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IMPROVING THE EFFICIENCY OF PROCESSES AND EQUIPMENT OF BAKING PRODUCTION

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Abstract: *The Scientific School of Bakery Processes and Equipment, which operates at the National University of Food Technology (Kyiv, Ukraine), has a number of scientific developments that take into account the world's leading trends in the industry and significantly improve product quality, productivity and hygiene requirements. The essence of the proposals concerns the following processes:*

– *Use of kneading machines with cam working elements. This allows to ensure the high quality of the third stage of kneading – plasticization.*

– *Combination of dough fermentation operations and forming pieces under pressure in one unit. This reduces fermentation time, reduces the number and metal consumption of equipment.*

– *Combination of baking and drying processes for some varieties of bread products, in particular, rusks and chopsticks. This avoids heat consumption for reheating the products, the amount of equipment.*

– *Rational use of heat of steam of hygrothermal processing and heat of secondary steam which is formed during baking of bread.*

– *Vacuum cooling of bread products. This ensures fast cooling of bread before cutting and packing.*

– *Stream cutting of different types of bread.*

– *The use of packaging equipment based on integrated technical complexes created on the basis of mechatronic functional modules, each of which is a functionally and structurally independent product with a large number of synergistically interrelated characteristics and parameters.*

Each of these proposals is examined by competent experts and substantiated. The total result is an increase in product quality, productivity and safety, ensuring hygienic requirements, reducing the number of equipment and ensuring its versatility.

Keywords: *bread, equioment, kneading, fermentation, forming, recuperation, baking, cooling, cuttinf, packaging.*

INTRODUCTION

Trends of improvement of processes and equipment of bakery productions which allow to expand the range of production, to provide its quality, to reduce energy consumption, quantity of the equipment and production areas are considered.

It is taken into account scientific developments of the scientific School of Bakery Processes and Equipment, which operates at the National University of Food Technology (Kyiv, Ukraine).

- Innovations relate to the following processes and equipment:
- Kneading machines with cam working elements.

- Combination of dough fermentation operations and forming pieces under pressure in one unit.
- Combination of baking and drying processes for some varieties of bread products, in particular, rusks and chopsticks.
- Rational use of heat of steam of hygrothermal processing and heat of secondary steam which is formed during baking of bread.
- Vacuum cooling of bread products.
- Stream cutting of different types of bread.
- Packaging equipment based on integrated technical complexes created on the basis of mechatronic functional modules

EXPOSITION

New metod of rusk production

It has been proposed a new method for the production of bakery products from yeast dough, in which the all process of dough treatment takes place in one fermentation-forming unit (extruder). Fermentation of the dough and the accumulation of carbon dioxide, necessary for loosening the dough pieces, is carried out in a closed container. Forming and simultaneous loosening of the dough at the exit from the matrix is carried out directly under mesh of tunnel stove. The saturation of the dough with carbon dioxide, which depends on the fermentation time of the dough in a closed container, affects the loosening of the formed dough rope and, accordingly, the porosity of baked products (Telychkun et al., 2010).

When the dough is saturated with carbon dioxide, its viscosity decreases, which makes it possible to significantly reduce the molding pressure at a sufficient flow rate and reduce the risk of annular scoring and roughening on the surface.

The structure of the looseness of the test rope is influenced not only by the absolute value of the pressure, but also by the nature of its fall along the length of the channel. An increase in the rate of pressure drop contributes to an increase in the number of gas bubbles that have formed and, accordingly, to a structure with smaller pores.

Our proposed production method excludes the subsequent processing of the dough rope after leaving the forming channel, which determines the dimensions and quality indicators of finished products. Expansion of the range of rusks and an increase in demand for small-diameter rusks lead to the creation of specialized industries. In the traditional production method (Figure 1a), rusks are molded by extrusion, however, further proofing on sheets does not allow using all the advantages of this molding method, and requires the use of manual labor. The new method of production of rusks by extrusion and machine-apparatus chart of continuous production is offered. In this method, the operations of intensive kneading, fermentation and forming are combined in one unit, and occur under pressure. The total fermentation time under pressure is an hour or less. Based on the research and using the proposed production method, it has been developed a flow-mechanized line for the production of crackers (Figure 1b).

After kneading on a kneading machine, the finished dough is fed into a fermentation-forming unit (Figure 2), at the exit from which the dough pieces are loosened and extruded directly under the tunnel oven. Loosening of the dough pieces occurs at the exit from the forming hole due to carbon dioxide, which has accumulated during fermentation in the tank of the unit. The use of fermentation-forming unit makes it possible to replace multifunctional, bulky equipment for dividing, forming and proofing with one unit.

When rusks of small diameter are produced, it is advisable to combine the processes of baking and partial drying of the biscuit plate (Figure 3).

The rusks are cut after baking-drying process in a stream using a macine with sqrue knife without preliminary cooling. After 3-4 minutes, the rusk becomes fragile and cannot be cut.

The rusk is cooled in a rotary vacuum chamber. The rotor with the product dose is stopped, a vacuum is created in the chamber, and the rusk is cooled for 2 minutes.

The effect of the line (Figure 3) in comparison with the existing ones is to increase the productivity of production, ensure its flow rate, reduce the amount of intermediate equipment, and improve the quality of finished products.

Traditional method of rusks production

- Kneading of dough
- Fermentation of dough, 3-4 hours
- Forming of rusks
- Proofing in profer, 60 mim
- Baking in stove
- Cooling and aging in coolers, 6-18 hours
- Cutting
- Drying in stove or other aparatus
- Cooling
- Packaging

Total time – 12-24 hours

a

Innovative method of rusks production

- Intensive kneading of dough
- Fermentation of dought with pressure, 60 min
- Forming of rusks on conveyor of stove
- Combine baking and drying in stove, 20-30 min
- Cutting
- Cooling with vacuum to 30 °C
- Packaging

Total time – 2 hours

b

Fig. 1. Traditional (a) and innovative (b) methods of rusk production

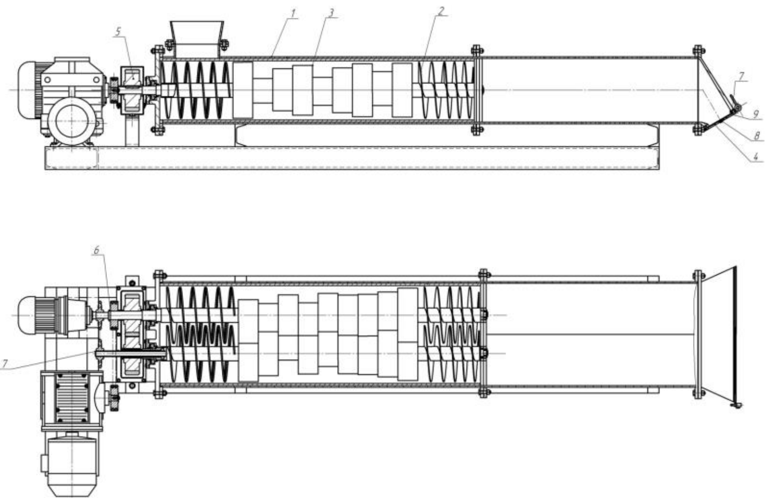

Fig. 2. Mixing-fermenting-forming unit

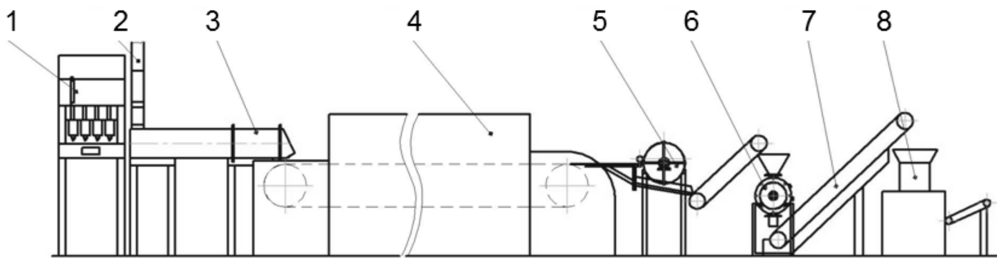

Fig. 3. Production line of rusks:
1 – Flour feeder; 2 – Dispencer of liquid components; 3 – Mixing-fermenting-forming unit;
4 – Stove for baking and drying; 5 – Cutting machine; 6 – Colling vacuum-aparatus;
8 – Packaging machine

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Justification of kneading machines with cam working elements

Based on the theoretical search and analysis of existing machines, we have developed a new experimental model. The aim – to justify the working element for intensive kneading of dough, with a fine-grained structure and evenly distributed porosity. The main research was carried out on a two-camer experimental installation (Figures 4, 5) using a different configuration of working elements: cam, screw and finger work elements.

During the kneading the dough, the energy required for the kneading, humidity, time, temperature and dough structure was determined. In the finished product, porosity was determined and the structure of the product examined.

The power consumed for mixing was determined separately for the working bodies (screw, pin, cam) with a device for measuring the electric power (wattmeter) connected to the motor of the dough kneading machine according to the corresponding scheme.

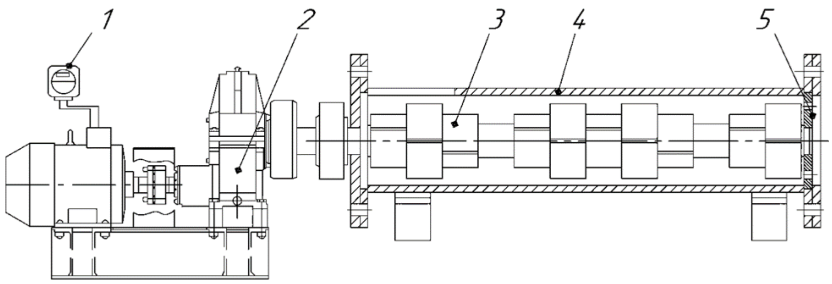

Fig. 3a. The scheme of an experimental installation with cam operating elements:
1 – device for measuring electric power; 2 – drive; 3 – working element;
4 – frame; 5 – stabilizing grate.

Different types of machines are used to mix the yeast dough, which, depending on the prescription composition and assortment, have different effects on the dough and its maturation. The quality of the dough mixing machines is determined by the quality of the finished product, among which the main indicator is the porosity of the finished product.

To analyze the porosity of the finished products, the tow was cut, photographed and, using the program ImageJ, found the porosity of the finished product and calculated the number of pores. ImageJ is an image processing program where you can calculate the area and level of detail of an image, statistics of user-defined selections, measure distances and angles, create density histograms and profile sections of the plot.

The solving the problem of intensifying the process of kneading under continuous tasting can be solved by applying cam, screw and pin working elements.

The cam (Figure 5), screw (Figure 6), pin working elements (Figure 7) and their influence during the mixing on the quality of the semi-finished product and the finished product were studied. The step of the the working elements, was being changed and the plane of the living section was being adjusted at the outlet of the yeast dough after mixing.

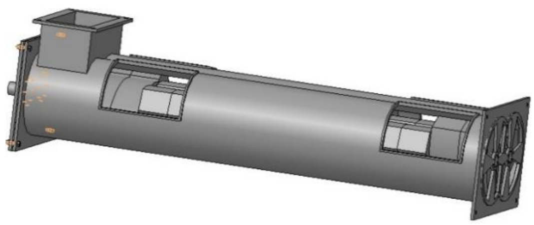

Fig. 4. Model of experimental installation with cam working elements inside

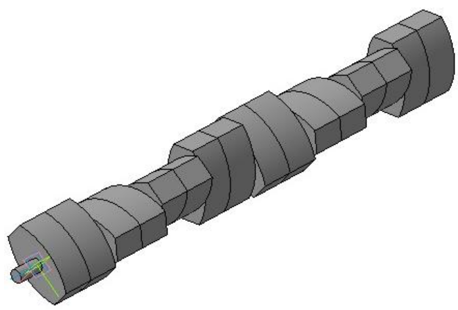

Fig. 5. Cam working element

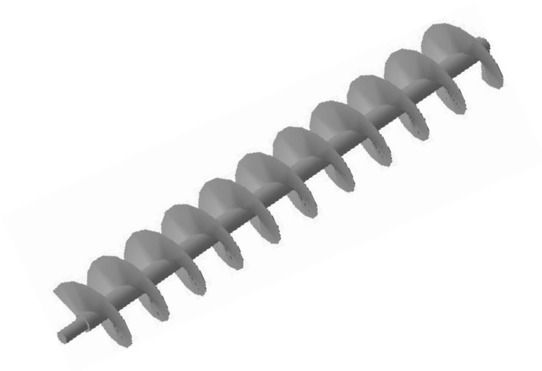

Fig. 6. Screw working element

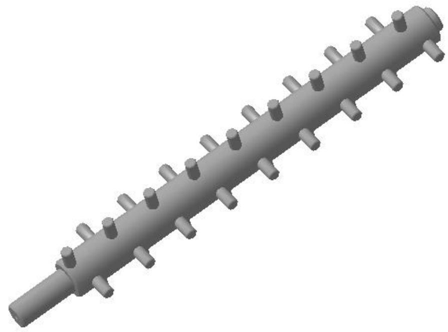

Fig. 7. Pin working elements

The conducted studies confirm the positive effect of enhanced mechanical processing of the dough during the mixing process. Due to the use of continuous action elements, the process of mixing the yeast dough is intensified, which makes it possible to shorten the dough fermentation period before processing.

The conducted comparative analysis confirms the expediency of using cam-working elements. Screw working elements, have good transporting properties and are highly productive during the use. The use of pin working elements is appropriate in combination with screw working elements at the beginning of the screw, such a working element will allow to mix in the beginning and subsequently transport the semi-finished product, then the actual masonry and plasticization will be carried out at the expense of the pin working elements.

In case of application of the cam working elements, an intensive mixing the yeast dough takes place and high porosity indicators of the finished product are observed.

Studies have confirmed that at the same time and intensity and duration of dipping affect the value of the share of specific work. Intensity, in turn, depends on the frequency of rotation of the worm shaft and the mechanism of its impact on the dough, that is, the construction of the dough machine. Thus, at the same intensity, a variety of specific work can be obtained by varying the duration of dipping and achieving the required parameters of the structural and mechanical properties of the dough and the high porosity of the finished product (Figure 8).

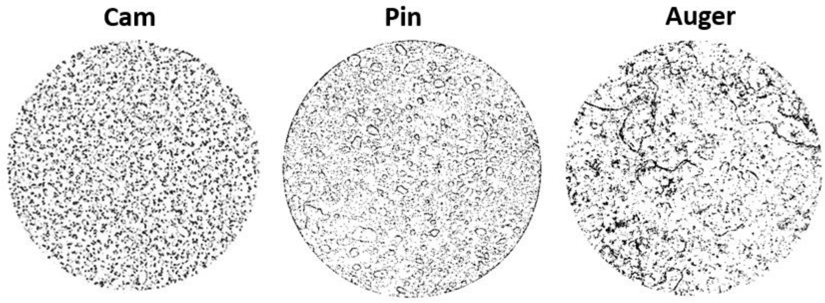

Fig. 8. Homogeneity of distribution of yeast dough components after kneading
The white mesh is a gluten-free frame. Black specks – starch.

Pay attention to the quality of the bread crumbs (Figure 9). If the dough is processed with cams, the crumb has the best porosity.

We suggest using kneading machines with cam shafts (Figure 10).

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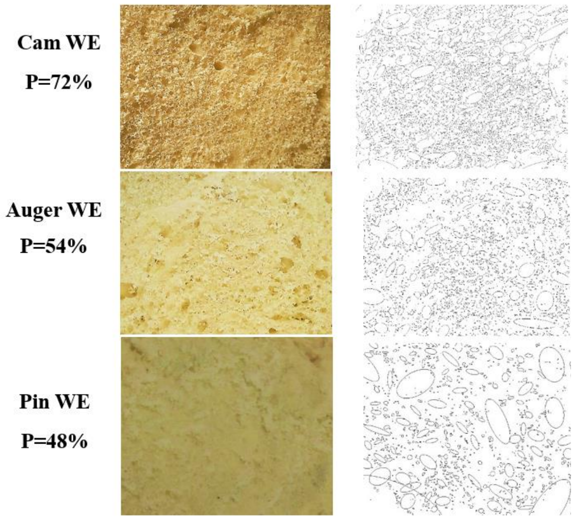

Fig. 9. Effect of type of working element on porosity of bread crumb

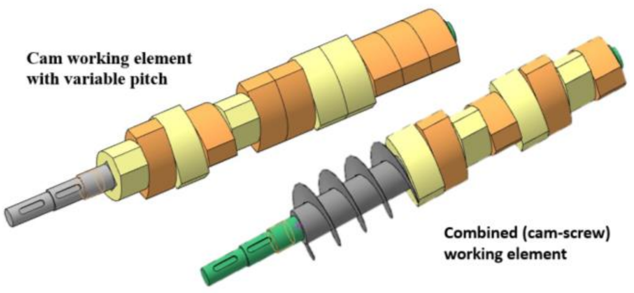

Fig. 10. Recommended design of working elements of dough kneading machine

This can be a Cam working element with a variable pitch. Where the step is small – there is a mixing, and where the step is bigger – there is intensive kneadind and formation of gluten. It can be reccomend using an auger in the first zone.

Rational use of heat of steam of hygrothermal processing and heat of secondary steam from baking of bread

It is known that bread in the first baking zone is treated with steam. Steam is also formed during baking. A lot of heat goes away with steam. It was suggested returning it to the oven.

Consider this scheme (Figure 11). The mixture of steam and air leaves the baking chamber and is compressed in the compressor to 3 atmospheres, and run to the heat exchanger. In the heat exchanger the steam condenses, and air is thrown out in the atmosphere. The formed condensate through the throttle is fed into the heat exchanger, and evaporates at atmospheric pressure due to the heat of condensation. The steam is fed back into the zone of hydrothermal treatment.

This solution allows you to reduce fuel consumption for the boiler, and under sometimes – to abandon the boiler.

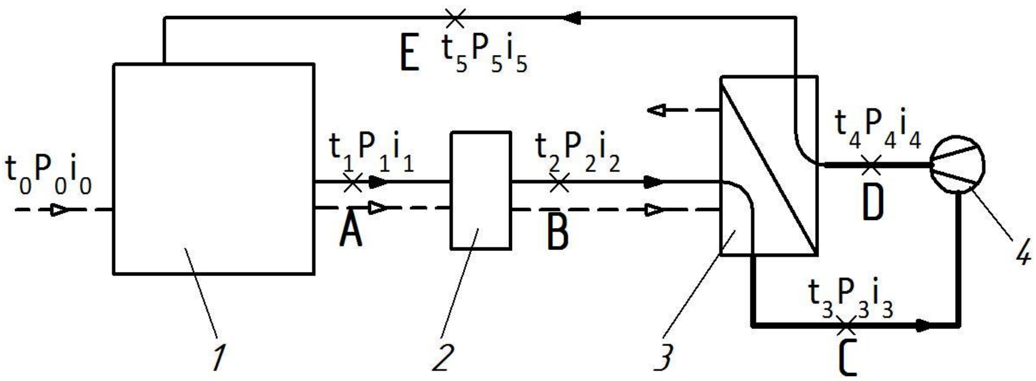

Fig. 11. Schematic diagram of steam regeneration in a baking chamber
1 – Stove; 2 – Heat pump; 3 – Heat exchanger ; 4 – Throttle

Vacuum cooling of bread

Cooling of bread is carried out to give the bread structural and mechanical characteristics that will allow the process of cutting and packaging, because under mechanical impact baked hot bread crumples, loses its shape, structure and porosity (Everington, 2003; Gavva, 2017; McDonald, 2001).

In practice, the most common are two methods of cooling: natural and air-conditioned (Telychkun, 2020). The main disadvantages of these cooling methods are: significant duration of the process, large size and weight of equipment for cooling bread, high energy costs, complex system of conveyors, requirements for working air conditions, uneven cooling, bacterial contamination of bread, the natural method of cooling requires manual labour.

An innovative way to cool food, including bread, is to use a vacuum method of cooling, its advantages include: reduction of cooling time, increase in volume, increasing the shelf life, improving structural and mechanical properties.

The disadvantages include: higher drying percentage, curing of the crust

The use of known equipment for cooling the finished product does not significantly reduce the duration of this process, so there is a need to create equipment for vacuum cooling of bread in the stream, which will intensify the cooling process.

For a long time, many scientists have been researching the process of vacuum cooling of bread, including scientists from our university. But the introduction of vacuum cooling in the flow requires improvement of both theory (Everington et al., 2003) and process parameters (Primo-Martín et al.,, 2008). For example, due to too intense pressure reduction there is a pressure gradient between the steam in the workpiece and the environment, which is accompanied by the destruction of the workpiece (Litvinchuk et al.,, 2014). In this regard, it is advisable to study the effect of the rate of vacuum on the quality of the finished product, to investigate the effect of vacuum cooling on the quality of bread.

The recommended mode (figure 12) of pressure change in the vacuum chamber (maximum rate of vacuum in the chamber is υmax = 4.5 kPa/s) required for cooling a loaf weighing 0.5 kg to a temperature of 30 °C, at which there are no destruction occurs, the maximum cooling time is 2 minutes.

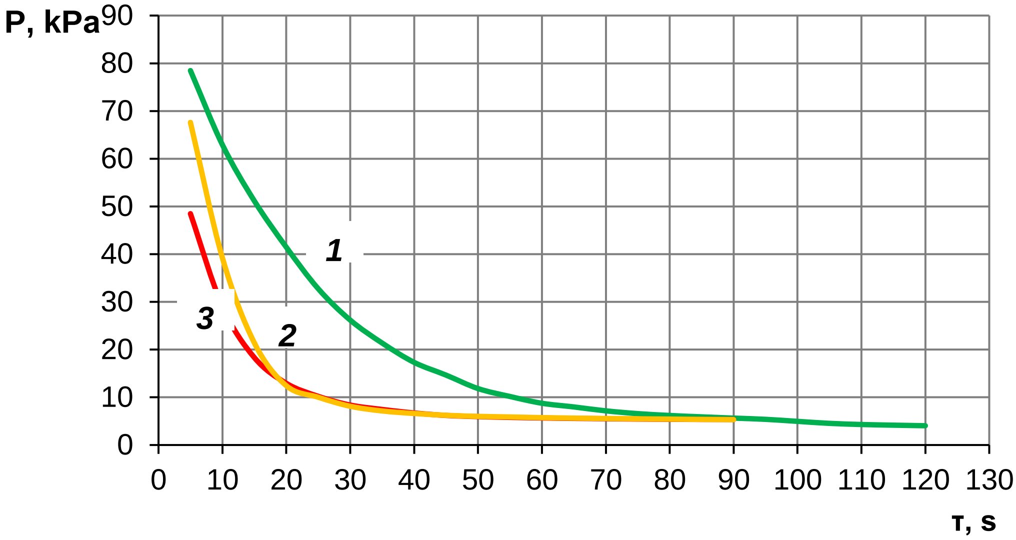

Fig. 12. Graph of pressure change over time in the vacuum chamber:
1 – Recommended mode of pressure change in the vacuum chamber for vacuum cooling of the loaf υmax = 4.5 kPa/s;
2, 3 – vacuum cooling modes at υmax = 5.5 kPa/s (2) and υmax = 8.8 kPa/s (3), at which the destruction of the loaf occurs.

In Figure 14 it is shown the prototypes cooled by vacuum in the modes shown in Figure 13.

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Fig. 13. Test samples cooled by vacuum:
1 – recommended mode of pressure change in the vacuum chamber for vacuum cooling of the loaf υmax = 4.5 kPa / s; 2, 3 – vacuum cooling modes υmax = 5.5 kPa/s (2) and υmax = 8.8 kPa/s (3), at which the destruction of the loaf occurs.

Table 1
Comparative table of indicators of structural and mechanical properties of the loaf under different methods of cooling and storage (Telychkun, 2020b)

Cooling method	Immediately after cooling			A day later in a plastic bag			In a day without packing		
	ΔH1	ΔH2	ΔH3	ΔH1	ΔH2	ΔH3	ΔH1	ΔH2	ΔH3
Vacuum cooling	161	141	20	58	53	5	60	55	5
Natural way of cooling	159	153	6	56	51	5	41	37	4

(H – initial height, ΔH1 is an indicator of the total deformation of the crumb compression; ΔH2 – characterizes the residual deformation of the crumb or its plasticity; ΔH3 – the difference between the values of ΔH1 and ΔH2 and characterizes the elasticity of the crumb).

Rational modes of bread cutting

It is known that fresh bread breaks down and deforms when is cut. However, it has been found an interesting dependence – for visco-plastic products, the cutting force decreases and the quality increases at high knife speed (Figure 14). Also, bread does not crumpled at the cut process.

Therefore, for example, for crumbs, we recommend a cutting element speed of more than 6 m/s. It is recommended applying the results to bread-cutting machines with belt knives. If the design of the drum is changed, the drums are turned (Figure 16) – it increases the distance between the knives, and, accordingly, the friction force is decreased and the quality of the product is improved (Guts et al., 2010).

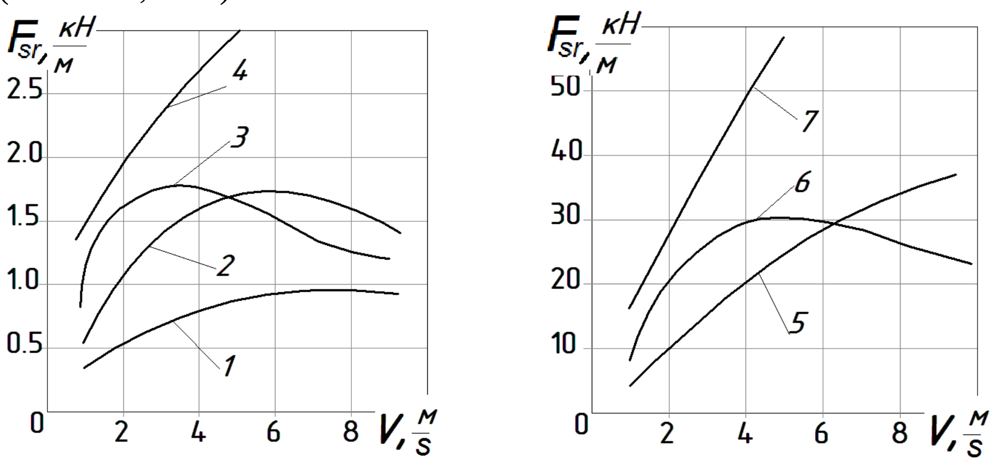

Fig. 14. Effect of knife speed on cutting force for different profucts:
1 – crumb of hot bread; 2 – crumb of bread after cooling for 6 hours;
3 – cheese; 4 – sugar beet; 5 – bread crust; 6, 7 – meat (pork) under temperature 5° C and -5°C.

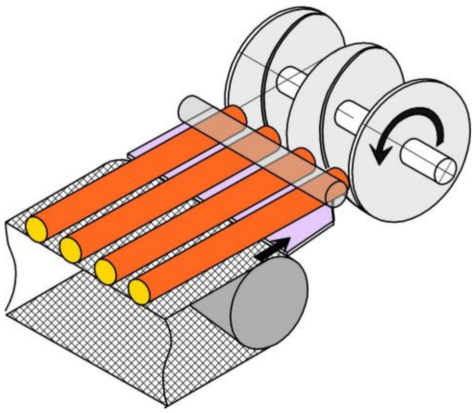

Fig. 15. Cutting of rusks in production line

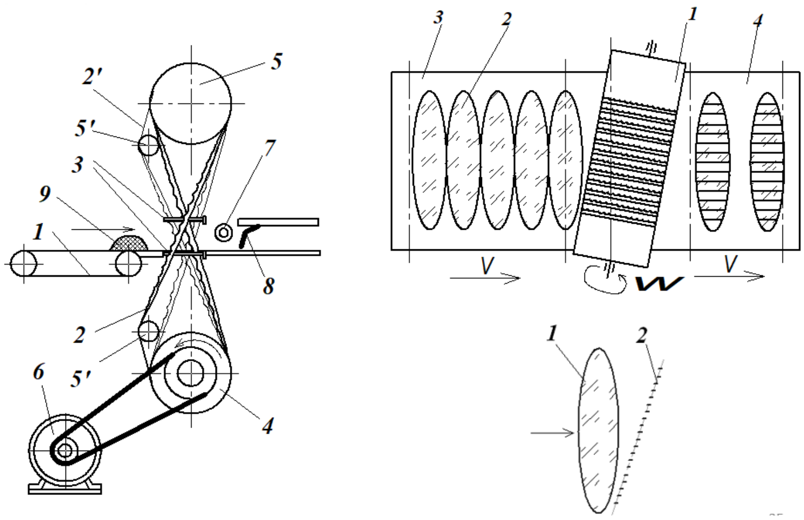

Fig. 16. Bred cutting machine with belt knives (drum 1 is turned).

Trends in novel packaging materials and technologies

Along known functions function of the packaging, today it is important to digitalize packaging, ie to create intelligent packaging (Ivanov V. et al., 2021).

The formation of packaging systems with the packaging-product interaction is carried out in packaging machines.

Modern models of packaging equipment are complex technical systems built on the aggregate-modular principle. The trend of development of packaging machines provides that the latest models of such equipment are integrated technical complexes created on the basis of mechatronic functional modules, each of which is both functionally and structurally independent product with a large number of synergistically interconnected characteristics and parameters. implementation of packaging technologies.

In recent years, general trends in the development of technology, which provide the restructuring of all areas of human activity, including the packaging industry. These trends were called the "fourth industrial revolution." Therefore, the current packaging industry is characterized by the active introduction of automated packaging production.

Creating a new generation of packaging equipment with flexible structure, which is universal for different products, and packaging materials is the main task today. Its solution requires a systematic approach, starting with the development of the concept of design of automated production lines of packaging and ending with the design of the working bodies of machines. Such a concept can be the concept of functionally oriented design using mechatronic modules, which allows to create clusters of functional modules, combine them, create a wide range of parametric

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series of packaging equipment of one functional purpose with a flexible structure of changes in processes at the automated control system and take into account the features of all stages of the life cycle of machines (Ivanov V. et al., 2021).

Logical design combines possible methodologies, techniques and methods of systems for designing new packaging equipment, providing the growing demands of consumers for its technical capabilities.

CONCLUSION

The essence of the proposals concerns the following processes:

– Use of kneading machines with cam working elements. This allows to ensure the high quality of the third stage of kneading – plasticization.

– Combination of dough fermentation operations and forming pieces under pressure in one unit. This reduces fermentation time, reduces the number and metal consumption of equipment.

– Combination of baking and drying processes for some varieties of bread products, in particular, rusks and chopsticks. This avoids heat consumption for reheating the products, the amount of equipment.

– Rational use of heat of steam of hygrothermal processing and heat of secondary steam which is formed during baking of bread.

– Vacuum cooling of bread products. This ensures fast cooling of bread before cutting and packing.

– Stream cutting of different types of bread.

– The use of packaging equipment based on integrated technical complexes created on the basis of mechatronic functional modules, each of which is a functionally and structurally independent product with a large number of synergistically interrelated characteristics and parameters.

An innovative approach to all stages of the technological process of bread production allows:

– Decrease in production areas
– Reduction of metal consumption
– Reduction of energy consumption
– Improving working conditions
– Ensuring sanitary and hygienic standards

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