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Original article

AN ENGINEERING APPROACH TO THE STUDY OF THE PROCESSES OF DOUGH FLOW IN THE PRODUCTION OF PASTA AT AGRO-INDUSTRIAL ENTERPRISES

A.B. Torgan, V.Ya. Grudanov, V.G. Barsukov, R.T. Timakova

Background. *In modern conditions, the provision of domestic pasta produced from durum wheat varieties on modern technological equipment is becoming important. At the same time, the quality of the finished pasta is also determined by the rheological properties of the pasta dough when passing through the pasta press matrix, which determined the purpose of the study to develop a method of computational evaluation for calculating the relationship between the speed parameters of the flow of pasta dough in the cylindrical sections of the channels of the molding matrix with pressure drops to overcome viscous resistance, the dimensions of the structural elements of the channel, as well as with indicators of the rheological properties of pasta dough.*

Materials and methods. *To study the flow of pasta dough, baking flour of the highest grade M-54 28 was chosen as a raw material in stepped cylindrical channels. The applied rheological model is described and a technique for mathematical modeling of the flow parameters of pasta dough in cylindrical channels is given. Due to the small contribution of the pasta dough shear strength to the total pressure loss, a rheological model of a nonlinear-viscous medium is used, which is described by a power equation containing physically determined constants. Neglecting the elastic deformations of the dough due to their smallness, we assumed the condition of constancy of the volumetric productivity for each cross section of the channel.*

Results. *Analytical dependencies are presented that relate the change in velocity over the channel cross section to the pressure developed necessary to overcome the* *viscous resistance, as well as to the radii and length of the channel, and to the rheological properties of the pasta dough. These dependences formed the theoretical basis of the method for calculating the parameters of pasta dough flow in cylindrical channels.*

Conclusion. *On the example of an industrial matrix of a pasta press, made in the form of a system of cylindrical channels of a stepped-variable diameter in the preforming zone, calculations were made to determine the average and maximum flow rates of pasta dough in each section of the channel and the developed pressure. The results of the research can be used in engineering practice when designing new matrices for forming pasta dough and in the production processes of enterprises to calculate their production capacities.*

Keywords: *rheological body; pasta dough; flow; velocity; pressure; step channel; calculation method*

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Научная статья

ИНЖЕНЕРНЫЙ ПОДХОД К ИССЛЕДОВАНИЮ ПРОЦЕССОВ ТЕЧЕНИЯ ТЕСТА ПРИ ПРОИЗВОДСТВЕ МАКАРОННЫХ ИЗДЕЛИЙ НА АГРОПРОМЫШЛЕННЫХ ПРЕДПРИЯТИЯХ

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Обоснование. *В современных условиях важное значение приобретает обеспеченность отечественными макаронными изделиями, вырабатываемых из твердых сортов пшеницы на современном технологичном оборудовании. При этом качество готовых макаронных изделий определяется также реологическими свойствами макаронного теста при прохождении через матрицу макаронного пресса, что и определило целью исследования разработку методики расчетной оценки взаимосвязи скоростных параметров течения макаронного теста в цилиндрических участках каналов формовочной матрицы с перепадами давления на преодоление вязкого сопротивления, размерами конструктивных элементов канала, а также с показателями реологических свойств макаронного теста.*

Материалы и методы. *Для исследования течения макаронного теста в качестве сырья в ступенчатых цилиндрических каналах была выбрана мука хлебопекарная высшего сорта М-54-28. В методической части работы описана применяемая реологическая модель и приведена методика математического моделирования параметров течения макаронного теста в цилиндрических каналах. В связи с малым вкладом сдвиговой прочности макаронного теста в общие потери давления использована реологическая модель нелинейно-вязкой среды, описываемой степенным уравнением, содержащим физически детерминированные константы. Пренебрегая упругими деформациями теста вследствие их малости, принимали условие постоянства объемной производительности для каждого поперечного сечения канала.*

Результаты исследования. *В основной части работы приведены аналитические зависимости, связывающие изменение скорости по сечению канала с величиной развиваемого давления, необходимого для преодоления вязкого сопротивления, а также с радиусами и длиной канала и с реологическими свойствами макаронного теста. Эти зависимости составили теоретическую основу методики расчетной оценки параметров течения макаронного теста в цилиндрических каналах.*

Заключение. *На примере промышленной матрицы макаронного пресса, выполненной в виде системы цилиндрических каналов ступенчато- переменного диаметра в предформовочной зоне, произведены расчеты по определению средних и максимальных скоростей течения макаронного теста на каждом из участков канала и развиваемого давления. Результаты исследований могут быть использованы в инженерной практике при проектировании новых матриц для формования макаронного теста и в производственных процессах предприятий для расчета их производственных мощностей.*

Ключевые слова: *реологическое тело; макаронное тесто; течение теста; скорость; давление; ступенчатый канал; методика расчета*

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Introduction

The technological development of the agro-industrial complex, including as a result of the growth of the yield of durum wheat, determines the possibility of closing the needs of the domestic market in pasta. The production of pasta products, such as molding extrusion, refers to a well-known technology and research is mainly aimed at the possibility of obtaining a quality product that meets the requirements of regulatory documents, based on the type of raw materials used and the technical parameters of drying [5, 17, 18, 35, 38].

An important parameter of the quality of finished pasta products is the gluten content in the grain, which can be increased as a result of the use of modern agrobiotechnologies at the stage of growing grain crops, such as feeding with vermicompost (up to 6 t/ha), as is noted in [23].

The finished pasta dough can be compared with polymers and plastic materials that have certain viscous, plastic, elastic, etc. properties of the rheological body, which requires research by methods of engineering rheology.

The most important structural elements of the molding matrices of pasta presses are cylindrical channels. Depending on the type of matrix, they can have a constant or step-variable length (depth) section. The flow of pasta dough in these channels has a significant impact on the productivity of the equipment, the pressure developed in the pre-matrix chamber and the uniformity of extrusion of molded products from individual dies. However, the patterns of pasta dough flow in these areas of the forming matrices have not been studied enough, which necessitates labor-intensive experiments to develop designs and molding modes in the manufacture of new types of products, as well as when replacing the dough composition by introducing functional additives. At the same time, engineering practice is based mainly on previous experience in the production of products similar in composition and design and technological support.

The purpose of the study**:** on the basis of the computational approach, to establish the regularities and features of the processes of the pasta dough flow in the cylindrical sections of the forming matrices of pasta presses.

Literature Review

Modern research will allow taking into account the rheological properties of the studied objects using the methods of engineering rheology [15] depending on the granulometric composition of flour [22], type and type [36, 41], composition of dry flour composite mixtures [1, 3, 27], humidity and dough temperature [34] and its viscosity [32].

To assess the rheological properties of the dough, various devices are used, depending on the goals set: a mixograph (according to the proposed method of N.S. Vasylchuk) [8]; a CHOPIN Mixolab device to control the dynamics of the rheological behavior of the dough during its kneading by the nature of the change in the torque value on the drive of the kneading tank at the most characteristic points of the resulting mixolabogram of the test sample – the point C_1 corresponds to the maximum consistency of the dough after the beginning of its kneading and is taken into account for calculating the water absorption capacity of flour, C_2 characterizes the minimum consistency of the dough at the initial stage of heating as a result of protein denaturation, C_3 – the maximum consistency of the dough during starch gelatinization, C_4 – the stability of the starch paste dough, C_5 – the rheological behavior of starch during cooling as a result of its retrogradation [1]. Starch contributes to the gelatinization of the dough and affects its gas-holding capacity [14]. A number of authors also note that the indicator reflecting the rheological state of the pasta dough during kneading is, in addition to the torque (Mcr), the consumed active electrical power (Np) [7].

At the same time, the works aimed at solving individual problems of rheological analysis of a practical orientation using approximate calculation schemes show the prospects of this research direction in relation to the flow of highly filled food systems [9], including caramel masses [4], pasta dough [16, 30, 39], sunflower pulp [19], bakery and confectionery dough [10], and pasta dough with carrots [12].

The issues of analyzing the rheological aspects of the pasta dough flow in cylindrical stepped channels are at the initial stage of mathematical modeling [19, 30, 39] and have not been brought to engineering calculation methods.

According to a number of authors, there is practically no moisture transfer in the pasta dough and the pore system in the dough with a high degree of probability consists of discrete regions [3, 25, 26, 41], this makes it possible not to take into account the influence of moisture content in the conditions of rheological modeling. At the same time, it is necessary to monitor the moisture content of the dough because an increase in the moisture content of the pasta dough gives a more stretchable sample, which may mean that moisture acts as a plasticizer [31].

Materials and methods

Traditionally, for the production of noodle products, according to the requirements of GOST 31463-2012 “Durum wheat flour”, high-grade flour from durum wheat with a mass fraction of crude gluten of at least 26% and having a reduced water absorption capacity is used. Along with this, noodle flour from high-glass soft wheat provides a significant content of raw gluten – at least 28% according to GOST 26574-2017 “Baking flour. Technical conditions”. To study the flow of pasta dough, baking flour of the highest grade M-54-28 (STB 1666 2006 “Wheat flour was selected as a raw material in stepped cylindrical channels. Technical conditions”), used by the UP “Borisovsky combine of bread products" of JSC "Minskoblkhlebprodukt", the largest producer of pasta (t_{flour} + 25-30 ° C), and water that meets the requirements of STB 1188 99 "Drinking water. General requirements for the organization and methods of quality control" (t_{water} + 40-50 ° C).

Rheological modeling of the pasta dough flow processes in the cylindrical sections of the forming dies was carried out in the form of three successive stages. At the first stage, a rheological model was chosen and justified to describe the deformation properties of pasta dough. At the second stage, a calculation scheme was compiled and flow equations were obtained, and at the third, final stage, calculations were made for specific channel sizes and compared with the available experimental data.

Research results and discussions

According to modern scientific concepts, pasta dough is a nonlinear visco-plastic rheological body (medium), the so-called pseudoplastic liquid [33, 38].

At the same time, the pseudoplastic behavior during shear is explained by the macromolecular characteristics of protein molecules, which are randomly arranged at low shear rates, but at high speeds are aligned in the direction of shear, thereby reducing the viscosity of the dough [2, 34, 37].

Since the mechanism of shear deformation prevails in the flow, it is expedient to use analytical dependences to describe the deformation properties that establish the relationship between shear stresses τ and shear rate $\dot{\gamma}$.

The study of rheological methods in the food industry shows that the flow of viscous-plastic media, including pasta dough, obeys with sufficient accuracy for technical calculations to the Bulkley – Herschel viscous flow law [11, 19, 39]:

$$\tau = \tau_0 + k\dot{\gamma}^n, \tag{1}$$

where τ_0 – is the shear strength of the material (the minimum values of shear stresses at which irreversible shear deformation of the material begins to occur); k – is an analogue of viscosity, called the consistency coefficient, n – is a medium parameter.

Previous studies have shown that the contribution of shear strength τ_0 to the total resistance to flow is small [19]. At the molding pressure in 6.0–12.0 MPa, the contribution of τ_0 is 0.3 MPa, i.e. does not exceed 2.5…5%. In addition, as the temperature increases, the ultimate shear stress (shear strength) of the material decreases. For example, for flour of the first grade: at 18^0C is 18.3 kPa, at 40^0C is 5.6 kPa, at 56 ^{0}C is 2.1 kPa [28, 40]. Therefore, in technical calculations, it is possible to carry out an analysis based on the power-law rheological equation of Ostwald-de-Waele [10, 19, 40]:

$$\tau = k\dot{\gamma}^n, \tag{2}$$

Since the dimension of *k* depends on the value of *n*, the parameter *k* is not a physicalquantity. This is the coefficient obtained as a result of approximating the flow curve (dependence of shear stresses on shear rate) by a power function [20, 42]. This circumstance does not allow us to consider equation (2) physically correct. However, the relatively high (sufficient for technical purposes) calculation accuracy predetermines the widespread use of this equation in engineering and research practice for thermoplastic melts [20, 24, 42], but also for other viscous materials, for example, food mixtures [4, 15, 19, 39].

At the same time, the analysis shows that the empirical power rheological equation (2) can be transformed by normalization to the form in which the parameters of this equation will have a physical (rheological) meaning. In particular, McKelvey [13] proposed two possible options of such a transformation. The first option is for shear stresses:

$$\tau = k_b\left(\frac{\dot{\gamma}}{\dot{\gamma}_b}\right)^n, \tag{3}$$

where k_b and $\dot{\gamma}_b$ – are the values of shear stresses and shear rates in an arbitrarily chosen base state.

The second option is for the effective viscosity η_r of the medium:

$$\eta_r = \frac{\tau}{\dot{\gamma}} = \eta_b\left(\frac{\dot{\gamma}}{\dot{\gamma}_b}\right)^{n-1}, \tag{3a}$$

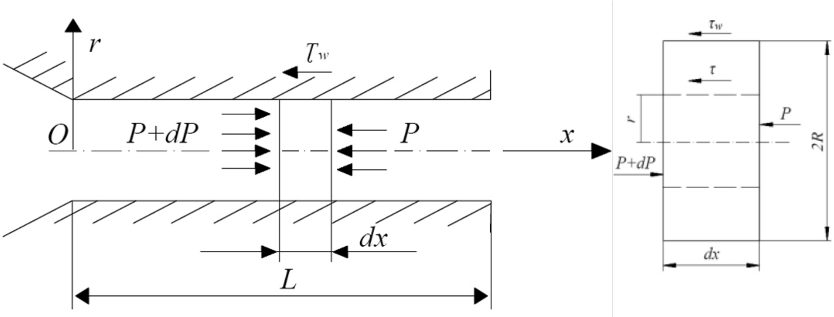
where η_b – is the viscosity of the Newtonian fluid in the same arbitrarily chosen base state.

For convenience of analysis, one usually takes $\dot{\gamma}_b = 1s^{-1}$ [13]. It is easy to verify that the value of $\eta_b$in equation (3a) in this case numerically coincides with the value of k_b in equation (3), differing from it only in dimension and physical meaning. In addition, k_b coincides numerically with the coefficient *k* of the approximating function (1). The expressions in brackets are the dimensionless design shear rate.

This approach makes it possible to use in calculations the previously determined values of the constants of the approximating function (2) for the analytical dependence (3), taking into account the dimension of the constant k_b (Pa). In [36], a mathematical apparatus was proposed for calculating the flow parameters in relation to the basic rheological equation in the form (4). At the same time, it is more convenient to apply the rheological equation in the form (3), which is done in this work. At the same time, it was taken into account that it is convenient to take expression (3) modulo the right side in order to match the directions of shear stresses and medium flow velocities. If they coincide, then the expression in brackets is taken with a sign (+), if they are opposite, then with a sign (-).

$$\tau = k_b \left| \left(\frac{\dot{\gamma}}{\dot{\gamma}_b} \right)^n \right|, \tag{4}$$

Let us consider the equilibrium conditions for an elementary cylinder of length *dx* and radius *R* (Fig.1), which is under the action of pressure p, which is under the action of pressure *dx* by *dp*. Shear stresses τ_w act on the side surface of the elementary cylinder.



a) b)

Figure 1. Calculation scheme for the analysis of the processes of flow of non-linear-viscous media in a cylindrical channel: a - scheme of the channel; b - elementary cylinder (compiled by the authors).

From the condition of equality of the projections of all forces on the *x* axis, we can write

$$\frac{dp}{dx} = \frac{2\tau_w}{R} \tag{5}$$

Passing from an elementary cylinder to the total channel length *L,* we obtain a formula for calculating the pressure drop *ΔP* along the channel length

$$\frac{\Delta P}{L} = \frac{2\tau_w}{R} \tag{6}$$

Further, in the central part of the elementary cylinder, we single out a micro-cylinder of the same length *dx*, but with radius *r*. It is also under the action of pressure *p,* which changes along the length of the element *dx* by the value *dp*. Shear stresses τ act on the side surface of an elementary micro-cylinder.

From the condition of equality of the projections of all forces acting on the micro-cylinder on the *x*-axis, we can write

$$\frac{dp}{dx}=\frac{2\tau}{r} \tag{7}$$

Since *dp/dx* in equations (5) and (7) represent the same value, then, by equating the right and left parts of these equations, we obtain

$$\frac{dp}{dx}=\frac{2\tau}{r}=\frac{2\tau_w}{R} \tag{8}$$

Where does the distribution of shear stresses along the radius *r* come from

$$\tau=\tau_w\frac{r}{R} \tag{9}$$

The highest shear stresses τ_w acting on the channel walls can be found from formula (6)

$$\tau_w=\frac{\Delta PR}{2L} \tag{10}$$

Substituting this value into formula (9), we obtain an analytical dependence for the distribution of shear stresses along the channel radius

$$\tau=\frac{\Delta Pr}{2L} \tag{10a}$$

Let us determine the change in the flow rates of the polymer melt along the radius over the channel section. We will proceed from the fact that the shear rate $\dot{\gamma}$ can be expressed in terms of the linear flow velocity *V* using the following differential relationship

$$\dot{\gamma}=\frac{dV}{dr} \tag{11}$$

From formulas (2) and (11), given that the direction of shear stresses is opposite to the direction of the medium flow velocity, we can write

$$\dot{\gamma}=\frac{dV}{dr}=-\dot{\gamma}_b\left(\frac{\tau}{k_b}\right)^{\frac{1}{n}} \tag{12}$$

Substituting in (12) instead of τ its value from (10a) and integrating it under the boundary conditions*r=R: V=0* we obtain the dependence for the distribution of the melt flow velocity over the channel section.

$$V=\frac{n}{n+1}\left(\frac{\Delta PR}{2k_bL}\right)^{\frac{1}{n}}\left[1-\left(\frac{r}{R}\right)^{\frac{n+1}{n}}\right]\dot{\gamma}_bR \tag{13}$$

It is easy to see that the expressions in round and square brackets in formula (13) are dimensionless complexes, and the product of the unit normalization factor $\dot{\gamma}_b = 1s^{-1}$ by the radius *R* ensures the fulfillment of the dimension rule for the velocity, which is the advantage of formula (13) over similar dependences obtained on the basis of the traditional notation of the rheological equation of Ostwald-de-Waele. Moreover, the velocity distribution over the channel section is described by a power function with zero velocity values on the channel walls (*r=R)* and the maximum value V_{max} in the center

$$V_{\max} = \frac{n}{n+1}\left(\frac{\Delta PR}{2k_b L}\right)^{\frac{1}{n}} \dot{\gamma}_b R \tag{14}$$

To determine the volumetric productivity, we select in the channel an annular element with a thickness *dr*. At a flow velocity *V* the elementary flow rate *dQ* of the liquid will be equal to the product of the velocity and the cross-sectional area *dA* of the elementary ring, calculated by the formula

$$dA=2\pi rdr \tag{15}$$

Then, taking into account (13) and (15), for the elementary consumption *dQ* of pasta dough, the calculation formula takes the form

$$dQ = V \cdot 2\pi rdr = 2\pi r \frac{n}{n+1}\left(\frac{\Delta PR}{2k_b L}\right)^{\frac{1}{n}} \left[1-\left(\frac{r}{R}\right)^{\frac{n+1}{n}}\right] \dot{\gamma}_b R dr \tag{16}$$

Integration (16) over the channel section gives the following expression for determining the volumetric flow rate of pasta dough

$$Q = \int_0^R V \cdot 2\pi rdr = \frac{\pi n}{3n+1}\left(\frac{\Delta PR}{2k_b L}\right)^{\frac{1}{n}} \dot{\gamma}_b R^3 \tag{17}$$

The average flow velocity V_m can be defined as the ratio of the volumetric efficiency *Q* to the cross-sectional area *A*

Since

$$A=\pi R^2, \tag{18}$$

then the average flow velocity V_m can be calculated from the formula

$$V_m = \frac{Q}{\pi R^2} = \frac{n}{3n+1}\left(\frac{\Delta PR}{2k_b L}\right)^{\frac{1}{n}} \dot{\gamma}_b R \tag{19}$$

The ratio of the current pasta dough speed value at a point at a distance *r* from the channel axis to the maximum value reached at the center can be obtained by jointly solving equations (13) and (19).

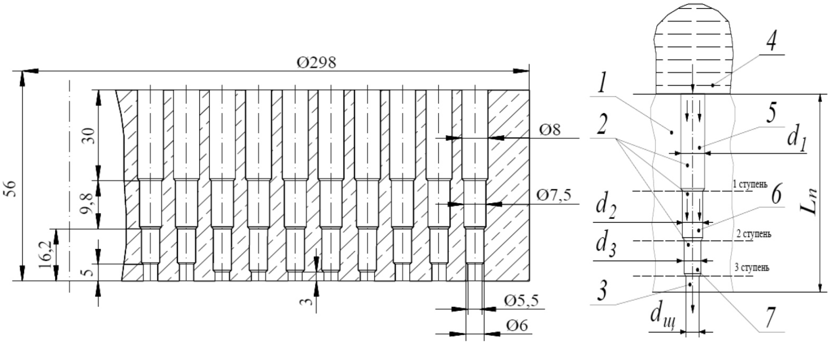
$$\frac{V}{V_{\max}} = 1-\left(\frac{r}{R}\right)^{\frac{n+1}{n}} \tag{20}$$

Similarly for the ratio of the current value of the velocity *V* and its average value V_m over the cross section, by jointly solving equations (13) and (10).

$$\frac{V}{V_m}=\frac{3n+1}{n+1}\left[1-\left(\frac{r}{R}\right)^{\frac{n+1}{n}}\right] \tag{21}$$

Thus, the results of the studies performed made it possible to develop design schemes and obtain physically normalized design dependencies for determining the speeds and volumetric flow rate of pasta dough during flow in a cylindrical channel.

The calculation method was tested on the example of an industrial matrix of a pasta press for the production of special noodle products, which is shown in Fig. 2 [6].



a) b)

Figure 2. Vertical section of the matrix with different heights of forming holes (a) the appearance of the matrix b) the forming holes of the matrix)

Notes on b): 1 – matrix; 2 – forming holes of the matrix; 3 – forming slit; 4 – prematrix chamber; 5 – entrance hole of the 1st stage; 6 – hole of the 2nd stage; 7 – hole of the 3rd stage; d_1 – diameter of the entrance hole of the 1st stage; d_2 – diameter of the entrance hole of the 2nd stage; d_3 – the diameter of the entrance hole of the 3 stage; d_s – the diameter of the forming slot; L_p – the full length of the channel of the forming hole

The presented matrix is a brass disc with a diameter of 298 mm and a thickness of 56 mm, which is made of brass. The forming holes of the matrix have different heights. Their number is 600 pieces. The area of the matrix is divided into three annular zones with different heights of forming holes. The peripheral zone has 192 holes with a forming slit height of 5 mm, the middle zone has 300 holes with a forming slit height of 3 mm, and in the central zone with a forming slit height of 7 mm, the number of holes is 108 pieces. This arrangement of holes and the height of the forming slot allows equalizing the speed of pressing noodle products over the area of the matrix and reduce production waste by up to 5-6% [6].

The calculated values of the constants k_b and n for the most common dough composition at a temperature of 40 ^{0}C are: the average value of the coefficient k_b =109.97 kPa and the coefficient n =0.473 [19].

At the same time, in the case under consideration, the contribution of conical transitional parts (chamfers) is negligible in comparison with the contribution of cylindrical sections for technical calculations was not taken into account.

Tables 1, 2, 3 show the calculated values of the speed parameters of the flow of pasta dough in different parts of the channel. At the same time, table 1 characterizes the average flow rate $V_m$of the dough in separate sections of the channel with a stepped-variable section, table 2 - the maximum values V_{max} of the flow rate in each of the channels at different values of pasta press productivity per single channel. The data in Table 3 show the uneven distribution of the pasta dough flow velocity over the channel section as the ratio of the calculated value of the velocity V at a point at a distance r from the channel axis with an outer radius R to the average value of V_m in this section and the maximum value of V_{max}.

When carrying out rheological calculations, the value of the density of the pressed pasta dough with a moisture content of 30% was taken to be 1300kg/m^3, which corresponds to the average values given in the scientific and technical literature [6, 21].

Table 1.

Calculated values of the average flow rates of pasta dough over the channel section in the pre-die zone

Productivity per single channel, kg/h	Average speed, mm/s, with channel diameter		
	8 mm	7.5 mm	6 mm
1.0	4.25	4.84	7.56
1.25	5.32	6.05	9.45
1.5	6.38	7.26	11.34
2.0	8.51	9.68	15.12
2.5	10.63	12.10	18.90
3.0	12.76	14.52	22.68

(Compiled by the authors)

Table 2.

Calculated values of the maximum flow rates of pasta dough

Productivity per single channel, kg/h	Average speed, mm/s, with channel diameter		
	8 mm	7.5 mm	6 mm
1.0	6.98	7.95	12.42
1.25	8.73	9.93	15.52

1.5	10.48	11.92	18.62
2.0	13.97	15.89	24.83
2.5	17.46	19.86	31.04
3.0	20.95	23.84	37.25

(Compiled by the authors)

Table 3.

Calculated values of velocity differences over the channel cross section in the pre-die zone

Relative-speedvalue	Relative distance from channel axis, *r/R*						
	0	0.2	0.4	0.6	0.8	0.9	1.0
V/V_{max}	1.0	0.993	0.942	0.796	0.501	0.280	0
V/V_m	1.642	1.631	1.547	1.307	0.822	0.459	0

(Compiled by the authors)

Table 4 characterizes the power parameters of the pasta dough flow process in each section of the channel for a wide range of changes in the mass productivity of the pasta press per one channel of the forming matrix, and table 5 is the total pressure drop to overcome the viscous resistance in these sections.

Table 4.

Calculated values of pressure increase in individual cylindrical sections of the channel

Productivity per single channel, kg/h	Pressure drop, MPa, in the channel section with dimensions d(mm)xL(mm)				
	8x30	7.5x10	6x9	6x11	6x13
1.0	3.68	1.43	2.21	2.70	3.19
1.25	4.08	1.59	2.46	3.00	3.55
1.5	4.45	1.74	2.68	3.27	3.87
2.0	5.10	1.99	3.07	3.75	4.43
2.5	5.67	2.21	3.41	4.17	4.93
3.0	6.18	2.41	3.72	4.53	5.37

(Compiled by the authors)

Table 5.

Calculated values of the total pressure increase in all sections of the channel

Productivity per single channel, kg/h	Pressure drop, MPa, when the channel is located in the matrix zone		
	central zone	peripheral zone	intermediate zone
1.0	7.32	7.81	8.31
1.25	8.13	8.68	9.23

1.5	8.67	9.46	10.06
2.0	10.16	10.84	11.52
2.5	11.29	12.08	12.81
3.0	12.39	13.21	13.96

(Compiled by the authors)

Conclusion

Since it is extremely difficult to carry out experimental measurement of pasta dough flow rates along the channel cross section, the given calculated dependences and the digital data obtained on their basis are of scientific and practical interest. They allow you to make a calculated estimate of the pasta dough flow rates at any point of the channel of the cylindrical section of the forming matrix, to find the maximum and average values of this speed for the required mass productivity of the pasta press per single channel. They also make it possible to calculate the pressure drops required to overcome the viscous resistance to the flow of pasta dough in each section of the channel.

In particular, the analysis of the tables shows that with an increase in the productivity of the pasta press, the pressure drops to overcome the viscous resistance in certain sections of the channel and in the forming matrix as a whole increase non-linearly. The average and maximum flow rates of pasta dough also increase non-linearly.

The obtained calculated values of pressure drops are in good agreement with the experimental data on pressure drops available in the scientific and technical literature [6], which confirms the correctness of the adopted calculation scheme.

Thus, the obtained dependencies can be a theoretical basis for calculating the performance of a pasta press, molding pressure, as a function of the structural dimensions of the molding channel and structural-mechanical (rheological) characteristics of the dough. They can be used in the design and calculation of a matrix for the production of pasta and a forming mechanism.

A method is proposed for calculating the flow rates of pasta dough in the cylindrical sections of the forming matrix, as well as pressure drops to overcome the resistance to viscous flow of pasta dough, taking into account the rheological patterns of dough flow in cylindrical channels of a stepped-variable section of the chamber of the pressing unit.

Approbation of analytical dependences was made on the example of an industrial matrix for the production of special pasta, which confirmed the correctness of the accepted calculation scheme and the results obtained on its basis. The results of the research can be used in engineering practice when designing new sizes of matrices for pasta dough molding, at food enterprises for the production of pasta et as well as in the educational process in the training of food production process engineers.

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