Justification of Vibroventrentic External Load During Mechanical Pressing of Glycerin-Containing Products

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Abstract. The research results established possible ways of using pharmacopeial or distilled glycerin in confectionery, microbiological, pharmaceutical, enzymatic, and other processing industries. The analysis of research in dehydration of dispersed materials shows that the technological process of glycerol purification is quite complex. It was established that all physical and mechanical properties of the final product and technical and economic characteristics of the equipment can significantly impact the quality of glycerol dehydration. The mechanical dehydration method of glycerin by giving the working drums planetary motion and additional oscillations in the horizontal plane was substantiated. The value of the pressure arising in the drum of the vibrating-planetary installation was determined. A comparative analysis of the vibrating component's influence on the pressure was studied depending on the angular velocities of water and drum and the loading degree. Existing schemes of moisture transportation and methods of dehydration of viscous and liquid materials were investigated. The analysis of diffusion, mechanical and thermal mechanisms, and their influence on moisture-binding properties of raw materials and the comparative analysis of driving force and speed of processes were carried out. A brief description of the diffusion mechanism and process of moisture transfer in products was given.

Keywords: Glycerin · Dehydration · Vibration-planetary motion · Driving force · Pressure · Process innovation

1 Introduction

Traditionally, in the food and processing industry, convective drying technologies are widely used, implemented in a variety of design dryers: shaft, belt, drum, in which the

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heat transfer to the raw material is carried out using a drying agent through the outer shell of the product to the inner layers. A detailed analysis of the most common technologies of convective drying [1] shows that drying equipment in terms of energy intensity, environmental regulations, product safety do not meet modern requirements. Traditional approaches to drying technology are faced with an insurmountable contradiction. On the one hand, to intensify the heat and mass transfer processes, it is required to increase the drying agent's speed (i.e., consumption). Therefore, with increasing coolant consumption, the amount of heat lost by the installation increases and vice versa. The way out for the solution of the indicated contradiction is connected with the change of the principles of energy supply to the product [2].

A new technical idea protected in this work is based on 2 provisions [3]. First, it is necessary to remove from the air the tasks of the coolant and leave only the tasks of the diffusion medium, the medium that ensures the effective "reception" of moisture from the product. Secondly, to organize a volumetric supply of energy to the product. Implementing the first position will significantly reduce heat loss from the exhaust air, and the second will significantly reduce the processing time.

Mechanisms of moisture transfer from capillary-porous bodies. According to the generally accepted classification of P.A. Rabinder, there are 3 forms of physical connection of moisture with the material. It seems that different types of communication in physical nature require different mechanisms for their breaking. Moreover, it does not necessarily have to be only diffusion processes [4]. All determine the driving forces that may have a diverse nature. Currently, new, promising types of equipment have been created, the effectiveness of which is difficult to explain from the standpoint of the modern theory of drying. Therefore:

1. The dehydration technique develops faster than the theoretical substantiation of the new principles of moisture removal;
2. The driving forces of these processes do not correspond to the diffusion principles;
3. Often, dehydration is a complex of combined processes involving processes that require proper consideration of the actual mechanisms of moisture transfer.

The problems arising from the description of the drying process are explained by the fact that the authors, supporters of the phenomenological approach, consider drying as a kind of one process with constant transfer coefficients and form models from these assumptions. This paper hypothesizes that drying is the result of the action, on the principle of superposition, of at least three processes: moisture transfer from the surface of a solid, moisture transfer in constrained capillary conditions, and moisture desorption. Each of these processes is characterized by the driving force and the kinetic coefficient of the process.

2 Literature Review

Analysis of research in dehydration of wet dispersed materials shows that this is a rather complicated technological process. Its course is primarily influenced by the physicomechanical properties of the product, such as initial moisture, elasticity, viscosity, plasticity, internal friction between particles of the solid phase, adhesion, cohesion, and other properties, as well as the characteristics and modes of operation of the process equipment [5]. In removing moisture, structural, mechanical, and technological properties of the product may vary within wide limits. This determines the complexity of the study of filtration rheological properties of technological raw materials and the process itself as a whole [6, 7].

Glycerin was discovered in 1783 by the Swedish chemist Carl Wilhelm Scheele, who showed that fragments of this compound formed the basis of all-natural fats and called it (sugar from fat) because the product had a sweet taste [8]. Scheele boiled olive oil with lead oxide (lead glitt). Wilhelm Scheele could not determine these fragments' exact composition and structure - organic chemistry was just beginning to develop [9, 10]. Pharmacopoeial or distilled glycerin is in increasing demand in confectionery, microbiological, pharmaceutical, enzyme, and other processing industries. In pharmaceutical practice, glycerin is used to manufacture a wide range of dosage forms, namely: solutions, syrups, elixirs, potions, suspensions, emulsions, ointments, pastes, candles, and others. It is also used as a drug with various pharmacological actions [11, 12].

Glycerin can be a solvent for various chemicals, has antiseptic properties and is used to prepare various medicinal solutions [13]. The antiseptic and preservative properties of glycerin are related to its hygroscopicity, due to which bacterial dehydration occurs. It is part of many cosmetics. When purifying crude glycerin in the first stage (long-term settling), many problems significantly affect the productivity of food (pharmacopoeial) glycerin [11].

Crude glycerin contains a non-volatile organic residue, fats, acids, salts, and ash, significantly complicating the separation process without prior long-term settling. From the whole complex chain of the technological process of obtaining glycerol, we distinguish the stage of separation of free (and non-free) moisture from intermediate raw materials. This is usually done by centrifugation, separation, rarely simple filtration [12].

The use of conventional centrifuges with a single rotating drum, where the product is exposed only to centrifugal force, is quite expensive in modern conditions since the working capacities of these machines must be quite large and dispersed to significant angular speeds [16]. The use of centrifuges with a planetary and at the same time vibrating movement of the working drums can significantly intensify and qualitatively improve the dehydration process, significantly increasing the driving force of mechanical squeezing, which determines the relevance and future of these studies [17].

It should also be noted that it is relatively easy to remove free and capillary-bound moisture when using mechanical squeezing, and considerable effort is necessary to extract the absorption-bonded and osmotic fluid.

The raw materials can be processed with heat or structured additionally [18, 19] to reduce the resistance during the fluid movement through the micropores of the product.

The results of scientific work are based on the research of A. Babicheva, P. Bernika, I. Blechmana, P. Zaiki, I. Palamarchuka, M. Pushanka, V. Sokolova, V. Stabnikov, L. Tishchenko, and others [20].

The use of vibrating equipment to separate inhomogeneous liquid systems is one of the effective ways to implement the process. Therefore, developing a vibrocentric machine for the primary purification of crude glycerin is an urgent scientific and applied task.

This research aims to evaluate the effectiveness and justification of the method for determining the driving force of mechanical dehydration of insulin-containing raw materials due to the comparative analysis and determination of the driving force of centrifugal centrifugal-planetary, vibration, and vibrational-planetary actions.

The following tasks were set to achieve the aim:

- conduct a comparative analysis of centrifugal, vibrational, planetary, and combined vibration-planetary technological actions in terms of the intensity of the created force field;
- choose a schematic diagram and an experimental model of the installation for the combined vibration-planetary dehydration of insulin-containing raw materials;
- evaluate the patterns of pressure created in the working zone from the kinetic characteristics of the investigated technical systems.

In the process of analysis of the studied oscillatory system as evaluation criteria, changes in external force load were accepted from the action of vibration, planetary and combined vibroplanetary influence on the mass of the technological environment, and the results of such action in the studied processes.

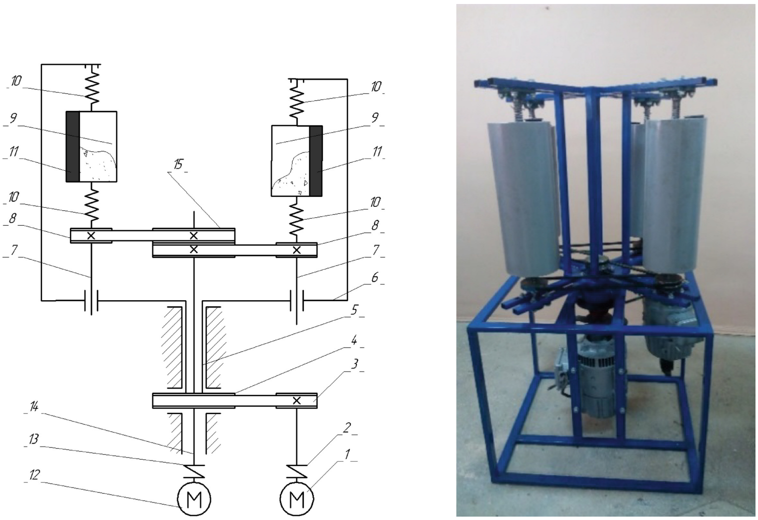
3 Research Methodology

Among the main parameters used in this study, we used the change in pressure inside the working tank; angular velocities of rotation of the carrier of the planetary mechanism and angular movement of the container; centrifugal forces, which arise respectively by vibrational, planetary, and vibroplanetary action; the value of the mass of the liquid phase, which is pressed under the corresponding external load.

The National University Life and Environmental Sciences laboratory of Ukraine has developed a set of equipment for the mechanical dehydration of food and processing industries, characterized by either vibratory, centrifugal, or planetary technological effects or their combination. Under centrifugal effects, the growth of the driving force is determined by the design parameters of the working bodies and the angular velocity of their rotation. Vibration action allows, due to alternating accelerations in the contact zone, to significantly increase the intensity of the force field. The planetary model of the movement of the working bodies due to the peculiarities of the mechanism kinematics makes it possible to significantly increase the potential of the mechanical effect on the processed products.

For evaluating the presented characteristics, an experimental model of a vibroplanetary machine for pressing the mass of the load in oppositely located containers was designed and manufactured (Fig. 1).

It is assumed that the combination of actions of the above factors creates the most favorable conditions for effective mechanical dehydration of elastic-plastic products in terms of both the intensification of the powerful effect and the reduction of the damage degree to the feedstock.



a) b)

Fig. 1. Vibration-planetary machine: a) schematic diagram; b) appearance; 1, 12 – drive motors; 2, 13 – elastic couplings; 3, 8 – V-belt transmission; 4 – driven drive pulley; 5 – hollow shaft; 6 – carrier; 7 – container drive shaft; 9 – container; 10 – springs; 11 – drum weight assemblies; 14 – central shaft; 15 – central pulley.

Features of this machine are the ability to change the above types of external load by appropriately replacing individual components of the drive mechanism, mainly removing or installing unbalanced masses 11, switching off or on engines 1 and 12.

One of the results of these works is a vibration-planetary machine. The schematic diagram and its appearance are shown in Fig. 1.

Performing such permutations on one installation indicates the purity of the experiment. The obtained dependencies were processed for the specified parameters of the studied processes using graph-analytical analysis in the mathematical environment Math CAD.

4 Results

A distinctive feature of this machine is the ability of the working drum to rotate simultaneously around its axis, the central axis, and perform vibrations in the horizontal plane. In addition, in the installation, there is the possibility of independent regulation of the angular velocities of rotation of the container and carrier, which allows choosing its operation modes within wide limits.

To determine the dynamic characteristics of the dehydrated products in a vibration-planetary machine, let's consider the scheme shown in Fig. 2.

Let's select inside the product layer inside the drum an elementary layer of thickness dr at a distance r from its axis of rotation and determine for comparison the pressure that will be created on this layer with only the rotational motion of the drum (normal centrifugation), with only planetary motion and with vibration its planetary movement.

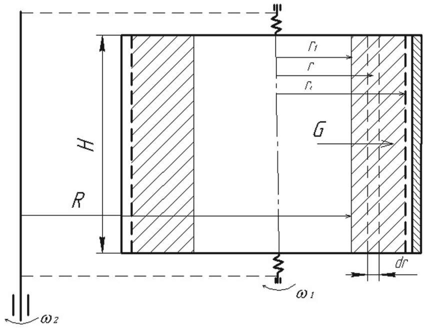


Fig. 2. Calculation scheme for determining the driving force of vibration-planetary dehydration.

The mass of the selected ring layer is equal to:

$$dm = 2\pi rdr \cdot H \cdot \rho \tag{1}$$

where: ρ – product density H – the height of the product layer.

It is known that in a conventional centrifuge, the pressure created on this layer of production can be determined by the formula:

$$p = \frac{1}{2}\rho\omega_1^2\left(r_2^2 - r_1^2\right), \tag{2}$$

where: ω_1 – the angular velocity of rotation of the centrifuge drum.

During the planetary movement of the working capacity, the working pressure on the specified product layer will be determined by the centrifugal force due to its rotation around its axis F_{b1} and the centrifugal force F_{b2} from the rotation of the carrier with containers. Simultaneously, considering (1):

$$dF_{b1} = 2\pi H\rho\omega_1^2 r^2 dr \text{ and } dF_{b2} = 2\pi H\rho\omega_2^2(R + r)rdr, \tag{3}$$

where: ω_2 – the angular velocity of carrier rotation.

Then the total pressure force will be equal to:

$$dG = dF_{b1} + dF_{b2} = 2\pi H\rho\omega_1^2 r^2 dr + 2\pi H\rho\omega_2^2(R + r)rdr, \tag{4}$$

The pressure created on the product (highlighted annular layer) is:

$$dp = dG/S \tag{5}$$

where: $S = 2\pi rH$ – the lateral surface of the annular cylinder.

Then

$$dp = \rho\omega_1^2 r^2 dr + \rho\omega_1^2(R + r)dr \tag{6}$$

Integrating this equality, let's obtain the expression for the average pressure during centrifugal planetary dehydration:

$$p_1 = \frac{1}{2}\rho\left(\omega_1^2 + \omega_2^2\right) \cdot \left(r_2^2 - r_1^2\right) + \rho\omega_2^2 R(r_2 - r_1) \quad (7)$$

If simultaneously with the planetary motion, the drum of the installation oscillates in a horizontal plane. Then an additional force will act on the selected loading layer:

$$dF_{виб} = m_\partial \omega_1^2 e \frac{dr}{r} \quad (8)$$

and extra pressure

$$p_2 = m_\partial \omega_1^2 e / 2\pi H \cdot (1/r_1 - 1/r_2) \quad (9)$$

where: m_d – drum weight assembly mass; e – eccentricity.

The total pressure inside the drums of the vibration-planetary machine will be

$$p = p_1 + p_2 = \frac{1}{2}\rho(\omega_1^2 + \omega_2^2)(r_2^2 - r_1^2) + \rho\omega_2^2 R(r_2 - r_1) + \frac{m_\partial \omega_1^2 e}{2\pi H} \cdot \left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad (10)$$

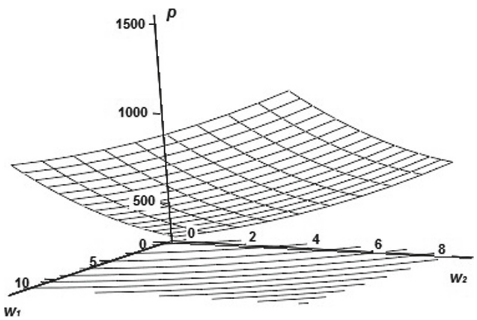


Fig. 3. The dependence of the pressure inside the drum on the ratio of the angular velocity of the working capacity and carrier.

Figure 3 shows the resulting pressure as a function of the ratio of the angular velocities for the working capacity and the carrier. The graph shows the increase in pressure from increasing specified angular velocities.

The influence of the vibration movement of working tanks on the pressure generated on the processing load is also investigated (11):

$$q = \frac{p}{p_1} = \frac{\frac{1}{2}\rho(\omega_1^2+\omega_2^2)(r_2^2-r_1^2)}{\frac{1}{2}\rho(\omega_1^2+\omega_2^2)(r_2^2-r_1^2)} + \frac{\rho\omega_2^2 R(r_2-r_1) + \frac{m_\partial \omega_1^2 e}{2\pi H}\cdot\left(\frac{1}{r_1}-\frac{1}{r_2}\right)}{\rho\omega_2^2 R(r_2-r_1)} \quad (11)$$

The increase in pressure depending on the degree of drum loading is shown in Fig. 4, from changes in the angular velocity of carrier rotation – in Fig. 5, and from the change in the angular velocity of container rotation – in Fig. 6

As can be seen from the graphs, as obtained from the research, vibration has a significant effect on many indicators: the pressure decreases with increasing load, increasing angular velocity of the carrier, and increasing angular velocity of the container.

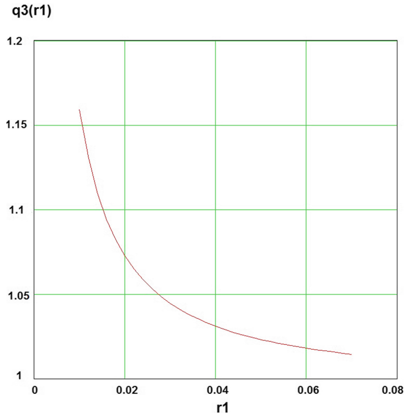


Fig. 4. The effect of the degree of container loading on the change in pressure due to its vibratory motion

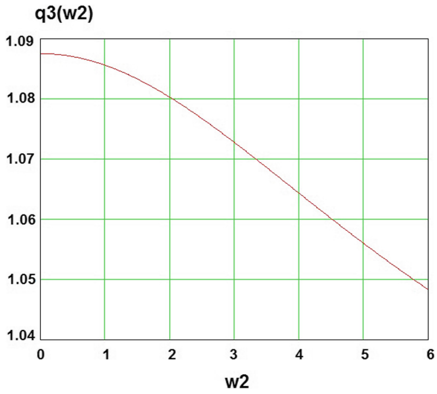


Fig. 5. The effect of the angular velocity of carrier rotation on the change in pressure due to its vibratory motion

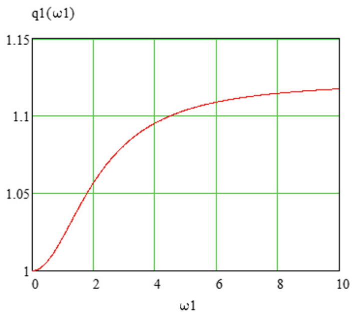


Fig. 6. The effect of the angular velocity of the container on the change in pressure due to its vibratory motion

5 Conclusions

Effective technological schemes for the implementation of dehydration of elastic-plastic products are presented, or such evaluation criteria as performance, energy, and material costs, damage to the feedstock.

A schematic diagram and an experimental model of a vibration-planetary machine for dehydration of glycerin-containing products, in which a combination of the above power factors of influence are implemented.

The pressure occurring inside the drum, which makes a vibration-planetary motion, is determined.

Graphic dependences of the influence of the kinematic characteristics of the investigated technical systems on the driving force of these processes are obtained, which display:

- increase in pressure on the processing load with an increase in the angular velocities of the carrier and the working drum;
- influence of the vibration component on the pressure inside the drum, which decreases when the angular velocity increases;
- alignment of the influence of the vibration component at the level of 10–11% with an increase in the angular velocity of the container.

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