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Original scientific paper

THEORETICAL AND EXPERIMENTAL STUDY OF MUD INJECTION POROUS DRAINAGE IN FILTERS WITH FLOATING LOADING

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Abstract: The paper discusses up-flow filters with floating loading that intensify the process of filtering water for drinking purposes by improving filtering parameters and reducing power consumption. It is established that the problematic part of such filters are drainage systems. As a result of the analysis of drainage systems, it was found that the most promising material is porous polymer concrete. The proposed construction of drains is based on porous polymer concrete, which increases the reliability and durability of the filters with floating loading. The drainages based on porous polymer concrete, which intensify reliability and working life of filters, are offered. Mathematical model of the mud injection process of lower polymer concrete drainage with suspended matters, kept in damp water is designed. Experimental studies have shown the validity of the obtained model.

Keywords: filters with floating load; mud injection; polymer concrete drainage

1 INTRODUCTION

Water filtration through grain loadings is the most popular way of getting necessary water quality. Over the last years, the fast filters with floating loadings, which have a number of advantages in contrast to filters with sand loadings, have been spread due to the possibility of the reception of necessary quality water under the worst qualitative features of source water, absence of the capacities and pump for keeping and presenting of washing water, smaller number of utility systems and valves and pumping.

The most spread are filters with floating loadings with rising flow. The main advantage of such filters is that washing is produced by clean water from upper loading space. In the case of the lack of washing water, the upper loading spaces of several filters are united.

The filters include the upper drainage, consisting of metallic lattices with micromesh, expanded polystyrene loading and lower drainage produced of perforated asbestos-cement or plastic pipes.

The problematic part of such filters is the drainage system [2-4] due to the corrosion of metallic element of upper drainage-distributing system and to carrying away resin charge, which occurs quite often.

There are designs of these filters with drainage systems in the form of slotted pipes or caps. However, it is worth noting that these drains are not widely used due to the high costs [1].

According to the analysis of drainage systems in [1], the most promising material for drainage is porous polymer concrete. The reliability of the drainage systems from porous polymer concrete has been repeatedly proven not only in laboratory conditions, but also at the existing water treatment plants [5].

The polymer concrete material produced from granite gravel and epoxy resin of the mark ED-16 or ED-20is allowed by the Ukrainian Ministry of Health to be used in systems of drinking water-supply [5].

The use of polymer concrete drainage in filters with floating loading completely prevents the entrainment of loading grains, it does not contain metallic elements, and also reduces the overall height of the filter. However, the main issue that arises when using these structures is their possible mud injection with polluted water.

The novelty of this article is to develop the structures of polymer concrete drainage systems (section 2), to create a mathematical model of mud injection porous drainage with polluted water (section 3), and to confirm the mathematical model in the laboratory (section 4).

2 THE DRAINAGE SYSTEM OF A POROUS POLYMER CONCRETE IN FILTERS WITH FLOATING LOADING

In filters with floating loading, upper draining-distributing system can be made in the form of polymer concrete slabs put on supporting designs. Polymer concrete aggregate fineness is selected to prevent loading being carried away and to provide sufficient capacity discharge.

Lower drainage system can be made in the form of polymer concrete drainage tray-type [5], in which porous plates pack on supporting concrete walls, forming a pallet. Given design prevents carrying away filtering loading, provides the uniform collection of washing water and supply of damp water on filtration, as the bottom of the drainage has a variable section on length with the slope to collecting channel [6]. The thickness of upper and lower drainage porous polymer concrete layer is not more than 60 mm, and aggregate fineness is 3-5 mm.

General scheme of such filter is given in Fig. 1.At filtration, the source water is supplied to a lower drainage-distributing system 2, where it is distributed on the filter uniformly, gets through expanded polystyrene loading 1 and accumulates in the upper loading space, where it is drained off on pipe line 5 beyond the filter. At a wash-off, loading is prevented by upper drainage system 3. When washing, cleaned water from the upper loading layer moves downwards, washing off suspensions expanded polystyrene loading 1, and then is gathered in lower drainage-distributing system 2 and is conducted to pipe line 6.

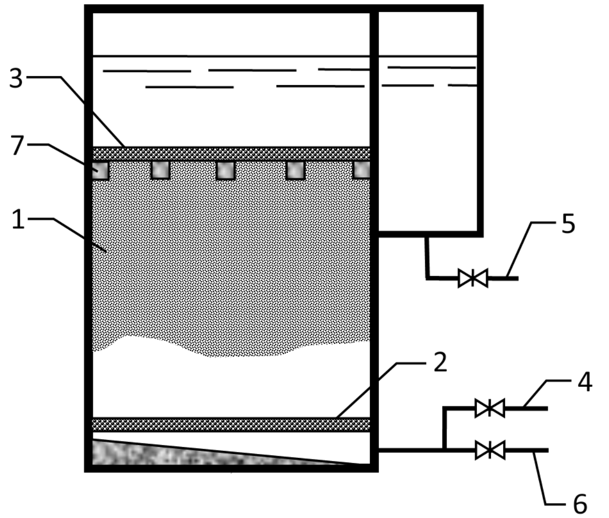

Figure1 The Scheme of the filter with floating loading with rising flow: 1 - floating loading; 2 - lower drainage system from porous polymer concrete of tray-type; 3 - upper drainage system from porous polymer concrete; 4 - supply of source water; 5 – product water bleed-off; 6 – bleed-off of wash water; 7 – supporting structures.

In the process of expanded filter polystyrene service with porous drainage, mud injection with suspension may occur, kept in damp water that will lead to the growing resistance. Therefore, this requires studying the mud injection process.

3 MATHEMATICAL MODELS OF THE DRAINAGE MUD INJECTION PROCESS WITH SUSPENSION

The process of low-concentrated suspension filtration through porous grain layer was studied by many authors. However, the model developed by D. M. Minc [7] is considered the most reliable. According to it, simultaneous removing of water contaminations and taking off earlier stuck particles occur under the influence of hydrodynamic power of the flow. The kinetics of this process is described by means of equations:

$$\frac{\partial \rho}{\partial t} = bVC - a\rho, \tag{1}$$

where $\rho(x, t)$and $C(x, t)$ – a mass concentrations setting in porous layer and suspension in fluid phase, variable on the coordinate x and at time t; b and a – parameters of filtration, defining intensity of the adhesion and particles take-off and depending from the filtration velocity V, layer density ρ, grains diameter and suspension characteristics adequately. Besides, D. M. Minc used the equation of the balance material under constant filtration velocity:

$$\frac{\partial \rho}{\partial t} = -V\frac{\partial C}{\partial x}, \tag{2}$$

The Eqs. (1) - (2) are solved at the condition:

$$C(0, t) = C_0;\ \rho(x, 0) = 0, \tag{3}$$

The solution of the system (1) - (3) and multiple experiences have enabled [6] obtaining the methods of technological modeling of the filtration process. Dependencies of filtration parameters have been found - a and b from velocity and grains size loadings d, typical for natural water purification practice.

At filtration of source water in filter with floating loading, polluted flow at the beginning gets through lower drainage, consisting of porous layer of coarse-grained material of small thickness. As suspension sizes of the particles are significantly smaller than the size of the pores ($d_B/d_n \leq 1$), arising of the film from contamination on the partition surface is improbable. Evidently, resistance increasing will occur here in account of mud injection of porous space inside the layer.

In solving the problems, in accordance with filtration of polluted suspension through coarse-pore layer, the change of the overall amount of sediment setting at time is the most important, which can influence the carrying capacity of the porous layer. Less significant is the change of suspension concentration and setting on the layer thickness.

Such an approach allows simplification of the description of the mud injection process significantly and presupposes that suspension concentration on the layer thickness is slightly changed, i.e. $C \approx C_0$.

The conditions for such admissions are:

– Small thickness of the partition (up to 10-20 calibers of grains);

– Big (in ~3-5 times) fineness of grains in contrast to water purifying loadings filters.

In accordance with formula (1), the major effect in purifying the porous layer will be at the beginning of the cycle, when $\rho = 0$; in such a case:

$$C / C_0 = \exp(-bx), \tag{4}$$

Parameter bx according to D. M. Minc is proportional to value:

$$B = \frac{x}{d} Re^{-0.7},$$

where $Re = Vd/\nu$ – a number of Reynolds, ν – kinematic liquid viscosity.

In water purifying on high-rate filter x/d value, the order is $(1–2)\times10^3$, but number is usually found within the range 1-4. Then B is a value of the order 10^3. For thick-grained thin layers parameter B = 20-50, consequently, bx for thick-grained partitions decreases 20-50 times in comparison with the loading of water purifying filter. If $b = 5\ \mathrm{m}^{-1}$, and $x = 0{,}7$ m [3], then in accordance with formula (4) $C/C_0 = 0{,}03$. At the reduction of bx 20-50 times, $C/C_0 = 0{,}84–0{,}93$. Consequently, suspension concentration on output from thick-porous fine layer is a little different from the input concentration that confirms the possibility of the suggestion $C \approx C_0$ usage.

In this case, Eq. (1) changes into common differential equation, which is easily integrated. The equation of the balance (2) in these conditions loses its sense and hereinafter is not used.

Taking into consideration the porous layer, which alternately works in mud injection mode, $C \approx C_0 > 0$, and then regeneration – $C \approx 0$. Such mode is typical for the considered problem, i.e. lower porous drainage filter with floating loading. The period length mud injection t_1 and regeneration period $-t_2$ are assumed. Since the flow velocity (as well as its direction) at mud injection and regenerations is different, then filtration periods and parameters will be diverse: for mud injection $-a_1$, b_1, for regeneration $-a_2$, b_2. Sediment content in partition is assumed at the beginning of mud injection ρ_{0k} then, integrating (1), we get:

$$\rho_k = C_0 V \frac{b_1}{a_1} - \left(C_0 V \frac{b_1}{a_1} - \rho_{0k} \right) \exp(-a_1 t), \tag{5}$$

The period of regeneration is described by equation:

$$\rho_p = \rho_{0p} \exp(-a_2 t), \tag{6}$$

where ρ_{0p} - a sediment concentration in porous partition at the beginning of regeneration, defined in (5) at $t = t_1$. The behavior of the change $\rho(t)$ in Eqs. (5) and (6) is shown in Fig. 2.

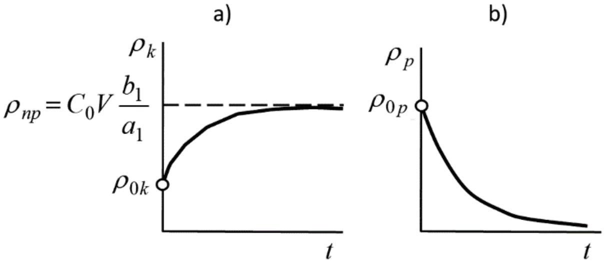

Figure 2 The dynamic pattern of the sediment concentration changes in the porous layer: mud injection (a), regeneration (b)

Run of a curve of mud injection (Fig. 2a) answers the physical ideas about the process: porous medium at $t \to \infty$ is silted up to a determined limit, and not unlimited. The similar effect - a limiting saturation of a porous space, at which velocities in pores are so great that further sediment fastening is already impossible - is noted at the analysis of the full model (1)-(3) D. M. Minc.

The value $\rho_{np} = C_0 V b_1 / a_1$ is identified as limiting saturation [6].

The run of the regeneration curve (Fig. 2b) shows that at $t \to \infty$ full removal of fixed sediment filler in pores can be reached. It can be explained that, as at regeneration (the mode of the fast filter washing), velocities of the motion speed of the fluid flow in the lower porous drainage vastly exceed the velocities at filtration, outwash from porous drainage accumulated for the period of suspension filter cycle occurs.

However, this differs from physical ideas about the process, in accordance to which zones can be in porous space, from where sediment will not be completely removed at given velocities. To overcome this contradiction, it should be considered that there is separated unwashed-out sediment ρ_n, depending on suspension features, structures of the porous medium and filtration velocities, and the above-mentioned description of the process obtained refers only to the washed-up form. It should be noted that suggestion about unwashed-out sediment corresponds to the two-component filtration models [8]. Then, under values ρ_k and ρ_p in Eqs. (5) and (6) we understand surplus on unwashed-out sediment of its amount. Consequently, formulas (5) and (6) can be used hereinafter without correction. It should be noted that ρ_n is a dynamic feature of the system, depending on suspension features, structures of the porous medium and filtration velocities [8]. Thus, to predict beforehand, the value ρ_n is impossible and it is necessary to undertake research studies.

With known parameters C_0, a_1, a_2, b_1, t_1, t_2 and ρ_n, it is possible to find values p_0 after any number of cycles. These calculations can be done manually, but they are easily solved using a PC.

When enumerated parameters remain to be unchangeable from cycle to cycle, it is possible to get quite a simple analytical decision.

$$\begin{aligned} \rho_{pi+1} &= e^{-T_2} \left\lfloor \rho_{np} (\rho_{np} - \rho_i) e^{-T_1} \right\rfloor = \\ &= e^{-T_2} \left[\rho_i e^{-T_1} + \rho_{np} (1 - e^{-T_1}) \right] = \rho_i e^{-T_1} + \rho_1, \end{aligned} \tag{7}$$

where $T = T_1 + T_2$; $T_1 = a_1 t_1$; $T_2 = a_2 t_2$. Sediment content after the first cycle:

$$\rho_{1=} \rho_{np} e^{-T_2} (1 - e^{-T_1}), \tag{8}$$

The Eq. (7) is a geometric progression, consequently, after N cycle:

$$\rho_N = \rho_1 \frac{1 - e^{-NT}}{1 - e^{-T}}, \tag{9}$$

and at $N \to \infty$:

$$\rho_\infty = \rho_1 (1 - e^{-T_1})^{-1}, \tag{10}$$

The full amount of delayed sediment taking into account unwashed-out part is defined by expression:

$$\rho_N = \rho_n + \rho_1 \frac{1 - e^{-NT}}{1 - e^{-T}}, \tag{11}$$

From the expression (11), it is seen that at $N \to \infty$ the amount delayed sediment ρ_N will tend to reach the maximum saturation of porous space. Consequently, in the process of operation, the porous drainage resistance increases to a defined limit, after that it stabilizes.

Thereby, the carried out approximate theoretical analysis indicates the possibility of the porous material use in design of drainages of high-rate filter with floating loading, working with rising flow of water, but its experimental verification is necessary.

4 EXPERIMENTAL STUDIES OF THE MUD INJECTION PROCESS

Validity of the mathematical model was researched using the laboratory installation, the presenting model of the high-rise filter with floating polystyrene foam loading (Fig. 3).

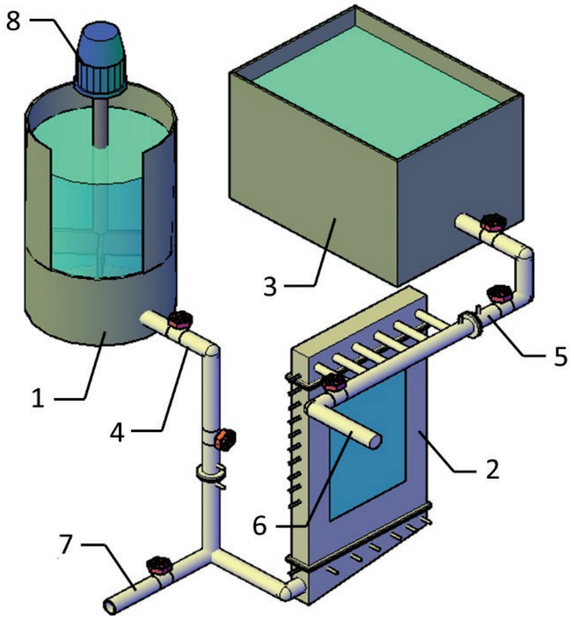

Figure 3 Scheme of laboratory installation for experimental studies of mud injection process: 1 – turbid water tank; 2 – filter; 3 – washing water tank; 4 – water supply pipeline for filtration; 5 – water supply pipeline for flushing; 6 – filtrate discharge pipeline; 7 –wash water discharge pipeline; 8 – mixer.

The installation comprised tank 1, in which water up to given concentration was clouded, and was supplied to the pipeline 4 into filter 2 in sizes 0.6×1.0×0.1 m. Then, passing the lower drainage, filtering loading and upper drainage, water was conducted on pipeline 6 beyond the filter. Supporting constant concentration of suspended materials in tank 1 was done by means of mechanical mixer 8. When washing clean water from tank 3 on pipeline 5 it went through filter 2, moved overhand-downwards and in pipeline 7 was conducted to its limits. For observation of the filtering level loading, the front filter wall was made transparent. Upper and lower drainages were made in the form of polymer concrete slabs with aggregate size 3-5 mm, thickness of 50 mm. Connecting material for polymer concrete aggregate was epoxy of the mark ED-20.

The experiment was conducted in two stages: in the beginning the hydraulic features of the drainages on clean water were researched, and in the second stage, mud injection dynamics with polluted water was researched.

The estimation of mud injection degree of porous polymer concrete was conducted with the comparison of the coefficient of the hydraulic resistance K with its initial importance K_0 [6], defined from the formula:

$$h = K\delta \nu^{2-n} V^{n}, \tag{12}$$

where h – loss of the pressure in the sample; δ – a sample thickness; ν – coefficient of kinematic viscosity of water; n – factor degree, defined empirically.

The coefficient K in formula (12) depends neither on the flow velocity, nor on the water temperature, but it is defined with granulometric composition and laying of grains aggregates, as well as its porosity. At the pores, size changes because of porous layer mud injection, thus the coefficient K will be changed too. At constant filtering velocity and the temperature of the water is $K/K_0 = h/h_0$.

Foamy expanded polystyrene in size $d_{з}$ = 0,63-3 mm, d_{eq} = 1,25 mm and of layer height of 800 mm was accepted as the filtering loading.

Source water was clouded with silt from river Dnestr up to concentration 13-15 mg/l (the turbidity of water defined on photoelectric colorimeter KFK-2) and filtered at the speed of 7m/h. Washing the installation was conducted with clean water with the intensity 16-18 l/s·m^2 during 3-4 min.

While investigating polymer concrete dynamics with coagulated water 0.5% solution of the coagulant was prepared, as which alum sulphate was accepted. The received solution was mixed with previously clouded water and taken into filter 2. The dose of the coagulant varied within the range of 1-5 mg/l.

Fig. 4 presents a graph of the resistance changes of lower porous polymer concrete drainage at time $\overline{K}(t)$ for damp water, and in Fig. 5, using the coagulant dose from 1 to 5 mg/l is presented.

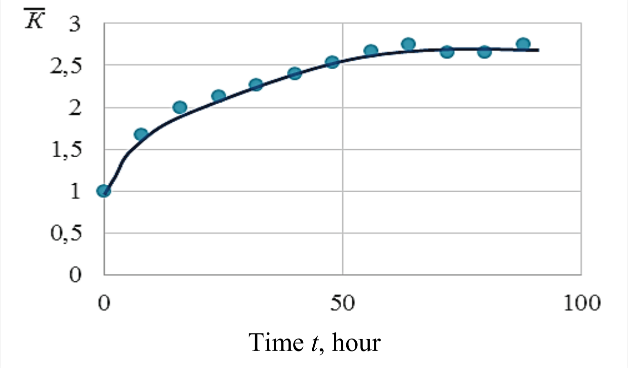

Figure 4 The graph dynamics of low polymerconcrete drainage with damp water.

The analysis of graphics in Fig. 4 shows that resistance of the lower drainage in the beginning grows, but then it is stabilized and hereinafter does not change under given filtering velocities and quality of source water. At that, relative coefficient of the hydraulic resistance grew approximately 2.7 times.

As can be seen in Fig. 5, nature of received curves is similar to graphic on Fig. 4. It should be noted that with the increasing of the coagulant dose, coefficient of the hydraulic resistance is higher. In such a case, mud injection degree and maximum value $\overline{K}$ turned out to be higher here than at filtration of non-coagulated water. This circumstance can be explained, as contact coagulation occurs in polymer concrete pores. In this case, formed sediment has greater size and, consequently, silting up of polymer concrete drainage porous space takes place more intensively.

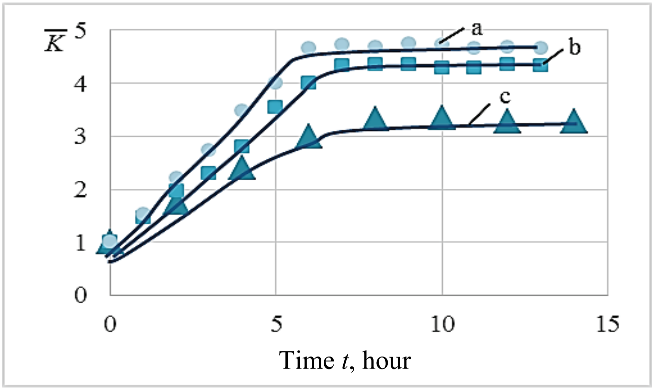

Figure 5 The graph dynamics of low polymer concrete drainage with damp water, using the coagulant: a - a dose of the coagulant 5 mg/l, b - a dose of the coagulant 3 mg/l, c -a dose of the coagulant 1 mg/l.

5 CONCLUSION

According to the analysis of drainage systems, it was found that the most promising material for drainage is porous polymer concrete. Designed drainage constructions based on polymer concrete in filters with floating loading will increase the reliability and durability of such filters. The obtained approximate mathematical description of porous drainages mud injection has confirmed it quite acceptable with experiments in the laboratory conditions and can be used for development of technological modeling methods of such processes.

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