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Justification, development of new technology and design for drying seeds of desert fodder plants

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Abstract. Proposals for the development of highly efficient new resource and energy-saving technologies and designs for seed drying are substantiated in the paper-based on theoretical research and scientific results. The developed new improved design of a vacuum drying unit with a heat transfer fluid and a heat accumulator for drying seeds of desert fodder plants, a diagram of the energy storage process, an irradiation scheme using heat waves of a flat layer are substantiated and presented.
The positive effect of external physical fields on drying processes is substantiated and determined by mathematical simulation and experimental methods. Design basics of drying equipment of desert fodder plant seeds are developed in analytical solutions based on numerical values of key parameters. Extensive information is provided on the previously obtained results of an analytical study and computer implementation of the developed advanced mathematical models; the solution to the problem of seed drying in an analytical form for non-stationary and stationary problems of the known system of A.V. Lykov differential equations are given.

1. Introduction

With the aim to further improve agricultural engineering, the issues of creation and improvement of modern technique, innovative ideas and technologies, the justification of effective engineering solutions, and the development of competitive products are of great importance. One of the fundamental bases for further development of the industry is the intensification of research on machines, apparatus, assemblies, and machine-building installations. Moreover, it is necessary to develop scientific grounds with the widespread use of the achievements in classical mechanics, the theory of mechanisms and machines, the theory of vibrations, and the theory of partial differential equations. Many research centers in the leading countries all over the world conduct scientific research aimed at developing resource-saving methods and new scientific and technical solutions for the technological process of production of dried seed and fruit and vegetable products. In this regard, it is urgent to develop scientific and methodological grounds for increasing the productivity of energy and resource-saving drying machines, apparatuses, units, and assessing their economic efficiency and resource due to production processes mechanization.

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However, in these studies, the issues of substantiating a unified approach to the parameters of seed drying units and the creation of energy-saving devices are not sufficiently reflected. The development of energy-efficient devices for drying seeds of desert fodder plants and the designs of mobile drying units is insufficient. The theoretical grounds for the development of aggregates used for seed drying are also not sufficiently developed. Thus, it seems necessary and urgent to intensify research on the development of scientific and technical solutions to improve the drying and cleaning technologies of desert fodder plant seeds.

2. Methods

Large-scale scientific research aimed at creating new technologies and designs of technical equipment for drying seeds and fodder crops is carried out in the Republic of Uzbekistan, in leading world scientific centers and higher educational institutions, including Germany, France, Portugal, Turkey, China, Russia, etc. These studies are aimed at reducing energy and resource consumption; increasing the productivity of dryers; for separation based on processing during drying of seeds, fruits, and vegetables, creating technologies, which ensure preserving biologically active substances; developing drying and temperature regimes to select the parameters for drying; the creation of drying units that provide artificial propagation of seeds for drying; the design of drying equipment for seed drying in field conditions; the creation of new effective technologies and technical tools for simultaneous drying and processing of seeds to increase the speed and productivity of drying; the development of convective-radiation and vacuum drying[1,2,3,4,5]; step-by-step technology for post-harvest processing of seeds, fruits, and vegetables, [6,9,12,14,20].

Consider the technological process of preparing seeds for storage, presented in the form of a structural diagram (Figure 1).

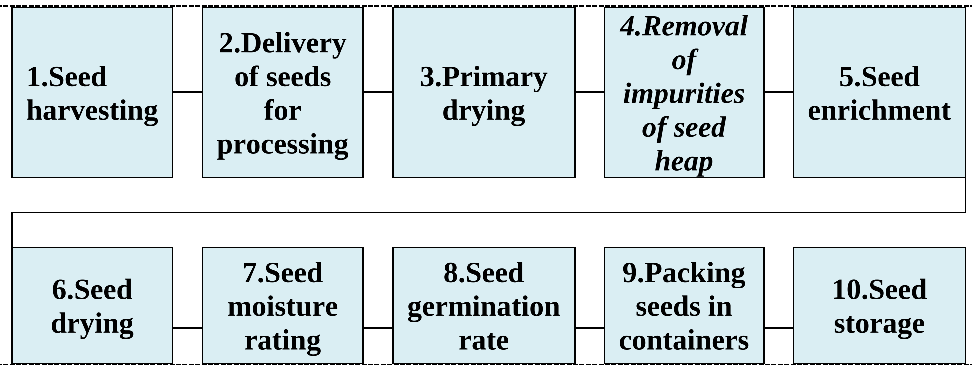

Figure 1. Scheme of technological process of preparation and storage of desert plant seeds

A new design of a cleaner has been developed; it produces seed heap with significant (70-80%) amount of hardly separated weed impurities (generative shoots, wings, defective and weak seeds). The proposed device for cleaning seeds of desert fodder plants has been manufactured and successfully tested on an experimental depot (Figure 2). Industrial development and use of the device will improve the technology for preparing seeds of desert fodder plants for drying [10, 11].

The vacuum drying unit proposed by the authors with a heat transfer fluid and a heat accumulator for drying seeds of desert fodder plants in the form of a manufactured pilot sample has been successfully tested in experimental depot (Figure 3) ("Device for seed cleaning" No. FAP 00979. 2015).

The unit operates as follows. Sliding racks with seeds of fodder desert plants preliminarily cleaned of impurities, for example, prostrate summer cypress seeds with a moisture content of 40%, a layer thickness of 7 sm are placed in the vacuum drying chamber. After sealing with a vacuum pump through the nozzles a working pressure of 800-900 Pa is created in the drying chamber. Then the

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boiler with T1500U brand transformer oil is heated to a temperature of 250°C and the taps are opened to supply hot heat transfer fluid to the heat accumulator radiator through the nozzles [15, 16, 17, 18, 19].

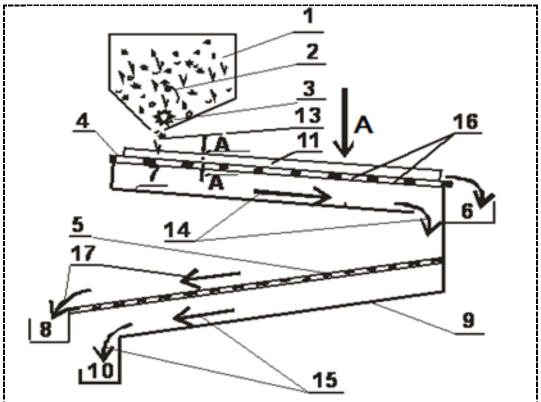

Figure 2. Device for seed cleaning of desert fodder plants

At temperature increase to 200-250^{0}C, oil begins to circulate in a closed cycle due to the pressure difference created by the oil density difference before entering and after leaving the chamber. An increase in oil temperature occurs due to heating from a source of thermal energy. Instead of a boiler, it is possible to use thermal energy from a solar installation.

The process of heating paraffin placed in the cavity of the heat accumulator, loaded in an amount of 60% of its free volume, is carried out by the heat carrier through the radiator walls

with the boiler turned on for 1 hour until the temperature reaches 150^{0}C.

Then the boiler is turned off, the taps are closed and the drying in a vacuum drying chamber is conducted at a temperature of 45-50^{0}C by supplying a heat carrier through the heat supply nozzles coming from heated paraffin located in the heat accumulator through the radiator pipes. The thermal energy of the heat accumulator (paraffin) is enough for 4 hours of dryer operation. The drying time of desert fodder plants seeds up to a standard moisture content of 11-12% was 0.3 hours. Germination check of dried seeds showed good results - 75-90%.

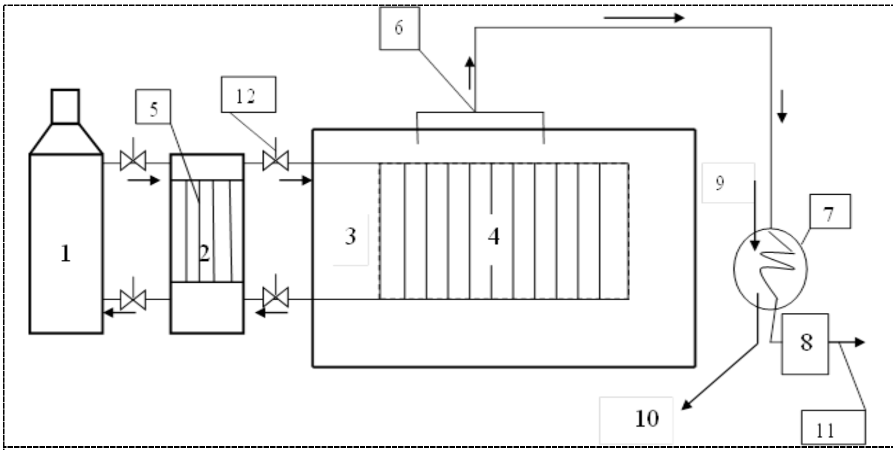

Figure 3. Schematic diagram of a vacuum drying unit with a liquid coolant and heat accumulator for drying seeds of desert fodder plants; 1 – boiler (transformer oil heater); 2 - heat accumulator (paraffin); 3 - drying vacuum-evaporating chamber; 4 - heat exchanger (working heat

carrier); 5 - heat exchanger storage material; 6 - steam + other gases (cooled by water); 7 - heat exchanger (vapor cooling); 8 - liquid-packed ring air-vacuum pump (AVP 1/3); 9, 10 - inlet of cold water; 11 - condensate outlet; 12 - valves

The drying chamber is a cylinder of 2 meters long and 2 meters high (diameter), with convex side surfaces, one of them is a door with the corresponding fastenings. The inner frame, consisting of stiffening ribs (reinforcement truss), increases resistance to external pressure. In the chamber, a pump creates a deep vacuum up to – 0.9 atm, in the operating mode (0.8 – 0.9) atm - low pressure. This pressure allows us to bring the boiling point inside the chamber to 45 – 50^{0}C. The amount of steam released at the first stage of the drying process is so large that it is necessary to strengthen the capacity of the air-vacuum pump of AVP (1/1.5 - 1/3) brand. All technological process parameters are set and controlled by instrumentation.

Thus, the proposed unit is quite simple to manufacture, it is done of inexpensive materials, allows getting high-quality seeds of desert fodder plants at low temperatures and low consumption of thermal energy. Besides, this vacuum-drying unit can be successfully used for drying vegetables, fruit, and herbs.

New technologies in the drying processes, such as the thermal field for product heating, a vacuum drying unit with a heat transfer fluid, and a heat accumulator for drying products, and some other innovations are undoubtedly catalysts and accelerators of chemical reactions in technological processes of production[21, 22, 23].

Discrete drying is known to be more effective than continuous drying, as there is time to level moisture and temperature between the internal and external parts of the product to be dried. Using the accumulation of energy allows drying to continue with the heating mode off (Fig. 4). In the above method, using the appropriate properties, it is proposed to turn off external heating due to energy storage at lower temperatures heat transfer.

Heating the heat transfer fluid to a temperature of no more than 95^0 C does not allow for intense heat irradiation with rays. Also, the low thermal conductivity of paraffin further reduces the energy recovery process due to the accumulated energy. With the indicated energy accumulated in the normal operating mode, when the boiler operates rationally, the overheating does not occur. In the process of this cycle, the boiler efficiency increases with the average power increment of additional energy by $\frac{\lambda M}{\tau}$, where τ is the time of paraffin heating.

Consider the case of overheating. In practice, transformer oil used as a heat transfer fluid can overheat over time. In this case, the system (Figure 4) does not overheat; for paraffin, the boiling point is 600-650^{0}C. Hot oil can be heated up to more than 250 ^{0}C, if there is no tank and a heat transfer fluid pipes system.

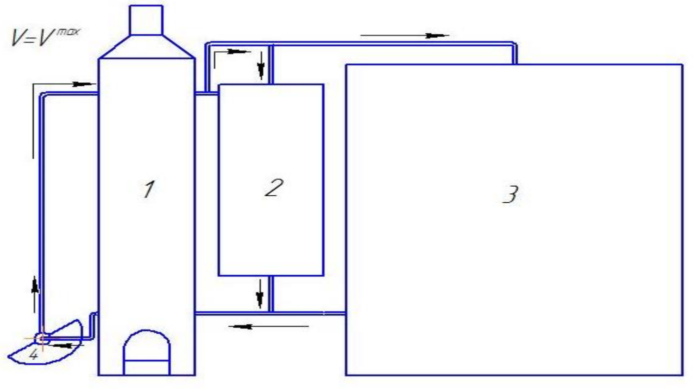

Figure 4. Energy storage process diagram

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1 – a boiler with a heat transfer fluid; 2 – thermal energy accumulator; 3 - a vacuum chamber; 4 - parabolic solar oil heater

It is seen that the requirement for the paraffin mass from below is limited, that is, it must compensate for excess heat. In special cases, other steam heat limiters can be used. Inside, heat is released in the form of thermal radiation. The energy from heat transfer inside the vacuum chamber can be neglected. Thus, at this stage, the dryer operates without the stored energy of the phase transition.

Next, consider stage – 2 the process of using accumulated energy in a closed system, which consists, among other things, of a heat energy generator, working due to the phase transition of the heat transfer fluid, i.e. due to paraffin hardening at 60^0C. Here the process occurs at a turned off boiler.

The total return energy is

$$\lambda M + MC\Delta t = Q$$

where $MC\Delta t$ is the energy given off by paraffin; C is the specific heat capacity, Δt is the cooling temperature drop from 250 to 60^0C, with a difference of 190^0C.

The effectiveness of product drying is shown in the example using paraffin.

In the direction of mechanization of the drying process of desert fodder plants seeds, the studies were carried out to develop a vacuum drying device with a heat transfer fluid, using local raw materials as an energy source. The device is shown in Figure 6, it consists of a vacuum drying chamber, a heat accumulator, and a heating boiler.

The development and implementation into the production of technical means for seed cleaning and drying will allow mechanizing the technological processes of post-harvest processing and pre-sowing preparation of seeds of desert fodder plants, which in turn will maintain germination and improve their sowing qualities with minimal labor and money.

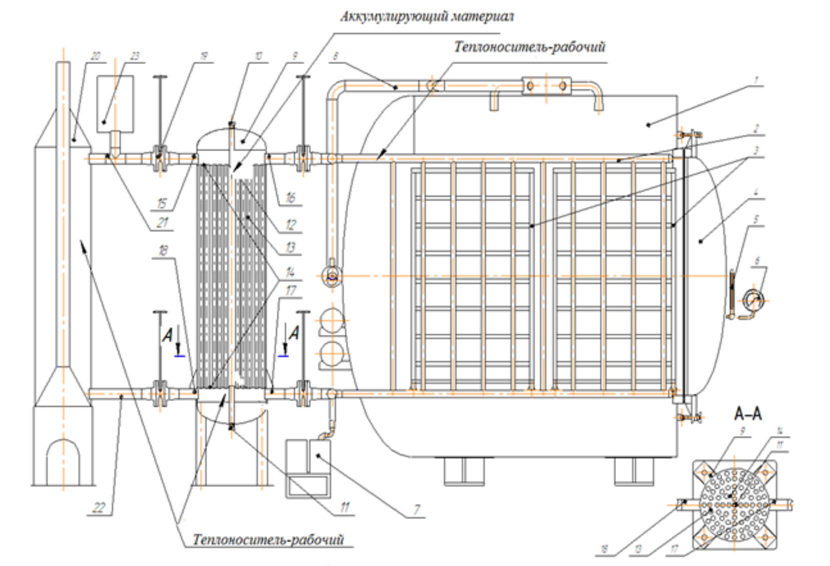

Figure 5. Diagram of a vacuum drying unit with a heat transfer fluid and heat accumulator

Thus, the results of tests of a vacuum drying unit with a heat transfer fluid allow evaluating the performance of the proposed device. To increase the efficiency of the vacuum drying unit, the principle of accumulation of thermal energy by paraffin was used. Besides, a solar heater was used in the form of a cylindrical parabola, on which the sun's rays were concentrated, which heated the black tube mounted on the focus of the parabola and the working fluid. This decision contributes to the environmental friendliness of this unit.

3. Results and discussion

In [7, 8], the results of analytical studies were presented. In particular, analytical studies have been carried out and mathematical models of the drying process of desert fodder plant seeds under thermal irradiation for unsteady and stationary problems have been compiled, the statement and solution of stationary problems of heat and mass transfer processes to dry the sorbents have been substantiated, mathematical models of the drying process have been developed and analytically implemented using external physical fields.

In general, in many studies, the description of heat and mass transfer in the drying process is based on the well-known generally accepted differential equations of drying [13].

The linear form of a system of nonlinear differential equations is:

$$\begin{cases} C_s \dfrac{\partial T}{\partial t} - \varepsilon \dfrac{\partial W}{\partial t} = \lambda \dfrac{\partial^2 T}{\partial x^2} + Q \\ (1-\varepsilon)\dfrac{\partial W}{\partial t} = D \dfrac{\partial^2 W}{\partial x^2} + D_T \dfrac{\partial^2 T}{\partial x^2} \end{cases}, \quad (1)$$

where ε is the criterion for the phase transformation of a liquid into steam, C_S is the heat capacity of the medium, λ is the local coefficient of thermal conductivity, D, D_T are the coefficients characterizing the porosity of the body, determined empirically.

Analytical studies were carried out on the basis of the following calculated drying scheme using heat waves of a flat layer (Figure 6).

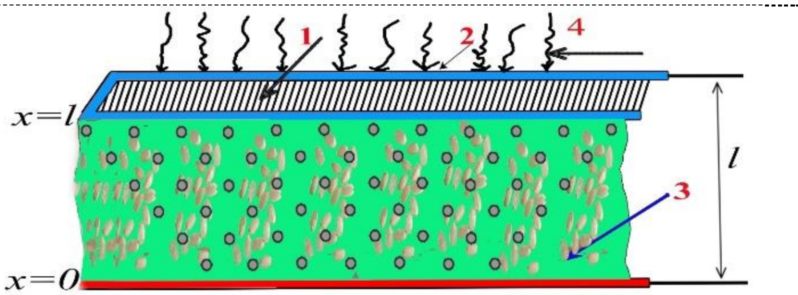

Figure 6. The scheme of drying (irradiation) using heat waves of a flat layer: 1 is upper surface of the medium, heating layer; 2 is medium of heating layer surface; 3 is dehydrated medium of thickness l; 4 is heat wave

For system (1) the boundary conditions are assumed such that evaporation and heating occur from the upper surface due to irradiation by heat rays. From the bottom surface of this flat layer, there is no energy exchange and drying. The processes of absorption of heat rays allow writing the law of heat reception under heating due to electromagnetic waves. The penetration depth is small compared to the total thickness l; i.e. much less than the thickness of the dehydrated material, where the Lamberg absorption law is applied.

Based on analytical studies, the following functional dependences of changes in the key parameters of the studied mechanical system were obtained:

$$\begin{cases} T = \sum\left[U_\gamma(x) + \alpha V_\gamma(x)\right]\cdot T_0 e^{-a_\gamma^2 t} \\ W = \sum\left[\beta U_\gamma(x) + \mu V_\gamma(x)\right]\cdot W_0 e^{-a_\gamma^2 t}. \\ \gamma = \gamma_n,\ \ n = 0, \pm 1, \pm 2, ... \end{cases} \quad (2)$$

The obtained scientific results based on analytical studies can be used in the development of technical means and designs of new mechanisms not only for drying sorbents and seeds but also for fruit and vegetables.

4. Conclusions

1. A method and an improved mathematical model are developed, the solution to the problem of seed drying in an analytical form is obtained for non-stationary and stationary problems of the known system of A.V. Lykov differential equations. The method will become the basis for the development of energy-saving technology for drying desert fodder plant seeds.

2. The obtained analytical solutions for non-stationary and stationary conditions of the technological processes of drying seeds of desert fodder plants became the development of the general theory of analytical research and A.V. Lykov mathematical model. The results obtained make it possible to apply the laws of changes in the key parameters for stationary and non-stationary tasks in heat transfer processes used in machine units for drying seeds of desert fodder plants.

3. The basics of designing the drying equipment for seeds of desert fodder plants are developed on the basis of numerical values of the key parameters in analytical solutions. These results allow creating a technical design and an automatic control system when developing the plants for seed drying.

4. Mathematical simulation and experimental methods substantiate and determine the positive effect of external physical fields on drying processes. This method allows us to determine the optimal mode of drying seeds of desert fodder plants.

5. A mathematical model of the drying process using external physical fields to calculate the drying parameters has been developed. This mathematical model allows conducting engineering calculations for the drying process of seeds of desert fodder plants.

6. A new improved design of a vacuum drying unit with a heat transfer fluid and heat accumulator was developed. This will reduce the energy efficiency of drying seeds of desert fodder plants by 18-20%.

7. A two-stage technology for drying seeds of desert fodder plants has been developed, which allows increasing the drying efficiency of seeds by 25-30%.

8. The design of a vacuum drying unit equipped with a heat transfer fluid and heat accumulator has been developed. This design will increase the drying performance of seeds by 12%.

9. A resource-saving technology has been developed for using a vacuum drying unit with heat transfer fluid and a heat accumulator for drying seeds of desert fodder plants. This technology will increase the life of the drying unit by 1.2-1.3 times.

10. Low-pressure vacuum technology has been developed to increase seed germination of desert fodder plants. This technology will increase the seed germination of desert fodder plants by 12-14%.

A fundamentally new cleaner was developed to remove the impurities and enrich the seed heaps of desert fodder plants ("Device for cleaning seeds" No. FAP 00979 - 2015). The implementation of this design allows cleaning the seeds of desert fodder plants from various impurities.

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