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ANALYSIS OF THE PREFORM BLOWING STAGE WHEN OBTAINING A POLYMERIC PRODUCT USING THE EXTRUSION BLOW MOLDING METHOD

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Отримано залежності, що зв’язують геометричні параметри полімерної заготовки і параметри кінцевого відформованого виробу, з технологічними параметрами процесу екструзійно-видувного формування виробу (швидкість витяжки полімерної заготовки, в’язкість розплаву полімеру, внутрішній тиск роздування, коефіцієнт витяжки, час формування). Наведені ілюстрації моделювання різних технологічних режимів. Показано, що процес роздування полімерної заготовки має дві характерні стадії

Ключові слова: поліетилен, екструзійно-видувне формування, полімерна заготовка, коефіцієнт витяжки, швидкість витяжки, час формування

Получены зависимости, связывающие геометрические параметры формуемой полимерной заготовки и параметры конечного отформованного изделия, с технологическими параметрами процесса экструзионно-выдувного формования изделия (скорость вытяжки полимерной заготовки, вязкость расплава полимера, внутреннее давление раздува, коэффициент вытяжки, время формования). Приведены иллюстрации моделирования различных технологических режимов. Показано, что процесс раздува полимерной заготовки имеет две характерные стадии

Ключевые слова: полиэтилен, экструзионно-выдувное формование, полимерная заготовка, коэффициент вытяжки, скорость вытяжки, время формования

1. Introduction

Extrusion blow molding is the method of obtaining products from thermoplastic materials, at which a closed air cavity is formed in a molded product. A special feature of this method is obtaining a preform from a polymer melt in the form of a hollow cylindrical sleeve using the method of extrusion [1]. In this case, for cans, bottles, children’s toys with air cavities, vehicle tanks and tanks for working fluids, either there are no alternative methods for manufacturing or they are too expensive.

Today the global market of plastic blown molded products makes up about USD 179 billion and is expected to reach USD 191.6 billion by the year 2025 [2].

Changing a technological mode or a transition to another batch of raw materials requires from a technologist an operative prediction and assessment of the parameters of obtained products in order to provide its quality. Thus, it is a relevant task to obtain analytical dependences that would link geometrical parameters of the molded polymeric preform to technological parameters of the process of extrusion blow molding of a polymeric product, which is fabricated based on it.

2. Literature review and problem statement

The process for obtaining extrusion preforms of cylindrical shape, intended for further blowing, is considered in detail in paper [3]. Specific features and «bottlenecks» of this process that predetermine the patterns in their blowing and molding are indicated.

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The task on obtaining polymeric preforms for a blown product was addressed in paper [4] from the viewpoint of optimization of a wall thickness. A combination of numerical methods of finite elements, an artificial neural network, and a genetic algorithm, was applied. This made it possible to optimize the objective function and estimate thickness of the wall of a product.

Article [5] described computer research into a similar process of blowing a preform for obtaining a product from polyethylene terephthalate. Paper [6] tackles the issues of optimization of shape and thickness of a product by changing a shape of a preform [6]. The authors simultaneously performed a set of tests at the engineering level to refine the adequacy of the model.

The process of blow molding of a product from thermoplastic polymeric materials was numerically investigated using specific examples [7]. The task on determining structural-technological parameters in this case was resolved based on the example of molding an extrusion-corrugated product.

The sets of studies, aimed at obtaining specific blown products and conducted using specialized software, are described in article [8]. Carrying out such computations is related to the need of using the specialized commercial software BlowSim. Authors of paper [9] employed the software ANSYS Workbench to calculate parameters of the process for obtaining blown polypropylene products. Using commercial software increases the cost of scientific research significantly, as well as design and technological work for designers and technologists-manufacturers.

Thermal peculiarities in the behavior of a polymeric preform in contact with a metal of the mold and polymer's layers are considered in paper [10]. Analysis of the process of welding the layers of a thermoplastic preform was conducted. A similar process is implemented when semi-molds of a blowing machine close.

Technological features of designing blown products and a structure of molds are outlined in [11]. The approach, specified in paper [12], makes it possible to take into consideration peculiarities of radiation heat exchange when molding polymeric preforms. Specific features of the developed engineering approach were studied using the heating of a blown preform made of polyethylene terephthalate as an example. The possibility of solving a direct (obtaining a product from a preform) and a reverse (determining the shape of a preform for a specified product) technological problem is shown in paper [13].

Analysis of the above studies allows us to conclude that the efficiency of the developed methods of numerical modeling and computer simulation is confirmed by the excellent detailing of the results obtained. Due to the character of the applied modern numerical calculation methods, such approaches are employed to study a particular specified blown product (its geometry and molding technology). At the same time, in order to obtain generalized results, it is necessary to perform dozens or even hundreds of labor-intensive virtual experiments. In addition, analytical equations for generalizing dependences will have to be obtained exclusively by the methods of approximation of the results of virtual experiments. Thus, the considered approaches, in the general case, fail to produce generalizing (including analytical) dependences between structural and technological parameters, which can be operatively used in engineering practice.

3. The aim and objectives of the study

The aim of present research is to obtain analytical dependences that would link geometrical parameters of a molded preform (diameter, thickness of a wall), parameters of a finished molded product (diameter, thickness of a wall) and technological parameters (pressure of preform blowing, tangential drawing rate, viscosity (melt temperature) of the process of extrusion blow molding of a polymeric product.

To accomplish the aim, the following tasks have been set:

– to determine dependences of tangential drawing rate of a polymeric preform on its dimensions and technological parameters of the blow molding process;

– to identify influence of technological parameters of the blow molding process on the thickness of the wall of a polymeric preform;

– to determine the character of change in the factor of tangential drawing of a preform in the process of its blowing;

– to obtain dependences of the time of blowing a polymeric preform on its diameter and thickness of the wall.

4. Rate of tangential drawing of a polymeric preform

An extruded preform for obtaining a blown product is a thin-walled shell made of melted polymeric material that has a negligibly small rigidity [14].

We will select a ring of height dz on the vertical z coordinate in the wall of a polymeric shell perform (Fig. 1).

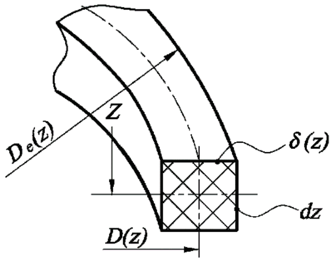

Fig. 1. Geometry of the examined section of a polymeric preform: $\delta(z)$ is the thickness of wall of a polymeric preform, m; $D_e(z)$ is the outer diameter of a polymeric preform, m; $D(z)=D_e(z)-\delta(z)$ is the median diameter of a polymeric preform, m

Under the influence of internal overpressure p, a polymer preform undergoes drawing deformations. It should be noted that deformations in the direction of OZ axis are limited by the structure of a mold for extrusion blow molding and cannot be taken into consideration. Thus, polymer preform drawing occurs in tangential direction. This process is accompanied by an increase in outer diameter $D_e(z)$ and a correspondent decrease in thickness of the wall of a polymer preform $\delta(z)$.

Stresses, influencing the ring (Fig. 1) in tangential direction, can be written as follows:

$$\sigma(z)=\frac{p\cdot D(z)}{2\delta(z)}, \tag{1}$$

where p is the internal blowing pressure, Pa.

On the other hand, the flow of the polymer melt in the wall of a polymer preform at its deformation is accompanied by tangential stresses of viscous flow:

$$\sigma(z)=\frac{2\eta}{\pi}\cdot\frac{\partial v}{\partial D(z)}, \qquad (2)$$

where $v(z)$ is the tangential component of flow rate of polymer melt, m/s; η is the effective dynamic viscosity of polymer melt, Pa·s.

Equating expressions (1) and (2) and solving the resulting equation relative to $v(z)$, we will obtain the following dependence for tangential drawing rate of a polymeric preform:

$$v(z)=\frac{\pi}{8}\cdot\frac{p}{\eta\cdot\delta(z)}\cdot D(z)^2. \qquad (3)$$

Given that the wall is thin, stresses $\sigma(z)$ are considered constant for the thickness of the wall of a polymer preform $\delta(z)$. Respectively, distribution of velocities $v(z)$ will also be constant for the thickness of the wall of a polymeric preform $\delta(z)$. Thus, velocity $v(z)$ will correspond to rate tangential (transverse) drawing of the wall of a polymeric preform.

Fig. 2 shows dependences of tangential drawing rate $v(z)$ of the wall of a polymer preform on a change in the diameter of its wall $D(z)$. The results were obtained for the case of the influence of internal blowing pressure $p=(5\text{ kPa};\ 10\text{ kPa};\ 15\text{ kPa})$ and thickness of the wall of a polymer preform $\delta(z)=0.004$ m. Material of a preform is high density polyethylene at temperature of 200 °C and shearing rate up to 10 s^{-1}. The value of effective dynamic viscosity of the polymer melt $\eta=8300$ Pa·s was accepted based on data from [15].

With an increase in the rate of tangential drawing of the wall of a preform $v(z)$, machine time for product manufacturing decreases. At the same time, the probability of obtaining spoilt products increases dramatically. Output of a product that has critically non-uniformed walls or a deformed product (even a break) can be expected. A significant increase in pressure in the cavity of a preform can be implemented after the contact of a preform with the surface of the metal molds for high-quality molding during cooling of polymer melt to the state of plastic.

Analysis of the results, presented in Fig. 2, suggests that at diameters of a polymer preform $D(z)>0.1$ m, internal pressure of blowing of a preform should be considerably restricted. Thus, at internal pressure of blowing of a preform $p=10$ kPa, rate of tangential drawing $v(z)$ of the wall of a preform exceeds 1 m/s for diameter $D(z)=0.1$ m. And at $p=15$ kPa and $D(z)=0.2$ m, rate of tangential drawing of the wall of a preform $v(z)=7.09$ m/s. In this case, there is an actually explosive character of the deformation of a preform.

Thus, the main factor, which limits the rate of blowing of a polymer preform due to an increase in internal blowing pressure, is the maximal dimensional diameter of a molded product. It is necessary to decrease drawing pressure in inverse proportion to square of change in the diameter of a preform in order to stabilize tangential drawing rate. It is proposed in paper [16] to control the pressure of blowing a preform.

Dynamic viscosity of polymer melt η depends primarily on the melt temperature. It is worth mentioning that the temperature modes of processing of high density polyethylene lie in the range from 120 °C to 280 °C. A significant increase in temperature of a polymer preform can cause a flow and even a break. That is why a polymer preform is extruded in moderate temperature modes (up to 200 °C).

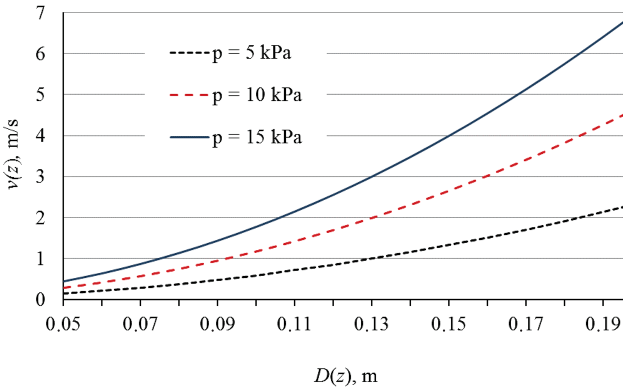

Fig. 2. Dependence of rate of tangential drawing of the wall of a polymer preform $v(z)$ on its diameter $D(z)$

Fig. 3 shows dependences of tangential drawing rate $v(z)$ of a polymer preform on dynamic viscosity η. Dynamic viscosity η varies from 6,500 Pa·s to 16,500 Pa·s, which corresponds to a change in the temperature of a polymer melt from 120 °C to 220 °C at the above shearing rate.

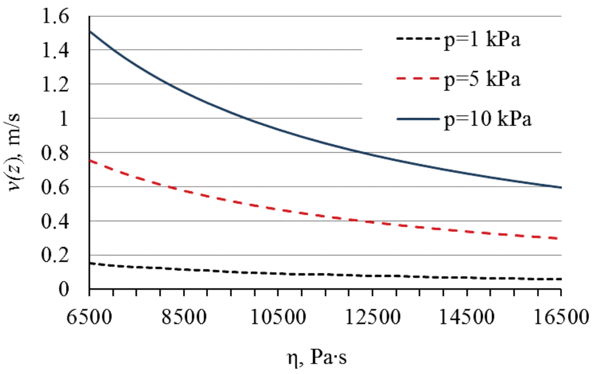

Fig. 3. Dependence of tangential drawing rate $v(z)$ of the wall of a preform on effective viscosity of polymer melt η

If we accept a technologically reasonable magnitude of the rate of tangential drawing of the wall $v(z)=0.5$ m/s, it is not possible to reach this value at pressure $p=1$ kPa, as can be seen from Fig. 3. At $p=5$ kPa, effective viscosity of polymer melt η is limited on the upper limit by value $\eta=10^4$ Pa·s. At $p=10$ kPa, the process is implemented in the whole range of values of effective viscosity (hence in the whole range of thermal modes of processing).

5. Thickness of the wall of a preform at molding

At any moment of molding τ for each ring dz (Fig. 1), the conditions for maintaining the volume of material are met:

$$\pi D(z)\delta(z)dz=\text{const}\big|_z;$$

$$T(z)=D(z)\delta(z),\ \ T(z)\neq f(\tau),\ \ T(z)=\text{const}\big|_z. \qquad (4)$$

The geometry of a polymer preform at the moment of extrusion is typically known [17]. The average diameter of an extruded polymeric preform can be considered the same over its entire length.

Then:

$$\delta(z)\big|_{\tau=0}=\delta_0(z);\quad D(z)\big|_{\tau=0}=D_0, \tag{5}$$

where $\delta_0(z)$, D_0 are, respectively, the thickness of the wall and the average diameter of a polymer preform at the moment of start of the blow molding process.

Expressing $\delta(z)$ from equation (4) and substituting in dependence (5), we will obtain the following dependence for tangential drawing rate:

$$v(z)=\frac{\pi}{8}\frac{p}{\eta T(z)}D(z)^3. \tag{6}$$

On the other hand, the rate of tangential drawing $v(z)$ of the wall of a polymer preform can be determined through derivative from time $d\tau$:

$$v(z)=\pi\frac{dD(z)}{d\tau}. \tag{7}$$

Equating expressions (6) and (7), taking into consideration (5), we will obtain dependence:

$$D(z)=2D_0\sqrt{\frac{\eta T(z)}{4\eta T(z)-D_0 p\tau}}. \tag{8}$$

We will use condition (4) to replace D_0 and $D(z)$ in equation (8). This allows obtaining the expression for determining thickness of the wall $\delta(z)$ of a polymer preform depending on blowing time τ:

$$\delta(z)=\frac{\delta_0(z)}{2}\sqrt{4-\frac{T(z)p}{\eta\delta_0(z)^2}\tau}. \tag{9}$$

Fig. 4 shows graphical illustration of dependence (9). Results were obtained at the following values of parameters: $\delta_0=5\cdot10^{-3}$ m; $\eta=8300$ Pa·s; $T(z)=2.5\cdot10^{-4}$ m^2.

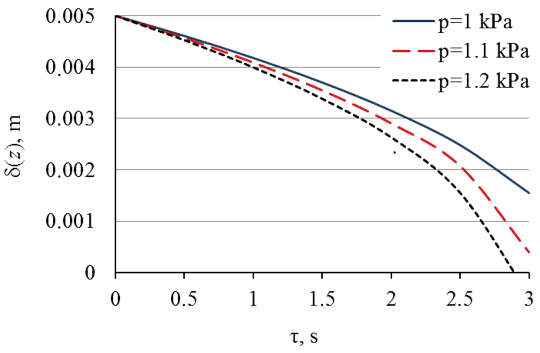

Fig. 4. Change in the thickness of wall of a polymeric preform $\delta(z)$ at time τ

Fig. 4 has two characteristic sections, which can be easy to linearize. The first section ($\tau<2$ s) characterizes the normal flow of the process of tangential drawing of the wall of a polymer preform. In this case, thickness decreases by two times. Next, the deformation process accelerates sharply, which can lead to defects of a product.

6. Factor of tangential drawing of a preform

Tangential (transverse) drawing factor according to [14] is equal to:

$$k=\frac{\delta_0(z)}{\delta(z)}. \tag{10}$$

Based on equation (8), it is possible to obtain an expression for tangential (transverse drawing factor k in the following form:

$$k=\sqrt{\frac{1}{1-\frac{T(z)p}{4\eta\delta_0(z)^2}\tau}}\quad\text{or}\quad k=\sqrt{\frac{1}{1-\frac{D_0 p}{4\eta\delta_0(z)}\tau}}. \tag{11}$$

The magnitude of tangential drawing factor normally does not exceed 4. The region of determining function (11) is limited, but expression (11) allows determining dependence $k=k(\tau)$ within the specified limits (Fig. 5) for the following input data: $D_0=0.05$ m; $\eta=12{,}500$ Pa·s; $\delta_0=5\cdot10^{-3}$ m.

Dependence (8) has a substantial drawback – calculations are possible when the condition is met:

$$\tau<4\frac{\eta}{p}\delta_0(z). \tag{12}$$

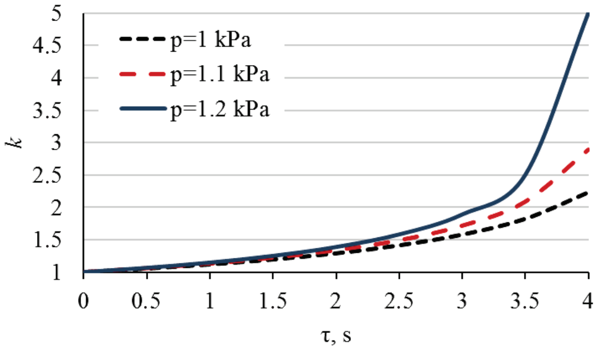

Fig. 5. Change in the factor of tangential drawing of a polymeric preform k on blowing time τ

The value of effective viscosity $\eta=12{,}500$ Pa·s in this case makes it possible to illustrate behavior of dependence $k=k(\tau)$ within $\tau=4$ s of the time of blowing of a polymer preform.

As well as in the case, shown in Fig. 4, in Fig. 5, it is possible to separate two characteristic deformation zones (stages), the boundaries between which are in the range $\tau=(3...3.5)$ s. The first blowing stage is characterized by a decrease in wall thickness by two times (by 50 %) and accompanied by a moderate slope of curve $k=k(\tau)$. Under a given mode, dependence $k=k(\tau)$ is practically linear in character. It is followed by a sharp increase in the angle of slope of curve $k=k(\tau)$. This stage of blowing of a polymer preform can also be linearized. Moreover, the higher the internal blowing pressure p, the greater the risk of obtaining a spoilt product (even local breaks of a polymer preform) during the second blowing stage.

7. Time of polymeric preform blowing

If calculation time τ exceeds the specified limit (12), it is possible to use the inverse dependence in the form of

$\tau=\tau(D)$, which is shown below and does not have the above limitations:

$$\tau=\frac{4\eta T(z)}{p}\left[\frac{1}{D_0^2}-\frac{1}{D(z)^2}\right]. \qquad (13)$$

If we consider that gravitational drawing of a preform does not essentially contribute to the change of the thickness of wall $\delta_0(z)$ along the length of preform z ($\delta_0(z)=\delta_0$), $T(z)=T$, the expression (13) can be essentially simplified. In this case, for practical application it is convenient to proceed from average diameter D to structurally known outer diameter D_e:

$$\tau=2\frac{\eta}{p}\left[D_e-\frac{D_{0e}^2}{D_e}\right], \qquad (14)$$

where D_{0e}, D_e are structurally known outer diameters of a polymer preform at the moment of extrusion and at the moment of the contact of the molding surface of a metal mold, respectively, m.

Fig. 6 shows dependence $\tau=\tau(D_e)$ for the following input data: $D_{0e}=0.055$ m; $\eta=8{,}300$ Pa·s.

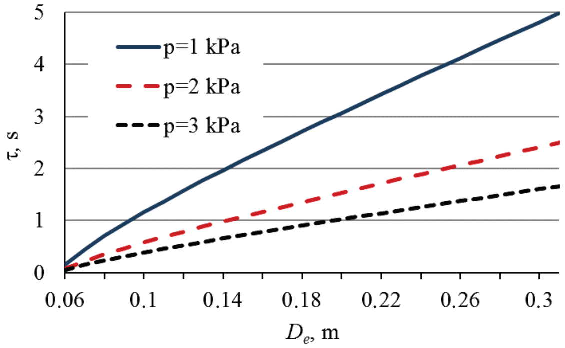

Fig. 6. Inverse dependence of time of blowing of a polymeric preform τ on diameter of molded product D_e

It is possible to obtain a product with the outer diameter $D_e=0.18$ m at internal blowing pressure $p=1$ kPa at time $\tau=2.7$ s. At an increase in internal blowing pressure up to $p=3$ kPa, the time of product molding will amount to $\tau=0.9$ s.

Similar to expression (14), it is possible to write the inverse dependence for function (9) in the form $\tau=\tau(\delta)$:

$$\tau=4\frac{\eta}{p}\left[\frac{\delta_0}{D_0}-\frac{\delta(z)^2}{T}\right]. \qquad (15)$$

Fig. 7 shows dependence $\tau=\tau(\delta)$ for the following input data: $\delta_0=5\cdot10^{-3}$ m; $T(z)=2.5\cdot10^{-4}$ m^2; $D_0=0.05$ m; $\eta=8{,}300$ Pa·s.

At internal pressure $p=1$ kPa within molding time τ=3.2 s, thickness of the wall of a preform decreases up to $\delta(z)=10^{-3}$ m. Within molding time $\tau=1$ s, at internal pressure p, equal to 1 kPa, 2 kPa and 3 kPa, thickness of the wall $\delta(z)$ of 0.048 m, 0.039 m, and 0.015 m, respectively, will be obtained. It should be noted that at an increase in the blowing time, angle of slope of curve $\tau=\tau(\delta)$ decreases. This indicates a progressive decrease in thickness of the wall of a polymer preform over time.

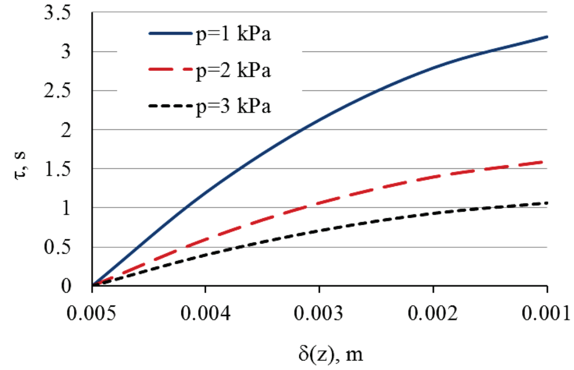

Fig. 7. Inverse dependence of time of blowing a polymeric preform τ on thickness of wall of molded product $\delta(z)$

Both an increase in the internal blowing pressure and a decrease in the effective viscosity of the polymer melt reduce the limits of possible application of equation (11). To expand the region of applicability of dependence (11), we will record it relative to τ:

$$\tau=4\frac{\eta}{p}\frac{\delta_0}{D_0}\left[1-\frac{1}{k^2}\right]. \qquad (16)$$

Using expression (16), it is possible to obtain data on a change in the tangential drawing factor during blowing of a polymeric perform (Fig. 8) without a limitation for blowing time τ. Dependence $\tau=\tau(k)$ was obtained for the following input data: $\delta_0=5\cdot10^{-3}$ m; $T(z)=2.5\cdot10^{-4}$ m^2; $D_0=0.05$ m; $\eta=8{,}300$ Pa·s.

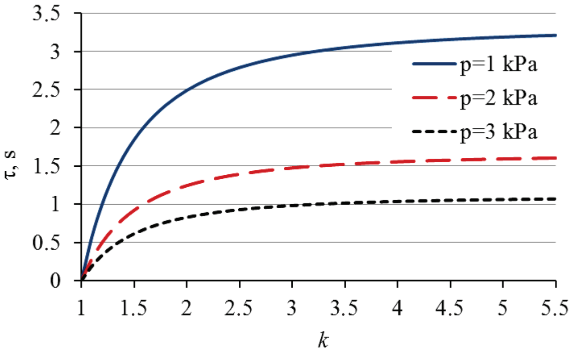

Fig. 8. Inverse dependence of time of blowing of a polymeric preform τ on tangential drawing factor k

In practice, the magnitude of tangential drawing factor k most often lies within $k=(1.8...3)$ and it seldom exceeds value $k=4$. The reason for this fact is easily explained by Fig. 8. It is obvious that at $k>(2...2.5)$, there starts the mode of a dramatic increase in tangential drawing factor k.

It should be noted that an increase in tangential drawing factor k under this mode has an «explosive» character. A polymeric preform, even if it does not have mechanical defects, will come into contact with the inner surface of a metal mold with a bang. In this case, the air between the surfaces of the mold and of a preform may not have time to leave some of the local zones. Then bubbles and craters can be possibly formed on the product.

For internal blowing pressure $p=1$ kPa, this mode occurs at the third second of molding. If we increase internal blowing pressure up to $p=2$ kPa, the mode of a catastrophic growth for tangential drawing factor k occurs at $\tau=2.5$ s, and for $p=3$ kPa, it already occurs at $\tau=2$ s.

8. Estimation of adequacy of the proposed approach

The proposed approach to the study of the stage of blowing of a polymer preform is based on the following hypothesis. It is expected that mechanical membrane stresses in the wall of a polymer preform, developing under the influence of internal blowing pressure, cause the material flow in the tangential direction and, respectively, the stress of viscous flow of polymer.

The following experiment was conducted to verify the adequacy of this assumption. Sleeve polyethylene preforms with the outer diameter of $D_e=0.1$ m and $D_e=0.14$ m were extruded on the extruder of brand CP 45×20, equipped with a pipe head. A hot preform was compressed from both edges and a closed cavity was consequently formed.

A socket of compressed air feed was put to the cavity from one edge of a preform, and a connecting pipe of the manometer KM-22 was put from the other edge (pressure measuring limits are from 0 kPa to 4 kPa, absolute error of measurement is no more than 0.06 kPa). The switching contact device, fixed at the required distance from the wall of an extruded preform, was used to limit the diameter of a preform during its blowing to the diameter of finished product D_e. Linear dimensions were measured with a precision of up to 1 mm.

Preforms were subjected to blowing with compressed air under conditions of restriction of axial deformations. When a supply of compressed air began, the electronic stopwatch PVE-07/1 started automatically. The measured range was from 0 s to 9.999 seconds; count sampling was 0.001, absolute measurement error was not more than 0.002 s. The blowing lasted up to the moment the outer surface of a blown preform touched the contact device, which determined the outer diameter of the finished product D_e. At this moment, a contact device switched off the feed of compressed air and stopped the stopwatch.

Extrusion temperature was maintained at the level of 120±2 °C by the temperature control system of the extruder. Accordingly, the value of dynamic viscosity for the studied polymer melt for $\eta=6{,}500$ Pa·s was accepted.

Experimental blowing time τ^* of the sleeve polyethylene preform was compared with calculated value τ, obtained based on dependence (14). The respective results measurements of geometric and technological parameters are given in Table 1.

Three measurements were performed for each experimental value of the parameter, presented in Table 1, and arithmetic mean was entered in Table 1. Error Δ of calculations of time of blowing a preform τ in relation to experimental values τ^* was determined as follows:

$$\Delta=(|\tau-\tau^*|/\tau^*)\cdot 100\ \%. \qquad (17)$$

As data in Table 1 show, the maximal calculation error Δ is 18.2 %. It should be noted that error Δ decreases in each of the two cycles of experiments at an increase in blowing time. This is due to the peculiarity of compressed air feeding into the cavity of a molded polymer preform. It is obvious that pressure p in the cavity increases not instantaneously.

Table 1

Results of comparison of experimental and calculated data of geometrical and technological parameters of the process of extrusion blow molding of a polymeric preform

Outer diameter of the preform D_{0e}, m	Outer diameter of the product D_e, m	Internal blowing pressure p, kPa	Blowing time, s		Error Δ, %
			Experiment, τ^*	Calculation, τ	
0.10	0.20	1.26	1.174	0.9654	17.8
	0.30	1.26	2.02	1.7247	14.6
	0.40	1.25	2.813	2.4134	14.2
0.14	0.20	1.25	0.806	0.6597	18.2
	0.30	1.26	1.411	1.5253	8.1
	0.40	1.26	2.51	2.2702	9.6

The process of extrusion of a polymeric preform can take up to 10 seconds. In this case, the temperature of a polymeric preform in the surrounding medium even before blowing becomes slightly lower than the temperature of extrusion and it means that polymer melt viscosity η must rise in time. In addition, the calculations do not take into consideration the elastic component of the polymer melt deformation. These two factors explain a systematic understatement of the calculated values of the time of blowing a sleeve polyethylene preform τ relative to experimental values τ^*.

9. Discussion of results of research into the stage of polymeric preform blowing

It is shown in present paper that the process of polymeric preform blowing has two characteristic stages. Stage 1 is characterized by moderate modes of deformation and is limited to tangential drawing factor $k=2$. Stage 2 has a more intense character, which under condition of absence of control of technological parameters (pressure, drawing rate) can lead to spoilage in the finished product. Similar research into the influence of blowing pressure has already been carried out for a similar process of obtaining products from performs [18].

Illustration of application of the above dependences based on simulation of different technological modes makes it possible virtually entirely to determine structural-technological parameters of the process of extrusion blow molding. At the same time, this article does not address the following issues, which are of scientific and practical interest.

Principles of «effective viscosity», used in this work made it possible to significantly simplify the differential equation (2), which greatly facilitated obtaining an analytical solution. However, as can be seen from Fig. 2, 3, kinematic characteristics of the process of extrusion blow molding are substantially variable. Because polymer melt is nonlinear viscous and elastic-viscous medium, subsequent studies are also possible in the direction of consideration of these peculiarities of melt behavior.

Similar approach is known; it refers, however, to a double-stage processes of obtaining products from polyethylene terephthalate at significantly lower temperatures: [19] – viscous-plastic model, [20] – elastic-viscous-plastic model. In addition, non-homogeneity of parameters of the process of extrusion blow molding is associated primarily with non-uniformity of thickness of the wall of extrusion preform δ_0. While non-uniformity of thickness of the wall of an extrusion preform on the circumference can be eliminated technologically by adjusting of an extrusion head, a change of its thickness along its length z is related to the influence of gravitational forces.

There are some known attempts of taking into account gravitational forces [21] and the extrudate swelling effect [22]. That is why, tracing dependence $\delta_0=\delta_0(z)$, it is possible to obtain relevant information about distribution of the considered parameters by the length of a preform z.

A promising direction of simulation of the process of extrusion blow molding of the studied product is an integrated approach, implying structural-parametric modeling of separate technological operations of the molding process [23].

10. Conclusions

1. Analytical dependences of the rate of tangential drawing of a polymeric preform on the diameter of a preform, and the rate of tangential drawing of a preform on polymer melt viscosity, were obtained. It has been shown that the main factor that limits the rate of blowing of a polymeric preform because of an increase in internal blowing pressure is the maximal dimensional diameter of a molded product.

2. We studied the influence of basic technological parameters of the blow molding process (pressure of preform blowing, tangential drawing rate, melt viscosity (temperature) on the wall thickness of a polymer preform. It was noted that a change in the thickness of the wall of a polymeric preform passes two characteristic phases: at value of tangential drawing factor $k\leq 2.5$ – the mode of moderate deformations, and at $k>2.5$ – the mode of a catastrophic increase in the tangential drawing factor, caused by a sharp change in the thickness of the wall of a preform.

3. It was established that one of the ways to prevent spoilage at the values of tangential drawings factor $k>2.5$ is a decrease in the internal operating pressure of preform blowing. Therefore, to stabilize tangential drawing rate, it is necessary to decrease tangential drawing pressure inversely proportionally to the square of change in the diameter of a preform.

4. Dependences of the time of blowing of a polymeric preform on its diameter and thickness of the wall were obtained. We performed analysis of change, over time, in the tangential drawings rate, the thickness of wall and the diameter of a polymeric preform for the blowing stage at extrusion blow molding of a polymeric product. It was shown that an increase in the diameter of a preform over time has the character, which is close to linear, while an increase in tangential drawing factor is progressive in character. The conducted experiment demonstrated adequacy of the proposed approach: the error did not exceed 18.2 %.

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