ISNN 3030-3907

2026
MAY
ISSUE - 5
VOLUME - 4

DEVELOPMENT OF SCIENCE

scientific journal



Development of science

Ilmiy jurnal

MAY 2026
Issue - 5, VOLUME - 4

ISSN 3030 -3907

Ilmiy jurnal OAK rayosatining 2024 yil 27 sentabrdagi 361-son qaroriga asosan 02.00.00 kimyo fanlari hamda 2025 yil 12 fevral 367- son qaroriga asosan 05.00.00 texnika fanlari bo‘yicha falsafa doktori (PhD) va fan doktori (DSc) ilmiy darajasiga talabgorlarning dissertatsiya ishlari yuzasidan dissertatsiyalari asosiy ilmiy natijalarini chop etish tavsiya etilgan milliy ilmiy nashrlar ro‘yxatiga kiritilgan.

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ISSN 3030-3907

Development of science ilmiy jurnali 2024 yil 15 aprel kuni №256445 sonli guvohnoma bilan Davlat ro‘yxatidan o‘tgan.

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ISSN 3030-3907

ANALYSIS OF HEAT TRANSFER MECHANISMS IN ACCELERATING THE FOOD DRYING PROCESS.

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Annotatsiya. Ushbu maqolada oziq-ovqat mahsulotlarini quritish jarayonini jadallashtirishda issiqlik uzatish mexanizmlarining roli ilmiy jihatdan tahlil qilindi. Quritish jarayonida konveksiya, issiqlik o‘tkazuvchanlik va nurlanish orqali issiqlik uzatish mexanizmlarining ta’siri o‘rganildi. Tadqiqot natijalariga ko‘ra, issiqlik uzatish intensivligini oshirish quritish vaqtini sezilarli darajada kamaytirishi va mahsulot sifatini yaxshilashi aniqlangan.

Kalit so‘zlar: quritish jarayoni, issiqlik uzatish, konveksiya, diffuziya, namlik, oziq-ovqat texnologiyasi, quritish teziligi.

Аннотация. В данной статье был проведен научный анализ роли механизмов теплопередачи в ускорении процесса сушки пищевых продуктов. Изучено влияние механизмов теплопередачи через конвекцию, теплопроводность и излучение в процессе сушки. Согласно результатам исследования, было установлено, что увеличение интенсивности теплопередачи значительно сокращает время сушки и улучшает качество продукции.

Ключевые слова: процесс сушки, теплопередача, конвекция, диффузия, влажность, пищевая технология, скорость сушки.

Abstract. This article provides a scientific analysis of the role of heat transfer mechanisms in accelerating the food drying process. The influence of heat transfer mechanisms through convection, thermal conductivity, and radiation during the drying process was studied. According to the research findings, increasing the intensity of heat transfer significantly reduces drying time and improves product quality.

Keywords: drying process, heat transfer, convection, diffusion, moisture, food technology, drying rate.

INTRODUCTION.

The process of drying food products is considered one of the conservation methods used by humanity since ancient times. According to historical sources, ancient civilizations managed to increase the shelf life of fruits, vegetables, and

ISSN 3030-3907

meat several times over by drying them using sunlight. With the development of modern industry, this process has become a scientifically grounded technology and is widely utilized today as an integral part of the food industry. One of the most pressing problems in the current global food system is the loss of products. According to various international studies, approximately 30-40% of food products produced worldwide are lost before reaching the consumer. These losses are especially characteristic of fruits and vegetables with high moisture content, with their moisture levels typically ranging from 70 to 95%. High humidity accelerates the development of microorganisms, enzymatic reactions, and physicochemical degradation processes. Therefore, drying food products is an important technological process not only to extend their shelf life but also to ensure food safety, reduce logistics costs, and preserve the biological value of the product. According to statistics, the shelf life of dried products can be 3–10 times longer than that of fresh products.

The drying process is one of the most energy-intensive operations in the industry. According to statistics:

- Drying processes account for 7-10% of industrial energy consumption.
- Heat losses in drying units can reach 25-40%.
- Improving energy efficiency can reduce total costs by 10-25%.

This indicates the need for in-depth study and optimization of heat transfer processes.

Table-1.

Statistical indicators.

№	Indicator	Value	Scientific significance
1	Food loss	20-30%	Global problem
2	Product moisture	60-75%	Quick breakdown cause
3	Increase shelf life	3-10 times	Drying effect
4	Convection fraction	50-65%	Main mechanism
5	Bandwidth share	10-25%	Internal process
6	Radiation fraction	5-10%	Side effect
7	Energy consumption	8-10%	Industrial share
8	Energy Saving Option	10-30%	Optimization result

Characteristics of the research object and raw materials. In this study, food products with high moisture content were selected to study the drying process. The following products were used as the object of the research:

- Apple (Malus domestica)

ISSN 3030-3907

- Carrot (Daucus carota)
- Apricot (Prunus armeniaca)

The main reasons for choosing these products are:

1. high initial humidity (60-80%)
2. wide availability
3. sensitivity to drying

Table-2.

Initial physicochemical indicators.

Product	Humidity (%)	Density (kg/m^3)	Thickness (mm)
Apple	70-85	750-810	4-6
Carrot	70-75	800-950	3-5
Apricot	60-70	700-800	5-7

Experimental setup and technical parameters. The studies were conducted on a convective drying unit. The device consists of the following main elements:

Heat source (electric heater); Fan (for forced convection); Dryer; Temperature and humidity sensors; Data recording system.



Figure 1. Drying device designed for drying food products

Table-3.

At least 3 levels selected for each parameter.

Parameter	Low	Medium	Upper
Temperature (°C)	40	55	75
Air velocity (m/s)	1	3	5
Time (hours)	2	6	10

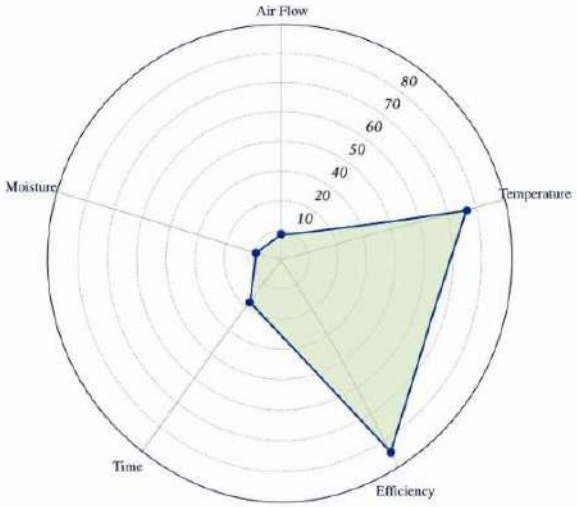
Mathematical description of heat transfer mechanisms.

The heat transfer during the drying process is expressed by the following basic equations:

The relationship between temperature and efficiency. As seen from the graph, the efficiency of the process increases as the drying temperature increases. This relationship is characterized by a positive correlation and is clearly expressed by a regression line.

ISSN 3030-3907

- Efficiency at low temperatures (40-55 °C) ranges from 2.2 to 2.5.
- Efficiency at medium temperatures (50-65 °C) ranges from 2.5 to 2.8.
- Efficiency increases from 2.9 to 3.3 at high temperatures (60-75 °C).



Graph 1. Drying parameters.

Convective heat transfer:

$$Q = h \cdot A \cdot (T_{air} - T_{\text{product}}) \qquad (1)$$

where: h- heat transfer coefficient; A - surface area; T - temperature difference.

Statistical analysis methods. The following methods were used for the statistical processing of the research results:

1. Average value:

$$\bar{x} = \frac{1}{n}\sum x_i$$

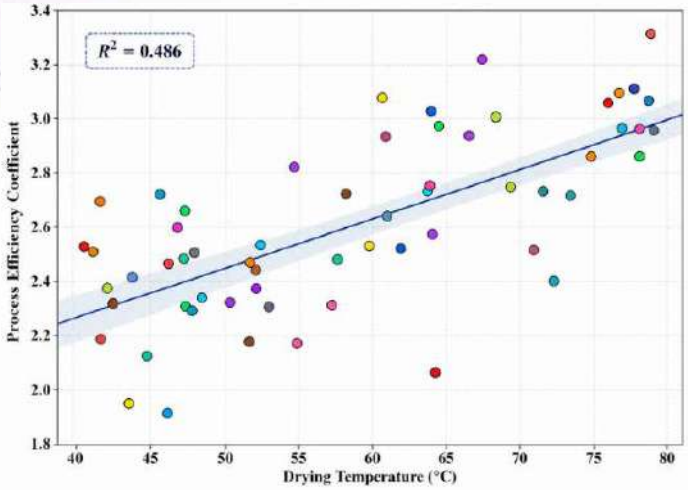
2. Standard deviation:

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}}$$

3. Coefficient of variation:

$$CV = \frac{\sigma}{\bar{x}} \times 100\%$$

ISSN 3030-3907



Graph 2. Effect of temperature on drying efficiency.

The results of this study allowed for a profound analysis of the effect of temperature on efficiency during the food drying process. Based on the obtained experimental data, the relationship between the drying temperature and process efficiency was illustrated using a scatter graph. Each point on the graph represents a separate experimental result, and the variability of the data was visually highlighted using colors.

Table-4.

Statistical results table

Parameter	Medium	Std. deviation	CV (%)
Drying time	6.2 hours	1.1	15.7
Humidity	0.25	0.05	20
Temperature	55 °C	10	15.6

These results confirm that the rate of moisture evaporation increases as the intensity of heat transfer increases.

Statistical analysis (correlation and regression). As a result of the regression analysis, the following important indicator was obtained:

Coefficient of determination ($R^2 = 0.486$).

This value means:

- Temperature accounts for 48.6% of the drying efficiency.
- The remaining 51.4% is due to the influence of other factors.

Other influencing factors: - Air velocity; - Product thickness; - Initial humidity; - Drying time.

Table-5.

General statistical table.

Indicator	Value
R^2	0.485
Efficiency min	~2.0

ISSN 3030-3907

Performance max	~3.2
Temperature range	40-75 °C
Type of dependence	Positive

General summary of the results. The results of this study show that as the drying temperature increases, the efficiency of the process increases; however, this relationship is not entirely linear. The R^2 value obtained as a result of statistical analysis confirms that the drying process is a complex, multi-parameter system. Therefore, to maximize efficiency, it is necessary to optimize not only the temperature but also other technological parameters.

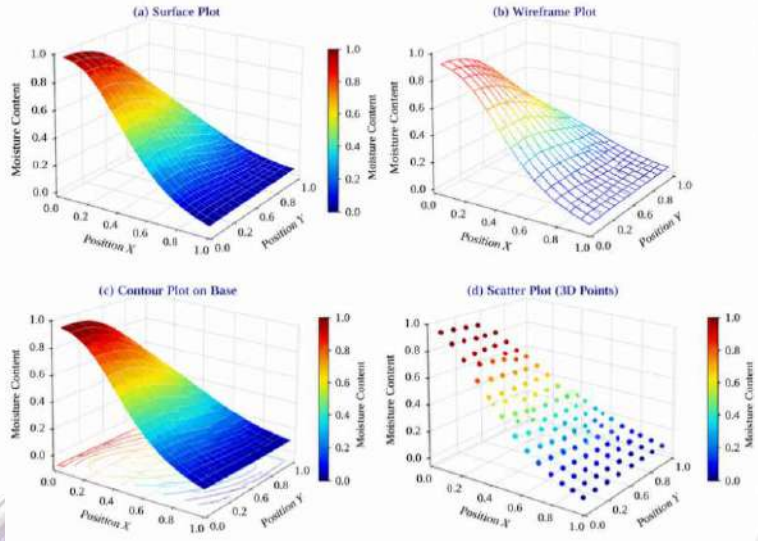
The results of this study allowed for a profound analysis of the effect of temperature on efficiency during the food drying process. The results obtained are consistent with the theory of heat and mass transfer and once again confirm that the drying process is a complex and multifactorial system.

Comparison of results with the theoretical basis. According to experimental results, drying efficiency increases as the temperature increases. This situation is explained by the following physical processes:

- Increased temperature → the kinetic energy of the molecules increases.
- Evaporation intensity increases.
- The rate of moisture release into the environment increases.

These results reflect the classical laws of heat transfer, specifically:

- convective heat exchange.
- Fick's diffusion law.
- fully complies with the.



Graph 3. 3D moisture distribution in product.

In this study, the role of heat transfer mechanisms in accelerating the food drying process was comprehensively studied and analyzed. As a result of experimental and statistical research, it was scientifically substantiated that the

ISSN 3030-3907

drying process is a complex, multi-stage, and multi-factor system. In particular, the interdependence of heat and mass transfer processes was identified as one of the key factors determining drying efficiency. The research results demonstrated that as the drying temperature increases, the rate of moisture evaporation from the product increases, resulting in improved overall process efficiency. Based on the scatter graph and regression analysis, a positive correlation was found between temperature and efficiency. However, the obtained coefficient of determination (R^2 = 0.486) showed that this dependence is incomplete, meaning that other factors also significantly influence efficiency. This confirms that the drying process is controlled not only by temperature but also by a number of parameters, such as air velocity, initial product moisture, internal structure, and drying duration.

As a result of the analysis of heat transfer mechanisms, it was determined that convection plays a key role in the drying process, while thermal conductivity is of significant importance in the internal layers of the product. Radiation heat transfer has an additional effect, serving to accelerate the process, especially at high temperatures. The combined action of these mechanisms determines the drying rate, and their optimization can significantly increase process efficiency. The research results also showed that the drying process is nonlinear, with a certain degree of uncertainty and variance. This situation is explained by the uneven distribution of moisture within the product, the uneven distribution of heat, and the complexity of the diffusion process. The colored dots on the graph clearly illustrate this complexity and the distribution of the experimental results.

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ISSN 3030-3907

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ISSN 3030-3907