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Current State of Automation Process of Convection Drying of Bulk Materials

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Abstract:

The work reflects the current state of the theory and practice of monitoring and managing the complex heat and mass transfer process of convective drying of bulk materials of plant origin. Obtaining an autonomous dynamic model of convective drying of a dense layer of granular materials using the example of corn grain. A method for modeling the convective drying process based on the Sabah kinetic dependence is presented.

Keywords: convective drying of granular materials, convective drying in a rarefied atmosphere, Sabah kinetic function, simulation modeling.

Automation of control of drying processes of bulk materials in food processing industries is one of the main directions in saving energy, raw materials and supplies, in the use of agricultural products and environmental protection. In the context of the current energy and nutrition crisis, reducing the cost of storing bulk materials by drying is extremely important for the economy of any country. The problem of storage and disposal of bulk materials faces all countries, but it is especially acute for countries producing bulk materials that are poor in energy resources, such as our country.

For high-quality storage of grain, it is necessary that its moisture content be below a certain limit. The natural achievement of the required grain moisture is associated with losses, which determines two main reasons for artificial drying: dependence on weather conditions and the specifics of the processes associated with grain ripening.

Drying processes are characterized by high heat capacity. According to various drying analysts, today humanity consumes about 10-15% of the energy needed for industry and agriculture. The wide range of application of the process and its relatively low efficiency (25...50%) determine the need for a scientifically based approach in the construction and operation of drying plants.

Various drying methods are known and practiced: convective, contact, infrared rays, microwaves, vacuum, ultrasound or various combinations, such as, for example, convective-pulse-vacuum-microwave. Each drying method has its own rationale and scope, but an acceptable alternative to convective drying of large quantities of grain has not yet been found [1].

The specificity of convective drying is the transfer of heat from the drying agent to the product and the removal of steam. High temperatures and drying agent speeds intensify the process, but this requires a large amount of heat, which, in turn, can increase production costs by more than 10%. The use of alternative drying methods improves energy performance, but turns out to be inapplicable for large grain masses. In the last century, scientists around the world have studied and analyzed drying, and a strong theoretical basis has been established for convective drying. Although achieved, the drying process is dependent on many factors, making it somewhat unique and difficult to predict.

Empirical study of the drying process requires the collection of data under natural conditions and the creation of complex and expensive laboratory setups. These activities are hampered by production and weather conditions, the exact moment of their implementation, generalization of the results obtained, etc.

The analysis shows that convective drying at low temperatures and low speeds of the drying agent significantly reduces energy costs, which in turn is a strategy of leading grain-producing countries. It should be concluded that it is necessary to use an integrated approach when designing and studying behavioral models that describe all processes.

As a result of the analysis of the process and drying methods, it can be summarized that grain drying is a necessary, but complex, multifactor and energy-intensive process, and grain dryers have high relative and total energy consumption; the use of low-temperature convective drying in a rarefied atmosphere can lead to a reduction in energy intensity and relative costs; to reduce overall heat losses, energy recovery from the drying agent can be used to heat the incoming grain; There are no published results of laboratory studies of low-temperature convective drying of grain in a thick layer; There are no models to describe the dynamic drying process in a thick layer [2,3].

Autonomous dynamic model of convective drying of bulk materials

The compiled autonomous dynamic model of the drying process is compared through parallel modeling on experimental data and an empirical calculation model.

Achieving accurate model results in a particular experiment and Sabah kinetic dependence modeling method does not imply applicability to other processes. There is evidence in the literature that the Sabah thin-layer model is inaccurate at low dryer speeds, while there is evidence of its use with active ventilation. In connection with the above, the following was developed and presented:

1. Simulation of thick bed corn drying in a continuous experiment.

The experimental setup (fig. 1) consists of a drying pipe with a height of 2 *m* and diameter 0.3 m. Air heated from 8 °C to 32 °C filters grain in the pipe during the day, and its consumption is 5.69 $m^3/(m^3 \cdot \text{min})$ .Experimental and model (using the Thompson model) results were obtained.

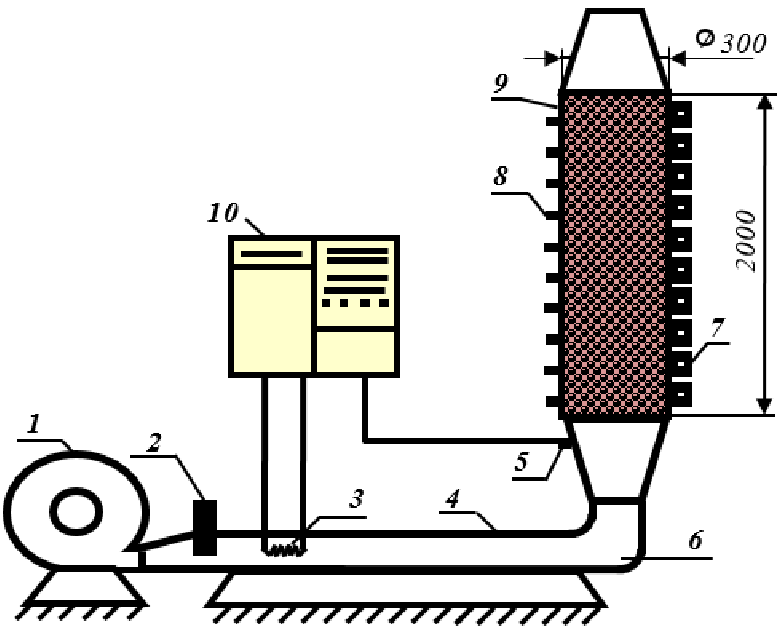

Fig. 1. Diagram of the experimental setup: 1 - fan, 2 - flow regulator, 3 - heater, 4 - tube, 5 - thermometer, 6 - base, 7 - sampling holes, 8 - thermometers, 9 - drying tube, 10 - thermostat.

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Based on the experimental data, a simulation model with a thin-layer Sabah kinetic function was compiled (fig. 2).

Experimental and model functions are compared with those of the present simulation.

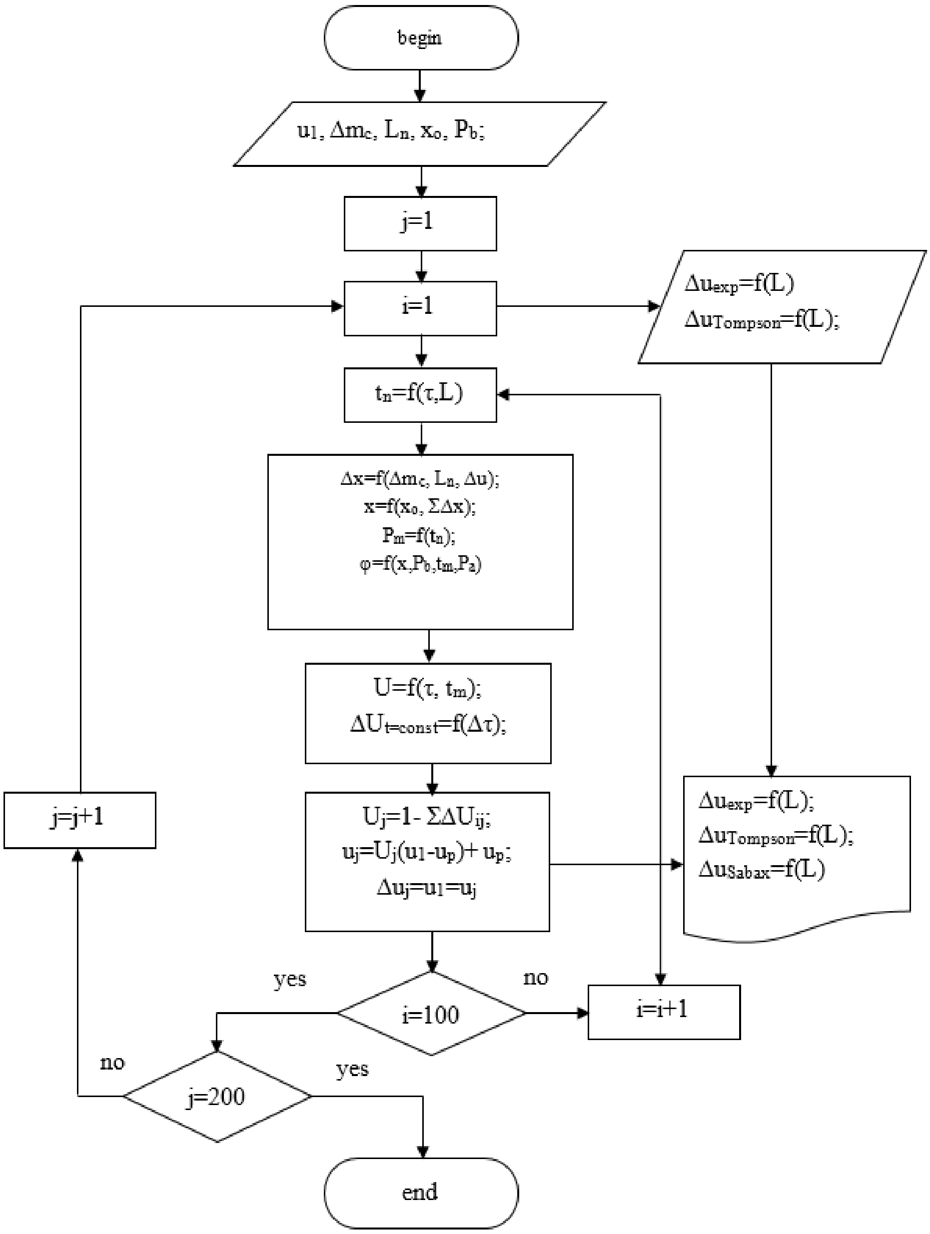

Fig. 2. Algorithm for model calculations with the Sabah kinetic function.

2. Simulation of a drying experiment with alternative kinetic dependence.

Parallel simulation of a drying experiment with two drying models (fig. 2) provides an opportunity for comparison. Simulations with various factors (temperature, speed, relative humidity, etc.) are necessary to prove the validity of the model based on the Sabah kinetic dependence [4].

Preliminary experimental studies

In accordance with the above and the need to clarify the stages of constructing a drying system and conducting tests, preliminary experiments were carried out.

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Study of the effect of rarefaction during convective drying and cooling

The purpose of this study is to obtain quantitative data on drying and cooling at different atmospheric pressures around the product. In accordance with the objectives of this study, an experimental setup was built (fig. 3).

The product placed in a vacuum chamber is filtered with heated air under reduced pressure. Time t, s is measured; temperature t_{env}, *°C*, relative humidity φ_{env},*%* and pressure p_{atm}, *kPa* incoming air; heated air temperature t_{inp}, *°C;* extract air temperature t_{out}, *°C;* residual pressure in the chamber p_{vac}, *kPa;* change in product mass Δm_{prod}, *gr;* initial and final moisture content of the product and heat loss in the system.

The object of study is corn grain of the "Andijan-2" variety with initial moisture content $w_{beg} = 33\%$. Four samples weighing 70 g were dried at negative pressure: 0 *kPa*; 20 *kPa*; 40 *kPa* and 50 *kPa*. The inlet air temperature is maintained t_{inp} = 60 °C and the flow rate is read from a previously measured and fitted curve $Q_{inp} = f(p_{inp})$, while maintaining a speed of 0.1 m/s. Three samples were cooled at initial humidity w=10% at negative pressure: 0 *kPa*; 25 *kPa*; 50 *kPa* and four samples with initial humidity w=14% under pressure: 0 *kPa*; 20 *kPa*; 40 *kPa* and 50 *kPa*. The temperature of the cooling air is maintained at 14...16 °C, and its humidity $\varphi = 65\%$. The obtained data is interpolated and displayed in a single coordinate system for comparison.

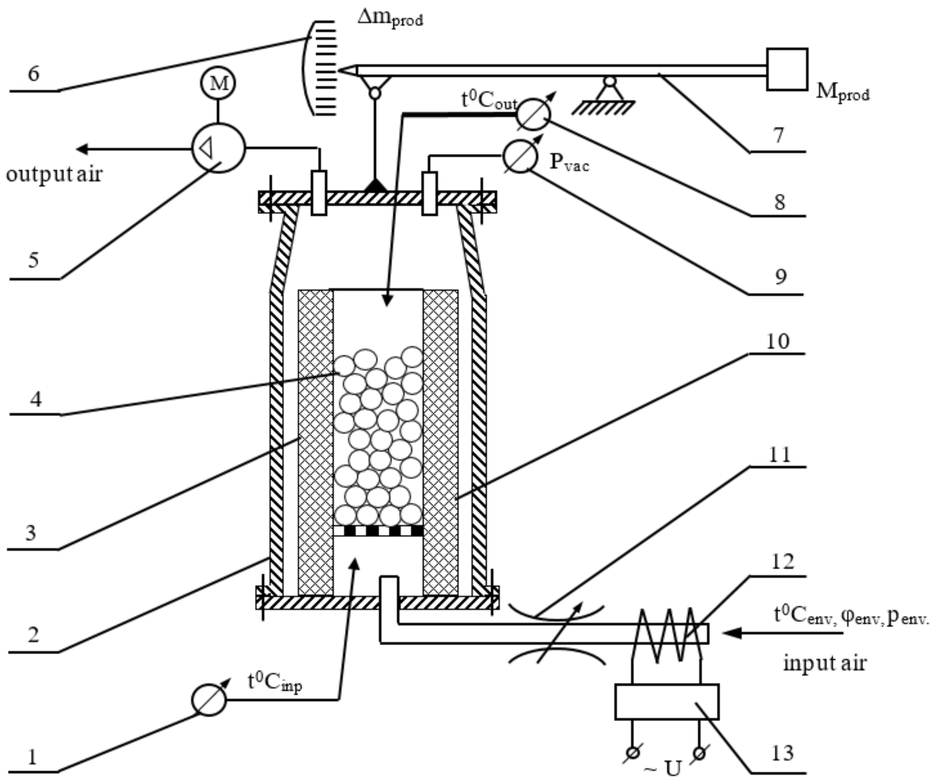

Fig. 3. Laboratory equipment for drying and cooling in a rarefied atmosphere: 1 and 8 – thermometer; 2 – vacuum chamber; 3 – heat-insulated container; 4 – grain; 5 – vacuum pump; 6 – scale; 7 - scales; 9 – pressure gauge; 10 – mesh; eleven -throttle; 12 – heater; 13 - thyristor regulator.

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Study of water vapor condensation

Condensation of water vapor from the drying agent is accompanied by the release of heat and is a fact of thick-layer drying. A device was designed (fig. 4), with which the following is studied:

- Condensation of water vapor under conditions: air temperature $t_{air} = 60^0 C$; air speed $v_{air} = 0{,}2; 0{,}8; 3{,}0$ m/s; relative humidity $\varphi = 100\%$; ambient and product temperature $t_{env} = 16^0 C$;
- Linear dimensions of the condensation area and its speed under the above conditions;
- Sorption of grain mass (together with water from wetting);
- Hydraulic resistance of a thick layer of product during filtration at different air velocities.

Study of some sorption properties of corn grain

This experiment is a continuation of the study "condensation of water vapor" and concerns the process of moisture sorption by corn grains at a temperature of the "grain-moisture" system from 20 °C to 60 °C; air humidity 100 % and process duration 2...20 minutes.

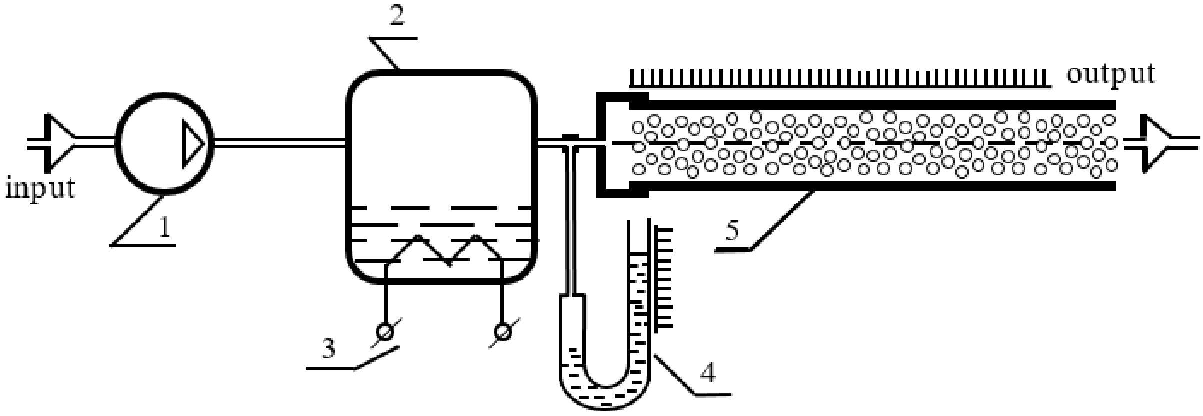

Fig. 4. Laboratory equipment for studying the condensation of water vapor: 1- compressor; 2- steam generator; 3- heater; 4- "U" - pressure gauge; 5 - glass tube with product.

Laboratory equipment for studying the condensation of water vapor. The objects of the experiments are three batches: the first early variety of the 2017 harvest; the second is a mid-early variety, harvested in 2018, and the third is a mid-early variety, harvested in 2019. The purpose of the three batches is to establish the possible difference in the sorption properties of new and old grain, etc. in case of differences in varieties. The results of the experiment are reflected in tabular and graphical form. The obtained time decay values are approximated and interpolated in Matlab using the least squares method [5].

The compiled dynamic drying model is adequate; the need for complete modeling of the "heating-drying-cooling" process is substantiated; the possibility of modeling the process through heat and mass balance is substantiated; the need to create complex models that include all processes of heat and mass transfer is substantiated; it is necessary to establish acceptable limits of applicability of simulation models.

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