Determining Reasonable Parameters for the Functional Module of Moldable Foods Batching

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Design of both process and packaging equipment for food production facilities requires taking consideration of all factors affecting its operation and maintenance one way or another. This article proposes a method for scientifically substantiated determination or parameters for the functional module of moldable foods batching and sealing into consumer packages, taking into account the rheological parameters of foods, device structure, and the batching and sealing modes.

Keywords: moldable foods, functional module, piston batcher, nozzle.

The moldable foods, depending on their physico-chemical and biological properties, as well as market demand, is dispensed into various types of packaging material and types of consumer containers. Depending on the routine, the machines could be classified into: packaging by wrapping separate servings, mostly regularly shaped; packaging by filling pre-fabricated consumer containers; and packaging into containers made by thermal sealing or gluing, concurrently with product batching and prepacking. Along with this, packaging can be done in atmospheric or modified gaseous environment or in vacuum. The above factors heavily influence the structural specifics of batching and prepacking devices. Appropriate additional treatment of of moldable foods is required to increase efficiency of batching device operation, as well as to ensure longer storage of moldable foods [5].

Volumetric batching (flow-line or unit) is the most featured for moldable foods [3]. Flow-line procedure is used to shape the product into cord or to roll it into a band of uniform thickness and unit weight, to be then separated into regular batches. This method is used for solid elasto-plastic foods (yeast, confectionery), for which batching precision is ensured by homogenous consistence (also depending on the quality of premolding units) and stable movement speed of the products [4]. When unit batching is used, the product batches are filled into measuring containers, and then, depending on the packaging process, are dispensed into consumer packages or served into the intermediate chamber where the necessary product shape is molded. The first method is usable for any moldable foods, whilst the other one, for elasto-plastics preserving the selected shape for a long time.

The design of both processing and packaging machines requires taking into consideration the most important physical properties of foods. Для науково обґрунтованого врахування цих властивостей в різних областях техніки і технології харчових виробництв необхідна систематизація даних про фізико-механічні характеристики продуктів.

The key physico-mechanical features can be classified by the mode of external forces applied to the product and the deformations caused: shearing is displayed when tangential forces are applied; compression, when normal forces are applied; and surface behaviour, for shearing or disruption of the product from hard surface.

The moldable foods see themselves classified as disperse systems into emulsions, possessing a dispersed medium and liquid dispersed phase (butter) and suspensions (minced meat) [7].

The structural and mechanical properties describe the product’s behaviour under the stressed condition and enable to establish a connection between the stresses, deformations or deformation rates in the course of applying force. They are not the ‘pure’ constants of a certain material and substantially depend on the shape and dimensions of a body, stress rate, condition of the contacting surface, impact of the environment, temperature, structure, and other factors.

These features being known enable calculating the values of stresses or deformations, thus obtaining the required parameters for the process and the equipment unit, that is, enable strength and process calculations. Besides, the objective features of the product enable to judge on its quality. Special significance is attached to the form of equation establishing, through the constants being its features, the connection between the strength and deformation for each specific type of food.

The output of modern batchers for moldable foods depends both on their structural parameters and appropriate selection of batching conditions and on products' rheologic features.

From this viewpoint the hydraulic friction at the pipe cross-sections and the force applied by the active member to the moving product are the most important features for the batching units and batching modes, respectively [2], because the other parameters of batching units and batching modes will not be so significantly changed during the batching process.

Batching units for moldable foods vary very much in design, yet no method of sufficient amplitude could be found at research and information resources for determination of reasonable parameters of similar batching units.

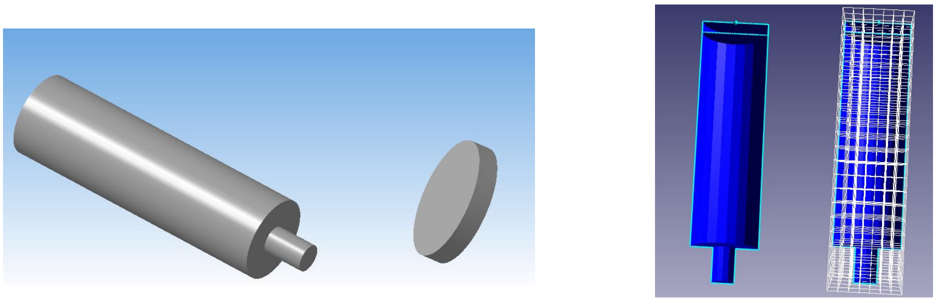
Thus, a conclusion can be drawn that the shortage of information regarding the batching parameters for moldable foods results in considerable difficulties for designers, bringing the necessity of 'playing safe', adopting overstated values for certain parameters, which negatively impacts the cost, quality, and efficiency of the resulting designs.

This article sets forth the research results of piston type batchers for moldable foods, aiming to develop the method to determine the reasonable values of their power consumption and operational reliability, depending on the aggregate friction ratio for the product movement, the effective clear opening of pipeline, and kinematic parameters of piston's movement [1].

Flow Vision software system was selected to conduct the research, designed for modelling three-dimensional flows of liquids and gases within technical and natural environments and providing computer visualization for such flows. The flows subjected to modelling include steady and unsteady; compressible, weakly compressible, and non-compressible liquid and gas flows. The use of varied turbulence models and an adaptive calculation grid enables modelling the complicated movement of liquids. FlowVision is based on the finite volume method of solving the hydrodynamic equations and applies rectangular adaptive grid with local refinement. For increased precision approximation of curved geometry, FlowVision uses the sub-grid geometry resolution technology. This technology enables importing the geometry from CAD systems and exchanging data with finite element analysis systems.

The task in question was resolved using non-compressible liquid turbulence model. This model describes the flow of a moldable food for low and high (turbulent) Reynolds numbers. Minor changes in specific weight are permitted, enabling to take the lifting force naturally into account. The model includes equations of Navier-Stokes, energy, and convection-diffusion transport for impurities concentration.

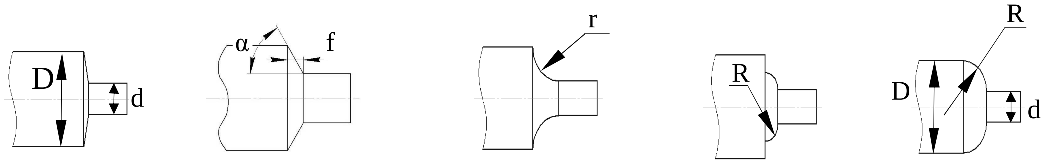
The first stage of research was used to create the geometry of batching unit's active members. To that end models of the research unit were built using the Compass software and then those images were transferred to the FlowVision system (Fig. 1).



a) b) c)

Fig. 1. Research unit models and its images within the FlowVision system: a) piston and cylinder with the nozzle; b) loaded model with piston; c) calculation grid applied.

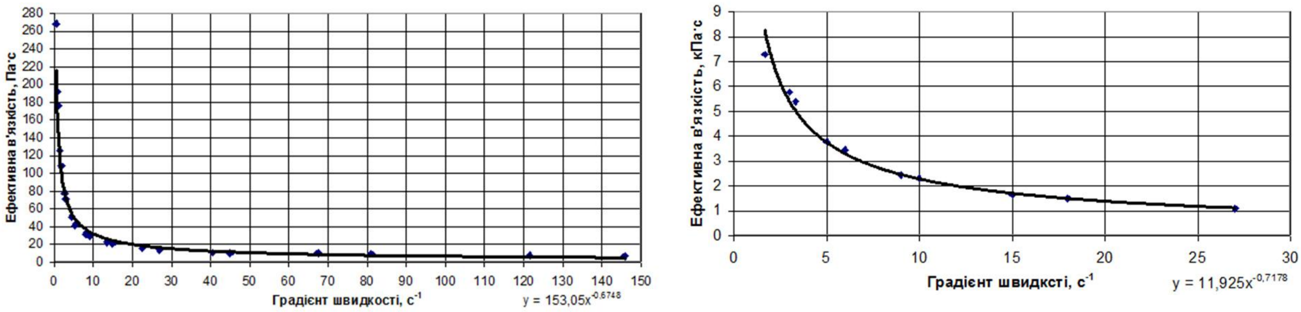
Various designs of the batching unit's nozzle were considered during the research (Fig. 2).



a) b)

Fig. 2. Designs of the batching unit's nozzles: a) with a varied size chamfer by the nozzle base; b) with curvatures by the nozzle base

Further the calculation model was selected in accordance with the batching process, limit conditions established, and the incoming rheological parameters set: temperature, density and effective viscosity of the moldable food as a function of its velocity. To determine the effective viscosity of studied products, PEOTECT 2 rotational viscosimeter was used and a number of correlations were established as represented in a form of graphs or analytical correlations (Fig. 3).



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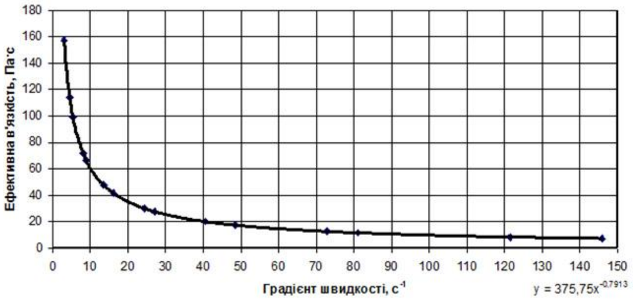


c)

Fig. 3. Graphs showing effective viscosity of studied foods as a function from the velocity gradient and functional correlations describing them: a) butter; b) dough; c) minced meat.

The results of studies of moldable foods movement with a piston feeder were step by step recorded into the file, and pressure-to-time dependence diagrams were built based on the data received.

Using the ‘pressure chart’ layer superposed on a longitudinal section of the batcher (Fig. 4) pressure distribution along the batcher was studied, and the pressure on the piston required to feed the product with a constant piston velocity.

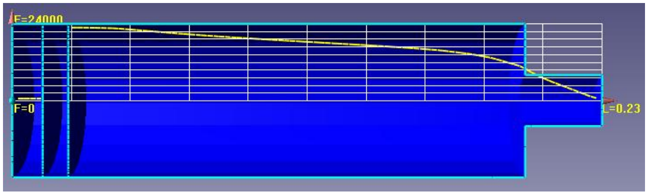
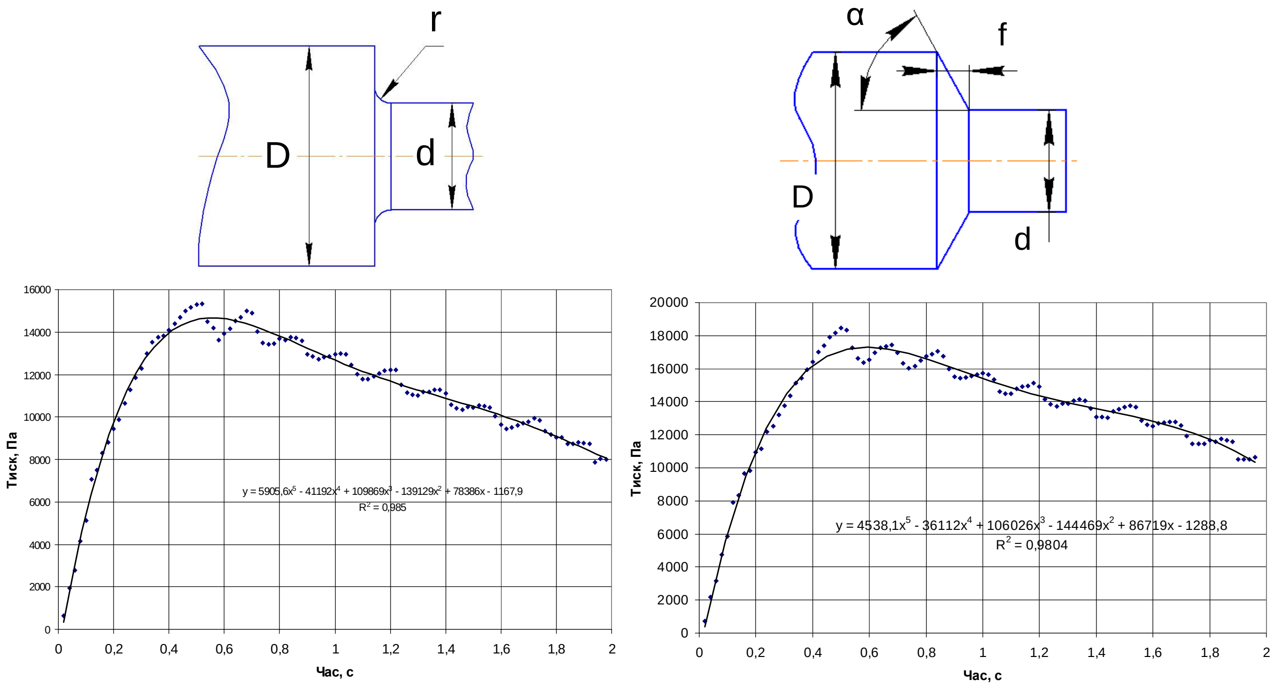


Fig. 4. Pressure change graph along the axis of the batcher cylinder

During the experiment, the following geometrical parameters of the batcher were varied: D – feeder cylinder diameter, d – nozzle diameter, r – curvature radius at the nozzle base, f – chamfer length, α – chamfer point corner. The obtained experimental data were stored and processed using the methodology developed for mathematical statistical research [6], further transformed into an empirical dependence in a form of a mathematical model stating the way and the degree of influence of geometrical parameters and the product viscosity on the batching speed.

Based on the experiments run with the different types of nozzles, a number of pressure dependences were found, demonstrating that, from the standpoint of energy efficiency, batchers with a 45° chamfer at the base (Fig. 5b) or with a curvature at the base of the nozzle (Fig. 5a) would be the most appropriate options.



a) b)

Fig. 5. Options of batcher design and research results: a) model with a concave curvature of R20 and the chart describing dependence of pressure on the piston axis from time; b) model with a 10 mm chamfer (α=45°) and the chart describing dependence of pressure on the piston axis from time.

The mathematical model of extracting the product from the measuring cylinder, obtained through a multi-factor experiment for the nozzle with a curvature, has the following form:

$$\begin{aligned} P &= 720{,}6 + 470{,}5 \cdot r + 3710{,}04 \cdot (D/d) + 1999{,}2 \cdot Kv_{\max} + 170{,}82 \cdot r \cdot (D/d) - \\ &- 695{,}8 \cdot r \cdot Kv_{\max} + 3162{,}86 \cdot (D/d) \cdot Kv_{\max} - 281{,}14 \cdot r \cdot (D/d) \cdot Kv_{\max}, \end{aligned} \qquad (1)$$

where P is maximal pressure required for the piston’s movement, Pa; r, curvature radius, mm; D/d, ratio between diameters; Kv_{max}, maximal value of speed ratios.

The mathematical model of extracting the product from the measuring cylinder, obtained through a multi-factor experiment for the nozzle with a chamfer, has the following form:

$$P = -6173.5 + 1554.6 \cdot f + 8544.8 \cdot (D/d) + 6241.2 \cdot Kv_{\max} - 604.3 \cdot f \cdot (D/d) - \\ -1602.7 \cdot f \cdot Kv_{\max} - 989.8 \cdot (D/d) \cdot Kv_{\max} + 647.7 \cdot f \cdot (D/d) \cdot Kv_{\max}, \qquad (2)$$

where P is maximal pressure required for the piston's movement, Pa; f, chamfer length, mm; D/d, ratio between diameters; Kv_{max}, maximal value of speed ratios.

As it becomes evident from the dependences obtained, the nozzle shape is the least relevant of the factors in consideration, yet when the feeding speed increases, so does its role. The ratio between the feed cylinder and the output channel diameters exerts the heaviest influence on the moldable food friction. Applying the constant speed piston movement law allows reducing the power consumption required for batching, and the sinusoidal motion law enables shock-free motion.

CONCLUSIONS. Previous research enabled the conception of a mathematical model for the process of extracting moldable food from the feed cylinder and the method for selecting the parameters for a functional module to dispense moldable food into consumer packages, taking into account rheological features of the products, design parameters, and batching modes. It was established that, with the feeding speed increasing, the impact of the nozzle shape grows significantly, requiring appropriate calculations using the output data.

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