Study of the strength of granules of instant drinks in a drum vibrating unit

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Abstract. In conditions of high employment, the question of proper and balanced nutrition is becoming more and more acute, since it is not always possible to get all the substances necessary for the body with food. In this regard, the development of functional instantiated products is an urgent task. The paper investigates the new design of a drum vibrating unit, namely, determining the strength of the obtained granules depending on the design and operating parameters of the process. The object of research was instantiated jelly in the form of granules with dimensions of 1 – 3 mm. Another task was to determine the effect of mechanical activation of potato starch on the strength of the resulting granules. From the analysis of the obtained data, it can be concluded that the greatest influence on the strength of the granules is exerted by the dynamic component, namely, the frequency and amplitude of vibrations, and the rotation frequency of the kneading unit does not have a significant impact, but directly affects the time when the product is in the drum unit. Analysis of the effects of mechanical activation of potato starch showed that granules obtained based on native potato starch have less static crushing strength. This is because during the mechanical activation of starch agglomeration centres are formed, which ultimately leads to an increase in strength.

1. Introduction

The relevance of improving food production is directly related to solving the problems of reducing the cost of finished products along with increasing their biological value to reduce the lack of functional products. The use of perishable products requiring the creation of special conditions for the storage and transportation of fresh plant products in food technology is limited, due to the complexity of the organization of their implementation, which in turn leads to an increase in their cost and an increase in production risks associated with spoilage of finished products. The use of dry instantaneous forms of long-term storage is economically justified and technologically rational [1, 2].

The use of plant materials for the production of instant products is justified in terms of the content of necessary micronutrients for the human body [1].

A special place among plant materials in the south of Western Siberia belongs to fruit and berry raw materials, since berry crops are unpretentious, have high productivity and nutritional value [3]. Also, studies prove [2] that the use of locavore for the population who lives in this territory is justified [3].

Given the high employment of the population, and often the inability to provide balanced nutrition, it is necessary to use ready-made and balanced food products obtained by manufacturers in their diet.
One of such products for the conditions of Kuzbass can be a traditional drink - jelly, based on berries or fruits [3]. To increase its shelf life, dissolution rate, transportation, etc., jelly is made in the form of granules with sizes from 1.5 to 2.5 mm. This reduces the caking of the product, reduces the entrainment of the product during drying, improves the appearance of the product, so if the multicomponent product is transported, segregation occurs under the influence of vibration during transport, and ultimately a multicomponent mixture of dry powdery ingredients fractionally divided into layers is delivered to the consumer [4, 5].

In recent years, a large number of studies have been associated with structural changes in components to increase their final organoleptic properties [5]. In [5, 6], it was pointed out that when applying solid-phase mechanical activation of potato starch, the viscosity of the solution based on it exceeds the viscosity of the solution from native starch 1.5 times, which significantly changes the formulation of the finished product, but the effect of starch mechanical activation has not yet been studied with the production of instant granular food products (IGFP).

2. The purpose of the study
From the improvement of the granulation process in controlled segregated flows of instantiated polydispersed products based on potato starch subjected to solid-phase mechanical activation during convective drying in a drum vibrating unit due to the selection of rational operating modes.

3. The object of the study
As a result of the literature and patent review of equipment for carrying out the process of structure formation and drying of dispersed systems, the advantages and disadvantages of each of the methods were identified, the design of a new drum vibrating unit for producing granules of a given particle size distribution and other structural and mechanical properties was also proposed. The design of a new drum vibration unit (DVD) (Patent No. 2693772 IPC B01J 2/18) is shown in Figure 1.

DVD works as follows - the initial mixture of granular components enters the DVD, where a vibration field from the vibration exciter is superimposed on it, as a result of which the mixture is transferred to the vibration-fluid state and a binder solution is supplied to its surface. The granules are moved to the outlet pipe due to vibrational impact, the unformed granules move in the opposite direction and are lifted to the top of the machine by a belt mixer. Formed granules in DVD enter elastic sleeve 3 in DVO-C 2.

The DVO-C experimental setup had the following geometric parameters: inner diameter of the body 144 mm; length of the working part of the body 750 mm; the diameters of the inlet and outlet nozzles for wet granules, the finished product and the heat agent were 50 mm. The parts of the housing and the working unit were made from plexiglass (XT/GS) to visualize the process.

The DVO-C installation (Figure 2) works as follows – under the influence of a vibration field created by a vibration exciter of an off-balance type 17, 18, the formed granules move towards discharge pipe 14.

The drying agent is fed through a branch pipe 9 installed tangentially to the body of the vibrating roller 1 and moves along a spiral path to the branch pipe 21 of the drying agent, also located tangentially to the body. If only the agitator is being stirred, without taking into account the vibration effect, particles of different sizes will be randomly located in the material thickness, to intensify the drying process, as well as to obtain more durable granules for abrasion and crushing, it is proposed to impose a dynamic load in the form of a vibration field in this installation.

Under the influence of a vibration field, the dispersed product was transferred to a vibro-liquefied state, resulting in a process of segregation of granules of different sizes, but of the same density, i.e. large granules occupied the upper position, and small ones with less energy occupied the lower position, where they were captured by a stirrer and moved on rectangular blades located at an angle of 45 ° along the periphery of the inner surface of the body, from where they were poured under the action of gravity.
Figure 1. Drum vibration unit:
1 - drum vibration granulator;
2 - drum vibrocoiler-dryer;
3 - elastic sleeve

Figure 2. Drum vibrocoiler-dryer: 1 - shell; 2 - loading branch pipe; 3 - shaft; 4 - core; 5 - spiral mixer; 6 - scapula; 7 - clamp exciter support; 8 - support collar; 9 - pipe supply of a drying agent; 10 - flange; 11 - cover; 12, 20 - bearing assembly; 13 - mixer motor; 14 - pipe unloading the finished product; 15, 19 - compression spring; 16 - base; 17 - unbalance; 18 - vibration exciter motor; 21 - nozzle outlet of the drying agent

The contact of the heat carrier and the material to be dried (figure 3) is observed in the lower part of the apparatus $Q_1$, as well as in the zone of downward flow from the agitator blades are conventionally depicted as $Q_2$ and $Q_3$. 
Figure 3. Scheme of the cross-section of the DVO-C

The following factors explain the conversion of a dispersed medium to a managed segregated stream – since small particles form a denser stack, the drying of this material is complicated by a low-temperature gradient and moisture migration, which also makes it difficult to dry large particles, which require more time for dehydration of the material and the drying agent to be in direct contact with the convective drying. Figure 3 shows that the agitator blade is immersed to a specified depth \( h \) captures small granules and moves them up to the contact zone with the coolant \( Q_2 \) and \( Q_3 \). After the fine particles are poured from the blades onto the contact zone \( Q_4 \) they move to the lower part (under large granules) under the action of a vibration field, then the cycle repeats. In this case, large particles are in contact with the drying agent almost constantly. As a result of the above, it is possible to intensify the drying process at the first stage, where moisture is removed from the surface layers of the processed material.

4. Materials and methods
Along with studies of the abrasion strength of pellets, briquettes or tablets, crushing studies are also conducted. To determine the degree of influence of the regime parameters of the process on the final static strength of the granules, as well as the influence of mechanical solid-phase activation of potato starch, the destruction of the granules on KP-3 was carried out.

To eliminate the difference in the humidity of the finished granules, they were placed in the desiccator for 24 hours, before and after drying in the desiccator, the finished granules were weighed on analytical scales with a division price of 0.001 mg. After the final drying, the pellets were placed in a special container 6 mounted on a lifting table, the disk 7 was installed so that the surface of the pellets came into contact with the surface of the disk.

To balance the moving parts of the device, a counterweight was used, thrown over the block (not specified in the diagram). The mobile part of the laboratory unit was subjected to loading using weights of accuracy class M2 according to GOST 7328-2001 until the destruction of the granules. The time of the destruction of the granules was assessed visually. To determine the average strength of the granules, 20 tests were performed, then the average value was determined depending on the size of the test granules. The process boundary conditions are shown in table 1.
Table 1. Parameters and boundary conditions for experimental research

| Factor                              | Designation of factors | Levels | Centre of experiment | Variation step |
|-------------------------------------|------------------------|--------|----------------------|----------------|
| Oscillation amplitude (A), (mm)     | X₁                     | 0,5    | 1,5                  | 1              | 0,5           |
| Frequency (ν) Hz                    | X₂                     | 20     | 50                   | 35             | 10            |
| Mixer rotation frequency (n), rpm   | X₃                     | 1      | 9                    | 5              | 2             |
| DVD tilt angle (α),°                | X₄                     | 0,5    | 2,5                  | 1,5            | 1             |
| The speed of the drying agent (V), m/s | X₅                  | 1      | 3                    | 2              | 1             |
| Drying agent temperature (t),°      | X₆                     | 45     | 65                   | 55             | 10            |

5. Discussion of the results
The resulting granules are subjected to both static and dynamic loads during transportation, which can lead to the formation of a fine fraction, which in turn leads to increased traceability, increased hygroscopicity, deterioration of product appearance, etc. Therefore, the strength parameter of the obtained granules is one of the main parameters when selecting parameters for the process.

The graph shown in figure 4 shows the dependence of the strength of the obtained granules depending on the frequency and amplitude of vibrations. The graph shows that with an increase in both the frequency and amplitude of vibrations, the strength of the resulting granules increases. Analyzing the literature data of similar studies, we can conclude that the increase in strength is associated with a denser laying of particles in the agglomerate. At the same time, during the crystallization process and the formation of solid bridges, the process of compaction of the particles of the initial bulk mixture is also observed. When considering the impact of frequency of rotation of the kneading on the strength of the obtained granules (figure 5), we can conclude that it has no significant effect on the process, however, this parameter must be considered in conjunction with convection drying, since the speed increase could increase the heat transfer coefficient.

Figure 4. Dependence of the strength of the obtained granules on the frequency of vibrations: 1-A = 0.5 mm; 2-A = 1 mm; 3-A = 1.5 mm

Figure 5. Dependence of the strength of the obtained granules on the speed of rotation of the kneading unit
The strength of the resulting granules is also not significantly affected by the speed of the drying agent, although it affects the direct drying speed in the first period, however, the rate of evaporation of moisture from the surface layers does not have a significant effect. Analysis of the literature data shows that the rate of evaporation of moisture can also lead to negative phenomena, such as cracking, which ultimately affects the strength, but during the drying process in DVO-C granulated jelly from honeysuckle berries, the temperature of the coolant was not high and was 40-50 °C because, at temperatures above, the destruction of thermolabile elements contained in the honeysuckle extract occurs.

The strength of the resulting granules is also affected by the structural and mechanical properties of the original dispersed medium, so when using potato starch that has undergone solid-phase mechanical activation, the strength increases compared to the native starch (figures 6 and 7).

![Figure 6](image1.png)  
*Figure 6. Dependence of the strength of the obtained granules on the frequency of vibrations (α=0.5 °; t=50 °C; n=7 min⁻¹; V = 3 m/s; A = 0.5 mm): 1 - granules based on native potato starch; 2 - based on potato starch subjected to solid-phase mechanical activation*  

![Figure 7](image2.png)  
*Figure 7. Dependence of the strength of the obtained granules on the rotation frequency (α=0.5 °; t=50 °C; V = 3 m/s; A = 0.5 mm): 1 - based on potato starch subjected to solid-phase mechanical activation; 2 - granules based on native potato starch*

On average, the strength of the granules is 15-25% higher in different process modes. This is due, in our opinion, to the denser structure of the mechanoactive starch and the presence of centres of structure formation during the structuring process.

To determine the degree of influence of both structural and regime factors on the strength of the obtained granules based on potato starch subjected to solid-phase mechanical activation, experimental statistical models were obtained when processing a fractional factor experiment on a computer in the statistical analysis package STATISTICA 6.0. The strength of the obtained granules \( Y \) was adopted by the output parameter \( Y \sigma_2 \):

\[
Y_2 = 0.0625 + 0.0658 \cdot X_1 + 0.0098 \cdot X_2 - 0.0053 \cdot X_1 \cdot X_5 + 0.0078X_1 \cdot X_6 + 0.01039 \cdot X_5 \cdot X_6 \quad (1)
\]

At \( R = 0.928 \), equation (1) is confirmed within the boundaries of the variable parameters indicated in Table 1. The significance of the obtained coefficients of the regression equation was checked using the t - criterion. The greatest influence as can be seen from equation (1) strength of the obtained granules having a frequency and amplitude, the speed of the drying agent and its temperature belongs to an effect only in combination that indicates a change in the drying rate from the free surface of the granules.
6. Conclusion
Thanks to the conducted research, it can be concluded that the crushing strength is most related to the dynamic load that was imposed in the form of a vibration field. This makes it possible to significantly improve the structural and mechanical properties of the finished product. Along with the operating parameters of the process, the strength is also affected by a change in the structural and mechanical properties of the feedstock (potato starch), which indicates the prospects of this direction.

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