ENERGY SAVING THROUGH QUALITY OF TECHNICAL WATER: NEW TYPES OF MECHANICAL SCREEN FILTERS FOR VARIOUS LINKS OF WATER TREATMENT

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Abstract

Energy saving in the industry is directly connected to the quality of water that is used in technical installations. One of the ways of technical water treatment of mechanical impurities is a screen filter. However, despite a diversity of existing automated filters, an analysis shows that not all links in a water treatment chain are equipped with automatic filters that meet corresponding requirements.

The object of research is constructive parameters of screen industrial mechanical filters, including special conditions of their operation.

The goal of the paper is to develop brand-new technical solutions on screen industrial mechanical filters, including special conditions of their operation.

Research methodology: detection of weak spots in characteristics of water treatment devices through an analysis of its separate links, development of main technical requirements to improvement or creation of new filters for these links, development of brand-new technical solutions that meet the developed requirements, development of methods of calculation of main elements of new filters.

Main paper conclusions: specific links of water treatment systems of industrial facilities are established, for which optimal technical solutions on screen filters are absent; technical solutions to new constructions of such filters are developed; theoretical justifications are performed and methods of calculation of constructive parameters of main elements of new filters are developed.

1. Introduction

Energy saving in the industry is directly connected to the quality of water that is used in technical installations. It is known from [1] that clogging of pipes and condenser plates leads to a reduction of coefficient of efficiency by 2-5% and more, which, in turn, leads to increased consumption of electric energy or to reduction of energy generation in power units.

One of the widely used modern ways of technical water treatment of mechanical impurities is automated filters.

Filtration is well-developed and is widely used in the industry as an element of technical water treatment. A multitude of automated filters is developed, which covers all ranges of flow rates, pressures, nominal filtration degrees, and conditions of filter usage.

However, an analysis of literary sources and real water treatment systems of Ukrainian and foreign manufacturers indicates that not all links of water treatment are equally equipped with automatic filters that meet the corresponding requirements.

Thus, creation of a new construction of industrial filters and a theoretical justification of their main constructive parameters is an actual scientific and technical problem.

The goal of the paper is a scientifically justified development of brand-new technical solutions on screen industrial mechanical filters, including their special operation conditions.

Solution methods of the formulated problem:

- detection of weak spots in characteristics of water treatment devices through analysis of their separate links;
- development of main technical requirements to improvement or creation of new filters for these links;
- development of brand-new technical solutions that meet the developed requirements;
- development of methods of calculation of elements of new filters.

2. Selection of filters, which require attention of specialists, analysis and development of technical requirements to filters

Consider some filters of the main links of water treatment, which require further improvement based on our analysis:

- water intake filters, through which the water is taken from reservoirs of different types;

- downstream pipeline filters, which are installed before the water consumers. These filters must provide coarse and fine filtration under given flow rates. They require large screen surface areas and large contaminant capacity, must be insensitive to large debris, so that there is no need for a cascade of filters in front of them;

- brush filters with a hydraulic drive based of filtrated water.

These filter types require further improvement based on our analysis.

2.1. Water intake filters. Water intake from rivers and reservoirs is the most crucial stage of water treatment for industrial installations. It should be noted, that water intake for the largest facilities is usually performed at a very high level of quality from a technical standpoint considering substantial financial investment. And it's hard to ignore the fact that large volumes of water from natural sources are consumed by smaller and medium facilities or separate pumping installations. Multiple water intake installations are put into operation in order to increase water intake for technical needs when the facility already runs.

Water intake automatic filters are the least developed and aren't generally shipped to facilities.

A screen stretched on a carcass and submerged in water is most often used as a water intake filter. Maintenance of such filters is complicated or almost non-existent.

Requirements to water intake filters:

- possibility to be installed directly into a reservoir and a discharge of filtering byproducts directly back to the reservoir;

- maintenance simplicity: filtering-purifying block must be in one piece and easily removable through an open top lid for maintenance at the surface;

- the drive must be a jet without a rotating shaft that reaches the surface and without electric power supply;

- one of the main requirements is that the filter must operate at low temperatures, at freezing reservoirs and have an easily removable filtering-purifying block.

New technical solutions on intake filters and a construction of a water intake filter are considered further (application number a 2020 01035 for an invention patent of Ukraine).

2.2. Multi-chamber automated filters with zig-zag-shaped screen.

A wide application of highly efficient, modern, and costly equipment in technological cycles requires ever-larger amounts of water finely treated of mechanical impurities.

Screen filters with a flat or cylindrical shape of the filtering element are simple and relatively inexpensive but in most cases cannot handle the increased requirements by the factor of contaminant capacity (amount of debris caught by the filtering element during the period between back-flushes).

It is well known that the smaller the nominal filtration degree, the larger the filtering element surface area must be in order to provide a required contaminant capacity and intervals of filter back-flushes [2].

The filtering block screen has a cylindrical shape in the known constructions of screen filters with a back-flush of the filtering element. The filter size increases proportionally to the size and surface area of the screen. However, the screen surface area, filter size, and its cost grow drastically when a fine filtration of large amounts of water is required. In order to provide the required flow rate, an array of filters is installed in one pipeline. Some manufacturers install a few filters in one filter body [3, 4].

The cost, general dimensions of such arrays of filtering installations, the cost of separate filtering installations and their maintenance are very high.

A trend to refusal of screen filter usage is outlined to solve the described problems with further transition to filters with a disc [5], a slotted spiral cone [6] and other filtering elements. Such filters are smaller, but require special complex technologies and equipment to produce these filtering elements. This conditions the high cost of technology development and the filters in general. In addition, the cost is much higher than the cost of screen filters, despite equal filtration quality.

The works on improvement of screen filters are systematic at Oceanmasenergo Ltd. (Dnipro, Ukraine) with participation of staff of the department of engineering and design in machinery industry of Dnipro University of Technology (Dnipro, Ukraine). The works indicate that the screen filters are still viable, and that the technical qualities of filters can be as high as of new filter types through developing new technical solutions while retaining relative simplicity and low cost, which are characteristic of screen filters.

Considering the indicated, it should be noted that the research of screen filters on substantial increase of screen surface area and contaminant capacity remains actual.

The authors together with other Oceanmasenergo Ltd. specialists have found new technical solutions on screen filters with a zig-zag-shaped screen, which allow significantly increasing screen surface area and contaminant capacity while the filter dimensions remain the same.

Technical requirements to new automated filters with a zig-zag-shaped screen and increased contaminant capacity can be formulated as follows:

- the filter must have a screen, a relatively simple construction and be easy to maintain;
- the screen surface area must be several times larger than the screen surface areas of similar filters with a cylindrical screen while the filter dimensions remain the same;
- the screen back-flush must be performed consecutively through different screen sections;
- large debris must be collected in special chambers and removed by a dirt collector, the filter must be insensitive to relatively large debris;
- filter body dimensions must be constant for filters of fine and coarse filtration of equal flow rate with a possibility of compact placement of screens of required surface areas.

New filters require new theoretical studies for their design, which are performed by authors and are presented further.

New automated filters with a zig-zag-shaped screen that correspond to all formulated requirements are developed by Oceanmasenergo Ltd. (FK filter series) and are shipped to industrial facilities (Patent of Ukraine number 109211 “Vitaliy Kuzminskiy Filter”).

It should be noted that filters with manual screen cleaning are used for cases of relatively clean water. The manual cleaning is performed through creating a reverse flow of water by switching the water flows manually.

Thus, the principle of zig-zag-shaped screen placement is also used during development of simple manual filters with a zig-zag-shaped screen (FZO filter series).

It is the most expedient to produce simple zig-zag-shaped filters with two chambers. The consecutive back-flush of each chamber with isolation of the currently back-flushed chamber from water intake makes screen cleaning exceptionally efficient compared to regular cleaning of the entire filter with a back-flush of water from filter inlet.

These filters can also be automated. To achieve this, the valves of filter must have drives and be controlled by a control box.

Two chamber filters with a zig-zag-shaped screen have substantial pros compared to other filters with a simple design. They provide large contaminant capacity and quality screen cleaning by consecutive cleaning of each chamber (application number a 2020 01034 for an invention patent of Ukraine).

2.3. New brush filters with hydraulic drive on filtered water. Brush filters are quite widely used just as filters with screen back-flush and filters with dirt collectors. Brush filter usage is conditioned by some specific features of solid debris in water, algae presence in water, water organics, and a relatively smaller price of these filters and other factors.

Brush filters are well-developed and showed good results in practice. Despite all this, there are things that require improvements. These are simplification of construction of the filtering block, change of arrangement of units in the filter aimed at simplification of its maintenance.

Despite this, it is expedient in many cases to have a brush filter with a hydraulic drive on water without electric power supply.

Thus, the main requirements to a brush filter are:

- the filtering block must be light, consisting of a screen stretched on a carcass of rings without transverse connections inside the screen so that they don’t interfere with brushes. This filtering block is easy to manufacture, maintain and repair;

- filtering and brush blocks must be united in a single filtration-cleaning block, which can be removed from the filter body for maintenance;

- the filter drive must exceed a force of total resistance of brushes moving along the screen, a resistance in rod guides of brushes considering water counter pressure, and a resistance that occur from the action of contaminants on the filtering element screen.

The first two requirements are realized and tested in real constructions of filter series FRU and in a representative of the second generation of brush filters – the filter of FB (Patent of Ukraine number 113232 Brush filter).

The brush is made in a shape of a disc; a hydraulic drive is installed inside the filter body in a form of a hydraulic cylinder, which operates on filtered water, in a new FBC series filter (application number a 2017 10068 for an invention patent of Ukraine). There are no issues with a required force value with this type of a hydraulic drive. A new method of filter calculation and hydraulic cylinder is developed. A series of hydraulic cylinders, which operate on water, is developed for brush filters.

3. New technical solutions on filters and new filter types

3.1. Water intake filters FZM

Water intake filters FZM of upstream pipelines are created considering all technical requirements to modern filters of pump upstream pipelines. FZM filters perform water intake from open reservoirs, including the ones that freeze in the cold season.

FZM filters (fig. 1) consist of a tubular body 1 with a watertight lid 2, an inlet nozzle 3, a removable filtering block 4, which is outside the body 1, and installed fixedly by the upper flange 5.

The upper flange 5 and the lower flange 7 are connected with each other through a cylindrical carcass 8. The screen 9 is stretched on the carcass 8; the ends of the screen are constricted by the metal plate 10 and screws.

The lower hub 11 with spokes is welded to the lower flange 7. The removable upper hub 12 with spokes is installed on the upper flange 5. Blind openings are made in the lower and upper hubs 11 and 12. The central pipe 13 of the jet dirt collector 14 with injectors 15 is put in the blind openings with a possibility of rotation. Injector axes are placed at a certain angle in order to be able to rotate the jet dirt collector by using the reactive force of water streams. Flushing water inflows through the opening 16.

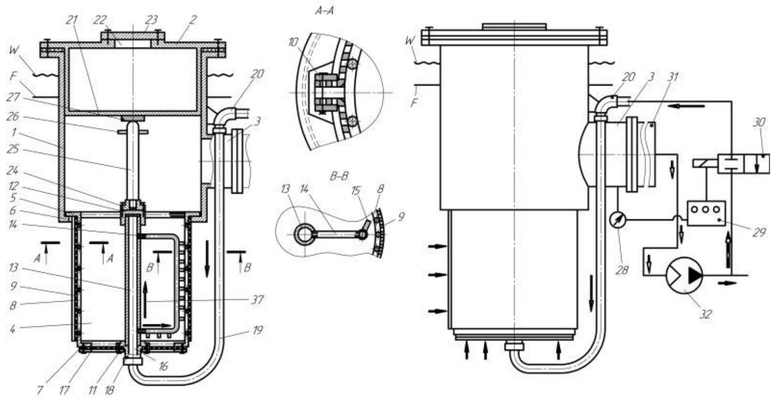


Fig. 1. Water intake filters FZM of upstream pipelines

The lower screen 17 and the fitting 18 are installed on the lower hub 11. The flexible flush pipe 19 is connected with the fitting 18 by one end and with the flush nozzle 20 by the other.

Water level W and the lower level of water freezing L in the reservoir in the filter installation zone are shown in fig. 1.

The cavity extruder 21 is at the bottom of the lid 2. The extruder enters the filter body 1 in such a way that when the lid is closed, the air and the water is pushed down from the filter cavity lower than the level of possible freezing F.

The opening 22 is made at the top of the lid 2 and is closed by the lid 23.

The shoe 24 is fixed on the upper hub 12. The shoe 24 has a threaded opening, in which the bar 25 is screwed, while resting on the buffer 27 with the upper end. The bar 25 pushes the filtering block 4 by the upper flange 5 to the inner flange 6 of the filter body when the lid 2 is shut.

The vacuum gauge 28 is installed on the inlet nozzle 3 of the filter. The gauge 28 sends the signal about the water vacuum value in the inlet nozzle 3 to the control box 29, which is electrically connected with a normally closed electromagnetic valve 30.

The filter is installed stationary at the reservoir, and the lid is located over the upper level of water surface W. Inlet nozzle 3 is located underwater, lower than the level of possible freezing F and is connected with the inlet pipeline 31 of the pump 32, with which it is used. A pipeline is laid from the pump downstream pipeline through a normally closed electromagnetic valve 30 into the flush nozzle 20.

The cavity extruder 21 pushes the air and water from the filter cavity 1 down lower than the level of possible freezing F when the filter is installed and the lid 2 is closed. Because of this, there is no air in the filter body and the water doesn't freeze. The rotation of the jet dirt collector is performed by a reactive force of water streams of injectors 15.

The filter has two operating modes - **filtration mode** or **flushing mode**.

In the filtration mode the electromagnetic valve 30 is closed, pressurized water doesn't flow through injectors 15, the jet dirt collector 14 doesn't rotate. Vacuum is created in the filter body cavity 1 and in the filtering block cavity 4 from a suction pipe of the pump 32. Because of this, water from the reservoir is sucked through the screen 9 of the filtering block 4 and, already filtered, through the filter body cavity 1 and the inlet nozzle 3 enters the pump 32.

When operating in the filtration mode the screen 9 clogs, and because of this, the vacuum increases over time and the water pressure in the inlet nozzle 3 and in the inlet pipeline 31 decreases. Vacuum gauge 28 transmits a signal about pressure decrease to the control box 29, and when the vacuum reaches the pre-defined value, the control box switches the filter into the flushing mode. For this, the control box opens the normally closed electromagnetic valve 30.

In the flushing mode, pressurized water from the pressure pipeline of the pump 32 through the open electromagnetic valve 30, the flush nozzle 20, the flexible flush pipe 19, the opening 16 and the central pipe 13 enters the injectors 15 and flows out of them under pressure in a form of streams. At the same time, the jet dirt collector rotates under the action of reactive forces of jets. The streams from injectors 15 during the dirt collector rotation hit the screen 9 and the lower screen 17 with high velocity streams cleaning them. Due to the screen cleaning, the vacuum in the inlet nozzle is reduced, and when it reaches a pre-defined initial value, the control unit, having received a signal from the vacuum gauge 28, closes the electromagnetic valve 30. The filter switches back to the filtering mode. **The filtration does not stop during the flushing mode**.

Industrial implementation of FZM water intake filters of upstream pipelines. Sets of working design documentation for a series of FZM filters are developed (fig. 2). FZM filters cover flow rates through filters from 226 to 2700 m^3/hr and diameters of the inlet nozzles from 200 to 800 mm.

Thus, a scientific and technical problem of creation of a new construction of industrial **water intake filters of upstream pipelines** is solved. The main features of such filters are absence of a special electric drive for filtering element cleaning and a possibility of filter operation in open reservoirs, including the ones that freeze in the cold season.

3.2. Filters with zig-zag screen of filtering element.

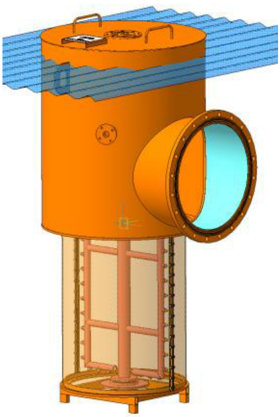


Fig. 2. 3D-model of water intake FZM filter of upstream pipelines

Filters with a zig-zag screen of a filtering element are created considering all technical requirements to modern filters for downstream pipelines (subsection 2.2)

Filters of FK series consist of a cylindrical body 1 (fig. 3), an inlet nozzle 2, an outlet nozzle 3, a flush nozzle 4, and also a filtering block 5, which is rigidly fixed on a central pipe 6. The central pipe is installed on a filter body pipe via bearings 7 and 8 with a possibility of mutual rotation with a filtering block.

An upper disc 9 and a lower disc 10 are parts of the filtering block 5, and are rigidly connected together via spacer rods. Band-shaped filtering screen 13 is stretched and wrapped around inner 11 and outer rods 12 in a zig-zag manner. The zig-zag filtering screen 13 is located between the upper disc 9 and the lower disc 10.

The filtering screen 13, stretched in this way, and the upper and lower discs form outer 14 and inner 15 chambers in the filtering block 5. Thus, the filtering block 5 is connected with the cavity 16 of the central pipe 6 via openings.

A static dirt collector 18 is fixed on the inner surface of the filter body 1. The dirt collector partially wraps the filtering block 5. The dirt collector is connected with the flush nozzle 4 via an opening 19. When the filtering block 5 rotates, its outer chambers consecutively connect with the flush nozzle 4.

The central pipe 6 is connected with an electric drive 20.

A flush valve 21 with an electric drive is installed on the flush nozzle 4. When opened, the flush valve connects the flush nozzle with the discharge.

The filter has two operating modes – filtration mode and flushing mode. When the flushing is active, the filtration does not stop.

Fig. 3 shows a water flow path in the filtration mode and a reverse water flow through the filtering element with arrows in a zone of the outer chamber 14, which is currently being flushed in the flushing mode.

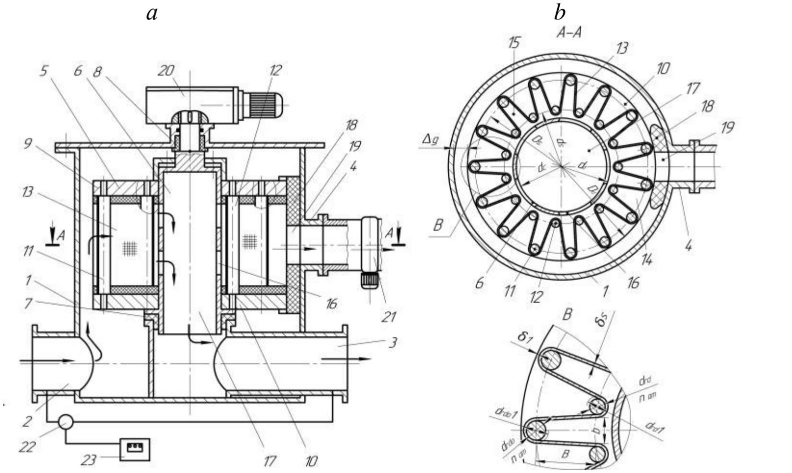


Fig. 3. FK series filter with zig-zag-shaped screen: a – vertical cross-section: b – lateral cross-section

In the filtration mode the flush valve 21 is shut and the electric drive 20 is switched off. The filter is installed in a downstream pipeline. Water with debris flows through the inlet nozzle 2 (fig. 3) into the cavity of the filter body 1. Then – through all outer chambers 14 of the filtering block and through the filtering screen 13 into the inner chambers 15 of the filtering block. It further flows, already purified, through openings 16, into a cavity 17 of the central pipe 6 and, lastly, into the outlet nozzle 3.

The filtering screen 13 gets clogged over time, which leads to an increase of the pressure drop between the inlet nozzle 2 and the outlet nozzle 3. A differential manometer 22 monitors this pressure drop and transmits an executive signal to the control box 23. When the pressure drop reaches a pre-determined value, which is a signal of the filtering block 5 clogging, the control box switches the filter into the **flushing mode**.

In order to engage the flushing mode, the control box switches on the electric drive of the flush valve 21, which opens the valve, and switches on the electric drive 20, which starts rotating the central pipe 6 and the entire filtering block 5 together with it.

When the filtering block 5 rotates, every outer chamber 14 consecutively aligns with the opening 19 of the static dirt collector 18 and temporary connects with the flush pipe through an open flush valve 21. Water pressure inside the filter is higher than in the flush pipe, therefore a reverse flow (back-flush) of water occurs through the outer chamber 14, into the opening 19 and through the open flush valve 21 to the flush pipe. This reverse flow of water washes off and carries away the debris, which cakes up on sections of the filtering screen 13 in this outer chamber. Thus, when the filtering block 5 rotates, the entire screen and the outer chambers are flushed consecutively.

The debris is gradually washed off the filtering screen 13 as a result of the back-flush and the pressure drop between the inlet nozzle 2 and the outlet nozzle 3 reduces. When the pressure drop reaches the initial value, the control box shuts off the flush valve 21 upon the differential manometer signal. The filter is transferred to the filtration mode. And the cycle continues.

A method of calculation of FK filters is developed, which allows determining all geometrical and hydraulic design parameters of FK filter using initial data with empirical values.

The assumed filtration velocity V_f has a substantial role when designing a filter and is determined by the flow rate Q through the screen with a surface area S_s

$$V_f = Q / S_s \tag{1}$$

The correctly assumed filtration velocity provides a sufficient time interval between flushing cycles and an optimal value of a screen surface area S_s depending on the flow rate Q and the screen mesh size α.

Numerous research were previously conducted by Oceanmasenergo specialists on establishing filtration velocity. Filtration velocity that should be assumed when designing and selecting a filter, linearly depends on the mesh size α for screen with a large mesh (a=0,5-5 mm and more), but for a screen with smaller mesh a=0,02-0,5 mm and in a range of real flow rates Q through the filter it has a more complex dependency, like

$$V_f = \int (a, Q) \tag{2}$$

An algorithm of selection of filter and its filtering screen surface area is shown in [2] for the basic assumed parameters – flow rate Q and a screen mesh size a.

The calculation order for each filter of the dimension type series is as follows:

- parameters, which are pre-obtained through project development and pre-calculations, are selected for each basic filter;
- all parameters of the filtering block of the basic filter are calculated (a=0,2 mm);
- particular parameters of screens of other filters of the dimension type series are specified (for the assumed a>0,2 mm);
- the rest of filter parameters are calculated.

After consideration of a series of geometric and hydraulic dependencies in order to determine five parameters, obtain the system of five equations (2), which connect these parameters. The parameters are: amount of rods n in the filtering element, inner diameter of the screen d_s, coefficient of screen width $k = B/H$, where B and H – height and width of the screen in one chamber respectively, b – maximum distance between the nearest screen sections (see fig. 3b), coefficient of flow rate for the flushing $\alpha = q/Q$, where q and Q – short-term flow rate for the screen surface flushing in one chamber and the entire screen respectively.

$$\begin{cases} \pi d_s - (b + d_{rd1})n \\ d_s = d_d + d_{rd1} + yb \\ 2jkH^2V_f = Q \\ jbHV_b n = Q \\ \alpha = \frac{2jkH^2V_f}{Q} \end{cases} \tag{3}$$

In this system of equations: d_{rd1} - diameter of the inner rod of the filtering block considering the thickness of the screen wrapped around it, d_d - the inner diameter of the disc of the filtering block, j - amount of filtering blocks, V_b - water flow velocity through a gap between the neighboring rods of the filtering block.

Obtain the main ratio for determining the amount of rods n in the filtering element through solving a system of equations with respect to unknowns

$$n = -\frac{p}{2} \pm \sqrt{\left(\frac{p}{2}\right)^2 - q_1} \quad (3)$$

where

$$p = \frac{A - \pi(d_d - d_{rd1})}{d_{rd1}} \quad (4)$$

$$q = -\frac{\pi A}{d_{rd1}} \quad (5)$$

And further, determine the other unknowns of the system of equations from the equation (3).

The parameters calculated in this way considering the assumed values during project development and pre-calculations allow determining other hydraulic and geometric filter parameters:

- outer D_s screen diameter $D_s=d_s+2B$
- outer diameter of the filtering block disc $D_d=D_s+d_{rd1}+2\delta_1$

gap between the filtering block disc and the filter body $\Delta_g \cong \frac{Q}{\pi D_d V_g}$ filter body diameter $D_b=D_d+2(\Delta_g+\delta_b)$

Industrial implementation of filters with zig-zag screen of filtering element. Over 10 FK1.100, FK-1530 and FK-2700 filters have been produced and operated at PJSC “ArcelorMittal Kryvyi Rih” and PJSC CGOK (fig. 4) in 2014-2020 (numbers in filter type – nominal flow rate through the filter in m^3/hr). The filters have been operating for a long time, have fully confirmed their characteristics, and have been filtering water perfectly.

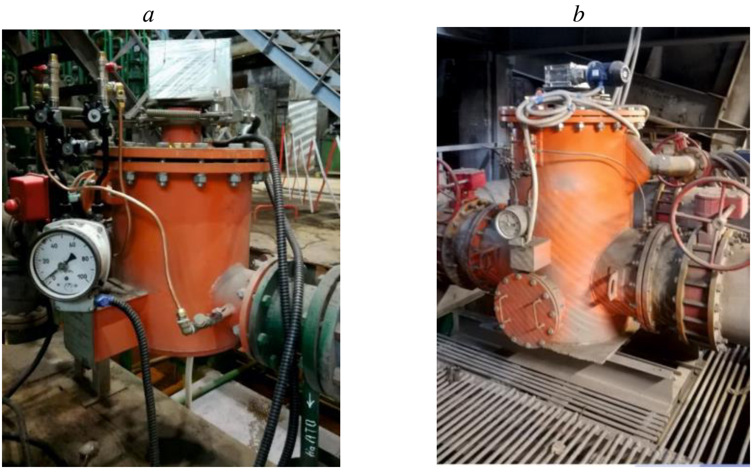


Fig. 4. Automated self-cleaning filter FK: *a* –FK1.100; *b* – FK-1530

Thus, a scientific and technical problem of creating a new construction of a universal industrial filter with zig-zag shape of placement of a screen of filtering element. The main features of such filters are a zig-zag shape of screen placement, a formation of chambers for large debris with these ‘zigs’, and insensitivity to relatively large debris. These construction features provide high contaminant capacity of filtering elements while having relatively small filter body dimensions, longer intervals between back-flushes (compared to traditional flat or cylindrical filtering elements), and smaller water loss for filter back-flush.

3.3. Brush filters FBC with hydraulic drive on filtered water

Known brush filters are quite complex in regards to construction or they require special electric of pneumatic drives for brush dirt collector rotation. The problem of filter construction simplification can be solved by using a disc brush as a dirt collector. The disc brush is installed on a hydraulic cylinder rod with a possibility of cleaning the cylindrical filtering block during reciprocating motion of the dirt collector. The energy source for driving hydraulic cylinder operation is filtered water from a pipeline.

Brush filter consists of a filter body 1, an inlet nozzle 2, an outlet nozzle 3, a flush nozzle 4, and a lid 5. An inlet chamber 6 is under the lid 5, and a debris bunker 7 is at the bottom of filter body 1. The inlet nozzle 2 enters the inlet chamber 6, and the flush nozzle 4 exits the debris bunker 7.

A screen with a cylindrical shape of the filtering element 8 is rigidly fixed in the filter body 1. A dirt collector 9 with a rod 10 is installed co-axially to the filtering element 8 with a possibility of reciprocating motion. The disc brush 11 is installed on the rod 10.

Hydraulic cylinder 12 is installed on a flange on the outer side of the filter body 1 bottom. Hydraulic cylinder 12 with a piston 13 and a bush neck 14 form rod cavity 15 and piston cavity 16. At the same time, the piston 13 is fixed on the rod 10, which is simultaneously a rod of the hydraulic cylinder 12. The bush neck 14 is a guide for the rod 10.

A normally closed flush electromagnetic valve 17 is installed on the flush nozzle 4. Valve 17 can connect the bunker 7 with the flush through the flush nozzle 4.

Normally closed electromagnetic valves 18 and 19 are provided for controling the hydraulic cylinder 12.

A differential manometer 20 is installed on the filter body.

All electromagnetic valves and the differential manometer 20 are electrically connected to a control box 21 via control cable lines 22, 23, 24, and 25.

The filter operates in one of two modes: long filtration mode or short flushing mode.

a *b*

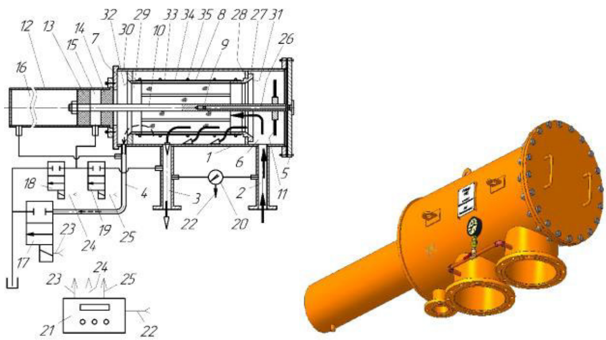


Fig. 5. Brush filter with hydraulic drive of disc dirt collector: *a* – filter cross-section with hydraulic scheme; b – filter 3D-model

In the **filtration mode** electromagnetic valves 17, 18, and 19 are closed, the dirt collector 9 and its disc brush are in the extreme right position.

Dirty water inflows through the inlet nozzle 2 into the inlet chamber 6 of the filter body 1, flows through the filtering element 8 from the inside and further, already purified, through the outlet nozzle 3. Debris is partially removed by water into the bunker 7, and partially sediments on the inner surface of the filtering element 8.

The filtering element 8 gets clogged over time, which leads to an increase of the pressure drop between the inlet nozzle 2 and the outlet nozzle 3. A differential manometer 20 monitors this pressure drop and transmits a signal to the control box 21. When the pressure drop reaches a value determined during filter installation, the control box 21 switches the filter into the **flushing mode.**

In order to engage the flushing mode, the control box opens the electromagnetic valve 17, which connects the bunker 7 for debris with the flush pipe through the flush nozzle 4, where the pressure in lower than in the filter.

A water flow already occurs from the filter inner cavity through the bunker 7, the flush nozzle 4, and through the flush pipe. This flow of water carries away the debris from the bunker 7 and the filter inner cavity to the flush pipe. A reverse flow of water occurs through the filtering element 8, which partially washes off the debris from the filtering element and carries it away to the bunker 7 and further to the flush pipe.

The debris that isn't washed off by the back-flush, stay on the inner surface of the filtering element 8. The disc brush 11 of the dirt collector 9 brushes off this debris from the filtering element 8 during its reciprocating motion along the filtering element 8 axis. In order to do this, the control box 21 opens the electromagnetic valve 19 already after the electromagnetic valve 17. The valve 19 connects the rod cavity 15 with the outlet nozzle 3, where high pressure is present, just as in the filter inner cavity. At the same time, low pressure like in the flush pipe is present in the piston cavity 16, which is constantly connected with the flush nozzle 4. This is because the flush electromagnetic valve 17 is open and the flush nozzle is connected with the flush pipe.

Pressurized water flows into the rod cavity 15 and moves the piston 13 right to left (fig. 5a). The dirt collector 9 and the disc brush 11 move together with the piston 13. At the same time, the disc brush 11 moves along the inner surface of the filtering element 8, while brushing the debris off the filtering element and exits to the bunker 7. The debris is carried out to the bunked by water and further to the flush pipe.

Control box 21 then closes electromagnetic valves 17 and 19 and opens the electromagnetic valve 18. The pressure in the rod cavity 15 gets as low as in the flush pipe. Pressure in the flush nozzle 4 after closing the electromagnetic valve 17 equalizes with pressure in the filter cavity, which is high. Water under high pressure flows into the piston cavity 16 from the flush nozzle 4, because it is constantly connected with the flush nozzle 4 via a pipeline. The piston 13 moves left to right because of the action of water under pressure, which flows into the piston cavity 16. The dirt collector 9 and the disc brush 11 move left to right together with the piston 13, while additionally cleaning the inner surface of the filtering element 8. The filtering element is clean, the differential manometer 20 sends the signal to the control box 21, and the control box closes all electromagnetic valves. The high pressure equal to the inner filter cavity pressure sets in the rod cavity 15 and the piston cavity 16 of the cylinder 12. Reciprocating motion of the dirt collector stops. The filter is transferred to the filtration mode.

A method of calculation of main elements of brush filters FBC is developed. When developing the method, theoretical achievements on designing the first generation of brush filters FRU are creatively used. This is why only main dependencies in regards to determining parameters of elements that are different from analogical elements of FRU filters are given. These elements are circular wire brush and water driving hydraulic cylinder.

A brush in the FBC filter loses contact with the screen at the end of each travel during the reciprocating rod motion along the longitudinal axis of the filtering element when screen cleaning is performed. Then, the brush contacts the screen again, but moves along the screen in the opposing direction. Each brush wire bends one way and then the other during motion along the screen.

The problem of calculating the brush is to select the brush parameters in such a way that the alternating bending stresses in wires are less than the yield strength of wire material. The calculated parameters are: brush wire material and permissible bending stress [σ], wire diameter *dw*, wire length *L*, wire protrusion length over the screen inner surface when not in contact with the screen (in brush extreme positions) *X*, wire deflection during movement along the screen *f*, an amount of wires in a bunch n_{bum}, a force, occurring in a bunch during movement along the screen P_{bum} (pre-defined).

Brush wire can be considered as a console beam of length *L* rigidly fixed at one end (fig. 6). The wire deflects by a value *f* when subjected to force *P*. At the same time, the free end of wire moves to the point *C* by the value *X*. The wires bend along a curve, which can be represented as an arc of a radius *R*. Considering a relatively small value of deflection *f*, this substitution doesn't introduce a substantial error to the solved problem.

Moment of resistance and deflection of a circular wire

$$J = \frac{\pi d_w^4}{64} \tag{6}$$

(7)

Assume the value *f* based on design considerations and prior developments.

Obtain the following from the triangles OAC and ADC by writing the expressions for determining the same line segment L_1 of the line AC and by excluding L_1

$$2R\sin\alpha = \sqrt{f^2 + (L - X)^2} \tag{8}$$

It can be seen in fig. 6, that

$$\alpha = arc\tan\frac{f}{L-X} \tag{9}$$

$$\alpha = \frac{360L}{4\pi R} = \frac{90L}{\pi R} \tag{10}$$

Equations (8), (9), (10) represent a system of equations with unknowns α, R, X.

Exclude *R* from the system. From (10)

$$R = \frac{90L}{\pi\alpha} \tag{11}$$

By transforming (8) and (11) denominate the following

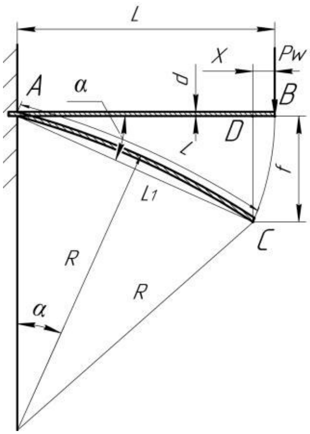


Fig. 6. Computational scheme of determining deflection of brush wire

$$A = \sqrt{f^2 + (L - X)^2}$$

$$B = \frac{180L\sin\alpha}{\pi\alpha}$$

By equating the two obtained equations and using the iterative method, determine the value of X (wire protrusion length over the screen inner surface when not in contact with the screen).

Obtain the following from the known dependencies of strength of materials and from fig. 6:

From the known dependences of the resistance of materials and from fig. 4 we get

- the moment bending a single wire $M_w = P_w L$;

- normal stresses that occur in a single wire under the bending moment action $\sigma = M_w / W$;

- moment of resistance of a wire cross-section: $W = 0{,}1d_w^3$.

Determine a force that occurs at the end of a single wire during movement along the screen

$$P_w = \frac{\sigma W}{L} \tag{12}$$

Obtain the maximum force that occurs at the end of a single wire during movement along the screen from (12) and the condition of strength of material

$$P_{w.\max} = \frac{[\sigma]}{L} = \frac{0{,}1[\sigma]d_w^3}{L} \tag{13}$$

Obtain the expression for calculation of maximum permissible wire deflection by substituting the value of $P_{w.\max}$ from (13) to (7)

$$f_{\max} = P_w L^3 / 3Ej \tag{14}$$

The fulfillment of condition $f \leq f_{max}$ is checked by a value of f assumed earlier from design considerations.

The calculated value of the force occurring at the end of a single wire during movement along the screen

$$P_w = P_{w.\max} \frac{f}{f_{\max}} \tag{15}$$

The maximum calculated tractive force $P_{br.\max}$ for brush movement along the screen of the filtering element can be obtained in the first approximation by multiplying the value of P_w from (15) and the amount of wires in the disc brush.

The problem of calculation of the driving hydraulic cylinder, which operates on filtered but yet containing small debris particles water (fig. 7), is determination of operating diameters of the piston and the rod. The rod and piston diameters must be such that the tractive force output by the hydraulic cylinder is sufficient to provide traction to move the brush along the screen of the filtering element and to overcome friction forces in sealing systems of the hydraulic cylinder. When operating on dirty water, the dirt gets into the bush neck and piston and may jam the rod movement. Polyamide (PA) is selected as a material for the bush neck, the piston, and their seals in order to reduce wear. It is expedient to constructively combine the seals with the piston and the bush neck.

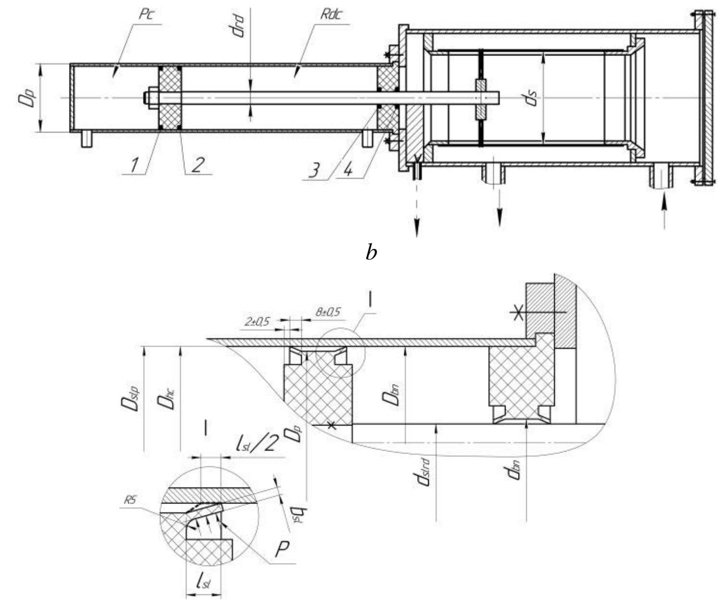
The piston must create a small gap in a place of interaction with the cylinder and the bush neck in a place of interaction with a rod to achieve the following goals:

- prevent jamming when the PA expands because of water;
- prevent jamming when small dirt particles get through the seals, especially when the seals are partially worn out, but yet water leakage through the seals remains permissible;
- allow a certain clearance in order to compensate the skewing during hydraulic cylinder installation on the filter body.

The axial forces output by the hydraulic cylinder when water under pressure p is pumped to the piston and rod cavities (fig. 7) must be determined considering friction forces in the sealing systems of the hydraulic cylinder.

Fig. 7. Schemes to calculation of water hydraulic cylinder:

a



a – scheme to determining forces of rod movement; *b* – scheme to calculation of forces of friction in piston and bush neck

The seals are made of PA, are relatively rigid, have a thickness b_{s1}, and one of the seal sides is rigidly connected with the piston or the bush neck. Assume that under the pressure *p* just a half of the seal length $l_{s1}/2$ attaches to the support (hydraulic cylinder or rod) over the ring with surface area of $\frac{l_{s1}}{2}\pi D_p$ (for the piston) and $\frac{l_{s1}}{2}\pi D_{rd}$ (for the rod) and is pushed to them with a pressure *p*.

Then normal forces *N* at a pressure from the seals p, which create resistance to the cylinder movement due to friction, are determined from the expressions

$$N_1 = N_2 = \tfrac{1}{2}\pi D_p l_{s1} p \quad (16)$$

$$N_2 = N_4 = \tfrac{1}{2}\pi d_{rd} l_{s1} p \quad (17)$$

While under the pressure *p* in the piston cavity, the seals 1 and 4 create the resistance during the rod movement left to right (the brush returns to the starting position, fig. 5*a*). While under the pressure p in the rod cavity, the seals 1 and 3 create the resistance during the rod movement right to left (the brush cleans the screen). The seal 4 is in the flush zone, since the flush valve is open.

Axial resistance to movement, created by the seals of the piston and the rod

$$F_{s1ap} = f(N_2 + N_3) \tag{18}$$

$$F_{s1ard} = f(N_1 + N_4) \tag{19}$$

or considering (16) and (17), the axial resistance from seals on the rod of the hydraulic cylinder during pressurized water inflow to the piston and the rod cavities respectively

$$F_{s1ap} = F_{s1ard} \cdot p - \tfrac{1}{2}\pi d_{s1}(D_p + d_{rd})p \tag{20}$$

The axial force, created at the rod of the hydraulic cylinder during pressurized water inflow to the piston cavity

$$F_{ap} = \frac{\pi D_p^2}{4} \cdot p - \frac{1}{2} \cdot \pi d_{s1} \cdot (D_p + d_{rd}) \cdot p \tag{21}$$

after transformations

$$F_{ap} = \frac{1}{4} \cdot \pi p \cdot [(D]_p^2 - \frac{1}{2} - 2l_{s1} \cdot (D_p + d_{rd})) \tag{22}$$

The axial force, created at the rod of the hydraulic cylinder during pressurized water inflow to the rod cavity

$$F_{ard} = \frac{\pi p \cdot [(D]_p^2 - d_{rd}^2)}{4} \cdot p - \frac{1}{2} \cdot \pi d_{s1} \cdot (D_p + d_{rd}) \cdot p \tag{23}$$

after transformations

$$F_{ard} = \frac{1}{4} \cdot \pi p[((D]_p^2 - d_{rd}^2) - 2l_{s1} \cdot (D_p + d_{rd})) \tag{24}$$

It is possible to calculate the unknown diameters of the rod d_{rd} and the piston D_p of the hydraulic cylinder from the conditions $P_{br.\max} \le F_{ard} \le$ and $P_{br.\max} \le F_{ap}$ with known operational water pressure p in the pipeline.

Industrial implementation of brush filters with hydraulic drive on filtered water. Sets of working design documentation for a series of FBC filters (Fig. 8) and their driving hydraulic cylinders, which operate on filtered water, are developed. The series of filters covers flow rates through filters from 170 to 2100 m^3/hr and diameters of the inlet nozzles from 200 to 700 mm.

Conclusions

1. The quality of technical water directly influences energy saving, specific links of water treatment systems are detected, which require improvement of filters for ensuring the required water treatment quality.

These are water intake filters, downstream pipeline filters of predominantly fine filtration at large flow rates, brush filters that are used predominantly in special conditions of water contamination (i.e. foliage, polyethylene film, etc.)

2. Through an analysis of literary sources and real water treatment systems of Ukrainian and foreign industrial facilities main requirements on development and improvement of constructions of the selected filters are detected and justified, main technical solutions on the constructions are suggested.

3. A construction of the new water intake filter with a jet drive and screen cleaning is developed, which does not have an electric drive (FZM type filter). The filter is installed in the open reservoir while providing simple maintenance by removing the filtering-purifying block through an open top lid.

The main feature of this filter is that it operates and is easily maintained even at frozen reservoirs.

4. The construction of a brand-new filter for downstream pipelines is developed. It has significantly larger screen surface area while the filter dimensions remain relatively small.

This is a filter with a zig-zag-shaped screen (FK type filter).

Theoretical justifications of calculation of such filters and their main geometrical and hydraulic parameters are developed.

The zig-zag-shaped screen allows creating chambers by its ‘zigs’, in which relatively large debris is collected before flushing. This allows using the filter without installing another one or a cascade of pre-treatment filters before it. The filter cleans itself automatically by a consecutive back-flush of chambers.

The filters are shipped to industrial facilities since 2014 and have operated very well (for example, during cooling of the blast furnace number 8 of PJSC “ArcelorMittal Kryvyi Rih”, Ukraine).

5. A new brush filter type is developed (FBC filter type). It has a hydraulic cylinder for a drive, which operates on filtered water, and a cylindrical brush operates together with a hydraulic cylinder.

A theory of calculation of FBC type filter is developed, which allows determining the necessary screen surface area, brush movement resistance considering the resistances from water and debris on the screen during cleaning.

A type range of hydraulic cylinders is developed, which can be used during filter designing.

FBC type filters don't have an electric drive, are suitable for fire systems, the filter data are requested by project organizations for usage in projects on fire systems.

6. Series of all types of filters (FZM, FK, FBC) are developed for the entire range of parameters required by industrial facilities.

The developer is ready for further shipping of any of the filters in the developed range.

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