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SOFTWARE FOR PRODUCTIVITY CALCULATION OF POLYPROPYLENE FILTERING ELEMENT IN DEPENDENCE FROM ITS APPLICATION

Досліджені процеси фільтрації рідини в пористому середовищі. Встановлено, що в залежності від галузі застосування фільтруючі елементи виконують, переважно, функції дренажу або фільтрації. Запропоновано методику для організації розрахунків кількості фільтруючого матеріалу певної структури в залежності від процесу фільтрації. Розроблено прототип програмного засобу, який дозволяє проводити підбір структури та розмірів фільтруючого елементу в залежності від галузі застосування та середовища.

Ключові слова: *фільтрація рідини в пористому середовищі, підбір структури та розмірів фільтруючого елементу, автоматизація процесу.*

1. Introduction

Filtering (from the Latin word filtrum) refers to processes of separation of heterogeneous systems using porous partitions that separate only the phases. The concepts «filtration» and «filtering» are distinguished, denoting the first of them the processes of the motion of liquids and gases through porous systems under natural conditions, and the second – the processes of separation of multiphase systems in industrial and laboratory conditions [1].

To carry out the filtration process, the filter must meet the technical requirements imposed on it by the consumer. To implement these requirements, in order to select the optimal filtering device, it is necessary to have information about the mode of the filtration process. Therefore, it is important to calculate the productivity of the filter element, depending on the field of application and the filter characteristics.

2. The object of research and its technological audit

The object of research is the process of liquid filtration through a multilayer filter element.

In this paper, let's consider fibrous filtering elements (FFE) based on fiber-forming polypropylene for filters for cleaning natural gas, air, water and aqueous solutions, hydraulic and turbine oils, petroleum products and other organic liquids. The basis for the FFE production is a filtering volumetric nonwoven material (FVNM), obtained by aerodynamic spraying of the polymer melt. This polymer has a high chemical resistance, a low tendency to swell in meadows, acids and petroleum products. This property allows the use of this material for the manufacture of filter elements for a wide range of applications. In particular, in various filters and separator filters intended for purification of natural and associated gas from solid particles, drip moisture, oil aerosol and gas condensate, as well as in filters used to filter various liquids. And such feature of the FVNM structure, like autohesion of the fiber connection at the points of their intersection, makes it possible to use them effectively as coalescers [2].

Let's consider the process of manufacturing elements from porous polypropylene by pneumoextrusion. The method consists in forming molten polypropylene through spinnerets, followed by stretching the uncoiled extrudate with a stream of hot air and applying it to a rotating helical cylindrical rod. The design of the receiving device makes it possible to provide a continuous process for the formation of frameless elements.

The obtained structure of the cartridges is rigid and stable, because it is fixed by thermal cross-linking of microfibers and slightly premolded by special roller. Given the apparent simplicity of the technology, the operator must control a sufficiently large number of process parameters, given the input quality control of the feedstock. Changing the key parameters, it is possible to obtain cartridges of different micron rating from 0.3 to 100 μm, of different length and diameter.

The field of application of elements made of porous polypropylene is quite diverse (Table 1). This includes the arrangement of water wells, filtration of fuels and lubricants, use of filters in industry, filtration of gases and air, use of drainage systems in agriculture and construction, etc. (Fig. 1).

Table 1

Examples of application of filter elements in various industries

Industry	Application
Water preparation	Industrial filters. Household Filters. Industrial wastewater treatment
Food industry	Purification of drinking water. Filtration of wine, beer, juices. Cleaning of vegetable oil
Chemical industry	Purification of water and chemical solutions. Purification of galvanic solutions. Purification of varnishes, emulsions, paints
Biotechnology	Purification of culture liquids. Microfiltration. Filtration as a sterilization
Engineering industry	Purification of transformer turbine oils. Purification lubricating cooling liquids. Fuel purification
Medical industry	Purification of aqueous solutions. Purification of non-aqueous solutions

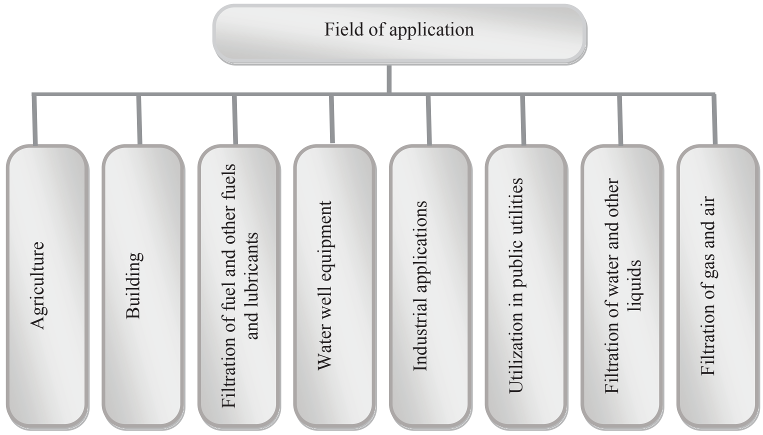

Fig. 1. Fields of application of elements made of porous polypropylene by pneumo-extrusion

The structure of the filter elements is formed on the basis of calculations made on the basis of the technical requirements for a particular filter-separator and the composition of the liquid. The task of the calculations is determination of the FVNM design parameters (the design of the filter elements and their number in a particular filter), which in turn must provide the main operational parameters: density, filtration efficiency, allowable initial pressure drop.

One of the most problematic areas is the determination of the required number of layers in the filter element, their density and the thickness of the layer, depending on the field of application. A filter with the selected parameters must satisfy the condition of maintaining the maximum performance of this element. In modern production conditions for filter elements, the selection of these parameters is carried out empirically, and the productivity is verified experimentally. This process requires additional material and time resources and does not always guarantee the receipt of a high-quality product.

3. The aim and objectives of research

The aim of research is construction of a method for calculating the productivity of a filter element, depending on the type of filter element and the field of its application, can be practically applied in production.

To achieve this aim, it is necessary to perform the following tasks:

1. To analyze the main areas of application of elements that are made of «foamed» polypropylene. To highlight the purpose, technical requirements, load modes and use of these elements.
2. To select the main filter characteristics and determine the empirical coefficients that affects the performance of the filter element.
3. To get calculations to find the amount of filtering material of a certain structure, depending on the filtration process.
4. To develop a prototype software tool that allows to select the structure and size of the filter element, depending on the application and environments.

4. Research of existing solutions of the problem

A large-scale research work on the properties of polypropylene (PP) and the use of filter materials (FM) based on them was conducted at the State University of Technology and Design, Kyiv, Ukraine [3]. In this section, let's note their most important results and conclusions on the PP application [4].

Filtering elements, differing in design features, usually contain three compulsory layers: filtering for the retention of mechanical impurities, a coalescent or coagulating layer and a drainage or water repellent layer [5, 6].

According to the technical essence, the closest filter element considered above is a multilayer fibrous filter element made of thermoplastic polymer fibers, including polypropylene, described in RU 2182509 [7].

The patent RU 2326716 proposes the creation of an inexpensive multi-layer filtration element of the filter-separator, provides a high degree of purification of gaseous and liquid media such as natural gas and liquid fuel, both from mechanical impurities and free moisture contained in the medium, is filtered in the form of aerosols [8].

The basic structural unit of the developed FM is ultrathin fibers with a unique surface structure: each micron-sized fiber is coated over the whole surface with thin microfibrils that depart from the base fiber [9]. As a result, let's obtain an extremely developed surface and high sorption properties and contaminant capacity will be ensured. There are no such fibers in nature, and they can't be obtained by traditional technologies. To date, filters have been developed and already widely used in polypropylene (PP) microfibers with a purification density of 1; 0.45; 0.3 μm. In Fig. 2, *a* FONM structure with a different pore size, recommended by placement relative to the flow of the liquid to be cleaned, is enlarged.

Given the chemical inertness and resistance to corrosive environments, as a result of toxicological tests, fine-fiber PP filters are recommended for purification of drinking water in domestic conditions, drugs that are injected into the blood. To date, filters have been already widely used in the medical-biological, food, radio-electronic industry. These are such enterprises of Ukraine as: OJSC «Dniprofarm» (Dnipro), PC «Zdorovye» (Kharkiv), PD «Darnitsa» (Kyiv), JSC «Farmak» (Kyiv) and Belarus – «Belmedpreparaty» (Minsk), as well as many other enterprises.

To date, FVNM production from foamed polypropylene has been mastered in Ukraine and is produced by the following enterprises:

– PC «Unifilter» (Brovary);
– JSC «Ukrfilter» (Chernihiv);
– LLC «TPK» (Kyiv);

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– SPA «Ecosoft» (Irpin);
– LLC «Selton» (Kyiv);
– LLC «PNEVMOTECHNIKA» (Simferopol);
– LLC «TRICORD» (Dnipro), etc.

The main advantages of polypropylene filter elements (filter elements) are:

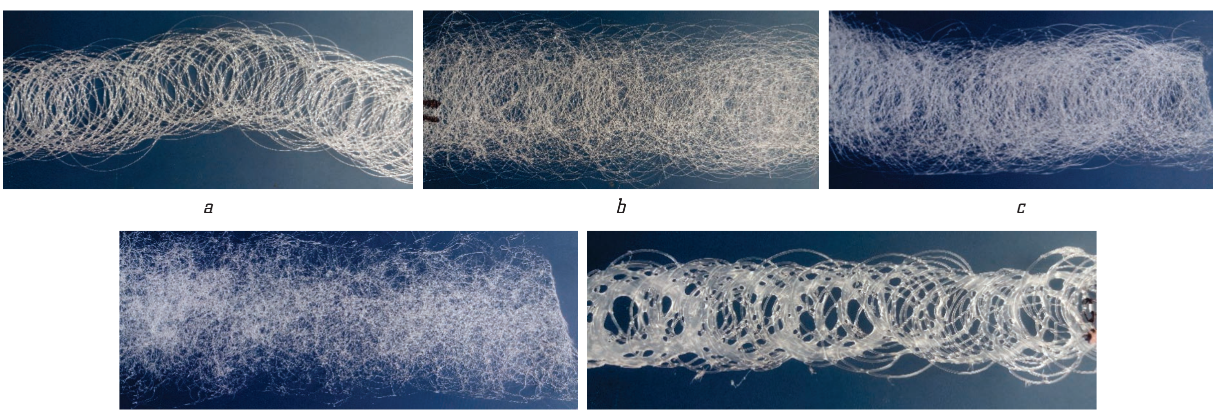
– a wide range of filter elements with a particle retention efficiency of 0.3 μm to 200 μm;
– a range of filter elements (filter cartridges) of various lengths to ensure the required performance of the filtration process;
– a multilayered porous structure provides increased contaminant capacity of the filter element in comparison with analogues;
– absence of migration of fibers from the filtering layer of the cartridge;
– high chemical resistance to a wide range of chemical reagents;
– absence of connective substances, oils and surfactants in production.

Two main classes of filter elements are manufactured with FVNM, differing in the principle of action for purification from mechanical impurities and filter elements-coalescers.

The base polymer for FFEs is polypropylene, since it has a high mechanical strength (breaking stress at a tension up to 35 MPa). This makes it possible to use it in the filter element (FE), not only as a filter material, but also as part of the frame structure of the FE. That is, in some cases, replace the internal perforated framework, for example, a metal frame, with a coarse frame of coarse polypropylene fibers thermally bonded at the points of intersection with each other.

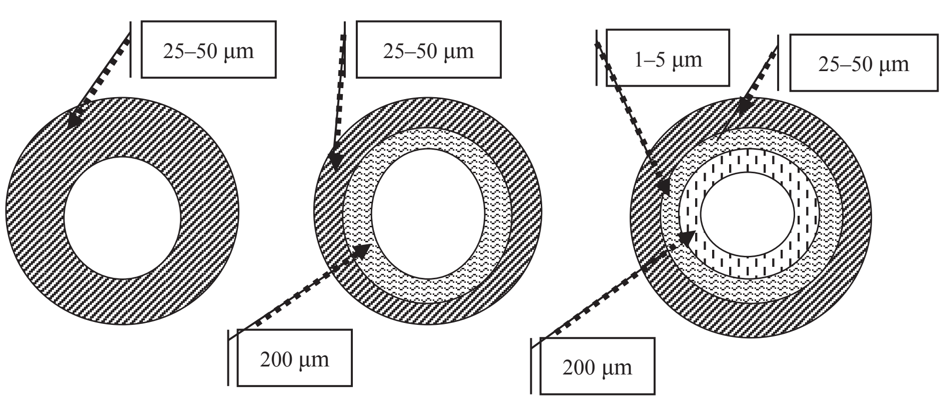
It is important to note that coalescers differs from conventional filters in that they perform both a function of filtering fine solids and coalescing (fusing small droplets) and separating liquid from the gas stream. Such filters have, as a rule, a multilayer structure (5 or more layers) with the use of the effect of changing the velocity of gases in these layers [8]. Therefore, the criteria for determining optimal sizes for coalescers are very important for ensuring high productivity and efficiency. Reduced size of coalescers will lead to a secondary fluid entrainment and will be sensitive to any changes in the process. The performance of such coalescers can rapidly decrease with a significant increase in the liquid content in the volume of the filter material [2, 4].

Filtering elements are used to clean liquids and gases that have a certain amount of mechanical impurities of different size and physical properties. They usually have three or more layers of different structures with fiber diameters and material densities. For example, a cartridge filter element that operates with a liquid supply from the outside to the inside has a strong and coarse inner carcass ply. It is superimposed with a fine-grained dense filtering layer and further, a surface layer of lower density, which functions as a contaminant accumulator [8, 10, 11] (Fig. 3).



a b c d e

Fig. 2. The structure of the filtering material with different pore size is located relative to the liquid flow:
a – a contaminant capacity layer with a pore size of 50 μm; *b* – a wavy layer with a pore size of 35 μm; *c* – a prefiltering layer with a pore size of 20 μm; *d* – a filter layer with a pore size of 1–5 μm; *e* – inner (skeleton) layer with a pore size of 200–300 μm



a b c

Fig. 3. Example of the arrangement of layers in a cartridge filter element:
a – single-layer filter element; *b* – two-layer filter element; *c* – three-layer filter element

A common opinion about the number of layers in the filter element, their percentage and density, which this particular filtration process requires, does not exist [10]. In practice, they can be obtained, for example, by varying the air pressure on the molten polypropylene. Obviously, the choice of the most acceptable technical solution should be based on data taken from a real operating complex. With experimental change in input parameters, measurements of the obtained layers and their density, the performance results of the obtained element are compared depending on the field of application. The empirical method determines the maximum throughput of the filter element, taking into account its permissible strength.

In the works of researchers, new technologies in the field of filter materials, filter structures, raw materials are considered most often [12–20]. Also, attention is paid to the very process of filtering the liquid through the filter element [10–13]. In particular, in [14], quantitative information is obtained on the effect of reinforcement of polypropylene with different proportions of nanolayers. In work [15], influence on concrete elements reinforced with polypropylene fibers is investigated.

A dispersion analysis is performed to achieve high strength of the polypropylene element, taking into account the main parameters of the manufacturing process, namely temperature, barrel temperature and screw speed in the work [16]. Attention has been paid to the structure of equipment for the manufacture of elements from polypropylene in [17]. In this work, it is stated that the screw profile of a twin-screw extruder can be designed to contain elements that cause different levels of degradation in the polymer melt. The paper [18] considers the unique properties of polypropylene and gives attention to the structure of elements from «foamed» polypropylene. It is noted that the initial modulus of composites increases with increasing fiber fraction, while the short fiber orientation distribution has little effect on composites; the stress-strain curves do not practically change. It is established in [19] that shrinkage behavior of polypropylene composites based on polypropylene thermoplastic elastomers is similar to that of conventional polypropylene.

In [20], studying the structure of elements from «foamed» polypropylene, it is found that in polypropylene mixtures either joint crystallization or phase separation can be obtained depending on the crystallization conditions.

Paying attention to the strength of the element made from the «foamed» polypropylene, a high-strength polypropylene fiber, which is made from polypropylene clay composite by the melt burning method, is investigated in [21]. The results show that the polypropylene composite has a better resolution and provided fibers with improved mechanical properties when the clay is placed at 10 %.

The photodegradation of polypropylene and polypropylene containing pyrene as an additive is considered in [22].

Thus, the results of analysis of the literature and practical experience of Ukrainian producers allow to conclude that the issue of manufacturing elements made from «foamed» polypropylene is quite promising and widespread, thanks to the unique properties of polypropylene. The production process of such elements has been introduced in many countries of the world. But as for the automation of the production of cellular polypropylene elements by the pneumoextrusion method, until today there is no similar research in this direction.

5. Methods of research

The well-known mathematical model of fluid filtration in a porous medium is based on the equation of continuity and Darcy law for a hollow porous cylinder [11, 23].

Let's note that in the general case the order of the system of equations to which the solution of the Darcy equation [23] can be reduced may amount to several millions, so this system has to be solved by iterative methods. For example, the simple iteration method is used, the Seidel method, the conjugate gradient method, the stabilized method of biadjoint gradients, and the like. To accelerate the solution of the resulting system of equations, parallel computing is used on multi-core CPUs, as well as on GPUs (in particular, CUDA technology is used).

After solving the system of equations to which the solution of the Darcy equation is reduced [23], the approximate value of the velocity vector of the filtration is found by numerical differentiation of the measured hydraulic head.

Obviously, this method is purely theoretical and, accordingly, almost impossible for its application in practice.

Let's select the main parameters that determine the selection of the appropriate filter and its performance characteristics.

1. The volume of filtered water per unit time (filter output) (l/min).
2. The amount of mechanical impurities in the filtered water (mg/l).
3. Time of continuous filter operation (hours).
4. Filter rating (μm).
5. Hydraulic resistance of the filter.
6. Viscosity and temperature of the liquid.

These are the main indicators on the basis of which it is possible to calculate the filter. Additional parameters, such as the chemical composition of the liquid and impurities, affect only the selection of the filter housing material.

The parameter, which is the main factor in calculating the geometric dimensions of the filter (which determines its size and cost), is termed contaminant capacity [24].

The filter's contaminant capacity M is the mass of pollutants that the filter can hold to a stop.

It is necessary that the contaminant capacity of the filter is determined by the amount of liquid flowing W (l/h), the time of continuous operation of the filter t_0 (h) and the concentration of impurities in the initial liquid (kg/l):

$$M = W \cdot C \cdot t_0.$$

The sediment volume (in m^3) formed is:

$$V_S = \frac{M}{\rho T / (1-\delta)},$$

where ρT – the density of the dewatered sediment (kg/m^3); δ – sediment humidity (the volume of liquid in the sediment, referred to the volume of the sediment).

6. Research results

6.1. Calculation technique. The calculation technique consists of the following steps:

1. To determine the initial data, such as: the type of filtered substance, the amount of impurities in the substance, the performance of the filter, the time it works.

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2. To calculate the contaminant capacity of the filter element and the total volume of the sediment.

3. To calculate the amount of filter material of a specific structure, depending on the filtration process.

6.2. Calculation examples.

6.2.1. Technical specifications. *6.2.1.1. FFE productivity.* There are several performance definitions. The minimum, nominal, maximum capacity is determined by calculation, for example, for the calculation of surface wastewater, or the technological process of an industrial enterprise. The calculation is usually carried out at nominal and average capacity [25]. This is due to the fact that the filter, ideally, should have a stable characteristic. Then the operator is easier to conduct the technological process, no need to make changes in the technological scheme. Nominal capacity determines the stability in the efficiency of water treatment, as it makes it more predictable, with stable characteristics of the quality of the purified water. The transition from nominal to minimum performance does not cause significant changes in the filtration process associated with efficiency and hydraulic resistance. The reverse process of changing the performance from the minimum – nominal – to maximum – can cause a sharp increase in FFE hydraulic resistance and a change in efficiency. Therefore, these changes must be carried out stepwise, discretely, and as smoothly as possible, evenly and under the supervision of the operator. The operator must pay attention to:

– the mirror surface of the filter, so as not to be observed a «wall effect»;
– the filtration pressure on each FFE layer;
– water quality at the inlet and outlet of the plant [2, 4].

Force majeure situations can cause FFE emergency performance. These situations are real in the production process and it is necessary to be ready for them. An example of such situations may be operator errors in regulating the performance of fluids that are cleaned at the FFE, as a rule, this happens on pumping equipment or valves – rupture of filtering material and the like. Such situations can be seen by the operator, but it will be better if they appear with a pressure sensor or a water level sensor. The alarm signal from these sensors must have an output to the light or sound signaling, with the possibility of creating an automatic circuit for disabling the necessary equipment.

FFE productivity Q is calculated by the formula:

$$Q = S \cdot U,$$

where S – filter area; U – filtration rate.

According to the experience of the filter module, let's take a maximum filtration rate of 100 m/h, a nominal filtration rate of 50 m/h and a minimum filtration rate of 25 m/h

6.2.1.2. The qualitative composition of wastewater. For effective FFE operation, it is necessary to know the granulometric composition of liquids, for example, to purify, for example, wastewater. This is one of the main conditions for FFE effective operation.

Under the FFE effective operation, its economic component is also implied: operational costs associated with electricity consumption, labor costs, filter material consumption, and the like. Therefore, in the granulometric composition of purified wastewater, let's only have in mind wastewater that has undergone sedimentation treatment for 15, 20, 25, 30 min. This is ideally for a complete granulometric analysis. In a shortened analysis, it is possible to manage the 15-minute sedimentation of treated wastewater. The practical essence of this characteristic is that the filter can be fed with effluent without pretreatment. By such purification is meant only sedimentation in a dynamic settler.

Granulometric analysis should be carried out at different capacities: minimum, nominal and maximum, which indirectly characterize the different composition of wastewater, are cleaned. The granulometric composition of wastewater can be determined by the conductometric method of dispersion analysis or by the method of small angles in photometric measurements, allowing one to find the distribution of particles by mass or size [4].

Through layers of filter material with pore sizes of 60, 25, 10, 5, 1 μm, the contaminant-contained water was filtered by drainage water in an amount of 20 m^3. After this filtration, the filter material was dried and a sample of 8 mm in diameter was made with samples of filter cloth.

Samples once again dried, solved, after which they are processed with pure hexane to remove the products. Then the samples are finally dried and solved.

The distribution of the filtrate according to the particle size is as follows:

– 1–5 m μm – 28.84 %;
– 5–10 μm – 25 %;
– 10–25 μm – 17.25 %;
– 25–60 μm – 11.2 %;
– More than 60 μm – 17.71 %.

The essence of the granulometric analysis is determination and distribution of the FVNM technological load. For example, if in the filtering process there is a layer with only a pore size of 1 μm, then all parts larger than 1 μm will be retained on it. With successive use of two layers with pores of 20 and 1 μm, the technological load is distributed differently. At first, parts of 20 μm or larger are retained, and further fractions with a particle size of 20 to 1 μm will be delayed. Thus, the task is evenly distribution of the technological load between FVNM layers with different pore sizes, that is:

$$N = \int_{0.3}^{80} f(\delta),$$

where δ – size of the FVNM pores.

The components of the integral must be equal. It should be borne in mind that this load during FVNM operation will change in the direction of increasing filter layers with a large pore size. This is due to the so-called «wash-up effect», when the FVNM pores will partially overlap with the delayed impurities and thereby reduce their size. As a result, smaller particles will be retained.

Externally, this will manifest itself in a change in pressure during filtration. If at the initial moment the pressure drop before each layer is the same, then in the future on the lower layers this difference will be greater. This should be taken into account when determining the filter cycle, subject to pressure limitations on the FVNM.

6.2.2. Calculation and selection of FFE structural elements. *6.2.2.1. Determination of the number of FVNM layers.* From a technological point of view, the more FVNM layers with different pore sizes, the more efficiently the filter unit should work, where each layer, on average, has a relative efficiency in the range of 30 to 50 %. This relative efficiency does not vary with respect to the filtration rate, but from the granulometric composition of the liquid, it is purified at the time of sampling. By the condition of the FVNM manufacturer, the rating of pores can be from 60 to 0.3 μm. It is assumed that the pore size from layer to layer should differ 4–8 times (coefficient *N*δ). This is due to the conditions for effective FVNM regeneration and maximum filter cycle time. If break the FM pore rating in the range 60–0.3 μm with *N*δ=5, the following series will be obtained: 60; 12; 2; 0.3 μm. This series should be checked for load by the granulometric composition of purified liquids. If the load is significantly different, it is necessary to make correction for the coefficient *N*δ. Let's believe that the maximum number of FM layers can be, for constructive reasons, no more than 5, the minimum is 2. The densest layer, with pores 0.3 μm, can be unstable due to its texture. Therefore, let's propose to strengthen it with a mechanically strong top layer of FVNM with a maximum pore size of 60 μm and a thickness of 5 mm. Between each layer it is necessary to install intermediate frames with a minimum thickness of 10 mm for hydraulic unloading of the layers along the sediment layer and strengthening the mechanical strength of the lower filtering layer.

6.2.2.2. Calculation of the parameters of filter design elements – FFE system. Based on the minimum filter limit conditions – the FFE system, it can consist of two filter modules located one above the other. This is due to the conditions of reliability, interchangeability, redundancy for maximum performance. One horizontal level of the FFE forms a filter section (FS). Since the FFE horizontal levels can be from two or more, accordingly the same number may be of the filter sections. The filter section can consist of one, two, three or more filtering unified modules (FUM), depending on the maximum dimensions of the filter insert. In the investigated case, filter cartridges with maximum dimensions of 650×550 mm were used, which is «clean» to the size of the filtering area of the unified module of about 0.25 m^2.

From the conditions of serviceability, if the production area allows, filters from two filter sections are offered. The number of PCBs in a section can be 1, 2, 3, 4, 6, 8, 10 and the like.

Nominal FUM capacity is calculated for a filtration rate of 50 m/h:

$$Q_{mn} = 0.25 \cdot 50 = 12.5 \text{ m}^3/\text{h}.$$

Let's determine the FUM amount in the FFE filter system using the formula:

$$N_m = \frac{Q}{Q_{mn}}.$$

The result is rounded to the nearest maximum number from the next number series: 2, 4, 6, 8, and so on. For example, if the result is 3.4, then let's choose a number N_m equal to 4, if 4.2 then $N_m = 6$ m.

For the selected value, specify the nominal (as well as the maximum, minimum) FFE productivity.

6.2.2.3. Recommendations for the determination of the FFE filter cycle. The filter cycle is determined by the time from washing to washing of FVNM. The main condition of the filter cycle will be the maximum pressure drop (from 0.1 to 0.4 MPa), for which we recommend calculating the FFE.

The following parameters influence the filter cycle:

1. FUM filtration loading.
2. Quality of purified water.
3. Filtration speed.
4. Quality of FVNM regenerations.

Theoretically, it is very difficult to calculate the filter cycle, therefore, it is recommended to study this problem with the help of an experimental FFE.

Example. Let's consider an example of a cylindrical filter element with a filtration method from the outside:

I. Initial data:

1. Liquids – water.
2. Filter performance: $W = 10000$ l/h.
3. The amount of mechanical impurities in the filtered liquid: $C = 100$ mg/l.
4. Time of continuous filter operation: 1 working day, $t_0 = 22$ hours.
5. Additional data: the density of the material of the dry sediment is 1.5 kg/l, the precipitate humidity is 75 %.

II. Calculation of the contaminant capacity of the filter and the total volume of the sediment (Table 2).

Table 2

Calculation of the contaminant capacity of the filter and the total volume of the sediment

No.	Physical quantity	Calculation	Value
1	Necessary contaminant capacity of the filter	$0.1(\text{g/l}) \cdot 10000(\text{l/h}) \cdot 22(\text{h})$	22 kg
2	The total volume of the sediment (let's consider the humidity of the sediment to be equal to 75 % and the density of solid particles is 1.5 kg/l, the safety factor is 1.2)	$\frac{22(\text{kg}) \cdot 1.2}{1.5(\text{kg/l})/(1-0.75)}$	71 l

III. Calculation of parameters of filters for mechanical purification.

The total area of the filtering surface is equal to the ratio of the total volume of the sediment to the thickness of the sediment layer, which is chosen equal to 5 mm. This thickness of the sediment layer is traditionally chosen for low-pressure filters (up to 12 atm.) (Table 3), based on the condition of acceptable pressure drop on the filter element – no more than 2–3 atm.:

$$S = \frac{0.071\ (\text{m}^3)}{0.005\ (\text{m})} = 14.2\,\text{m}^2.$$

The internal diameter of the filter element is chosen equal to the diameter of the inlet and outlet nozzles of the filter. For a flow rate of 10000 l/h, the optimum diameter of the filter nipples is 60 mm.

The outer diameter of the filter element is chosen equal to 120 mm.

Accordingly, the inner diameter of the filter box is chosen equal to 150 mm.

Based on the calculated area of the filter surface, let's determine the total height of the filter elements:

$$\frac{14.2(\text{m}^2)}{\pi \cdot 0.12(\text{m})} = 38 \text{ m}.$$

Let's take the height of one filter element 0.9 m.

So, for the water purification, according to the given specifications, it is necessary 42 filter elements.

Table 3

Determination of hydraulic characteristics

No.	Productivity W_t, l/min	The pressure at the inlet of the filter P_{in}, kgf/cm^2	The pressure at the outlet of the filter P_{out}, kgf/cm^2	Differential pressure on filter P, kgf/cm^2
1	500	0.35	0.2	0.15
2	670	0.45	0.25	0.2
3	900	0.7	0.4	0.3
4	1000	0.8	0.45	0.35
5	1100	0.95	0.55	0.4
6	1000	0.8	0.45	0.35
7	900	0.7	0.4	0.3

6.2.2.4. Means for designing a filter element. To calculate the necessary parameters (filter size, diameter, number of layers, layer density), a software prototype was developed, the appearance of the prototype development environment is shown in Fig. 4.

To implement the application, the MVC design pattern (Model-View-Controller) was used. The main idea of the pattern is the distribution of responsibilities, where each part of the MVC architecture is clearly defined and autonomous. This template divides the system into three parts: the data model, the data view, and the controller that manages the data exchange. Each part performs only its specific functions.

Applying this template to the design of this application, the following main components can be distinguished:

– Controller.
– Service.
– Repository.
– Configuration.
– Data model.
– User interface.

Using an object-oriented approach to programming the components of this software will increase the reuse, testing and flexibility of the developed tool.

In this work, the software development is built on the basis of three-level architecture, shown in Fig. 5.

To develop this software, an object-oriented approach to programming has been chosen. This choice is justified by the following factors:

– possibility of code reuse;
– no need to develop classes from scratch, due to inheritance;
– increase the security of the code due to encapsulation;
– flexibility in the modification and expansion of the system;
– general orientation of object-oriented technology for development of information systems, as a class of software, etc.

The design of the physical representation of the system is shown in Fig. 6.

In addition to the selection and distribution of levels and their components, it is important to design an architecture that provides a weak link between layers. That is, the layer should not disclose internal details, on which the other can depend. To implement it, the chosen approach was based on interacting with components of other layers directly through calling their methods or accessing their properties. At the same time, a common class is used for interaction between layers, encapsulates all details of interaction and provides a general model for handling exceptions and errors in the layer of business logic.

On the basis of the conducted analysis of the subject area, a conceptual model was constructed using the language of ER-modeling.

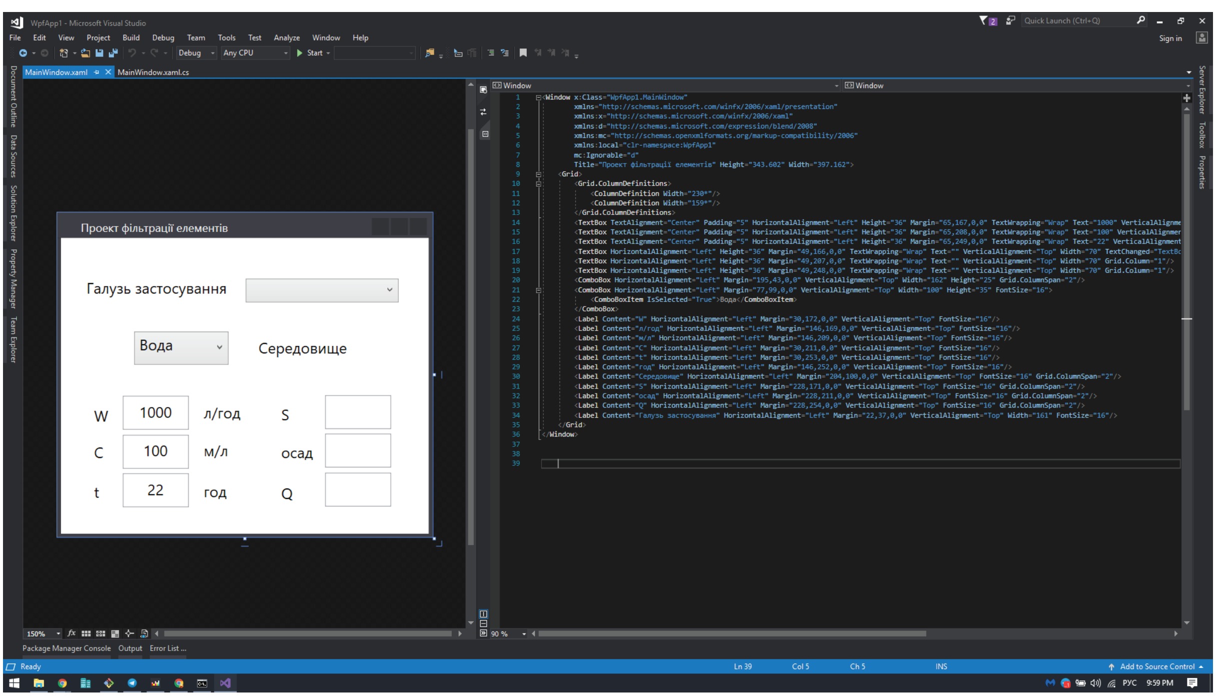

Fig. 4. Appearance of the prototype development environment

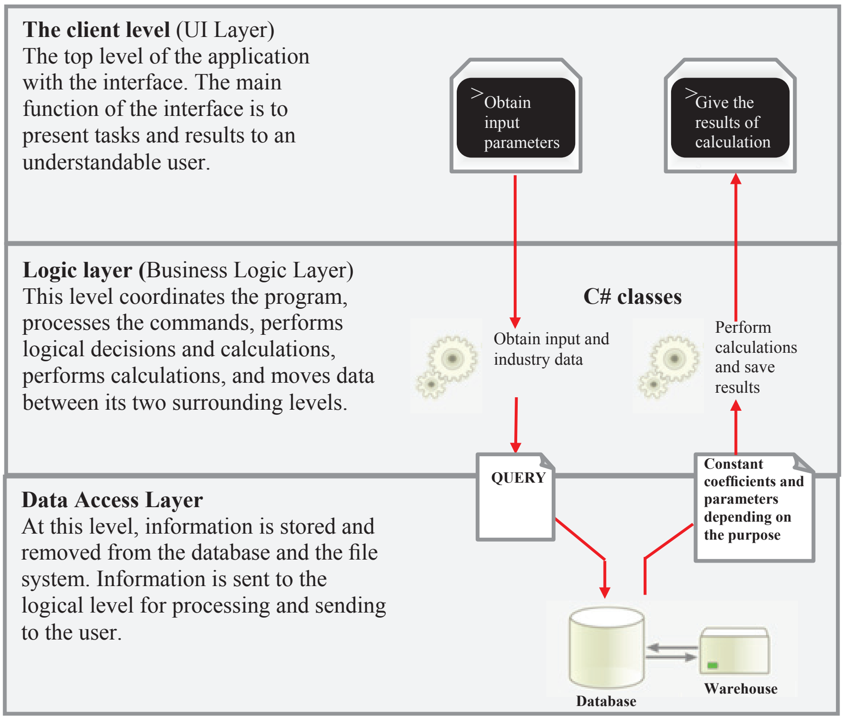

Fig. 5. Three-level architecture of the created software

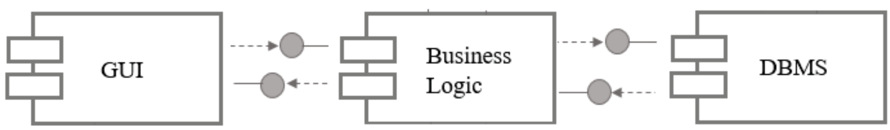

Fig. 6. Three-level groupings of components of the created software

Database design includes logical design, which is the development of the logical structure of a database system without binding to a particular database, storage structures, access methods, etc.

Demonstration of work can begin with the main function – the calculation of key parameters, depending on the field of application and the environment in which the filtration passes.

This prototype makes it possible to carry out a model calculation of the filter element (Fig. 7), namely, to select the structure and dimensions of the filter element, depending on the application and media.

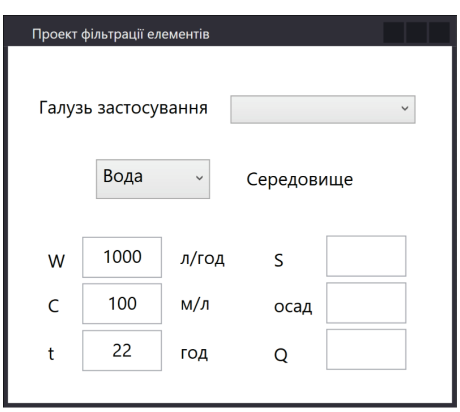

Fig. 7. The prototype interface for a model calculation of the filter element

The results of the calculation are compared with the results of full-scale tests of filter elements under real conditions. The comparison shows a sufficiently high agreement of the results, which makes it possible to use the prototype as a basis for development of software for the design of a filter element, which will later be implemented in the production of filter elements.

7. SWOT analysis of research results

Strengths. Among the strengths of this research is the possibility of practical use of its results in the design of filter elements in the production process with reference to specific application conditions. Linking the research results to the design of the filter elements will make it easier to select and sequence the operating modes of the equipment that produces filter materials during their manufacture, and also to shorten the time for the filter design process itself.

Weaknesses. The deterrent side of research is the need to attract additional funds for the services of highly qualified specialists, computer equipment for solving the tasks set, as well as obtaining a quick and guaranteed result.

Opportunities. The proposed technique will allow to automate the production of filter elements in order to optimize the number of layers with their structure and volume to achieve certain properties of the filter. The main aspects of the filter elements are contaminant capacity, pressure drops, filtration characteristics, performance and the characteristics of the filtered suspension.

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Threats. The need for this technique and software is due to the fact that the production process traditionally uses methods and programs based on the practically developed approach, which, as a rule, contain seven filter layers with averaged value of the filter thickness [8]. At present, Ukrainian enterprises do not use automatic production of multilayer filter elements. The introduction of this technique at enterprises requires additional costs. This is a re-equipment and expansion of the material base of production, laboratory studies of experimental samples of filter elements with a given density and layer thickness, and the like. But the introduction of this technique as a whole will positively affect the work of the enterprise.

8. Conclusions

1. The main areas of application of the elements, which are made of «foamed» polypropylene, are analyzed. As a result of the analysis it is revealed that the main functions that these elements perform are mainly drainage or filtering. A one-component model of suspension flow through a porous medium is considered and granulometric analysis of the purified liquid is carried out. Thus, the percentage state of the filtrate is obtained depending on the particle size.

2. The main filter characteristics are identified and the main parameters influencing the performance of the filter element are determined. It is found that, depending on the field of application and the purpose of the filter element, it can have a different number of layers and a different structure of these layers. For example, for drainage systems, this is usually a single layer with a density of 100–200 μm, and for filter elements it is at least three layers: skeleton, filtering and contaminant capacity. Moreover, the number of layers can be either discrete or continuously changing in the direction of passage of the liquid with a change in the pore sizes in the structure of the filter element.

3. Calculations of the main parameters influencing the size and structure of the filtering element are obtained: this is the occupancy rate and the volume of the sediment. The condition for maintaining the maximum capacity of the filter element, which depends on the area and the rate of filtration, is taken into account. It is experimentally justified to construct a multilayer filter element by changing the air pressure on the equipment to form a FVNM. The technique for organization of calculations of the amount of filtering material of a certain structure is obtained depending on:

– filtration process that involves determining the input data of a liquid or gas that will be filtered;

– formulas for calculating the luminous efficiency of the filter and the filtration performance. This technique is practical in nature and can be applied in production.

4. A prototype of a software tool designed to select the structure and dimensions of the filter element depending on the field of application and media is developed. Currently, this prototype is at the testing stage at the enterprise engaged in the production of filter elements for a wide range of applications. After the testing phase, this software will be used as one of the modules of the process automation system for the production of polypropylene mechanical cartridges with subsequent introduction at the enterprises that manufacture filter elements.

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ПРОГРАММНОЕ СРЕДСТВО РАСЧЕТА ПРОИЗВОДИТЕЛЬНОСТИ ФИЛЬТРУЮЩЕГО ЭЛЕМЕНТА ИЗ ПОЛИПРОПИЛЕНА В ЗАВИСИМОСТИ ОТ ОБЛАСТИ ЕГО ПРИМЕНЕНИЯ

Изучены процессы фильтрации жидкости в пористой среде. Установлено, что в зависимости от области применения фильтрующие элементы выполняют преимущественно функции дренажа или фильтрации. Предложена методика для организации расчетов количества фильтрующего материала определенной структуры в зависимости от процесса фильтрации. Разработан прототип программного средства, позволяющего проводить подбор структуры и размеров фильтрующего элемента в зависимости от области применения и среды.

Ключевые слова: фильтрация жидкости в пористой среде, подбор структуры и размеров фильтрующего элемента, автоматизация процесса.

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