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RESULTS OF VACUUM-ATMOSPHERIC DRYING OF LARGE-DISPERSED FOOD MATERIALS

Abstract. In the given article the results of researches of heat and mass transfer for vacuum-atmospheric drying of large-dispersed food materials as crushed tubers of topinambour, potato, apple and peas are considered. Optimal regimes of vacuum-atmospheric drying of the given materials are developed. Results of vacuum and atmospheric drying of large-dispersed materials are studied. Depending on height of layer of drying material, pressure of medium into vacuum camera, temperature level of drying the numerical values of coefficients of heat and mass transfer and equations of heat and diffusion Nusselt criterions are received. Comparison on adequacy to real conditions is conducted in order to check the criterion equations. Meanings of experimental and calculated data of heat and mass transfer coefficients have satisfied convergence.

Keywords: vacuum, drying, large-dispersed, method, heat, mass, transfer, atmospheric.

Introduction

Currently, advanced areas for development of technology of food drying are: study of heat and mass transfer in drying, development and improvement of existing designs of drying plants and optimization of technological parameters of drying [1].

The analysis of results of modern researches shows that the most preferable method of dehydration of large-dispersed food materials is vacuum sublimation from the point of view of maximum preservation of biochemical composition and useful properties of dried material. However, along with high quality, finished product dried in a vacuum freeze dryer has an increased cost associated with high energy consumption for implementation of drying process.

Experimental methods

Development of dryers for large-dispersed food materials which implement a method of vacuum-atmospheric drying is assigned to improve efficiency and reduce energy consumption of dryers.

Vacuum-atmospheric drying includes combination of separate processes of vacuum and atmospheric drying. Combination of the processes is carried out in such a way as to ensure a uniform nature of drying process of studied material, i.e. implemented method of vacuum-atmospheric drying includes vacuum drying the material to certain intermediate moisture content and its atmospheric final drying to final moisture content. The processes of vacuum and atmospheric dehydration in drying plant are carried out simultaneously by including a heat pump in it scheme. In this case, the drying modes are selected by such way that identical drying curves should be peculiar to dried material at the moment of its transition from vacuum to atmospheric dehydration.

The developed experimental vacuum-atmospheric dryer includes the following units [2]: unit of vacuum drying, in which the process of vacuum dehydration from initial moisture content of the material to intermediate one is conducted; unit of atmospheric drying - for drying the material from intermediate

humidity to the final one; heat pump [3-5] unit on the basis of a single-stage refrigeration machine designed for heating and cooling the elements of drying plant and reduce the load on a vacuum pump.

Studies on vacuum and atmospheric drying of large-dispersed food materials were carried out on the experimental dryer. Crushed topinambour (Jerusalem artichoke) tubers, potato tubers, apples and green peas were selected as materials for investigation.

It is revealed that intensity of drying mainly depends on the height of bulk layer of dried material. Generalization of research results of influence of height of bulk layer of material being dried on drying kinetics during vacuum dehydration shows that changing the layer height from 0.01 m to 0.04 m leads to a decrease in the rate of drying of apples by 175 %, potatoes - by 195 %, topinambour tubers – by 205 %, and green peas - approximately 210 %. Analysis of drying curves obtained in the process of atmospheric drying at the heights of bulk layer of material 0.01; 0.02; 0.03 and 0.04 m shows that they have a drying kinetics similar to drying curves with same heights of bulk layer during vacuum dehydration. Therefore, it is concluded that during vacuum-atmospheric drying of large-dispersed material, the optimal height of the bulk layer should be 0.01-0.02 m.

Results and discussions

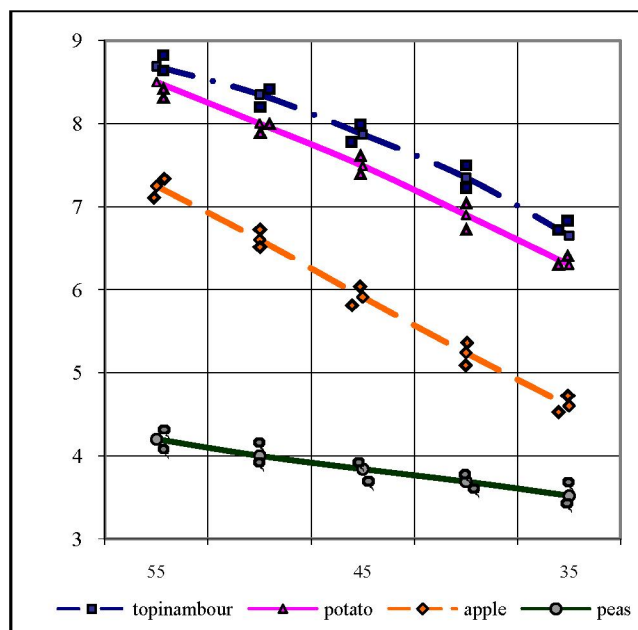
As experimental data show, the pressure in vacuum chamber is also one of the main factors determining the drying rate of large-dispersed materials. Changing the pressure in vacuum chamber leads to a corresponding change in drying rate of the materials. Thus, when the pressure increases from 2 to 10 kPa, the drying time of Jerusalem artichoke tubers increases from 3.5 to 10 hours. At the same time, reducing the pressure in vacuum chamber from 4 to 2 kPa leads to less significant increase in drying rate than with other pressure changes. Therefore, it can be recognized that the most optimal for vacuum drying are the pressure interval from 4 to 6 kPa.

The temperature level of vacuum drying process also directly affects the drying rate. In this regard, taking in mind analysis of experimental results on quality of finished product and duration of vacuum drying process, the recommended temperature intervals for heating the vacuumed medium were determined. The recommended lower limit for heating the medium in a vacuum chamber, which provides a sufficiently high drying intensity, is 40 °C. Drying of materials at a temperature 60 °C and above leads to deterioration sensory characteristics, and therefore, the offered upper limit of medium heating is 55 °C. Results of experimental studies of atmospheric drying show that there is a significant gap between the drying curves at 40 and 35 °C. This temperature range can be called a boundary, which separates the areas of intensive (temperature of medium in the chamber above 40 °C) and low-intensive (temperature of medium below 35 °C) drying. Also the optimal rate of drying agent in the device for final atmospheric drying was determined. It is established that the optimal speed of drying agent having the optimal heating temperature (36 ÷ 40) °C should be within (0.25 ÷ 0.4) m/s.

Drying is a complex operation involving simultaneous heat and mass transfer processes [6]. Study of heat and mass transfer processes in drying plants, both vacuum and atmospheric, is based on the determination of heat and mass transfer coefficients.

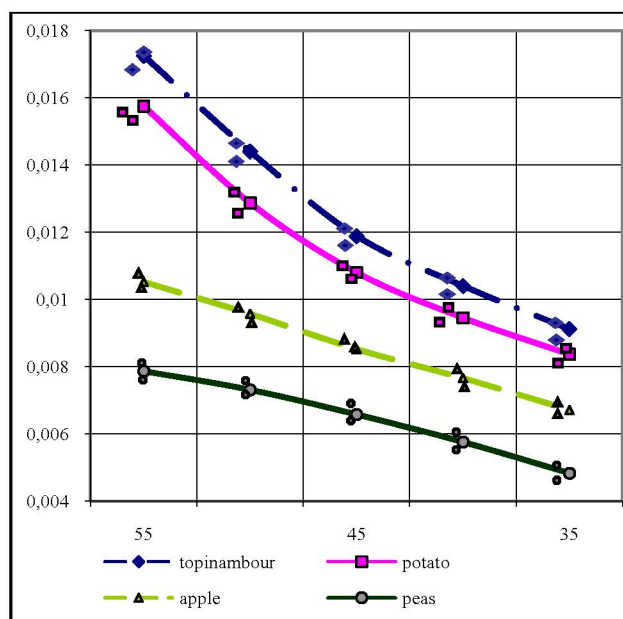
Experimental studies of heat and mass transfer for vacuum-atmospheric drying were carried out depending on pressure and temperature of medium during vacuum drying and temperature and air rate during atmospheric drying. Figures 1-6 show the dependences of heat and mass transfer coefficients for the above mentioned parameters. From the data shown in figures 1 and 2 it can be seen that heat and mass transfer coefficients have the highest values at heating temperature of vacuum medium 55 °C. This means that compare to heating temperatures 35 and 45 °C the intensity of heat and mass transfer is higher when it is heated at 55 °C. The analysis of experimental data shows that during vacuum drying, the change in the height of the bulk layer of the material has a much greater impact on heat transfer intensity than change in pressure or temperature of vacuum medium (figures 5 and 6). At the same time, the change in height of bulk layer of material has a slightly smaller effect on values of mass transfer coefficients. Thus, the change in height of bulk layer of topinambour tubers from 0.01 to 0.04 m leads to decreasing meanings of heat transfer coefficients from 10.23 to 5.81 W/(m²K) that is by 1.76 times. Accordingly, potato tubers - from 10.01 to 5.54 W/(m²K) – 1.81 times; apples – from 9.14 to 4.4 W/(m²K) - 2.08 times, and green peas - decrease in values of heat transfer coefficients occurs from 4.96 to 2.65 W/(m²K) that is 1.87 times. The values of heat and mass transfer coefficients during atmospheric at height of bulk layer of material 0.02 m drying are calculated depending on air temperatures (figures 7 and 8). It can be seen that the highest heat

and mass transfer intensities are observed at air temperatures 40 °C. At this temperature, the numerical values of heat transfer coefficients of Jerusalem artichoke tubers 8.78; potatoes – 8.43; apples -7.09 and green peas - 4.16 W/(m²K). The corresponding values of mass transfer coefficients are: 0.0169; 0.015; 0.0089 and 0.0081 s/m. That is, at this pressure, values of heat transfer coefficients of topinambour tubers are 1.04; 1.24 and 2.11, and mass transfer coefficients are 1.13; 1.9 and 2.09 times, respectively, higher than compared products. Comparison of ratios of numerical values of coefficients of heat and mass transfer of the materials received in processes of their vacuum and atmospheric drying shows their rather satisfactory coincidence.



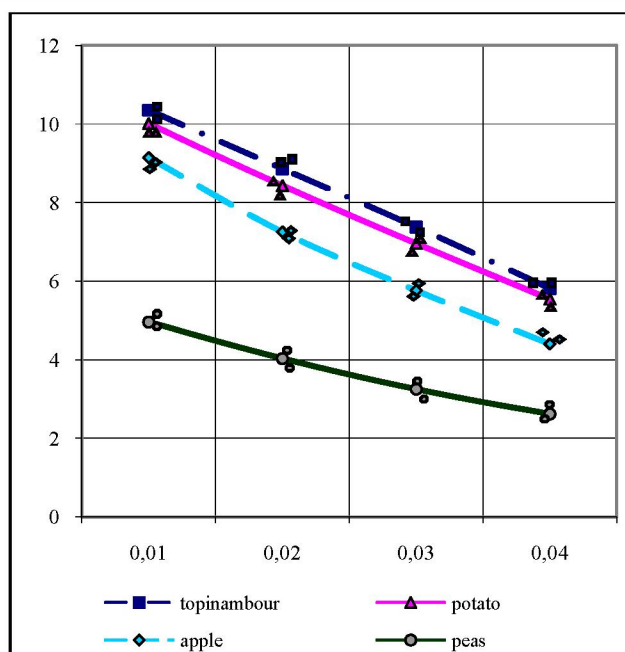
abscissa axis - heating temperature, °C; ordinate axis - heat transfer coefficient, W / (m²K).

Figure 1 - Dependences of heat transfer coefficients of dried materials on heating temperature at a medium pressure 4 kPa and height of material layer 0.02 m.



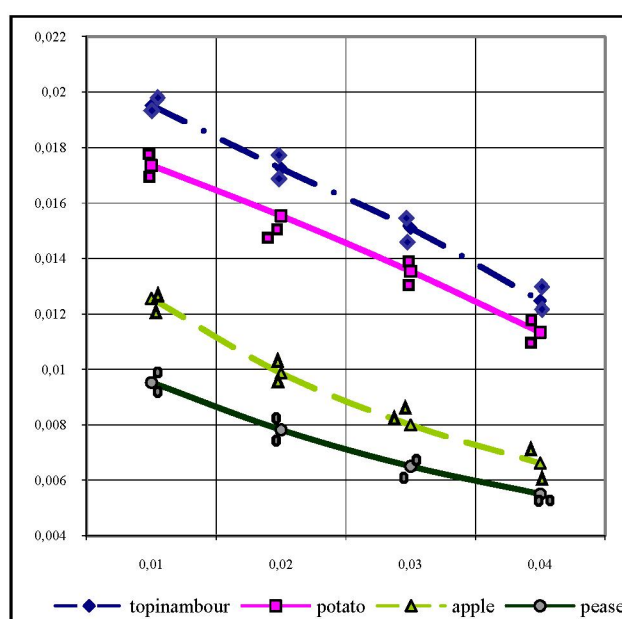
abscissa axis - heating temperature, °C; ordinate axis - mass transfer coefficient, s/m.

Figure 2 - Dependence of material mass transfer coefficients on heating temperature at medium pressure of 4 kPa and layer height of material 0.02 m.



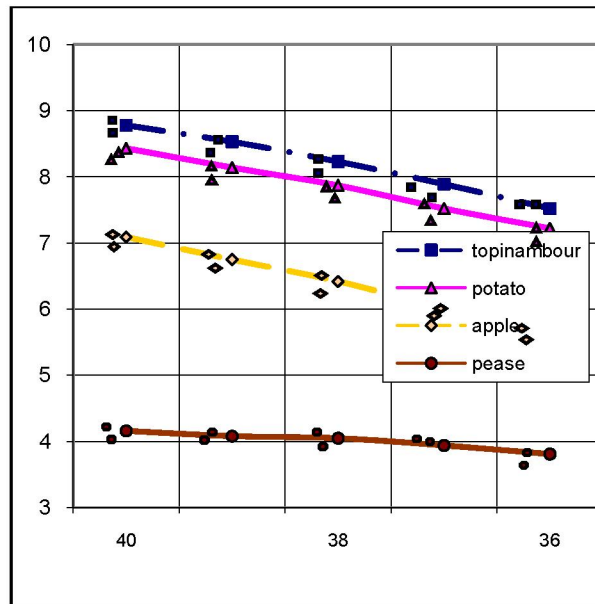
abscissa axis - layer height, °C; ordinate axis - heat transfer coefficient, W / (m²K).

Figure 3 - Dependences of heat transfer coefficients on height of layer of dried materials at pressure of medium pressure 4 kPa and temperature of medium 55 °C.



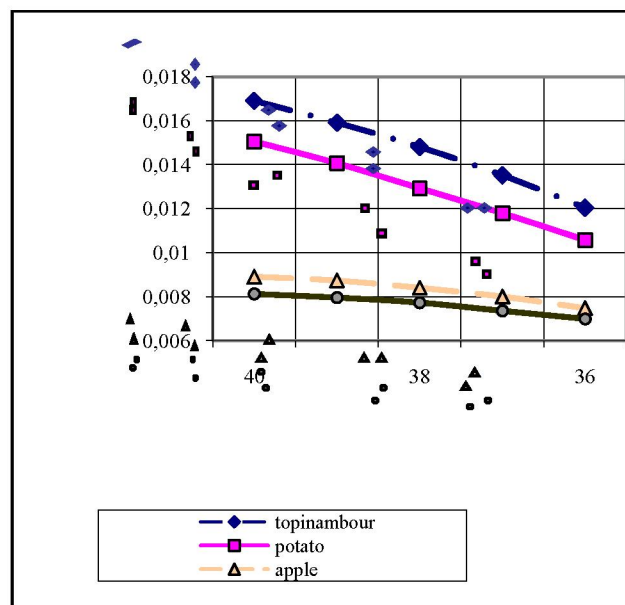
abscissa axis - layer height, m; ordinate axis - coefficient of mass transfer, s/m.

Figure 4 - Dependences of mass transfer coefficients on height layer at pressure of medium 4 kPa and temperature of medium 55 °C



abscissa axis – air temperature, °C; ordinate axis - heat transfer coefficient, W / (m²K).

Figure 5 - Dependences of heat transfer coefficients of the dried materials on the air temperature at air velocity 0.4 m/s and layer height of material 0.02 m during atmospheric drying



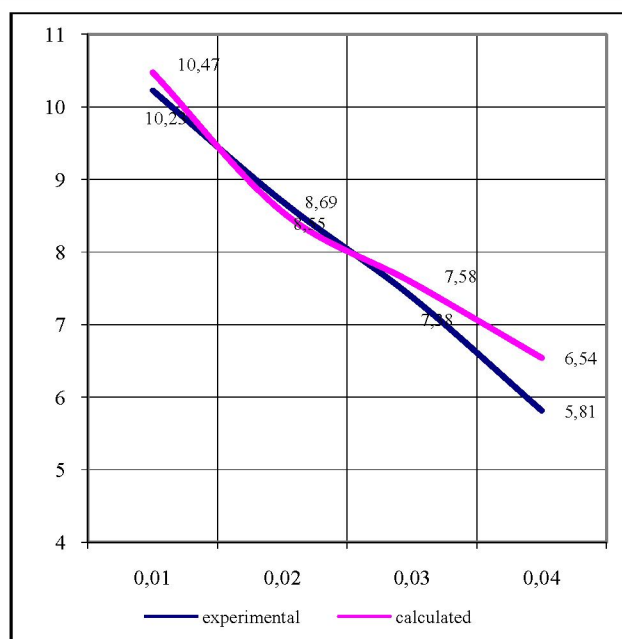
abscissa axis – air temperature, °C; ordinate axis - mass transfer coefficient, s/m.

Figure 6 - Dependences of mass transfer coefficients on air temperature at air rate 0.4 m/s and height layer 0.02 m during atmospheric drying.

On the base of analysis of experimental data on heat and mass transfer drying of large-dispersed materials for processes of vacuum drying the following equations of heat and diffusion Nusselt criteria are obtained:

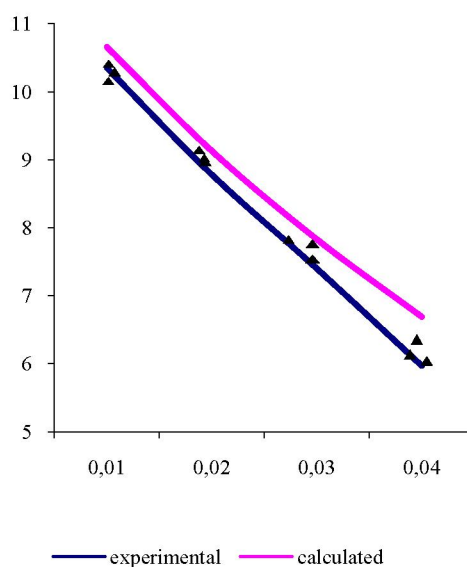
$$Nu = 1,21 Re^{0,154} Gu^{0,21} Pr^{0,33} \Gamma^{0,135},$$

$$Nu_m = 0,29 Re^{0,85} Gu^{0,16} Pr^{0,33} \Gamma^{0,045},$$



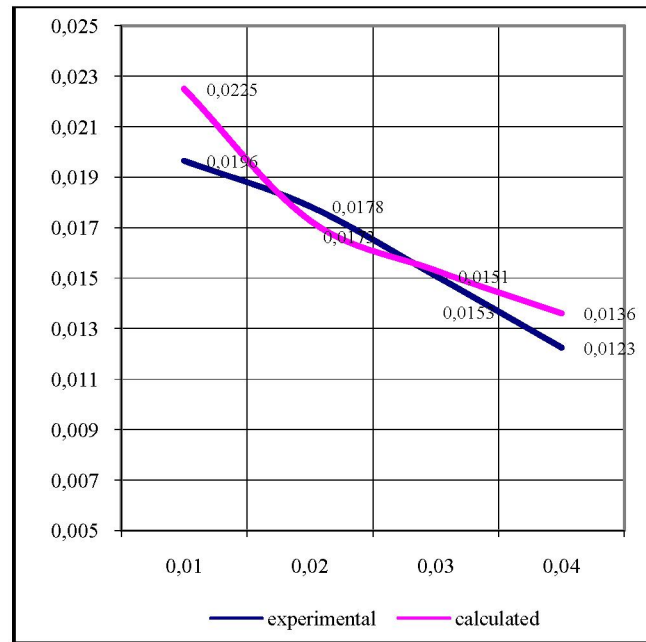
abscissa axis – height layer, m; ordinate axis - heat transfer coefficient, $W/(m^2K)$.

Figure 7 - Dependences of experimental and calculated coefficients of heat transfer on height layer of dried material at pressure of medium 4 kPa and temperature of heating 55 °C



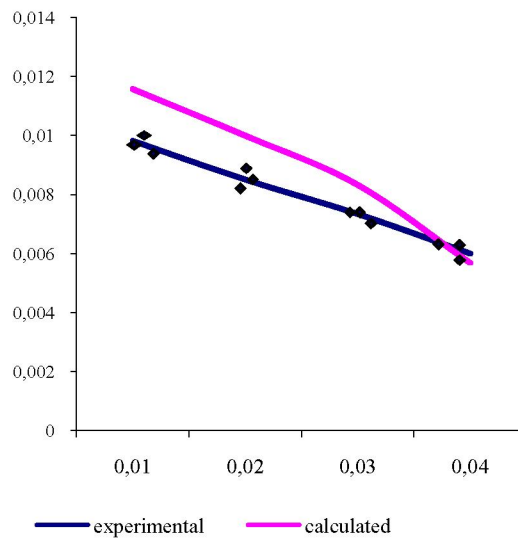
abscissa axis – height layer, m; ordinate axis - heat transfer coefficient, $W/(m^2K)$.

Figure 8 - Dependences of experimental and calculated coefficients of heat transfer on height layer of dried material at air temperature 40 °C and air rate 0.4 m/s.



abscissa axis – height layer, m; ordinate axis - mass transfer coefficient, m/s.

Figure 9 - Dependences of experimental and calculated coefficients of mass transfer on height layer of dried material at pressure of medium 4 kPa and temperature of heating 55 °C



abscissa axis – height layer, m; ordinate axis - mass transfer coefficient, m/s.

Figure 10 - Dependences of experimental and calculated coefficients of mass transfer on height layer of dried material at air temperature 40 °C and height layer 0.02 m.

Also on base of experimental data the following equations of heat and diffusion Nusselt criteria for atmospheric drying are obtained:

$$Nu = 0,54 Pr^{0,33} Re^{0,35} Gu^{0,17},$$

$$Nu_m = 0,34 Pr_m^{0,33} Re^{0,35} Gu^{0,17}.$$

Conclusion

Comparison on adequacy to real conditions is conducted in order to check the criterion equations. Numerical meanings of experimental and calculated coefficients of heat and mass transfer at vacuum drying depending on height layer of dried material at pressure of medium 4 kPa and heating temperature 55 °C are given in figures 7 and 8. Meanings of heat and mass transfer coefficients depending on air rate at air temperature 40 °C and height layer 0.02 m at atmospheric drying are shown in figures 9 and 10.

As it seen from the figures, meanings of experimental and calculated data of heat and mass transfer coefficients have satisfied convergence. Divergence of experimental and calculated mass transfer coefficients does not exceed 17.5%.

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ІРІДИСПЕРСТІ ТАҒАМДЫҚ МАТЕРИАЛДАРДЫ ВАКУУМДЫ-АТМОСФЕРАЛЫҚ КЕПТІРУДІҢ НӘТИЖЕЛЕРІ

Аннотация. Ұсынылған мақалада асбұршақ, ұсақталған жер алмұрты, картофель және алма сияқты ірідисперсті тағамдық материалдарды вакуумды-атмосфералық кептіру кезіндегі жылу-масса алмасуды зерттеу нәтижелері қарастырылған. Осы онтайлы вакуумды-атмосфералық кептірудің режимдері әзірленді. Ірі дисперсті материалдарды вакуумды және атмосфералық кептірудің нәтижелері зерделенді. В зависимости от высоты слоя высушиваемого кептірілуші материал қабатының биіктігіне, вакуумды камерадағы ортаның қысымына, кептірудің температуралық деңгейіне тәуелділігіне байланысты Нуссельттің жылу- және масса алмасу критерийлерінің теңдеулері және жылу- және массатасымалдау коэффициенттерінің сандық мәндері алынды. Критериялы теңдеулерді тексеру мақсатында оларды нақты жағдайларға ұқсастығын сараптау үшін талдау жүргізілді. Жылу- және массатасымалдау коэффициенттерінің эксперименталды және есептік мәліметтерінің мәндері олардың қанағаттанарлық сәйкестігін көрсетеді.

Түйін сөздер: онтайлы, жер алмұрты, эксперимент, зерттеу, масса алмасу, режим.

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РЕЗУЛЬТАТЫ ВАКУУМНО-АТМОСФЕРНОЙ СУШКИ КРУПНОДИСПЕРСНЫХ ПИЩЕВЫХ МАТЕРИАЛОВ

Аннотация. В данной статье рассмотрены результаты исследований теплообмена при вакуумно-атмосферной сушки крупнодисперсных пищевых материалов, таких как горох, измельченные клубни топинамбура, картофеля и яблок. Разработаны оптимальные режимы вакуумно-атмосферной сушки данных материалов. Изучены результаты вакуумной и атмосферной сушки крупнодисперсных материалов. В зависимости от высоты слоя высушиваемого материала, давления среды в вакуумной камере, температурного уровня сушки получены численные значения коэффициентов тепло- и массопереноса и уравнения тепло- и массообменных критериев Нуссельта. С целью проверки критериальных уравнений проведен анализ сходимости их реальным условиям. Значения экспериментальных и расчетных данных коэффициентов тепло- и массопереноса показывают их удовлетворительное совпадение.

Ключевые слова: оптимальный, топинамбур, эксперимент, исследование, массообмен, режим.

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