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DETERMINATION OF THE DEPENDENCE OF THE PHYSICO-MECHANICAL PROPERTIES OF ALFALFA SEED PODS ON MOISTURE CONTENT

The object of research is the physical, mechanical and thermophysical characteristics of the alfalfa seed crop mixture as factors of the drying process. This issue is of great importance for the energy efficiency of the drying process, as it directly depends on the temperature of the drying agent. Determining the physical, mechanical and thermophysical characteristics of the material will significantly simplify the procedure for determining the maximum permissible temperature of the drying agent. This, in turn, significantly simplifies the procedure for conducting energy and ex-energy analysis of the process.

The study presents the results of experimental investigations focused on determining the thermophysical characteristics of alfalfa seed mass, including heat capacity and thermal conductivity, under varying moisture content. Graphical dependencies illustrate the influence of moisture content on these parameters, demonstrating that the heat capacity and thermal conductivity of alfalfa beans increase as moisture content rises. During the study, standard and original methods were used, which allowed to obtain the dependences of the main physical-mechanical and thermophysical characteristics of the components of the harvest mixture of alfalfa seeds on humidity. In particular, it is determined that the thermal conductivity coefficient of alfalfa beans has a maximum value in the region of 25–30% humidity. This anomaly can be explained by the transition of internal moisture from a free to a bound state.

The research findings contribute to a better understanding of heat and mass transfer mechanisms in biological materials, which is crucial for optimizing drying technologies in agricultural production. The results can be used to improve the efficiency of drying equipment, reduce energy consumption, and enhance the quality of dried alfalfa seeds. The study highlights the importance of selecting appropriate drying parameters to maintain product quality while ensuring energy-efficient processing. The obtained results will allow to significantly simplify and increase the accuracy of determining the rational parameters of the drying process of alfalfa crop mixture. Also, the obtained data will allow to determine the result of the energy and ex-energy drying process much more accurately.

***Keywords**: alfalfa seeds, thermal conductivity, heat capacity, thermal diffusivity, density, convective drying, humidity of the material.*

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1. Introduction

The basis of sustainable development of the animal husbandry industry is to provide it with the high-quality feed in sufficient quantity. Many sources emphasized that the unsatisfactory state of fodder production in Ukraine is explained, among other things, by the insufficient level of production of high-yielding seeds, including alfalfa. In particular, this is noted in the Concept of the development of fodder production in Ukraine for the period until 2025 [1, 2]. It states that the potential of domestic alfalfa varieties is capable of providing a seed yield of 5–6 t/ha, although in most farms it does not exceed 2 t/ha.

These missing 3–4 t/ha are a consequence of the imperfection of modern technologies collecting grass seeds. Most of these technologies are based on using grain harvesters with the appropriate devices or even without them.

The authors have already highlighted the issue of analysis of the technology of grass seed collection, for example [3, 4], with the aim of choosing rational options for their implementation. In these and many other works, it is stated that the most accepted is the combination of combine harvesting in the field and additional processing of various types of harvest mixture in the stationary.

This opinion can be confirmed by publications [5–7], which also state that the main reason for the shortage of quality seeds is the insufficient efficiency of harvesting technology, as opposed to issues of growing seeds of perennial grasses. And even specialized and modernized grain harvesters with various attachments require additional processing of part of the crop to reduce total losses [8].

For the successful execution of the technological operations of wiping and separation, the seed mass must be brought to a moisture content of 19–21%, at which these operations take place with the greatest effect. The seed mixture comes from the field with much higher humidity.

In general, the drying operation is available in almost all agricultural processing technologies. It is used both as a preparatory operation for the successful implementation of subsequent technological operations. Also, it can be carried out at the final stage when preparing material for long-term storage. In some cases, almost half of all energy spent on processing is used for the realization of the production process.

The work [4] analyzes in detail means for drying of various agricultural products, including the harvest mixture of leguminous grasses, in particular the main one of them – alfalfa. It is noted that one of the possible effective options is drying in a stationary ball due to blowing with a heat carrier, which acts as heated atmospheric air.

The intensity of the drying process depends to a large extent on the parameters of the coolant (the main ones are its temperature and speed), the design features of the drying equipment, and the physical and mechanical properties of the material itself. In order to produce the correct version of the drying process, it is necessary to have maximum information about the material. First of all, it is useful to know about the form of moisture connection with its structural basis, the main physical, mechanical and thermophysical characteristics, etc. This is especially important when conducting theoretical research, in which the criterion-based forms of representation of the solution to the problems are usually used, and the criteria themselves are a combination of various characteristics of the material and the coolant.

In works [9, 10], the results of the theoretical studies of drying of plant materials in a dense stationary ball were carried out. Based on the results of the research, the temperature distribution of the heat carrier and material was determined by the thickness of the dense immobile ball. Equations that determine the mathematical model of drying dynamics are presented in a criterion form, for which it is necessary to know the thermophysical characteristics of the material and the coolant. It should be noted that similar studies are conducted not only to study the drying of plant materials, but also materials of inorganic origin. For example, in [11] the study of heat exchange in a stationary ball of granular expanded clay with a moving air medium is highlighted. Also, it should be noted that the processes of drying of plant materials have a more complex character than most inorganic materials due to the peculiarities of the connection of moisture with the skeleton of plants.

As noted in works [3, 4], the main method of drying alfalfa seed mass is active ventilation. In works [12, 13], the results of the theoretical and experimental studies of drying of alfalfa and grain pellets by the method of active ventilation are given. As in previous cases, criterion equations are used for the theoretical studies. It is possible to emphasize once again that in order to determine these criteria, it is necessary to have information about the relationship between moisture and the material and the thermophysical characteristics of the material.

The versatility of the drying process also lies in the fact that various equipment is used for its implementation, including those with a vibration effect on the material, as well as various energy sources. Such a case is described in paper [14], where similarity criteria are also used to describe the process of heat and mass transfer in a vibrating dryer with an infrared heat source.

Summarizing the review of the latest sources and publications on the research of drying processes of various materials, it can be concluded that in most cases, criterion equations are used to create mathematical models of heat and mass transfer. For their assembly and solution, knowledge about the physical and mechanical properties of materials is necessary, in particular the form of moisture connection with the base of the material and the thermophysical characteristics of the material. The condition of the drying process involves a change in the moisture content of the material from initial to final, and this interval has different values in specific technological cases. This requires knowing the dependence of the thermophysical characteristics of the material on its humidity within the limits determined by the technological process. This work is devoted to the definition of these characteristics.

This work is devoted to the study of the characteristics of the alfalfa seed mixture as an object of the drying process.

The aim of research is to increase the efficiency of the process of drying the seed mass of alfalfa at the stage of the theoretical and experimental research. It is possible to do it by determining the physical, mechanical and thermophysical characteristics of the material depending on its moisture content.

2. Materials and Methods

The intensification of the drying process can be achieved in two ways: by increasing the temperature difference between the drying agent and the material, and by increasing the heat transfer coefficient. When drying thermolabile materials, such as alfalfa seed pods, the temperature difference can only be increased within certain limits so as not to compromise the quality of the dried material. The heat transfer coefficient depends on the physical properties of both the material and the drying agent, the nature of their interaction, the aerodynamics of the drying agent flow, etc.

To determine the thermophysical characteristics of the post-harvest mixture of alfalfa seed pods, experimental samples alfalfa pods were tightly packed into thermally insulated parallelepipeds with dimensions of $35 \times 36 \times 60$ mm. A flat electric heater with a surface area of 34×34 mm^2 was placed between the parallelepipeds. The heater's power was regulated using a varies in the range of 20 to 50 W. The faces of the parallelepipeds facing the heater were not thermally insulated. Temperatures Δt_n and Δt_x were measured using differential thermometers, whose cold junctions were located far from the hot junctions to ensure that the temperature at the cold junctions remained constant during the experiment. The distance X was varied within the range of 5 to 15 mm. Temperature values Δt_n and Δt_x were recorded using a mechatronic system of the X9C104 type.

The test material – alfalfa seed pods – was loaded into the parallelepipeds, and the heater was turned on. Simultaneously, a potentiometer was activated to record temperatures Δt_n and Δt_x, and a sample of the material was taken to determine its moisture content. During each individual test, the power of the heater remained constant.

For material of the same moisture content, experiments were conducted at distances $X = 5$ mm, 10 mm, and 15 mm, and at heater power levels of $P = 20$ W and 50 W. The duration of each test was 7 minutes.

3. Results and Discussion

The drying process can be simplified as the subtraction of moisture from the dry mass of the material. But a certain amount of energy must always be spent on the implementation of this "subtraction" process. The intensity of the drying process depends on the amount of this spent energy. In turn, the amount of energy depends on several factors, first of all, on the form of moisture connection with the material, as well as the conditions of moisture evaporation into the environment.

The classification of forms of moisture connection with the material is based on a scheme according to which this form is determined by the energy spent on the destruction of this connection.

All forms of moisture connection with the material divides into four types (in case of decreasing energy) and chemically bound moisture, physico-chemical and physico-mechanical. Chemically bound moisture is most strongly connected to the material and can only be removed when the material is heated to high temperatures or as a result of a chemical reaction. This moisture cannot be removed from the material during drying.

In the drying process, as a rule, only the moisture that physically, chemically and mechanically is bound to the material is removed. Mechanically bound moisture can be removed most easily, which, in turn, is divided into macrocapillary and microcapillary moisture (capillaries smaller than 10^{-7} m). Macrocapillaries are filled with moisture when it comes into direct contact with the material, while moisture also enters microcapillaries as a result of its absorption from the environment.

Moisture in macrocapillaries can be removed not only by drying, but also mechanically. Physico-chemical connection combines two types of moisture that differ in the strength of the connection with the

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material: adsorption and osmotically bound moisture. Adsorbed moisture is firmly held on the surface and in vapors of the material. Osmotic moisture, or swelling moisture, is inside the plant cells and is held by osmotic forces. Adsorption moisture requires much more energy for its removal than osmotic moisture.

Paying attention to the drying process, the moisture in the material is classified in a broader sense into free and bound. Free moisture is characterized by the rate of evaporation of water from a free surface.

External factors can affect the stretching of moisture in the skeleton of the material. Of course, this primarily concerns the influence of the temperature of the environment on the material, but the other factors, such as the pressure of the external environment [15], can affect the redistribution of moisture.

According to the form of the moisture connection with the material, all bodies, as objects of drying, are divided into capillary, porous, colloid and their combinations. It is generally accepted that all plant materials, including alfalfa and its parts, belong to capillary-porous colloidal bodies.

Let's study some properties of alfalfa as a drying object. The main object of drying in the seed mass of alfalfa is the bean with seeds. The shape of the beans depends on the variety of alfalfa and can be cylindrical, sickle-shaped or ring-shaped.

The appearance of alfalfa beans is presented in Fig. 1.

The seeds in smaller beans are small (equivalent diameter is 2.5–3.5 mm), the weight of 1000 pieces of most varieties is 1.8–2.2 g.

The experience of harvesting of alfalfa seeds [3] shows that under unfavorable weather conditions for harvesting, and the weights are usually such during harvesting) the moisture content of the seed mass is 35–55%. The moisture content of different components of the seed mass differs by 5–6%, and the moisture content of the beans is higher than the moisture content of the stems and leaves.

Field research shows that grasses have more moisture 35–40%, there is free moisture, and with excess moisture is thermodynamically bound moisture [16]. This is confirmed by the analysis of drying curves of leaves and stems of herbs. At the same time, the period of constant drying speed passes until the moisture content is 30–40%, and then the drying speed drops.

When drying herbs, the bound moisture is only 10–20% of the total amount of moisture that must be evaporated, so the energy of binding moisture is only 0.2–0.4% of the heat that needs to be spent to convert the liquid into steam.

The share of heat to overcome the energy of moisture connection with the material during drying of herbal materials is very small and can be neglected. This is explained by the fact that the seed mass is not dried until moisture is completely removed from it, but to a moisture content of 20–25%, which is necessary for the following technological operations – wiping and separation. These remaining 20–25% of moisture form precisely those water molecules that are most tightly bound by the colloids of the material cells.

All these data are related mainly to single alfalfa beans as a drying object. Indeed, it is considered the main object in the seed mass that comes from the field to the station. This seed mass consists of a significant number of seed parts, leaf and stem pieces, and beans. All these components of the seed mass have different mechanical, aerodynamic and thermophysical characteristics, of course, it is primarily interested in the characteristics of the beans that are not wiped.

So, for example, the bean element, which is the main object of drying – the seed with the shell surrounding it, has a surface area of 28–30 mm^2, and a piece of stem 30 mm long has a surface area of 90–100 mm^2. Due to this, the bean, a piece of the stem, and other components of the seed mass will have different temperatures during the drying process. This forces to make certain assumptions in the theoretical studies of the process of drying alfalfa seed mass. Thus, thermophysical characteristics are not determined for each individual component of the seed mass (bean, seed, stem, leaf, etc.), but an integral value is determined that characterizes the entire seed mass as a drying object as a whole). When analyzing the drying process, the main attention is paid to the bean of alfalfa, the temperature on its surface and the surface of the seeds. The main task of the process is to dry the pile to condensation moisture without reducing the sowing qualities of the seeds.

The aim of each study in the field of drying processes is to increase its intensity. One of the ways to intensify the process of drying materials is to increase the heat exchange coefficient. This coefficient depends on the type of the material, the design and technological parameters of the dryer, the hydrodynamic and thermal characteristics of the drying agent flow, and the physical and mechanical properties of the material.

At first glance, increasing the temperature of the drying agent can be considered the most effective way. But the temperature of the drying agent is limited by the danger of overheating the seed mass, including its most valuable part – the beans. Overheating of seeds in beans can lead to deterioration of seed quality, so the temperature difference between the drying agent and beans can only rise to a certain value.

Detailed studies on determining the maximum allowable heating temperatures of grain materials were carried out in [17]. It obtained dependencies for determining the maximum allowable heating temperature of wheat grain depending on its initial moisture content, and made an attempt to explain the mechanism of the influence of heating temperature on the sowing qualities of seed grain.

For the constant exposure of the drying process $\tau = 3600$ s, the formula was offered

$$\tau_{gr} = \frac{235}{C}, \tag{1}$$

where C – heat capacity of the grain in $\left[\frac{\text{calories}}{K^2 \cdot {}^\circ C}\right]$.

Fig. 1. Appearance of alfalfa beans

To determine the heat capacity of the grain, the dependence was offered

$$C=\frac{0.37(100-W)+W}{100}, \qquad (2)$$

where W – initial grain moisture, %.

The speed of chemical reactions occurring in the grain depends on its temperature. One of these reactions – protein coagulation is accelerated under the influence of temperature and has a negative effect on grain germination.

Formula (1) has the disadvantage that it is given only for one fixed heating exposure $\tau=90$ minutes. Formulas were proposed for cases with different exposure to wheat grain heating

$$t_з=\frac{23.5}{C}+20-10\text{tg}\tau, \qquad (3)$$

where τ – the temperature action time, min;

$$t_з=122-5.4\text{tg}\tau-44\text{tg}W. \qquad (4)$$

These dependencies (1)–(4) are not acceptable for practical use in alfalfa research. Experimental studies were conducted to determine the maximum permissible heating temperature of alfalfa beans.

The standard method [18] was used as the basis of research on determining the maximum permissible seed temperature. The material was mixed in a glass vessel with thin walls, tightly closed and stirred in a thermostat. The temperature of the bean layer during exposure of heat was recorded. The quality of seeds after heat treatment was evaluated based on their similarity. The task was complicated by the fact that it was necessary to determine the maximum temperature at which seed germination does not decrease. Previously, this temperature was set approximately according to formulas (3), (4). For pure alfalfa seeds, it was smaller, and therefore the real maximum allowable heating temperature was determined by a stepwise increase in the heating temperature with an interval of 3°C, while simultaneously fixing seed germination in this experiment.

Initial humidity and heat exposure were constant in this series of experiments. For seeds in beans, the initial temperature was set 10°C higher than for pure seeds.

In order to obtain a mathematical dependence of the maximum allowable seed heating temperature, the method of experimental planning of experiments was applied [19].

As a result of conducting experiments and processing the obtained data, the dependence of the maximum permissible heating temperature of alfalfa beans depending on their initial humidity and exposure to heating was determined

$$t_{gr}=0.0005(94.4-\tau)^2+0.005(84.3-W_n)+41.5, \qquad (5)$$

where τ – heating exposure, min; W_n – initial moisture content of beans, %.

Graphical interpretation of this dependence is presented in Fig. 2.

As can be seen from (5), both factors affect unidirectional at the maximum permissible temperature, that is, if both factors increase, the temperature decreases, and vice versa. But the initial moisture content of the beans has a greater influence on the value of the maximum permissible temperature than exposure to drying. Thus, a 10% change in initial moisture (in one direction or another) with unchanged heating exposure will cause a corresponding change in the maximum allowable temperature by an average of 3%, while a similar change in heating time with an unchanged initial humidity causes a corresponding change in the maximum allowable temperature on average by only 0.07%. For practical use, recommendations can be made that when the material with a higher initial moisture content is submitted for drying, the drying exposure should be reduced, reducing, for example, the specific load of the material layer, and vice versa, in the case of a decrease in the initial moisture content, the drying exposure can be increased. In this case, the temperature of the drying agent can be increased, which will allow the drying process to be carried out more efficiently.

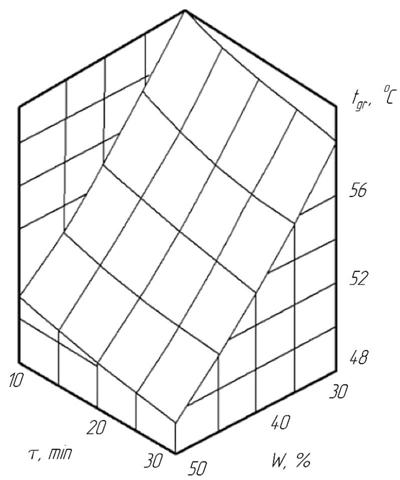

Fig. 2. Dependence of the maximum permissible heating temperature of alfalfa beans on the initial humidity and exposure of drying

Each technological line, including the technological line for drying alfalfa seed mass, is a system consisting of a certain number of elements, the nomenclature of which depends on the specific conditions of technology implementation. Of course, all elements of the technological line must be selected according to their technological characteristics, including productivity, that is, the productivity of the elements should increase from the first machine to the last in the technological series. This requirement ensures the continuity of the elements of the technological line, prevents the accumulation of wet material. After all, with the accumulation of a significant amount of wet seed mass, an undesirable process of its self-heating may begin. The release of a significant amount of heat occurs as a result of various microbiological processes and insufficient thermal conductivity of the seed mass.

The amount of heat released in the seed mass depends on its initial humidity and ambient temperature.

When studying the process of self-heating of alfalfa seed mass, it was placed in a cylindrical metal container with a diameter of 0.7 m and a height of 1.5 m.

The temperature of the seed mass was measured at nine points in the container: at points with a radius of $r_1=0$ m; $r_2=0.5$ m; $r_3=0.3$ m and at three heights $h_1=0.25$ m; $h_2=0.75$ m; $h_3=1.25$ m. Then the average volume temperature of the seed mass was calculated. It should be noted that the mass temperature measured at one height was practically the same for all three radii. At height, the temperature change was more significant, and it decreased from the top of the container to the bottom, which can be explained by the different conditions of the bacteria's life activity due to the lack of air in the lower part of the container.

The change of the average temperature of the seed mass over time depending on its moisture content is shown in Fig. 3.

The analysis of the obtained results shows that the seed mass with a moisture content of 29% reaches a dangerous (from the point of view of reduced seed germination) temperature after 12 hours of storage. In most cases, the mass with approximately this moisture content arrives from the field to a stationary point and can be stored there without ventilation and mixed for no more than 10–12 hours.

As have already been noted, in most cases, similarity criteria are used for the theoretical studies of drying processes. Data on the main criteria used in these studies are presented.

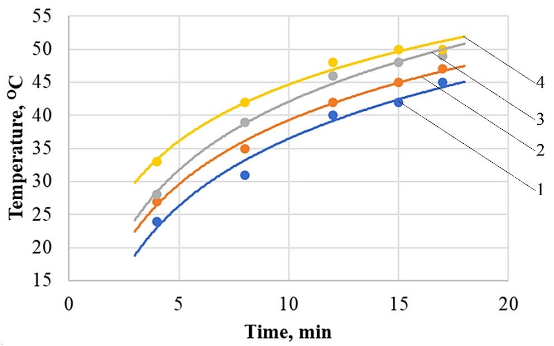

Fig. 3. Dependence of the average self-heating temperature of alfalfa seed mass on time and initial humidity: 1 – humidity 20%; 2 – humidity 29%; 3 – humidity 37%; 4 – humidity 45%

The Reynolds criterion (Re) is a similarity criterion based on the ratio of the inertia of the fluid flow to its viscosity. It is possible to pay attention that from a physical point of view, the heated air, which is used as a drying agent, is also considered a liquid. The Re criterion can be defined for a number of different situations where the liquid (drying agent) is in relative motion to the surface of solids (e. g. alfalfa beans). It depends on the density and viscosity of the liquid, as well as its speed and the characteristic size of the solid body.

Mathematical notation (expression)

$$\mathrm{Re}=\frac{\rho\cdot u\cdot l}{\eta}=\frac{u\cdot l}{\vartheta}, \tag{6}$$

where ρ – density of liquid or gas; u – characteristic speed; l – determining body size; η – dynamic viscosity of liquid or gas; ϑ – kinematic viscosity of liquid or gas.

The Fourier criterion (Fo) characterizes the relationship between the rate of the change of thermal conditions in the environment and the rate of change of the temperature field within the studied system. It depends on the size of the body and its coefficient of thermal conductivity.

Mathematical notation

$$\mathrm{Fo}=\frac{a\cdot\tau}{l^2}, \tag{7}$$

where a – the coefficient of thermal conductivity of the body; τ – characteristic time of change of external conditions; l – characteristic body size.

The Bio criterion (Bi) is one of the criteria for the similarity of stationary heat exchange between a heated or cooled solid body and the surrounding environment. In the case of drying solid bodies, it characterizes the ratio of the amount of heat that is supplied to the body and the heat that is removed from the surface into the body.

Mathematical notation

$$\mathrm{Bi}=\frac{a\cdot l}{\lambda}, \tag{8}$$

where a – the coefficient of heat transfer from the surface of the body to the environment; λ – the coefficient of thermal conductivity of the material of the body.

Part of the ratio of coefficients a and λ is denoted

$$H=\frac{a}{\lambda}, \tag{9}$$

then

$$\mathrm{Bi}=H\cdot l. \tag{10}$$

The Nusselt criterion (Nu) is one of the main criteria for the similarity of thermal processes, which characterizes the ratio between the intensity of heat exchange due to convection and the intensity of heat exchange due to thermal conductivity (in conditions of a stationary medium).

Mathematical notation

$$\mathrm{Nu}=\frac{q_c}{q_\lambda}=\frac{a\cdot l}{\lambda}, \tag{11}$$

where q_c – the heat flow due to convection; q_λ – the heat flow due to thermal conductivity; a – the heat transfer coefficient; λ – the coefficient of thermal conductivity of the medium; l – a characteristic size.

It should be noted that always $Nu\geq 1$, that is, the heat flow due to convection, always exceeds the heat flow due to thermal conductivity in its value.

These are the main similarity criteria used in the study of drying processes. In addition to the mentioned above, it is possible to add, for example, the criteria of Prandtl (*Pr*), Péclet (*Pe*), Pomerantsev (*Po*) and the others. But all criteria include several basic material properties in various combinations: material density and heat capacity, thermal conductivity, thermal diffusivity of the material.

As for density, it is only possible to talk about its value for individual elements. For the entire seed mass, it is possible to talk about volumetric mass and bulk mass.

Of the constituent parts of the heap, the most important for our drying process are alfalfa beans with seeds. The dependence of the density of beans on their moisture content was determined. The moisture content of the beans was determined according to the known method by complete drying and weighing. The results of these experiments in a graphical interpretation are presented in Fig. 4.

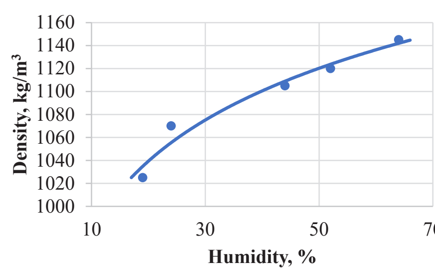

Fig. 4. Dependence of the density of alfalfa beans on humidity

All criteria that are used in the study of drying processes include the following thermophysical characteristics and heat capacity C (J/kg°C), thermal conductivity a (m^2/s) and thermal 3 conductivity λ (W/m°C). In order to realize successfully the tasks of drying, it is necessary to know their dependence on the initial moisture content of the seed mass.

The main thermophysical characteristics of the material are connected by the ratio

$$C=\frac{\lambda}{a\cdot\gamma}, \tag{12}$$

where γ (kg-m^3) – the density of the material.

The heat capacity of a material is numerically equal to the amount of heat that should be added to a unit mass of the material to raise its temperature by one degree.

The heat capacity of plant materials depends on the heat capacity of water and dry matter. The heat capacity of water is higher than the heat capacity of dry matter, therefore, during drying, the heat capacity of plant materials, including alfalfa seed mass, decreases. In addition, the heat capacity also depends on the temperature of the material – it increases as the temperature increases.

The coefficient of thermal conductivity characterizes the ability of a material to conduct heat and is numerically equal to the amount of heat that passes per unit time through a unit surface when the temperature changes by one degree per unit length of the material. The thermal conductivity of the material depends on its structure, humidity, density, and temperature. When the humidity decreases in the process of drying the material, its thermal conductivity decreases. The thermal conductivity of the seed mass is lower than the thermal conductivity of its individual components due to the presence of air spaces between them.

The coefficient of thermal conductivity determines the rate of development of a non-stationary thermal process, i. e. the ability of material particles to equalize the temperature in its separate places when heated or cooled. The coefficient of thermal conductivity depends on the intensity of moisture transfer inside and the characteristic connection of moisture with the material [20].

The method described in [21] was used to determine the thermophysical characteristics of the seed mass.

The method is based on the use of laws of non-stationary heating of two semi-limited rods, at the point of contact of which a heat source of constant power is placed.

The theoretical justification of the method, the main equations and graphical regularities underlying the method are detailed by the authors in [21]. Therefore, in this paper, let's present the results of the experimental studies on determining the thermophysical properties of the components of the alfalfa seed mass. The schematic diagram of the laboratory unit and its appearance are presented in Fig. 5 and Fig. 6.

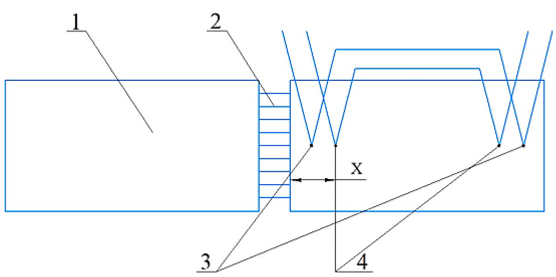

Fig. 5. Schematic diagram of a laboratory setup for determining thermophysical properties of alfalfa: 1 – thermally insulated parallelepipeds; 2 – flat electric heater; 3, 4 – differential thermocouples

Fig. 6. General view of the laboratory setup for determining the thermophysical properties of alfalfa

As a result of conducting the research and processing of the researched data, the dependences of thermophysical properties of alfalfa beans on its moisture content were obtained, which are shown in Fig. 7.

The analysis of these graphs show that the heat capacity and thermal conductivity of alfalfa beans increases with an increase in the moisture content of the material. Thermal diffusivity has an inflection point in the humidity area of 25–30%. This crossing can be explained by the transition of water from a free to a bound state.

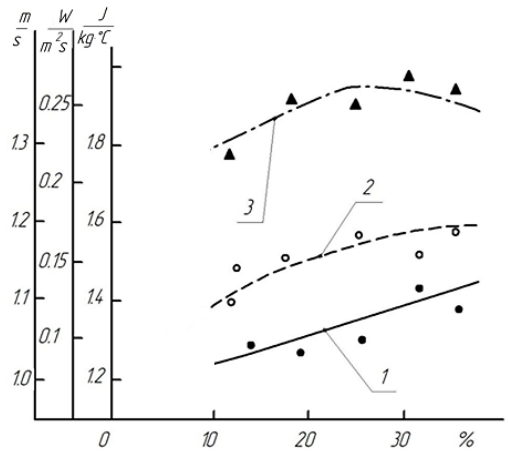

Fig. 7. Dependence of thermophysical characteristics of alfalfa beans on their humidity: 1 – heat capacity; 2 – thermal conductivity; 3 – thermal diffusivity

Practical significance. The obtained results will allow to determine the rational parameters of the drying process of alfalfa harvest mixture. The use of the research results presented in this article will allow to increase the efficiency of the technological operation of the drying process and the entire technology of processing of alfalfa seeds at the base.

Research limitations. The obtained results can be used for planning and implementing the drying process of alfalfa seed crop mixture on installations of various types and different energy sources. That is, they will be used not only for designing drying processes on active ventilation installations, as it is in our research, but also on the other convective, conductive and radiation dryers.

Prospects for the further research. The results presented in this article are the basis for the further development of theoretical and experimental principles for studying the drying processes of various agricultural materials, primarily leguminous seed plants. The research will be used in the development of mathematical models of drying processes of various materials in the form of criterion equations. This method of developing mathematical models will allow to predict more effectively the prospects for the use of various types of drying equipment.

4. Conclusions

Previous experience in processing alfalfa seed mass at a stationary point shows that for successful threshing, its moisture content should be 19–21%. Usually, during harvesting, the moisture content of the mass is 30–35%, and sometimes more. This requires a special operation of drying the seed mass.

For successful research into drying processes, it is necessary to know the magnitude of the physical and mechanical characteristics of the seed mass components. Of particular importance are the thermophysical characteristics, namely: heat capacity, thermal conductivity, thermal diffusivity of alfalfa beans.

To conduct research on determining the thermophysical characteristics of alfalfa beans, a laboratory unit was created, the main element of which is two semi-exchanged rods with a constant power heat source.

As a result of the research, the dependence of the change in the thermophysical characteristics of alfalfa beans on their moisture content was obtained.

In the humidity range of 10–40%, the heat capacity varies from 1.2–1.45 J/kg·°C; thermal conductivity from 0.13–0.18 $W/m^2 \cdot s$; thermal diffusivity from 1.3–1.45 m/s.

In the humidity range of 30–35%, the dependence graphs have an inflection, which is associated with a change in the form of the moisture-material bond.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship or other, which could affect the research and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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