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# ВПЛИВ КОНСТРУКЦІЇ ВНУТРІШНЬОГО НАГРІВАЧА НА КІНЕТИКУ СУШІННЯ ВИНОГРАДНИХ ВИЧАВКІВ У МАСООБМІННОМУ МОДУЛІ

**В.О. Потапов, Є.М. Якушенко**

*Наведено результати досліджень кінетики вологовмісту та температури в процесі сушіння змішаним теплопідведенням (ЗТП-сушіння) виноградних вичавок у масообмінному модулі (МОМ) із внутрішнім нагрівачем.*

***Ключові слова:*** *сушіння, кондуктивна сушарка, кінетика, виноградні вичавки.*

# ВЛИЯНИЕ КОНСТРУКЦИИ ВНУТРЕННЕГО НАГРЕВАТЕЛЯ НА КИНЕТИКУ СУШКИ ВИНОГРАДНЫХ ВЫЖИМОК В МАССООБМЕННОМ МОДУЛЕ

**В.А. Потапов, Е.Н. Якушенко**

*Приведены результаты исследования кинетики влагосодержания и температуры виноградных выжимок в процессе сушки смешанным теплоподводом (СТП-сушка) в массообменном модуле (МОМ) с внутренним нагревателем.*

***Ключевые слова:*** *сушка, кондуктивная сушилка, кинетика, виноградные выжимки.*

# EFFECT OF DESIGN OF INTERNAL HEATER ON THE DRYING KINETICS OF GRAPE POMACE IN MASS TRANSFER MODULE

**V. Potapov, E. Yakushenko**

*The paper presents the results of a study of the drying process of grape pomace in the mass-transfer modules (MTM) with conductive heat supply, allowing to obtained a highly porous, fast recovery dried foods at high rates of efficiency and quality.*

*Next modules, that differ arrangement and design of the heater, were investigated in experiments: internal flat heater; inner tubular heater, the heater, which is located on the mass transfer surface. The results of these experiments allow to find, that the greatest intensity drying provides by inner tubular heater.*

*Empirical equation, which describe the kinetics of water content and allow to calculate the drying time in the MTM with conductive heat supply, has been proposed.*

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*The diffusion coefficient of moisture and its dependence from temperature were found after regression analysis of the experimental drying kinetics.*
***Keywords:*** *drying, conductive dryer, kinetics, grape pomace.*

**Formulation of the problem in general.** The priority direction of the Ukrainian agriculture in the near future is the policy of resource conservation. Modern food processing enterprises of Ukraine are inherent production with high energy costs. The most energy costs and material costs processes are the heat exchanging processes of food industry, that indicate the problematic task for their carrying out.

The problem of food stuff enriched with various dietary supplements, is extremely relevant for Ukraine in terms of economic and environmental crisis. This led to an increase in morbidity caused by largely existence deformation of food rations. Fruits, berries and vegetables are a major source of vital human organic substances - vitamins, minerals, pectin and others. Consumption of fruits, especially berries, is seasonal, so most of the year they are consumed in canned form. The downside industrial processing of fruits (sterilization, pasteurization, homogenization, tooling etc.) is the destruction of vitamins and other biologically active aromatic and moreover the high level of waste. Need for fruit and berry products for baby food in Ukraine is satisfied not more than 20%.

Production of the powders obtained by different methods of drying, allows to implement waste-free processes processing of agricultural products, which is one of the most promising ways of rational use of agricultural raw materials. Nonstandard products can be recycled in powders because the powder has low humidity, and it is almost entirely terminated biochemical processes that prolong the preservation powders in 2 - 3 times concerning the term of preservation of fresh raw materials.

For production of a powder of fruits berries and vegetables, are used various types of heat drying (spray, roller, conveyor, conductive, tunnel, etc.) and in the case of grinding it is used various grinders, crushers impact, which provide a relatively homogeneous product. The grinding in such crushers are carried out from blows of hammers on material particles, particle strikes on crusher housing, and particle collision and friction. Thus the stage of thermal drying and grinding leads to lost much of vitamins and other biologically active substances, during the drying process are formed decomposition products with an unpleasant odor and caramelization products, resulting in changing taste, color and aroma.

The high quality of fruit and vegetable powders can be obtained by freeze drying of juice and puree. The main advantage of method of sublimation is that the biological, physical and chemical changes in the product are minimal, vitamins are stored at 96...98%. Freeze drying not often applied in the food industry because of its high cost [1].

**Analysis of recent research and publications.** For example MHT-drying process is carried out in the functional capacities [2] with the mass transfer surface, less then surface evaporation which made from vapor tight material. Reducing the external surface of the mass transfer creates conditions in which the rate of evaporation of moisture in the product exceeds the rate of removal of steam from the functional capacities, leading to a sharp intensification of the drying process and the formation of a porous structure.

In this connection it is of practical interest in the study of ways of drying in the mass transfer modules (MTM) with the conductive heat supply to produce highly porous, fully recovered product, including powders. Due to the possibility of obtaining of powder with low final moisture content (5…6%) in a relatively short time (1.5...2 hours), drying in MTM is an alternative to freeze drying because of high quality and low power consumption [1].

In scientific work [4] determined that use internal heaters in MTM can increase drying efficiency index on 20…30% relative to the conditions of convective heat transfer to MTM. The above defined goal of this work.

**Purpose of the article** - the study of the kinetics of drying grape pomace in mass transfer modules with different types of internal heaters.

**The main materials of research.** During the research grape pomace were used. The study included conducting such experiments: defining opportunities in the course of the drying process in MTM with non vapor permeable barrier (heater) that divided MTM in half; research drying kinetics during conductive heat transfer (flat internal heater inside MTM, inner tubular heater inside MTM, heater located on the outside surface of the mass transfer MTM) (Fig. 1); study the kinetics of the temperature of the material in the drying process with conductive heat transfer.

Study of drying kinetics were performed using MTM with dimensions in the plane of 200 × 120 mm, the size of the gap between the plates 0.5 and 3.5 mm and variable thickness MTM - 30 and 60 mm. Kinetics moisture content were measured by the direct way during the drying process so the drying chamber with MTM, filled with grape pomace, were placed on electronic scales. The kinetics of the average temperature of the material in the drying process was determined by averaging the temperature in the center, on the surface of the MTM and the inner surface of the heater. Temperature was measured by thermocouples connected to the device MIT-12TC.

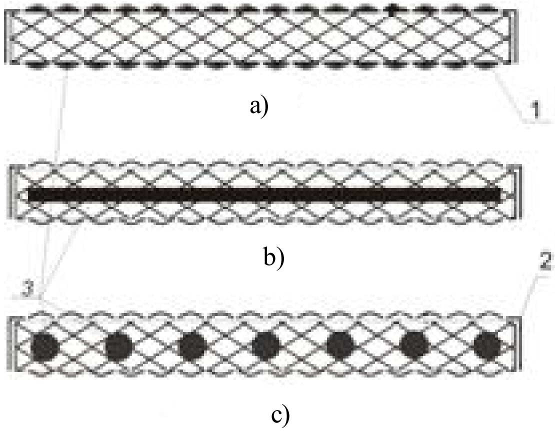



**Fig. 1. Scheme of the mass transfer module with a variety of heaters: a) flat surface heater; b) internal flat heater; c) inner tubular heater; 1 – material; 2 – MTM; 3 – heater**

The drying process was investigated in the temperature range of the internal heater 60 to 90°C at a constant temperature of air, which had not been heated and had ambient temperature. The temperature of the internal heater were maintained constant for the whole period of drying by heater power regulation. In this series of experiments, the air speed was the same – 5 m/s, were used MTM thick 60 mm a gap between the plates 1 mm. In MTM grape pomace were loaded with the same weight, it is allowed to avoid the influence of the initial moisture content to the outcome of experiments. Experiments were repeated three times for each temperature heater.

Fig. 2 shows the kinetic curves of moisture content and temperature during drying grape pomace in MTM with the internal heater. The results showed that the internal heater temperature significantly affects to drying time. When you change the temperature from 90 to 60°C, the drying is increased in 2 times. There is a change in the shape of kinetic curve, which can be observed depending on the drying speed of moisture. This led to the conclusion that at low temperatures the intensity of mass transfer reaches a maximum more later than under high temperatures.

As in a traditional convection heat transfer during MHT-drying on the obtained thermograms can distinguish three typical stages: heating, maximum speed drying and declining drying speed.

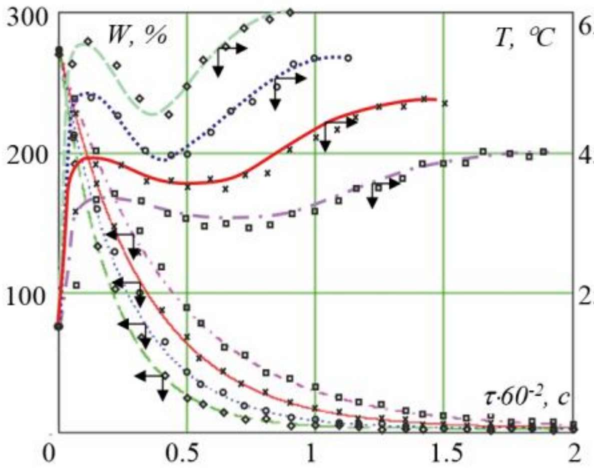
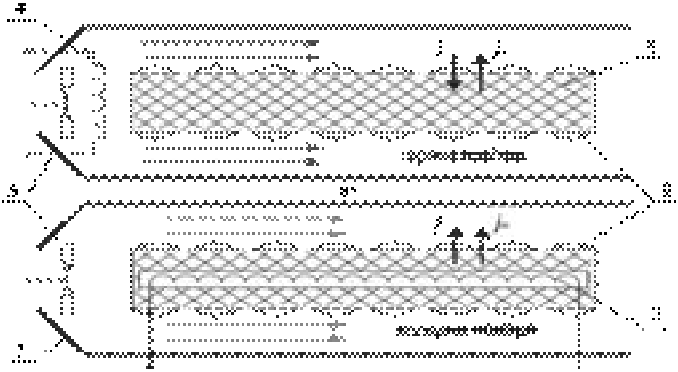



**Fig. 2. Drying kinetics of grape pomace in mass transfer modules with conductive supply of heat at different temperatures of the internal heater (υ=5 m/s, $t_c$=20°C): -◇–◇- 90 ° C; ·○··○·- 80 ° C; ×—× - 70 ° C; -□· ·□·- 60 ° C**

There is a big difference between these kinetic curves from those which observed under conditions of convection heat transfer to MTM, significant reduction (almost 2 times) heating period, so on the kinetics curves this period is not fixed – drying rate is constantly decreasing. This is due to the fact that under conductive heat transfer the thermal resistance of the heat source to the material much smaller, than from drying agent to the material in the case of convective heat transfer. As result, moisture quickly moved inland from the heater to the mass transfer surface, causing a great rate drying at this stage.

In the second stage, a layer of material with low moisture content are appeared near the internal heater and maximum evaporation zone moves closer to mass transfer surface. The heat flux can not transfer from the heater due to increased thermal resistance of dry layer and the temperature of the material is significantly reduced.

After evaporation of most of the free water in the capillaries begins the third period, when the temperature of the material gradually grow closer to its equilibrium value. It should be noted that the average temperature of the material at the end of drying is lower than the temperature of the internal heater as dried material creates a thermal resistance between the heater and drying agent.



b)

**Fig. 3. Scheme of the mass exchange module: a) convective heat input; b) conductive heat input; 1 – drying chamber; 2 – MTM 3 – internal heater; 4 – external heater; 5 – fan; 6 – product; *j* – heat flux; $j_m$ – mass flow**

A similar view has with kinetic relationships between moisture content and temperature in the drying in MTM with other types of heaters: flat surface heater and internal flat heater. The results of these experiments allowed to find, that the greatest intensity drying provides by inner tubular heater. This is due to the fact that with the flat surface heater the heat flux directed towards with mass flow, as in a traditional convection heat transfer (Fig. 3).

The inner flat heater creates the vapor tight barrier between mass transfer surfaces of MTM, resulting in complicate diffusion into the bulk material and the drying rate decreases, especially in the third stage.

To approximation of the experimental data was used the equation proposed in the monograph [5]. Approximation error data determined in dependence (1) within 5...7%:

$$W(\tau, T_m) = W_p + (W_0 + W_p) \cdot e^{-a_{m0} \cdot \left(\frac{T_m}{T_0}\right)^n \cdot \frac{\tau}{R^2}}, \qquad (1)$$

where $W$ – moisture content, kg/kg;

$a_{m0}$ – diffusion coefficient of moisture on the initial temperature of the material, m²/s;

$n$ – empirical coefficient;

$R$ – half thickness MTM, m;

$W_p$ – equilibrium moisture content, kg/kg;
$W_0$ – initial moisture content, kg/kg;
$T_m$ – average temperature of the material over the entire drying period, K;
$T_0$ – initial temperature of the material, K;
$\tau$ – drying time, s.

After data regression analysis were obtained $a_{m0}$ value and $n$ value for different types of internal heaters. The relevant data are presented in Table 1. This made it possible to offer a simple formula to determine the drying time of grape pomace in the MTM with of conductive heat transfer from the internal heater.

$$\tau(T_m) = -\ln\left[\frac{(W_k - W_p)}{(W_0 - W_p)}\right] \cdot \frac{R^2}{a_{m0} \cdot \left(\frac{T_m}{T_0}\right)^n}. \quad (2)$$

Calculations by this formula show that under the same conditions at the drying heater 70 °C MTM using internal tubular heater is 10% less than with internal flat heating element, and nearly 30% less than the flat surface of the heater.

**Table**

**The coefficients of mass transfer during drying MTM with different types of domestic heaters**

| Heater type | $a_{m0}$, $m^2/s$ | $n$ |
|---|---|---|
| flat surface heater | $1.74 \cdot 10^{-7}$ | 9.3 |
| internal flat heater | $2.46 \cdot 10^{-7}$ | 7.0 |
| inner tubular heater | $2.43 \cdot 10^{-7}$ | 8.3 |

**Conclusions.** Thus, on the basis of study effect of design of the internal heaters to drying in MTM on the kinetics of grape pomace, we set the reducing the period of heating material almost in half, causing the greater speed drying in the first stage, compared with drying in MTM with convection heat transfer. The greatest intensity drying observed in the case of internal tubular heater, which is 10% higher than with internal flat heater, and 30% higher than the flat surface of the heater. The equation for calculating the duration of the drying grape pomace in MTM with internal heaters were obtained.

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**Потапов Володимир Олексійович,** д-р техн. наук, проф., кафедра холодильної та торговельної техніки, Харківський державний університет харчування та торгівлі. Адреса: вул. Клочківська, 333, м. Харків, Україна, 61051. E-mail: potapov@bigmir.net.

**Потапов Владимир Алексеевич,** д-р техн. наук, проф., кафедра холодильной и торговой техники, Харьковский государственный университет питания и торговли. Адрес: ул. Клочковская, 333, г. Харьков, Украина, 61051. E-mail: potapov@bigmir.net.

**Potapov Volodymyr,** Doctor Of Science, Professor, Head of the Refrigeration and Trade Equipment Department, Kharkiv State University of Food

Technology and Trade. Address: str. Klochkivska, 333, Kharkiv, Ukraine, 61051. E-mail: potapov@bigmir.net.

**Якушенко Євген Миколайович,** канд. техн. наук, доц., кафедра холодильної та торговельної техніки, Харківський державний університет харчування та торгівлі. Адреса: вул. Клочківська, 333, м. Харків, Україна, 61051. E-mail: papelats@ukr.net.

**Якушенко Евгений Николаевич,** канд. техн. наук, доц., кафедра холодильной и торговой техники, Харьковский государственный университет питания и торговли. Адрес: ул. Клочковская, 333, г. Харьков, Украина, 61051. E-mail: papelats@ukr.net.

**Yakushenko Evgen,** Candidate of Sciences (comparable to the academic degree of Doctor of Philosophy, Ph.D.) Associate Professor, Refrigeration and Trade Equipment Department, Kharkiv State University of Food Technology and Trade. Address: str. Klochkivska, 333, Kharkiv, Ukraine, 61051. E-mail: papelats@ukr.net.

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# МОДЕЛЮВАННЯ РОЗПОВСЮДЖЕННЯ ТЕПЛОВИХ ПРОМЕНІВ ВІД СЕГМЕНТНИХ РЕФЛЕКТОРІВ

**Ю.М. Тормосов, С.Ю. Саєнко**

*Досліджено розподіл теплоти на приймачеві від спрощення відбивальної поверхні рефлекторів у інфрачервоних апаратах харчової промисловості завдяки заміні криволінійної форми рефлектора на сегментовану у вигляді прямолінійних відрізків.*

***Ключові слова:*** *рефлектор, випромінювач, відбивання, інфрачервоне випромінювання.*

# МОДЕЛИРОВАНИЕ РАСПРОСТРАНЕНИЯ ТЕПЛОВЫХ ЛУЧЕЙ ОТ СЕГМЕНТНОГО РЕФЛЕКТОРА

**Ю.М. Тормосов, С.Ю. Саенко**

*Исследовано распределение теплоты на приемнике от упрощения отражательной поверхности рефлекторов в инфракрасных аппаратах*