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ОСОБЛИВОСТІ КІНЕТИКИ СУШІННЯ ТВЕРДИХ ВІДХОДІВ ПТАХОФАБРИК ЯК ОСНОВА УДОСКОНАЛЕНННЯ СХЕМИ ВИРОБНИЦТВА ОРГАНІЧНИХ ДОБРИВ

У статті наведено результати експериментальних досліджень параметрів кінетики сушіння твердих відходів птахофабрик. Встановлено початкову середню вологість матеріалу та структуру зв'язку вологи з курячим послідом. На основі аналізу отриманих даних запропоновано вдосконалення машинно-апаратурної технологічної схеми установки утилізації курячого посліду із отриманням якісного органічного добрива

Ключові слова: *вологість, оптимальні параметри, процес сушіння, кінетика, тверді відходи, курячий послід, бюкси, сушильна шафа, машинно-апаратурна схема, сушильні агрегати.*

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FEATURES OF THE KINETICS OF DRYING SOLID WASTE FROM POULTRY FARMS AS A BASIS FOR IMPROVING THE PRODUCTION SCHEME OF ORGANIC FERTILIZERS

The article presents the results of experimental studies of the kinetics of drying solid waste from poultry farms. The initial average moisture content of the material and the structure of the moisture-chicken manure bond were determined. Conditions for constant and decreasing drying rates were identified. Based on the analysis of the data obtained, improvements to the technological scheme of the machine and equipment for the chicken manure disposal plant were proposed, resulting in the production of high-quality organic fertilizer.

Keywords: *moisture content, optimal parameters, drying process, kinetics, solid waste, chicken manure, weighing bottles, drying cabinet, machine and equipment diagram, drying units.*

Statement of the problem. The use of advanced technologies and new equipment is associated with in-depth studies of the laws of physical and chemical processes in devices intended for the processing of raw materials and food production [1].

Over the past decade, poultry farming in Ukraine has undergone rapid development. This is evidenced by data from the State Statistics Service of Ukraine. Thus, the number of poultry increased from 123.3 million in 1998 to 210.4 million as of July 1, 2024, which is 70.6%. Such an active development of poultry production has led to a significant accumulation of production waste, in particular manure, at the level of 2.5 million tons per year [2].

Today, one of the most important environmental issues is preventing the accumulation of waste at poultry farms. Modern poultry farms are increasing the number of livestock to generate more profits. This leads to an increase in the volume of solid and liquid waste. Chicken manure is a solid waste at poultry farms. Chicken manure is processed using drying units to produce organic fertilizers.

Drying is the process of extracting moisture from solid, wet, paste-like, and liquid materials by evaporating it and removing the resulting vapor. In this case, moisture is removed from the material by diffusion from the inner layers to the surface and its evaporation into the environment [3]. Drying of wet materials can be divided into three consecutive periods: moisture movement to the surface of the material, evaporation of moisture from the surface (vaporization), and moisture movement in the form of steam from the product surface to the center of the air flow. The movement of moisture in a material is a diffusion process driven by the difference between the moisture concentration in the depths of the material and its surface. Since moisture evaporates from the surface of the material, its concentration in the depths of the material is higher than on the surface [4].

This is what makes drying different from other methods of moisture removal, such as absorbing it with chemicals or mechanical removal. The drying process is energy intensive. Therefore, the improvement of drying units is aimed at reducing energy consumption. To do this, first of all, the drying kinetics of a particular material is studied, which can be used to determine the moisture content of the material and the quantitative ratios of the forms of moisture bonding with the material. The form of moisture bonding with the material affects the amount of energy required to break this bond and is an important parameter that determines the choice of an efficient design of drying units and approaches to improving machine and equipment technological schemes for the utilization of chicken manure to produce high-quality organic fertilizer.

Analysis of recent research and publications. The mechanism of drying wet materials is determined mainly by the form of moisture bonding with the material and the drying regime. This issue was studied by scientists M.I. Pogozhkhykh, V.O. Potapov, A.O. Pak, M.V. Zherebkin, O.O. Tertyshnyi, O.A. Pivovarov, V.S. Koshulko. The classification of the form of moisture bonding with the material is based on the scheme of P.A. Rebinder. According to this scheme, the following types of bonding are distinguished [5]

- chemical bond (moisture bonding with the material in exact quantitative proportions);
- physical and chemical bonding (moisture bonding with the material in different, not precisely defined proportions);
- mechanical bonding (moisture bonding with the material in uncertain proportions).

To date, in Ukraine, the issues of improving the mechanism of waste recycling are dealt with by such scientists as: S.I. Sadchenko, S.V. Panukarenko, V.G. Smolyar, G.G. Geletukha, E.M. Kuzminsky, as well as a number of research and production associations, among which the SEC "Biomass" and LLC NPO "Technologies of the Future" make a significant scientific contribution.

Chicken manure is a moist material containing a significant amount of water. It is the object of study. Chicken manure is a colloidal body by nature and a capillary-porous material by structure. Water is in various bonds with the dry skeleton of the material, the pores of which can be filled with water, water vapor, and air. The drying process largely depends on the nature of the moisture bond with the material [5]. To find the moisture content of the material and the ratio of the mass of moisture that has a particular type of bonding with the material, drying kinetics graphs are used.

Most authors characterize the drying kinetics by four types of graphs [5]:

- a drying graph plotted in the coordinates ω (average moisture content of the material) and τ (drying time);
- drying rate graph in the coordinates $d\omega/d\tau$ (drying rate) and τ (drying time);
- drying rate graph in the coordinates $d\omega/d\tau$ (drying rate) and ω (average moisture content of the material);
- temperature curves in the coordinates θ (material temperature) and ω (average moisture content of the material).

Given the purpose of the work, the first two graphs are important. They will reveal the quantitative correlations of the nature of the moisture bond with the material and will make it possible to develop a methodology for obtaining material samples with the required moisture content.

If a material is dried at a constant air temperature t and relative moisture content φ, from which it is necessary to remove mechanically and physicochemically bound moisture, the dependence of moisture change on time is shown in the graph (Fig. 1). When removing mechanically bound moisture, the drying rate increases at the first stage, stabilizes to a constant value at the second stage, and begins to decrease at the third stage. Point C in Fig. 1 is called the critical point, it corresponds to the beginning of the removal of physicochemically bound moisture from the material. The moisture content corresponding to this point is called the critical moisture content of the material.

In Fig. 1, the period τ_0 corresponds to the time required to heat the material, the period τ_1 corresponds to the time required to remove free or mechanically bound moisture, and τ_2 corresponds to the time required to remove physically and chemically bound moisture.

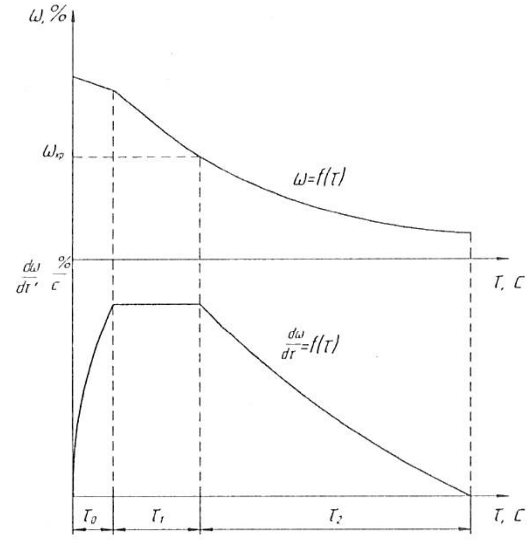

Fig. 1. **Typical graphs of changes in moisture content ω and drying rate $d\omega/d\tau$ with time τ under conditions $t = const$, $\varphi = const$.**

Objective. To obtain a graph for drying chicken manure, determine the moisture content of the material and track the quantitative indicators of the nature of the moisture bond with the material. Based on the analysis of the results obtained, to propose improvements to the technological scheme for the production of organic fertilizer based on chicken manure.

Presentation of the main material.

Equipment and research methods. Experiments on the kinetics of drying chicken manure were conducted in the laboratory.

Fig 2. **Drying chamber type SNOL 75/350**

The following equipment was used in the course of the experiment: a drying cabinet of the SNOL 75/350 type (Fig. 2); digital laboratory scales TVE "Technowagy", error 0.01 g; aluminum bins (aluminum bins No. 3 are used in many industries as a sample storage facility and for dried samples of grain seeds, sandy soil, fiber, sand, and other bulk materials); digital thermometer TFA 301018; chronometer; desiccator (glass vessel for storing dried samples in a dry atmosphere).

Experiments to determine the moisture content of chicken manure were conducted by the gravimetric method in accordance with DSTU EN 12049: 2005.

For the study, samples of material weighing from 19 g to 20 g were selected. Aluminum bins with manure were weighed on a digital scale. After that, the bins with open lids were placed in a drying oven heated from 95 °C to 105 °C. The material was dried to a constant weight, which was established by periodic weighing at intervals of 30 minutes. Prior to weighing, the aluminum bins removed from the drying oven were placed in a desiccator to cool to room temperature. When the difference in weight did not exceed 1% of the weight of the previous batch (the amount of substance accurately weighed for analysis), the study was terminated.

Results of the study.

Three weights were taken for the study, and their arithmetic mean was taken as the final result [6]. The experimental data are shown in Table 1.

The moisture content of the material was determined by the following formula [7]:

$$\omega = \frac{m_н - m_c}{m_н} \cdot 100\%, \qquad (1)$$

where ω – material moisture content, %;

$m_н$ – weight of the wet material sample, g;

m_c – weight of absolutely dry material, $m_c = 26{,}90$ g

Table 1.

Weight of chicken manure depending on drying time

Bin number	Empty bin weight, g	Weight of the bin with manure, g							
01035	19,55	40,72	39,81	37,41	34,40	31,44	27,79	26,97	27,06
01036	19,41	40,44	38,20	35,04	32,01	29,87	27,13	26,80	26,90
01037	19,31	40, 62	39,18	36,37	32,94	28,39	27,16	26,99	26,74
The average weight of the bin with manure, g		40,56	39,06	36,27	33,11	29,90	27,36	26,92	26,90
Experiment duration, min		0	30	60	90	120	150	180	210

The moisture content of chicken manure calculated by formula 1 is shown in Table 2.

The drying rate graph was obtained by differentiating the drying function [8] $\omega = f(\tau)$ using the formula:

$$\omega' = f'(\tau) = \frac{d\omega}{d\tau} = \tan\alpha, \qquad (2)$$

where α – is the angle of inclination of the tangent at the point of the graph $\omega = f(\tau)$ to the abscissa axis.

Table 2.

Changes in moisture content of chicken manure depending on drying time

Duration of the experiment, min	0	30	60	90	120	150	180	210
Moisture content, %	33,69	31,13	25,83	18,76	10,03	1,68	0,07	0

Based on the experimental data, we plot the kinetics of drying chicken manure (Fig. 3).

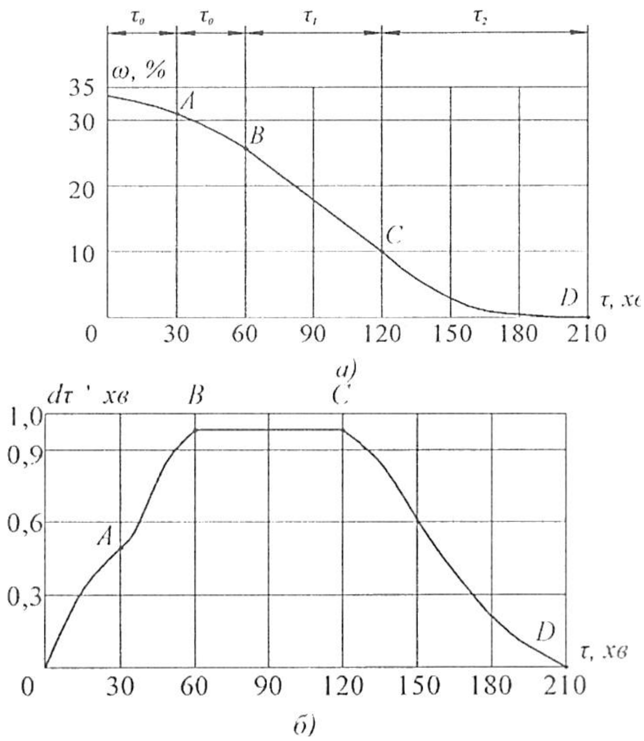

Fig 3. **Graphs of the kinetics of drying chicken manure**
a – graph of moisture content changes with drying time, *б* – graph of changes in drying speed versus drying time

Analyzing the drying graph for chicken manure, there are four stages of change in the drying rate:

The first stage. The drying rate at this stage is the lowest, because at this time the process of heating first the outer and then the inner layers of the material takes place during time τ_0.

The second stage. The evaporation rate increases, but does not reach its maximum value, because the internal layers of the material have not yet reached the required temperature (time τ_0' in Fig. 2). This stage does not exist in a typical material drying graph. This is because chicken manure has a peculiar structure, the composition of which is determined by solid lumps ranging in size from 0.1 mm to 1 mm, which have external and internal porosity. External porosity is the result of incomplete adhesion of particles. This structure of the material reduces the thermal conductivity of the material.

The third stage (time τ_1 in Fig. 2). The evaporation rate reaches a maximum and is constant over the entire time interval. The maximum drying rate is achieved by heating both the outer and inner layers of the material to the required optimum evaporation temperature, as well as by the structure of free moisture that is mechanically bound to the material.

The fourth stage (time τ_2 in Fig. 2). Point C corresponds to the critical moisture content $\omega_к$, which is the beginning of the release of physicochemically bound moisture from the material. Subsequently, the rate decreases to a minimum and tends to zero. Only chemically bound moisture remains, the removal of which would lead to the destruction of the material and change its chemical and biological structure.

Paper [9] proposes a basic technological scheme for the production of organic-mineral fertilizer based on chicken manure, which consists of the following stages:

1. Averaging the litter material in a mixer to achieve homogeneity;
2. Granulation in a closed-type screw granulator to the size of granules with a diameter of 4 mm to 6 mm and a length of 15 mm to 20 mm;

3. Drying the granules to a moisture content of ≈ 30% in a filtration drying unit at a temperature of T = 25 ^{0}C;

4. Packing of the marketable fraction.

Taking into account the results of the research, we propose to change the technological process and the basic technological scheme of organic fertilizer production.

The technological process consists of:

1. Fermentation process. The initial stage of the production line is the fermentation of organic matter. During the preparation stage, the compost will be fed into the mixer for stirring, which will increase the efficiency and speed of fermentation.

2. Crushing process. During this process, the compost block is crushed through a crusher, ready for the pelletizing process,

3. The granulation process. The screw granulator is used for granulation of fertilizers.

4. Drying process. In order to change the shape of the granules and better preserve them, the moisture content of fertilizers should not exceed 14%. The filtration drying plant is widely used for drying fertilizer granules. Hot air is supplied by an electric heater.

5. Sieving process. It takes place on a vibrating screen. Too small or large fertilizer granules will be re-crushed and re-granulated.

6. Packaging process. The packaging process is the final stage of the entire plant. Generally, an automatic packaging machine will be more efficient for packing fertilizer into bags for sale.

7. Dust collecting system. Ash and dust will be collected in the cyclone, the air will be discharged into the atmosphere.

A schematic flow chart for the production of organic-mineral fertilizer based on chicken manure is shown in Fig. 4.

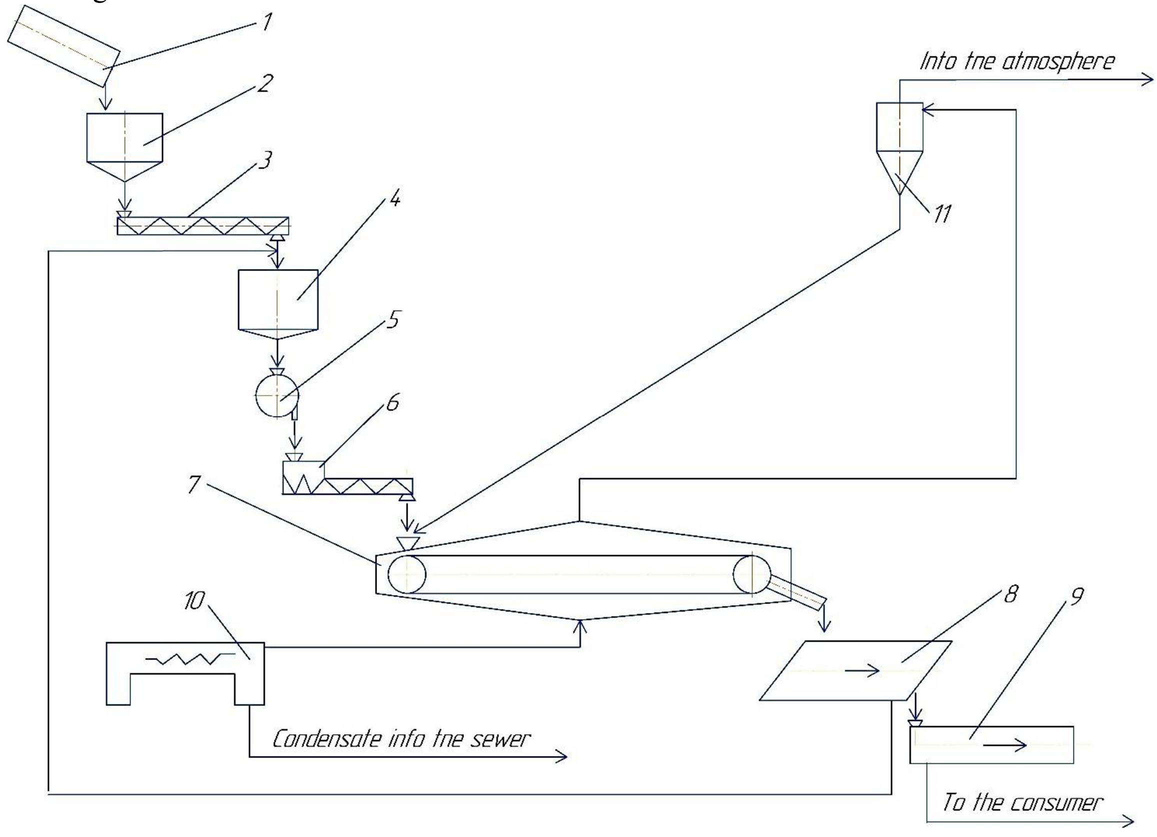

Fig 4. **Schematic diagram of the production of organic fertilizer based on chicken manure**
1 – tractor trailer; 2 – receiving hopper; 3 – screw conveyor; 4 – mixer; 5 – shredder; 6 – pelletizer; 7 – filtration drying unit; 8 – vibrating screen; 9 – packing machine; 10 – electric heater; 11 – cyclone

Chicken manure with bedding additives (e.g. sunflower husks, wood shavings, chopped corn cobs, sawdust, peat, straw) is delivered to the receiving hopper 2 by a tractor trailer 1. Then, the bedding material is fed by a screw conveyor 3 to a mixer 4, a shredder 5 and a pelletizer 6. The pellets are fed to the filtration drying unit 7, which is supplied with hot air from the heater 10. After drying, the pellets are fed to the vibrating screen 8. The pellets that meet the requirements are fed to the packing machine 9 and sent in bags to consumers. Substandard pellets are fed to the mixer for re-processing. Ash and dust will be collected in the cyclone 11, and the air will be discharged into the atmosphere. Condensate from the heater is discharged into the sewer.

Conclusions.

1. The initial average moisture content of the material was found to be 33.69%. This parameter is extremely important for the selection and calculation of the optimal parameters of drying units.

2. Based on the obtained drying graphs, the structure of moisture bonding with chicken manure was determined: 20% of moisture is mechanically bound moisture, 10% of moisture is physicochemically bound moisture.

3. It was found that at an average moisture content of ω = 31.13%, a period of constant drying rate or a period of constant diffusion begins, and at an average moisture content of ω = 10.03%, a period of decreasing drying rate or a period of internal diffusion begins.

4. Based on the analysis of the results obtained, it is proposed to improve the technological process and the basic technological scheme for the production of organic fertilizer based on chicken manure.

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