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## Technical and Economic Substantiation of the Process of Semi-Fluidisation Treatment of Fruit and Berry Products

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**Abstract.** The search for effective patterns for implementing the semi-fluidisation process for freezing and partial freezing of fruit and berry products under the condition of minimising energy consumption and high productivity of the process constitutes the relevance of the research. The purpose of the study is to develop energy-efficient and reliable technological solutions for the implementation of vibro-wave refrigeration processing of fruit and berry products based on the development of a vibration transport and technological fluidisation machine; determination of power and energy characteristics of the semi-fluidisation process; substantiation of rational speed modes of raw material movement in the processing zone. Based on a comparative analysis of the design and technological characteristics of wave, conveyor and vibration machines, the main trends in their development were substantiated; the main power and energy parameters of the developed oscillatory system were determined. A comparative analysis of the technological schemes of semi-fluidisation using the transport movement of products by belt and vibrating wave conveyor was carried out, which allowed substantiating the effectiveness of the use of the corresponding drive mechanisms of the studied machine. Graph-analytical analysis of the speed and energy parameters of the studied semi-fluidisation process on the basis of the obtained theoretical and experimental data allowed to verify the adequacy of the developed mathematical model and to substantiate the main parameters of the operating mode of the technological load advancement along the processing zone. The conducted research using the developed experimental model and the classical belt conveyor showed an increase in the speed of transportation of raw materials by almost 2 times with a decrease in energy consumption for the process by 1.4 times for the vibro-wave scheme. In the developed vibrating transport-technological semi-fluidisation machine, the vibration effect provides a decrease in technological resistance in the mass of products, significantly reducing the force effect on it, as a result of the generated travelling wave on the surface of the load-carrying body, the movement of the processed material along the belt and continuous mixing or renewal of product layers are provided. The practical value of the study includes the use of a combined scheme for creating a fluidised layer of products due to the oscillation of the belt and bubbling with the flow of coolant; the use of the belt wave to create the movement of products in the production area

**Keywords:** vibration, wave conveyor, small-scale raw materials, unbalanced oscillation system, low-temperature processing, unbalanced vibration exciter

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## Introduction

The search for favourable conditions for the intensification of the production process with effective action on the object of the processing; implementation of technological movement in a continuous mode; maximum reduction of unproductive labour when performing auxiliary functions by the system; mutual coordination of technological influences in controlling the dynamic state of the system, in particular, with the multifunctionality of the components of the technological system and their harmonious application are the main trends in the development of processes and equipment, in particular in the processing and food industries. Among the machines that meet these properties, one can distinguish vibrating transport and technological machines, which include semi-fluidisation devices. During the operation of these machines, technological and transport movement are realised in one unit and two quite common technological actions are combined: the use of advanced technologies with the involvement of low-frequency oscillations in the conveyor form of the organisation of the treatment process.

The technical term “conveyor” comes from the English “convey”, which defines the equipment for the transportation or continuous movement of certain goods, which are divided into bulk, lumpy, elastic, viscous or bound [1; 2]. The current or technologically continuous method of implementation of technologies makes it possible to realise such production factors as proportionality, dynamism and direction of the technological process, which is the potential for increasing productivity, reducing the labour intensity of manufacturing products and allows processing on automated production lines. Such lines in automated or complex mechanised operating modes practically eliminate contradictions between transport and technological movements, creating conditions for harmonious and rational use of technological equipment.

The use of low-frequency oscillations in the processing of products provides an increase in the intensity of processing by increasing the surface of heat and mass transfer, softening the force action on the particles of raw materials, reducing the internal coefficient of friction and viscosity, which reduces energy consumption for the process and in aggregate allows realising new technological possibilities. The latter are often unique, allowing to significantly increase the efficiency of the implementation of such common operations in food technology as separation, mixing, movement of products with specific properties, homogenisation, filtering, grinding, dehydration and drying, a saturation of technological masses with specific ingredients and media under conditions of mechanical and heat and mass exchange processes [3; 4].

The complex application of vibration impact in conveyor technology, which takes place during the operation of conveyor semi-fluidisation machines, corresponds to the highest form of interaction of technological and transport movements in the implementation of low-temperature processes, namely, the implementation of technological action during transport movement, which allows automating the production process, determines the optimal functioning of the main structural components of the technical system, increases the efficiency of volumetric action on technological masses, which determines the relevance of this study.

Semi-fluidisation apparatuses are transport and technological machines in which such low-temperature operations as freezing and partial freezing are implemented, carried out in the conditions of a fluidised layer of products, which at the same time is moved by a conveyor with a flexible load-carrying body. Among the machines, the structure of which combines the above-mentioned technological factors of increasing the efficiency of technological equipment, it is possible to note vibrating transport and technological machines.

In terms of technical and economic efficiency of the studied technical system, conveyor machines perform not only a purely transport function, but are also used as transfer devices in technological automated lines for certain product processing. The focus of technological and transport action, and the simplicity of automation of conveyor control determine them as an integral part of modern production processes and devices, regulating the pace of production and realising its rhythmicity. This can significantly improve the technical and economic parameters of production, increasing labour productivity and output tenfold, to ensure synchronisation and proportionality between transport and technological movements, between the main and auxiliary operations, expanding the functionality of the equipment; complex mechanisation and automation of production processes, which is systematised in the studies by V.N. Poturaev [5], O.V. Tsurkan [6], I.P. Palamarchuk [7].

An essential feature of the conveyor vibration technological machine under study is the possibility of using low-frequency vibrations to create a fluidised layer of products with the current method of organising low-temperature processing. The transport process under such conditions can be defined as an integral and auxiliary part of the technological movement. Vibration action is the main dynamic factor in the processing of products, usually loose or small pieces, which include fruits, berries and small vegetables, as expressed in studies by R. Leruk [8], G. Semenov [9], I. Chang [10], H. Yang [11], L. Wei [12]. At the same time, depending on the design of conveyor-type equipment, the implementation of transport and technological movements may differ in time and functional content. Therefore, the performance of production tasks in the process of moving the masses of products or technological media eliminates the contradiction between transport and technological movement, which brings the design perfection of this equipment closer to its highest forms.

Unlike vibrating conveyor machines, which move products in different horizontal directions and altitude levels, transport and technological machines are of a higher level of perfection, carrying out in the process of transportation and technological processing of the bulk product being moved, in particular, drying, extraction, crystallisation and other heat and mass transfer processes. The multifunctional nature of such technical systems is characterised by the complication of the design of their elements, and the establishment of practically separate transporting elements, which are often quite complex, eliminating the advantages of the current structure of production. At the same time, the challenge of increasing the level of mechanisation and automation of production causes difficulties in the mutually coordinated functioning of transport and technological links. Obviously, the implementation

of effective conveyor technical systems in the conditions of low-frequency oscillations in the processes of low-temperature processing is relevant and widespread.

Semi-fluidisation or semi-fluidisation is realised in common devices by ventilation with a jet of cold air in the direction from bottom to top through perforations on the moving belt at a speed not exceeding the critical value. The intensive heat and mass exchange effect on the surface layer of the raw material creates issues of its overcooling and unevenness of layer-by-layer processing; there is relatively high energy consumption when creating a fluidised layer due to significant resistance when bubbling the product with a flow of coolant. In addition, the disadvantages of these machines are the complex design, the creation of an uneven vertical movement of the product layer in the device, low heat exchange intensity and relatively low process productivity.

Harmonious in constructive and technical and economic terms, the combination of the directions of vibration processing and transportation systems is a high potential and prospects for the development of production processes were traced in the scientific works of both well-known vibration technologists and designers of the food technology industry, namely, O. Avci [13], as one of the first founders of the development of vibration technological machines; P.S. Bernyk and I.P. Palamarchuk, who in their designs combined vibromechanical, pneumodynamic and electromagnetic technological influences specifically for the processes of processing and food technologies [14]; J. Rapur and R. Tiwari [15], who initiated the broad application of vibrating machines in food production; O. Spivakovskiy and A. Chervonenko [16], the pioneers of the conveyor machines development and use; and recognised founders of technologies and equipment of food and processing agricultural production, O.G. Burdo [17], V.D. Popova [18], V.N. Stabnikov [19] and other prominent scientists.

*The purpose of this study* is to reduce energy consumption during intensive refrigeration processing of fruit and berry products by developing a structural and technological scheme of a vibrating wave fluidisation machine; determine the power and energy characteristics of this semi-fluidisation process; substantiation of rational speed modes of raw material movement in the processing zone. The scientific novelty of this investigation consists in the development of a vibromechanical source for creating a travelling and standing wave of a flexible load-carrying body. To achieve this goal, the following main tasks were set:

- based on the analysis of structural links of conveyor, wave and vibration machines, to substantiate their functional features and main trends in the development

of vibration-wave transport and technological technical systems;

- determine the main power and energy parameters of the developed oscillatory system and a typical scheme of transport and technological movement of the mass of bulk or small-lump loading;

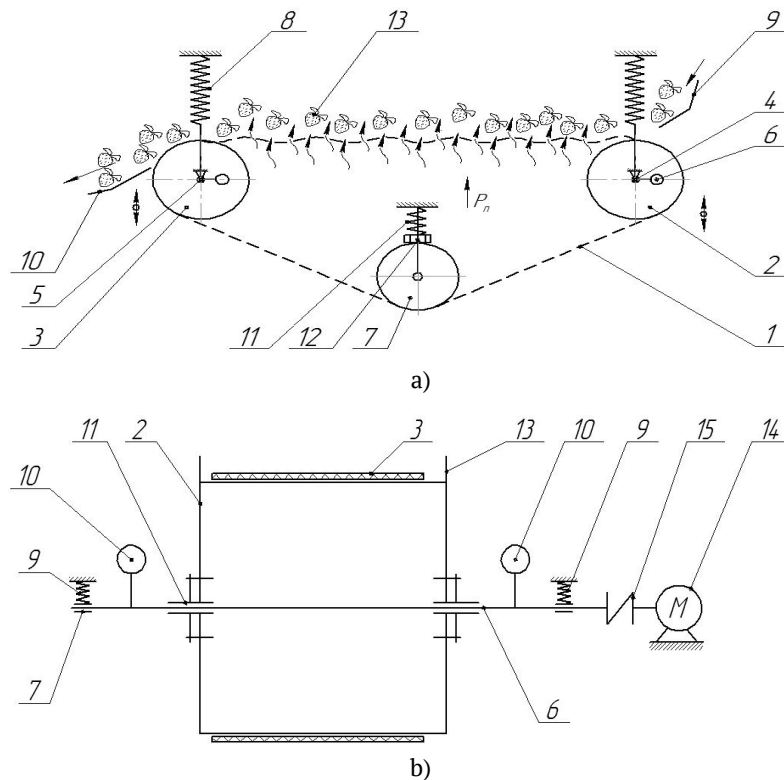
- substantiation of rational speed modes of raw material movement in the processing zone under the condition of minimising energy consumption for the process and ensuring high intensity of processing.

## Materials and Methods

Among the main stages of the research conducted during 2018-2022 are the development and manufacture of a pilot plant for the implementation of the semi-fluidisation process; compilation of the necessary measuring base for estimating the electromechanical and heat exchange parameters of the process; analytical determination of the main kinematic, power and energy parameters using the characteristics of the experimental model; determination of the power and energy parameters of this process for 2 options: with the vibration-wave movement of products and during its transportation by a conventional belt conveyor; processing and graphical interpretation of the comparative analysis of the two presented semi-fluidisation schemes; verifying the validity of the developed mathematical model.

This study shows that the use of a wave conveyor provides both the formation of a fluidised layer and the transfer of products in the production area at a controlled speed [20]. In this case, the transport wave is created due to the vibration of the belt support roller. In such vibration transport and technological infrared machine, the vibration exposure provides a reduction in technological resistance in the mass of products, significantly reducing the force effect on it, as a result of the generated travelling wave on the surface of the load-carrying body, the movement of the processed material along the belt and continuous mixing or renewal of product layers are provided.

For experimental assessment of the transport parameters of fruit and vegetable products during their low-temperature processing, the developed experimental model of a vibration-wave semi-fluidisation machine was used. In this installation (Fig. 1), vibration has a complex effect on the technological parameters of heat and mass transfer treatment: loosens the mass of raw materials, increasing the area of heat exchange with the coolant; constantly mixes and renews the surface layers of the product; creates a standing or travelling wave on the supporting transporting surface to move the product in the production area along a controlled trajectory.



**Figure 1.** Vibrating semi-fluidisation machine (a) with spatial vibration drive in support rollers (b):  
 1 – driving roller; 2 – supporting roller; 3 – conveyor belt; 4 – processed products; 5 – infrared emitters;  
 6 – eccentric shaft of the vibrating exciter; 7 – supporting unit of the vibration exciter;  
 8 – a platform of the vibration exciter; 9 – elastic elements of the supporting unit of the vibration exciter;  
 10 – counterweight; 11 – supporting unit of the roller; 12 – vibration supports; 13 – roller flange;  
 14 – motor of the drive of the vibration exciter; 15 – an elastic clutch of the vibration exciter;  
 16 – drive motor of the drive roller; 17 – drive pinion of the drive roller; 18 – driven gear of the drive roller;  
 19 – supporting units; 20 – elastic coupling of the drive roller; 21 – drive axis of the drive roller;  
 22, 23 – supporting units of the axis of the drive roller; 24 – debalance

To obtain the necessary base of experimental data, a set of devices of the microcontroller system was developed and used, which is presented in more detail in [19]. Such a system contains electrical devices; sensors for evaluating heat exchange parameters; vibrometers for determining the amplitude-frequency and force characteristics; aerometers and accelerometers for measuring and regulating the amplitude-frequency and force parameters, kinematic characteristics of the coolant flow of the semi-fluidisation process under study.

In the developed fluidisation apparatus, a fluidised layer is created using a kinematic eccentric vibration drive (Fig. 1) contains a working surface 1, a support roller 2, a conveyor belt 3, tension rollers 4,5, a drive eccentric shaft 6, a support unit 7 of the device, a support for an elastic suspension 8, an elastic suspension 9, a counterweight 10, bearings 11, a support unit 12 of the roller, a flange 13, a drive motor 14, a spring clutch 15. A conveyor belt 3 with tension rollers 4,5 is installed on the working surface 1 of the support roller 2, a kinematic eccentric vibration drive, the drive eccentric shaft 6 is fixed in the support unit 7, the elastic suspension 9 is fixed on the support of the elastic suspension 8, to level the parasitic inertial loads, a counterweight 10 is installed, bearings 11 in the supporting unit 12 of the roller, place the flange 13 above the conveyor belt 3, the shaft 6 is connected to the drive motor 14 by means of

a spring clutch 15 to prevent the transmission of vibrations to the motor 14. During the operation of the device, the bulk material is delivered to the conveyor belt 3. The drive motor 14 through a flexible coupling 15 provides torque to the eccentric shaft 6, the rotation of which ensures the passage of a dynamic travelling wave on the surface of the belt 3, creating a fluidised state of the processing material and its translational movement along the surface of the load-carrying body. Such a vibration drive is characterised by a decrease in oscillating masses, which reduces energy consumption by 1.5-2 times for the implementation of the oscillatory process compared to the unbalanced one [21]. The oscillating movement of the rollers is transmitted to the flexible conveyor belt 3, forming a travelling or standing dynamic wave on its surface. The kinematic characteristics of this wave, namely the phase frequency and amplitude of oscillations determine, respectively, the speed of product advancement and the thickness of the formed fluidised layer. These characteristics can be changed by adjusting the ratios of amplitudes and frequencies of oscillations for the drive eccentric shaft 6. Thus, the bulk mass of products receives a transport movement due to changes in the parameters of the generated wave, and not due to the longitudinal movement of the conveyor belt.

The use of an accelerometer in the mode of an autonomous probe allows evaluation the effect of vibrations

on the formation of wave motion of the product mass through the response of kinematic parameters and processing time.

The developed microcontroller system is used to determine the main heat and mass exchange parameters of the semi-fluidisation process under study. Besides measuring temperature and humidity values, the system measures the speed of the refrigerating medium, which determines its flow rate and the necessary data for the current calculation of the humidity of the products in the production area. The system has a timer feature. The current temperature and humidity data is automatically stored, and it is possible to pre-set timestamps with an accuracy of up to a minute. The values measured at these points will also be recorded. Data and checkpoint memory are energy-dependent. The accumulated and current information about the parameters of the dewatering process can be transmitted to a computer for further analysis, processing and calculation using the Mathcad programme.

When connected, the microcontroller and computer clock are automatically synchronised. The calculation of the current moisture content of the product is performed by a computer using the obtained values of the coolant moisture content and the entered constants that characterise this process. The application of the developed system provides normalised values of the cooling temperature and allows monitoring of the heat and mass transfer process to determine the rational parameters of the process.

Modern concepts of the theory and basic provisions of the mechanics of deformable solid bodies, solid and bulk media, elasticity theory, vibration processing and transport theory are used for theoretical research [22]. When performing experimental studies, German Robotron equipment was used to assess the kinematic parameters of vibration, and electromechanical equipment to ensure a slow change in the speed of rotation of the drive shaft of the vibration exciter.

## Results and Discussion

The technological effect of vibration can be branched into three main components: targeted effect on the mass of processed products, on the working container and on the working bodies of the machine; targeted change in the technological resistance of the system; functional universalisation when using vibromechanical elements, which are presented in detail in Figure 1. The vibration effect is especially effective for the intensification of heat and mass transfer processes due to a significant increase in the contact area in the conditions of a vibration-weighted layer; improvement of the uniformity of layer-by-layer processing and smoothing of thermal stresses in the material, which is quite important for thermolabile systems; simplicity of implementation and ease of coordination of transport and technological movements in the working area of the devices.

Well-known scientists have proved that the processing of bulk or small lumps of products is characterised by the high dynamic action of the working bodies; the acoustic effect of shock waves can be traced in complex with it [23; 24]. Vibratory movement of technological masses is carried out, as a rule, with a constant or slowly variable speed; which is explained by the phenomena of alternate change of withdrawal movements – displacement of equilibrium positions, the appearance of one or more discrete

positions of quasi-equilibrium; imaginary transformation of dry friction into viscous friction. As a result of reducing the effective coefficient of friction and internal viscosity under conditions of low-frequency oscillations, which leads to an increase in the uniformity of processing up to 100% of the active contact surface in a fluidized layer with a 2-3 times reduction in the processing time and a corresponding decrease in energy consumption [25; 26]. Thus, vibromechanical processing in combination with pneumatic and hydrodynamic actions gives a high potential for effective changes in the physical and chemical processes of product processing, which substantiates vibration processing as one of the most effective types of technological action, becoming increasingly common in food production [27].

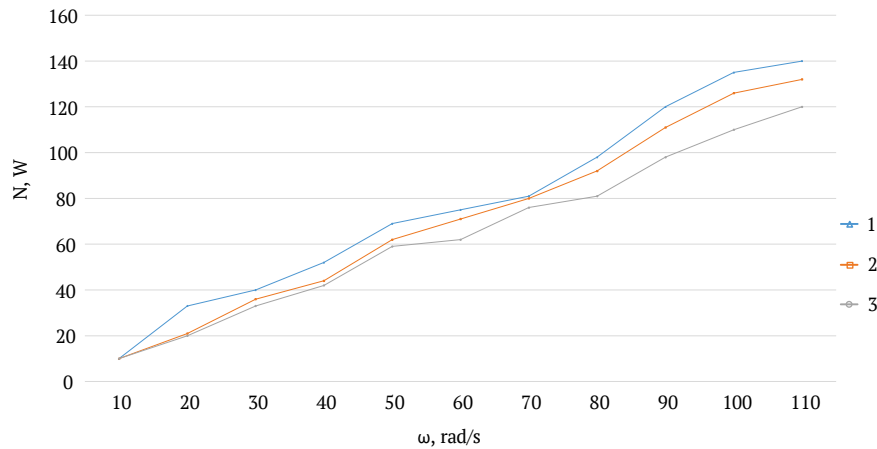
Application of the kinematic forced vibration drive of the proposed design, by installing the drive eccentric shaft, support roll, counterweight, bearings of the support roll, support roll assembly, flange, tension rolls, spring clutch; the presence of elastic suspension of volumetric action, the working rolls carry out forced reciprocating and oscillatory motion, which forms a pseudo-rarefied layer, which allows to simplify the design, improve the vertical movement of the product, increase the intensity of heat and mass transfer due to bringing to 100% the contact surface with the coolant.

Using devices for monitoring vibration parameters, the developed microcontroller system analysed the main technical and economic parameters through the speed and energy characteristics of the technical system under study. The study was conducted at different angles of the imbalances relative to each other to estimate the force action from mechanical vibration exciters. The latter are double gallet elements, the mass of which is not symmetrical with respect to the axis of the drive shaft. Therefore, when changing the angle between these fillings from 0 to  $\pi$  (0, 60°, 90°, 120°, 180°) the inertia force of unbalanced masses decreased inversely from the maximum value to zero. Changing the relative location of the imbalances allowed to trace their influence on the above parameters of low-frequency oscillations. Changes in the positions of unbalanced elements relative to the vertical axis of the machine create an effect on the drive body by force, moment or their combinations, which causes states or modes of force, moment and combined unbalance in the oscillating system and allows determining the corresponding characteristics of the vibration-wave transportation of technological masses. The levelling of parasitic oscillations is realized in the presence of a spring-loaded suspension of the guide belt of the developed semifluidization machine, which can be traced by the changes in the amplitude of oscillations of the supporting unit of the vibration exciter by almost an order of magnitude [28; 29].

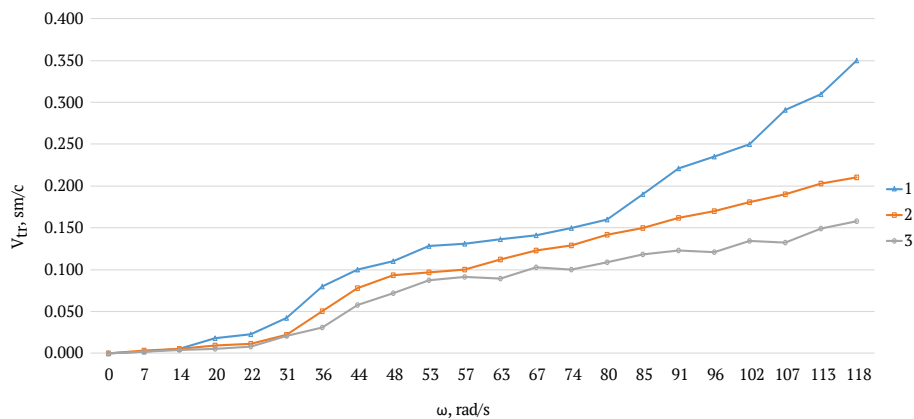
To generate low-frequency vibrations and convert them into wave motion of the belt during interoperative transportation of fruit and berry products in the studied machine, the use of two mechanical inertial or power vibration exciters mounted in the support rollers of the belt mechanism was provided. The machine uses vibration drives with inertial elements – debalances 10 (Fig.1). Changing the angle between these elements and the relative position to the roller 2 allows implementing alternative schemes of mechanical vibration excitation: eccentric or forced kinematic and unbalanced inertial vibration drives.

Accordingly, at the force unbalance of the oscillating system, that is, under the action of only inertial loads, only unbalanced forces act on the drive shaft, at the momentary

unbalance – the result of the action of only moments and at the combined unbalance – when both forces and moments affect the actuator (Figs. 2, 3).



**Figure 2.** Power consumption of the drive body of the machine from the frequency characteristics for such modes of power technological action: 1 – for combined unbalance; 2 – for momentary unbalance; 3 – for power unbalance



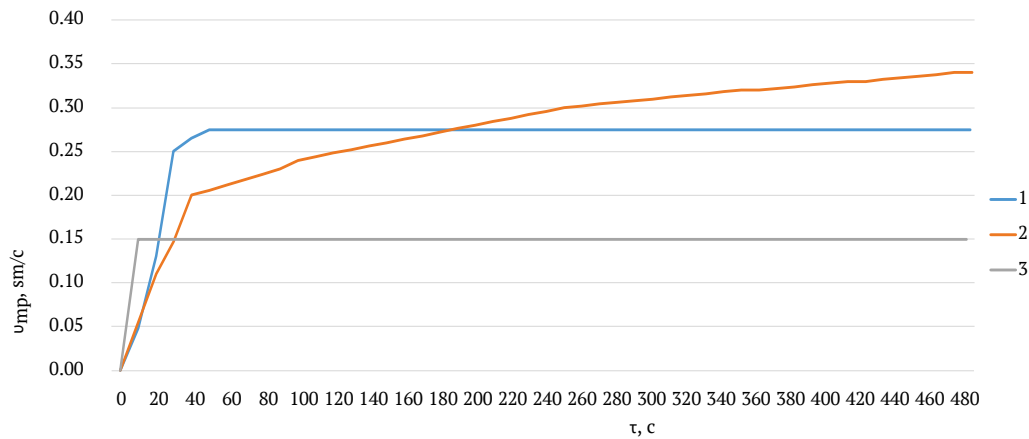
**Figure 3.** The speed of transportation of processed products depending on the angular speed of rotation of the drive shaft  $\omega$  for such modes of power technological action: 1 – for combined unbalance; 2 – for momentary unbalance; 3 – for power unbalance

As a result of reducing the oscillating masses of the eccentric vibrating exciter by 1.5-2 times, the dynamic loads from the specified forces and moments are reduced, which makes it possible to reduce energy consumption accordingly, while maintaining high performance of the supercooling or freezing process, which for the investigated oscillating technological system is determined by the possibility of one passage of the product mass along the processing zone to acquire the required operating temperature, in particular – 10 °C on the product surface.

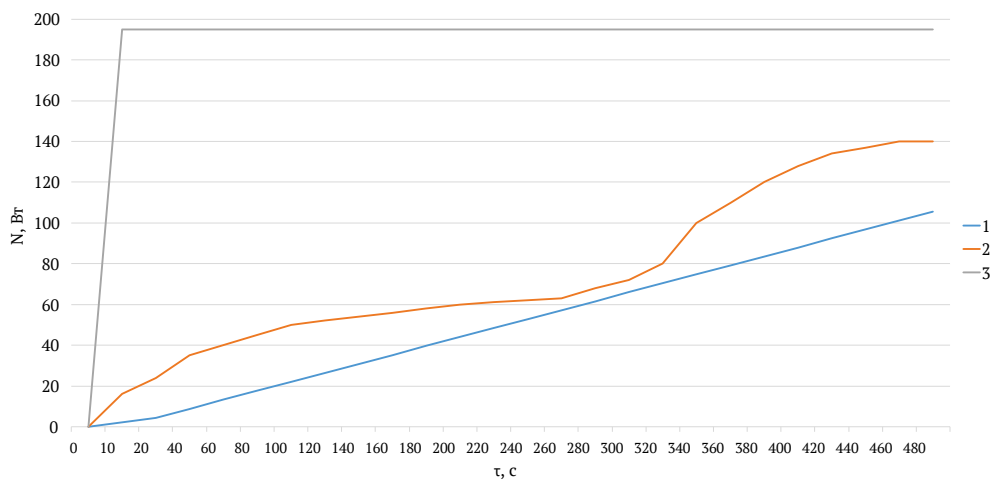
According to the results of experimental studies, for the frequency operating mode range of 80...100 rad/s, energy consumption varies within 17.3...19.1% (Fig. 2), and the change in the transport speed of the processed products is 31...50% (Fig. 3). Evidently, the implementation of the combined unbalance of the oscillating system makes it possible to minimise energy consumption and increase the speed of movement of the technological mass by 27-33% in the production area (Fig. 2) from the wave motion of the belt while maintaining an intensive vibropulse processing mode.

Kinematic and energy parameters were used as criteria for evaluating the conducted studies. As kinematic parameters, the speed of movement of the product flow was determined, which characterises the mass productivity of the vibrating conveyor installation. The power consumption to drive the machine actuators for low-temperature processing in the fluidised layer of the product was used as an energy parameter for evaluation. The given kinematic and energy parameters obviously determine the technical and economic efficiency of the developed refrigeration process. The presented characteristics were determined for two methods of implementing the semi-fluidisation process in the moving product layer (Figs. 4, 5):

- in case of transportation of the mass of products by the movement of the conveyor belt;
- in the case of moving products by the motion of the belt, which is the working body of the wave conveyor, receiving alternating circular motion from the oscillations of the support rollers.



**Figure 4.** Speed characteristics of the load-bearing body of the machine: 1 – the results of analytical calculations and 2 – the results of experimental analysis for the vibro-wave conveying scheme; 3 – the speed of transportation of products using a typical belt conveyor



**Figure 5.** Energy characteristics of the process: 1 – results of analytical calculations; 2 – results of experimental analysis; 3 – power consumption of the belt conveyor drive

When transporting the mass of products by the movement of the travelling wave formed on the surface of the belt, the speed  $v_{tr}$  of the latter is higher by 44-52% according to the results of analytical calculations and experimental analysis (Fig. 4) compared to the traditional belt conveyor when moving technological masses, that is, when transporting the mass of products by the movement of the conveyor belt. To ensure the specified mass productivity of the machine and bring supercooling to the operating temperature in one pass of the production area, we assume that the corresponding speed parameters are:  $v_{pr} = v_{tr} = v_c$ .

When processing products under the conditions of a vibration wave conveyor, the speed of transportation of products on the belt can be assumed to be equal to the vibration velocity  $v_x$ :

$$v_{pr} = v_x = A_x \omega_k, \tag{1}$$

$$A_x = A_{x1} + A_{x2}, \tag{2}$$

$$\omega_k = \frac{2\pi}{T_k}, \tag{3}$$

$A_{x1}, A_{x2}$  – components of the oscillation amplitudes from the drive vibration exciters;  $\omega_k$  – frequency of vibrations of the wave conveyor.

The results of experimental and theoretical studies in determining the speed of product transportation in the processing zone and energy consumption for the process were within the permissible values for almost all frequency modes (curves 1 and 2 in Figs. 4, 5). At the same time, the speed of transportation of products by the movement of the belt conveyor was 44% lower than when using a vibration wave propulsion system, which indicates the high kinematic qualities of the latter and the reserves for increasing the productivity of the process under study (Fig. 4). Power consumption in the studied process for the 1<sup>st</sup> mode was higher by 28...39% for the range of operating frequencies than when using the developed vibration-wave drive of oscillatory movement of the load-carrying belt (Fig. 5).

### Conclusions

1. Based on the analysis of the characteristics of vibrating and wave transporting machines, their classification was developed, the main qualities for effective use in the food and processing industries were substantiated and the following structural and technological advantages over other types of equipment were identified:

- simplicity of design for the implementation of complex transport and technological traffic;
- high level of structural restoration, in particular, ease of technical and technological operation, ease of changing and adjusting the trajectory of product flow;
- high reliability parameters, in particular, durability characteristics under severe operating conditions due to the presence of elastic suspension of the supporting rollers of the conveyor belt and elastic elements of the supporting units of the exciter;
- maintainability and interchangeability of components;
- the possibility of combining transport operations with the simultaneous implementation of certain technological processes, in particular heat and mass exchange.

2. Comparative analysis of the kinematic and energy parameters of the processes of transportation of bulk products in the production area using the developed vibratory wave conveyor machine and the classical belt conveyor revealed an increase in almost twice the speed of transport movement and a reduction in 1.4 times the energy consumption for the process for the designed scheme.

3. The developed drive mechanism of the semi-fluidisation machine intensifies the process of heat exchange in the production area, realising the following processing parameters: product conveying speeds within the value of product conveying speed in the range from 0.125 to 0.25 cm/s with energy consumption for the process in the range of 120-140 W for the frequency range of 80...100 rad/s.

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## Техніко-економічне обґрунтування процесу семіфлюїдаційної обробки плодоягідної продукції

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**Анотація.** Пошук ефективних схем реалізації процесу семіфлюїдації для підморожування та заморожування плодоягідної продукції за умови мінімізації енерговитрат та високої продуктивності на процес становить актуальність проведених досліджень. Метою дослідження є розробка енергоефективних та надійних технологічних схем реалізації віброхвильової холодної обробки плодоягідної продукції на основі розробки вібраційної транспортно-технологічної флюїдаційної машини; визначення силових та енергетичних характеристик процесу семіфлюїдації; обґрунтування раціональних швидкісних режимів просування сировини у зоні обробки. На основі порівняльного аналізу конструктивно-технологічних характеристик хвильових, конвеєрних та вібраційних машин було обґрунтовано основні тенденції їх розвитку; визначені основні силові та енергетичні параметри розробленої коливальної системи. Проведено порівняльний аналіз технологічних схем семіфлюїдації при використанні транспортного руху продукції стрічковим та віброхвильовим конвеєром, що дозволило обґрунтувати ефективність застосування відповідних приводних механізмів досліджуваної машини. Графоаналітичний аналіз швидкісних та енергетичних параметрів досліджуваного семіфлюїдаційного процесу на основі отриманих теоретичних та експериментальних даних дозволив перевірити адекватність розробленої математичної моделі та обґрунтувати основні параметри робочого режиму просування технологічного завантаження вздовж зони обробки. Проведені дослідження при використанні розробленої дослідної моделі та класичного стрічкового конвеєру довели підвищення швидкості транспортування сировини майже у 2 рази при зменшенні енерговитрат на процес у 1,4 раза за віброхвильової схеми. У розробленій вібраційній транспортно-технологічній семіфлюїдаційній машині вібраційний вплив забезпечує зменшення технологічного опору у масі продукції, істотно знижуючи силову дію на неї, внаслідок утвореної біжучої хвилі на поверхні вантажонесучого органу забезпечується переміщення оброблюваного матеріалу по стрічці та неперервне перемішування або оновлення шарів продукції. До практичної цінності проведеної роботи належить застосування комбінованої схеми створення псевдорозрідженого шару продукції за рахунок колювання стрічки та барботування потоком холодоносія; використання хвилі стрічки для створення переміщення продукції у робочій зоні

**Ключові слова:** вібрація, хвильовий конвеєр, дрібнокускова сировина, незрівноваженість коливальної системи, низькотемпературна обробка, дебалансний вібробудувач