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Development of Filters with Minimal Hydraulic Resistance for Underground Water Intakes

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Abstract

The development of modern structures of water wells filtering equipment with enhanced performance characteristics is a vital task. The purpose of this work was to create filters for taking water from underground sources that have high performance, long service life, quickly and economically replace or repair in case of performance loss. The selection of the filter device must be made taking into account all the geological features of the aquifers, the performance characteristics of the filter devices and the size of the future structure. Filter equipment designs for water intake wells have been developed in this study. These filters have low hydraulic resistance, high performance and are easy to repair. This article presents the dependency of flow inside the receiving part of the well, the dependence of filter resistance at various forms of the cross section of the filter wire and the selected optimal section. The paper proposes a method for selecting the optimal cross-section of the filter wire used in the manufacture of a water well filter. The proposed structures of easy-to-remove well filters with increased productivity allow replacing the sealed well filter with a new one easily, reducing capital and operating costs, and increasing the inter-repair periods of their operation. Based on the presented method, examples are given for selecting the parameters of the filter wire cross-section. The above calculations showed that the use of the hydraulic resistance criterion at the design stage of underground water intakes can significantly reduce the cost of well construction. Studies have found that the minimum hydraulic resistance to ensure maximum filter performance is achieved when using filter wire teardrop and elliptical shapes.

Keywords: Hydraulic Resistance; Filter; Water Well; Resistance; Filter Wire; Capacity.

1. Introduction

Groundwater use is 70% of the total water consumption in some European countries with the best rates in quality of life for the public. These countries are Germany, Austria, Denmark, Belgium, Switzerland, and several others. More than 300 million groundwater intake structures have been drilled around the world over the past 25-30 years [1-2].

The use of groundwater for water supply of the population has many significant advantages. High water quality in the water supply source helps to avoid the necessity for preparation equipment using due to protection from external contamination and seasonal changes of indicators. The capacity of a water well depends on hydrogeological characteristics of soil and groundwater, as well as the structure of intake portion of a well and pumping equipment. Therefore, the development of modern structures of water wells filtering equipment with enhanced performance characteristics is a vital task.

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The main element of a downhole water intake is a water intake well. The quality of its design and construction influences the water intake operation. The main requirements for a water intake well (tubular well) are as follows: production of the required amount of water with the quality corresponding to the requirements of consumers, efficiency and reliability in operation. The main elements of the well design are: guide column, conductor, intermediate columns (technical columns of casing pipes), production column, cement or other protection and water intake part. The purpose of tubular well filters is to keep the soil from collapsing and at the same time ensure free passage of water into the well bore. Filters must meet the requirements:

- Have the necessary mechanical strength;
- Ensure that water flows into the well with minimal hydraulic resistances and without mechanical impurities;
- Have high corrosion resistance;
- Ensure maintainability and the ability to extract from the well.

The following types of downhole filters are used: frame-and-rod; tubular with slotted or round holes; with wire winding; reticular; polymer ring. Their choice depends on hydrogeological conditions, depth of occurrence and types of rocks of aquifers. Frame-and-rod filters are considered to be the most efficient one. A single filter surface (profiled wire) is available for chemical and mechanical cleaning, since there are no dead spaces between the filter and support surfaces. The consumption of metal on a core frame is about half that of a perforated pipe frame. Filters on core frames are used in wells up to 200 m deep.

Filters on a tubular frame with a wire winding are also common due to the ease of manufacture. The duty cycle of these filters is 20-25%. Their disadvantage is that there is an accumulation of colmating connections between the wire and the frame. The cross-section shape of the filter wire can be round, teardrop, elliptical, trapezoidal, rectangular, or other. Wedge Wire Screens made by “Johnson”, pressed filters with tunnel-holes and plastic slot-type filters are popular abroad [3-5].

The most common filters in Russia are mesh and wire filters with perforated tubular frame. The main reasons that impede the selection of a filter are the difficulty of determining the filter's open ratio and the variability of the distance between the loops of the filter’s round wire during manufacture. In our opinion, structures of easy-removable frame-and-rod filter-frames which have a fixed size hole and made of anticorrosion materials are advanced ones. However, water intakes from underground aquifers also have drawbacks. The most common problem of well operation is incrustation. Regular well cleanout has a temporary effect [6-8]. The well capacity gradually decreases with increasing resistance to the flow of water from an aquifer. This demonstrates the importance of the development of construction technology of wells that have stable debit and can withstand the harmful effects of fine sand-grains contained in the pumped water, which leads to incrustation and severe abrasion of structural elements of an underwater pump [9].

2. Development of Easy-Removable Filter Frames with a Fixed Size Hole

The tasks of designing well filters are to determine the optimal design and technological parameters. The main technological parameters of borehole filters are their borehole capacity and hydraulic resistances of the filter surfaces. Increasing the filter life allows you to reduce its length and diameter, and therefore the cost of filters.

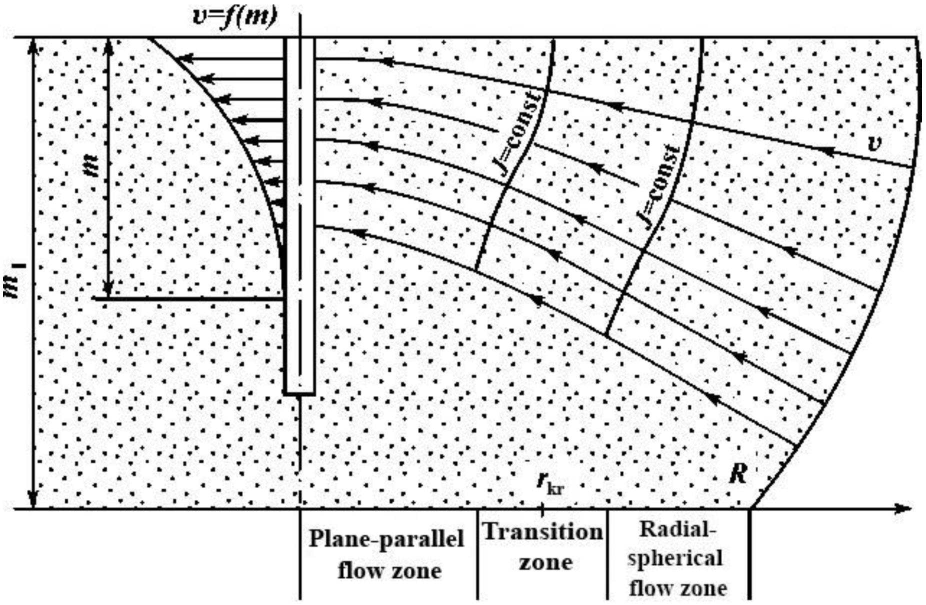

Figure 1. The nature of filtration in the well, taking into account the minimum energy costs

The length of the filter determines the capacity, structure, and type of aquifer. The length of the filter exceeding 10 m is not appropriate; this is due to the fact that the length of the filter reduces the load on it from the pump unit to the sump located in the lower part of the well bore. Calculations carried out by V. G. Tesla show that when the filter diameter increases from 168 mm to 325 mm, the specific flow rate increases only for 9.2%, but the cost of constructing with a larger diameter well may increase more than twice [7].

The physical meaning of the flow pattern easily explained in Figure 1. By integrating the pressure plot according to the reservoir power, you can determine a point in the reservoir at an equal distance from the well, to which the pressure gradient of the moving flow is directed in any interval. The location of the desired point will be significantly shifted from the upper limit of the exploited interval. Therefore, it is advisable for the flow in remote areas characterized by low velocity (v) to move in the direction of the pressure gradient, i.e. in a radially spherical flow. As the flow moves toward the well, its cross section decreases and the flow rates increase significantly, which means that the hydraulic head loss increases. At a certain distance from the well, the flow begins to run out, the "live" section increases, which helps to reduce the filtration rates and transition to a more energy-efficient form of movement. Despite the fact that the length of the current line increases, the possible increase in pressure losses due to this is compensated by their decrease due to a decrease in filtration rates.

Taking into account one of the basic laws of hydraulics, which assume the flow movement along the path of least resistance with minimal energy costs, a radial - spherical flow is formed in the reservoir in remote areas, which begins to transit gradually to a flat-radial one in some areas. The highest flow rate is observed in the upper intervals of the reservoir, where the current line thickens to the maximum. In the lower intervals of the reservoir, the frequency of the current line is significantly reduced due to the mismatch of the direction of movement with the pressure gradient, which indicates lower inflow intensity than in the upper intervals.

One of the most important conclusions that follow from the presented diagram is the possibility of determining of the formation part that is intensively loaded. The highest load is taken by the upper intervals of the formation, which are separated from the upper boundary at a distance of $m = r_{\text{кр}} m_1 / R$. Well performance is determined by hydraulic head losses in all sections of the flow. The coefficients of laminar and turbulent hydraulic friction are generalized. There is a relationship between the well performance and the resulting drop in levels corresponding to the head loss in the well-formation system. The resistance coefficients are generalized and are considered as a function of the sum of the laminar and turbulent resistances of each element of the system. The most optimal operating modes should provide a laminar filtration mode in all elements of the hydraulic system of the water intake well.

In the case of laminar filtration mode, an increase in the reduction is accompanied by a directly proportional increase in well productivity. When the flow is turbulized on one or more traffic elements the decrease begins to be accompanied by an increasingly slow growth of productivity. If the system is switched to a turbulent operation mode, the decrease does not lead to a significant increase in the flow rate and operation becomes economically unprofitable.

The relationship between well performance and reduction is permanent only in the case of steady-state operation. In real conditions, at the initial moment of operation or testing by pumping, developing levels, connecting and shutting down neighboring wells, and others, the dependence of the reduction and flow rate begins to change over time. This is due to the inertia of the well-formation system. It should be noted that with an increase in productivity caused by a decrease in hydraulic resistance in the elements of the well - formation system, the head distribution will change step by step. Increasing well productivity can be achieved by reducing the hydraulic resistance to flow movement on one of the elements of the well-formation system.

Scientific publications and patents research of the existing design and technological solutions for the water wells incrustation prevention provides the basis for the following conclusion: one of the most effective solutions to this problem is to ensure easy replacement of the incrusted well filter during operation. Several core frame filters with various forms of wire were developed in the South-West State University together with the company "Ecopromservice" [10-13]. The Figure 2 shows a diagram of a core frame well filter [14-16].

The filter has the following construction [17-19]. The filter support frame (1) is a perforated metal pipe. It is a continuation of the drive tube (6) lower part [20]. The support frame is designed to hold gravel pack in the aquifer and to fix the filter units in the face of the tubular well. The support frame is located outside the concertina wire (2) that is applied to the sag rods (3). There are vertically fixed centring slabs (7) with the angle 120° relative to each other between them. It helps to avoid the filter shifting towards the well center. The centring slabs are anchored on the connections sleeves (4, 5). Sag rods has ellipse configuration and are located outside the connections sleeves. The well filter height can be adjusted by adding filter sections. The filter can be removed by a gripping tool in case of repair or replacement, which is fixed to the lower surface of the upper coupling (8) and uses a traction device to remove the filter from the borehole.

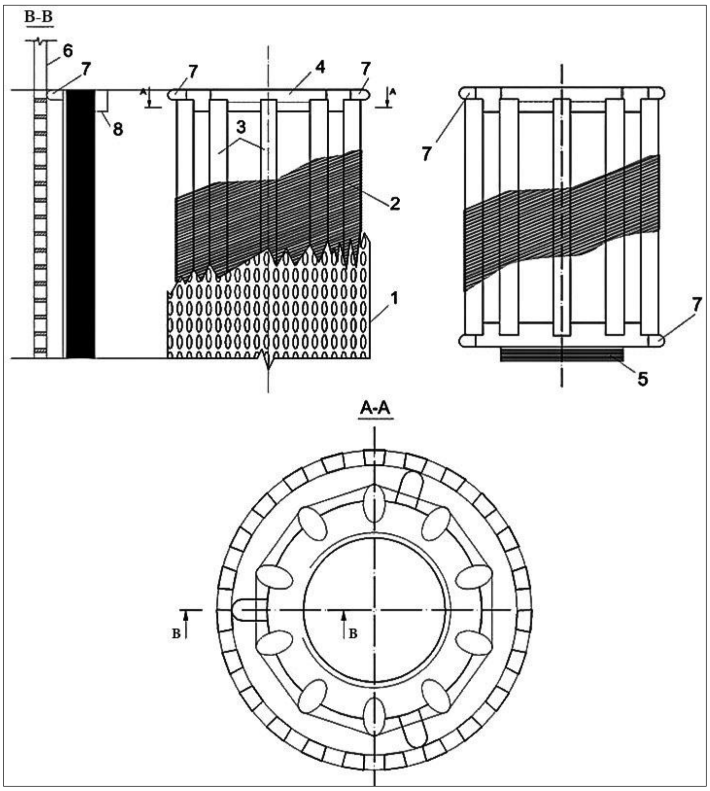

Figure 2. Structure of the tubular well filter: (1) Support frame, (2) Concertina wire, (3) Sag rods, (4) Upper connection sleeve, (5) Lower connection sleeve, (6) Drive tube, (7) Centring slabs, (8) Lower part of upper connections sleeve

3. Hydraulic Modeling of the Intake Part of the Well Filter

Geological features of an aquifer, performance characteristics of filtering devices and the size of the future structure must be considered for the filtering device selection. Besides, it is important to have minimal hydraulic resistances for water entry into the filter elements. The lowest hydraulic resistances do not depend on hydrogeological conditions and are provided by the use of filters with slits oriented in the horizontal plane [21-23]. The most suitable filters that meet this condition are wire-wound frame-rod filters. The performance characteristics of a well are primarily determined by the presence and the pressure loss rate of intake portion that depends on the filter structure, drilling-in methods and other factors [24].

Previous studies have shown that there is an optimal number of holes (optimal borehole). The increase of the number of holes, although it contributes to the overall increase in the total flow rate, leads to the reduction of resistance and slowes down due to the increased interaction of holes (interference effect). Thus the more holes will be put into operation the overall effect of increasing of the total debit will decrease faster [25-27].

Let's consider some hydrodynamic solutions to the problem of inflow to a well equipped with a filter, without taking into account the imposition of rocks and reducing the well life of filters, as well as the possibility of chemical overgrowth of filters. At the same time, filter resistance can be evaluated only in conditions of captage of stable rocks, when the effect of overlaying water-bearing rocks on the water-receiving part of wells does not affect. In some cases, the values of filter resistances will be underestimated. Since the geometry of the filtration flow near the well is determined by the shape of the inlet holes, it is best to classify filters for these purposes on this basis. Analytical solutions for the flow of liquid to a filter with round holes were obtained by M. Masket and A. L. Hein. When solving the problem, round holes were replaced by drains placed along the filter pipes. It is obvious that such a scheme does not provide physical similarity, since the impenetrability of the walls is not taken into account, but it is assumed that this disadvantage is compensated by the effect of effluent interference [25-27].

It was found that the value of the filter resistance is almost independent of the well diameter. V. I. Shchurov compiled curves by approximating M. Masket's analytical solutions using the same type of empirical equations for three hole diameters: 6.4, 12.7, and 19 mm. The value of the filter resistance depending on the number of holes and their diameter for the filter installed in a homogeneous formation. These dependencies were studied in detail By V. I. Shchurov using the method of electrohyrodynamic analogies and as a result, refined graphs of the filter resistance dependence on the parameters $\alpha = d_0/D$ and $\beta = nD$ (d_0 is the diameter of the holes, n is the number of holes per 1m of the filter length, D is the filter diameter) were obtained [25-27].

A. L. Hein obtained solutions for determining the inflow to a filter with round holes in conditions of unsteady movement. As a result, it was proved that the effect of unsteady flow in the filter zone can be traced for very short period, so in practical calculations of filters, we can limit ourselves to considering the stationary filtration mode [25-27].

Filters with vertical slits are divided into two groups: filters with slits whose length is equal to the thickness of the reservoir, and filters with slits of limited length. The first group includes filters made of rods without wire winding. When determining the resistance value for these filters, very similar results were obtained using various methods. These results were verified by the experimental method of electrohyrodynamic analogies, and satisfactory results were obtained. A similar result was obtained by A. L. Hein when calculating the resistance of a filter with vertically positioned holes without limiting the borehole. To determine the resistance of a slotted filter with rectangular slits of limited length placed vertically along the filter formation, A. L. Hein obtained a corresponding solution, and on the drainage surface, he assumed a certain average velocity of the liquid movement, and on the impervious sections of the filter – a potential gradient equal to zero. This solution is very cumbersome and does not lead to calculated dependencies. A. L. Hein's calculations show that the approximate resistance of filters with vertical slits of limited length can be found by graphs of V.I. Schurov for filters with round holes by reducing a rectangular hole to an equally large round one [25-27].

In this paper, we consider the hydraulic resistance of the filter without taking into account the contact head loss. This resistance depends on the shape of the holes, their number (borehole), the size that determines the flow dispersion, the nature of the location on the water-receiving surface of the well, and their interaction. The filter hydraulic resistance is the most important part of the total resistance of the near-wellbore. The distribution of head losses, intake velocity, and water influx rate should be considered for identifying common factors of flow movement within the intake portion of a well. The following conditions were accepted for a hydraulic model of the intake portion of a well development. The filtering surface consists of wire loops on the frame. It is considered as a screen area that has equal thickness of the rods and the wires. The width of the rods gaps is equal to the spacing between the wire loops.

The liquid that flows towards filtering surface is compressed in its holes and leave these holes as separate streams with a high speed for the face of a well. Thus, these losses are associated with water inlet and sharp expansion at the filtering surface outlet into the filter internal part (Figure 3). The coefficient of resistance of the filter surface depends on the coefficient of the live section, the shape of the edges of the holes and the Reynolds number. At low coefficients of the live cross-section of the filter surface, the flow rate in the holes can reach high values, especially in places where the streams are most compressed. If the cross-section speeds are not evenly distributed, the filter surface aligns the incoming flow. The resistance created by the filter surface redistributes the incoming liquid flow over the surface and at the same time allows the liquid to pass through the filter holes.

The degree of alignment of the liquid flow on the filter surface depends on its geometric parameters. Since these parameters determine the coefficient of resistance of the filter surface, the results of liquid flow redistribution are a function of the coefficient of hydraulic resistance. As the coefficient of hydraulic resistance increases, the degree of flow alignment over the area of the filter surface also increases. However, thin-walled filter surfaces, unlike bulk obstacles, have their own characteristics: when a certain value of the hydraulic resistance coefficient is reached at the outlet of the filter surface, the velocity profile becomes inverted in the opposite direction. At the same time, it can be observed that the flow is uneven, where the maximum speed behind the filter surface corresponds to the minimum speed in front of it [25-26]. When the liquid flows along the front surface of the filter, the flows are curved, since the filter is thin-walled, the holes have no guide surfaces, and the transverse direction of the flow is maintained after the liquid flows through the filter surface. This leads to further spreading of the liquid and movement of the flow in the radial direction. The greater the hydraulic resistance of the filter surface is, the sharper the flow curve becomes and there is a significant curvature of the flows coming out of the filter holes [25-27].

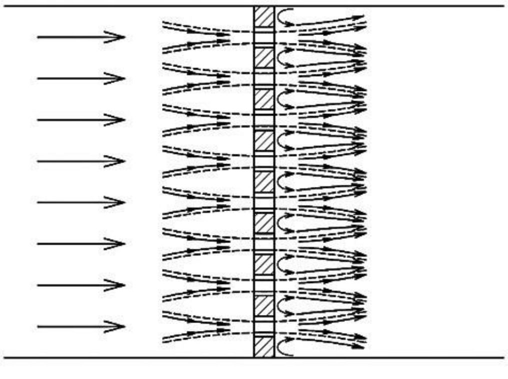

Figure 3. Water flows through the filtering surface

Two filtering surfaces set-up close to each other should not lead to an increase in resistance because the fine alignment of both surfaces is the reason of the holes increasing along the stream. The filtering surfaces partially overlap each other. That is why the flow section decreases slightly and the resistance increases. The total resistance can be defined as the sum of the resistance coefficients of individual parts in case of two filters set-up at some distance [25-26]. In that case, the distance between the sag rods, on which the filtration wire is wound, is much larger than the diameter of the wire. That is why compensating resistance can be neglected. It is known that the overall hydraulic resistance of any element of a chain is determined by the Equation 1 [26]:

$$\Delta p = \xi \frac{\rho \omega_1^2}{2} = \xi \frac{\rho}{2} \left(\frac{Q}{F} \right)^2 \qquad (1)$$

Where; Δp – Stagnation pressure reduction (Pa); ξ – Hydraulic resistance coefficient; ρ – Liquid density, kg/m^3; ω_1 – flow velocity (m/sec); Q – volume fluid flow rate (m^3/sec); F – total area of filtering holes (m^2).

The overall losses of filtering surfaces that are made of various form of section wire consist of inlet losses, friction losses, and sharp expansion loses at the outlet. Some form of section and filter wire parameters are shown in Figure 4.

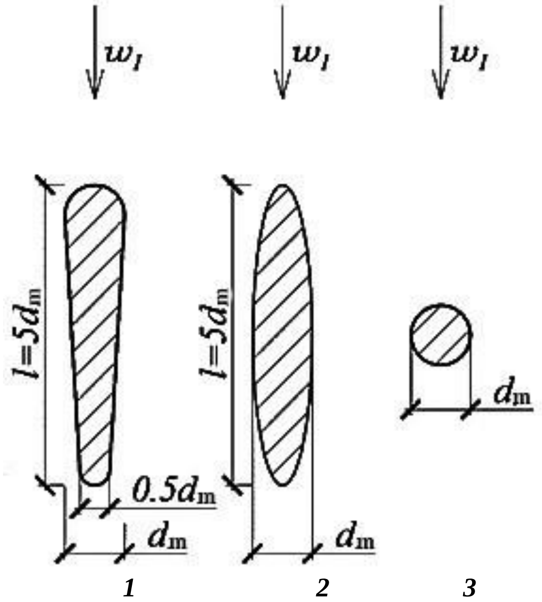

Figure 4. Form of section of filtering wire with minimal hydraulic resistance: (1) Drop-shaped; (2) Elliptic; (3) Circular

If $l/d_m = 5$ and $d_0/S_1 \geq 0.5$, coefficient of screen resistance can be determined by Kirshmer's Equation [26-28]:

$$\xi = \frac{\Delta p}{\frac{\rho \omega_1^2}{2}} = \beta_1 k_1 \sin \Theta \qquad (2)$$

Where: β_1 – coefficient of rods shape (Table 1); $k_1 = \left(\frac{S_1}{d_0} - 1 \right)^{4/3}$ (Table 2, Figure 5); $k_1 = f\left(\frac{d_0}{S_1} \right)$; θ – Angel of wire slope to flow; d_m – Width (diameter) midsection of filter wire (m); d_0– space between two adjacent wire loops (m); S_1 – Space between two adjacent wire loops axis (m); l – Sectional length of filtration wire (m).

Table 1. Coefficient value β_1 for various rods shape

№ rods	**1**	**2**	**3**
β_1	0.87	0.71	1.73

Table 2. Value $k_1 = f\left(\frac{d_0}{S_1} \right)$

d_0/S_1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
k_1	∞	18.7	6.35	3.09	1.72	1.00	0.58	0.32	0.16	0.05	0

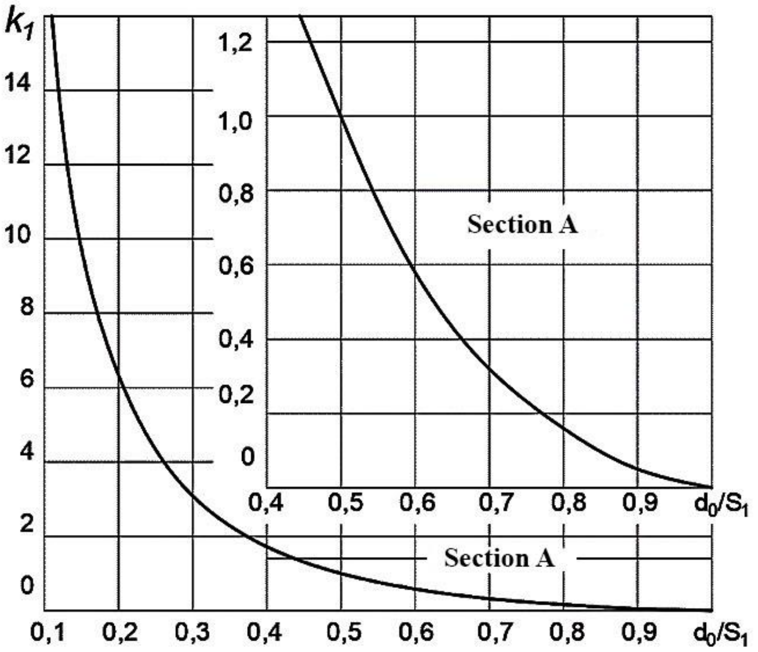

Figure 5. Dependency graph

According to Equation 1, it follows that the volume fluid flow rate is equal to:

$$Q = F\sqrt{\frac{2\Delta p}{\xi\rho}} = F\sqrt{\frac{2\Delta p}{\beta_1 k_1 \sin\Theta\,\rho}} \tag{3}$$

Thus, the volume fluid flow rate is inversely related to the hydraulic resistance. Accordingly, the greater the value of hydraulic resistance the lower the filter capacity.

As a matter of practice, the filtration wire of circular section is commonly used. However, according to the Table 1, drop-shaped and elliptical wires have the smallest value of hydraulic resistance. Filter capacities that have circular section wire Q_{wir}, elliptic Q_{el} and drop-shaped Q_{d-shap} were compared. If $\beta_{wir} = 1.73$, $\beta_{el} = 0.71$, $\beta_{d-shap} = 0.87$ and other equal terms:

$$Q_{wir} = F\sqrt{\frac{2\Delta p}{\beta_{wir} k_1 \sin\Theta\,\rho}} = F\sqrt{\frac{2\Delta p}{1.73 k_1 \sin\Theta\,\rho}} = 1.08F\sqrt{\frac{2\Delta p}{k_1 \sin\Theta\,\rho}} \tag{4}$$

$$Q_{el} = F\sqrt{\frac{2\Delta p}{\beta_{el} k_1 \sin\Theta\,\rho}} = F\sqrt{\frac{2\Delta p}{0.71 k_1 \sin\Theta\,\rho}} = 1.7F\sqrt{\frac{2\Delta p}{k_1 \sin\Theta\,\rho}} \tag{5}$$

$$Q_{d-shap} = F\sqrt{\frac{2\Delta p}{\beta_{d-shap} k_1 \sin\Theta\,\rho}} = F\sqrt{\frac{2\Delta p}{0.87 k_1 \sin\Theta\,\rho}} = 1.52F\sqrt{\frac{2\Delta p}{k_1 \sin\Theta\,\rho}} \tag{6}$$

After transformations Equation 4 to 6, the following results were obtained:

$$Q_{d-shap} = \frac{1.52}{1.08} Q_{wir} = 1.41 Q_{wir} \tag{7}$$

$$Q_{wir} = \frac{1.7}{1.08} Q_{wir} = 1.41 Q_{wir} \tag{8}$$

$$Q_{el} = \frac{1.7}{1.52} Q_{d-shap} = 1.41 Q_{d-shap} \tag{9}$$

Equations 7 and 8 shows that the capacity of filters with drop-shaped wire is 1.41 times more than the capacity of filters with circular wire and 1.57 times more than the capacity of filters with elliptic wire. In our opinion, the most promising designs of downhole filters are frame-rod, easily removable filters with a fixed slot size and using a drop-shaped filter wire made of materials that are resistant to corrosion.

4. Conclusion

Water wells with incrusted filters research have shown that the best solution for lifetime extension is to use in-place repairable, highly efficient and easy-removable filters. The main requirements for a water intake well (tubular well) are the extraction of the required amount of water with a quality that meets the requirements of consumers, as well as cost-effectiveness and reliability in operation. Important technological parameters of downhole filters are their downhole capacity and hydraulic resistances of filter surfaces. Increasing the working cycle of the filter reduces its length and diameter. The length of the filter determines the capacity, structure, and type of aquifer. Filter length exceeding 10 m is not suitable.

The selection of a filter device must take into account all the geological features of aquifers, the operational characteristics of the filter devices and the size of the future structure. At the same time, it is necessary to ensure that the hydraulic resistance for entering incoming water into the filter elements is minimal. The use of filtering wire with the drop-shaped form of section allows reducing hydraulic losses during fluid flux through filters. Therefore, it improves the performance characteristics of water wells and minimizes capital commitment by extending the overhaul periods. Studies have shown that the minimum hydraulic resistance to ensure maximum filter performance is achieved by using a filter wire with a teardrop and elliptical shape. In our opinion, the most promising designs of downhole filters are frame-rod, easy-to-remove filters with a fixed slot size and using a teardrop-shaped filter wire made of materials that are resistant to corrosion. The resistance created by the filter surface redistributes the incoming liquid flow over the surface. The degree of alignment of the liquid flow on the filter surface depends on its geometric parameters. As the coefficient of hydraulic resistance increases, the degree of flow alignment over the area of the filter surface also increases. The designs of easily extracted downhole filters of increased productivity are proposed to eliminate the possibility of filter breakage during production, i.e. to provide easy replacement of a sealed downhole filter with a new one.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Zektser, I. S. “Groundwater as a Component of the Environment.” Geology and Ecosystems (2006): 91–105. doi:10.1007/0-387-29293-4_8. Available online (Russia): https://msd.com.ua/podzemnye-vody-kak-komponent-okruzhayushhej-sredy/sovremennoe-sostoyanie-i-osnovnye-principy-racionalnogo-ispolzovaniya-podzemnyx-vod/ (accessed on 14 March, 2019).

[2] Shcherbakov, V. I., A. A. Akulshin, V. S. Pereverzeva, and I. G. Shapovalov. “Selection of Parameters of the Filter at Design of Water Wells.” Proceedings of the Southwest State University 22, no. 3 (June 28, 2018): 6–12. doi:10.21869/2223-1560-2018-22-3-6-12.

[3] Moss, Roscoe, and George E. Moss. Handbook of ground water development. New York: Wiley-Interscience, 1990.

[4] National Uniform Drillers Licensing Committee. Minimum Construction Requirements for Water Bores in Australia. National Water Commission, 2012.

[5] Brassington, Rick. “Book Review: Water Wells and Boreholes, by Bruce Misstear, David Banks and Lewis Clark (John Wiley & Sons, 2006).” Hydrogeology Journal 19, no. 5 (April 19, 2011): 1115–1116. doi:10.1007/s10040-011-0729-y.

[6] Pereverzeva V.S., Akulshin A. A. “Prevention of work and maintainability of water wells.” Building-2016. Materials of the II Bryansk International Innovation Forum. (2016): 6-11.

[7] Shcherbakov V. I., Akulshin A. A. “Water intake structures from underground sources.” LAP Lambert Academic Publishing. Saarbrucken. Germany (2017).

[8] Akulshin, A. Bredihin, V. Bredihina, N. Pereverzeva V. “A method of calculating filtration rate of an infiltration water intake in Kursk region.” Journal of Applied Engineering Science no.3 (March 2017): 208-211. doi: 10.5937/jaes15-14644.

[9] Kopansky A. G. “Investigation of the parameters of the technological process, which provides a high degree of permeability of the filter of a water intake well.” Bulletin of civil engineers no. 5(52) (May 2015): 110-118.

[10] Patent 138784 Russian Federation, IPC E 21 B 43/08. Borehole filter / Akulshin A. A., Shalai I. S., Akulshin V. A. and et al. ; patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - № 2013147076/03; declare 10.22.2013; publ. 03/20/2014, Byul. №8.

[11] Patent 141921 Russian Federation, IPC E 21 B 43/08. Borehole filter / Akulshin A. A., Pereverzeva V. S., Akulshin V. A. and et al. ; patent holder Federal State Budgetary Institution of Higher Professional Education "South-West State University". - № 2013155798/03; declare 12/16/2013; publ. 06/20/2014, Byul. №17.

[12] Patent 142252 Russian Federation, IPC E 21 B 43/08. Borehole filter / Akulshin A. A., Pereverzeva V. S., Akulshin V. A. and et al. ; patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - No. 2014105964/03; declare 02/18/2014; publ. 06/27/2014, Bull. №18.

[13] Patent 152601 Russian Federation, IPC E 21 B 31/20. Filter borehole / Akulshin A. A., Akulshin V. A., Pereverzeva V. S. and et al.; patent holder Federal State Budgetary Institution of Higher Professional Education "South-West State University". - No. 2014140405/03; declare 10/07/2014; publ. 06/10/2015, Byul. №16.

[14] Patent 156372 Russian Federation, IPC E 21 B 31/20. Filter borehole / Akulshin A. A., Akulshin V. A., Pereverzeva V. S. and et al.; patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - No. 2015111209/03; declare 03/30/2015; publ. 10.11.2015, Bull. №31.

[15] Patent 52441 Russian Federation, IPC E21B 43/08. Borehole filter / Akulshin A. A., Pozdnyakov A.I .; Patentee State Educational Institution of Higher Professional Education "Kursk State Technical University" - No. 2005133651/22; declare October 31, 2005; publ. 27.03.2006, Byul. №9.

[16] Patent 168625 Russian Federation, IPC E 21 B 43/08. Filter borehole / Akulshin A. A., Akulshin A. A. patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - № 2016129450; declare 07/18/2016; publ. 02.13.2015, Bull. №5.

[17] Patent 173488 Russian Federation, IPC E 21 B 43/08. Filter borehole / Akulshin A. A., Shcherbakov V.I., Pereverzeva V. S. patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - № 2017108967; declare 17/03/2017; publ. 29.08.2017, Bull. №25.

[18] Patent 175222 Russian Federation, IPC E 21 B 43/08. Filter borehole / Akulshin A. A., Akulshin A. A., Shcherbakov patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - № 2017131544; declare 08/09/2017; publ. 28.11.2017, Bull. №34.

[19] Patent180192 Russian Federation, IPC E 21 B 31/20. Filter borehole / Akulshin A. A., Shcherbakov V.I. Patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - № 2018111097; declare 28/03/2018; publ. 06.06.2018, Bull. №16

[20] Patent 188988 Russian Federation, IPC E 21 B 31/20. Filter borehole / Akulshin A. A., Uchaev A.S., Pereverzeva V. S. Patent holder Federal State Budgetary Institution of Higher Professional Education "Southwest State University". - №2018146545; declare 26/12/2018; publ. 06.05.2019, Bull. №13

[21] Shcherbakov, Vladimir, Aleksandr Akulshin, Aleksandr Bachmetev, and Anatolyi Akulshin. "Selection of Filter Parameters of Individual Water Supply Systems." Edited by O. Kalinina. E3S Web of Conferences 110 (2019): 01072. doi:10.1051/e3sconf/201911001072.

[22] Shcherbakov, V. I., A. A. Akulshin, V. S. Pereverzeva, and I. G. Shapovalov. "SELECTION OF PARAMETERS OF THE FILTER AT DESIGN OF WATER WELLS." Proceedings of the Southwest State University 22, no. 3 (June 28, 2018): 6–12. doi:10.21869/2223-1560-2018-22-3-6-12.

[23] Shcherbakov, Vladimir, Alexander Akulshin, Konstantin Chizhik, and Mikhail Tolstoy. "Design of Interacting Wells for Optimization of Investments and Operating Costs While Constructing Water-Diverting Structures." Edited by A. Volkov, A. Pustovgar, and A. Adamtsevich. MATEC Web of Conferences 251 (2018): 03037. doi:10.1051/matecconf/201825103037.

[24] Akulshin A.A., Shcherbakov V.I., Pereverzev V. S. "Improving Well Designs at Infiltration-Type Intakes." Industrial and Civil Construction no.4 (April 2017): 77-81.

[25] Petrosov D.A. "Recommendations for improving the design of filters to reduce head losses." News of higher educational institutions. Geology and exploration (March 2007): 52-56.

[26] Idelchik, I. E. "Reference book on hydraulic resistance." Mashinostroenie, Moscow (1975).

[27] Akulshin, A. A., V. I. Shcherbakov, and I. R. Yarovoy. "Modeling the Flow Distribution and Control Vodopjanikha Stations on Mastroianni Stage." Proceedings of the Southwest State University 22, no. 6 (March 27, 2019): 81–91. doi:10.21869/2223-1560-2018-22-6-81-91.

[28] Akulshin, A A, V I Shcherbakov, and A S Uchaev. "Selection of Well Screen Parameters as Aspect of Water Well Design." IOP Conference Series: Materials Science and Engineering 687 (December 10, 2019): 044018. doi:10.1088/1757-899x/687/4/044018.