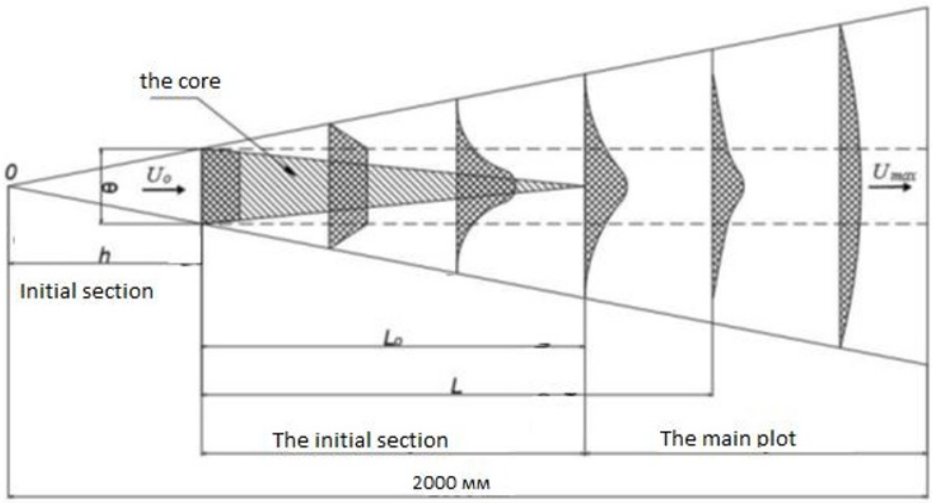

Fig. 2. Free jet structure

The dependence of the velocity change on the main section is inversely proportional to the distance from its pole. The characteristics of the jet under such conditions can be expressed by a single constant α, while for a flat jet coming out of the atomizer α = 0.9

Relative air velocity in the main area

$$\frac{U_{max}}{U_o} = \frac{1,2}{\sqrt{0,4 + \frac{al}{B_o}}} \tag{1}$$

where U_{max} – maximum velocity on the axis of the jet at a given distance from the outlet of the jet;

U_o – outlet velocity of the jet;

a – constant;

l – distance to the measuring point from the outlet;

B_o – half-width of the jet at the outlet of the nozzle;

It should be noted that when determining the U_{max} speed at a given distance from the nozzle l, we take the distance to the processing object, depending on the width of the shredder B, the height of the installation of the device H and the place where the sprayer is fixed on the frame part of the shredder.

According to preliminary calculations, the U_o is in the range of 20-50 m/s.

1.2 Calculation of the jet generator of a pneumatic slot sprayer

Consider the outflow of a compressible liquid (gas) from the hole.

The gas is the air entering the slot nozzle of the atomizer from the compressor of the combine at pressures from 0.1 to 0.3 MPa.

We assume the outflow to be adiabatic, when, with a significant pressure difference, the potential energy of the gas is converted into kinetic energy at such a high speed that the flow does not have time to give heat to the medium where it flows out [4].

When flowing through the holes, the expression can be used to determine the mass flow rate of gas

$$M = \mu\omega\sqrt{P_0\rho_0} \quad (2)$$

where ω - size of the gas outlet hole

μ - reduced flow rate for the outflow of the compressible fluid

P_0 - air pressure from compressor to sprayer

ρ_0 - air density

The nature of the change in flow parameters depends on the degree of expansion of the flow, rotation at an angle of 90°, sharp narrowing of the flow and smooth expansion, which we observed in the diagram (Figure 3).

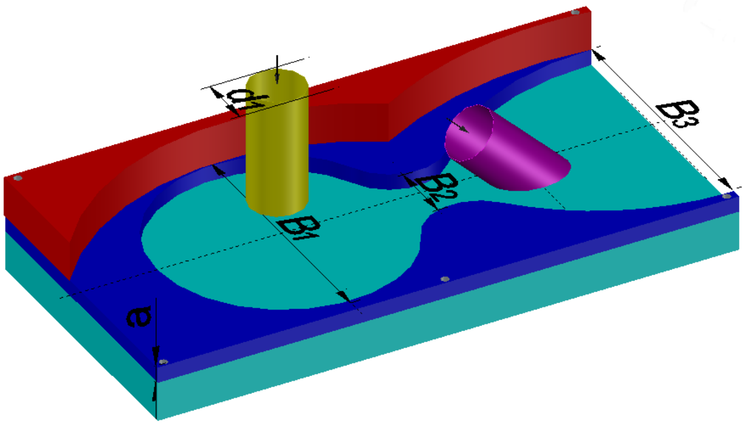

Fig. 3. Diagram of a pneumatic slot atomizer converter

Parameters of the slot sprayer

a- nozzle thickness a=1.5 mm

$B_1=d_2$ – width of the nozzle at the inlet, In B_1 = 25 mm;

B_2- sleeve width, B_2=8 mm;

B_3- width of the outlet, B_3=20 mm;

The nature of the change in flow parameters depends according to the scheme on the degree of expansion of the air flow,

$$n = \frac{\omega_2}{\omega_1} \quad (3)$$

$$\omega_1 = \frac{\pi d_1^2}{4}; \omega_2 = a \cdot b$$

где ω_1 - cross-sectional area of the pneumatic pipe of circular cross-section

ω_2 - cross-sectional area of the inlet having a jet-forming nozzle

For subsequent rotation at an angle of 90°, the resistance coefficient is taken

$$\xi_n = k \cdot \xi_n^{'}; \xi_n = 0{,}58 \cdot \xi_n^{'} \quad (4)$$

where *k* – coefficient that takes into account changes in the shape of the pneumatic line;

$\xi_{n'}$- coefficient of rotation in case of a sudden change in the direction of movement, $\xi_{n'}$=0,7;

Associated with a change in the parameters of the air flow [4, 5]. The nature of the change depends on the degree of narrowing of the flow,

$$n = \frac{\omega_2}{\omega_1} \quad (5)$$

where ω_1-cross-sectional area of the flow in the pneumatic duct, circular in diameter B_1=25 mm

ω_2- cross-sectional area of the slit nozzle having a width b = 5 mm and a thickness a = 1.5 mm.

That is, $\omega_1=a\,B_1$, $\omega_2=a\,B_2$

where B_2 – sleeve width

Accordingly

$$n = \frac{\omega_2}{\omega_1}$$

The coefficient of resistance of sudden narrowing of the flow is described by the formula:

$$\xi_c = 1{,}5\ (1 - n) \tag{6}$$

That is ξ_c=0,2

The expansion of the flow after exiting the nozzle sleeve is taken into account to determine the resistance coefficient ξ_{exp2}, while

$$n = \frac{\omega_{c_2}}{\omega_c}$$

$$\xi_{p_2} = (1 - n)^2;\ \xi_{p_2} = 0{,}28$$

Thus, the coefficient of resistance of the jet generator

$$\xi_{co} = 0{,}21 + 0{,}7 + 0{,}2 + 0{,}28 = 1{,}39$$

1.3 The interaction of the air jet with droplets

An inclined airflow is used to direct a drip jet to the treatment object, and most often for treatment with biological products.

The air flow affects the droplets of the working fluid, carries them over long distances, the dimensions of which are determined by the width of the drum picker and the distance to the selected roll from the rows of installed sprayers [5]. At the same time, heavier droplets deviate less from the vertical, and less heavy droplets are placed at large distances from the source of their formation [6]. Therefore, it is possible to consider the distribution of droplets by an inclined flow depending on the windage coefficient k_n or the critical velocity V_{kp}.

At the same time, quite complex phenomena occur and therefore, in order to clarify the general nature of the droplet distribution, some simplifications must be made.

We will consider the air flow to be flat with a constant magnitude and direction of velocity at any point of its flow, and the droplets move freely in the flow, like material bodies without colliding with each other [7].

The flow is characterized by a velocity U directed at an angle α to the horizon (Figure 4). A material body m entering the stream with a certain initial velocity C_o directed coaxially to the flow velocity will be affected by gravity $G = mg$ and air flow resistance:

$$R = k\frac{\gamma}{g}FV_0^2 \tag{7}$$

where K - windage coefficient of the drop;

γ - specific gravity of a drop;

F - area.

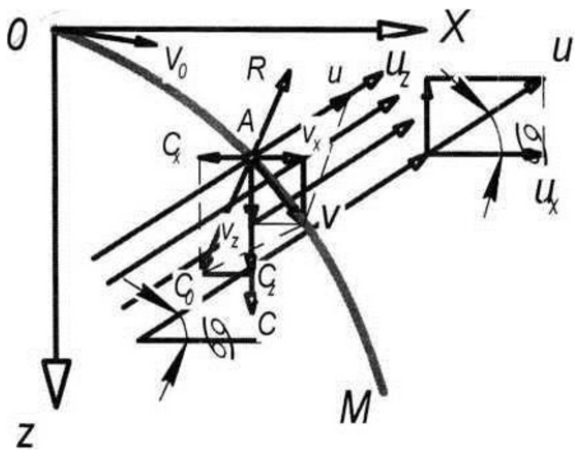

Fig. 4. Interaction of an inclined airflow with a drop of working fluid

The resistance force *R* is directed in the direction opposite to the relative velocity of C_o.

According to U, C, γ0, the value of the relative velocity V_0 is given, which is determined by the expression:

$$V_0 = \sqrt{(U_0^2 + C_0^2 - 2U_0C_0Cos\gamma_0)} \quad (8)$$

and the direction of speed according to the formula:

$$sin\alpha = \frac{C_0}{V_0} sin\gamma_0 \quad (9)$$

The direction of the full velocity is determined by the angle α_c from the condition:

$$tan\alpha_c = \frac{Ucos\beta - V_y}{V_x - Usin\beta} \quad (10)$$

With the relative velocity approaching the vertical direction, when V_x $V_{Kp,}$ and V_y0 expression for *tan(*α_c*)* gives a solution:

$$tan(\alpha_c)_k = \frac{Ucos\beta}{V_{kp} - Usin\beta}$$

2 Results

To analyze and determine the main design and operating parameters, we used sprayers with pneumatic slot sprayers and with Laval nozzle type jet generators.

To substantiate the parameters of the slot sprayer, we conducted theoretical studies and determined the flow coefficients of a Laval nozzle-type jet generator. The mode of supply of the working fluid to the air jet and the process of formation of an airborne jet are considered. Formulas are proposed for the theoretical determination of the velocity characteristics of drops of working fluid in an air jet and their supply to hay during the selection process followed by pressing.

References

1. Soft hay and haylage from cereals and legumes / N. N. Zabashta, E. N. Golovko, A. Yu. Marchenko, N. G. Izhevsk // Collection of scientific papers of the Krasnodar Scientific Center for Animal Science and Veterinary medicine. – 2022. – Vol. 11, No. 1. – pp. 285-289. – DOI 10.48612
2. The use of a new complex bioconservant "Prolaxim-BK" in the harvesting of alfalfa haylage / A. Yu. Marchenko, N. N. Zabashta, N. A. Bedilo, E. P. Lisovitskaya // Feed production. – 2023. – No. 6. – pp. 23-27. – EDN IFCZTT.
3. S. Papusha, F. Kozhura, V. Zhadko, Combined Unit for the Introduction of Ultra-Low-Volume Biological Products with Simultaneous Embedding in the Soil, AIP Conference Proceedings., 1 (2503), pp. 030046, (2022)
4. S. Papusha, V. Zhadko, F. Kozhura, To justification of parameters of ultra-low-volume spraying with pneumatic slot sprayers, E3S Web of Conferences, 285 (07029), (2021)
5. Improvement of technological processes and technical means for field breeding / V. B. Rykov, S. I. Kambulov, N. V. Shevchenko, S. V. Belousov; Ministry of science and higher education of the Russian Federation, Agrarian Scientific Center "Donskoy", Don State Technical University, Ministry of agriculture of the Russian Federation, Kuban State Agrarian University named after I. T. Trublina. – Krasnodar: Kuban State Agrarian University named after I.T. Trubilin, 2023. – 262 p. – ISBN 978-5-907668-68-3. – EDN NOEGAG.
6. Patent No. 2775408 C1 Russian Federation, IPC A01M 7/00. Sprayer for applying liquid concentrated fertilizers : No. 2021112926 : application 04.05.2021 : publ. 30.06.2022 / S. V. Belousov, Yu. V. Khanin, A. I. Belousova ; applicant Federal State Budgetary Educational Institution of Higher Education "Kuban State Agrarian University named after I.T. Trubilin". – EDN SAXUDU.
7. Borisenko, I. B. The influence of the volumetric 3-d effect on the qualitative parameters of spraying when applying pesticides by the strip method / I. B. Borisenko, M. V. Meznikova, S. V. Belousov // Polythematic network electronic scientific journal of the Kuban State Agrarian University. - 2022. – No. 175. – pp. 41-55. – DOI 10.21515/1990-4665-175-003. – EDN HGZNFH.