Development techniques such as green roofs and permeable surfaces, aimed at collecting, evaporating and infiltrating rainwater directly in the urban catchment area, which allows reduction of peak flows and runoff volume, as well as the load of discharged pollutants to the rivers.

This paper contains the numerical assessment of LID application (in the form of green roofs and water-permeable surfaces) influence on pollutants concentrations and loads discharged from the selected small urbanized catchment area. The studies were performed for an industrial basin located in Lublin, Poland. Four variants of rainwater management were studied, including zero variant assuming the actual conditions without LIDs application. The other variants assumed variable installation of extensive green roofs and permeable pavements. The numerical calculations were conducted in SWMM 5.2, EPA, USA modeling software for three real rainfall events of different intensity. The performed qualitative calculations covered TSS, TP and TN buildup and washoff from the catchment. The obtained results allowed assessment of LID installation influence on concentrations and loads of pollutants discharged from the selected basin.

ON APPLIED OPTIMIZATION OF IRON REMOVAL FROM DEEP GROUNDWATER USING RAPID FILTERS

Poliakov V.L.[1], Martynov S.Y.[2]

[1] Institute of Hydromechanics of National Academy of Sciences of Ukraine, Ukraine, Kyiv, vpoliakov.ihm@gmail.com

[2] National University of Water and Environmental Engineering, Ukraine, Rivne, s.y.martynov@nuwm.edu.ua

In Ukraine, the reagent-free aeration method is most often used for iron removal from deep groundwater, as it is simpler and cheaper than other physicochemical and biological methods [1]. Based on the results of our own experimental data and the conceptual model [1], we have developed a mathematical model of iron removal consisting of interconnected joint clarification and hydraulic compartments [2]. The mathematical model assumes the presence of two forms of iron retained in the pore space of the packed bed. The clarification compartment is represented by equations describing, first, the transport, adsorption and oxidation of ferrous iron, secondly, the transport and sorption of ferric iron, and also boundary and initial conditions [3].

In general, the applied optimization of the operation of any water treatment filter should consist of choosing the least expensive process control algorithm from a variety of possible ones, ultimately reducing the water treatment cost. It is customary to operate with the concept of a representative filter run (is identified with the standard operation period) for rapid filter-clarifiers [4]. The filter control algorithm, during their prolonged operation, can be interpreted as a sequence of unified filter runs in the first approximation. Therefore, they have the same and the greatest duration considering the technological limitations. Abrasion of the packed bed elements (grains) is not taken into account. Thus, it is often possible to significantly reduce the cost of the filter-clarifier operation by implementing such an algorithm in practice and sometimes prevent excessive deterioration of the filtrate quality.

The objectives of our work at the first step were elaboration of the procedure of numerous consecutive technical and economic calculations of the operation of rapid filters under conditions of deposit consolidation, formation and accumulation of its non-washable component as a consequence; comparative analysis of technological process control algorithms used in the practice of physicochemical iron removal from deep groundwater and on its basis the development of recommendations on selection of the most economical algorithm.

In particular the optimal interval $\bar{t}_f$ (the fixed duration of the filter run) was established, at which the reduced costs will be minimal when the filter is operated in accordance with the regular algorithm (I). Fig. 1 shows three graphs of this dependence, which correspond to the basic values Ψ_0 (the initial ratio of the concentrations of two iron forms), moderate contamination of the water supplied to the filter (C_0 = 1 mg/dm^3).Therefore, it is obvious that the optimal relative value $\bar{t}_f$ is related to Ψ_0 respectively. Thus, it is enough to specify the function $RC\left(\bar{t}_f\right)$ in order to reduce the cost of the treated water to the minimum, using the algorithm I for a given initial ratio between the forms of iron. Approximate values of the desired optimums for $\bar{t}_f$ and RC correspond to the lowest point on this curve. Three values of $\bar{t}_f$, corresponding to the condition $RC = \min$, namely $\bar{t}_f = 800$, are obtained in this case at $\Psi_0 = 1$, $\bar{t}_f = 700$, at $\Psi_0 = 0.5$, $\bar{t}_f = 630$ and at $\Psi_0 = 0$. It is logical that the range of the practical values $\bar{t}_f$ decreases when C_0 increases and Ψ_0 decreases. Finally, this procedure of applied optimization of the technological process becomes impractical if $C_0 \geq 2.5$ mg/dm^3 and $\Psi_0 = 0$, since the filter cannot process such high levels of contamination.

As a result of a detailed analysis of the dependence of the reduced costs on the content and composition of contamination, the method of controlling the technological process, we concluded that the reduced costs with a decrease in the percentage of ferrous iron increase significantly in the case of the regular algorithm and a moderate iron content at the filter inlet. In general, the initial concentration of iron has a significant impact on the value of the reduced costs. The sensitivity of the reduced costs to the contamination composition increases multiple times with its increase. The reduced costs rise non-linearly as a level of contamination and the proportion of the ferric iron form in it increase. In this case, the efficiency of the filter is sharply reduced down to a critical level (the filter is initially unable to function; the regular duration of the filter run is less than the minimum allowable). In such situations, it is necessary to improve the design of the filter, apply multi-stage filtration, etc.

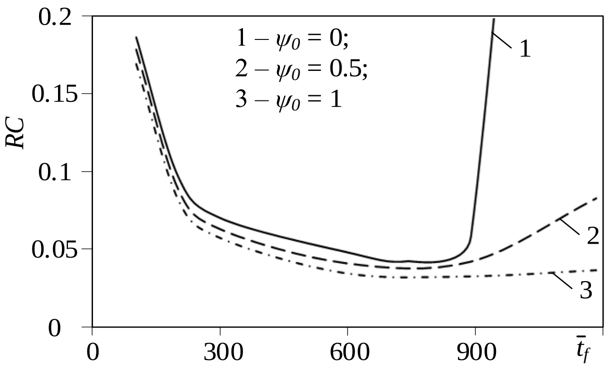

Fig. 1. Dependence $RC(\bar{t}_f)$ at C_0 = 1 mg/dm^3.

One of the effective ways to increase the efficiency of the filters under consideration is a scientifically based choice of their design parameters. The height of the filter bed L and the (equivalent) diameter of the grains of the filtering material d_g are of decisive importance for the duration of filter runs, for the service life of the media, and ultimately for the cost-effectiveness of iron removal. In general, the design parameters of the bed have a serious and varied effect on its ability to remove iron. In principle, it is not difficult to identify this effect and quantify it if the specified parameters are purposefully changed when performing serial technological and economic calculations. Such procedure usually has both positive and negative consequences for the functionality of the filter plants. Thus, due to an increase in height *L*, the adsorption capacity of the bed and, accordingly, its protective ability rise. In this case, the hydraulic resistance of the filter medium increases, but only slightly due to, as a rule, weak contamination of the conditionally added part.

More economically significant are the complications with backwashing the bed, since fluidizing it now requires more energy (in proportion to the increase in *L*). More importantly, the increased consolidation of deposit over time does not allow the adsorption capacity (also increases in proportion to the increase in *L*) to be fully used.

In turn, the hypothetical enlargement of grains, on the one hand, causes a significant improvement in the permeability of the filtering material during modeling (the filtration coefficient is proportional to d_g^2 for a clean homogeneous granular medium). On the other hand, the active surface area of the granular adsorbent is reduced, as well as the number of vacant places for contamination particles. Finally, the kinetics of interphase mass transfer significantly depends on the grain size.

The resulting effect is largely determined by the conditions in which the filter operates and is generally expressed in a corresponding increase or decrease in the intensity of the technological process. It is possible to objectively assess the possibilities for optimizing the cleaning effect of a filter by improving its design by continuously varying the above-mentioned parameters and performing a large body of technological and economic calculations

The subject of economic analysis in applied research is often the reduced total costs, a key indicator of the feasibility of engineering measures in value terms. At the second step, we established such (rational) values of the height of the bed and (equivalent) grain diameter at which the total costs of equipment and operation of the filter were the lowest on the basis of technological and economic calculations. Here, the purpose of the technological and economic analysis of deep groundwater deferrization was to substantiate rational values of the indicated design parameters for both regular and irregular control algorithms. Attention was focused on numerical and analytical calculations of the relationship between the reduced costs *RC* and the dimensions of the bed (height L) and its elements (equivalent grain diameter d_g).

Their ultimate goal was to systematically search for the relative values of $\bar{L}$ и, and $\bar{d}_g$, at which the value RC reaches a minimum. In general, applied optimization of key design parameters can be an important reserve for increasing the efficiency of iron removal at rapid filters. Formally, the dependence of RC on two independent variables was considered, which varied in the above-mentioned ranges. In fact, the impact of $\bar{L}$, $\bar{d}_g$ on economic indicators was assessed separately, so that in fact the subject of the final numerous calculations was continuous functions $RC(\bar{L})$ for fixed values of $\bar{d}_g$, as well as $RC(\bar{d}_g)$ for fixed $\bar{L}$.

First of all, the influence of design parameters on the long-term deferrization of groundwater was considered in the case of deep aeration using the technical and economic analysis. Thus, pre-ferrous iron is almost completely oxidized to the oxide form. The change in the relative concentrations of the suspended (at the outlet $\bar{C}_{he}$) and deposited $(\bar{S}_h)$ particles of ferric iron and head losses in the bed $\Delta\bar{h}$ is strictly described by the following dependencies on the relative coordinate $\tilde{z}$, time $\tilde{t}$ and height of the bed $\bar{L}$

$$\overline{C}_{he}(\tilde{t},\overline{L})=\frac{1}{1+e^{-\tilde{k}_h\overline{C}_{h0}\tilde{t}}\left(e^{\psi\tilde{k}_h\overline{L}}-1\right)},$$

$$\overline{S}_h(\tilde{z},\tilde{t},\overline{L})=1-\left[1-\overline{S}_h^0(\tilde{z},\overline{L})\right]\frac{1}{1+e^{-\overline{S}_{hm}\tilde{k}_h\tilde{z}}\left(e^{\tilde{k}_h\overline{C}_{h0}\tilde{t}}-1\right)},\ \Delta\tilde{h}(\bar{z},\overline{L})=\int_0^{\overline{L}}\frac{d\eta}{f_k\left(\overline{S}_h(\eta,\tilde{t},\overline{L})\right)},$$

where $\overline{L}=L/L_0$; L, L_0 are the variable and reference values of the bed height; f_k is the symbol of the permeability function; $\tilde{k}_h$ is the reduced coefficient of the hydroxide particles deposition rate; $\overline{S}_{hm}=S_{hm}/(n_0C_0)$, S_{hm} is the adsorption capacity of the filter medium relative to the hydroxide particles, n_0 is the porosity of the pure medium, C_0 is the initial iron concentration; S_h^0 describes the initial distribution of the non-washable deposited particles (usually this distribution is almost even and then S_h^0 is constant). The value S_h^0 was calculated every time after the end of the previous filter run using the empirical hydrodynamic resistance factor as function of its duration [5]. The subject of the calculations was the reduced costs, including capital and operating costs, as a function of $\overline{L}$. The initial concentration of trivalent iron in water and constant duration of the filter run changed discretely during the calculations.

Therefore, a technique has been developed and tested in real conditions that allows to rationally select the height of the packed bed and the grain diameter of the filtering material and thereby minimizing the reduced costs for physical and chemical deferrization of deep groundwater.

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