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Design of the forming device with a vertical blow head for the production of synthetic fibers intended for filter process in the mining industry

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It is generally known that the underground water is also extracted into the mining process during the mining of rocks, solids or different liquid substances. These mining processes need to be drained and, given the increased demand for organic processes, water has to be separated from undesirable substances. One of the undesirable substances in the mining process is the oil from the hydraulics mining machines that can contaminate this water. Various technologies and devices are used for filtration, for example, separators. These separators contain filters that can also be made from synthetic fibrous materials. The synthetic fibrous materials for the filters are manufactured by different technologies. The article presents the technology of producing synthetic fiber material by vertical blowing method from thermoplastic raw materials. Namely, the characteristics of the fiber forming device (blow head with an annular converging nozzle) are defined and designed. As a result of the blow head investigation, the values of air rarefaction and air flow in the central hole of the annular nozzle were determined from the process parameters. Also, the result of the blow head study is the determination of the design characteristics, the influence assessment of various design and operational factors on its work, allowing the elementary fibers to be drawn out in a single technological cycle to form a fibrous material for the filters.

Key words: *Filter process, mining industry, blow head, vertical blowing method, synthetic fiber material, annular converging nozzle, rarefaction in the central channel.*

Introduction

In the mining process, besides the semiliquid mixture, mud, slurry, and rocks, there are large volumes of water to remove in order to keep production moving (Qazizada et al., 2018). The authors (Straka et al., 2014) investigated potential reactive materials for the removal of heavy metals from contaminated water. One of the undesirable substances in the mining process is the oil from the hydraulics mining machines that can contaminate this water. Various technologies and devices are used for filtration, for example, separators. These separators contain filters that can also be made from synthetic fibrous materials. Also can be used a highly effective sorbent - a synthetic fibrous material made on TU-2282-001-49396305-99 from the source of raw materials: goods polypropylene, polyethylene terephthalate, waste products of polypropylene and polyethylene terephthalate. The sorbent is a fine-fibred such vata mass ð color from light grey to dark grey (colorless raw materials). The bulk density of the sample fibrous materials is between 160 and 174 kg/m at porosity from 81 % to 81.5%. It is designed for the production of filter materials and other products for cleaning of water, air and soil from pollution with oil products, heavy metals also in the mining industry (Sentyakov et al., 2016; Charvet et al., 2018).

Currently, for most industrial consumers, preference is given to materials that are easy to use, show high efficiency and have a low cost. Therefore, work in the direction of creating a modern technology to reduce production costs while ensuring quality material with high performance is an important task. (Ryauzov et al., 1980).

A well-known traditional technological process of obtaining synthetic fiber materials from primary thermoplastic raw consists in extruding the polymer melt through the spinneret thin holes into the shaft, where the jet is pulled to a predetermined diameter and cooled to a temperature corresponding to the solid state of the thread (Ryauzov et al., 1980). The cured thread is wound on the receiving device and is subjected to stretching and corrugation. At the next stage of the technological process, the tow is cut into elementary fibers (Yankov et al., 2006). The traditional technology of producing staple fibers is a rather complicated and energy-intensive production, involving the use of expensive technological equipment at the stages of the finished fiber production.

In addition, the traditional method is focused on the processing of high-quality industrial raw materials of a certain composition. It is proposed to use household and industrial thermoplastic wastes as raw materials, which are not homogeneous in composition and contain foreign inclusions. As a result, this material has a lower

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viscosity, melting point, as well as low mechanical characteristics, which do not allow winding devices to be used in such conditions. For this reason, it is not possible to obtain from them fibrous nonwoven material according to traditional technology.

From the production point of view, the relevant technology challenge for producing synthetic fibrous materials from secondary thermoplastic raw is the creation of a line that combines the technological operations of elementary threads molding and extrusion, which reduces the number of labor-intensive technological operations and transitions in the processing of fibers and canvas formation, while ensuring the required physical and mechanical properties of the resulting products (Yang, et al., 2017). This circumstance is the main direction of increasing the technical and economic efficiency of the technological process of obtaining fibrous materials from thermoplastic materials (Domnina and Repko, 2017; Shirobokov, 2008).

Of practical interest is the method of obtaining fibrous materials from thermoplastic raw materials melt by vertical blowing method with air, the installation scheme, which is presented in Figure 1 (Sentyakov et al., 2014, Elbakian et al., 2018). The proposed method is fundamentally different from the traditional methods of obtaining elementary fibers and is the most promising in its technical and economic indicators. Such technological process allows to combine the elementary fibers formation and extrusion, reduces the number of labor-intensive technological operations and transitions in the fibers processing and canvas formation, which significantly reduces the production cost (Shirobokov, 2008).

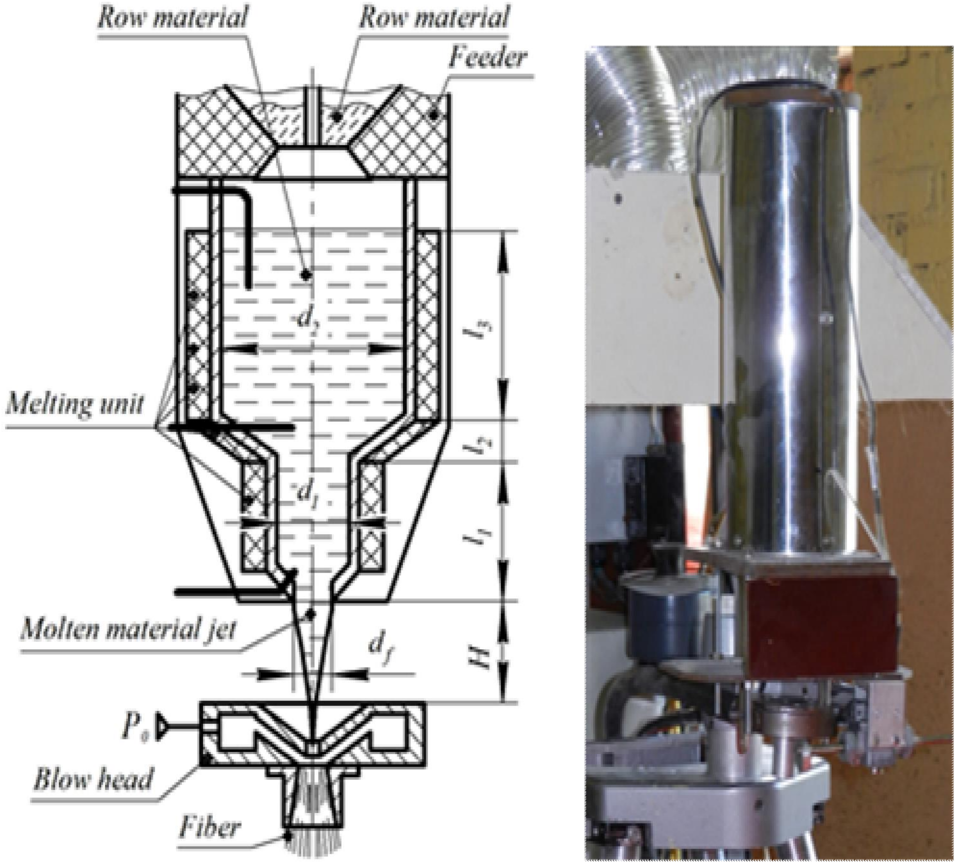

Fig. 1. The experimental setup design for the production of fibrous materials from a thermoplastic melt.

The creation results of new technology for producing fibrous materials from a thermoplastic melt by the method of vertical blowing of the molten material jet, flowing out of the die plate, with air, confirmed its positive qualities, including a significant reduction in the production cost of such fiber compared to traditional technology. In addition, such a technological scheme for obtaining a fibrous material is simple and one-stepped, since all transitions from the raw materials loading to the finished material output are carried out on a single unit. The raw material is a poisonless primary or secondary thermoplastic used for the plastic food dishes manufacture. The finished product is white staple fiber if it is obtained from primary raw materials, and gray, if it is obtained from secondary raw materials - crushed plastic bottles. Such a fiber can be obtained in the form of cotton wool or in the form of canvases, in which the elementary fibers are held together by either natural adhesion or by gluing part of the fibers under the temperature influence. The average elementary fibers diameter can be obtained from 1 to 100 microns, and length - from 1 to 500 mm. The density of cotton wool or canvases is from 10 to 100 kg / m^3. The material has a low hygroscopicity, high strength, and elasticity. It is steady in acids, alkalis, acetone, dichloromethane, is not exposed to microorganisms. The operating temperatures range is from - 60 to 170 ° C. Heat conductivity coefficient - 0.037 ... 0.040 W / (m · K).

The fiber formation from a thermoplastic melt by vertical blowing with air is accompanied by a number of complex and specific phenomena. Therefore, the creation of new advanced technologies, high-performance machines, and units for the production of such materials is impossible without modeling the technological process, which allows to significantly reduce the field tests amount, reduce the cost and development time, as well as select the optimal equipment operation modes.

The research goal was to determine the characteristics, to assess the influence of various design and operational factors on its work, allowing the elementary fibers drawing process to be carried out in a single technological cycle (Hofmann et al., 2018).

Materials and methods of experiment

The effectiveness of such fibrous materials production technology largely depends on the operation of the device, carrying out the process of the molten material jet interaction with the air flow. A distinctive device feature lies in the fact that the elementary staple fibers drawing force is created by an air stream that is specifically directed and determines, in many respects, the productivity and quality of the obtained products. The main factors in the device operation are the air flow parameters, which significantly depend on the device design features (Fabian et al., 2015).

At this stage of the study, the task is to determine the fiber-forming device characteristics, assess the influence of various structural and operational factors on its operation.

The constructive scheme of the blow head with an annular converging nozzle (Sentyakov et al., 2014) is shown in Figure 2.

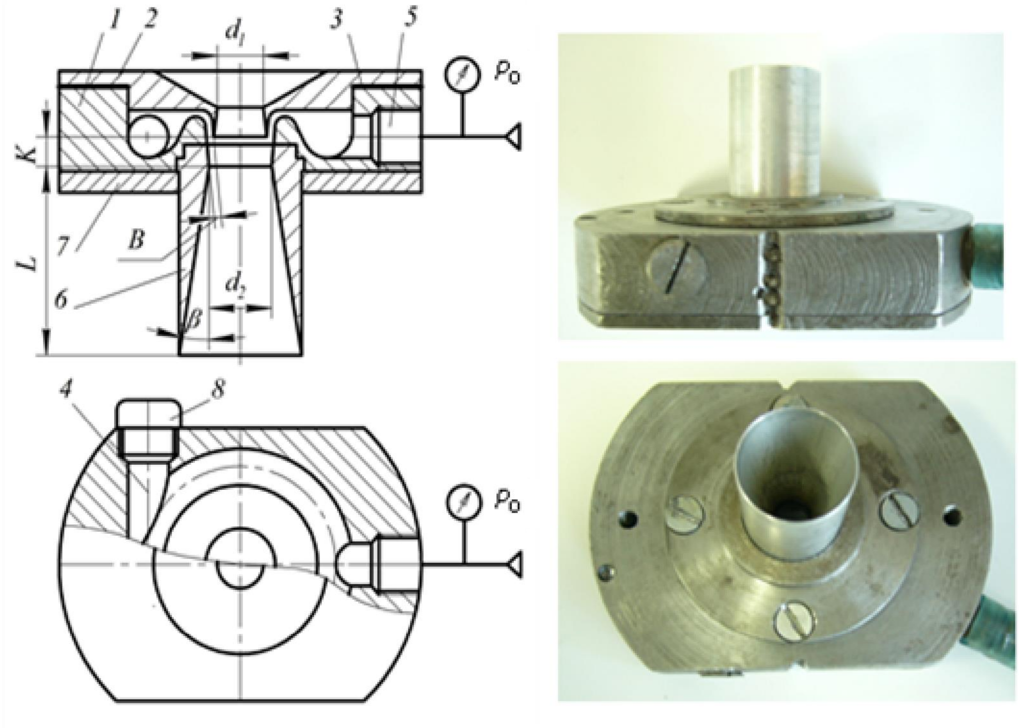

Fig. 2. Blow head design with annular nozzle.

The blow head consists of the lower 1 and upper 2 parts of the body, between which a sealing adjusting washer 3 is installed. The lower 1 and upper 2 parts of the body form an internal annular cavity with channels 4 and 5 for the supply of compressed air and an annular converging gap of width h, through which the compressed air flows into the atmosphere. On the lower part 1 of the body coaxially with an annular nozzle is installed a diffuser 6 of length L, which is fixed by a clamping ring 7. In the upper 2 part of the body, there is a central channel for introducing a molten material jet. One of the supply channels 4 is made tangentially to the inner annular cavity, and the other - channel 5, radially to it. To obtain a swirling air flow at the exit from the blowing head annular nozzle, air is fed with pressure p0 through channel 4, and without swirling - into channel 5. The channel that is not used is closed by a plug 8. A general view of the scheme for determining the rarefaction value in the central channel is shown in Figure 3.

The investigated blow head may be transformed in design by changing the method of supplying compressed air for its power, namely via the radial or tangential channel by connecting or separating the diffuser from the body, placing the steel ball head in the vortex chamber and changing the width of the annular gap B, through which the air flows, by changing the thickness of the sealing adjusting washer 3 between the upper and lower parts of the body. Variants of such blow head structural changes are shown in Table 1.

In the course of blow head experimental studies, the annular gap B width in each of its five versions took values from 0.3 to 0.6 mm, and the rarefaction in the central channel was measured at different supply pressures p_0 - from 10 to 200 kPa.

Tab. 1. Determination of characteristics depending on the blow head design.

A variant of blow head construction	**Presence (+) or absence (-) of swirling airflow**	**Presence (+) or absence (-) of a diffuser**	**The presence (+) or absence (-) of the ball in the vortex chamber**
1	-	-	-
2	-	+	-
3	+	-	-
4	+	+	+
5	+	+	-

Experimental dependencies of rarefaction p_b and the flow rate Q of ejected air in the central channel of the blow head of designs 1 and 2 (according to table 1) on the supply pressure p_0 at different widths of the annular gap B are presented in Figure 3 and 4, which implies that the rarefaction significantly depends not only on the specified parameters p_0 and B, but also on the presence of the diffuser at the blow head outlet. The use of a diffuser allows not only to increase the rarefaction in the central channel, but also to ensure uniform distribution of the airflow parameters downstream of the jet. In the absence of a diffuser, the jet significantly deviates from the blowing head axis due to the non-concentricity of the annular gap (Balog and MaČcovský, 2015).

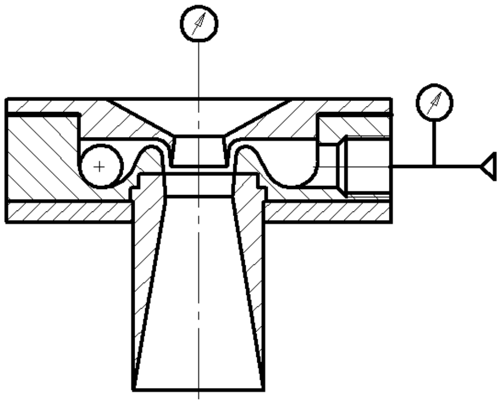

Fig. 3. Scheme for determining the rarefaction value in the blow head central channel.

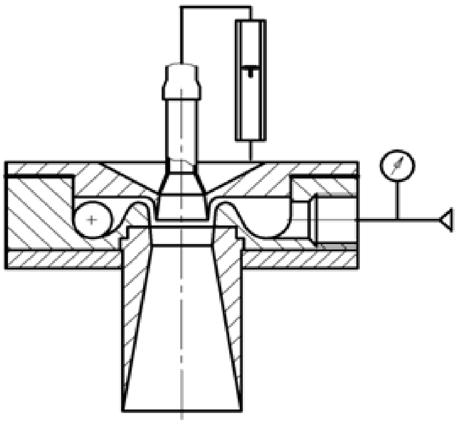

Fig. 4. Scheme for determining the ejected air flow rate through the blow head central hole.

Tab. 2. Levels of factors variation.

Level of factor	Variable factors		
	Supply pressure p_0, [kPa]	**The width of the annular gap** B, [mm]	**Diffuser length** L, [mm]
Upper	200	0.6	40
Lower	50	0.3	0

Tab. 3. The matrix of experiment design.

- experiment	Factors and their interactions								The response function $q = p_{e}/tc_{0}$
	Z_0	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	
1	+	-	-	-	+	+	+	-	0.015
2	+	+	-	-	-	-	+	+	0.035
3	+	-	+	-	-	+	-	+	0.035
4	+	+	+	-	+	-	-	-	0.1
5	+	-	-	+	+	-	-	+	0.06
6	+	+	-	+	-	+	-	-	0.17
7	+	-	+	+	-	-	+	-	0.095
8	+	+	+	+	+	+	+	-	0.285

Note. The experiment design matrix is constructed in accordance with the recommendations given in the book (Adler and Varygin, 1978). The sign (+) means that the corresponding normalized factor in the corresponding experiment takes the value +1, and the sign (-) - the value -1.

Experiments to determine the rarefaction in the central channel of 1 and 2 blow head versions turned out to be sufficient for processing the results using the theory of experiment design. A matrix of the full factorial experiment was used for three factors varying on two levels. The response function was the dimensionless rarefaction q, determined by the ratio of rarefaction p_b in the central channel of the blow head to the atmospheric pressure p_a. The supply pressure p_0, the width of the annular gap B and the length of the diffuser are taken as independent factors. The values of the variable factors are given in Table. 2. The matrix of experiment design with the results of the experiment is given in Table 3 (Shilyaev et al., 2008).

Presented in Table 3, normalized factors are:

$$Z_1 = 2(p_0 - 125)/150\,;\; Z_2 = 2(h - 0{,}45)/0{,}3\,;\; Z_3 = 2(L - 20)/40$$
$$Z_4 = Z_1 \cdot Z_2\,;\; Z_5 = Z_1 \cdot Z_3\,;\; Z_6 = Z_1 \cdot Z_3\,;\; Z_7 = Z_1 \cdot Z_2 \cdot Z_3$$

Taking the response function in the form of a linear polynomial with the factors interaction and calculating the regression coefficients, we obtain the mathematical dependence of the dimensionless rarefaction q in the central channel of the blowing head without swirling the air flow on the above factors:

$$q = 0{,}1 + 0{,}048Z_1 + 0{,}029Z_2 + 0{,}053Z_3 + 0{,}016Z_4 + 0{,}027Z_5 + 0{,}008Z_6 - 0{,}0044Z_7 \tag{1}$$

After conducting experiments on the rarefaction measurement in the central channel of the blow head with intermediate values of the factors p_0, B and L, the adequacy of the obtained formula (1) for calculating the dimensionless rarefaction was checked. The test results are presented in Table 4, where it follows that the discrepancy between the calculated and experimental data in the accepted ranges of factors variation is from 10 to 15 %.

Tab. 4. Check the of the formula (1) adequacy for calculating the dimensionless rarefaction q.

- **experiment**	**Factors**			**Experiment result** q	**Response function** $q = p_b/p_0$	**Error** [%]
	p_0, [kPa]	B, [mm]	L, [mm]			
1	100	0.3	0	0.025	0.0216	13.3
2	125	0.4	0	0.035	0.0391	-11.7
3	150	0.46	0	0.07	0.0598	14.57
4	70	0.6	0	0.05	0.0457	8.6
5	100	0.3	40	0.1	0.0987	1.3
6	150	0.4	40	0.16	0.1627	-1.69
7	70	0.46	40	0.115	0.099	13.9
8	125	0.6	40	0.21	0.19	9.5

Experimental studies of the process of obtaining a fibrous material using a blow head of this design showed that the expansion of intervals indicated in Table 4 is impractical. For example, an increase in the supply pressure p_0 of more than 200 kPa and an annular gap width B of more than 0.6 mm results in a significant increase in airflow and noise level of the blowing head without changing the quality of the produced fiber. Experiments have established that the desire to increase the rarefaction in the central channel of the blow head does not always lead to a positive result. For example, a test of 8 blow head version according to Table. 4, which had the highest rarefaction in the central channel, showed the impossibility of obtaining fibrous material. In this case, there is an intensive cooling of the molten material jet by air flows ejected from the atmosphere and a continuous thread with a diameter of 0.2 ... 0.4 mm is formed. To obtain a fibrous material, the rarefaction in the central channel of the blowing head should be minimal (Farias et al., 2015).

During the blow head investigation, it was revealed that the quality of the obtained fibrous materials is also influenced by the diffuser design parameters, namely, the length L and the cone expansion angle β (Fig. 2).

The diffuser length choice is determined by the need to obtain the maximum degree of the jet stretching and the optimal rarefaction value p_b. A general view of the scheme for determining the rarefaction value in the central channel is shown in Figure 3.

The experiments were carried out with the diffuser constant parameters (Fig. 2): d_1 = 9 mm, β = 12 degrees, d_2 = 11.8 mm and with variable parameters: K = 6.2 ÷ 6.96 mm, B = 0.3 ÷ 0.6 mm, L = 0 ÷ 35 mm. Before each experiment, the annular gap size was established by replacing an adjusting washer, and then the characteristic of the device was taken. Seven diffuser designs with the length L: 5; 10; 15; 20; 25; 30; 35 mm. were investigated (Liu et al., 2016).

Another important diffuser parameter is its shape; therefore, at the second stage of the experiment, the task was to investigate the influence of the diffuser expansion angle β on the rarefaction value p_b in the central channel. The experiments were carried out with the diffuser constant parameters (Fig. 2): d_1 = 9 mm, d_2 = 11.8 mm, L = 20 mm and with variable parameters: K = 6.2 ÷ 6.96 mm, B = 0.3 ÷ 0.6 mm. β = 0 ÷ 14 degrees. Seven diffuser designs with expansion angle β = 0; 3; 5; 8; 10; 12; 14 degrees were investigated;

The pressure p_0 at the inlet to the blow head was measured with an exemplary manometer with a measurement limit of 0.4 MPa accuracy class 0.6. The rarefaction value in the central hole of the device was measured by a TNMP-52 type pressure gauge with a measuring limit of 1250 mm.w.c. Moreover, the flow rate of injected air through the central hole of the device was measured with a PM-04 rotameter with a working measuring range of 0.75-4.3 m^3/h (Domnina, 2017; Volosov and Ped, 1974).

Results and discussions

The experimental study results of the dependence of the rarefaction value in the central hole on the process parameters are shown in Figure 5 and 6. As a result of the dependence analysis, it was found that the rarefaction value is significantly influenced by the value of the annular gap h, and the nature of the swirling airflow through the device's annular cavity, as well as a significant increase in the rarefaction value, is observed with increasing the diffuser length to L = 20 mm. The performed tests allowed us to establish the optimal diffuser length, corresponding to doubled central hole diameter d_1.

Studies have also shown that the rarefaction in the central channel p_b increases with increasing angle of expansion **𝒃** = 12 degrees (Fig. 7). A further increase in the angle of expansion **𝒃** leads to the airflow separation from the diffuser walls, resulting in the rarefaction value decrease in the central hole.

The results illustrating the dependence of the air flow rate through the annular gap on the pressure in the device are shown in Figure 8.

Studies have shown that air flow rate through the central opening of the device increases with increasing width of the annular gap (Daristotle et al., 2017).

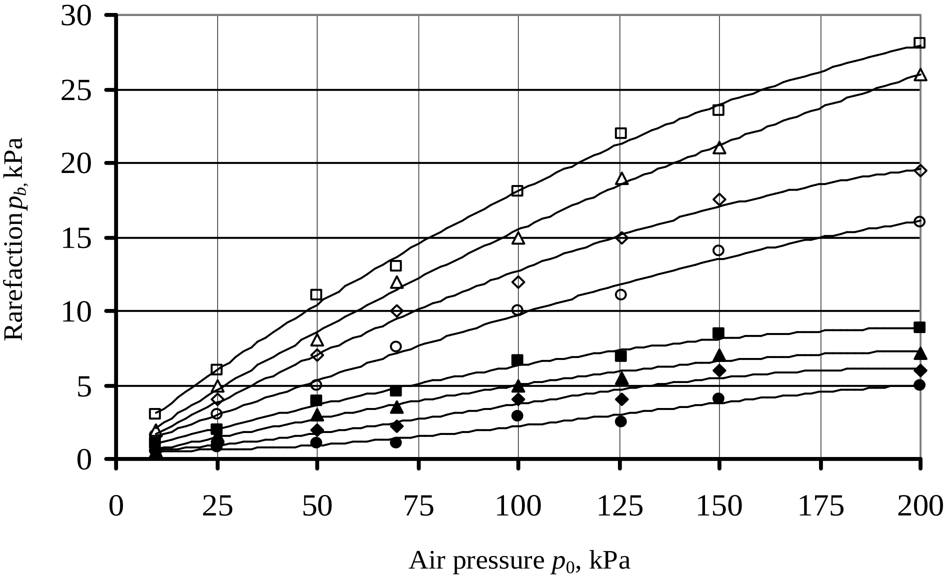

Fig. 5. The dependence of the rarefaction p_b in the central hole on the air pressure in the device p_0: air flow without swirling - **Ĭ** *- at B = 0.6 mm, K = 6.96 mm;* **ɸ** *- at* **J** *= 0.46 mm,* **ş** *= 6.7 mm;* **ö** *- at* **J** *= 0.4 mm,* **ş** *= 6.4 mm***;** **ʒ** *- at* **J** *= 0.3 mm,* **ş** *= 6.2 mm; air flow with a twist -* **ʃ** *- at B = 0.6 mm, K = 6.96 mm;* **ƶ** *- at* **J** *= 0.46 mm,* **ş** *= 6.7 mm;* **Dž** *at* **J** *= 0.4 mm,* **ş** *= 6.4 mm***;** **ŏ** *- at* **J** *= 0.3 mm,* **ş** *= 6.2 mm.*

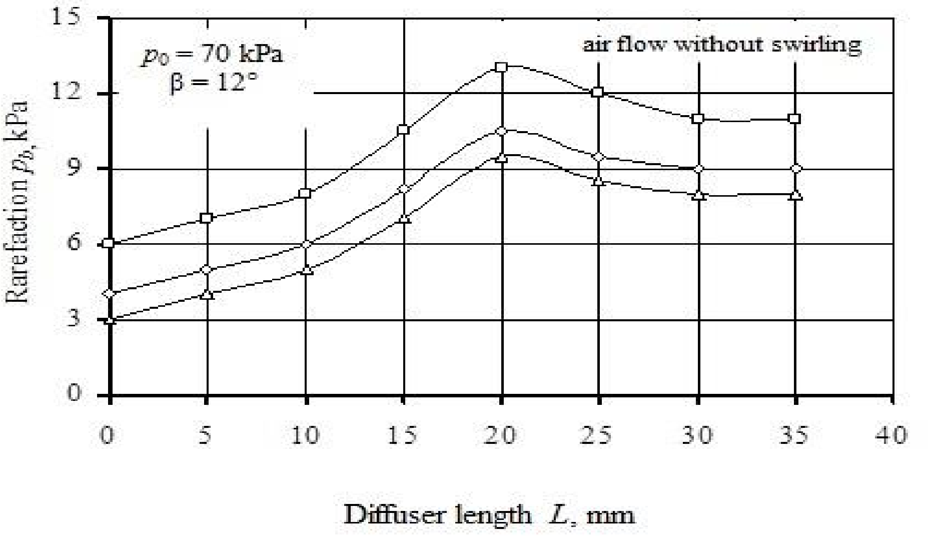

Fig. 6. The dependence of rarefaction in the central hole p_b on the diffuser length L.

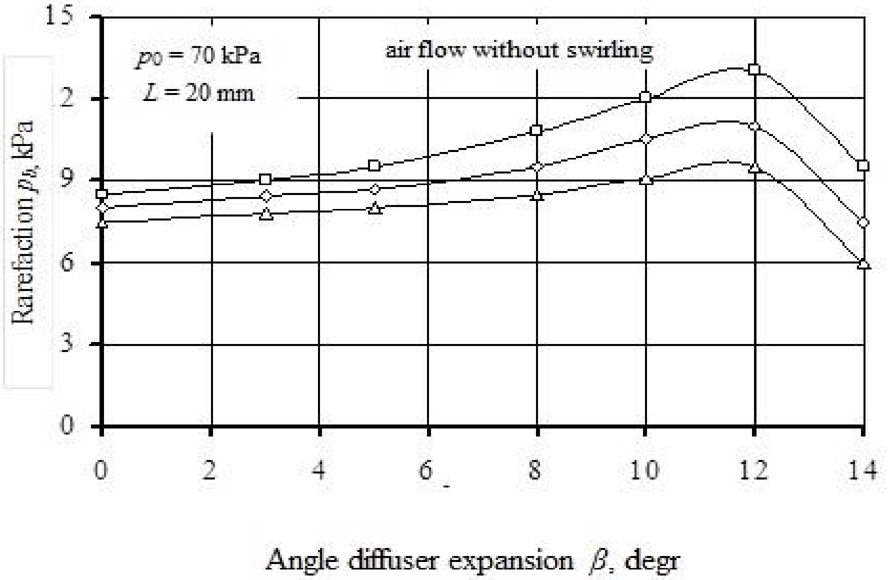

Fig. 7. The dependence of rarefaction in the central hole on the angle of diffuser expansion ***б****.*

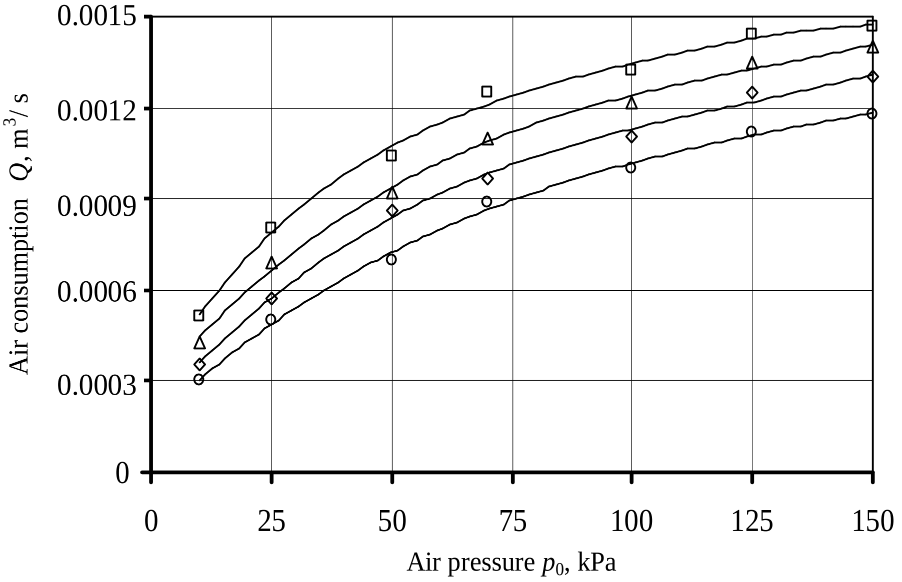

Fig. 8. The dependence of the flow rate Q in the central hole on the air pressure in the device p_0: air flow without swirling - ***Ĭ*** *- with h = 0.6 mm, K = 6.96 mm;* ***φ****- at h = 0.46 mm, K = 6.7 mm;* ***ö*** *- when h = 0.4 mm, K = 6.4 mm;* ***ƺ*** *- at h = 0.3 mm, K = 6.2 mm.*

Summary

Thus, as a result of research carried out on a blow head with an annular converging nozzle to obtain a fibrous material using a vertical blowing of molten material jet with air flow, rational parameters of its flow part, rational pressure range for supplying it with compressed air, and the effect of these parameters on the rarefaction value in the central channel were determined. Quality of the received fiber depends on these parameters (Paschoalin et al., 2017). The obtained characteristics are the initial data for the design of such devices and the development of the technological process and equipment to obtain fibrous materials by the vertical blowing method with the required quality air, which in turn are the basis for the manufacture of construction materials based on polymers. The future potential research will deal with testing of the filtering process with filters from synthetic fibrous materials for the contaminations removal from the underground water that can also be soiled during the mining processes.

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