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IMPROVING THE DESIGN OF THE EXTRUDER TO IMPROVE THE QUALITY OF POLYMER PRODUCTS

The object of research is an extruder for the manufacture of polymer products. The article considers the problem of improving the quality of polymer products on the basis of improving the design of the extruder. The selected design of the extruder with the execution of a three-section worm in the compression zone with different heights of barrier gaps in each section. The ratio of the length of individual sections to the total length of the compression zone should be in the range of 0.1–0.5. In this case, the height of the barrier gap in the first section should exceed the height of the gaps in subsequent sections by 1.1 times between adjacent turns of the worm. In the first section with a larger gap, there is an intensive dissipation of the mechanical energy of the drive, which leads to the melting of the polymer and the release of heat. At the same time, a significant part of the unmolten material is retained before entering subsequent sections with a smaller gap. Thus, the worm does not experience a sharp increase in pressure in the compression zone and local overheating of the material along its length in the compression section. In subsequent sections, further separation of the melt and solid particles of the polymer occurs, and the clearance height decreases gradually, ensuring a controlled distribution of heat flows in the material. The proposed design of a worm in the compression zone with a closed barrier gap $h = 0.001$ m and open barrier gaps h at 0.0105 m and 0.0075 m is illustrated by the example of an extruder ($D = 0.63$ m; $\varphi = 17.1°$) in the processing of recycled high-pressure polyethylene. The use of open barrier gaps between the worm and the extruder body reduces heat dissipation on its working surfaces by almost three times than with closed barrier gaps, as demonstrated by the obtained dependence of the dissipation function on the worm rotation speed. This reduces the risk of material degradation, the thermal conditions of the polymer stay are mitigated, the homogeneity of the melt increases and will contribute to improving the quality of finished polymer products, in particular polymer pipes, films, etc.

Keywords: *extruder, extrusion, worm, turns, three-section compression zone, barrier gap, reducing polymer degradation, melt uniformity, quality improvement.*

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1. Introduction

Polymers in the modern world play a key role and are the basis of many everyday products, such as polyethylene pipes, bags, films, etc., which must meet high quality standards. Therefore, the development of new technologies to optimize the production process of polymer products and improve their quality is an urgent issue for scientists.

There are many equipment and technologies for the production of various polymer products, but most often extruders are used for this. Extrusion is one of the common ways to process various types of plastics.

Plastic extrusion is a technological process of continuous molding of products by mechanically pushing a heated polymer material through a molding head with a hole corresponding to the profile of the finished product [1].

Polymers are used to make various polymer products, such as: pipes, composite profiles, windows, films, etc. The process of continuous production of polymer products by extrusion has high efficiency and productivity.

The relevance of this research lies in the fact that the extruder is one of the important elements of equipment in the technological lines of various industrial and food industries, on the operation of which the quality of finished polymer products depends.

The peculiarity of the extruder itself is that it has the main elements of equipment worm and body, which are subject to the greatest wear and tear as a result of the operation of the extruder. The design of the extruder worm can be different and has a great impact on the extrusion process and the quality of finished products. It is the worm that plays a key role in the mixing of polymeric materials in the extruder body, which directly affects the quality of the finished product. Therefore, in this paper it is proposed to consider and choose one of the ways to improve the design of such an extruder element as a worm in order to improve the quality of production of polymer products.

The solution to the problem of improving the quality of finished polymer products in extruders is considered by scientists both for chemical engineering and for various industries. Efficiency of production of polymer products (plastic pipes, PVC and composite profiles, plastic threads, windows, doors, polymer films, etc.). In extruders, it depends on many working bodies like worm, body, extruder head, which ensure the quality of the resulting product.

Extrusion is the most common method of continuous processing of polymeric materials, which is most often implemented on single- and double-worm extruders. Usually, two-worm extruders have high productivity, and single-worm extruders are relatively easy to operate, have a good mixing effect and therefore are more in demand. The rotating worm is the main working body in a single-worm extruder [2]. Let's consider the methods of improvement existing in science extruder designs to improve the quality of finished polymer products.

Issues of improving the design of the extruder are considered in educational, patent, scientific literature in several aspects:

– technological description of the features of the extrusion process in extruders [1–3];
– adjustment of the geometry of the interturn space in the extruder and the creation of barrier gaps [4, 5];
– increasing the efficiency of extrusion [5];
– production of products with stable size and shape [6];
– achieving a high dispersion and mixing effect of the worm [4, 6, 7];
– execution of the worm tip with a rod, a piston at its end; increasing the efficiency of extrusion and the quality of finished products [5, 8];
– structural design of the extruder worm with dynamic elements (pins, longitudinal rods, spiral grooves, jumpers, etc.) [2, 4, 8–10];
– regulation of the temperature of the working surface of the worm, the extruder body along its length [5, 8, 11, 12];
– application of optimization of melt temperature settings using the control system [11, 12];
– achievement of improving the quality of polymer products [5–12].

In the paper [3], it is believed that the most preferable elements are those that do not require significant changes in the design of the basic machine. These elements are most often installed on one or both worms or are made as one whole with them. Making mixing or mixing-dispersing elements as one whole with a worm is advisable in the case of completing a stable production line with an extruder, when there is no need to switch to another recyclable one polymer composite material. And vice versa, the design of removable, easily replaceable elements provides significant flexibility of technological equipment in case of frequent changes in the material to be processed, productivity or standard size of the resulting products.

The source [4] discusses the design of the worm section with pins to the extruder head, which provides adjustment of the height of the pins above the surface of the worm. This provides the ability to adjust the geometry of the interturn space and expands the technological capabilities of the worm by processing a wider class of materials. The application of pins in the worm area to the extruder head actively affects the material to be processed due to the change in the shear stresses in the working channel in the area of the worm with pins. As a result, a continuous redistribution of elementary material flows and a high dispersion-mixing effect of the worm as a whole are ensured.

In the source [5], a worm extruder with a worm is proposed, which has the following zones in the direction of material flow: feed (or load), barrier (or compression) and uniformity (extrusion). The barrier zone of the worm is divided by its length and consists of at least two segments, preferably n segments, which are formed in such a way that the ratio of the length of individual segments to the length of the barrier zone is preferably in the range of 0.1–0.5. It is desirable to have the ratio of the height of the barrier gap of the first section of the barrier zone to the height of the barrier gaps of subsequent sections higher than 1.1 between adjacent worm gaps. The clearance height is the value indicated between the outer surface of the worm barrier coil and the inner surface of the extruder body. This combination of design features of the geometric elements of the worm barrier zone allows the plasticization process to be carried out with an increased extrusion efficiency of up to 15% and with a low degree of degradation of the material, and as a result, ensuring the quality of the resulting product.

The paper [6] proposes the design of an extruder with a worm tip with a rod with a piston located at its end. In this case, part of the shaft hole between the tip and the piston is filled with a viscous liquid, as well as a fixed throttle washer is placed in the shaft hole, which significantly expands the technological capabilities of such a worm. The enhancement of the extruder worm based on a tip with a piston at its end provides effective smoothing of melt flow pulsations over a wide range of values and changing speeds. This allows for the production of products with stable dimensions and shapes and contributes to improving the quality of finished products.

In the source [7], it is proposed to improve the design of the extruder worm, in which longitudinal rods with cylindrical end sections are used as mixing and dispersing elements. They are located in the grooves of the ridge of adjacent turns of the worm screw threading. Also, the middle part of the rotating elements can be made with a cross-section different from the round one, for example, square. Worm, due to increased shear deformations, its intensive mixing occurs, as well as dispersion of the components of the processed material, which improves the quality of products.

The source [8] discusses the design of the extruder worm, which is made in the form of an equipped screw threading of the shaft with a cavity for the location of two coaxial-concentric pipes for the supply and removal of refrigerant. At the same time, between the outer pipe and the wall of the shaft cavity, hollow sealed ring bushings are installed, which are filled with porous material impregnated with an easily evaporable liquid. It should be noted that adjacent sealed ring bushings can be heat-insulated from each other. Such an improvement in the design of the extruder worm makes it possible to adjust the temperature of the worm's working surface along its length, which expands the technological capabilities of the worm and helps to improve the quality of finished products.

The paper [9] proposes a worm containing a shaft head connected to a speed reducer, a shaft core connected to a shaft head, and a threaded part surrounding the surface of the shaft core. The free end of the shaft core is connected to the die. The melting and extrusion section, the compression section and the mixing section are sequentially divided between the shaft head and the free end of the shaft core according to the threaded part. Several spiral furrows. These spiral grooves are arranged in specific positions of the worm to form the weave of raw materials in the worm. This worm design provides a low cost of equipment modification, and, first of all, allows achieving a higher molecular orientation in the transverse direction, and also improves the film-forming property.

There is also a way to improve the extruder [10], in which the polymer worm has a jumper that runs in a spiral around the core. In this case, the jumper is formed under the middle on its active side, which transports in the direction of material transport, at least in the cross-section of the worm. The basic principle of this design solution is that the melt is accelerated from the base of the worm to the inner wall of the extruder body through the passage holes. The flows are twisted together in a certain way by the rotating movement of the mixing ring, whereby a particularly strong mixing effect is achieved and thus a good homogenization of the material occurs.

The source [11] states that the main polymer processing technology such as polymer extrusion is a continuous process. This process is influenced by the properties of the material, the extruder and the process parameters, which together determine the final quality of the product. Precise controls of key process parameters such as casing temperature and melt pressure are critical to ensure good product quality in the extrusion process. An extruder of two independent control circuits: melt pressure control at the outlet of the die with one input-one output and drum temperature control with multiple inputs-multiple outputs. First, the dynamic behavior of melt pressure and drum temperature was analyzed. The characteristics of the melt pressure dynamics were nonlinear and variable over time, while the extruder body temperatures were non-linear, slow response. Advanced management algorithms have been applied to manage these key parameters. The performance of the entire control system has been tested by product quality. The quality of the products has improved significantly thanks to the proposed extruder control system.

The paper [12] proposes a fuzzy logic controller for a single-worm extruder to achieve high melt quality based on maintaining the melt pressure and temperature at the desired levels.

As the analysis of literature and patent sources [2–12] shows, most scientists propose various ways to improve the design of the extruder worm to ensure a more efficient process of mixing polymeric materials

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and obtaining high-quality polymer products in the extrusion process. Based on the analysis of methods for improving the extruder to improve the quality of polymer products of extruders, it is possible to conclude that this is a question for scientists can be solved in various aspects. Therefore, the problem of improving the quality of production of polymer products of extruders cannot be considered completely solved, which confirms the relevance of the study in the work.

The aim of research is to identify the effect of the extruder worm design on improving the quality of polymer products.

2. Materials and Methods

The object of research is an extruder for the manufacture of polymer products. A polymer extruder is equipment for the production of products by extrusion of polymeric raw materials [1].

In lines for the production of composite materials and the formation of products from them, extruders are used as polymer melters. Extruders are also polymer mixers with fillers, dyes and other additives. They are plasticizers and are used for granulation of the resulting composition or pushing the prepared melt through the extrusion head in order to obtain products [2].

The single-worm extruder is one of the most common types of process equipment used in the polymer production and processing industry, and in recent years they have begun to be applied in other industries as well. The scope of their application is determined by those processes that can be implemented in the working bodies of extruders. As mentioned above, the main working bodies of extruders are the body and the screw-threaded worm in which it rotates [2].

At present, there is a trend in the design of extruders, which consists in the creation of specialized machines instead of universal machines, that is, designed for processing a specific material and producing the selected product. Special extruders are characterized by relatively high extrusion efficiency.

The most characteristic classification can be considered the division of extruders according to design features:

– *extruders with the same type of working body*: roller, plunger, gear, disc, worm (single-worm, double-worm, multi-worm);
– *extruders with a special working body*;
– *extruders with a combined working body*: worm-disk, disk-worm, worm-worm;
– *extruders with spaced working bodies*: cascade extruders with different or identical working bodies [2].

The most common types of extrusion machine designs are piston and screw (worm) type extruders [1].

It is proposed to consider the design of a single-worm extruder and the principle of its operation. Raw materials are fed into the loading area through a cone-shaped container for loading raw materials 5. Usually, the polymer raw material for the extruder is granular bulk material. Polymer granules are moved to the zone of the cylindrical body of the extruder 2 with the help of a worm 4. Due to the operation of the electric motor 7, the worm rotates through the gearbox 6 (Fig. 1) [1].

The extruder body can be roughly divided into 3 zones. The area where the polymer is loaded and not yet melted is called the loading (or feeding) zone. And where the polymer heats up, it is the melting (or compression) zone. The third zone is the molding (or extrusion) zone, when the molten polymer is squeezed out through the molding head and takes the desired shape.

Heating of the extruder body is carried out by heaters 3, which are placed outside and tightly cover the entire surface. As electric heaters for the extruder, industrial heaters of the ring type or flat, if the extruder body is square, but still ring heaters are more often used. Also, in each of the zones of the extruder body, cooling fans can be used in the design in order to remove excess heat from the heaters. It is possible to use a special type of ring heaters – clamp heaters with cooling [1].

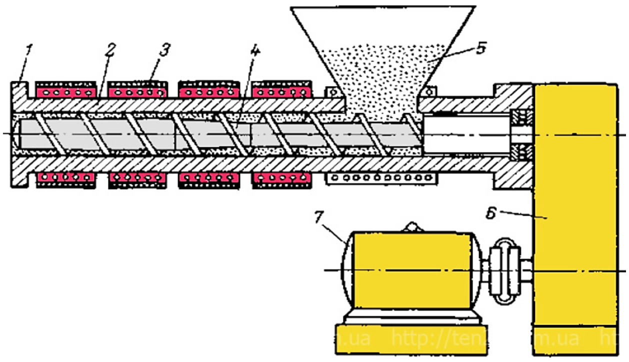

Fig. 1. Design of a single-worm extruder: 1 – flange for attaching the molding head; 2 – body; 3 – heater; 4 – worm; 5 – hopper for loading raw materials; 6 – reducer; 7 – main drive motor

During the rotation of the worm, the material is transported through a screw channel formed by the inner surface of the body and the threading of the worm. Transportation is accompanied by intense deformations of the material and an increase in pressure during the simultaneous passage of a wide variety of processes: heating of the material due to the energy of dissipation and energy supplied from the cylinder heating system. They are initiated by increasing temperature and pressure, chemical, phase and other transformations, compaction and monolithization of bulk materials, mixing of components, extraction of gaseous and other components from materials, etc. Due to this variety of processes, extruders are used at different stages in technological schemes for the production of polymers and products from them, for the processing of composite materials using polymers, for the processing of bioraw materials, secondary raw materials and other materials [2].

The process of extrusion of polymeric materials is complex and requires careful control of various parameters to obtain a product of proper quality. One of the key elements of the extruder, which significantly affects the course of the process, is the design of the worm, especially its compression zone.

Traditionally, the worm compression zone is performed as a continuous section with a constant gap between the turns of the worm and the inner surface of the extruder cylinder. However, this approach has certain drawbacks. In particular, in the case of unfavorable extrusion conditions, there may be a significant increase in pressure at the inlet to the compression zone, where unmelted polymer particles are still present. This leads to local overheating of the material and its degradation, which negatively affects the quality of the final product.

As a result of the literature and patent search [1–10] of the design features and the principle of operation of extruders, it was found that the extruder is a very common type of equipment in industries of various industries. The choice of the most expedient design of the extruder was made with the improvement of the worm to improve the quality of polymer products. A prototype of the extruder worm design with different turns in height in the compression zone was chosen, which consists of 3 sections with gaps of different sizes between the worm turns and the inner body of the extruder. This ensures the gradual separation of the molten polymer from the unmelted particles as the material flows through the sections of the compression zone [5].

From the analysis of the literature on the features of extruders, the following main advantages of extruders can be identified: ease of maintenance, versatility, flexibility of adjustment, high productivity, etc. The disadvantages of extruders are: sensitivity to wear of the main working bodies (body and worm), decrease in product quality, loss of mechanical properties, increase in cooling time, etc.

Based on the above considered design features and the principle of operation of a single-worm extruder, it can be noted that the worm is one of the most important working bodies in an extruder, the design of which determines the quality of mixing polymeric raw materials and the final product.

3. Results and Discussion

A method of improving the design of the extruder based on the prototype of a worm with three sections in the compression zone was chosen. In each section, turns of different heights are used along the worm. This design provides different heights of gaps between the worm and the inner body. This is the most expedient method from the considered existing methods to improve the design of the worm extruder for polymers to improve the quality of products.

In Fig. 2, *a* it is proposed an improved design of an extruder worm with 3 sections with different turns in height in the compression zone for the production of polymer products. Fig. 2, *b* shows a longitudinal section A–A (1:1) for threaded fastening of the extruder head with a worm. Fig. 2, *c* shows a longitudinal section B–B (1:1) for the worm turn in the compression zone with the largest gap between the worm turn and the inner body of the extruder. Fig. 2, *d* shows for clarity the cross-section C–C (1:1) at the place of cutting the tail of the worm. Fig. 2, *b*, *d* are shown as important areas for attaching the extruder worm on both sides, and in Fig. 2, *c* for clarity, the dimensions of the turn in the proposed worm design are presented.

Let's take a closer look at the worm compression zone designed in the drawing, which is divided into three sections along its length (Fig. 2). As is seen, the first section of the worm compression zone with a length of 677.5 mm has the largest gap height of 10.5 mm along the turn of the worm to the inner body of the extruder. The second section with a length of 400 mm has a lower gap height of 7 mm along the turn of the worm to the inner body of the extruder. The third section of the compression zone, also with a length of 400 mm, has the smallest gap height of 3.5 mm along the turn of the worm to the inner body of the extruder in accordance with the designed design of the worm in Fig. 2 according to the chosen method of improving the design of the extruder.

The compression zone is a cylindrical section of a worm consisting of at least two segments, mostly n segments. The height of the barrier gap is the gap between the turns of the worm and the inner body of the extruder. The ratio of the length of individual segments to the total length of the compression zone is in the range of 0.1–0.5. According to the prototype of the selected worm, the height of the barrier gap in the first segment should exceed the height of the gaps in subsequent segments by 1.1 times or more between adjacent turns of the worm [5].

The material reaching the beginning of the barrier gap between the worm turn and the inner body of the extruder must be plasticized by at least 25%. However, this state of plasticization of the polymer material in these areas of the worm is not always observed. It significantly depends on the extrusion conditions, on the efficiency of this process, as well as on the thermal and rheological properties of the extruded material. In case of unfavorable extrusion conditions, there is a significant increase in the pressure of the material at the beginning of the barrier zone in the channel of the solid material. However, the above-mentioned action reduces the quality of the plasticized polymer material, and when the barrier is closed, the plastic often overheats above the recommended processing temperature, which means that its partial degradation occurs. The material is heated, in particular, in the worm channel through the walls of the body and the worm due to thermal conductivity. A layer of molten material is formed around the solid material. To accelerate the plasticization of the polymer material, i.e. the penetration of heat into the non-plasticized particles, it is necessary to separate the plasticized and non-plasticized plastic phases in the barrier zone [5].

The design of the compression zone of the advanced extruder worm described above will contribute to the gradual separation of the polymer melt from the unmolten particles of the material as it moves through sections along its length. The proposed adjustable reduction of the height of the barrier gaps from the first to the last segment in each section of the worm compression zone will allow controlling the distribution of heat flows, as well as reducing the shear stress in the melt of the polymer material. This will help prevent both local overheating and curb polymer degradation in the extruder worm.

Operational assessment of the impact of the proposed worm design can be performed on the basis of the analysis of the value of the dissipation function in the smallest design gaps between the extruder body and the worm. Model equations for such calculations are given in many works on the theory of single-worm extrusion, the review and analysis of which are performed in the source [13].

The dissipation function q can be defined by the equation

$$q=\mu\sqrt{\left(\dot{\gamma}_x\right)^2+\left(\dot{\gamma}_z\right)^2}, \tag{1}$$

where q – the dissipation function, W/m^2; μ – the dynamic viscosity, Pa·s; $\dot{\gamma}_x, \dot{\gamma}_z$ – the shear velocity in the corresponding direction (the x coordinate is directed perpendicular to the cutting ridge, and z is along the worm channel), s^{-1}.

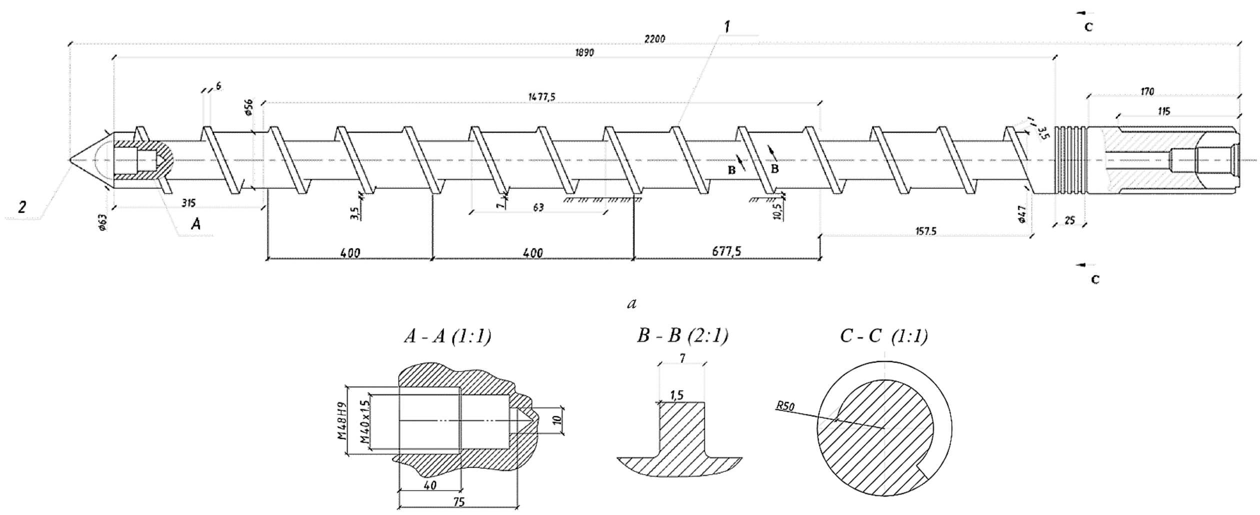

Fig. 2. Improved design of the extruder worm: *a* – worm with three sections in the compression zone; *b* – threaded fastening of the extruder head with a worm; *c* – longitudinal section of the worm coil; *d* – cross-section of the cutting of the tail part of the worm; 1 – extruder head; 2 – worm

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The corresponding expressions (2) and (3) for shear velocities are given below:

$$\dot{\gamma}_x = \pi Dn \cdot \sin\varphi \left(\frac{6y}{h^2} - \frac{2}{h} \right), \tag{2}$$

$$\dot{\gamma}_z = \pi Dn \cdot \cos\varphi \left(\frac{6y}{h^2} - \frac{2}{h} \right). \tag{3}$$

The maximum values for the dissipation function according to the formula (4) will be implemented at the $y = h$, where the y coordinate y – along the channel height

$$q = 4\mu \frac{\pi Dn}{h}, \tag{4}$$

where D – the outer diameter of the worm, m; φ – the angle of inclination of the screw threading of the worm; h – the structural gap in the shear zone, m; y – the current coordinate (from 0 to h), m; n – the speed of rotation of the worm, s^{-1}.

The operation of a closed barrier zone and open barrier zones is illustrated by the example of an extruder ($D = 0.63$ m; $\varphi = 17.1°$) in the processing of secondary high-pressure polyethylene, the dynamic viscosity of which is described by the equation

$$\mu = 7038 \left(\sqrt{(\dot{\gamma}_x)^2 + (\dot{\gamma}_z)^2} \right)^{-0.534} \cdot \exp\left(-0.00609(T-120)\right), \tag{5}$$

where T – the melt temperature, K [13].

The viscosity of the melt of secondary high-pressure polyethylene in the design gaps h depends on its temperature and on the shear rates (2), (3), corresponding to the speed of rotation of the worm. Fig. 3 shows a diagram of the dependence $\mu = \mu(n, T)$ at $h = 0.0105$ m for the selected extruder size. Viscosity dependencies for other values of h will have a similar form and are not given in the work.

It is possible to pay attention to Fig. 3, that when the melt temperature changes from 423 K to 463 K, the viscosity decreases by 21%. At the same time, when the number of revolutions of the worm changes from 1 s^{-1} to 5 s^{-1}, the viscosity value decreases by 3.6 times. This reflects the rheological features of the polymer used, which are taken into account when calculating the dissipation function.

Fig. 4 shows the dependencies $q = q(n)$ for a closed barrier zone ($h = 0.001$ m), an open barrier zone with a gap $h = 0.0105$ m and an open barrier zone with a gap $h = 0.0075$ m (Fig. 2, *a*).

As can be seen from Fig. 4, due to the use of open barrier zones, heat dissipation on the working surfaces of the extruder is reduced by almost three times. The risk of destruction is reduced, the thermal conditions of the polymer are mitigated, and the temperature homogeneity of the melt increases significantly.

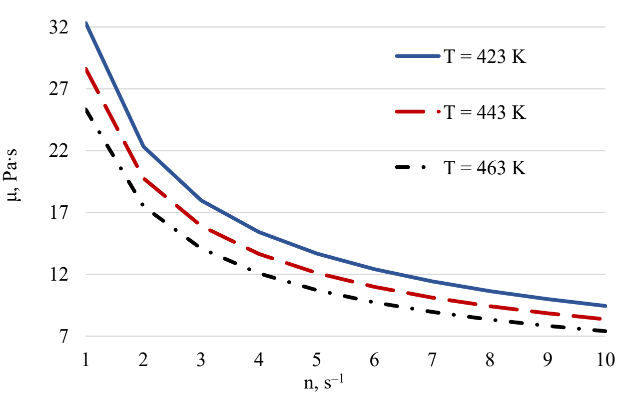

Fig. 3. Dependence of viscosity on the speed of rotation of the worm at different melt temperatures

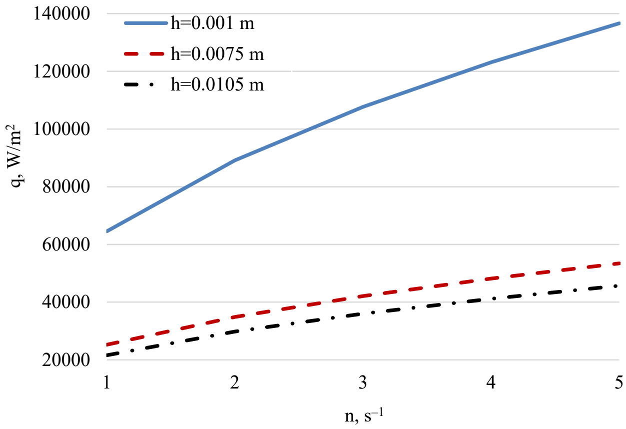

Fig. 4. Dependencies of the dissipation function on the worm speed $q = q(n)$ for a closed barrier zone ($h = 0.001$ m), an open barrier zone with a gap $h = 0.0105$ m and an open barrier zone with a gap $h = 0.0075$ m

Based on the results of the study, a way to improve the design of the extruder was searched for and a three-section worm in the compression zone with different barrier gaps from turns to the inner casing in each of these sections along the worm was chosen as a prototype. This will allow gradually controlling the temperature of the material in each section of the worm separately, which will ensure a more uniform heating of the polymer material in the worm and will contribute to improving the quality of manufacturing polymer products by the extruder.

From a practical point of view, the design of a three-section worm in the compression zone is designed. Each section is made with different barrier gaps along the worm from the turns to the inner body of the extruder. Thus, the applied aspect of using the obtained scientific result is the possibility of manufacturing the designed design of the extruder worm for production of polymer products. This is the prerequisite for the transfer of the obtained technological solutions for the proposed design of the extruder worm to improve the quality of polymer products.

Limitations of research. There are objective difficulties associated with determining the exact size of the gaps in the worm compression zone, because there is insufficient certainty of the information in the extruder worm prototype regarding the dimensions of the barrier gaps. To solve these difficulties, the barrier gaps in the three-section worm compression zone were designed in the study drawing in accordance with the recommendations in the prototype of the selected worm design.

In further research, it is planned to analyze the directions of improvement of the extruder during wear of the body, as an important working part in interaction with the worm for high-quality mixing of polymeric materials. Usually, the worm and the body are most subject to constant wear and tear from the friction of the material being mixed.

4. Conclusions

It was chosen as the most expedient and effective way to improve the extruder design – on the basis of a prototype of a three-section worm in the compression zone with different barrier gaps in each section. The design of a three-section worm in the compression zone with barrier gaps of different heights h of 0.001 m, 0.0105 m, 0.0075 m. The operation of a closed barrier zone with a gap $h = 0.001$ m and open barrier zones with gaps of 0.0105 m and 0.0075 m is illustrated by the example of an extruder ($D = 0.63$ m; $\varphi = 17.1°$) in the recycling of recycled high-pressure polyethylene. The dependence of the melt viscosity of secondary high-pressure polyethylene is obtained, which shows that when the melt temperature changes from 423 K to 463 K, the viscosity decreases by 21%. At the same time, when the number of revolutions of the worm changes from 1 s^{-1} to 5 s^{-1} the viscosity value decreases by 3.6 times and reflects the rheological features of the polymer used, which are taken into account when calculating the dissipation function. The dependencies of the dissipation function on the worm speed $q = q(n)$ for a closed barrier zone with a gap $h = 0.001$ m and open barrier zones with gaps $h = 0.0105$ m and $h = 0.0075$ m, which show that due to the use of open barrier zones, heat dissipation on the working surfaces of the extruder is reduced by almost three times than with closed barrier gaps. The proposed design of an extruder worm with open barrier zones in the compression zone will gradually control the temperature of the material in each section of the worm separately, which will ensure a more uniform heating of the polymer material in the worm. This will help reduce polymer degradation, better melt homogeneity, and improve the quality of finished polymer products by the extruder. The applied aspect of the study is the possibility of manufacturing the designed structure of an extruder worm for the production of high-quality polymer products, in particular polymer pipes, film, etc.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal nature, authorship or other nature, which could affect the research and its results presented in this article.

Financing

The research was conducted without financial support.

Data availability

This manuscript is related to the data stored in the repository, since it is a continuation of a study in which one of the elements was previously described in [5].

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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