ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ
Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Казахский национальный исследовательский
технический университет им. К. И. Сатпаева

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Kazakh national research technical university
named after K. I. Satpayev

SERIES
OF GEOLOGY AND TECHNICAL SCIENCES

6 (438)

NOVEMBER – DECEMBER 2019

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

«ҚР ҰҒА Хабарлары. Геология мен техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктенуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).
Қазақстан республикасының Мәдениет пен ақпарат министрлігінің Ақпарат және мұрағат комитетінде 30.04.2010 ж. берілген **№10892-Ж** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Мерзімділігі: жылына 6 рет.
Тиражы: 300 дана.

Редакцияның мекенжайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., 220, тел.: 272-13-19, 272-13-18, http://www.geolog-technical.kz/index.php/en/

Редакцияның мекенжайы: Қазақстан, 050010, Алматы қ., Қабанбай батыра көш., 69а.
Қ. И. Сәтбаев атындағы геология ғылымдар институты, 334 бөлме. Тел.: 291-59-38.

Типографияның мекенжайы: «Аруна» ЖК, Алматы қ., Муратбаева көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан (г. Алматы)
Свидетельство о постановке на учет периодического печатного издания в Комитете информации и архивов Министерства культуры и информации Республики Казахстан **№10892-Ж,** выданное 30.04.2010 г.

Периодичность: 6 раз в год
Тираж: 300 экземпляров

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, ком. 219, 220, тел.: 272-13-19, 272-13-18,
http://nauka-nanrk.kz /geology-technical.kz

Адрес редакции: Казахстан, 050010, г. Алматы, ул. Кабанбай батыра, 69а.
Институт геологических наук им. К. И. Сатпаева, комната 334. Тел.: 291-59-38.

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA "National Academy of Sciences of the Republic of Kazakhstan" (Almaty)
The certificate of registration of a periodic printed publication in the Committee of information and archives of the Ministry of culture and information of the Republic of Kazakhstan N 10892-Ж, issued 30.04.2010

Periodicity: 6 times a year
Circulation: 300 copies

Editorial address: 28, Shevchenko str., of. 219, 220, Almaty, 050010, tel. 272-13-19, 272-13-18, http://nauka-nanrk.kz/geology-technical.kz

---

Editorial address: Institute of Geological Sciences named after K.I. Satpayev
69a, Kabanbai batyr str., of. 334, Almaty, 050010, Kazakhstan, tel.: 291-59-38.

Address of printing house: ST "Aruna", 75, Muratbayev str, Almaty

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 6, Number 438 (2019), 165 – 176 **https://doi.org/10.32014/2019.2518-170X.167**

UDC664.8.047
IRSTI65.53.33

B. T. Abdizhapparova[1], N. S. Khanzharov[2], B. O. Ospanov[1], I. A. Pankina[3], G. E. Orymbetova[1]

[1]M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan,
[2]International Humanitarian-Technical University, Kazakhstan,
[3]Peter the Great St. Petersburg Polytechnic University, Russia.
E-mail: atiko_96@mail.ru

A WAY OF VACUUM-ATMOSPHERIC DRYING OF JERUSALEM ARTICHOKE TUBERS

Abstract. Commercially Jerusalem artichoke tubers are valuable raw material to produce inulin, fructose, treacle and alcohol. Fast decreasing of quality at traditional storage as a tuber raw material makes difficult to apply it during a year. For that matter, drying is offered as the most suitable preservation method of Jerusalem artichoke tubers.The purpose of work is enhancement of efficiency and lowering energy consumption in a process of drying of crushed Jerusalem artichoke tubers. A method of vacuum-atmospheric drying of Jerusalem artichoke tubers is offered to solve the problem. The method includes conducting vacuum drying of the material up tointermediate humidity and atmospheric drying till final moisture content. Whereby final atmospheric drying is performed using-heat of refrigerant condensation circulated in a refrigerating machine which is a heat pump unit of the dryer. Final drying of the material by air from that source allows saving energy for atmospheric drying and decrease duration of vacuum dehydration. This method is based on combination vacuum and atmospheric drying in thesame drying installation and utilization refrigerant condensation heat. Last one is applied for final atmospheric drying of Jerusalem artichoke tubers.Final product is characterized by sufficiently high quality indicators.

Keywords: Jerusalem artichoke, tubers, vacuum-atmospheric drying, critical humidity, temperature, pressure.

Introduction. Jerusalem artichoke (Helianthus tuberosus) is perennial tuberous plant with remedial properties. Tubers contain soluble polysaccharide inulin, nitrogen substances, vitamin C and vitamin B complex, organic and fatty acids. Mineral substances of Jerusalem artichokeare zinc, silicium, phosphorus, iron, potassium, magnesium and copper. Many investigations confirm expediency of applying Jerusalem artichoke as a functional product [1-4].Jerusalem artichoke tubers may be used as a food additive at complex treatment diabetics, particularly, to correct metabolism. It is explained by carbohydrate composition of the tubers which is represented by polysaccharide inulin. At digestion inulin is split down to fructose [5-6]. In turn, fructose quickly transforms into glycogen,it does not increase sugar level in blood and is easily digested by human organism. Moreover, Jerusalem artichokeis able to remove heavy metals salts and some radioactive substances 2-3 times more intensively than pectin.

Commercially Jerusalem artichoke tubers are valuable raw material to produce inulin, fructose, treacle and alcohol [7]. Linxi Yang et al consider the tubers as a source of functional food, bioactive compounds, biofuels and chemicals [4]. Due to desirable taste properties the tubers may be applied as a food [8-9]. Fast decreasing of quality at traditional storage as a tuber raw material (e.g. cooled warehouse, storing bunker etc.)makes difficult to apply it during a year [10]. A gradual losing of mass takes place at storage. Control of relative humidity 95% and temperature 0-2 ^{0}C allows storing the tubers during 4-5 months [11-14]. Beyond this time applying the tubers seems impossible.For that matter, it seems that the most suitable preservation method is drying of Jerusalem artichoke tubers.

Various drying methods of Jerusalem artichoke tubers in order to produce semifinished products are known [15-19].

Dnishev T.M. et al sweet flour from finely divided till cubes Jerusalem artichoke tubers obtain by air drying during 120 hours and crushing till particles with sizes (20÷25) micrometers [15]. Initial humidity of Jerusalem artichoke tubers is about 75%. Temperature of dried material at residual moisture content 9,6% is 60 ^{0}C.

Peyker S.K. and Pirogova G.A. wash, grade, inspect and dry Jerusalem artichoke tubers by airflow with speed (5÷15) m/s and infrared light with rays length (0,7÷2,5) micrometers [16]. The drying is conducted in two stages: first one – at the temperature not above 78 ^{0}C from 20 min to 6 h; second one at the temperature not above 62 ^{0}C to final humidity (2-12) %.

Zelenkov V.N. [17] obtains concentrate of Jerusalem artichoke by air blowwith temperature not above 70 ^{0}C.

Kochnev N.K. and Kalinicheva M.V. obtain Jerusalem artichoke powderby preparation tubers, crushing till puree-like state, heating puree till (80÷90) ^{0}C, cooling till (35÷55) ^{0}C, fermentolysis and atmospheric drying at the temperature (55÷65) ^{0}C till final humidity (6÷12) %. The desired product is obtained by repeated crushing of dried product [18].

JunkoTakeuchi and Toshio Nagashima found that dried Jerusalem artichoke tubers show considerable water-holding capacity [19].

However all offered methods have the same risk of obtaining low-quality product caused by browning reactions due to action of air oxygen. As consequence, final product is characterized by not high sensory indicators and low rehydration ability.

Vacuum drying of Jerusalem artichoke compare to atmospheric one promotes better quality of dried product that is explained by the following factors:

- firstly, moderate temperature of vacuum drying conduces better maintenance biochemical composition of a material and prevents carbohydrates caramelization;
- secondly, vacuum drying inhibits browning of a material caused by oxidizing enzymes which are active at presence of oxygen;
- thirdly, sensory indicators of a dried product are better preserved at vacuum drying;
- finally, vacuum drying promotes better preservation of rehydration properties of a dried product.

At the same time atmospheric drying is characterized by low energy consumption and reduced duration of the process compare to vacuum dehydration.

Taking into consideration the mentioned above it seems efficient to combine these methods and carry out them in the united vacuum-atmospheric dryer.

Combination and selection of optimal modes of vacuum and atmospheric drying must provide unified character of the process which would have place at only vacuum or atmospheric dehydration.

Combination of the modes is possible by studying kinetics of vacuum and atmospheric drying, choosing humidity and temperature of material during the process, also selecting humidity of material till which vacuum drying will be conducted. Correspondingly, atmospheric drying will start at that humidity.It is accepted that vacuum drying will be conducted till critical moisture content that characterizes ending of period of constant rate of drying.

Meaning of final material humidity in vacuum chamber is reasonable to determine periods of constant and falling rate of drying in the both processes [20, 21].

Methods.

Vacuum-atmospheric drying. Design of vacuum-atmospheric dryer is described earlier [22].

Experimental investigations are carried out in the following order.

1. 30 minutes before starting experiment the compressor and electrical heaters are run in order to prepare drying installation. Necessary temperature of boiling of refrigerating agent (-4^{0}C) is set by regulation of expansion device. Atmosphere temperature in vacuum chamber is regulated in the limits(35÷55) ^{0}C by changing intensity of current supplied to electrical heaters.
2. Prepared material (Jerusalem artichoke cubes with sizes 5×5×5 mm) is put intonetted capacities by the diameters 30-50mm and height 50 mm. Thickness of material layer is varied from 10 till 40 mm.
3. Mass of material is weighted on analytic balance with accuracy 0.001g.
4. Capacities are placed on shelves into vacuum chamber. Lid of chamber is closed compactly.

5. Vacuum pump is gone on. Vacuum level in the chamber (2; 4; 6; 8; 10 kPa) is set up by vacuum valve. Moment of beginning of an experiment is fixed after achieving necessary level of vacuum.

6. Time interval between measurements of mass of dried material is 60 minutes. At that amount of evaporated moisture is defined. At first by the means of vacuum valve vacuum level in the chamber is decreased till 0.08 atm; then vacuum pump is switched off and lid is opened.

7. Moisture content in the material is calculated by the formula:

$$\omega = \frac{m_1 - m_2}{m_1} 100, \%, \tag{1}$$

where ω – moisture content of material relative to its initial mass, %; m_1 and m_2 – initial and final material masses, g.

7. Weighted material is placed in vacuum chamber and dried again with intermediate measurement loss in weight till achieving a critical humidity.

8. After achieving a critical humidity the material in the capacities is transferred from the vacuum chamber into the device for final atmospheric drying. Drying is continued with intermediate measurement loss in weight up to achievement final humidity 9%.

Jerusalem artichoke tubers grown inSouth Kazakhstan were investigated in the work. Initial moisture content in Jerusalem artichoke tubers was 77%.

Operating conditionsof drying. Operation conditions of developed process of vacuum-atmospheric drying are:

- in vacuum chamber – pressure of medium and temperature of heaters;
- in device for atmospheric final heat drying – temperature and rate of drying agent.

There is difficulty of selection of modes of vacuum and atmospheric drying because of at vacuum drying except temperature of heating of material and medium, pressure of medium is basic parameter regulating drying process; at atmospheric drying it is rate of moving of drying agent, i.e. air.

According to literature data [23, 24] it is efficient to hold the limited meanings of temperature of heaters into vacuum chamber at drying of thermolabile material not above 60 ^{0}C. It allows preserving biochemical composition and sensory indicators of the material at vacuum drying. Therefore, in vacuum chamber power of electric heaters provides heating of material in temperature range (35÷55) ^{0}C [25].

At selection of vacuum level in the chamber it is efficient to apply meaningsof pressure which are easily achieved at industrial conditions. So as a pressure level into vacuum chamber for conducting drying was chosen the interval (2÷10) kilopascals.

As it is mentioned before, a drying agent at atmospheric drying is air. In the developed dryer air is warmed by heat of condensation of refrigerant agent circulating into refrigerating system which is incorporated into the dryer by scheme of a heat pump.

The temperature level of air into the device for final atmospheric drying should provide favourable conditions for drying thermolabile material preventing it overheating at a final stage. Moreover, at choosing the temperature level of drying agent it is necessary to promote economy working mode of the heat pump. For the purposes a temperature of air in the device for atmospheric final heat drying is chosen in the limit (36÷40) ^{0}C taking in mind losses of heat into ambient medium.

The air rate into the device is held in the limit (0,25÷0,4) m/s. Deviation from the interval leads to increased energy consumption [18]. Lowering of air rate brings to elongation of duration of drying that promotes rising of energy consumption as well.

Biochemical analysis on investigated material. Biochemical analysis was carried out to determine quantity of dry substances, reducing sugars and vitamin C into raw sample, also in material dried by atmospheric, vacuum and vacuum-atmospheric ways. Atmospheric drying is conducted in drying cabinet at air temperature (45÷50)^{0}C. Vacuum drying is carried out at medium pressure 4 kPa and temperature of electric heaters 55^{0}C. Temperature of air at atmospheric final drying is (36÷40) ^{0}C.

Jerusalem artichoke tubers crushed in view cubes with sizes 5×5×5 mm are investigated. Height of layer of dried material is 20 mm. Final humidity of dried material is (9÷10)%. Dried material before analysis is exposed to rehydration up initial humidity.

At vacuum-atmospheric drying crushed Jerusalem artichoke tubers at first are dried in vacuum camera up to critical humidity, equal to 22.71%. Then they are finally dried into device for atmospheric final heat drying.

Determination of common content of dry substances by dehumidification method. Determination of dry substances is carried out according to the state standard GOST 8756.2 “Concentrated food products. Methods of determination of dry substances or moisture content”

Determination of reducing sugars at the presence of methylene blue. Determination of quantity of reducing sugars is carried out according to the state standard GOST 8756.13 «Products of processing of fruit and vegetables. Methods of determination of sugars».

Determination of vitamin C. Quantity of vitamin C is determined according to the state standard GOST 24556 «Fruit and vegetable canned food products. Methods of determination of vitamin C».

Heat- and mass-transfer coefficients. Meanings of heat and mass transfer coefficients are calculated by the equations:

$$\alpha = \frac{\Delta Q}{f\ \Delta t}, \tag{2}$$

$$\beta = \frac{\Delta M}{f\ \Delta p} \quad \text{or} \quad \beta = \frac{\Delta M}{f\ \Delta X}, \tag{3}$$

where β – masstransfer coefficient, s/m; α–heat transfer coefficient, W/(m^2·K); ΔQ – quantity of heat spent for heating of material, W; ΔM – quantity of moisture removed from drying material, kg/s; Δt – difference of temperatures of heat surface or medium and material, ^{0}C; Δp – difference of partial pressures of water steam corresponding to temperature of material and temperature of steam condensation, Pa; ΔX – difference of moisture contents of air on surface of material and into medium, kg/kg; f – surface area of evaporation, m^2.

Results. It is found out during experimental research that rate of drying mostly depends on height of layer of drying material. Variation of height of layer up 10 to 40mm leads to twofold decreasing of drying rate of tubers of Jerusalem artichoke.

The temperature level of vacuum drying influences directly on the rate of drying. Experimentally found that drying curves at 30, 35, 40, 45, 55 and 60^{0}C have sufficiently similar character. At the same time significant abruption is observed between drying curves at 40 and 35 ^{0}C. This temperature interval may be named as boundary one which divides fields of intensive (temperature is above 40 ^{0}C) and low intensive drying (temperature is low than 35^{0}C).

Results of experimental research of vacuum and atmospheric drying of crushed Jerusalem artichoke tubers are shown in figures 1 and 2. By experimental way such modes of atmospheric drying were chosen at which the character of rate of Jerusalem artichoke tubers with definite height of layer is analogous maximally to the performance in vacuum chamber. Thus, analysis of drying curves obtained during atmospheric drying at height of layer 20mm, temperatures of drying agent 34; 36; 38; 40°C and its motion speed 0.4 m/s, is shown that they have similar nature with curves of vacuum drying at pressure of medium 10; 8; 6; 4 kPa (figures 1 and 2).

The character of curves of vacuum drying at the pressure of medium 2 kPa is close to vacuum curves at 4 kPa and atmospheric curveat 40 ^{0}C. This indicates decreasing intensity of vacuum drying at 2 kPa therefore the interval of pressure for vacuum drying is accepted in the limit (4-8) kPa. At these modesall of curves of atmospheric and vacuum drying have accurate match both by initial periods, periods of constant and falling rate of drying and intensity of drying.

On the next stage of experimental research it is necessary to combine processes of vacuum and atmospheric drying. Existence of similar curves of drying obtained at vacuum and atmospheric drying for same height of layer of dried material allows combining these processes. At that main point of combination of the processes is selection of working modes of dryer at which curves of vacuum and atmospheric drying are coincided at most. Furthermore, curves of vacuum and atmospheric drying should fit together in the moment when moisture content in the material in both cases corresponds to critical point, when period of constant rate of drying is finished.

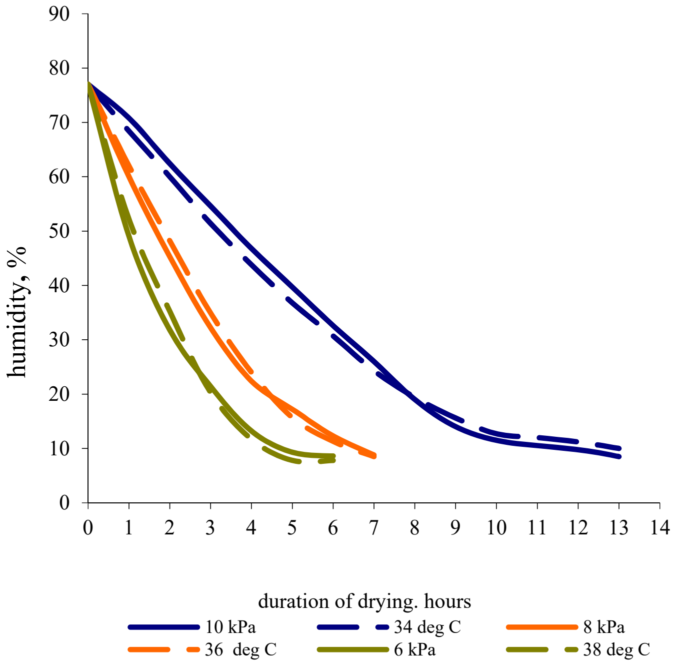

Figure 1 –
Curves of vacuum and atmospheric drying of Jerusalem artichoke tubers at pressure of medium into vacuum chamber 10; 8; 6 kPa and temperature of air into device for atmospheric drying 34; 36; 38 ^{0}C

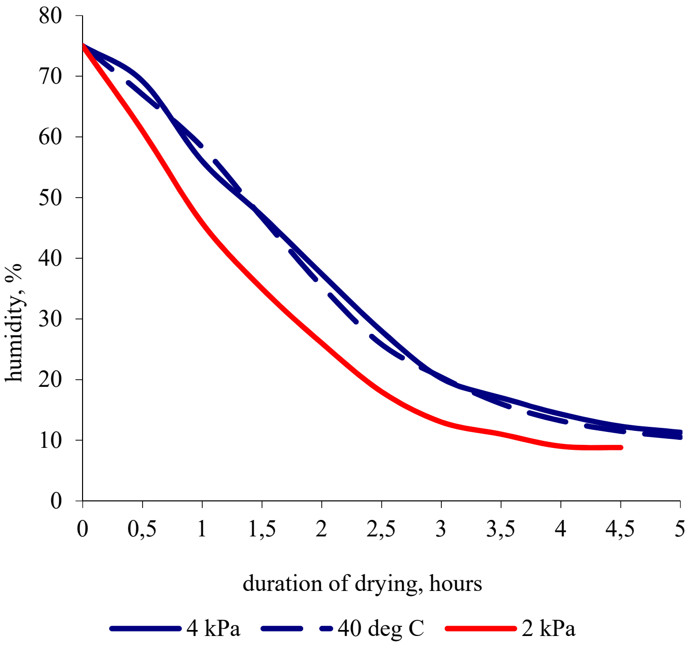

Figure 2 –
Curves of vacuum and atmospheric drying of Jerusalem artichoke tubers at pressure of medium into vacuum chamber 4; 2 kPa and temperature of air into device for atmospheric drying 40 ^{0}C

At studying rates of the processes it is found that at the same intensity of vacuum and atmospheric drying the character of curves of drying has similar view. Thus, at the selection of modes of vacuum and atmospheric drying with the same intensity in both cases it is possible to provide a behavior which would take place only at vacuum or atmospheric drying. At that duration of the process of vacuum-atmospheric drying should be equal to time of vacuum or atmospheric drying.

For example, for Jerusalem artichoke tubers to the suchvacuum drying modes as temperature of heating in vacuum camera 55 ^{0}C and pressure of medium 4, 6 and 8 kPa the regimes of atmospheric drying with rate of air 0.4 m/s and temperature of air 36, 38 and 40 ^{0}C correspondingly are match the most. According to figure 3, about same intensity (j=0,0010 kg/m^{2}s) havevacuum dryingmode at pressure 5.5-6.5 kPa and atmospheric dehydration regime at air temperature 37.5-38.5 ^{0}C.

However, the total coincidence of vacuum and atmospheric drying modes must be proved by closeness of the material temperatures in periods of constant rate of drying for both ways. In other words, material dried till critical humidity in the vacuum camera should have temperature level close to temperature of material which would be dried till critical meaning in the device for atmospheric drying. Otherwise, even at the same intensity of processes of vacuum and atmospheric drying thelowered or raised temperature of material may provoke decelerating of dehydration process.

Comparison of temperatures of Jerusalem artichoke tubers in periods of constant rate of drying at vacuum and atmospheric dehydration for modes selected above is shown n figure 4.

According to figure 4, for selected modes of vacuum and atmospheric drying the temperature of Jerusalem artichoke tubers in constant rate of drying is about 26^{0}C. Considering that temperature, it is possible to accomplish combination of vacuum and atmospheric drying into united vacuum-atmospheric drying process.

Combination of processes of vacuum and atmospheric drying for the purpose of creation of joint process of vacuum-atmospheric dehydration of Jerusalem artichoke tubers is carried out in the following way. For definite layer of material on the base of graphs shown in figure 4 the meaning of the pressure of medium into vacuum chamber was selected taking in mind that it corresponds to same intensity of dehydration in vacuum and atmospheric drying. Then, on the base of graph in figure 4, meanings of temperatures of drying materials were determined. At that values of selected temperatures for vacuum and atmospheric drying should match together. In a result of these operations the united curve of vacuum-atmospheric drying was achieved. Conducting drying according to the mode parameters providing joint curve of vacuum-atmospheric drying allows achieving high efficient and lowenergy consumed process. At that vacuum dehydration in the process of vacuum-atmospheric drying should be conducted up to critical humidity of drying material.

High intensity and low energy consumption of the process of dehydration were achieved by means of parallel realization into the dryer processes of vacuum and atmospheric drying.

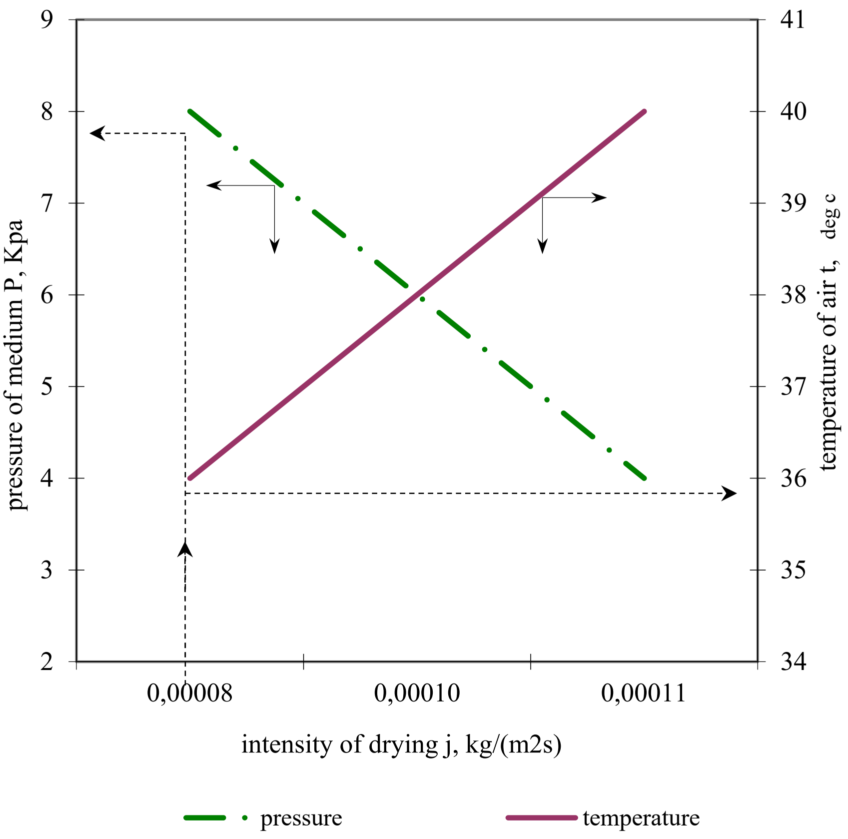

Figure 3 – Comparison of intensities of vacuum and atmospheric drying of Jerusalem artichoke tubers with height of layer 20 mm

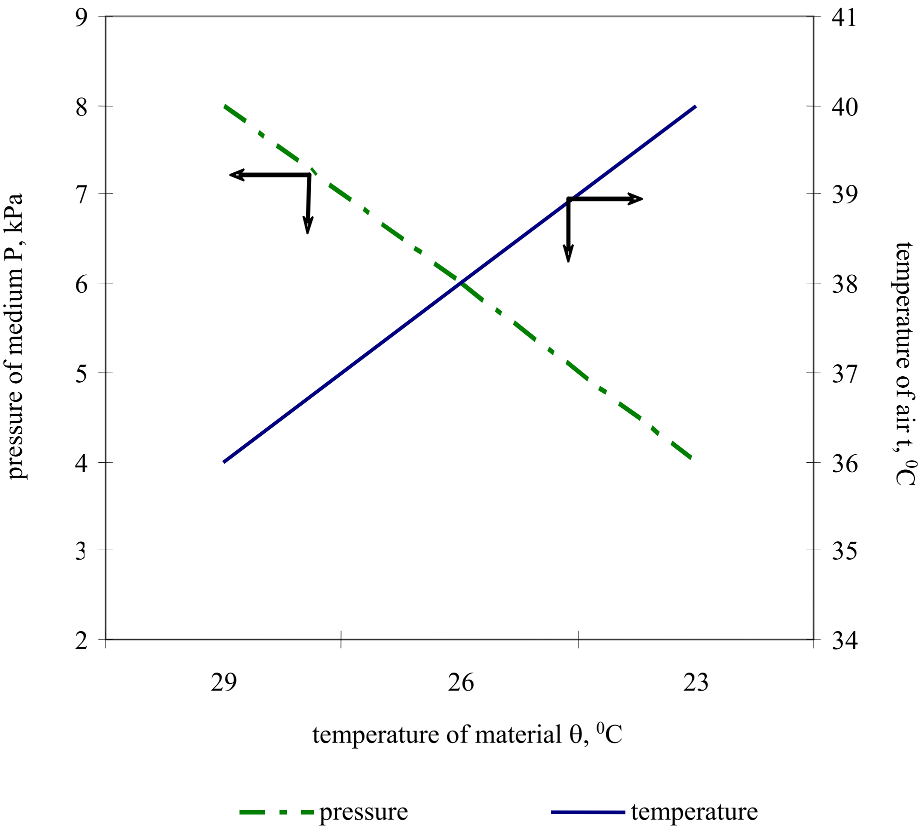

Figure 4 – Comparison of temperatures of material
in period of constant rate of drying at vacuum and atmospheric drying of Jerusalem artichoke tubers
with height of layer 0,02 m

Experimental data of vacuum-atmospheric drying of Jerusalem artichoketubers crushed in view cubes with height of layer 0.02 m, pressure into vacuum chamber 4 kPa and temperatures of heating 55; 45 и 35 ^{0}C are processed in view curves of drying (figure 5). To these heating temperature meanings the temperatures of air 40; 38; 36 ^{0}C at atmospheric drying correspond at all. The solid line determines period of vacuum drying and the dashed one is the period of atmospheric dehydration. The point characterizes critical moisture content of material that determines completion of drying period with constant rate and beginning drying time with falling rate.

As experiments show, the most efficient mode of drying for Jerusalem artichoke tubers is at temperature of heating 55 ^{0}C (figure 5). Comparably, at temperature 35 ^{0}C achieving of critical moisture content takes longer time approximately for 43%.

From figure 5 may be observed significant decreasing of energy consumption at vacuum-atmospheric drying. So, at drying of Jerusalem artichoke tubers, depending on the temperature of heating energy consumption is calculated for 2.8-4.6 hours i.e. till critical humidity of the material (figure 5). Further, drying is performed into device for atmospheric drying using disposable heat of condensation of refrigerant agent. At the same time, duration of drying only in vacuum chamber at 55 ^{0}C would be above 4.5 hours. Consequently, efficiency of the process of vacuum-atmospheric drying by time approximately for 37 % is higher compare to vacuum one.

Results of experimental investigation of vacuum-atmospheric drying of Jerusalem artichoke tubers are processed in view heat and mass transfercoefficients by equations (1) and (2).

Dependencies of heat and masstransfer coefficients at vacuum drying are shown in figures 6-11.As is clear from figures 6, 7, the highest intensities of heat and masstransfer are observed at pressures of medium into chamber 4 kPa. Heat and mass transfercoefficients have high meanings at temperature of heating 55 ^{0}C into vacuum chamber, as may be inferred from figures 8, 9.

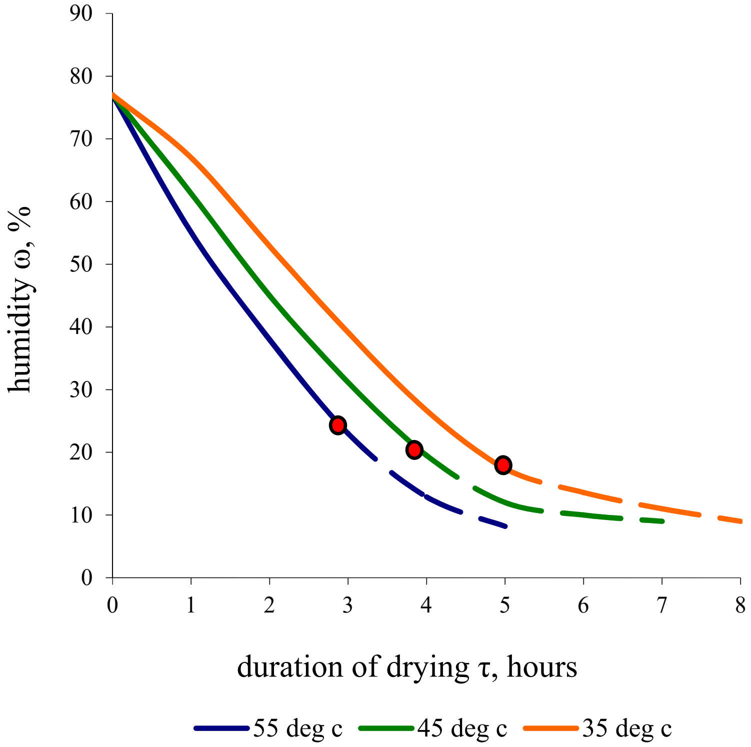

Figure 5 – Dependence of humidity of dryable Jerusalem artichoke tubers on duration of vacuum-atmospheric drying at P=4 Kpa and different temperatures of heating

Heat and mass transfercoefficients are calculated also at pressure of medium 4 kPa and temperature of heating 55 ^{0}C for height of layer 0,01; 0,02; 0,03 and 0,04 m (figures 10, 11). Analysis of calculated data shows that alteration of height of layer affects on intensity of vacuum drying much more than variation of pressures or temperatures. Thus, variation of heights of layer of Jerusalem artichoke tubers from 0.01 to 0.04m leads to decreasing of numeral meanings of heat transfer coefficient from 10.23 to 5.81 W/(m^{2}K), i.e. 1.76 times, and masstransfer coefficient 1.53times. It may be concluded that vacuum drying of Jerusalem artichoke tubers is efficient at height of layer from 0.01 to 0.02 m. Increasing of height more than 0.02 m leads to much consumption of time for drying and fixing layer low than 0.01 m results to lowering of efficiency of applying of working volume of drying chamber.

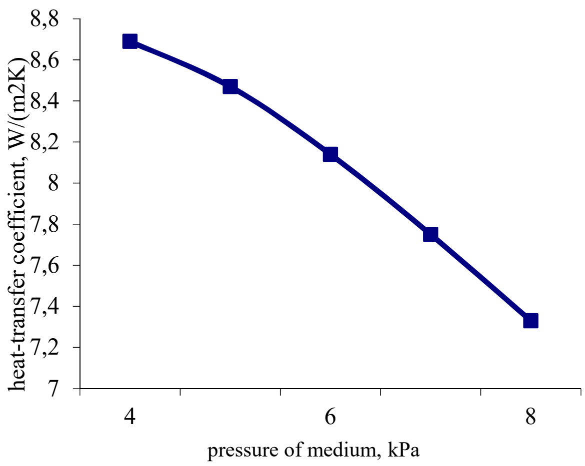

Figure 6 – Dependence of heattransfer coefficient from pressure of medium into vacuum chamber at height of layer 0.02 m and temperature of heating 55^{0}C

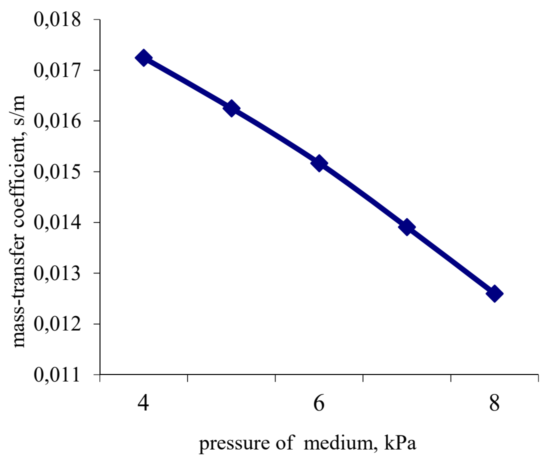

Figure 7 – Dependence of masstransfer coefficient from pressure of medium into vacuum chamber at height of layer 0.02 m and temperature of heating 55^{0}C

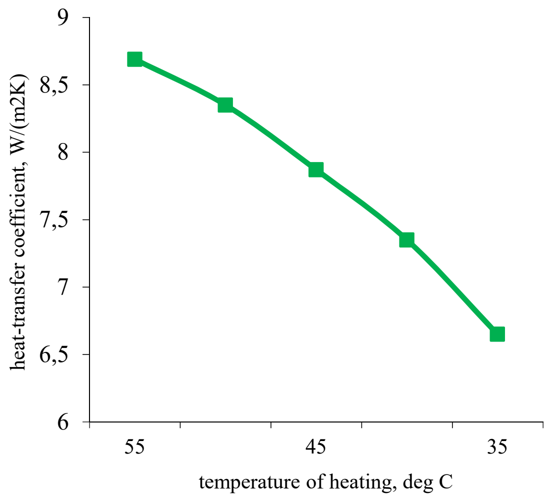

Figure 8 – Dependence of heat transfer coefficient from temperature of heating at pressure of medium into vacuum chamber 4 kPa and height of layer 0.02 m

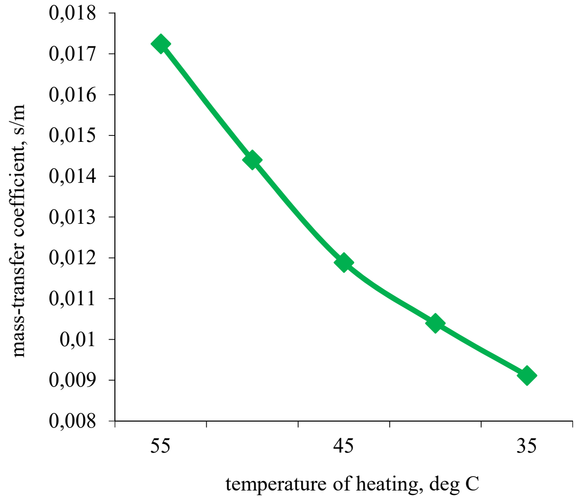

Figure 9 – Dependence of mass transfer coefficient from temperature of heating at pressure of medium into vacuum chamber 4 kPa and height of layer 0.02 m

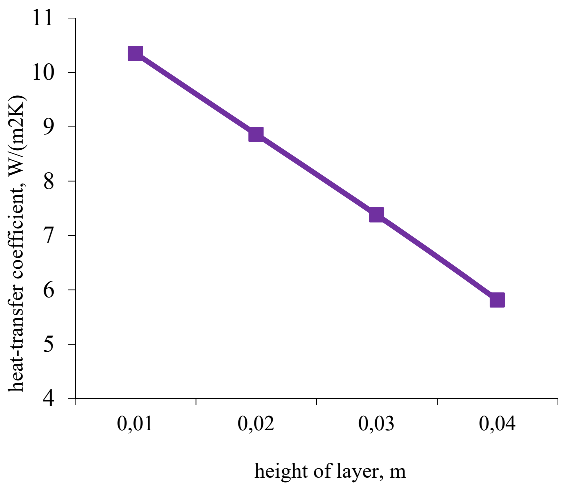

Figure 10 – Dependence of heattransfer coefficient from height of layer of material at pressure of medium into vacuum chamber 4 kPa and temperature of heating 55 ^{0}C

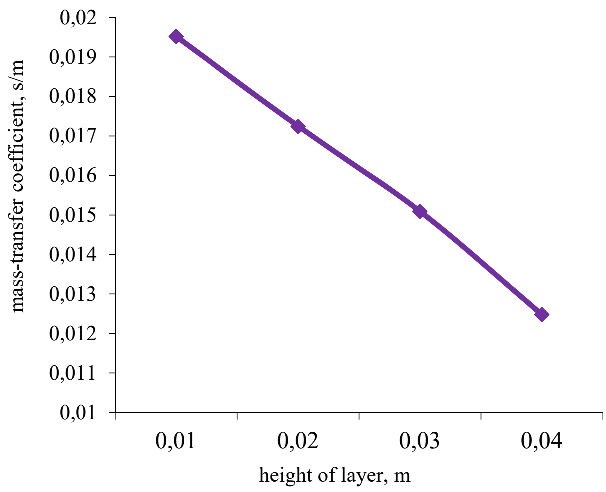

Figure 11 – Dependence of masstransfer coefficient from height of layer of material at pressure of medium into vacuum chamber 4 kPa and temperature of heating 55 ^{0}C

Dependencies of coefficients of heat and mass transfer at atmospheric drying are shown on figures 12 and 13. Meanings of coefficients of heat and mass transfer are calculated depending on temperature of air at height of layer 0.02 m. As it clear from the figures, the highest intensity of heat and mass transfer is observed at air temperature 40 ^{0}C.

Comparison of correlations of heat and mass transfer coefficients of vacuum and atmospheric drying reflects their sufficient coincidence. It follows thence those modes of vacuum and atmospheric drying of Jerusalem artichoke tubers are selected correctly for their combination and realization in vacuum-atmospheric dryer.

On the base of analysis of experimental data of heat and mass transfer at vacuum drying and in respect [26], the equations of heat and diffusionNusselt criteria are obtained:

$$Nu=1,21Re^{0,154}Gu^{0,21}Pr^{0,33}\Gamma^{0,135}, \quad (3)$$

$$Nu_m=0,29Re^{0,85}Gu^{0,16}Pr_m{}^{0,33}\Gamma^{0,045}, \quad (4)$$

where Pr and Pr_m – heat-and-mass exchange Prandtl criteria; Re - Reynolds criterion; Gu – Guhman criterion; Γ – geometric simplex, which is equal to relation of half height of layer to distance between electrical heaters r, $\Gamma = (h/r)$.

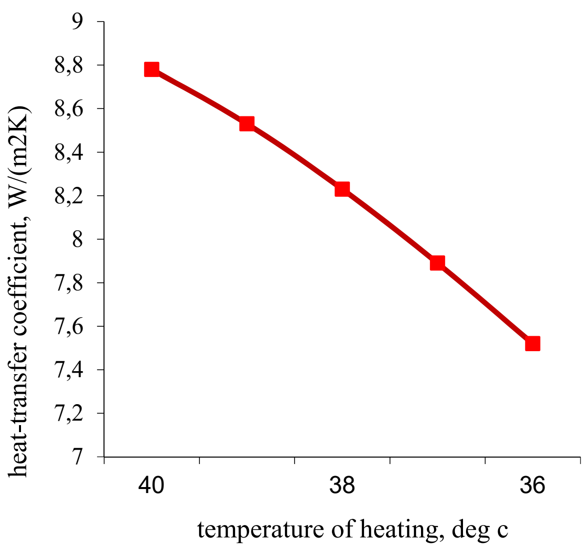

Figure 12 – Dependence of heat transfer coefficient from temperature of air at rate of air 0.4 m/s and height of material layer 0.02 m

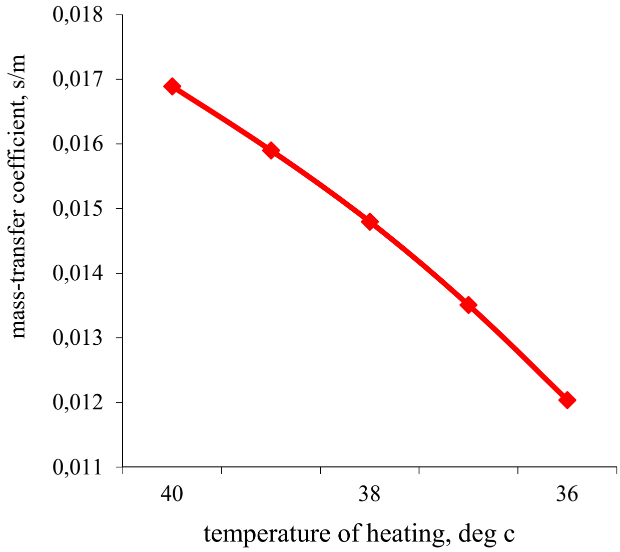

Figure 13 – Dependence of masstransfer coefficient from temperature of air at rate of air 0.4 m/s and height of material layer 0.02 m

Analogous equations of heat Nu and diffusional Nu_m Nusselt criteria are obtained for atmospheric drying:

$$Nu = 0{,}54Pr^{0{,}33}Re^{0{,}35}Gu^{0{,}17}, \tag{5}$$

$$Nu_m=0{,}34Re^{0{,}37}Gu^{0{,}24}Pr_m^{0{,}33} \tag{6}$$

Obtained equations of heat Nu and diffusional Nu_m Nusselt criteria are suitable to apply at engineering design of new drying installations.

Results of chemical analysis are given in the table.

Result of analysis of Jerusalem artichoke tubers

Material	Content of solids, %	Content of reducing sugar, % in calculation on solids	Content of vitamin C, mg/gg
Raw Jerusalem artichoke tubers	23÷25	13,19	0,493
Jerusalem artichoke tubers dried by atmospheric way	9÷10	9,15	0,369
Jerusalem artichoke tubers dried by vacuum way	9÷10	12,6÷12,9	0,423÷0,465
Jerusalem artichoke tubers dried by vacuum-atmospheric way	9÷10	12,4÷12,8	0,418÷0,457

Discussion. Increasing of temperature of heating into vacuum chamber above 60 ^{0}C is inexpedient because it leads to insignificant growth of rate of drying. At that partial caramelization of sugars leads to deterioration of sensory indicators takes place as well. Heating at temperature low than 30 ^{0}C in vacuum chamber reduces intensity of drying considerably. The optimal mode of drying into vacuum-atmospheric dryer is pressure of medium in the range (4-8) kPa and temperature level of heating is 55 ^{0}C.

As is clear from table, the highest content of vitamin C and reducing sugar is in raw material. Content of vitamin C and reducing sugars in samples dried by vacuum-atmospheric method is small lower than in tubers dried by vacuum way. The lowest meanings have samples dried by atmospheric method. These indicators give evidence aboutprospectivity of vacuum-atmospheric method at producing other plant products as well.

The idea of combination of vacuum drying with other methods is also proposed by other scientists. Thus, hybrid drying is proposed, which includes the combination of vacuum drying with traditional and novel methods of drying, such as drum, microwave, infrared, ohmic drying [27].

The essence of combining vacuum drying with atmospheric one is to include a heat pump in the vacuum drying unit, which suppliesheat to the process of atmospheric drying of the material and cold to dehumidification process (freezing of moisture) during vacuum drying.

Alongside with good preservation of the biochemical composition of dried products the developed method of vacuum-atmospheric drying promotes a reduction in the energy consumption as compared with the vacuum one by 13-15%.

Thus, the developed method of vacuum-atmospheric drying meets the requirements for advanced drying technologies, which makes the process cost-effective and reduces energy consumption.

Б. Т. Абдижаппарова[1], Н. С. Ханжаров[2], Б. О. Оспанов[1], И. А. Панкина[3], Г. Э. Орымбетова[1]

[1]М. Әуезов атындағы Оңтүстік Қазақстан мемлекеттік университеті, Шымкент, Қазақстан,
[2]Халықаралық гуманитарлық-техникалық университет, Қазақстан,
[3]Ұлы Петр атындағы Санкт-Петербург мемлекеттік политехникалық университеті, Ресей

ЖЕР НӘГІ ТҮЙІНДЕРІНІҢ ВАКУУМДЫҚ-АТМОСФЕРАЛЫҚ КЕПТІРУ ТӘСІЛІ

Аннотация. Өнеркәсіптік тұрғыдан жер нәгінің түйндері инулин, фруктоза, сірне және спирт өндіруге арналған құнды шикізат болып табылады. Жер нәгінің түйіндерін дәстүрлі сақтау кезінде сапаның тез төмендеуі оны жыл бойы қолдануды қиындатады. Бұл тұрғыда кептіру жер нәгі түйнектерін сақтаудың ең қолайлы тәсілі болып табылады. Жұмыстың мақсаты жер нәгінің ұсақталған түйнектерін кептіру процесінде энергия шығынын төмендету және тиімділігін арттыру болып табылады. Қойылған міндетті орындау үшін жер нәгінің түйнектерін вакуумдық-атмосфералық кептіру әдісі ұсынылған. Ұсынылған әдіс материалды вакуумдық кептіруді аралық ылғалдылыққа дейін және атмосфералық кептіруді соңғы ылғалдылыққа дейін жүргізуді қамтиды. Бұл кезде соңғы атмосфералық кептіру кептіргіштің жылу сорғысы болып табылатын тоңазытқыш машинасында айналатын хладагент сұйылту жылуын пайдалана отырып жүзеге асырылады. Осы көзден алынған ауамен соңғы кептіру энергияны атмосфералық ылғалсыздандыруға үнемдеп, вакуумдық кептірудің ұзақтығын қысқартуға мүмкіндік береді. Бұл әдіс бір кептіру қондырғысында вакуумдық және атмосфералық кептіруді біріктіруге және тоңазытқыш агенттің сұйылту жылуын пайдалануғабағытталған. Сұйылту жылуы-жер нәгі түйіндерінің соңғы атмосфералық кептіруі үшін қолданылады. Дайын өнім жоғары сапалы көрсеткіштермен сипатталады.

Түйін сөздер: жер нәгі, түйін, вакуум-атмосфералық кептіру, критикалық ылғалдылық, температура, қысым.

Б. Т. Абдижаппарова[1], Н. С. Ханжаров[2], Б. О. Оспанов[1], И. А. Панкина[3], Г. Э. Орымбетова[1]

[1]Южно-Казахстанский государственный университет им. М. Ауэзова, Шымкент, Казахстан,
[2]Международный гуманитарно-технический университет, Казахстан,
[3]Санкт-Петербургский государственный политехнический университет им. Петра Великого, Россия

СПОСОБ ВАКУУМНО-АТМОСФЕРНОЙ СУШКИ КЛУБНЕЙ ТОПИНАМБУРА

Аннотация. С промышленной точки зрения клубни топинамбура являются ценным сырьем для производства инулина, фруктозы, патоки и спирта. Быстрое снижение качества при традиционном хранении топинамбура как клубневого сырья затрудняет его применение в течение года. В этом отношении сушка является наиболее подходящим способом сохранения клубней топинамбура. Целью работы является повышение эффективности и снижение энергозатрат в процессе сушки измельченных клубней топинамбура. Для решения поставленной задачи предложен способ вакуумно-атмосферной сушки клубней топинамбура. Способ включает проведение вакуумной сушки материала до промежуточной влажности и атмосферной сушки до конечной влажности. При этом окончательная атмосферная сушка осуществляется с использованием тепла конденсации хладагента, циркулирующего в холодильной машине, которая является тепловым насосом сушилки. Окончательная сушка материала воздухом из этого источника позволяет экономить энергию на атмосферную сушку и уменьшить продолжительность вакуумного обезвоживания. Этот метод основан на комбинировании вакуумной и атмосферной сушки в одной сушильной установке и утилизации теплоты конденсации холодильного агента. Последняя применяется для завершающей атмосферной сушки клубней топинамбура. Конечный продукт характеризуется достаточно высокими качественными показателями.

Ключевыеслова: топинамбур, клубни, вакуумно-атмосферная сушка, критическая влажность, температура, давление.

Information about authors:

Abdizhapparova B. T., M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan; https://orcid.org/0000-0001-8277-8243

Khanzharov N. S., International Humanitarian-Technical University, Kazakhstan; https://orcid.org/0000-0002-7406-0386

Ospanov B. O., M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan; atiko_96@mail.ru; https://orcid.org/0000-0002-6437-5579

Pankina I. A., Peter the Great St. Petersburg Polytechnic University, Russia

Orymbetova G. E., M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan

REFERENCES

[1] Radovanovic A., Stojceska V., Plunkett A., Jankovic S., Milovanovic D., Cupara S. (2015) The use of dry Jerusalem artichoke as a functional nutrient in developing extruded food with low glycemic index // Food Chemistry. 177: 81-88. DOI: 10.1016/j.foodchem.2014.12.096 (in Eng.).

[2] Afoakwah N.A., Dong Y., Zhao Y. Xiong Z., Owusu J., Wang Y., Zhang J. (2015). Characterization of Jerusalem artichoke (Helianthus tuberosus L.) powder and its application in emulsion-type sausage, LWT // Food Science and Technology. 64 (1): 74-81. DOI: 10.1016/j.lwt.2015.05.030 (in Eng.).

[3] Roberfroid M.B. (1993).Functional food: concepts and application to inulin and physiological effects // Crit. Rev. Food Sci. Nutr. 33: 103-148 (in Eng.).

[4] Linxi Yang, Quan Sophia He, Kenneth Corscadden, Chibuike C. Udenigwe. (2015). The prospects of Jerusalem artichoke in functional food ingredients and bioenergy production // Biotechnology Reports. 5: 77-88 (in Eng.).

[5] Franck A. (2002) Technological functionality of inulin and oligofructose // British Journal of Nutrition. 87: 287-291 (in Eng.).

[6] Kim G. Jackson, Gary R. J. Taylor, Anna M. Clohessy, Christine M. Williams (1999) The effect of the daily intake of inulin on fasting lipid, insulin and glucose concentrations in middle-aged men and women // British Journal of Nutrition. 82:23-30 (in Eng.).

[7] Krikunova L.N., Aleksandrova M.M. (2001) Energy and resource-solving technology of ethanol from topinambour // Storage and processing of agricultural raw material. 4:48-50 (in Russ.).

[8] Zarickaja N.E., Amirbekova S. (1997) Possibilty to expand an assortment of dietary vegetable preserves with applying new kind of raw material // Food technology and service. 1:10-13 (in Russ.).

[9] Shaihova M.K., Chomanov U.Ch. (2000) Influence of plant additives on quality of molded meat products // Materials of international scient.-pract. conf. 'Problems of stabilization and development of agriculture of Kazakhstan, Siberia and Mongolia'. Almaty, Kazakhstan. P. 385-386.

[10] Sinjavskij Ju.A., Timofeeva I.K. (1991) Production of specialized and the raupetic food products. Alma-Ata: KazNIINKI.

[11] Duke J.A. (1983). Handbook of Energy Crops.

[12] Swanton C.J., Hamill A.S. (1994) Jerusalem Artichoke. Factsheet, Ministry of Agriculture and Food, Ontario, Kanada.

[13] Grassi G., Gosse G. (1989) Topinambour (Jerusalem Artichoke), Commission of The European Communities, Luxembourg.

[14] Chabbert P. Braun, Guiraud J.P., Arnoux M., Galzy P. Productivity and fermentability of Jerusulem artichoke according to harvesting date (1983) // Biomass, 3: 209-224.

[15] Dnishev T.M., Tanashev N.B., Vitavskaja A.V., Chernis I.O., Davydenko T.N., Nurakov A.T., Tusupov N.A. (1996) Method of preparation of sweet flour from inulin-containing plants. Preliminary patent Republic Kazakhstan (in Russ.).

[16] Pejker S.K., Pirogova G.A. (1998) Method of production of dehydrated plant raw material and preparation courses from it. Patent Russian federation (in Russ.).

[17] Zelenkov V.N. (1999) Dried concentrate of topinambour. Patent Russian federation (in Russ.).

[18] Kochnev N.K., Kalinicheva M.V., Beglov S.Ju. (2002) Method of production of powder from topinambour tubers. Patent Russian federation (in Russ.).

[19] Junko Takeuchi, Toshio Nagashima. (2011) Preparation of dried chips from Jerusalem artichoke (Helianthus tuberosus) tubers and analysis of their functional properties // Food Chemistry. 126(3): 922-926 (in Eng.).

[20] Krisher O. (1961) Scientific bases of drying technics. Izd-voinostr. lit-ry, Moskow, USSR.

[21] Ostrikov A.N., Kuznecova I.V., Zuev I.A. (2004) Investigation of forms of moisture bonds in topinambour by method of differential and thermal analysis // Storage and processing of agricultural raw material. 7:33-35.

[22] Khanzharov N.S., Abdizhapparova B.T., Ospanov B.O., Dosmakanbetova A.A., Baranenko A.V., Kumisbekov S.A., Serikuly Zh. (2018) Designs of dryers based on combination of vacuum and atmospheric drying of food products // News of the Academy of sciences of the Republic of Kazakhstan. Series of geology and technical sciences. 5(431):141-149 (in Eng.).

[23] Shuljak V.A., Dovidovich D.V. (2004) Problems of drying of spice-aromatic gross // Storage and processing of agricultural raw material. 3:29-34 (in Russ.).

[24] Korneeva O.S., Omel'chenko O.M., Kononkov P.F. (2001) Investigation of process of drying of non-traditional inulin-containing raw material // Storage and processing of agricultural raw material. 1:42-43 (in Russ.).

[25] Lomachinskij V.A. (2004) Perspective ways of energy saving at processing of plant raw material // Storage and processing of agricultural raw material. 7: 11-12 (in Russ.).

[26] Lykov A.V. (1968) Theory of drying. Jenergija, Moscow, USSR.

[27] Singham Pragati, Birwal Preeti (2014). Technological Revolution in Drying of Fruit and Vegetables // International Journal of Science and Research (IJSR). 3 (10):705-711 (in Eng.).

Publication Ethics and Publication Malpractice
in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайте:

www:nauka-nanrk.kz

ISSN 2518-170X (Online), ISSN 2224-5278 (Print)

http://www.geolog-technical.kz/index.php/en/

Верстка *Д. Н. Калкабековой*

Подписано в печать 15.11.2019.
Формат 70x881/8. Бумага офсетная. Печать – ризограф.
19,7 п.л. Тираж 300. Заказ 6.

Национальная академия наук РК
050010, Алматы, ул. Шевченко 28, т. 272-13-19, 272-13-18