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The flexural stiffness and tension state of basalt filter

Upogibna togost in napetostno stanje bazaltnega filtra

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Abstract

In recent years, there is a growing demand in Uzbekistan for new, cheap and competitive products from local raw materials, the demand being directly connected with the expansion and development opportunities of the mining, metallurgical and processing industries. In such conditions, the need for providing a solution of the problems faced by these industries is a very urgent one and requires further comprehensive studies. One of these tasks includes assessment of the force parameters and bending stiffness of basalt fibre filters, aimed at further improving the efficiency of local basalt raw materials and aiding in the manufacture of new, long-lasting, reliable and high-quality products.

In this case, we studied the interaction of basalt fibre filter with a gas or liquid medium, the deformed state of the fibres under the action force of the gas or liquid, and the filter recovery process after removal of the load, all of which occur during mechanical filtration.

These tasks are of interest because during the mechanical filtration of a gas or liquid (hereinafter, mechanical filtration) from solids, all attention is paid to the quality of the filtering process. The filtering quality, as known, is determined by the degree of contamination in the liquid undergoing treatment, duration of separation of the pulp into solid and liquid phases during the decantation process of the mixture and the amount of gas/liquid released into the atmosphere along with carbon monoxide and toxic impurities. At the same time, the state and behaviour of the filtering material remain as minor factors, the consideration of which can play a decisive role in the establishment of filter life and work capacity. Solutions to these problems are very urgent and

Povzetek

V Uzbekistanu zadnja leta narašča povpraševanje po novih cenenih konkurenčnih izdelkih iz domačih surovin, kar je v neposredni zvezi s širitvijo in priložnostnimi možnostmi rudarstva, metalurgije in predelovalne industrije. V teh okoliščinah predstavlja reševanje v članku obravnavanih problemov zelo aktualno nalogo, ki narekuje izvedbo vrste celovitih raziskav. Ena od teh obsega določitev trdnostnih in deformacijskih lastnosti filtrov iz bazaltnih vlaken z namenom nadaljnjega izboljšanja učinkovite uporabe domačih bazaltnih surovin in proizvodnje novih trajnejših in zanesljivih visokokakovostnih izdelkov.

V danem primeru gre za proučitev interakcije med filtrom iz bazaltnih vlaken in plinastim ali kapljevinskim medijem, deformacije vlaken pod vplivom sile plina ali kapljevine ter pogojev sprostitvenega procesa v filtru po prenehanju obremenitve z mehansko filtracijo.

Te omembe so pomembne zato, ker pri mehanski filtraciji trdne snovi iz plinov ali kapljevin (procesu mehanske filtracije) vso pozornost namenjajo predvsem kakovosti filtracije. Znano je, da je filtracijska sposobnost določena s stopnjo očiščenja kontaminirane tekočine, trajanjem ločevanja pulpe v trdne in tekoče faze med procesom usedanja zmesi in količino izpustov v ozračje z ogljikovim monoksidom in toksičnimi primesmi. Pri tem ostajata stanje in obnašanje filtrskega materiala manj pomemben dejavnik, čeprav utegne imeti obravnava tega vprašanja odločilno vlogo pri opredelitvi življenjske dobe filtra in njegove zmogljivosti. Za rešitev teh perečih problemov bo potrebno v proizvodnji bazaltnih filtrov uvesti nove tehnološke postopke, temelječe na poznavanju parametrov obremenitve in upogibne

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allow one to create new technologies for the production of basalt filters based on force parameters and bending stiffness, wherein the purification occurs without the intervention of chemicals.

Key words: filter, basalt rock, research, gas flow, gas purifying facilities, process variable, filter material.

togosti materiala filtrov, namenjenih za prečiščevanje brez uporabe kemikalij.

Ključne besede: filter, bazaltne kamnine, raziskava, plinski tok, prečiščevanje plinov, procesna spremenljivka, filtrski material.

Introduction

This study was conducted to assess the flexural rigidity parameters, during filtration of a fluid, of the filter made from the fibres of basalt rocks in Uzbekistan. Analysis of the information from technical literature and the data obtained from the Internet indicate that in the calculations of mechanical filtration, the following factors were paid less attention: elastic and plastic deformation, flexural stiffness (FS) and resistance to bending of basalt fibres, interactions of the filter material with the environment and the force parameters [3-4].

Calculations were carried out mainly to determine the liquid volume (clean from admixtures), filtrate mass, velocity and productivity of the filtration process, aerosols' weight as well as the geometrical and technological parameters of treatment facilities.

One of the advantageous features of basaltic filter is its suitability for filtration of gases from dust and degeneration of the liquid phase from the solid, as well as the possibility of extending the service life of the material. The high efficiency of use of basalt fibre with predetermined force and bending stiffness parameters as filter material proved that the basalt fibre has good prospects. Especially, the positive technological characteristics of such filters, which are far superior to the existing filter materials used, e.g., for filtration of waste water and gold-containing pulp, are noted.

Recent data give a good recommendation for the use of basalt filter material for the mechanical filtering of inhomogeneous media.

On the whole, after analysing the data obtained in the laboratory during the process of filtering the gold-containing pulp using the existing filter made from traditional filter material and comparing the indices with the technological capabilities of the basalt filter, we have found the practicability of the latter in the process of filtering inhomogeneous media.

While studying the capacity of basalt filter materials with preestablished force parameters and bending stiffness, it is shown that this type of filter has the following properties:

— Does not retain the sludge and other harmful impurities on the front surface;
— Holds the particulate matter of the sludge well;
— Has sufficient hydraulic resistance to the flow of the filtrate;
— Can be easily separated from the sedimented slurry;
— Is resistant to the chemical substances that need to be separated;
— Does not swell upon contact with the liquid phase of the sludge and the washing liquid;
— Has sufficient mechanical strength;
— Is resistant to heat at the high filtration temperature [1–2].

During the studies, we have achieved the opportunity to expand the scope of use of local basalt raw materials. This will allow reduction of the cost of production of basalt products, foreign exchange assets and manufacture of environmentally clean products.

Materials and methods

In earlier works, the results of the experimental investigation into filtration of gas from dust via basalt filter were outlined. The facts related to the possibility of using basalt filter for the filtration of gases from the dust of foundries of steel plants were given. This article discusses the results of the theoretical and experimental studies on the determination of the possibility of using the hydrometallurgical route of production for basalt filter made from Uzbekistan basalts. The analysis showed that the filters made of Uzbekistan basalt compete perfectly with the traditional imported filter materials, for instance, in the process of degeneration of the liquid phase from the solid phase. These basalt filters retain their efficiency longer. In this case, parameters of filter materials, such as strength, stability and flexural rigidity, played a significant role.

In early research works of the authors [2], it was noted that the amount of bending of the filter basalt, as well as all other filter materials, depends on the pressure of the gas or liquid flowing into the filter. For the calculation of force parameters, it is recommended to take into consideration a correction factor, the value of which depends on the geometric parameters of the filter material. Thus, by varying the amount

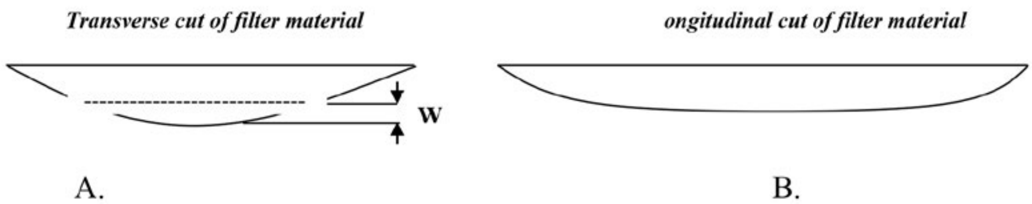

Figure 1: *The conventional form of the filter in longitudinal and transverse sections.*

of pressure, it is possible to calculate the indices of basalt filter flexion.

Results and discussion

Experience shows that the impact of the force parameters associated with the mechanical filtering process is one of the most important indicators that determine the bending stiffness, the performance under different operating conditions, the durability and the quality of the filters. In this case, of practical interest is the study of the filter condition under the influence of force parameters and bending stiffness during mechanical filtration.

The study found that the basalt filter material takes convex or concave shape, as any other filter, during filtration. If the length of the filtering object has a significant value, the convex and concave shapes have a small value. At the same time, the FS of an object is the sum of the convex and concave parts of the object. While studying the state of the basalt filter under static and dynamic conditions, we addressed the issue of the behaviour of crystalline basalt fibre during the process of work and at rest. There, we considered the popular formula for calculating the basalt filter behaviour without considering the flexion of its fibres [3–7].

Basalt filter materials, as other materials, may have a circular or quadrangular form depending on the purpose. In the working area, filters can be in loose contact or show pinching at the edges. In this case, the basalt filter is clamped at the edges, i.e. along the perimeter, thereby providing immobility at the perimeter of the filter.

This phenomenon can be explained by the fact that during the increase in pressure from the liquid or gas phase, brought about by a concentrated force applied to the middle surface of the filter material, the filter adopts a cylindrical shape. Such an exemplary conventional form is shown in Figure 1A and B (in this case, a quadrangular filter shape is considered).

Figure 2 shows the bending moments on the pinched locations of the basalt filter. Here, the torques do not occur in sections that are parallel to the coordinate axes of the test filter and $\mathbf{M_{xy} = 0}$.

It is found that in the case of cylindrical bending, mechanical stress, deformation and flexure “**W**” depend only on a single coordinate “**X**” [8–9]. Applying a known technique, in our case, from the displayed object of research, we allocate a strip with a width of 1 cm and consider the bending of the strip (the beam) with the boundary conditions that are found on all sides of the basalt filter. For such cases, in theory, we apply the equation that Zharma-Lagrange designed to calculate the bending of a beam.

Comparing the known equations of the bending beam $EI\frac{d^2w}{dx^2} = M$ and $EI\frac{d^4w}{dx^4} = q$, with the equation for calculating the beam bending, we note that in our case, the basalt beam with width of 1 cm has the flexural rigidity EI corresponding to the cylindrical shape of the body,

$$D = \frac{Eh^3}{12(1-\mu^2)}.$$

It should be noted that in the middle section of the basalt filter, stresses and bending moments are two times less than those at the joints, and the maximum bending stresses occur at the end sections. The maximum plate flexion at midspan corresponds to the results of the well-known strength of materials.

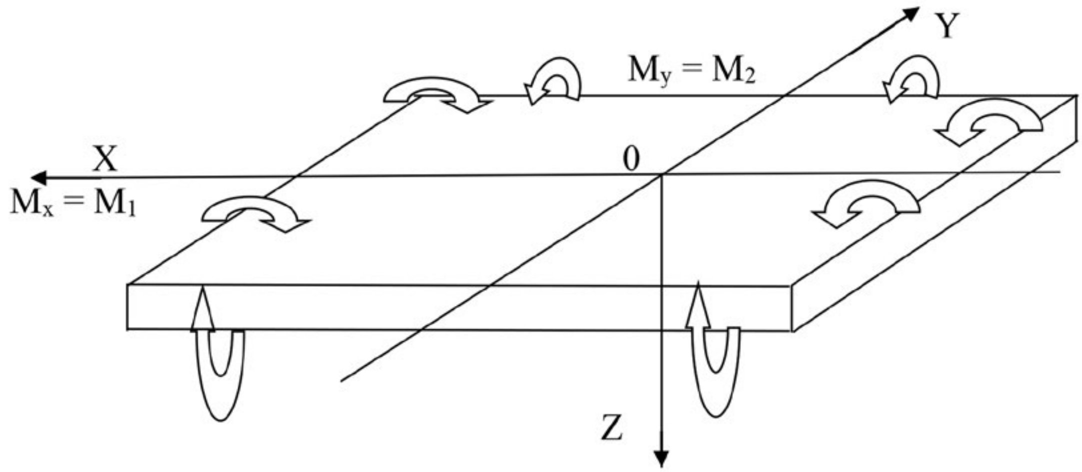

Figure 2: *Bending moments on the fixed positions of basaltic filter.*

Using the method of Bubnov, proposed in 1902, and the calculation formula, we introduce a correction factor depending on the ratio of the width of the filter taken under specific conditions to the length, which was not considered previously:

$$w = \Theta \frac{qa^4}{16u^4 D}\left[\frac{ch(1-2x/a)}{chu} - 1\right] + \frac{qa^2 x}{8u^2 D}(a - x) \quad (1)$$

(where Θ is a correction factor).

Analysis has shown that at significant value of "q", the stress in the basalt filter with immobile, clamped edges would be significantly less along the perimeter. The maximum flexion in the middle of the filter also is small, because the mechanical state of stress of the filter depends on the flow pressure of the liquid/gas, which can be controlled, and thus the former can be easily derived by calculation. Thus, the calculated value of the pure bending of basalt filter material can be found. Pure bending of the filter in this case is flexion, whereby shear stress in the cross-sections of the material is equal to zero, and the cross-section is rotated, staying flat and normal to the deformation axis.

Thus, knowing the amount of air or liquid pressure supplied through a pipeline, it is possible to calculate the necessary force parameters. In this case, to calculate the pure flexion of basalt filter, we use constant moments M_1 and M_2:

$$w = -\frac{1}{2D(1-\mu^2)}\Theta\left[\,(M_1 - \mu M_2)x^2 + (M_2 - \mu M_1)y^2\,\right] \quad (2)$$

Equation (2) made it possible to develop an algorithm using a computer programme and to get a certificate from the Uzbekistan Republic Office for Intellectual Property for calculating the parameters for the state of stress of the mechanical basalt filter [10].

In general, bending moments comprise the conditions for detecting the geometric parameters of the basalt filter, via which it is possible to calculate the filter's flexion. Knowing the pressure of the gas or fluid, one can control the pressure using gauges. Such calculation helps to determine the pure bending of the filter material under a certain force, which determines the design of the filter of the future and its purpose.

Stress state of basalt filter. In either case, the mechanical filtering process of a gas or liquid is carried out by the interaction of forces of the phases during separation. Depending on the diverse materials used in the filters, these forces can affect differently on the surface of the filtering object. These forces are one of the factors determining the performance and durability of the filter media. In this case, this material is basalt fibre [1–6].

No information was found in the technical sources about the deformed state of basalt filter material under the influence of gas or liquid flows. Because the behaviour of the filter material is one of the factors affecting the quality of filtering, we considered it necessary to study the condition of basalt filter. Therefore, well-known laws of physics and mechanics were used, as well as correction factors introduced, which have not been used previously in other sources.

It is known that the degree of influence of the forces acting in the first place will depend on the laminar or turbulent flow of gas or liquid (hereinafter, flux) passing through the filtering object. In laminar flow, interaction with the surface force occurs throughout the front surface of the filter. When the stream provides turbulent flow, the interaction of forces occurs in the middle of the filter surface. Then, the process of action force on the surface of the filter can be seen as an object, resembling a wave hit. However, there will not be a strong wave to filter from the flow as from the moment of receipt of the flow in the pipe and then to the filter, the value of the exerted pressure will gradually increase to the maximum value set by the device or user and hence will be temporary.

Basalt filter is material formed as a result of compression of multiple layers of numerous basalt fibres. The basalt filter may have different stiffness and thickness values depending on the size and press-fit condition of the preload. In this case, if the filter is under basalt flow pressure, the force of the latter will be distributed throughout the body surface. This force is assumed to be a uniformly distributed force. In this case, the influence on the flow surface of the filter can be considered bulky, because the force is not applied to a specific point [1-2].

In addition, the influence of the flow load on the filter is not instantaneous but gradually increases from zero to its set value. Because, in this case, the effect of the load remains the same, it can be thought of as static. At this time point, we can assume that the filter will finally act on the pressure of the laminar flow.

As mentioned already, the effects of the flow force on the filter are not instantaneous but increase gradually and are uniformly distributed over the entire surface. Obviously, the flow pressure can be adjusted by means of hardware. Under the influence of the stream, the filter is affected by the pressure, which is the cause of deformation of the body in general. As a result, the deformation of the body of the filter material causes internal mechanical tension, which tries to pull the filter down. In this case, the filter will experience uniaxial compression and bending, because the direction of flow occurs linearly, based on the filtering operation object.

The force due to the flow pressure is on the surface, whereas the gas or liquid contact points are located on the front side of the filter. Such distribution of flow pressure across the body surface can be found in practice, for example, the steam pressure within the cylinder of a turbine, when the gas or fluid pressure occurs on the inner surface of a pipeline, the pressure of an internal combustion engine, the pressure within non-homogeneous media during the filtration process of gold-containing pulps, etc.

Given the crystal structure of basalt fibre, it can be noted that a basaltic filter carries a small elastic deformation and plastic deformation of the total, as pressurised stream cannot stretch basalt fibre. It will have a slight deformation and a minor weakening of the form due to the flow pressure, which cannot be ignored after restoration of the filter.

One of the hypotheses on which to base this result is the " volumetric strain elasticity hypothesis" [8–10]. According to this theory, the volume of deformation is directly proportional to the average normal stress on the body as a whole. For an analysis of the mechanical state of stress, we use the proportionality factor "**K**", which links the volumetric strain "Δ" and medium voltage σ_0.

$$\Delta = \frac{\sigma_0}{K}; \; K = E \big/ [3(1-2\mu)]; \; \mu = 1 \big/ \varphi \div 1.3$$

where *E* is the elastic modulus of the filter material.

For such cases, the authors recommend to use the system of formulas that link the bending and torsional moments M_x, M_y and M_{xy}, per unit width of the filter, the effort "N_x, N_y and T" per unit width of the filter, as well as the parameters m, G and f.

Table 1 *Technical characteristics of basalt filter*

№	Name of indicators	Indicators of basalt filter samples				Volume of water passed through the filter, mL
		I	II	III	IV	
1	Dimensions of the basalt filter before and after pressing: - thickness, mm - diameter, mm - area of transverse section, mm²	10* 120 130	10 120 113	10 120 113	10 120 113	-
2	Humidity of basalt fibre material before mechanical filtration, %	13	13	13	13	-
3	Weight of samples, before soaking and after pressing and drying, g: - before - after	 9.3 12	 9.3 24	 9.3 17	 9.3 15	-
4	Liquid flow pressure on filter, kg/cm²	0.3	0.6	0.9	1.2	-
5	Value of real flexure of basalt filter, mm	1.5	3.3	5.3	5.4	-

Notes: **F:en = 1: 2.74, Class - 0.074, 90%, laboratory technology and geotechnology results of the Central Research Laboratory of the state enterprise Navoi Mining and Metallurgical Combinat. ** Chemical analysis of the filtered water was carried out, according to the "GD (guideline document) 118.3897485.6-92".*

$$\left.\begin{aligned}
&N_x = \frac{Eh}{1-\mu^2}(\varepsilon_x^0 + \mu\varepsilon_y^0) + m + \mathrm{Gf};\; N_y = \frac{Eh}{1-\mu^2}(\varepsilon_y^0 + \mu\varepsilon_x^0) + m + \mathrm{Gf}\\
&T = \frac{Eh}{1-\mu^2}\frac{1-\mu}{2}\gamma_{xyz}^0 + m + \mathrm{Gf};\; M_x = D(\eta_x + \mu\eta_y) = -D(\frac{\partial^2 w}{\partial x^2} + \mu\frac{\partial^2 w}{\partial y}),\\
&M_y = D(\eta_y + \mu\eta_x) = -D(\frac{\partial^2 w}{\partial y^2} + \mu\frac{\partial^2 w}{\partial x^2});\; M_{xy} = D(1-\mu)\chi = -D(1-\mu\frac{\partial^2 w}{\partial x \partial y}).
\end{aligned}\right\}$$

The equations are formulated as follows: *D*, the value of FS per unit length of basaltic filter; *m*, the mass of the impurities remaining on the filter; Y, a correction factor that takes into account the ratio of the width to the length of the basalt filter; G, the traction force of filter due to gravity; and f, the flow coefficient of friction on the surface of the basalt. This option is known as "flexural rigidity" and it takes into account the formation of the cylinder shape [6-7].

During the research, it has been revealed that in the process of mechanical filtering of gases and liquids, there is practically no stretching of the crystalline fibres. It is in full accordance with the characteristics indicative of basalt fibres. It is noticed that concavity of the basalt filter material occurs due to the movement of basalt fibres relative to each other. The magnitude of concavity, which could lead to rupture of the filter material, depends on the pressure exerted by the gas or liquid on the filter material and the fibre flexion.

The value of bending stiffness index varies depending on the gas pressure or fluid flow and is highly specific. This indicator allows us to calculate the value of a filter's material tension, which is a function of time, and prevents the overload of the filter and its rupture. Based on the results of the theoretical research on flexural rigidity and other force design parameters, we are representing the specifications of the basalt filter material and created databases, which are presented in Table 1.

Based on these data, we made prototypes of basalt filter for tests of their production. All geometric parameters of the filters basalt samples (in experimental studies, wastewater used) remained unchanged. The results of the exper-

Table 2 *Results of the chemical analysis of wastewater after filtration using basalt filter*

No.	Name of studied item	Weight of solid matters	General mineralisation (dry weight)
1	Wastewater before purification	16.135 g/L	2.443 g
2	Wastewater after purification	0.0275g/L	1.630 g
3	Total		0.813 g

imental studies have shown that in terms of filtering time, the second and third samples of basaltic filter have the ability for purification of wastewaters, according to the dry weight of the residue, which exceeds that from the traditional filter material, thus proving the efficiency of the basalt filter for purifying wastewater. This conclusion is enabled by the results of chemical analysis of the filtered water. The results are shown in Table 2.

The data presented in Table 1 were used for the experimental determination of the force parameters and bending stiffness. For the experiments, the authors took into account the characteristics of Uzbekistan basalts. Therefore, the actual values of the quality indicators are obtained through experiments. During the experiments, we considered the following characteristics of the fibres: the crystal structure, the virtual absence of plastic deformation, resistance to the chemical substances to be separated at the time of capture of the solution's major chemical species and easy separation from the precipitation suspension.

Observations of the basalt filters' conditions as the pulp's solid particles accumulated have shown the actual absence of fibre stretching. The appearance of filter material concavity occurred as the result of a slight mutual displacement of the basalt fibres relative to each other, while encountering the pressure of the pulp on the filter (because there is no intellectual property certificate in Uzbekistan for using this method, the main production parameters for the proposed calculation are not shown or will be presented by authors in further scientific works).

Thus, in the degeneration process of the pulp's liquid phase from the solid ones, basalt filters with predetermined force parameters and bending stiffness showed themselves as worthy of good operation, wherein the force parameters and bending stiffness were controlled, which gave control over the flow speed during the mechanical filtration process. It allowed checking of the working capacity of the basalt filter with predetermined calculations of the force parameters and bending stiffness and then matching them with the experimental ones.

The efficiency of basalt filter during the mechanical filtration of wastewater was characterised by preliminary and final chemical analyses of the wastewater. This experiment is explained with the changes in the indices of chemical composition (to obtain an answer to the question of whether the chemical composition of the liquid will change after mechanical filtration of wastewater) obtained at the end of the experiment involving mechanical filtration, which removes larger particles of impurities. The results of the experimental studies are presented in Table 2.

According to results of the chemical analysis of wastewater, conducted before and after mechanical filtration using basalt filter, a significant degeneration of wastewater from solid particles and admixtures is seen. And the chemical composition of the water remains unchanged. If before filtration, the weighed matter was 16.135 g/L, it weighed only 0.027 g/L after filtration, and the total mineralisation was 1.630 g/L. Thus, the necessity of using basalt filter material with predetermined calculation of the force parameters and bending stiffness for the mechanical filtration of wastewater under industrial conditions is proved. On the basis of the calculated and experimental data obtained, we arrived at the value for flexion of basalt filter from fluid pressure (Table 3).

The predicted and experimental values for the flexion of filter fibre (fibre bending value depends on the pressure value set by the user or

Table 3 *The calculated and experimental values of the indicators of bending for basalt filter obtained from the fluid pressure*

N	Average value of bending, mm		Indicators of fluid pressure, N/m²	
	Calculated	Experimental	Experimental	Calculated
1	0.6	0.9	16	18
2	3.6	4.0	28	28
3	5.3	6.2	87	88
4	10.0	10.8	118	120

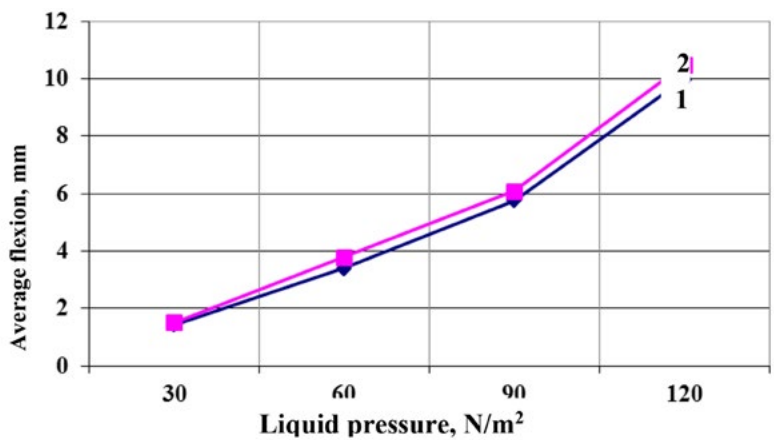

Figure 3: *Graphs of the dependence of basalt filter bending on the fluid pressure force: 1. Theoretical indicators. 2. Experimental indicators.*

the measuring instrument) are different slightly, approximately ranging from 0.5% to 1.3%, which is positive (permissible limit: 1.1%). Comparison of the theoretical and experimental data has shown that the process of mechanical filtration of wastewater in industrial conditions can be improved. This can happen if predetermined force parameters and bending stiffness that allow reduction of filter flexion value up to a minimal value and extension of its life service are considered [12].

In general, the research results proved that all types of basalt filters, in terms of time, resistance to chemicals and filtration quality, are good for filtering. The pressure and speed of wastewater flow can be regulated as required. It is established that in the process of mechanical filtration, basalt filters excel traditional filtering materials in terms of the purification of wastewater and the dry sediment obtained. This proves the necessity for consideration of a filter's predetermined force parameters and bending stiffness, thereby creating appropriate conditions for providing stable quality and ensuring long-term service life of basalt filter material for all the areas in which it is used.

Conclusion

On the basis of mathematical calculations, we created an opportunity to analyse the parameters and state of strain of the original basalt filter. To strengthen the procedure, we have developed an algorithm for calculating the parameters of the deformed state of the filter material. These findings contribute to the proper selection of the load (which determines the rate of filtration of liquids or gases), dimensions of basalt filter, service life of the filter material and the durability associated with the filter use.

Under laboratory conditions, using the existing traditional methods, we have revealed that under the pressure of a gas or liquid, any filter material undergoes FS. As with all filters, on the surface of the filter material, a cylindrical concavity is formed in the basalt (convexity in the direction of current flow). It is revealed that the quality of filtering depends on the geometry (thickness, length and width) and the physical parameters, including force parameter. Currently, among the force parameters, the characteristic features are the flexural rigidity and the mechanical stress state of filter material, which appear in the process of filtering the liquid or gas phase. The study showed a proportional increase in the flexural rigidity and the deformation of the filter material.

It is found that the relatively high bending stiffness of basalt fibres, as compared to other mineral fibres, and its crystalline structure contribute to the mechanical strength and the high coefficient of resistance. The absence of the stretching ratio is favoured by the formation of an artificial lattice-type light net, which prevents the filter's deflexion and thereby accelerating the filtration process, capturing the large particles.

Experience has shown that the production of the basalt filter material turns chaotic due to the occurrence of fibres over each other, which – between them – forma free space for the flow of liquid. The lack of both hygroscopicity and swelling, as well as maintenance of a constant porosity, of the basalt fibres counteracts the formation of precipitation in the path of flow of the liquid mass through the filter, at any mechanical filtration rate, thereby ensuring high performance. The remaining particles on the basalt filter surface – precipitated auriferous slurry – can be easily removed by washing from the filter surface, which creates the conditions for reusing the filter in subsequent mechanical filtration processes.

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