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IMPROVING A TEMPERING MACHINE FOR CONFECTIONERY MASSES

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This paper reports the improved model of a tempering machine for heating the formulation mixture of marshmallow, characterized by heat supply to the working tank through the replacement of a steam jacket with heating by a film resistive electric heater of radiative type (FREhRT). The surface of the heat exchange of the device was increased by heating the stirrer with FREhRT; secondary energy (30....85 °C) was used by converting it by Peltier elements for the autonomous operation of superchargers for cooling the engine compartment. The proposed solution will lead to an increase in the efficiency of the device, which is explained by a decrease in its specific metal consumption through the use of FREhRT.

A reduction in the duration of heating (75 °C) a marshmallow formulation mixture was experimentally established: in the examined model, 530 s, compared with the analog, 645 s. That confirmed the reduction in heating time to the set temperature by 21.7 % compared to the MT-250 basic design. The calculations have established a decrease, by 13 %, in the specific energy consumption for heating the volume of a unit of product when using the improved structure, 205.7 kJ/kg, when using the basic one – 232.1 kJ/kg. The increase in the efficiency of the proposed structure is explained by a decrease in the specific metal consumption of the device from 474 kg/m^2 in the base apparatus to 273 kg/m^2 in the improved one.

The study results confirm the increase in the resource efficiency of the improved tempering machine, which is achieved by eliminating the steam jacket; increasing the heat exchange surface by heating the stirrer. The heat transfer by FREhRT simplifies the operational performance of the temperature stabilization system in a working tank. The reported results could prove useful when designing thermal devices with electric heat supply under the conditions of using secondary energy, which is relevant for ensuring resource efficiency

Keywords: tempering machine, confectionery, specific energy consumption, secondary energy

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1. Introduction

The introduction of innovative functional products into the diet will ensure the formation, preservation, and strengthening of the health component, taking into consideration modern trends in the development of the food industry [1]. In addition, the deterioration of the environmental situation in many countries causes an increase in demand for a balanced diet of natural origin with a minimum share of artificial dyes and flavors [2]. This trend also applies to confectionery products of daily consumption, which should have functional properties to strengthen immunity at different age stages [3]. This approach focuses the attention of the scientific and industrial community on the need to find innovative technological and equipment solutions aimed at meeting the needs of consumers in innovative food products based on plant raw materials.

The efficiency of the equipment and technological systems of confectionery production largely depends on the quality of all stages of component and equipment processing, in particular, this relates to mixing processes. Mixing confectionery components with various physical, chemical, and structural-mechanical properties requires a high-quality approach not only to the choice of components but also to the hardware implementation of the mixing process, implying resource-efficient solutions for the execution of processes. This is possible by reducing metal consumption when using modern techniques of heat supply, eliminating traditional methods involving steam-water heat supply and a network of heat carriers. In addition, of relevance today is the maximum utilization of secondary thermal energy for the technological needs of production, in particular, enabling the operation of auxiliary mechanisms (fans, etc.) or cooling certain technological objects along a continuous line. Therefore, research on improving the tempering machine for confectionery masses is relevant because the introduction of such solutions in confectionery production will help reduce metal and energy consumption, increase the efficiency of heat processing processes for raw materials. This will lead to comprehensive topical solutions for the introduction of new functional products of improved quality manufactured on more efficient equipment, and, therefore, such products will attain higher competitiveness.

2. Literature review and problem statement

Work [4] focuses on the need to promote healthy functional nutrition for the formation and further development of the immune component of consumers, especially in the context of the pandemic of the new coronavirus. As the practice of fighting diseases has shown, precious time is wasted to find effective solutions, although, in turn, the introduction of organic raw materials into diets prevents the rapid development of the disease. This is due to the fact that organic raw materials are a natural source of functional ingredients that can support and form the immune component. At the same time, out of sight is defining rational ways of blending organic ingredients in the composition of finished products for the formation of a high-quality immune component of the general group of consumers. Attention is focused on the need for research aimed at high-quality selection of formulation components when using organic raw materials and resource-efficient equipment and technological solutions for preserving the organic properties of components, in particular in confectionery products. To produce confectionery products, many heating and cooking processes are used with aging at the predefined temperature until the state of readiness. Cooking machines with a heating jacket are characterized by significant energy consumption necessary for their operation. This is due to the considerable low intensity of the devices with a jacket, where the heating process takes a significant part of the time of their work. Therefore, studying the process of warming up heating devices with a jacket and improving existing structures is a necessary task [5]. For example, one of the practical solutions confirming the increase in functional properties in confectionery products under the conditions of the introduction of organic components in their formulation is given in [6]. Confirming the need to identify innovative ways to increase the resource efficiency of heat and mass transfer equipment, taking into account technological needs.

Paper [7] considers the need to achieve preliminary crystallization when tempering cocoa oil in the production of chocolate as one of the factors in the qualitative implementation of the process. It is noted that the quality of crystallization is influenced not only by the interaction of formulation components but also the hardware factor, in particular, the degree of stabilization of temperature exposure. However, issues remain about the impact of the introduction of natural components into the cocoa oil mass and ensuring a clear stabilization of the temperature impact and uniformity of the mass received during crystallization, confirming the relevance of these studies. In particular, paper [8] reports the theory of the formation of dispersed combined systems consisting of fine particles, gas, and liquid. The proposed equation makes it possible to describe the interaction of the mixing energy of the centrifugal stirrer with a combined system but the equation does not take into consideration the interaction of complex stirrers on the homogeneity of the resulting structure of confectionery masses. This is due to the fact that those data are based on the results obtained using only centrifugal mixing, which does not provide us with an information picture of mass tempering when using combined stirrers with a heated surface. This emphasizes the feasibility of research in this scientific and practical area.

Paper [9] gives an analysis of the characteristics of the scraper surface heat exchanger with a fundamentally new arrangement of blades to achieve higher thermal efficiency by alternating blades in the processing of confectionery masses. The process of heating hazelnut paste is investigated taking into consideration the physical, chemical changes and structural-mechanical characteristics of the nut paste, as well as the heat transfer coefficient depending on the speed of blade rotation. The analysis of hydrodynamics and thermal profiles suggests that a higher efficiency of heat transfer is associated with the occurrence of the phenomenon of reverse mixing. However, the obtained profiles do not make it possible to obtain data on changes in the coefficient of heat exchange and structural-mechanical properties when tempering confectionery masses with the introduction of blended fruit and vegetable purees (pastes) into their formulation. For example, paper [10] reports a dimensional analysis of determining the ratios governing the network of foam formation using combined stirrers with an adjustable number of speeds. To process the obtained velocity profiles, a modified Froud criterion was introduced into the general equations since it was established that the aeration process requires a very low number of revolutions to achieve stable values in order to stabilize foaming. However, the study of foaming did not take into consideration the factor of clear stabilization of the confectionery mass when heated, which emphasizes the relevance of research in this area.

Therefore, in order to ensure a high-quality process of tempering confectionery masses, it is necessary to take into consideration the complex equipment and technological component for the formation of a resource-efficient competitive offer. Introduction into the formulation composition of blended fruit and vegetable purees (pastes) will reduce the share of imported artificial dyes and flavors, increasing the nutritional value of products [11]. Classical tempering machines have a steam-water heat supply network and heat-generating devices, which leads to an artificial increase in metal consumption, causing the need to replace them with modern electric heat generators [12, 13]. In addition, the efficiency of tempering confectionery masses depends on the type of combined stirrers, the surface of which, in order to increase the heat transfer coefficient, should be heated, thereby increasing the surface of heat exchange. The effectiveness of replacing steam shells with modern electric heat supply equipment on the example of rotary evaporator is discussed in [14]; the authors, however, do not fully consider the impact of heat supply on the structural and mechanical properties of raw materials. Work [15] confirms the effectiveness of the use of a film heater in a vacuum evaporator with simultaneous heating of the anchor stirrer, which makes it possible to significantly reduce energy consumption and reduce heating time. However, the issue of the use of such solutions in devices of such types is not fully disclosed.

Electric heating of the working capacity of tempering machines and surfaces of combined planetary stirrers with a modern film resistive electric heater of radiative type (FREhRT) [16] will provide stabilized and low-energy temperature heating, reducing metal intensity compared to a traditional device [17]. The introduction of blends of plant origin into the formulation of confectionery products requires a rational selection of equipment for the implementation of the technological process [18]. Their manufacture will provide the maximum positive effect in terms of product quality and energy saving in its production. At the same time, the use of secondary thermal energy for the needs of equipment and technological complexes, due to the transformation by Peltier elements into a low-voltage supply voltage or cooling effect, will increase the resource efficiency of the line as a whole. In particular, work [19] provides data analyzing the operation of generators under heat transfer conditions by 127 thermocouples with installed Peltier elements. The Peltier effect provides a 30 % increase in thermal potential with a difference between the hot and side of the element of 100 °C at the maximum output temperature of the generator. However, the analysis of the data was carried out under the conditions of using convective heat exchange from generators to Peltier elements. Thus, paper [20] reports data on the conductive use of elements in low-temperature heat-exchange equipment. This confirms, in general, the efficiency of convective-conducive heat exchange between the heating source and the surface of the Peltier elements, both to obtain a low-voltage supply voltage (fans) and to create a cooling effect. The introduction into innovative equipment and technological solutions of the specified scientific and practical results will ensure the resource efficiency and competitiveness of heat and mass exchange equipment and the quality of the products received, confirming the feasibility of research in this area.

3. The aim and objectives of the study

The aim of this work is to improve a tempering machine for confectionery masses by heating the working tank and planetary stirrer with a film resistive electric heater of radiative type, the presence of a cooling jacket, and the use of Peltier elements. The implementation of the proposed engineering solution will stabilize the temperature impact on the confectionery mass, eliminate the steam-water shell with heat-generating devices, ensuring the effective implementation of the technological process under the conditions of secondary energy utilization.

To achieve the set aim, the following tasks have been solved:

– to design a model structure of the improved tempering machine for confectionery masses with heating the working capacity and planetary stirrer with a film resistive electric heater of radiative type, the presence of a cooling jacket, and the use of Peltier elements;

– to establish and confirm, by calculation and experiments, the effectiveness of the proposed engineering and technological solutions when compared with the classical tempering machine.

4. The study materials and methods

Our scientific and practical research was carried out at the State Biotechnological University (Ukraine) by improving the tempering machine with heating the working capacity and planetary stirrer with FREhRT, the presence of a cooling jacket, and the use of Peltier elements. The engineering and technological solutions proposed in the improvement of the tempering machine provide optimal heat and mass exchange processes, in particular regime parameters, both from an operational point of view and technological needs. This is due to the use of a modern film resistive electric heater of radiative type, which does not have a metal high-temperature component (spirals, etc.), and, therefore, has a low-inertial component and explicit temperature dynamics of heating technological masses. This will also make it possible to implement heat and mass exchange technological processes for heating, mixing, dosing, blending formulation masses, followed by cooling, etc., specifically in the production of confectionery masses (marshmallow, chocolate, marmalade, etc.). We compared the hardware and technological parameters of the advanced tempering machine with a traditional machine (MT-250, Ukraine [21]) according to conventional methods of thermal calculations and based on the experimental data from the measuring equipment «OVEN» (Ukraine). To implement the measurement of temperature when heating a product, thermocouples were used, which were placed in the model structure of the equipment. The accuracy class of the measuring equipment «OVEN» was ±0.25 %. The hardware and technological testing of the improved tempering machine was carried out by preparing a marshmallow mass with blended fruit paste based on apples, cranberries, and hawthorn, as well as other formulation components for the further implementation of the planting stage.

5. Results of the experimental and estimation studies of the improved tempering machine for confectionery masses

5. 1. Design of the improved model of a tempering machine for confectionery masses

The improved model of a tempering machine for confectionery masses is shown in Fig. 1: in this case, it was tested at the technological stage of preparation of marshmallow masses based on blended fruit and vegetable pastes, followed by deposition. The tempering machine is mounted on bed 1 and is equipped with a working cylindrical capacity 2, the heating of which is carried out by a film resistive electric heater of radiative type (FREhRT) 3. To reduce the temperature of technological masses, the machine is equipped with a cooling jacket 4, which has the following engineering properties: when working tank 2 is heated, there is air in the jacket, which acts as an additional insulating layer. And if it necessary to cool the technological mass, jacket 4 is fed through pipes 5 running water, in addition, the jacket on the outside is wrapped with insulating material 6 to reduce heat loss to the environment.

To ensure uniform heat supply, mixing, and preventing the stratification of technological masses, in particular marshmallow based on blended fruit and vegetable pastes, in the center of working cylindrical tank 2, a combined planetary stirrer 7 is mounted. The tempering machine has a motor compartment 8 with electric motor 9 connected to worm gearbox 10 to ensure the rotational movement of vertical shaft 11 located in the center of tank 2. At the same time, at the top of vertical shaft 11, guide 12 is mounted, one end of which is connected to frame stirrer 13, and the second with the shaft of planetary stirrer 14. In the upper part of shaft 14, gear 15 is mounted, which is geared to fixed toothed disk 16 fixed on cylindrical protective shield 17, in the middle of which vertical shaft 11 is mounted. The shaft of planetary stirrer 14 additionally hosts blade stirrers 18, while heating the geometric surfaces of the stirrers: 14 (frame) and 18 (blade) with FREhRT, thereby increasing the heat exchange surface and uniformity of heating the mass. The rotation of guide 12 moves planetary stirrer 14 around vertical shaft 11, in addition, by moving gear 15 around fixed gear disk 16, rotation around its own axis is ensured.

The proposed technique for arranging blades and the procedure of heat supply with FREhRT to the surfaces of working cylindrical capacity 2 and stirrers (14 and 18) provide for the intensification of the technological process due to the uniformity of heating the mass without stratification of components. Thus, the qualitative properties of marshmallow masses during technological processing in an advanced apparatus are provided. Additionally, it minimizes the factor of warming up the device, as is observed in classic machines such as MT (Ukraine).

Loading of raw materials is carried out automatically by pumping liquid-like components with a pump through pipe 19, or dry ones through pipe 20. Removal of the tempering mass is carried out automatically through pipe 21, when technological parameters are reached on control unit 22 with the software control unit made by company «Oven» (Ukraine) connected to thermometer 23.

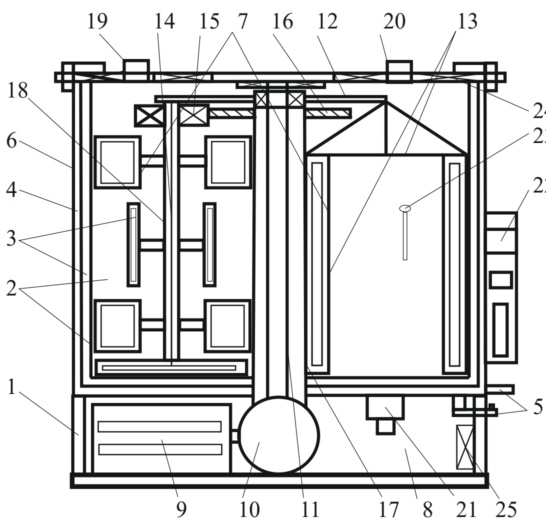

Fig. 1. Diagram of the improved model structure of the tempering machine for confectionery masses: 1 – bed; 2 – working cylindrical capacity; 3 – film resistive electric heater of radiative type (FREhRT); 4 – cooling jacket; 5 – pipes of injection and removal of running water; 6 – insulating material; 7 – combined planetary stirrer; 8 – engine compartment; 9 – electric motor; 10 – worm reducer; 11 – vertical shaft; 12 – guide; 13 – frame stirrer with a surface heated by FREhRT; 14 – the shaft of the planetary stirrer; 15 – toothed gear; 16 – fixed toothed disc; 17 – cylindrical protective case; 18 – blade stirrers; 19 – pipe of liquid-like components; 20 – pipe of dry components; 21 – nozzle of removal of tempering mass; 22 – control unit; 23 – thermometer; 24 – Peltier elements; 25 – supercharger fan

For the use of secondary energy, the lid of the tempering machine hosts Peltier elements 24 elements, which make it possible to convert thermal energy into a low-voltage supply voltage for discharge fans 25. It was established that at the temperature of tempering in a working tank of 30...85 °C, the voltage is provided of 3...15 W, which is enough for the autonomous operation of superchargers 25 designed for cooling engine compartment 8.

5. 2. Experimental and estimation studies of the impact of the proposed design and technological solutions on the process efficiency

Experimental studies were conducted during the preparation of marshmallow formulation mass based on a plant three-component paste in a tempering machine before whisking. The research was conducted to identify the main technological parameters for the further calculations of devices of this type. We determined a transitional characteristic of heating the marshmallow mass based on a fruit-vegetable paste to a temperature of 75 °C in the tempering machine shown in Fig. 2.

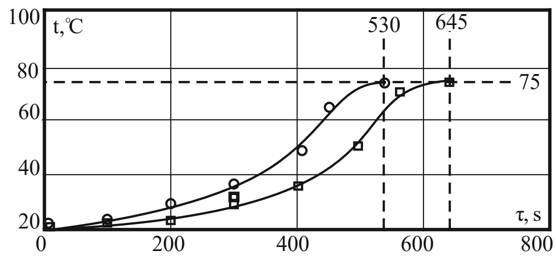

Fig. 2. Characteristics of the transient process of heating marshmallow mass based on a fruit and vegetable paste: ○ – experimental improved apparatus; □ – classic machine MT-250

Our comparative analysis of heating marshmallow mass (Fig. 2) indicates the effectiveness of the proposed structural and technological solutions to reduce the metal consumption of the tempering machine and increase the heat exchange surface by heating the stirrer with the help of FREhRT. The established duration of reaching the stationary temperature mode of heating up to 75 °C in the prototype of the apparatus for marshmallow mass is 530 s while in the base apparatus this indicator is 645 s. This confirms a reduction in the time to enter the stationary mode by the improved tempering machine by 21.7 % compared to the classic MT-250 machine.

The proposed design solution makes it possible to reduce the duration of heating a working tank with marshmallow mass, reducing energy consumption by increasing efficiency while reducing metal consumption and increasing the heat exchange surface.

To confirm the experimentally obtained indicators for determining the effectiveness of the proposed design solution for heating the formulation mixture of marshmallow mass, an estimated characteristic is given in comparison with the basic design of the MT-250. The calculations were performed without taking into consideration the total loss to the environment (Table 1).

We have established experimentally and by estimation that in the improved design of the tempering machine, the specific energy consumption for heating the volume of the unit of product (marshmallow mass) was reduced by 13 % compared to the base structure. This effect is explained by a decrease in the specific metal consumption of the device from 474 kg/m^2 in the base apparatus to 273 kg/m^2 in the improved structure. Additionally, this is confirmed by a decrease in the time to enter a stationary mode to the predefined temperature (75 °C). For a prototype of the device, 530 s, and for the base – 645 s, which reduces the temperature effect on the formulation mixture of marshmallow mass during the heat exchange warming process.

Table 1

Comparative characteristics of the improved structure of the device compared to the basic machine MT-250

Indicator	MT-250	Improved machine
The weight of the device	M^*=830 kg	M=520 kg
Weight of working capacity	m_1^*=575 kg	m_1= 275 kg
Specific costs	$q_{sp}=Q/m_{pr}$=69,630/300=232.1 kJ/kg	$q_{sp}=Q/m_{pr}$=61,710/300=205.7 kJ/kg
Heating time	$\tau=Q/F^*\cdot k\cdot\Delta t$=69,630/1.75·1,130·55=640 s	$\tau=Q/F^*\cdot k\cdot\Delta t$=61,710/1.9·894·65=522 s
Heat transfer surface area	F^*=1,75 m^3	$F=F^*+F_m$=1.75+0.15=1.9 m^3
Heating the working tank	$Q_{heat}=m_1\cdot c_c\cdot(t_2'-t_1')+m_2\cdot c_c\cdot(t_2''-t_1'')=300\cdot 0.48\cdot(75-20)+$ $+\,275\cdot 0.48\cdot(75-20)=7{,}920+7{,}260=15{,}180$ kJ	$Q_{heat}=m_1\cdot c_c\cdot(t_2'-t_1')=$ $=275\cdot 0.48\cdot(75-20)=7{,}260$ kJ
Heating the product	$Q_{pr}=m_{pr}\cdot c\cdot(t_k-t_n)$=300·3.3·(75–20)=54,450 kJ	$Q_{pr}=m_{pr}\cdot c\cdot(t_k-t_n)$=300·3.3·(75–20)=54,450 kJ
Total quantity	Q_{tot}=69,630 kJ	Q_{tot}=61,710 kJ
Device metal consumption	$m=M^*/F$=830/1.75=474 kg/m^2	$m=M/F$=520/1.9=273 kg/m^2

*Note: *Comparative data on the basic design MT-250 are taken from [21]*

6. Discussion of the received indicators of efficiency of structural solutions in the improved device for tempering confectionery masses

We report the experimental-practical and analytical data on the improved tempering machine, in which the working capacity and surfaces of planetary stirrers are heated by FREhRT (Fig. 1). Replacing the technique of heat supply with electric heating has made it possible to eliminate the steam-water component of traditional tempering machines, reduce metal consumption, and increase thermal stabilization of the process with a decrease in the duration of technological operations. The cooling jacket (Fig. 1, pos. 4) in the improved machine performs several tasks: when working tank is heated, there is air in it, which acts as an additional insulating layer, and if necessary, a flowing liquid enters the jacket. To cool engine compartment 8, secondary energy was used when converting it, by Peltier elements 24, into a low-voltage supply voltage of pumping fans 25, in particular, when tempering within 30...85 °C, the voltage is 3...15 W.

The implementation of the proposed engineering and technological solutions will ensure the qualitative execution of heat and mass exchange treatment of confectionery masses. It is established that due to the change in the technique of heat supply (FREhRT), the use of dual-purpose cooling jacket and Peltier elements, a significant advantage is achieved in terms of technical parameters compared to the basic designs. In particular, the duration of entering a stationary mode (75 °C) in the test apparatus for marshmallow masses is 530 s, in the basic one – 645 s (Fig. 2). The reduction of the duration of entering the stationary mode by 21.7 % of the improved tempering machine in comparison with the traditional machine MT-250 has been established. In addition, the specific energy consumption for heating the marshmallow mass volume was reduced by 13 %, due to a decrease in the metal consumption of the working capacity from 575 kg of the basic apparatus to 275 kg in the improved machine (Table 1).

The difference between traditional technological and equipment analogs for tempering food masses is the steam-water heat supply system, the absence of combined planetary stirrers, which leads to a decrease in the quality of the process implementation [22]. The main restriction in the tempering of confectionery masses is the clear stabilization of temperature exposure, especially under the conditions of using fruit and berry blends in technological formulations, to preserve the initial properties. To solve this technical task of classical machines with steam-water heating, we have proposed to use FREhRT with clear temperature stabilization and reduced metal consumption. Further research will be aimed at detailed studies of the hydrodynamic behavior of confectionery masses depending on the percentage of natural raw materials in them. This, in turn, will reduce the content of imported artificial dyes and flavors and expand the range of original functional and physiological confectionery products, which is relevant in the face of environmental and pandemic challenges of today.

7. Conclusions

1. An improved model of the tempering machine for heating and mixing the formulation mixture of marshmallow has been proposed, which differs in the technique of heat supply to a working tank and heating the mixing device with a film resistive electric heater of radiative type. The improved model makes it possible to use secondary thermal heating energy (30...85 °C) by converting it with Peltier elements into a low-voltage power (3...15 W) to ensure the autonomy of the superchargers intended for cooling the engine compartment of the device.

2. Experimentally, a decrease in the duration of entering a stationary mode (75 °C) was established when heating the formulation marshmallow mixture: for the experimental model – 530 s, compared to the analog – 645 s. Additionally, comparative calculations were performed, as a result of which a decrease of 15 % in the indicator of specific energy consumption for heating the volume of a unit of product in an improved structure was established – 205.7 kJ/kg, and in the basic MT-250 – 232.1 kJ/kg. The increase in the efficiency of the proposed design of the tempering machine is explained by a decrease in the specific metal consumption of the device, from 474 kg/m^2 of the basis apparatus to 273 kg/m^2 in the improved structure. Namely, a decrease in dimensional and weight indicators, energy and metal intensity, and an increase in the surface of the heat exchange in a working capacity, due to the stirrer heated by FREhRT.

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