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EXPERIMENTAL INVESTIGATION OF SUBSTANCE CONCENTRATION CHANGES WHEN FILTERING WATER WITH FILTERS

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Abstract. This study presents non-reagent groundwater removal technology at precipitation of substances (iron, ammonium and manganese) in sand filters of an experimental pilot plant (Fig 1). For experimental investigation the groundwater of Pagiriai watering place (Kirtimai watering place junctions) in Vilnius city was chosen. The ground water from this watering place does not meet the requirements of a satisfactory-quality class due to high concentrations of iron and manganese. Experiments were carried out from Aug 13 to Oct 15 of 2003 with the aim of removing iron, ammonium and manganese from groundwater subject to the depth of filters and rate of filtration. Groundwater was aerated and filtered through three experimental filters at a rate of 10, 15 and 20 m/h. The results of the investigation show that the concentrations of studied substances subject to the depth of filters are reduced. The investigated process of iron, ammonium and manganese removal at the filtration rate of 10 m/h ensures water quality that meets the requirements for a very high-quality class. Filtration of aerated water through filter 2 at 20 m/h rate does not ensure the concentration of manganese in the outlet less than 0,03 mg/l. If sand media is not enough unriped for manganese removal (filter 3), the concentration of manganese in the outlet does not ensure a good drinking-water quality class. For the mathematical description of changes in average substance concentrations at typical points polynomials were used. In conformity with this description it is possible to determine variation in concentrations of studied substances (iron, ammonium, manganese) at characteristic points in the filter medium.

Keywords: groundwater, iron, manganese, amonium, average concentration, filtration, non-reagent technology, polynomial, Mathematical Package Maple.

1. Introduction

A water engineer is often faced with a dual problem. On one hand, there is the need for a simple, stable and low-cost water treatment which often means the usage of groundwater. On the other hand, groundwater varies in quality and can show slowly increasing concentrations of iron and maganese. With regard to growing potable water quality standards [1], Fe and Mn removal from groundwater has become a problem of today in Lituanian water works. New Lituanian Hygiene Norms were prepared in November 1998. According to the new NH 24 „Drinking-water indicator analysis, measurement and using methods mandatory requirements“, drinking-water has three quality classes [1]. Very-high-quality water can contain no more than 0,1 mg/l of iron and not more than 0,02 mg/l of manganese. According to the monitored data about water quality in the completed analysis, only 3 % of Lithuanian waterworks have the concentration of Fe ≤ 0,1 mg/l and 39 % waterworks have the concentration of Mn ≤ 0,05 mg/l in raw water. Today there are about 100 iron and manganese removals from groundwater facilities in Lithuania, but the treatment has a low efficiency, and Fe, Mn concentrations remain the same. Manganese is one of the most difficult elements to remove from groundwater [2–6], so only a chemical treatment technology was used up to now. Today the process of Fe, Mn removal only in new Kirtimai, Sereikiškės and Antaviliai waterworks ensures water quality that meets the requirements for a very high quality class [7–9].

Lithuania needs to make a scientific study of iron and manganese removal treatment and supply system.

Physical-chemical processes historically used to remove iron and manganese from groundwater are reviewed and the problems typically encountered are discussed [10–11]. However, at present there is some information in technical literature about the possibility of removing iron and manganese by non-chemical methods, thus reducing the groundwater treatment cost and at the same time improving the quality of potable water [12–14]. This kind of process is new not only in Lithuania, but also in other countries, since its principles were developed only in the last decade [7]. The results of experimental investigations of Lithuanian scientists [7, 8, 15] in Vilnius, Viriai, Kirtimai, Sereikiškės, Kaunas Petrašiūnai waterworks (1996–2002) show that non-reagent iron and manganese removal is an attractive process for Lithuanian groundwater types. But capabilities of the present technology are still not fully revealed and the appreciation of the process optimization is relatively new. There are no formulae to evaluate the depth of the filter bed, when we have a desirable result of Fe, Mn removal. T. Karosas, L. Puteikis on the assumption that iron and manganese removal from water is a complex process introduced calculation of the filter aggregate height using the H. Kittner and L. Bohm formulas [16]. But the results of the experimental investigation show that there is a considerable difference between the calculated value and the experimental values giving the filtration aggregate height. Experiments were carried out with the aim of increasing knowledge and providing answers to questions related to the process that takes place in the filter bed while removing Fe and Mn from aerated underground water by one-power filtration and to suggest formulae to tally up extange of substance (Fe, NH_4, Mn) concentration.

2. Object and techniques

For the experimental investigation underground water from Pagiriai watering place (Kirtimai watering place junctions) of Vilnius was chosen.

The properties of raw water from this watering place are like the properties of water from other Lithuanian watering places and meet almost all the requirements except those for the concentration of iron and manganese (Table 1). Indicatory analyte values of raw water lead [3, 8] to remove Fe, Mn from water in one-step filtration. Because manganese oxidation and consequent precipitation was found to be strongly dependent on NH_4 iron concentration in water, NH_4 removal from aerated water was investigated too.

The pilot plant consisted of three 150 mm diameter and 1800 mm high filters, a stream equipment, an aerated water tank, a filtrate tank, an air blower, pumps, connected piping, fittings and process instrumentation. The filters 1 and 2 were filled with 0,71–2,0 mm quartz sand medium. The medium of the filters was taken from one of Druskininkai water treatment plants. Therefore, the medium was active (for biooxidation) and had enough microorganisms to remove manganese. Filter 3 was filled with a new quartz sand medium. There were 200 mm gravel layers following a sand bed in the filters. The filters were provided with taps for water sampling at different filtration aggregate heights (Fig 1).

Raw groundwater passing through the stream equipment was supplied to filters. Aerated water was filtered through experimental sand filters at a rate of 10, 15 and 20 m/h. The filter medium was backwashed once every 72 hours by raw groundwater for 10–15 minutes, backwash rate v = 40 m/h. The decision to backwash filter medium only with water was taken in order not to disturb iron bacterial growth. The head loss development was recorded logging of data. Head loss in filters medium was measured with the help of pressure gauges installed on the filtration column. Filtration rate v (m/h) was determined dividing aerated water yield Q (m^3/h) through the filter by the plan area of filter medium, i e: v (m/h) = Q (m^3/h) / S(m^2), when $S = \pi d^2$. The values of Fe, NH_4 and Mn ion concentration were evaluated by the „MERCK“ system „Aqua – quant“ tests. Concentration of dissolved oxygen in water was evaluated by oximeter WTW Oxi 330/SET, pH and temperature were measured by WTW gauge pH 325 – B/SET – 2. The polynoms describing range concentration of

Table 1. Chemical analysis of raw water at Kirtimai waterworks in Vilnius

Data	Water quality indicators														
	Calcium, mg/l	HCO_3, mg/l	Dry solids, mg/l	Conductivity, µs/cm	Permanganate value mg/l	Total alkalinity, mg – ekv/l	H_2S, mg/l	Aggressive carbon dioxide, mg/l	Amonium, mg/l	Total manganese, mg/l	Total iron, mg/l	Oxygen, mg/l	Eh, mV	pH	Temperature, °C
1997–2000	52,1–70,1	–	218–380	–	2,7	4,0–5,2	–	–	0,15	0,15	–	–	–	7,15–7,53	7–10,2
2000 05 12	59,6	312	–	–	0,52	5,1	0,095	–	0,12		2,14	0,1	25	7,54	9,6
2001	–	–	–	530	1,7	–	–	–	0,46	0,08	1,28	–	–	7,43	8,7
2003 08	–	–	–	–	–	–	–	–	0,5	0,2	1,2	–	–	7,5	8

substances (Fe, NH_4, Mn) in filtered water were calculated by the Mathematical Package Maple.

3. Experimental results

Investigation at the site, i e in Kirtimų watering place experimental stand, and the operation of the experimental pilot plant were started on 13 August 2003. Raw water was supplied and filtered through all the three filters at a filtration rate of 10 m/h. The effect of iron was observed on the same day. The concentration of iron 0,1 mg/l in filtered water was evaluated in tap 4 (at a 1,4 m filter bed depth). Manganese oxidation and removal were not so efficient. For the first time the concentration of Mn in filtered water (taps 6) from filters 1 and 2 was 0,02–0,03 mg/l. Filter 3 loaded with fresh quartz sand medium was got unriped for manganese removal and less (concentrations of 0,1 mg/l Mn and 0,1 mg/l NH_4 in filtered water from tap 6) effect was achieved. Good results of iron removal can be explained by physical and biological processes when there is 6 mg/l concentration dissolved oxygen in aerated water from tap 1 and 11 mg/l O_2 in filtered water from tap 6 (pH ≈ 7, 5). There is information in technical literature sources [8, 12, 15] that sand filter medium must be enough mature for Mn removal from water (during 3 months). Therefore, the concentration of manganese was 5 times higher in filtered water from filter 3 than the requirements for water of a very high quality [1]. Since 20 August, when in raw water there were 0,7 mg/l Fe, 0,2 mg/l Mn and 0,45 mg/l NH_4, filter 1 was working with filtration rate of 10 m/h and in filtered water from tap 6 concentrations of Fe, Mn and NH_4 ensured water quality that was equal to the class of a very high quality. The filtration rate of filter 2 increased up to 20 m/h. In the filtered water from filter 2 (tap 6) 0,02 mg/l Fe and 0,03 mg/l remained. There was still too much Mn and NH_4 in filtered water from filter 3.

Since 25 August filtration rate of filter 1 elevated to 15 m/h, and since 29 August – to 20 m/h. The experimental data of substance concentration changes show that in filtered water from filter 1 0,1 mg/l Fe and 0,01–0,03 mg/l Mn was left. It could be explained that the process of Fe, Mn and NH_4 removal from water became steady. Removal of Mn in filter 3 medium improved at the end of September. There were < 0,1 mg/l Fe, 0,05 mg/l Mn and 0,06 mg/l NH_4 in filtered water (tap 6) from this filter. During measurements head loss in filter media increased by about 1,2 m (with filtration rate of 10 m/h) and by about 3,5 m (with filtration rate of 20 m/h).

4. Treatment of experimental results

Experimental investigation was carried out during two months. The concentration of substances (Fe, Mn ir NH_4) was established 11 times in raw water, in the taps of 3 filters and in filtered water.

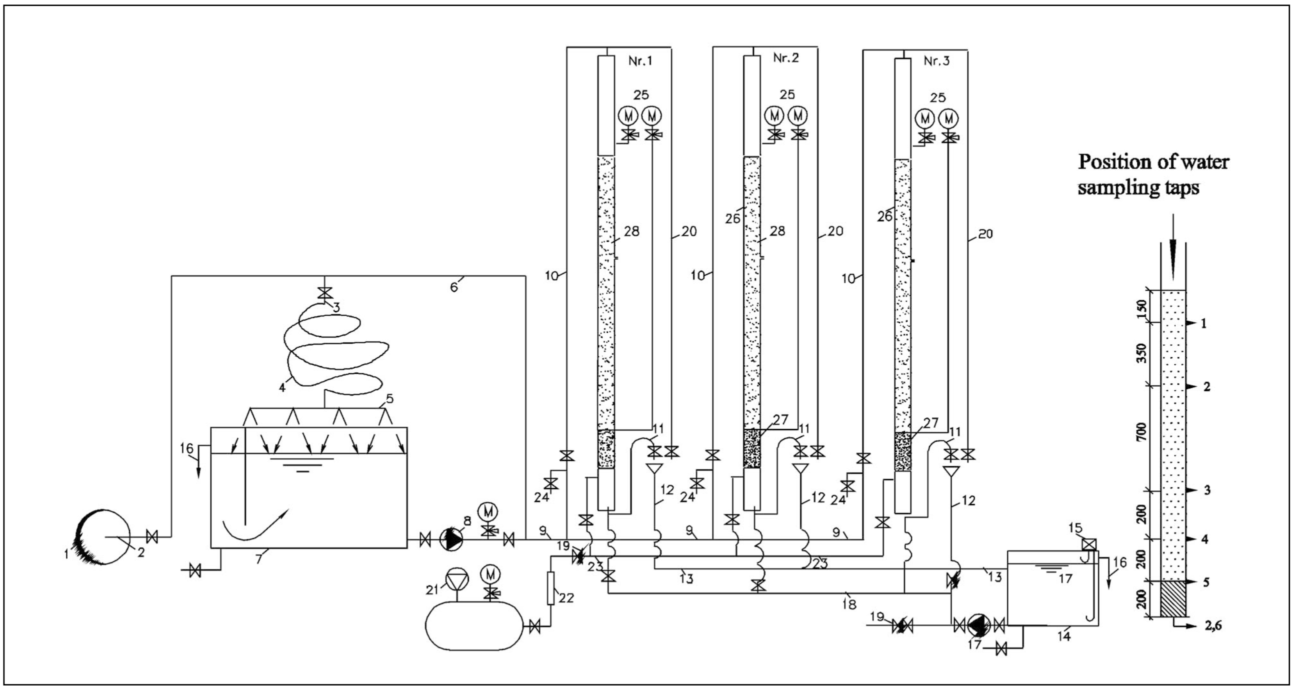

Fig 1. Scheme of experimental pilot plant principle: 1 – an underground raw water main; 2 – incision in to water – main; 3 – raw water supply; 4 – flexible pipe; 5 – streams equipment; 6 – a roundabout line; 7 – aerated water tank; 8 – aerated water feeding pump for filter models; 9 – aerated water distribution line; 10 – water feeding pipeline for filter models; 11 – a filtrate pressure pipeline; 12 – a filtrate pipeline; 13 – a backwash discharge pipeline; 14 – a filtrate tank; 15 – a water level relay; 16 – overflow pipes; 17 – a filtrate pump; 18 – a backwash supply pipeline; 19 – backwash valves; 20 – a backwash discharge; 21 – an air blower; 22 – a rotameter; 23 – a pressed air pipeline; 24 – water sampling taps; 25 – pressure gauges; 26 – water and sand sampling taps; 27 – gravel layers; 28 – qartz sand bed

It is possible to show changes in three substances concentration at the typical points of filters and in raw and filtered water (Fig 2). So at present only average concentration is presented in this paper (instead of 33 graphs). Average concentration at typical points is:

$$\bar{c} = \frac{1}{n} \sum_{i=1}^{k} c_i m_i \, , \qquad (1)$$

where c_i – concentration of substances at typical points, m_i – probability at recurrence of concentration; n – number of days; k – number of different values of concentration.

The averages of the concentration of substances (Fe, Mn ir NH_4) are described in Table 2. Changes in the average concentration of the substances at typical points (raw water, taps of filters, filtered water) with depth are presented in Fig 2. We can see from the graph that all the three filters are operating in a similar way, the average concentration of the substances under study dependent on the depth of filters is decreasing.

It is possible to describe mathematically the average concentration of substances $\bar{c}$ at typical points using polynomials:

$$\bar{c}(x) = a_o + a_1 x + \ldots + a_n x^n = \sum_{j=0}^{n} a_j x^j \, , \qquad (2)$$

where at $a_n \neq 0$, n – non-negative whole digit, named of one – variable x n-th degree polynomial.

$a_j, (j = 0, 1, \ldots, n)$ consequently polynomial $\bar{c}(x)$ multipliers and multiplier a_n – consequently general multiplier. The digit n – consequently degree of polynomial $\bar{c}(x)$ and marked $\deg(\bar{c})$.

With the aim of using the polynomials mentioned above, we will make use of Mathematical Package Maple [17, 18]. Maple – one of the best mathematical packages, computer algebra (symbolical and analytical) scale of notation. Having a few thousand of various operators, Package Maple allows us to do sums algebras, mathematical analysis, differential equations, statistics and many other ranges of problems.

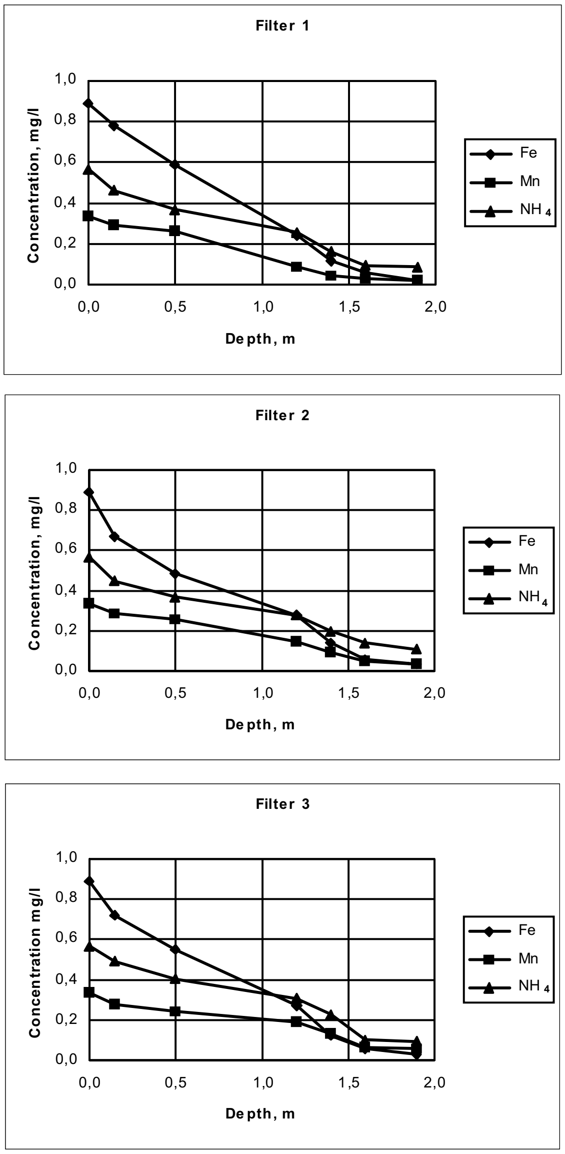

Fig 2. Average concentration of substances (Fe, Mn, NH_4) in the filters:
0,00 m – raw water; 0,15 m – tap 1; 0,50 m – tap 2; 1,20 m – tap 3; 1,40 m – tap 4; 1,60 m – tap 5; 1,90 m – filtered water

Table 2. Experimental data of substances (Fe, Mn, NH_4) in the filters by days

Depth, m (number of tap)	Average substance concentration (for 11 days), mg/l								
	Filter 1			Filter 2			Filter 3		
	Fe	Mn	NH_4	Fe	Mn	NH_4	Fe	Mn	NH_4
0,00 (raw water)	0,89	0,34	0,57	0,89	0,34	0,57	0,89	0,34	0,57
0,15 (tap 1)	0,78	0,30	0,46	0,67	0,29	0,45	0,72	0,28	0,49
0,50 (tap 2)	0,59	0,27	0,36	0,48	0,26	0,37	0,55	0,24	0,40
1,20 (tap 3)	0,24	0,09	0,26	0,28	0,15	0,28	0,27	0,19	0,31
1,40 (tap 4)	0,12	0,04	0,16	0,14	0,09	0,20	0,12	0,13	0,23
1,60 (tap 5)	0,06	0,03	0,10	0,06	0,05	0,14	0,06	0,07	0,10
1,90 (filtered water)	0,02	0,02	0,09	0,04	0,04	0,11	0,03	0,06	0,09

The polynoms are presented in Table 3.

With the aim of deciding which filter from the three ones operates more efficiently, Fig 3 is presented. We can see average concentrations of substances (Fe, Mn ir NH_4) in filtered water, and filter 1 worked better than filters 2 and 3. In filtered water from this filter the concentrations of substances are the lowest. Fe and NH_4 concentrations are the higest in the filtered water from filter 2, and Mn – in filtered water from filter 3.

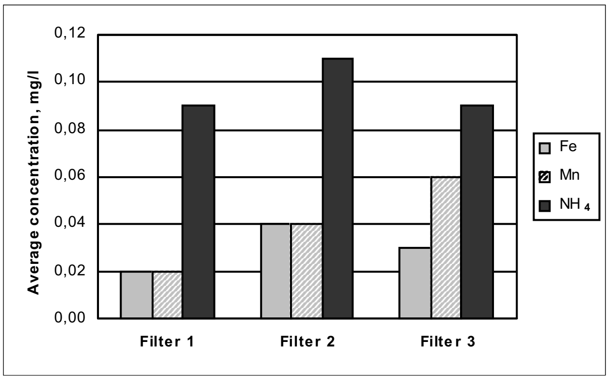

Fig 3. Average concentration of substances after filtration

Filtered water from filter 1 ensures quality that meets the requirements of a very high quality class (in filtered water Fe ≤ 0,1 mg/l, Mn ≤ 0,02 mg/l, NH_4 ≤ 0,5 mg/l). Water from filters 2 and 3 meets the requirements for Fe and NH_4 concentration and does not meet the requirements for Mn concentration.

Frequency of average concentration of substances (Fe, Mn ir NH_4) after filtration is presented in Fig 4.

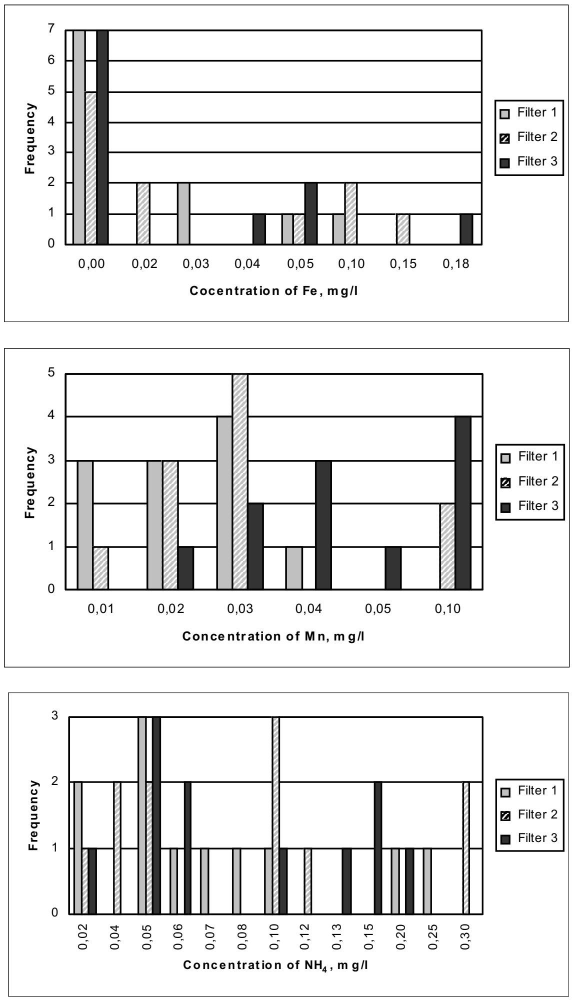

Fig 4. Concentration frequency of substances after filtration

Table 3. Polynoms describing concentration of substances at characteristic points of filters with depth

Substance	Polynom describing concentration (mg/l) of substances (Fe, Mn, NH_4) at characteristic points of filters with depth (where *x* – depth of characteristic points)		
	Filter 1	Filter 2	Filter 3
Fe	$Fe = 0,89 - 0,65x - 1,67x^2 + 5,02x^3 - 6,54x^4 + 3,47x^5 - 0,65x^6$	$Fe = 0,89 - 1,68x + 0,95x^2 + 4,39x^3 - 7,61x^4 + 4,27x^5 - 0,80x^6$	$Fe = 0,89 - 1,16x - 0,74x^2 + 7,46x^3 - 10,85x^4 + 5,95x^5 - 1,13x^6$
Mn	$Mn = 0,34 - 0,36x + 0,63x^2 + 0,01x^3 - 1,26x^4 + 1,04x^5 - 0,24x^6$	$Mn = 0,34 - 0,44x + 0,69x^2 + 0,10x^3 - 1,09x^4 + 0,76x^5 - 0,15x^6$	$Mn = 0,34 - 0,51x + 0,76x^2 - 0,07x^3 - 0,55x^4 + 0,30x^5 - 0,04x^6$
NH_4	$NH_4 = 0,57 - 0,74x - 0,57x^2 + 5,08x^3 - 6,96x^4 + 3,62x^5 - 0,66x^6$	$NH_4 = 0,57 - 1,00x + 1,29x^2 + 0,70x^3 - 2,42x^4 + 1,50x^5 - 0,29x^6$	$NH_4 = 0,57 - 0,77x + 2,13x^2 - 4,55x^3 + 5,32x^4 - 2,99x^5 + 0,62x^6$

5. Conclusions

1. As we can see from the results of experimental investigation (Table 2 and Fig 2), the average concentration of studied substances subject to the filter depth is decreasing.

2. The investigated process of iron, ammonium and manganese removal at the filtration rate of 10 m/h and 15 m/h ensures water quality that meets the requirements of a very high quality class when the filter medium is unriped for Mn removal.

3. Filter 3 was well-stocked with fresh quartz sand medium which was not active, and good manganese removal results were not obtained during two months.

4. Filtration of aerated water through filter 2 at the 20 m/h rate does not ensure the concentration of manganese in the outlet lower than 0,03 mg/l.

5. For the mathematical description of changes in average substance concentrations at typical points, polynomials were used. In conformity with such a description it is possible to determine the concentration variation of studied substances (Fe, Mn, NH_4) at characteristic points of the filter medium.

6. Filtered water from filter 1 is of the highest quality (concentration of all the substances is the lowest). Concentration of Fe and NH_4 is the highest in water from filter 2 and that of Mn – from filter 3 (Fig 3). Filtered water from filter 1 ensures quality that meets the requirements of a very high quality class (in filtered water Fe $\leq$ 0,1 mg/l, Mn $\leq$ 0,02 mg/l, $NH_4 \leq$ 0,5 mg/l). Water from filters 2 and 3 meets the requirements for Fe ir NH_4 concentration and does not meet those for Mn concentration.

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MEDŽIAGŲ KONCENTRACIJOS VANDENYJE KITIMO, KOŠIANT KOŠTUVAIS, EKSPERIMENTINIS TYRIMAS

A. Šaltenienė, O. Prentkovskis

S a n t r a u k a

Tiriama bereagentė priemaišų (geležies, amonio bei mangano) valymo iš požeminio vandens technologija, kai priemaišos sulaikomos eksperimentinio stendo smėlio koštuvuose. Eksperimentiniams tyrimams pasirinktas Vilniaus miesto Pagirių vandenvietės (Kirtimų vandentiekio mazgo) požeminis vanduo. Šios vandenvietės požeminis vanduo neatitinka labai geros klasės geriamajam vandeniui keliamų reikalavimų dėl per didelių geležies ir mangano koncentracijų jame. Eksperimentai vyko 2003 08 13 – 2003 10 15 laikotarpiu. Tirti geležies, amonio bei mangano šalinimo iš vandens rezultatai priklausomai nuo koštuvų užpildo gylio bei košimo greičio. Požeminis vanduo buvo aeruojamas ir košiamas trimis eksperimentiniais koštuvais 10, 15, 20 m/h greičiu. Kaip rodo eksperimentinių tyrimų rezultatai, tiriamų medžiagų koncentracija vandenyje priklausomai nuo koštuvo užpildo sluoksnio gylio mažėja. Tiriant geležies, amonio bei mangano šalinimo košiant vandenį 10, 15 m/h greičiu (1-asis koštuvas) rezultatus, pastebėta, kad iškošto vandens kokybė atitinka labai geros klasės geriamajam vandeniui keliamus reikalavimus. Košiant aeruotą požeminį vandenį 2-uoju eksperimentiniu koštuvu 20 m/h greičiu, nepavyko pasiekti, kad ištekančiame vandenyje mangano koncentracija būtų mažesnė nei 0,03 mg/l. Trečiojo koštuvo naujas smėlio užpildas nėra pakankamai brandus manganui šalinti, iškoštas vanduo pagal mangano koncentraciją neatitinka geros kokybės klasės geriamajam vandeniui keliamų reikalavimų. Medžiagų (geležies, amonio, mangano) vidutinės koncentracijos būdinguosiuose koštuvo taškuose kitimui matematiškai aprašyti taikomi daugianariai.

Raktažodžiai: požeminis vanduo, geležis, manganas, amonis, košimas, vidutinė koncentracija, bereagentė technologija, daugianariai, matematinis *Maple* paketas.

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ИЗМЕНЕНИЯ КОНЦЕНТРАЦИИ ВЕЩЕСТВ В ВОДЕ ВО ВРЕМЯ ФИЛЬТРОВАНИЯ

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Резюме

Исследуется технология безреагентной обработки подземных вод, когда примеси (железо, аммоний и марганец) удаляются из воды фильтрованием через песчаные фильтры экспериментального стенда. Для экспериментальных исследований использовалась подземная вода Пагиряйской водопроводной станции (Киртимайский водопроводный узел). Эта подземная вода не соответствует требованиям, предъявляемым к питьевой воде отличного класса, из-за слишком больших концентраций железа и марганца в ней. Экспериментальные исследования проводились в период 13.08.2003–15.10.2003, исследовался процесс удаления из воды железа, аммония и марганца в соответствии с глубиной песчаной загрузки фильтра и скоростью фильтрования. После аэрации подземная вода подавалась трем фильтрам. Фильтрование происходило на скоростях 10, 15, 20 м/ч. Результаты исследований показали, что концентрация примесей в воде уменьшается в зависимости от глубины проходимой песчаной загрузки. При фильтровании воды со скоростью 10, 15 м/ч замечено, что железо, аммоний и марганец устраняются из воды до такой степени, что качество фильтрата начинает соответствовать требованиям к питьевой воде отличного класса. При фильтровании аэрированной воды через 2-й экспериментальный фильтр со скоростью 20 м/ч не удалось получить концентраций, меньших чем 0,03 мг/л. Для успешного удаления марганца новая песчаная загрузка фильтра должна созреть (в фильтре 3). Пока этого не произошло, вода по концентрации марганца в ней не соответствует требованиям, предъявляемым даже к питьевой воде хорошего класса. С целью математически описать изменение концентрации исследуемого вещества в характерных точках фильтра используются полиномы. С помощью таких описаний можно определить изменения концентрации исследуемых примесей (железа, аммония и марганца) в характерных точках фильтра.

Ключевые слова: подземная вода, железо, марганец, аммоний, средняя концентрация, фильтрование, безреагентная технология, полиномы, математический пакет *Maple*.