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DESIGNING OPERATING PARAMETERS FOR EQUIPMENT USED TO COOL BAKERY PRODUCTS

ПРОЄКТУВАННЯ ЕКСПЛУАТАЦІЙНИХ ПОКАЗНИКІВ УСТАТКУВАННЯ ДЛЯ ОХОЛОДЖЕННЯ ХЛІБОБУЛОЧНИХ ВИРОБІВ

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Abstract. *The article presents the results of research and scientific justification for the design of operational parameters for equipment for vacuum cooling of bakery products. An analysis of the effect of vacuum intensity on the quality indicators of finished products was carried out, and correlations between the structural and mechanical properties of the crumb and the parameters of the rarefied environment were established. The main objective of the work is to determine the optimal operating characteristics of equipment for 0,5 kg Oval bread, which allow the cooling process to be intensified before cutting and packaging. Based on the developed methodology, operational parameters were established, in particular, critical values of pressure and air pumping speed, which ensure the preservation of structural integrity, increased porosity and volume of products. The results of the study made it possible to design a vacuum cooler, the use of which in current production provides a significant reduction in production space, minimisation of manual labour costs and an increase in the economic efficiency of the enterprise. The data obtained confirm that the transition to controlled operating modes of vacuum equipment is a key factor in stabilising quality and extending the shelf life of products in modern baking lines.*

Key words: *equipment design, performance indicators, vacuum cooling, bakery products, structural and mechanical properties of bread crumb, process intensification, energy saving, Oval bread.*

Анотація. *У статті представлено результати дослідження та наукового обґрунтування проектування експлуатаційних показників устаткування для вакуумного*

охолодження хлібобулочних виробів. Проведено аналіз впливу інтенсивності вакуумування на показники якості готової продукції та встановлено кореляційні зв'язки структурно-механічних властивостей м'якуша з параметрами розрідження середовища. Основна мета роботи полягає у визначенні оптимальних характеристик роботи обладнання для хліба «Овальний» масою 0,5 кг, що дозволяють інтенсифікувати процес охолодження перед нарізанням та пакуванням. На основі розробленої методики встановлено експлуатаційні параметри, зокрема критичні значення тиску та швидкості відкачування повітря, які забезпечують збереження цілісності структури, підвищення пористості та об'єму виробів. Результати дослідження дозволили спроектувати конструкцію вакуумного охолоджувача, застосування якого в поточному виробництві забезпечує значне скорочення виробничих площ, мінімізацію витрат ручної праці та підвищення економічної ефективності підприємства. Отримані дані підтверджують, що перехід до контрольованих експлуатаційних режимів вакуумного устаткування є ключовим чинником стабілізації якості та подовження терміну свіжості продукції в умовах сучасних хлібопекарських ліній.

Ключові слова: проектування устаткування, експлуатаційні показники, вакуумне охолодження, хлібобулочні вироби, структурно-механічні властивості м'якуша, інтенсифікація процесу, енергозбереження, хліб «Овальний».

Introduction.

In modern bread production, the cooling stage of finished products is one of the most time-consuming and resource-intensive processes. Traditional methods of cooling bread in natural conditions lead to a number of technological and economic problems: the occupation of significant production areas, the involvement of additional labour to handle trays, and disruption of the principle of continuous flow lines. Immediately after baking, the surface temperature of the product is 150–180°C, and at the boundary between the crust and the crumb, it is about 100°C with a crumb moisture content of up to 45%. Uncontrolled moisture loss (shrinkage) during slow cooling not only reduces the yield of finished products, but also negatively affects their structural and mechanical properties.

In view of this, designing the performance characteristics of equipment to intensify cooling is a strategic task for the industry. The use of the vacuum method not only reduces the time required to prepare products for cutting and packaging, but also significantly improves their quality characteristics: it increases the specific volume and porosity of the pulp, while ensuring strict compliance with food safety requirements and extending the shelf life [1-3].

Purpose and objectives of the study. The purpose is to scientifically substantiate and design optimal operating parameters for vacuum equipment for cooling bread. To achieve this purpose, the following objectives were set:

1. Analyse the current state and available equipment for cooling bakery products.
2. Develop an experimental methodology and investigate the physical and mechanical changes in the crumb under vacuum conditions.
3. Establish the effect of vacuum intensity on the quality indicators of bread and determine the amount of moisture released during the process.
4. Carry out an engineering justification of the operational parameters (pressure, speed, productivity) of equipment for cooling 0,5 kg of bread in a flow.
5. Calculate the economic efficiency of implementing the designed equipment.

Object of study: the process of vacuum cooling of 0,5 kg white 'Oval' bread in a batch mode before the cutting and packaging stages.

Subject of study: patterns of change in the structural, mechanical and quality characteristics of bread depending on the operating modes of vacuum cooling equipment [4-6].

Main text.

To study the process of vacuum cooling of bakery products, a specialised research facility was designed and put into operation (Figure 1). The basis of the facility 1 is a metal table made of profiled angle iron, which ensures the rigidity of the structure.

The key element of the system is a vacuum chamber 11, which is attached to the condenser 6 via a flange connection. The condenser is equipped with pipes for supplying 5 and draining 7 cooling water, as well as a pipe for draining condensate 4, which allows moisture to be effectively removed from the steam-air mixture. A vacuum pump 2 with a capacity of 25 m³/hour is mounted in the lower part.

A special feature of the design is a manual base 12 covered with 5 mm thick food-grade rubber, which ensures the tightness of the chamber when interacting with the product. For ease of movement within the laboratory, the unit is equipped with four swivel wheels with locks [7-9].

The experimental part of the work was carried out at the AVANT-AGRO private enterprise (Khodorivtsi village) during the actual technological process of baking Oval white bread. The methodology involved a comparative analysis of two cooling methods: natural (atmospheric) and vacuum.

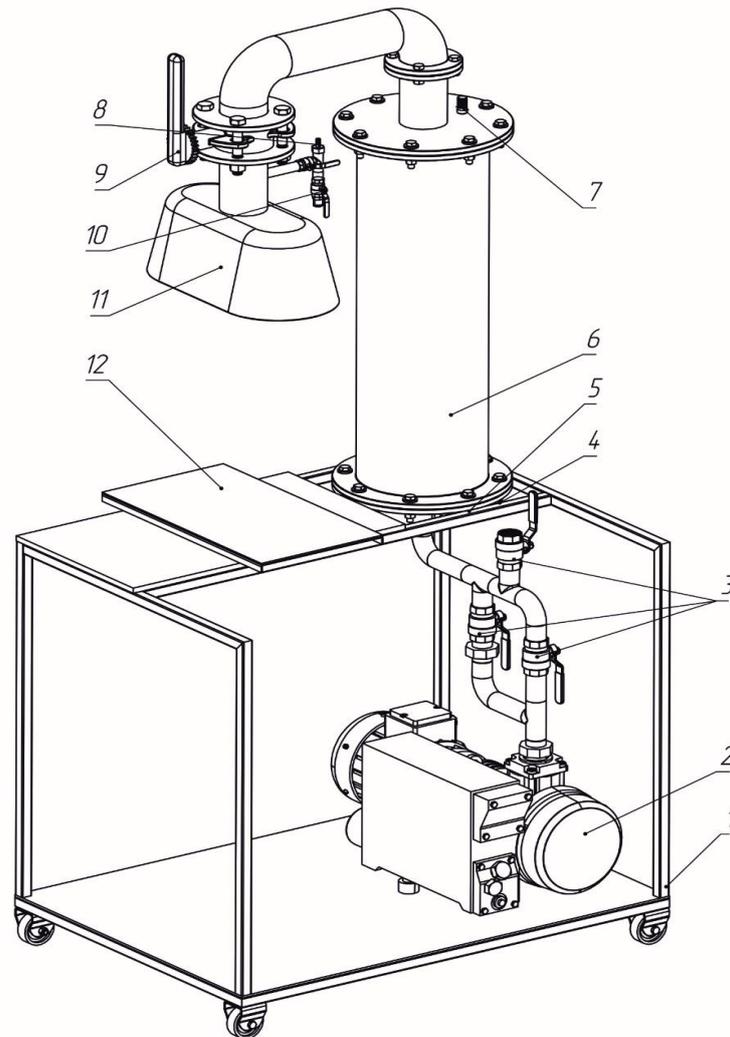


Figure 1 – Installation for researching vacuum cooling of bakery products

The research process began with the recording of initial parameters: freshly baked bread was weighed on precision electronic scales, and the temperature in the centre of the crumb was measured using a thermocouple connected to a voltmeter. During natural cooling, measurements were taken every 15 minutes for 3 hours. At the same time, vacuum cooling was carried out, where the time to reach the target temperature of 25-30°C and the change in the mass of the product were recorded.

Particular attention was paid to structural and mechanical properties. For this purpose, an AP-1 penetrometer was used. A 40 mm thick slice was cut from the cooled loaf and subjected to compression deformation [10-12].

The indicators were calculated using the following formula:

$$H_{el} = H_{tot} = H_1 - H_2 \quad (1)$$

where: H_1 (H_{tot}) – total compression deformation of the crumb;

H_2 (H_{pl}) – residual (plastic) deformation;

H_{el} – elastic deformation characterising the quality of the crumb structure.

During the research, it was found that achieving a vacuum of 97 kPa allows the temperature of bread to be instantly reduced to 30°C, but such an intense effect leads to undesirable defects – cracking and drying out of the crust. This necessitated the adjustment of operating parameters.

To prevent damage to the product, a two-stage vacuuming mode was proposed and tested. In the first stage (lasting 5 seconds), the air pumping speed was artificially limited for gradual adaptation of the crumb structure. In the second stage, the speed was increased to the maximum. It was found that a total vacuuming time of up to 10 seconds ensures the integrity of 0,5 kg loaves of bread, with the temperature decreasing evenly throughout the entire volume [13].

Analysis of penetrometry indicators confirmed the positive effect of vacuum on quality: the elasticity of the crumb H_{el} was higher than during natural cooling. This is explained by the fact that rapid evaporation of moisture inside the capillaries creates internal pressure, which «supports» the porous structure, increasing the specific volume of the product.

Thus, the designed operating parameters – pump capacity of 25 m³/hour, working pressure of 97 kPa and a two-stage control algorithm – allow achieving high product quality with a significant reduction in production costs [14-15].

Conclusions.

Based on a series of studies aimed at designing the operational performance of equipment for cooling bakery products, the following conclusions have been drawn:

1. Analysis of the current situation confirmed that traditional cooling methods are a limiting factor for the baking industry due to the significant duration of the process (up to 3 hours), large weight losses (shrinkage) and the need for large production areas. It has been established that vacuum cooling is the most promising alternative, allowing for intensified production and ensuring a high level of product hygiene prior to packaging.

2. As a result of experimental studies conducted at the AVANT-AGRO private enterprise, the kinetics of moisture release and temperature change in 0,5 kg Oval bread were studied. It was established that the use of vacuum rarefaction to 97 kPa reduces the cooling time to 25–30 °C by 10–15 times compared to natural cooling.

3. The optimal operating modes of the equipment were determined. The feasibility of using a two-stage vacuuming mode was scientifically substantiated: an initial period (5–7 seconds) with a reduced air pumping speed to stabilise the porous structure, followed by intensive vacuuming. This approach avoids mechanical damage to the crust and preserves the marketable appearance of the product.

4. Studies of the structural and mechanical properties of the crumb using an AR-1 penetrometer confirmed the improvement in the quality indicators of the finished product. It has been established that vacuum cooling contributes to an increase in the proportion of elastic deformation *Hel* by 12–15%, which has a positive effect on the porosity and specific volume of bread, as well as improving the conditions for its further industrial cutting.

5. The economic and technological efficiency of the designed equipment lies in ensuring continuous production flow, freeing up to 50% of the cooling compartment space and reducing technological moisture losses. The introduction of a vacuum cooler with a pump capacity of 25 m³/hour allows stabilising product quality and reducing the cost of operating expenses at the enterprise.

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