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IMPROVEMENTS OF THE CONTROL SYSTEM FOR THE TECHNOLOGICAL PROCESS OF DRYING BULK MATERIALS

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Annotation: *The issues of convective drying of bulk materials as objects of monitoring, control and advanced management are presented based on the results of simulation modeling of a complex heat and mass transfer process, taking into account the drying kinetics. As a result of the work of a number of them, in the last few decades neat hypotheses were formed about moisture migration in and around dried materials, which led to the creation of accurate mathematical models of drying behavior, with successfully applied in a wide range of fields. The reasons for this are the dynamics of processes in the drying tube, inertia during heating and temperature measurement, the inaccuracy of the selected model in the operating temperature range and the assumption of the isobaric nature of the process. The most important result of the simulation model created in this way is excellent coordination between the individual computing units, which is indicated by the normal speed and accuracy of the computing process.*

Keywords: *bulk materials, convective drying, mathematical and simulation modeling, criteria for controlling the process of dehydration of bulk materials.*

Annotatsiya: *Quritish kinetikasini hisobga olgan holda murakkab issiqlik va massa almashinish jarayonini imitatsion modellashtirish natijalari asosida monitoring, nazorat va takomillashtirilgan boshqarish obyektlari sifatida sochiluvchan materiallarni konvektiv quritish masalalari bayon etilgan. Shu bilan bir qatorda so'nggi bir necha o'n yilliklarda quritilgan materiallar ichida va uning atrofida namlikni ko'chishi haqida aniq farazlar shakllantirilgan, bu quritish harakatining aniq matematik modellarini yaratishga va keng doirada muvaffaqiyat bilan qo'llanishga olib keldi. Quritish quvuridagi jarayonlarning dinamikasi, isitish va haroratni o'lchash paytida inertsiya, ish harorati oralig'ida tanlangan modelning noto'g'riligi va jarayonning izobarik xususiyatini taxmin qilish mumkin bo'ladi. Shu tarzda yaratilgan simulyatsiya modelining eng muhim natijasi alohida hisoblash birliklari o'rtasidagi mukammal muvofiqlashtirishdir, bu hisoblash jarayonining normal tezligi va aniqligi bilan ko'rsatilgan.*

Tayanch so'zlar: *sochiluvchan materiallar, konvektiv quritish, matematik va imitatsion modellashtirish, sochiluvchan materiallarni suvsizlantirish jarayonini boshqarish mezonlari.*

Аннотация: *Излагаются вопросы конвективной сушки сыпучих материалов как объектов мониторинга, контроля и усовершенствованного управления на основе результатов имитационного моделирования сложного тепло– и массообменного процесса с учетом кинетики сушки. В результате анализ работ за последние несколько десятилетий были сформированы четкие гипотезы о миграции влаги внутри и вокруг высушенных материалов, что привело к созданию точных математических моделей поведения исследуемых материалов при сушке путем исследования динамика процессов в сушильной трубе, инерционность при нагреве и измерении температуры, неточность выбранной модели в рабочем диапазоне температур и предположение об изобарическом характере процесса. Важнейшим результатом созданной таким образом имитационной модели является отличное согласование между отдельными вычислительными блоками, показателем которого является нормальная скорость и точность вычислительного процесса.*

Ключевые слова: *сыпучие материалы, конвективная сушка, математическое и имитационное моделирование, критерии управления процессом обезвоживания сыпучих материалов.*

Introduction

Improvements of the control system for the technological process of drying bulk materials

Modeling of drying processes is an integral part of drying plant and process design, research and training. Different approaches and a variety of model dependencies are possible and applied, but empirically derived thin layer equations are some of the most accurate and most frequently applied. Unfortunately, as noted in, there are no universal models that describe the full complex of natural heat and mass exchange processes during convective grain drying. This circumstance necessitates partial modeling in a previously known range of mode parameters. Some authors are of the opinion that it is necessary to create complex models that include all elementary processes or to simplify and converge the known dependencies [1,2].

Empirical study of drying processes is associated with the expensive and complex technique, duration of the experiments, seasonality or insurmountable difficulties for conducting them. With the development of computational techniques and the availability of a rich base of analytical and experimental data, simulation modeling of drying has become an indispensable tool for researchers, designers and technologists [3].

Research shows and proves that the parameters of temperature and speed of the drying agent affect the energy consumption in the process, as well as the quality of the product. The drying process takes a relatively long time, so monitoring and changing them over a given period of time has a positive effect on the desired results, i.e. reducing the energy resources used to obtain a quality product. The conducted studies show a significant reduction in energy consumption for drying in a periodically controlled process compared to drying at constant values of the drying agent. Limits or acceptable values of drying agent are defined to maintain the nutritional value and quality of dried products [4,5]. The relationship between the parameters of the drying agent in terms of energy intensity and the duration of the process was determined. This is usually an inverse relationship - the shortest drying time requires more energy. Based on this, a comprehensive criterion for controlling the drying process is established using weighting coefficients that can be adjusted based on the goals: the least amount of energy consumed, the shortest process duration or the best product quality [6,7].

Regardless of the achieved results, it should be noted that when modeling the drying of grain in a thick layer, the elementary heat and mass exchange processes are in a complex relationship and, if relatively accurate thin-layer drying models are applied, ambiguous results are achieved. Along with the general questions in stepwise modeling (such as the discretization of intervals, for example), questions related to the specificity of drying quantities and processes arise in drying models [8,9].

Research Methods and the Received Results

Modeling the technological process of convective drying of bulk materials

Research in the field of grain drying and storage has a solid theoretical basis, and with today's computer technology it is possible to create models that save time and money, facilitate the analysis and synthesis of processes that improve machine control devices. The derived models are not universal and each specific situation must be approached individually [10].

There are different approaches to determining drying performance. In this work, the well-established method of layer-by-layer modeling using balance equations was chosen, consisting of the following (fig. 1):

- The drying agent filters the layer of grain, heating it and removing moisture from it;
- It is assumed that for a thin (single-grain) layer Δz the mode parameters remain constant, i.e.
- For the layer, Δz a certain kinetic function of the form is calculated: $u = f(\tau)$;
- All drying quantities involved in the balance equations are recalculated;
- To facilitate modeling, the pressure of the drying agent, mass flow rates of grain and air are assumed to be constant, heat exchange with the environment, etc. is not taken into account.

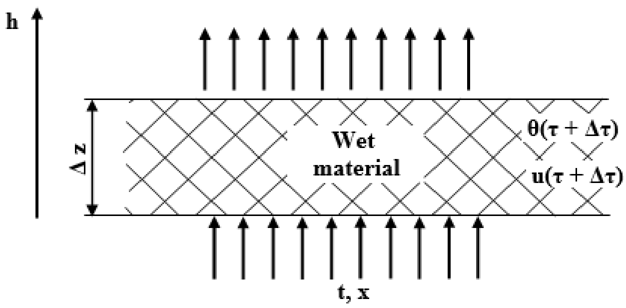

Fig. 1. ***Drying the material in a layer of thickness h at constant parameters in the layer*** Δz **.**

The empirical Sabah kinetic dependence was chosen as the basis for the work, which gives accurate results for grain models and is recommended for the temperature range from 25 °C to 75 °C, which corresponds to low-temperature drying. The dependence is of an empirical nature, which indicates that in the specified temperature range it accurately describes all real natural processes [11,12].

The dependency looks like:

$$\begin{cases} U = e^{(-K\cdot\tau^n)} \\ K = e^{(-z\cdot\tau^y)} \\ y = 0{,}125 - 2{,}197\cdot 10^{-3}\cdot U + (\frac{9}{5}\cdot t_{av} + 32)\cdot(2{,}3\cdot 10^{-5}\cdot U - 5{,}8\cdot 10^{-5}) \\ z = (6{,}0142 + 1{,}453\cdot 10^{-4}\cdot U)^{0,5} - (\frac{9}{5}\cdot t_{av} + 32)\cdot(3{,}353\cdot 10^{-4} + 3\cdot 10^{-8}\cdot U^2)^{0,5} \\ n = 0{,}664 \end{cases} \quad (1)$$

Where t_{av} – average air temperature, °C; t – time, h ; $U = \frac{(u - u_{eq})}{(u_1 - u_{eq})}$ – generalized humidity, in which u – current, u_1 – initial and u_{eq} – equilibrium grain moisture content.

Matlab and Simulink were chosen for the work, since its core contains the powerful Maple mathematical apparatus; Simulink offers good capabilities for fine-tuning, repeated and fast model reproduction, excellent visualization, and is widely used for scientific calculations and simulations.

The following are theoretically developed and presented here:

- Definition of the temperature field as a continuous function $t(\tau, L)$;
- Calculation of total humidity U (Sabah kinetic function);
- Calculation of current humidity;
- The amount of moisture released;
- Desiccant Humidity;
- Relative and equilibrium air humidity;
- Comparison of model and experimental data.

The construction of the simulation model was carried out in stages, the meaning of which lies primarily in functionality, and subsequently in accuracy, achieved through analysis and adjustment of the model. An illustration of the calculation process in the final, III version of the model and the two previous ones (for reference) is presented in fig. 2, where the generalized humidity function U consists of isothermal sections corresponding to the corresponding stationary drying process.

Calculations were carried out according to the algorithm in Fig. 3.

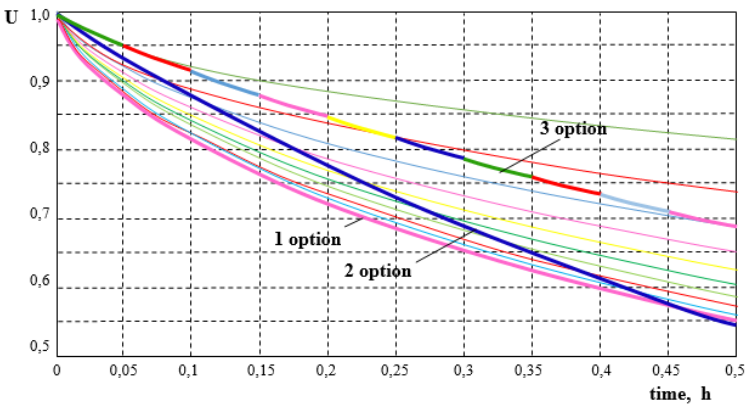

Fig. 2. ***Function U three variants for the level 5 sm from the beginning of the drying pipe.***

Algorithm for calculating the mathematical model of convective drying of bulk materials

The model compiled in this way, assessed as accurate, has one significant drawback: the need to know the temperature field of the drying agent in time and space. Preliminary definition of the drying chamber as a thermodynamic system allows one to draw up energy balance equations in which at each moment of time a certain power enters and leaves the system (temperatures can be calculated). After some simplification, the heat flow balance equation has the form:

$$\dot{Q}_{enter} = \dot{Q}_{rem} + \dot{Q}_{mat} + \dot{Q}_{env} + \dot{Q}_{exit} \qquad (2)$$

where $\dot{Q}_{enter}$ - is the power with the incoming desiccant , $\dot{Q}_{rem}$ - is the power to remove moisture from the material, $\dot{Q}_{mat}$ - is the thermal power of the material, $\dot{Q}_{env}$ - is the heat exchange with the environment, and $\dot{Q}_{exit}$ - this is the power with the output of the desiccant. Power consumption is represented by the enthalpy of the drying agent:

$$h_{(1+x)} = 1{,}006 \cdot t_{exit} + x \cdot (2500 + 1{,}86 \cdot t_{exit}), \quad kJ/(1+x)\,kg \qquad (3)$$

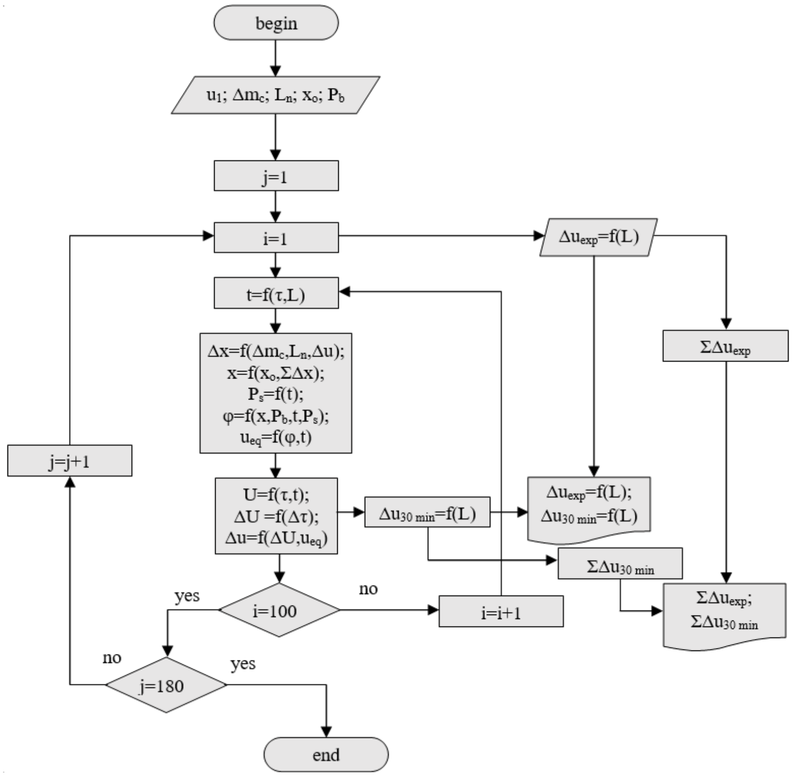

Fig. 3. ***Algorithm for calculating the simulation model.***

The heating power of the material is obtained from:

$$\dot{Q}_{mat} = \bar{c}_{mat} \cdot \Delta\bar{\theta}_{mat} \cdot \frac{\Delta m}{\Delta \tau}, W, \quad (4)$$

where $\bar{c}_{mat}$ - is the average specific heat capacity of the material for the current time interval $\Delta\tau_i$, and $\Delta\bar{\theta}_{mat}$ – temperature difference material for the same time.

Ability to release moisture from the material:

$$\dot{Q}_{rem} = r \cdot \dot{m} + E \cdot \dot{m} = r \cdot \dot{m} + \dot{m} \cdot R_n \cdot T_{cur} \cdot \ln\varphi, \quad (5)$$

where φ is the equilibrium relative humidity of the air for the current moisture content, T_{cur} is the current temperature calculated using the equilibrium model of Chang and P_{fost}.

Conclusion

This work allows us to study and simulate the process of cleaning large grains after heat losses in the air injection system. The effect of using heat losses from the air injection system to reduce overall energy consumption by 2% has been proven. It has been established that energy consumption when sucking in a drying agent is 10% lower compared to the injection principle, and the effect increases when the grain is cooled at the end of the drying process. The resulting simulation models of the drying process allow errors of less than 3% in the presence of the temperature field of the drying agent (model version III) and less than 10% in the autonomous (through heat and mass balance) model. The effectiveness of using combined drying principles in new designs of drying installations has been proven to reduce specific energy costs: up to 30% from thermal insulation, up to 50% from heat recovery, up to 10% when using a drying agent. The resulting simulation models can be successfully used in research, construction, training and drying process management

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