An analysis of the convective drying kinetics of wild grass seeds

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Abstract. The experimental results of the sorption properties and the capillary-vesicular structure of wild-growing seed grass are given in this study. This data can be applied to refining the drying process parameters. Methods for improvement of drying plants used for heat treatment of wild-growing seed grass, as well as for technical plant varieties are proposed.

1. Introduction

The relevance of the chosen topic is justified by the need to increase the production of wild grass seeds used for landscaping. The modern world has inherited the heavy legacy of the industrial era. To restore nature, it is necessary to eliminate the negative consequences of human activity over the past decades and take the vector onto a new technologically advanced, environmentally friendly way of developing energy and technology. In many ways, this determines the need for both the reproduction of the plant world on recreational lands and the integration of plants into existing landscapes. Various types of wild plants are used both to restore the natural landscape, damaged after human activity, and to arrange green spaces on the roofs of buildings, roadside territories.

To date, there are no proposals in the technical and scientific literature for the development and improvement of drying plants used for heat treatment of wild-growing seed grass, as well as for technical plant varieties. Drying processes in many companies are carried out using inefficient equipment and non-compliance with operating condition. This leads to the fact that the collected seeds are either completely deprived of active substances, or their quality is partially reduced, meaning the economic costs. To improve the quality and energy efficiency of the grass drying process and obtaining seeds, it is necessary to conduct experiments to study the processes of heat and mass transfer of plant materials. Drying processes investigation of such objects will allow us to develop the best modes and offer dehydration parameters for production needs. The demand for such plants is due to numerous projects being implemented in various countries to improve the environmental situation in territories where minerals were previously mined in an open way, for example, in Germany.
2. Moisture sorption equilibrium of wild grass seeds research

2.1. Experimental study of drying kinetics

The German company Nagola Re GmbH (https://www.nagolare.de) has been paying special attention to environmental projects since 2011 related to restoration of the natural vegetation cover of territories that were damaged as a result of open-pit brown coal mining. The annual increase in production capacity required a reorganization of the drying processes of seeds. An analysis of the state of production confirmed the need to study the kinetics of drying seed wild-growing grass to clarify the process parameters.

We carried out the experiments to study the processes of heat and mass transfer of plant materials, to analyze the vesicular structure and sorption properties of the studied plants. This results can be applied to increase the energy efficiency of drying grass and obtaining seeds from it.

One of the ways to study the mechanism of interaction between moisture and plants is to study the hygroscopic properties of both the whole object and individual parts of plants [1].

Equilibrium moisture content depends not only on the type of culture, but also on its variety. The database on the sorption properties and parameters of the capillary-vesicular structure of seeds is continuously updated. The data obtained for the convenience of kinetic calculation are described by the corresponding equations expressing the dependence of the equilibrium moisture content on the relative humidity and temperature [2], [3], [4], [5].

Based on the data on the drying kinetics, the drying time and parameters are determined.

In this paper, we examined three types of typical field plants. Seeds, inflorescences and stems of the following plants were studied as drying objects: Ähriger Blauweiderich / Veronica spicata (plant 1), Nachtkerze / Oenothera (plant 2), Braunelle / Prunella (plant 3), as well as mixtures of these components for plants 2 and 3. According to morphological characteristics, these plants belong to different groups [6]. For the study, the Multisample Dynamic Moisture Sorption SPS11-10µ water vapor sorption unit (https://proumid.com) was used. The experiment was conducted at «BTU Cottbus-Senftenberg at the department building physics and building technology» between October 2019 and February 2020.

2.2. Processing of data on drying parameters of wild herbs

On the obtained experimental data, graphical dependences of the equilibrium moisture content of the studied samples on the relative humidity of the air at a constant temperature of 20 °C were built.

The selection of temperature parameters is due to existing storage conditions at the factory.

Figure 1 shows the dependence of the equilibrium humidity of the material on the relative humidity of the air for plants 1-3 for various components of the materials.
The measurements started with RH=0%, went up to 90% and went down again to 0%.

Since the interaction of the material with water is a complex process, we used a polynomial dependence to describe the sorption isotherms. The processed experimental result showed that the obtained data are described with a sufficient degree of accuracy by polynomials of various degrees, where the fifth degree of the polynomial was maximum, and the third minimum. General view of the equation of polynomial of the fifth degree:

\[ W_p = a_0 + a_1 \varphi + a_2 \varphi^2 + a_3 \varphi^3 + a_4 \varphi^4 + a_5 \varphi^5 \]  

where \( W_p \) is the equilibrium moisture content of the material, %; \( \varphi \) is the relative humidity; \( a_0, a_1, a_2, a_3, a_4, a_5 \) – are the coefficients of the equation, depending on the material and temperature; \( R^2 \) is the value of reliability approximation.

The values of the coefficients of the equation for 11 samples are given in Table 1.

The obtained polynomial dependences make it possible to calculate equilibrium humidity at any relative humidity. Moreover, for plants from different morphological groups, it has a similar shape.

### Table 1. The values of the coefficients of the equilibrium moisture equation for the investigated materials

| investigated material | coefficients of the equilibrium moisture equation |
|-----------------------|---------------------------------------------------|
|                       | \( a_0 \cdot 10^{-8} \) | \( a_1 \cdot 10^{-8} \) | \( a_2 \cdot 10^{-8} \) | \( a_3 \cdot 10^{-8} \) | \( a_4 \cdot 10^{-11} \) | \( a_5 \cdot 10^{-15} \) | \( R^2 \) |
| **Plant 1**           |                     |                     |                     |                     |                     |                     |         |
| Seeds                 | -2025591            | 51534895            | -2247816            | 61138              | -715164             | 32475856             | 0.999   |
| Stem                  | 22259580            | 50075865            | -1015142            | 9632               | 0                    | 0                    | 0.997   |
| Inflorescence         | -1890561            | 71951572            | -3627507            | 97338              | -1207161            | 57944456             | 0.999   |
| **Plant 2**           |                     |                     |                     |                     |                     |                     |         |
| Seeds                 | -1724315            | 49378866            | -2013132            | 44200              | -434851             | 16498736             | 0.998   |
| Stem                  | 24919620            | 47341222            | -951969             | 9170               | 0                    | 0                    | 0.997   |
| Inflorescence         | 9892958             | 64205857            | -1874107            | 27374              | -118499             | 0                    | 0.997   |
| Mix                   | 11993967            | 54549929            | -1512976            | 20971              | -84248              | 0                    | 0.998   |
| **Plant 3**           |                     |                     |                     |                     |                     |                     |         |
| Seeds                 | 1926585             | 4978938             | -154306             | 2213               | -10163              | 0                    | 0.996   |
| Stem                  | 1931428             | 81029974            | -3339524            | 75105              | -766148             | 31319502             | 0.998   |
| Inflorescence         | 38210227            | 43368853            | -817147             | 7091               | 0                    | 0                    | 0.996   |
| Mix                   | 33409601            | 47654077            | -947318             | 8420               | 0                    | 0                    | 0.997   |

According to the results of measurements Figure 2 shows a comparison of the sorption isotherms for the studied plants by mixtures and seeds, respectively. The sizes of the studied seeds and their belonging to different groups according to morphological characteristics are analyzed. The dependences of achieving equilibrium humidity on the composition of the sample are revealed.
Figure 2. Change in the equilibrium moisture of the samples depending on the relative humidity of the air for mixtures of two plants with seeds at a temperature of 20 °C.

Based on the dependence shown in Figure 2, it can be concluded that the equilibrium moisture content of seeds is achieved at lower relative humidity values compared to the mixture. These data must be taken into account when developing plant operating modes and technological sheets for drying seeds together with other plant components.

2.3. Parameters of the capillary-vesicular structure of the drying object

Using sorption isotherms, it is possible to evaluate the state of moisture in the material and the form of moisture that must be removed during the drying process to achieve the desired final moisture content. The value of sorption isotherms is also important from the point of view of technology, the choice of drying mode and storage of dried material. The existing theory of phenomena of sorption and desorption does not have a rigorous analytical description of isotherms and general equations for them, which is due primarily to various forms of moisture contact with the material [7].

A significant role in the regulation of plant water metabolism is played by water-holding forces, which are mainly determined by the content of osmotic active substances in the cells and the ratio of macro- and microcapillaries in the drying object. The water retention capacity of cells depends on the growing conditions of the plants. In this case, the conditions of mineral nutrition of plants have a great influence. Under optimal conditions, the water-holding ability increases, the water loss in 30 minutes is only 4-6% of the initial value. To calculate the specific surface of the sorbents, which are characterized by S-shaped sorption isotherms, the BET equation was used [8]:

\[
\frac{\varphi}{x(1-\varphi)} = \frac{1}{x_m C} + \frac{C-1}{x_m C} \varphi
\]

where \( \varphi \) – RH of the air, %;
\( x \) – is the amount of sorbed substance, g / g
\( x_m \) – is the amount of substance in a continuous mono-molecular layer, g / g
\( C \) is a constant representing the ratio of the lifetime of molecules in the first layer and fluid, respectively;

\[
A_m = 1.091 \left( \frac{M}{\rho N_A^2} \right)^{2} \cdot 10^{16}
\]

\[
W_0 = \frac{x_{max}}{\rho}
\]

\[
S_{sp} = \frac{x_m}{M} \cdot N_A \cdot A_m \cdot 10^{-20}
\]

Where \( W_0 \) - total pore volume, cm³/g;
\( S_{sp} \) - surface area, m²/g

The results obtained are summarized in table 2. In this case, the seeds of the plant 1 from group II are characterized by a diverse disk-shaped symmetric or asymmetric form. The width of such seeds is usually at least twice as thick (1.2–1.6 mm long, 1–1.4 mm wide, 0.3–0.4 mm thick).
The seeds of plant 2 (fireweed) and plants 3 (labioecious) belong to group VII A (ribbed seeds). The irregular shape of the seeds of this group is distinguished by the obligatory presence of corners and ribs. They have a very complex structure, can have all kinds of spikes, teeth, bristles, hairs, both separately and in the form of a ball, the surface of the seeds resembles paper or soft skin.

The number of seeds in inflorescences is often very large and the seeds are accordingly small and due to the mutual pressure they are irregularly faceted. But each of the considered plants of one group has its own distinctive features. The seeds of the group of plants are cypress (0.3–5 mm long, 0.2–1.5 mm wide and thick) have a thickening and form a square or triangle in cross section. The seeds of the labioecious group (1.5–2.4 mm long, 0.9–1.4 mm wide, 0.7–1 mm thick) are characterized by a high content of essential oils. The obtained values for rice are determined on the basis of sorption isotherms from [3].

Table 2. Parameters of the capillary-vesicular structure of plants.

|       | $S_{sp}$, ($m^2/g$) | $W_0$, ($cm^3/g$) |
|-------|---------------------|-------------------|
| Plant 1 |                     |                   |
| seed   | 144.6               | 0.180             |
| stem   | 193.0               | 0.308             |
| inflorescence | 242.1  | 0.329             |
| Plant 2 |                     |                   |
| seed   | 160.7               | 0.157             |
| stem   | 256.4               | 0.281             |
| inflorescence | 246.9  | 0.336             |
| mix    | 221.7               | 0.224             |
| Plant 3 |                     |                   |
| seed   | 16.8                | 0.015             |
| stem   | 220.5               | 0.249             |
| inflorescence | 266.6  | 0.323             |
| mix    | 229.9               | 0.279             |
| Rise [3] | 192.46             | 0.227             |
| Leonurus [4] | 131               | 0.082             |
| Tussilago farfara [4] | 95.5              | 0.276             |

3. Options for circuit solutions for plants for drying wild-growing grass

Increasing the production of wild grass seeds is difficult, as it is necessary to dry the seeds together with inflorescences and stems. To obtain seeds, it is necessary to dry the seed box, and upon receipt of the product on the field, it is impossible to separate it from the plant. In devices for preparing seeds of wild grasses, it is necessary to provide both devices for preventing the removal of seeds, and to prevent their waterlogging in the lower layers of the structure. When using similar installations for the preparation of agricultural feed, active ventilation systems working on heated air are used.

The need to reduce energy consumption associated with the development of recommendations on optimal work settings air, the choice of methods of heating the air in the heater, reducing the flow of drying agent.

An analysis of the existing solutions of drying plants showed that none of them satisfies the requirements.

When choosing and creating a drying installation, it is important to consider a number of factors:
- thermal load of the apparatus;
- process temperature conditions;
- drying conditions;
- physico-mechanical parameters of the working environment;
• nature of hydraulic connections;
• type of material and its corrosion resistance;
• compactness and simplicity of the device;
• location of the apparatus;
• mutual direction of movement of working media;
• the ability to clean the surface from contamination;
• metal consumption per unit of transferred heat;
• other technical and economic indicators;

For drying the grass, convective type chambers are most suitable, using heated air as a heat carrier, changing the temperature of which can significantly increase productivity.

The parameters of the drying agent must ensure drying without moisture precipitation based on calculations.

The design basis for the convective drying installation was based on the Alvan Blanch mobile dryer, which is designed for grain and the model of the dryer shown in figure 3.

The drying process is as follows: damp grass is poured into the feed hopper from above, the dampers distribute it along the width of the sieve in an even layer, its thickness is regulated depending on the moisture content of the grain. Heated air enters the drying chamber, blowing the product from all sides. In the process of drying under the influence of vibrations when moving the dryer across the field, the seeds through a sieve fall on a pallet located under it.

![Figure 3. Design of a mobile convective drying unit.1-heater; 2-flue; 3-centrifugal fan; 4-loading hopper; 5-metal cover; 6-sieve; 7 – seed tray; 8 – support wheels; 9 – traction device.](image)

Due to the presence of wheels in the drying unit, the drying process begins immediately after collecting the grass, directly on the agricultural field. The heat of the exhaust gases of the car is used to heat the air that goes into the drying chamber, if the weather during the days of collection of seed grass is characterized by high humidity and low temperature. But when working indoors, the drying chamber uses air heated in a heater.

As a stationary solution, the best option for solving this problem is to offer a bunker drying unit for active ventilation.

This installation provides soft thermal drying, preservation of the biological viability of the grain, in-line processing of materials in one pass to condition, regardless of the initial moisture content of the material. The essence of the design (figure 4) is as follows: the hopper consists of a cylindrical metal casing, a metal cone-shaped removable lid, which is fastened using a bolted connection, an opening hatch for loading grass. The supply system of the drying agent consists of a heat exchanger for heating air, a supercharger, which is selected as a fan for supplying air to the duct, the elements of which are connected by flange connections. Through the air ducts, air is directed into a perforated pipe, which distributes air throughout the bunker. A grate is installed in the lower part of the cylindrical structure, which delays the drying product, preventing the grass from spilling out into the seed tray. Passing through the grate, the seeds fall into a sieve, which allows us to separate the drying product from the unwanted grass of small sizes. After passing through the holes in the sieve, the seeds are poured into the tank to collect the finished dried material.
Freshly picked grass is loaded into a removable roof, then it fills the completely cylindrical body of the drying unit, lowering it to a grate, the diameter of which coincides with the diameter of the cylindrical body. After filling the hopper, the roof is put on and tightly bolted to the housing. The discharge and heating equipment is turned on. The heat exchanger supplies heated air to the fan, and from there through the circular ducts, the elements of which are connected by means of flange connections, the air is directed up to the grill. Steel ducts have been selected, as they are distinguished by good strength and durability. After passing through the grill, the duct connects to the perforated pipe, which is located along the entire height of the cylindrical body. Heated air fills the entire space of the pipe, seeping through the holes, it fills the entire volume of the hopper. This is necessary in order to ensure the greatest uniformity of air distribution over the entire volume of the body of the cylindrical body of the drying installation. The dried grass lingers on the grate, and the seeds fall from the grass and pass through the holes in the sieve located at the base of the cylindrical body and fall into the seed tank. Then, after drying, the heat exchanger and fan are turned off, and the spent grass is discharged from the dryer by removing the grate and sieve through the bottom plate.

4. Conclusions
The analysis of the experimental dependences data of the of the equilibrium sorption moisture content isotherms (Figure 1) for the relative air humidity from 0 to 90% for seeds, inflorescences and stems and mixtures of three species of wild herb plants at 20 °C. The sorption curves for seeds of plant 1 and 2 are close in their values, and the curves of the mixture of the components of plant 2 and plant 3 are in the same region, while the region of values of the sorption curve of plant 3 seeds is located much lower, despite the morphologically similar plant characteristics.

For example, for a relative air humidity of 50%, the values of the equilibrium moisture content of seeds of plants 1, 3 in relation to plant 2 are less by 3% and 88%, respectively, for 90% air humidity - by 14% and 90.6%.

The equilibrium moisture content of mixtures of plant 3 at 50% and at 90% air humidity is 3% and 14% higher relative to plant 2.

To identify the reasons for the difference in the value of the equilibrium moisture content and thinning the calculations of the drying process, the parameters of the capillary-porous structure of the drying object were analyzed using the BET equation. For mixtures of plants 2 and 3, the total pore volume and specific surface area of solid matter differ by 3.7% and 2.5% with respect to plant 2, respectively. For seeds of plants 1, 3 in relation to plant 2, the total pore volume differs by 10% and 89%, the specific surface area of solid matter differs by 14.6% and 90%, respectively.

The sizes of the studied seeds and their belonging to different groups according to morphological characteristics were analyzed. Analysis of the capillary-porous structure and sorption properties of the studied plants showed that the duration of the drying process is influenced not so much by the size of the seeds and the belonging of the plant to different groups according to morphological characteristics, but by the content of similar nutrients and essential oils inside the drying objects.
On the basis of technical information from open sources on the designs of convective drying units, new circuit solutions for drying devices were proposed, which ensure uniform drying of the material and preservation of the biological properties of the product with a relative simplicity of the device for individual farms.

References
[1] Anisimova L V 1997 Analysis of isotherms of sorption of water vapor by buckwheat and millet grain News of universities. Food technology. chapter 6 pp 49-51
[2] Rudobashita S P, Zueva G A, Zuev N A 2015 Hygroscopic properties of seeds Chemistry and Chemical Technology Vol. 58 chapter 1 pp 68-71
[3] Togrul H; Arslan N 2006 Moisture Sorption Behaviour and Thermodynamic Characteristics of Rice stored in a Chamber under Controlled Humidity Biosystems Engineering Vol. 95 chapter 2 pp. 181–195
[4] Nazarov F, Safarov J E, Dadaev G T 2017 The study of the capillary-porous structure of medicinal plants. Tr. XXVI - scientific and technical. conf. young scientists, undergraduates and undergraduate students. Tashkent. pp. 471-472
[5] Soysal Y, Oztekin S 2000 Comparison of Seven Equilibrium Moisture Content Equations for some Medicinal and Aromatic Plants Postharvest Technology Vol. 78 chapter 1 pp 57-63
[6] Brouver V, Shtelin A 2010 Handbook of seed science of agricultural, forest and ornamental crops with a key for determining the most important seeds (Moscow: KMK Scientific Publications Partnership) p 694
[7] Akulich P V 2010 Calculations of drying and heat exchangers. Belarusian Science, p. 443
[8] Bahammou Y, Moussaoui H, Lamsyehe H, Tagnamas Z, Khouila M, Ouabou R, Lamharrar A, Idlimam A 2020 Water sorption isotherms and drying characteristics of rupturewort (Herniaria hirsuta) during a convective solar drying for a better conservation Solar Energy Vol 201 pp 916-926
[9] Li X Z , Simpson W R , Songa M L, Bao G S , Niu X L, Zhang H Z H , Xua H F, Liu X.,Li Y L , Li C J 2020 Effects of seed moisture content and Epichloe endophyte on germination and physiology of Achatherum inebrians South African Journal of Botany https://doi.org/10.1016/j.sajb.2020.03.022