



Aušra Mažeikienė

**RESEARCH AND APPLICATION OF INTENSIFICATION
OF ACTIVITIES OF IRON AND MANGANESE OXIDISING
BACTERIA'S FOR DRINKING WATER TREATMENT**

Summary of Doctoral Dissertation

Technological Sciences,
Environmental Engineering and Landscape Management (04T)

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Vilnius „Technika“ 2004

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Aušra Mažeikienė

**GELEŽĮ IR MANGANĄ OKSIDUOJANČIŲ BAKTERIJŲ VEIKLOS
INTENSYVINIMO GERIAMAJAM VANDENIUI RUOŠTI TYRIMAS IR
PRITAIKYMAS**

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Introduction

The problem

The analysis of groundwater, treated for drinking purposes in Lithuania show, that it contains too much iron and manganese, which quantity at some (in Nida, Preila, Daugai, Molėtai, Širvintos) places exceeds the Lithuanian hygienically acceptable standards up to six times following the value of manganese concentration. There are installed approximately 100 plants of iron removal from the groundwater in the Lithuanian domestic water-supplies, but requirements of HN 24:2003 for drinking water meet only some of them, such as e.g. Antaviliai, Sereikiškės and Kirtimai sites in the Vilnius city. Reasons of ineffective work are different: unsuitable technology (in Neringa sites), equipment of water supply is working at negative operating conditions, filter media of open filters is unsuitable, there are some organic substances in the groundwater, etc. Also there are water treatment plants, where iron is being removed effectively, but not manganese. Removal of manganese from the groundwater is much more complicated, than removal of iron because of much higher resistance of manganese complexes to oxidation and other chemical transformations. Usually for manganese removal from water some special chemical reagents, strong oxidisers are used and some harmful chemical products to human health can be formed, also the costs of water treatment increase. High investment is necessary for manganese removal. Therefore this problem must be solved in complexity by improvement of water quality, following removal manganese and iron at the same time.

Approximately 29 millions Lt were spent for construction of new (during 2001) Antaviliai manganese and iron removal plant in Vilnius. This water-treatment plant has a simplified non-reagent technological system of water aeration, after that water is being filtered through filters media of quartz sand in open filters. Although such equipment ensure water of a quite high quality, but the filtration rate is about 5-6 m/h only, and the volume of water, used for one filter wash (there are 8 filters) amount is up to 350 m³. These technological parameters are to be improved.

A new biological technology of iron and manganese removal from the groundwater begins to be used at few technically advanced countries (USA, Canada, Germany, Denmark, Finland, and Japan a/o.). This technology can ensure high quality and natural characteristics of drinking water and save some for investments, therefore it is a promising one if compared with other technologies in use. The new technology is based on the vital activity of microorganisms (iron bacteria's), which is of high importance for change of iron and manganese forms and concentration in the water. The biological removal of iron and manganese from the groundwater by use of slow filters is widely used in Finland. But the filtration rate is 0,05-0,3 m/h only. In the outside buildings filters the water can be covered with ice, so such equipment can work at sufficiently soft

climatic conditions. Therefore the remain the necessity of improvement of technological parameters.

This property of iron bacteria – to oxidise and adsorb the mentioned water admixtures is used in the drinking water treatment equipment. In the cultures of iron bacteria's at certain conditions their can took place also the reduction processes. All these processes are still not properly examined. Because of diversity of microorganisms, which conditionally are numbered among the group of iron bacteria's, their role in the iron formation in the groundwater can be very different.

To ensure of possibly reliable sanitary quality of drinking water and maximum saving of its natural characteristics oxidising technologies for removal of iron and manganese admixtures from the groundwater would be reliable. Therefore it is armful to examine by the bacteriological aspect the process of a non-reagent removal of iron and manganese from the groundwater and to adjust the optimal technological process to the activities of the iron bacteria, used for removal of the mentioned iron and manganese.

The work relevancy

Iron and manganese – the main components in Lithuanian groundwater, not following requirements of norms regulate the water quality. Now the most advanced method for removal of the mentioned substances is non-reagent technologies, where the important role is the on biological oxidation. However there are not established and not optimised such technological parameters of biological oxidation as filtration rate, duration and intensity of filter backwashing. Dependency of activity of iron bacteria's on the mentioned factors is not fully examined yet and not used, what is urgent nowadays.

The work objective

Examination of the non-reagent process of iron and manganese removal from the groundwater by bacteriological aspect. Establishment of the main technological parameters of biological process. Research of regularity of the iron bacteria's activities and methods of intensification of these activities. Proposals of the most advanced technologies of biological oxidation for removal of iron and manganese from the groundwater.

The main tasks of the work

- identification of bacteria, oxidising iron and manganese in Lithuanian water treatment plant;
- quantitative estimation of iron bacteria and examination of their distribution in some depths of filter media;
- analysis of factors, having influence on efficiency of activity of the bacteria in the process of iron and manganese removal of the water being filtrated;
- proposals of methods for intensification of iron bacteria activities.

Novelty of the work

This work includes experimental examination of the hypothesis, affirming that bacteria's, oxidising iron and manganese can grow in some Lithuanian water treatment and can increase the removal of iron and manganese substances from the water. The novelty is that the method of identification and cultivation of iron bacteria's presented in the foreign scientific publications was improved and adapted to research of such micro-organisms existing in the quartz sand filter media in the Lithuanian equipment of water treatment plant. For the first time in Lithuania there was examined quantitative distribution of iron and manganese oxidising micro-organisms in the sand thin coating in filters of drinking water purification and were found regularity and dependency of iron bacteria's activities on the main technological parameters in removal of iron and manganese substances from the water.

Practical applied of the obtained results

The methodology of identification and registration was improved and adapted to research of iron and manganese oxidising micro-organisms in the Lithuanian water treatment plant of drinking water purification.

It was established, that Lithuanian groundwater (from most of water works, some water analyses are similar to analysed water of Antaviliai and Kirtimai water treatment plants) is fit for physical- biological removal of iron and manganese and it naturally has iron bacteria's.

Experimentally there were found the main technological parameters, increasing activities of iron bacteria and enabling the proper removal of iron and manganese from water in the case of characteristic, suitable for this purpose.

Variation of iron, ammonium ions and manganese concentrations in the water was mathematically described by polynomials as the water filtering through the deeper layers of filters media.

Using the obtained results as a basis there were proposed recommendations for improvements of a new technology (removing iron and manganese substances from water only by physical and biological processes) into those plants of drinking water purification, where water quality characteristics are similar to ones of the examined water works in Antaviliai and Kirtimai.

The results dissemination

The main principles of this work and results of the scientific work were presented and discussed on three international and six republican conferences. Two articles on the subject of this work are published in the rewired scientific journals, one more article is accepted for publication.

DESCRIPTION of the work

1. Analytical review of scientific-technical literature on the subject of specific features of iron and manganese oxidising bacteria's and their use for purification of the groundwater into a high quality drinking

A wide range of autotrophic and heterotrophic organisms, related to oxidation processes of iron and manganese is attached to a class of iron bacteria's. They do not form a special physiological group with other „classical” species of iron bacteria's (*Gallionella*, *Leptothrix*, *Sphaerotilus*, *Siderocapsa*, *Metallogenium*, *Ochrobium* a/o.), iron and manganese oxides are accumulated by more than 20 species of bacteria's, microscopic algae's and microscopic fungi. Accumulation of metallic combinations are predetermined by interaction of oxidised ferrous iron or manganese with accumulated in the bacterial capsules or integument products of metabolism (Corstiens a/o., 1992; Gorlenko a/o., 1997– in Russian). So the development of reaction is predetermined by character of ecological specificity. Final products of reaction are influenced by rate of H_2O_2 formation because of microorganisms breathing and because of activity of catalysis. These factors depend on concentration of organic substances in the solution and on physiological status of the bacterial population. Physiological meaning of reactions, described above is detoxification of toxic products of metabolism. Because the product of metabolism H_2O_2 appears in many biological reactions, this fact explains the wide spreading of iron bacteria's in different biotops. As existing data show the volume of such organisms can reach 70-90 % of all bacterial plankton amount (Gorlenko a/o.; Dubinina, 1981– in Russian). Clearly, their geochemical activities have a great influence in cyclic transits of iron and manganese in the nature and in the ore formation. Accumulation of oxides of these metals sometimes exceeds the weigh of cells in ten times as much and more.

Transformations of biological oxidation are not sufficiently examined, therefore the heat amount can be calculated rather relatively, however the bacterium, which can precipitate iron and manganese must process 6 times more manganese than iron for extraction of the same energy amount. Finnish scientists Lundgren and Dean (1979) describe conditions, suitable for the growth and energetic activities of the iron bacteria. Activities of all species of iron bacteria's need a small amount of energetic resources and they have more inclination to dwell fastened themselves at a surface than floating in a solution. So existence of various surfaces stimulates the growth of bacteria's. For sediments of iron and manganese an influence there have such factors, as pH, temperature, source of electrons, bacteria's, amount of carbon, nitrogen and phosphorus, combinations of iron and manganese in water and their concentrations; dissolved oxygen and ions HCO_3^- , Ca^{2+} , NH_4^+ and pH (Hatva, 1989). It seems, that organic substance in the main obstacle in iron removal from water, for it forms conditions for iron dissolution. The relation of nutritious matter C:N:P in the medium of growth of the iron bacteria would be equal 125:11:1. Higher temperature stimulates

activities of the bacteria, but even at +2°C there were observed sedimentation of iron and manganese as a result of activities of the iron bacteria. The optimal conditions for growth of manganese sedimenting bacteria are when E_h is equal from +550 to +600 mV (25°C). Medium with, for instance, pH < 5.5-6.0 and E_h < 400 mV is unit for active growth of *Metallogenium* (Hatva, 1989), however iron oxidising bacteria grows well in such conditions. As pH increases, sedimentation of iron as well as manganese is going on easier. In acid waters (pH < 6.0) manganese sediments do not appear without alkalisation even if *Metallogenium* are present.

There is very small amount information about iron bacteria's in Lithuanian scientific issues. There was examined only they're spreading in layers of Lithuanian fresh groundwater. Scientists of Lithuanian Geological Institute suggest the following interval of optimal cultivation conditions of iron bacteria's: temperature – 8-12 °C; pH – 7-7.5; E_h – 125-200mV, rH – 19-22 [$rH = (E_h / 29) + 2$ pH], mineralization of water – 300-600 mg/l; hardness of water – 5-7 mg-ekv/l. Existing conditions influence the cultivation of bacteria's in complex method: the first two factors stimulate the growth of *Leptothrix* and *Siderocapsa* bacteria; too high concentration of gas in water ($CO_2 > 0.3$ mg/l) makes the grown slower. Most of the iron bacteria's are found in the water-bearing bearing horizons with residual oxygen concentration until 0.5 - 1.0 mg/l. Forms of iron bacteria, their evolution and quantitative relations depend on factors of environment in the water – bearing horizons. The biomass produced by iron bacteria's results in rapid blocking up of water-supply pipes and filters in water networks, but significance of these micro-organisms positive: they can helps in the better purification of water. Lately in the world practice activities of iron bacteria's begun to be used for Fe and Mn removal from the groundwater used for drinking purpose. Many of German scientists studied processes of physical and biological iron removal from water. There were found that iron bacteria increased up the process of water filtration. German scientists: Krems G., Wasser G., Hunerberg K. established, that iron and manganese bacteria's excrete hard Fe and Mn hydroxides in the case of very low concentrations of oxygen and quickly reduce the capacity of waterworks. It was deserved that in some conditions rate of sedimentation of iron and manganese hydroxides can be significantly increased even using larger gravel grains and under higher rate of water filtration. For use of Fe (II) and excretion of Fe (III) hydroxides the filtration rate suitable to siderophags must be less than 0.1 m/h, and concentration of Fe (II) must be more than 0.2 mg/l. For successful process of oxidation – reduction reaction a proper water potential is important for bacteria's (siderophags). It must be more than 10 mV. If it is less, the microorganisms will remain without sediments. If rate of filtration, concentration of Fe (II) and potential of oxidation – reduction increase and rate of filtration exceed the limiting one, the amount of sediments (Fe (III)) increases. Research performed by Hässelharth U. showed 17 mg/l Fe^{2+} consumption at filtration rate 10m/h. German scientists established, that the

number of active bacteria's can not be reduced more than necessary. When new filters are improved for biological removal of iron and manganese the simplest way of microorganism cultivation is to pass the groundwater containing any species of bacteria's through the filter media. More than 30 years for removal of Fe and Mn from the groundwater there is used some outline for initial water purification and slow filtration in Finland. Finnish scientists Hatva T. and others have suggested a two-phase initial and slow method of iron and manganese removal from drinking water. The first phase decreasing the iron concentration to the level so, that sand filters of slow filtration would not be stuffed up. Conditions for oxidation during the process gradually vary before the chemical and biological iron, ammonium and manganese removal can be applied. Research of Finnish scientists and their experience showed, that biological removal of iron and manganese is sufficient well when filtration rate in the slow filters is 0.1-0.3 m/h. It was found that in the case of use of iron bacteria's for iron removal from water, iron settles down on *Gallionella* and *Leptothrix* bacteria's on the filter media surface, while manganese settles in a lower zone, in the depth of 10 cm or deeper, depending on hydraulic load of the filter. But in some cases up to 50% of manganese is absorbed by iron hydroxides at filter media surface. It was found that if the strong control of water purification is used, the iron bacteria remain adhered to the sand grains and do not decreasing the quality of filtered water. French scientists affirm that because of different conditions for Fe and Mn removal there are necessary usually two stages of filtration. Such complete technology of water purification consists of: initial aeration, filtration, and adjustment of pH (by use of lime, caustic soda), secondary filtration (biological removal of Mn) and final disinfecting. Experimental research of English scientists showed that for biological removal of iron and ammonium are necessary minimum 2 different stages. In works, comparing the biological method with conventional physical and chemical methods of iron and manganese removal from water there are specified the following positive its features: a) size of installations is smaller, because there is higher filtration rate and filtration can be carried simultaneously with aeration in the same premises; b) longer lifetime of filters because of reason of formation denser sediments of Fe and Mn substances; c) more light silt in the washing water, which can be easier dried up; d) there is biggest amount of filtered water, because less amount of water is necessary for filter backwashing, also for backwashing of filter media a raw water can be used; e) chemical reagents are not used; f) quality of filtered water not takes a turn for the lowest; g) less expenses for exploitation. Also there was observed, that in the case, when iron and manganese coexist in complexes with such substances as humic acids, polyphosphates, silicon oxides a. o., which usually complicate application of physical and chemical methods, bacteria will remove these metals from water all the same (Gage et al, 2001). For implementation of technologies of Fe and Mn biological removal from the groundwater same additional conditions are necessary, therefore there is a need of deeper examination of mechanism of

iron bacteria's activities and of application for this purpose of an optimal technological process.

2. Experimental laboratory research of iron bacteria's identification and quantitative account

During 2000 – 2001 for experimental research of iron bacteria's a choice was made for water from Pagiriai watering place and for thin coating of quartz sand media – from the model of a filter, which is mounted in Kirtimai water – supply station, both in Vilnius outskirts. The groundwater from Kirtimai has water indications similar to ones as in many of Lithuanian water works. The experimental model, used for filtration was filled by quartz sand ($d_{\min} = 0.71\text{mm}$; $d_{\max} = 2.0\text{mm}$; depth of filling – 1650 mm) and crashed gravel for the filter media bottom ($d_{\min} = 5.0$; $d_{\max} = 10.0\text{mm}$; depth of filter media – 200 mm; in all 1850 mm). During this experiment there were used the following filtration rate: 7, 10, 15, 20 m/h, average cycle of filtration was from 4 to 5 days. Achieving that iron bacteria were have not washed out too much from the filter media, filters were being backwashed by raw water without reaching of clear backwashing water. Samples of water and thin coating of filter media were being taken through the special branch pipes (1-6 taps), mounted in the filter body in the depths of 250, 450, 850, 1250, 1450 and 1850 mm. For microbiological examinations there was used the “MOTIC” B 1223 A microscope with achromatic objectives, magnification up to 1000 times and photoability. From bacteria's, existing in the filter media (in samples of thin coatings) were collocated in the Laboratory of the Department of Water Supply and Management of VGTU according to the method of Russian scientist G. A. Dubinina and also photographed. Iron bacteria were identified by their morphological features; their photos are shown on Fig. 2.1.

For quantitative biomass evaluation of iron bacteria's there was used the method of chemical oxygen demand. Application of this method to oxidising of organic substances existing in thin coatings (there is a significant volume of biomass, containing iron bacteria's) of filter media results in the following chemical oxygen demand (2.1 formula).

$$ChDS = (b - a) \frac{8 / N}{3} F, \quad \text{mg } O_2 / g_u, \quad (2.1)$$

where: b – volume (in ml) of iron ammonium sulphate solution, used for titration of the idle sample; a – volume (in ml) of iron ammonium sulphate solution, used for titration of sample of the water under examination; N – normal concentration of iron ammonium sulphate ($N=0.125$); F – factor of mashing more accurate concentration of Moro salt ($F=20/n$); 3 – weight (g) of the dried up sample from the dried up sample from the corresponding depth of the filter media.

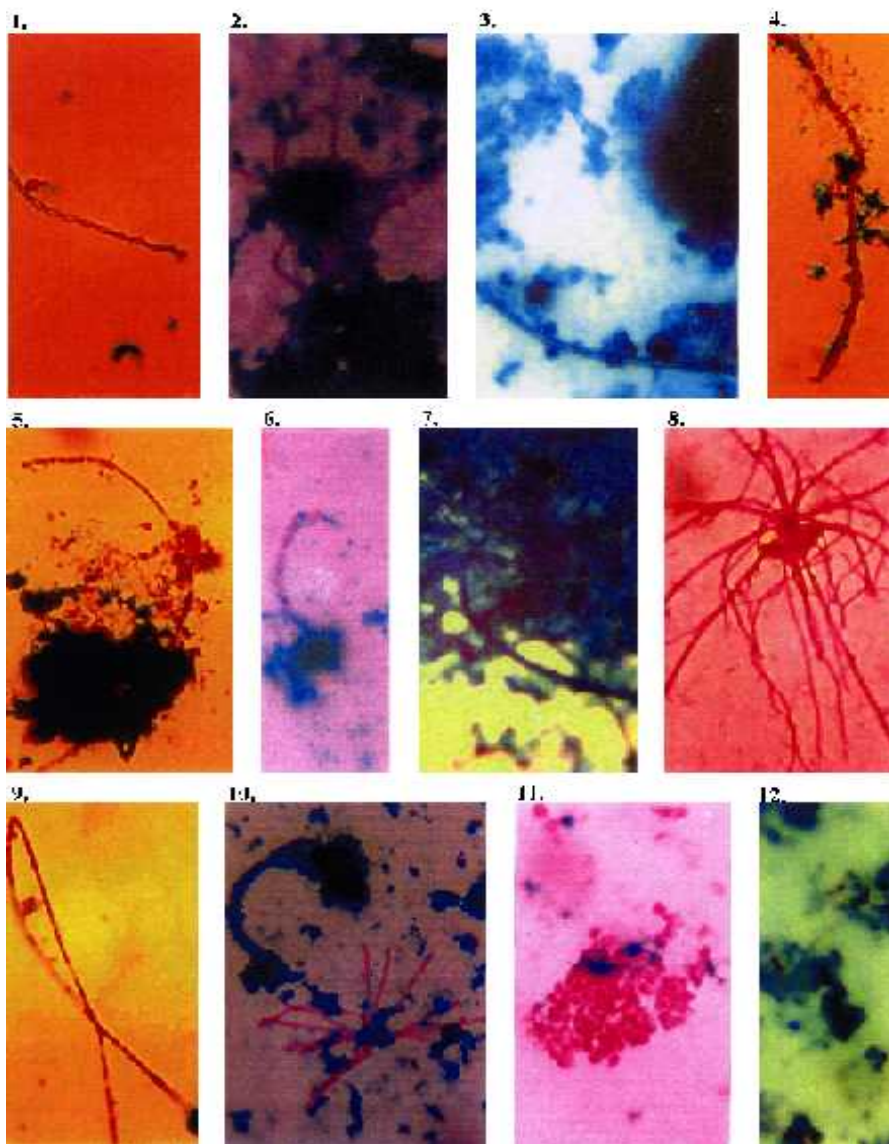


Fig. 2.1 Iron bacteria found in the experimental filter from Kirtimai water – supply station: photos 1-4 – bacteria, found in the water from the tap 1, photos 5-8 – ones from the tap 2, photos 9-12 – ones from the tap 3 (1. *Gallionella ferruginea*, 2-5. *Leptothrix oxracea*, 3-4. *Leptothrix disophora*, 6. *siderobacter latum*, 7. *Leptothrix disophora*, 8. *Leptothrix lapholea*, 9. *Clonothrix fusca*, 10. *Leptothrix lapholea*, 11. *Siderocapsa botryoides*, 12. *Leptothrix exinata*).

After analysis of the results it can be assumed, that: a) aeration and filtration of Pagiriai water works groundwater in the experimental quartz sand filter without any reagents, concentration of Fe, ammonium irons and Mn in water decreases with the depth of filter media; b) in all samples of thin coating from different depths (250, 450, 850, 1250 mm) of the filter filling there exist micro-organisms, characterised as “ iron bacteria’s” in the scientific literature according to their morphological signs, c) the morphological sings variety according to the depth of the sample extraction, therefore a presumption can be made, than there variety also their species. In the upper layers (in depth 0,25m) of the filter media there were found bacteria of genera having higher Fe-oxidising abilities (*Gallionella*-, *Sphaerotilus*-), in deeper layers there are Fe as well as Mn oxidizing micro-organism (*Leptotrix*-, *Crenothrix*-, *Siderocapsa*-), d) the indication COD (mg O₂/g of filter media) of biomass of iron bacteria’s is greatest in the filter layers, in which oxidation of two-valence Fe is going at the maximum rate, e) if more than 90% of Fe removal from the aerated groundwater in the experimental filter is achieved in the depth of the 3-rd tap (850 mm), oxidation of Mn will takes place also in deeper layers.

It rate of filtration is equal to 20 m/h, the effect of Mn removal in the filtered water is 67% only, f) if one-stage filtration of the groundwater is performed in a filter model at filtration rate of 10, 20, 15 and 7 m/h, Fe is absolutely removed, while Mn concentration remains equal to 0.01-0.02 mg/l and meets requirements of the hygienic norm HN 24:2003.

3. Experimental research of iron bacteria identification and distribution of their biomass in the open filters of water processing

Experimental research of iron bacteria’s in the equipment of non-reagent Fe and Mn removal at Antaviliai water-treatment plant were carried out, during April-May 2003. There were examined the raw groundwater, the aerated water before filtration, the filtered water and samples of sand thin coating (with iron bacteria’s). It was found, that filtration of the aerated groundwater at 5-6 m/h rate through the 1600 mm height (dept) quartz sand fillings of 1-2 mm grain size removed Fe and Mn substances only by physical and biological processes following Lithuanian hygienic norm HN 24:2003 for drinking water. The filters media (at all 8 items) was backwashed in average every 4 to 5 days be pressed air at 70 m/h rate, 19,5 l/s/m² intensity and backwashing water at 8 m/h rate, 2,2 l/s/m² intensity. At such technological parameters iron bacteria were found in all examined points in different depths of filter media. Identification and quantitative evaluation of Fe and Mn oxidising micro-organisms were performed by examination of thin coating from sand grains of the filter media under microscope and by use of a medium, selective to the growth of iron bacteria’s. The largest amount of iron bacteria was observed at 0,2 to 0,5 m depth of the filter media, where oxidation of reducing agents was extremely high.

4. Experimental research of physical and biological iron and manganese removal from the underground water

Later research of dependence of iron bacteria activities in the process of Fe and Mn removal from water on technological parameters were carried out during 2003 at Kirtimai water-treatment plant on the pilot sized plant equipment. The schematic drawing of this equipment is presented in Fig. 4.1.

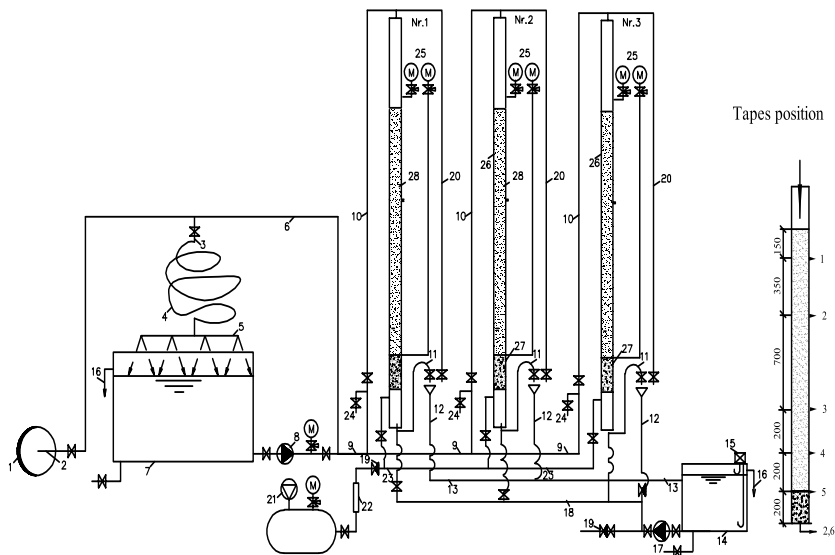


Fig. 4.1. The schematic drawing of the experimental equipment:

1 – an underground raw water main; 2 – incision into 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 – quartz sand bed

Three models of filters of 150 mm diameter and 2700 mm height, which are shown in the figure, were filled with quartz sand up to 1650 mm height, considered of grains, which size was from $d_{\min} = 0,71$ mm to $d_{\max} = 2,0$ mm and with fine granite broken stone (for holding layer), which grain size from $d_{\min} = 5,0$ mm to $d_{\max} = 10,0$ mm and height 200 mm. Total height of the filter filling was 1850 mm. Experiments were begun on Aug. 13, 2003, water to the installation was supplied from Pagiriai water works in Vilnius. Water quality of this water works are very similar to ones of many Lithuanian water woks. All analytes of

such groundwater meet the requirements of the hygienic norm to drinking water with the exception of Fe and Mn concentrations in the water, which exceed the requirements from 5 to 10 times.

There were established the following indications of water quality and filter media In control and evaluation of technological processes:

1. In the raw water before the aeration unit and in the raw aerated water:
 - a) temperature; b) pH; c) E_h ; d) concentrations of the total and two-valence iron; e) concentrations of manganese; f) concentrations of ammonium ions; g) amount of the dissolved oxygen; h) chemical oxygen demand (COD); i) number of bacteria's (units, which form settlements – u. f. s.).
2. In the filtered water taken from the different depth of the filtration layers:
 - a) concentrations of the total iron; b) concentrations of manganese; c) concentrations of ammonium ions; d) pH; 5) E_h ; e) amount of the dissolved oxygen; f) number of iron bacteria's (u. f. s.).
3. In the samples of the filtering fillings taken from the different depth:
 - a) chemical oxygen demand (COD); b) number of iron bacteria's (u. f. s.); c) density of Mn-oxidizing one-cell iron bacteria's in the silt (cells/l).

During Aug. 15, 2003-Oct. 15, 2003 there was examined the dependency of iron, ammonium and manganese removal from the water on the depth of filter media and filtration rate. The groundwater was aerated and filtered through three experimental filters at rate of 10 m/h. In the first working day of the filters there was deserved a positive effect of iron removal. Its concentration equal to 0,1 mg/l was found already in the 4-th tap (at depth 1400 mm). Oxidation and removal of manganese was less efficient. Concentration of manganese in the water remained equal to 0,02-0,03 mg/l after filtration in the filters No 1 and No 2, while concentrations of manganese and ammonium ions after filtration in the filter No 3 every remained equal to 0,1 mg/l. The aerated water pH was ≈ 7.5 , while amount of the dissolved oxygen in the 1-st tap was equal to 6,2 mg/l. These conditions were positive for physical and biological removal of iron in the all three filters while for removal of manganese they were positive in the filters No 1 and No 2. But in some scientific literature there is written, that for removal of manganese filter sand fillings are to be „ripened”. Such period of ripening sometimes can be 2-3 months. It may be, that for this reason the filter No 3 did not reduce the manganese concentration in the 6-th tap to the requirements of the HN 24:2003 Hygienic Norm ($\leq 0,05$ mg/l). From Aug. 20, 2003 the filtration of the 2-nd filter was increased from 10 m/h to 20 m/h. Then concentrations of Fe and Mn in the water, filtered in this filter, correspondingly 0,02 and 0,03 mg/l.

The working rate of this first filter was also increased. From Aug. 29, 2003 – up to 20 m/h. In the water, filtered from this filter (6-th tap) remained 0,1 mg/l of iron and 0,01-0,03 mg/l of manganese. In these filters processes of Fe, Mn and NH_4^+ removal from water stabilised. Indicators of water, filtered in the third filter

were worse than in the first two and their values stabilised by the end of September. The filters were backwashed by the filtered water ($v = 40$ m/h), backwash duration – 15 min without clear backwash water. In the period of two months (Aug.08 – Oct. 2003) concentrations of Fe, Mn and NH_4^+ were measured 11 times in the 1-5 taps of the three filters, the some in the aerated water and filtered water. Working results of the first filter are shown in the Fig. 4.2.

For avoidance of the necessity of drawing of 33 graphs (11 days x 3 filters) there were calculated the average concentrations of the admixtures under research (Fe, Mn, NH_4^+) in the characteristic points (taps 1-6). The standard statistical estimation error of the arithmetic average was $\approx 12\%$.

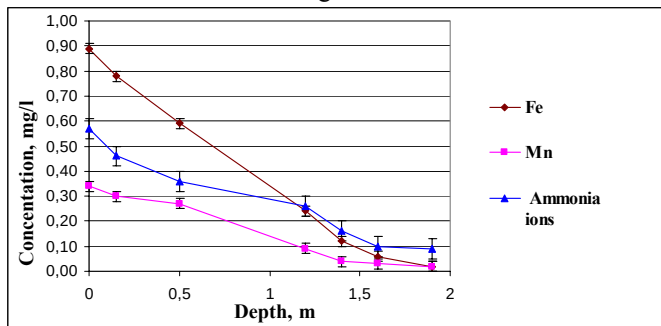


Fig. 4.2. Average concentration of substances (Fe , Mn , NH_4) in the filter No 1:

0,00 m – the dirty 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 – the filtered water

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

$$\bar{c}(x) = a_0 + a_1x + \dots + a_nx^n = \sum_{j=0}^n a_jx^j, \quad (4.1)$$

where at $a_n \neq 0$, n – non-negative whole digit, named of one – variable x n -th degree polynomial. a_j , ($j = 0, 1, \dots, n$) 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 to use the polynomials mentioned above, we will make use of Mathematical Package Maple. 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. Expressions of these polynomials are presented in the Table 4.1.

Table 4.1. Polynoms describing concentration of substances at characteristic points of filters on depth

Substance	Polynom describing concentration (<i>mg/l</i>) of substances (<i>Fe</i> , <i>Mn</i> , <i>NH₄</i>) at characteristic points of filters on depth (where <i>x</i> – depth of characteristic points)		
	Filter 1	Filter 2	Filter 3
<i>Fe</i>	$Fe = 0,89 - 0,65x - 1,67x^2 + 5,02x^3 - 6,54x^4 + 3,47x^5 - 0,65x^6$	$Fe = 0,89 - 1,68x + 0,95x^2 + 4,39x^3 - 7,61x^4 + 4,27x^5 - 0,80x^6$	$Fe = 0,89 - 1,16x - 0,74x^2 + 7,46x^3 - 10,85x^4 + 5,95x^5 - 1,13x^6$
<i>Mn</i>	$Mn = 0,34 - 0,36x + 0,63x^2 + 0,01x^3 - 1,26x^4 + 1,04x^5 - 0,24x^6$	$Mn = 0,34 - 0,44x + 0,69x^2 + 0,10x^3 - 1,09x^4 + 0,76x^5 - 0,15x^6$	$Mn = 0,34 - 0,51x + 0,76x^2 - 0,07x^3 - 0,55x^4 + 0,30x^5 - 0,04x^6$
<i>NH₄</i>	$NH_4 = 0,57 - 0,74x - 0,57x^2 + 5,08x^3 - 6,96x^4 + 3,62x^5 - 0,66x^6$	$NH_4 = 0,57 - 1,00x + 1,29x^2 + 0,70x^3 - 2,42x^4 + 1,50x^5 - 0,29x^6$	$NH_4 = 0,57 - 0,77x + 2,13x^2 - 4,55x^3 + 5,32x^4 - 2,99x^5 + 0,62x^6$

For comparison of the experimental results with the calculated ones there were used H.Kittner and L.Bohm formulas for calculation of the permissible rate of filtration in the case of removal solely iron or solely manganese. During the experimental research from Aug. 13, 2003 to Oct. 15, 2003 the filtering rate was held 10 m/h and 15 m/h. For comparison of the experimental results of changes of Fe and Mn concentrations in the water being filtered with the calculated ones there were calculated the remainder concentrations of total iron (formula (4.2) and of manganese (formula (4.3))

$$C_l = \exp \left(\ln C_z - \frac{(3 \cdot pH - 18,6) \cdot T_z^{0,8} \cdot h}{v^{0,78125} \cdot C_z^{0,1} \cdot d_v} \right), \quad (4.2)$$

When: $T_z = 9,3$ °C (untreated water temperature); $h_1 = 0,15$ m; $h_2 = 0,35$ m; $h_3 = 0,7$ m; $h_4 = 0,2$ m; $h_5 = 0,2$ m; $h_6 = 0,3$ m (h-height of filter media); $C_z = 0,98$ mg/l (total iron concentration of untreated water); $d_v = 1,5$ mm (active diameter of filter media particles); $v_1 = 10$ m/h; $v_2 = 15$ m/h (v-filtration rate).

$$C_l = \exp \left(\ln C_z - \frac{k_a^{0,625} \cdot (k_{Mn} \cdot n \cdot h \cdot A_m \cdot (pH - 5,6) \cdot C_{rk}^{0,2} \cdot (12,5 - K_b)^{0,3})}{d_v \cdot e^{5280/T} \cdot v^{0,625}} \right), (4.3)$$

When: $k_a = 0,7$ (reserve coefficient); $k_{Mn} = 9,3 \times 10^8$ (constant of non reagent manganese removal rate); $n = 0,3$ (porosity of wet media, part of 1, can be 0,2 up to 0,4); $h_1 = 0,15$ m; $h_2 = 0,35$ m; $h_3 = 0,7$ m; $h_4 = 0,2$ m; $h_5 = 0,2$ m; $h_6 = 0,3$ m (h-media height); $A_{m1} = 0,3$; $A_{m2} = 1,0$ (A_m - coated with manganese oxide microbiological living surface filter media; $1,0 > A_m > 0,3$); $C_{rk} = 4,6$, mol/m³ (carbonate concentration of untreated groundwater); $K_b = 3,25$ mol/m³ (total hardness of untreated groundwater); $d_v = 1,5$ mm (active size of filter media particles, $d_v = (d_{90} + d_{10})/2$); $C_z = 0,35$ mg/l (concentration of manganese with valence 2⁺ of untreated groundwater); $v_1 = 10$ m/h; $v_2 = 15$ m/h (filtering rate); T - absolute water temperature, °K.

In accordance with these formulae there are calculated concentrations of Fe and Mn for every depth between the characteristic points (in the intervals between h_1 - h_6), when concentration C_l in the water filtered through every upper layer is an initial one C_z for the next lower layer. Theoretically calculated values of concentrations of total iron and Mn²⁺ in the characteristic points of filter media depth (0.00; 0.15; 0.50; 1.20; 1.40; 1.60; and 1.90 meters) for all three filters are presented on Figure 4.4.

It is seen from the graphs in Fig. 4.4, that concentrations of iron and manganese variety depending on the depth of the characteristic points according to the polynomial dependencies For changes of concentration of iron at 10 m/h filtration rate coefficient of determination $R^2 = 0.9764$ for the experimental graphs and $R^2 = 0.968$ – for the calculated ones.

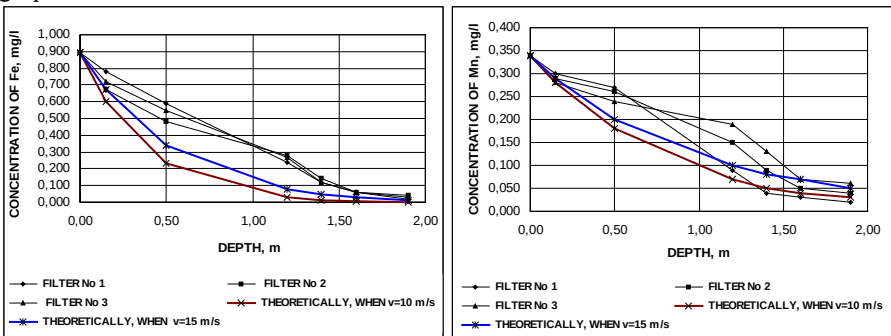


Fig. 4.4. Comparison changes of measured and calculated concentrations (when $A_m = 1.0$) of iron and manganese from the selected depths of the filter media

Corresponding values of R^2 for graphs of Mn changes were $R^2 = 0.9825$ for experimental graphs and $R^2 = 0.9979$ for calculated ones if the filtration rate was 10 m/h. As these coefficients of determination are near to one, the measured concentrations as well as calculated ones changed according to the polynomial dependencies with a sufficient accuracy. The measured Mn concentrations are higher than the calculated from the formulae on 12-33%. The empirical formulae (4.2) and (4.3) include many factors (formula (4.3) – as many as eleven) and some of them can be selected in the recommended intervals. Having the initial value C_z and the remainder one C_1 it can be drawn many graphs. There are drawn some of them only in this work. Besides, formulae proposed by L. Bohm and H. Kittner not exactly describe the analysed process, for there in the one-stage filtration was used for simultaneous removal of iron and manganese, while the mentioned authors suggested the formulae for mathematical description of the separate removal of Fe and Mn by non-reagent filtration processes.

With the purpose of intensification of activities of Fe and Mn oxidising microorganisms some artificially polluted water (with higher concentrations of iron and manganese sulphates) was supplied to these three filter models in the next stage of the research (during April 27 – May 11, 2004). For that purpose solutions of $MnSO_4$ and $FeSO_4$ were dropped into the tank of aerated water from a specially designed dropper. So the iron concentration in the filter intake was increased up to 2.0 mg/l and the manganese concentration – up to 0.2 mg/l. The first model continued its work at filtration rate of 15 m/h and was backwashed every 4-5 days by raw water with intensity of 9 l/s/m². Other two models were backwashed with the same intensity after initial blowing – through by air with intensity of 30 l/s/m² (all backwashes during 15 min). The second filter worked at filtration rate of 10 m/h, while the third one – at 20 m/h. The obtained results showed, that concentrations of iron, manganese and ammonium ions in the water, filtered in all three models meet the requirements of the hygienic norm HN 24:2003. Here the number of iron bacteria's if compared with the data in the various layers of the filter media was greater: in the 1-st filter – 3-4 times, in the 2-nd filter – 5-10 times and in the 3-rd filter – 2 times. Dependence of iron bacteria's on concentrations of total iron, manganese and ammonium ions in the different depths of the 2-nd filter is shown on the Fig. 4.5.

From the Fig. 4.5 it is seen, that concentrations of iron, manganese and ammonium ions in the water depending to the depth of characteristic points variety in accordance with the polynomial functions, when $R^2 \approx 0.986$. The number of iron bacteria in thin coatings of the 2-nd filter media (in the same points) changes according to the polynomial dependency for the filtration of the natural water while it changes according to the exponential dependency for the filtration of the artificially polluted water. Analysis of the received equations and indication R^2 makes possible the solution, that change of number of iron bacteria's in thin coatings of filter media in the analysed depth during filtration of the natural water can be rather reliably described by polynomial equations (value

of R^2 is near to 1), while filtration of the artificially polluted water at filtration rate of 15 or 10 m/h can be described by exponential equations ($R^2 = 0.9513$ and $R^2 = 0.9946$).

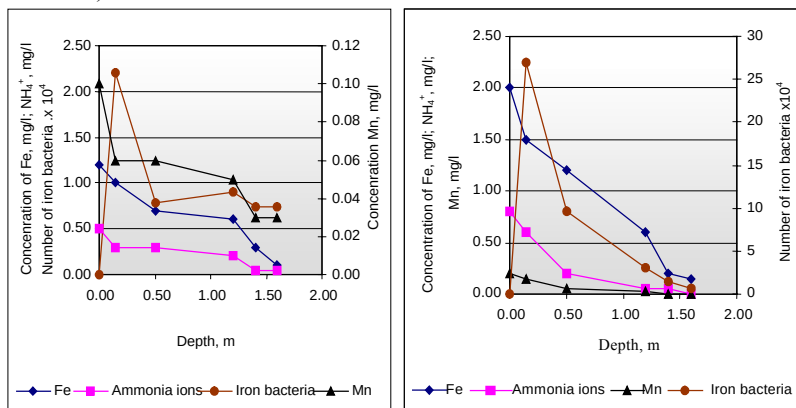


Fig. 4.5. Dependence of change of analyse indications on the depth of filling in the 2-nd filter: at left – for filtration of natural aerated groundwater (Mar. 03 – Mar.17) $v = 15$ m/h; at right – for filtration of artificially polluted water (April 27 – May 11) $v = 10$ m/h

During the research period (April 27 – May 11) the largest number (2.7×10^5 items per ml) of iron bacteria's was detected in the upper layer of the mostly slow filter No 2. In the deeper layers of the filter media the number of iron bacteria's decreased as there decreased concentrations of iron, manganese and ammonium ions and increased the electrochemical potential of the water. The second filter was the best one mostly effective compared with others; there were no substances in the filtered water, which need to be removed. Although the second and the third filters were backwashed more intensively than the first one (the first – only with water, others – with water, but they were blown through by air before backwash), iron bacteria's were not washed out completely. There was found even more iron bacteria's not washed out completely. There was found even more iron bacteria's in the filter media of the second filter, than of the first one. In the filter media of the third filter there was found the least amount of iron bacteria's; it can be explained by its higher filtration rate. When the filtration rate was 20 m/h, processes of oxidation were slower, although conditions were suitable for existence of iron bacteria's (the measured values of E_h , concentrations of oxygen, iron and manganese in the water were corresponding following to mentioned as positive in the scientific literature (Bohm, 1995; Mouchet, 1992)). For this reason in the water, filtered by the third model, there yet remained 0.03 mg/l of manganese and 0.05 mg/l of ammonium ions. After the concentrations of iron and manganese were artificially made higher, there significantly shortened the working cycle of the filter: instead of 6-7 days, filter backwash was to be carried out every 2-3 days. Although during April 26 to May 03 the filter media was

backwashed two times (April 28 and April 30), the number of iron bacteria's significantly increased. On April 26 there was supplied the natural aerated groundwater. It contained 1.2 mg/l of iron and 0.1 mg/l of manganese. The greatest number of iron bacteria's was in the depth of 150 mm of the filter media (1.2×10^3 units/ml). On April 27, when dropping of $\text{MnSO}_4 \times \text{H}_2\text{O}$ and $\text{FeSO}_4 \times 7\text{H}_2\text{O}$ solutions into the tank with the aerated water were begun, after 12 hours concentration of iron increased to 2 mg/l and of manganese – to 0,2 mg/l. The number of iron bacteria's in all examined layers of the filter media significantly increased after two days and later still more increased (to 1.9×10^5 units/ml at 150 mm depth) during next four days. Then further increase of number of iron bacteria's stopped. During of all the research period (April 27 till May 11) iron, ammonia ions and manganese substances were being removed effectively from the aerated water in all there filters, that concentrations of these substances in the filtered water were significantly less than are required by the HN 24: 2003 hygienic norm for drinking water quality.

CONCLUSIONS AND RECOMMENDATIONS

1. Micro-organisms, detected by the researcher during the laboratory investigation in thin coating of sand filter media of an industrial and experimental filters for purification of drinking water, according to their morphological indications, described in the scientific literature are very similar to iron bacteria's of *Gallionella*-, *Sphaerotilus*-, *Leptothrix*-, *Crenothrix*- and *Siderocapsa*- genera.
2. Microorganisms, existing in samples of thin coating of filter media were cultivated by the researcher in a selective medium and estimated. Growth of the bacteria's in some specified media and their coloration as described in methodise ascertained the fact, that they were namely the iron bacteria.
3. Changes of Fe, Mn and NH_4^+ concentrations in the characteristic points (in the depths of 1-6 taps) of the experimental filters, were described by the researcher by polynomials, also there were presented formulae and graphic, which shows, that, if the depth of the filter media increase, concentrations of the mentioned substances in the being filtered water decrease in accordance with polynomial dependencies ($R^2 \approx 0.98$).
4. The researcher examined distribution of the number of iron bacteria's (biomass) in the depth (if they are cultivated in a selective medium and in accordance with COD indication ($\text{mg O}_2/\text{g}_\text{d}$)) of one industrial and of three experimental filters; this distribution has influence on intensity of biological oxidation of iron and manganese. The number of iron bacteria's decreases as the depth of filter media increase and concentrations of iron, manganese and ammonia ions decrease as pH increases sedimentation of iron as well manganese is going on more effectively. According to some polynomial dependencies ($R^2 \approx 0.98$), if there is being filtered a natural aerated water;

this number of iron bacteria's also changes, but in accordance with some exponential dependencies ($R^2 = 0.9513$ for filtration rate 15m/h and $R^2 = 0.9946$ – for 10 m/h), when there is being filtered same artificially polluted water.

5. It was experimentally established, that water from water works of the Vilnius city, such as at Viriai, Pečiukai, Nemenčinė, Karveliškės and Kirtimai, is suitable for physical and biological removal of iron and manganese, iron bacteria are naturally living in it. It was established, that from the groundwater, similar to that of Antaviliai water treatment equipment and Kirtimai water works, iron and manganese substances can be removed only by physical and biological technologies following requirements of the hygienic norm HN 24:2003.
6. Physical and biological removal of ammonia ions from water following requirements of the hygienic norm HN 24:2003 is possible only after ripening of filter fillings, which can be approximately two months.
7. The recommended technological process for physical and biological removal of iron and manganese from water would be as follows: filtration rate – 10,15 m/h, backwash of filter media by raw water – 15 min with intensity of ≈ 30 l/s/m², the filters with quartz sand media ($d_{\min} = 0.71$ mm, $d_{\max} = 2.0$ mm, depth of filter media ≥ 1600 mm), raw water are to be supplied to the filters after aeration, when concentration of oxygen in the water is ≈ 5 mg/l, pH of the water is to be ≥ 7.5 , water temperature 8-10 °C. The amount of organic substances in the water must be low, than COD ≤ 15 mg, water characteristics need to be similar to applied in this work.
8. Iron, ammonia ions and manganese removal from groundwater technology evaluated following Lithuanian conditions (at investigated water works) is more advanced in comparison with convenience pollutants mentioned above removal technologies (reviewed at few scientific handbooks) because in the case pollutants mentioned above can be removed by one stage filtration from the water following requirements on hygienic norm. During removal of pollutants it is not necessary to use two or three different stages without additional aeration, that will have significant impact on costs saving.

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SANTRAUKA

Lietuvoje eksploatuojamų vandenviečių požeminio vandens analizė rodo, kad jame yra pernelyg dideli geležies ir mangano kiekiai, kurie vietomis (Nidoje, Preiloje, Dauguose, Molėtuose, Širvintose) viršija Lietuvos geriamojo vandens higienos normos reikalavimus šešis kartus pagal geležies analizės vertę ir keturis kartus pagal mangano analizės vertę. Lietuvos miestų vandentiekiuose veikia apie 100 geležies šalinimo iš požeminio vandens įrenginių, tačiau HN 24:2003 reikalavimus atitinkantį geriamąjį vandenį paruošia tik keletas, kaip pvz. Vilniaus m. Antavilių, Sereikiškių bei Kirtimų ruošyklos. Mangano šalinimas iš požeminio vandens yra daug sudėtingesnis, negu geležies. Iš vandens šalinant manganą, naudojami reagentai, stiprūs oksidatoriai, ko pasekimas vandenyje gali susidaryti žmogaus sveikatai žalingų reakcijos produktų, vandens ruošimas pabrangsta. Mangalui šalinti iš vandens reikia didelių investicijų. Todėl šią problemą reikėtų spręsti kompleksiskai, tobulinant vandens kokybės gerinimo metodus, įgalinančius manganą šalinti kartu su geležimi.

Naujų (pastatyti 2001m.) Vilniaus miesto Antavilių geležies ir mangano šalinimo įrenginių statybai prireikė apie 29 mln. litų. Šioje vandentiekio statyboje įdiegta bereagentė supaprastinto vandens aeravimo, košiant jį per atvirųjų kostuvų kvarcinio smėlio užpildus, technologinė schema. Nors minėtai įrenginiais gėrimui paruošiamas atitinkantis higienos normos reikalavimus vanduo, košimo greitis yra tik 5-6 m/h, kiekvieno kostuvo plovimui (jų yra 8) reikia apie 350 m³ vandens. Minėti technologiniai parametrai turi būti tobulinami.

Pastaruoju metu daugelyje pažangių šalių (JAV, Kanada, Vokietija, Danija, Suomija, Japonija ir kt.) pradėta naudoti nauja biologinio geležies ir mangano šalinimo iš požeminio vandens technologija. Ši technologija įgalina užtikrinti labai geras natūralias gamtines geriamojo vandens savybes bei sutaupyti lėšas jo paruošimui, todėl yra perspektyvesnė už visas kitas naudojamas technologijas. Nauja technologija pagrįsta mikroorganizmų (gelžbakterių) gyvybine veikla, kuri reikšminga geležies bei mangano formų ir koncentracijos vandenyje kitimui. Biologinis geležies bei mangano šalinimas iš požeminio vandens vyksta oksiduojant jų divalentes formas ir kaupiant susidariusius keturvalenčio mangano bei trivalentės geležies junginius gelžbakterių ląstelių paviršiuje. Gelžbakterių kultūrose tam tikromis sąlygomis gali vykti ir redukcijos procesai. Visi šie procesai dar mažai tirti. Dėl didžiulės mikroorganizmų, sąlygiškai skiriamų gelžbakterių grupių, įvairovės jų vaidmuo geležies formavimuisi požeminiame vandenyje gali būti labai skirtingas.

Siekiant užtikrinti galimai patikimesnę geriamojo vandens sanitarinę kokybę ir maksimaliai išsaugoti jo natūralias savybes, geležies ir mangano priemonėmis šalinti iš požeminio vandens labiausiai būtų vertos dėmesio fizinio-biologinio oksidavimo technologijos. Todėl tikslinga ištirti bereagenčią geležies ir mangano šalinimo iš požeminio vandens procesą bakteriologiniu aspektu ir pritaikyti gelžbakterių veiklai optimalų technologinį režimą, šalinant minėtas priemaišas.

Darbo aktualumas

Geležis ir manganas Lietuvos požeminiame vandenyje – svarbiausi komponentai, pažeidžiantys geriamojo vandens kokybės normatyvinius reikalavimus. Šiuo metu pažangiausias būdas minėtoms priemaišoms šalinti yra bereagentės technologijos, kur svarbus vaidmuo tenka biologiniam oksidavimui. Tačiau vykstant biologiniam oksidavimui, nenustatyti ir neoptimizuoti tokie technologiniai parametrai, kaip vandens košimo greitis, kostuvų plovimo trukmė bei intensyvumas ir kt. Gelžbakterių veiklos

priklausomybė nuo minėtų veiksnių dar nėra pilnai ištirta ir panaudota, kas aktualu šiai dienai.

Darbo tikslas

Ištirti bereagenčio geležies ir mangano šalinimo iš požeminio vandens procesą bakteriologiniu aspektu. Nustatyti šio proceso pagrindinius technologinius parametrus. Ištirti gelžbakterių veiklos dėsninumus ir tos veiklos intensyvinimo būdus. Pasiūlyti progresyvesnes geležies ir mangano biologinio oksidavimo technologijas šalinant šias medžiagas iš požeminio vandens.

Pagrindiniai darbo uždaviniai

- identifikuoti geležį bei manganą oksiduojančias bakterijas Lietuvos vandens ruošimo įrenginiuose;
- kiekybiškai įvertinti gelžbakteres ir ištirti jų pasiskirstymą tam tikruose koštuvų užpildo gyliuose;
- ištirti veiksnius, nuo kurių priklauso šių bakterijų veiklos efektyvumas šalinant geležį ir manganą iš ruošiamo vandens;
- pasiūlyti būdus gelžbakterių veiklos intensyvinimui.

Darbo naujumas

Šiame darbe atliktas hipotezės, kad geležį bei manganą oksiduojančios bakterijos gali augti kai kuriuose Lietuvos požeminio vandens ruošimo įrenginiuose ir įtakoti geležies bei mangano priemaišų šalinimą iš vandens, eksperimentinis patikrinimas. Nauja tai, kad gelžbakterių identifikavimo ir kultivavimo metodika buvo patobulinta ir pritaikyta Lietuvos geriamojo vandens ruošyklų kvarcinio smėlio apnašose esančių šių mikroorganizmų tyrimui. Pirmą kartą Lietuvoje ištirtas geležį bei manganą oksiduojančių mikroorganizmų kiekybinis pasiskirstymas geriamojo vandens ruošimo koštuvų užpildų smėlio apnašose, rasti gelžbakterių veiklos, šalinant iš vandens geležies bei mangano junginius, dėsninumai ir priklausomybė nuo pagrindinių technologinių parametrų.

Praktinė vertė

Gelžbakterių identifikavimo ir apskaitos metodika patobulinta ir pritaikyta Lietuvos geriamojo vandens ruošyklose esančių geležį bei manganą oksiduojančių mikroorganizmų tyrimui.

Nustatyta, kad Lietuvos požeminis vanduo (iš daugumos vandenviečių, kuriose vandens kokybės analizės artimos tirtajam Antavilių bei Kirtimų ruošyklų vandeniui) yra tinkamas fiziniam-biologiniam geležies bei mangano šalinimui ir jame natūraliai yra gelžbakterių.

Eksperimentiniais tyrimais nustatyti pagrindiniai technologiniai parametrai (vandens košimo greitis, koštuvų užpildų plovimo intensyvumas, užpildų medžiaga ir grūdelių dydis, aeravimas, vandens temperatūra, pH, ChDS_6), įtakojantys gelžbakterių veiklą ir užtikrinantys tinkamą geležies bei mangano šalinimą iš vandens, kai vandens kokybės analizės tam tinkamos.

Matematiškai daugianariais aprašytas geležies, amonio jonų bei mangano koncentracijų kitimas vandenyje, jam patenkant į vis gilesnius koštuvų užpildų sluoksnius, gautos formulės palygintos su iki šiol naudotomis bereagenčiam procesui aprašyti.

Vadovaujantis tyrimų rezultatais, pateiktos rekomendacijos naujos technologijos (kai geležies bei mangano priemaišos šalinamos iš vandens vien fizinių-biologinių procesų dėka) įdiegimui toms geriamojo vandens ruošykloms, kuriose vandens kokybės analizės atimos tirtajam Antavilių bei Kirtimų ruošyklų vandeniui.

DARBO APRAŠYMAS

1. Geležį ir manganą oksiduojančių bakterijų ypatybių ir jų pritaikymo požeminio geriamojo vandens ruošimui analitinėje literatūros apžvalgoje atlikta šių mikroorganizmų veiklos ir jos panaudojimo geriamajam vandeniui ruošti analizė. Aprašyti gelžbakterių grupei priskiriamų mikroorganizmų morfologiniai bei fiziologiniai požymiai, jų gyvybinei veiklai būtinos sąlygos. Šiame skyriuje išsamiai aprašytos biologinė oksidacija besiremiančios geležies bei mangano šalinimo iš požeminio vandens technologijos ir jų ypatumai lyginant su kitomis įprastomis minėtų priemaišų šalinimo iš vandens technologijomis. Apžvelgus literatūrą bei įvertinus biologinių procesų pagrindu veikiančių geriamojo vandens ruošyklų privalumus, galima teigti, kad tokių technologijų taikymo Lietuvoje problema yra aktuali. Tai skatina šius procesus giliau pažinti ir detaliau ištyrinėti.

2. Gelžbakterių identifikavimo ir kiekybinės apskaitos eksperimentiniai laboratoriniai tyrimai buvo atliekami VGTU Vandentvarkos katedros cheminėje laboratorijoje, naudojant iš gamybinių vandens gerinimo įrenginių (Vilniaus m. Kirtimų bei Antavilių ruošyklų) atsivežtus kostuvų užpildų smėlio su apnašomis mėginius. Įsisavinta ir patobulinta gelžbakterių identifikavimo ir apskaitos metodika. Gelžbakterių biomasės įvertinimui pritaikytas ChDS (cheminio deguonies suvartojimo) metodas.

3. Eksperimentiniai gelžbakterių identifikavimo ir jų biomasės pasiskirstymo atviruosiuose gamybinuose geriamojo vandens ruošimo kostuvuose tyrimai buvo atliekami Vilniaus m. Antavilių vandens gerinimo įrenginiuose (kur įrengta bereagentė geležies bei mangano šalinimo iš požeminio vandens technologija) ir tęsiami cheminėse laboratorijose. Nustatyta, kad šiuose įrenginiuose iš vandens geležis bei manganas pašalinami iki higienos normos reikalavimų geriamajam vandeniui ruošti vien fizinių bei biologinių procesų dėka. Atvirųjų kostuvų užpildų visuose tirtuose taškuose rasta gyvų gelžbakterių, nustatytas jų skaičius bei pasiskirstymas tų užpildų gylyje. Kostuvų smėlio užpildų apnašose mikroskopuojant aptiktos gelžbakterės išaugintos selektyviose terpėse ir pagal būdingą nusidažymą priskirtos vienai ar kitai šios grupės rūšiai.

4. Fizinio biologinio geležies bei mangano šalinimo iš požeminio geriamojo vandens eksperimentiniai tyrimai vyko eksperimentiniame stende, kurį sudarė trys kostuvų modeliai, aeravimo įrenginys, aeruoto vandens bakas ir kiti įrenginiai. Kontroluojant ir vertinant technologinius procesus eksperimentų metu buvo nustatyti šie vandens kokybės bei košiančiųjų užpildų rodikliai:

- žaliame vandenyje prieš aeravimo įrenginį ir žaliame aeruotame vandenyje:
 - 1) temperatūra; 2) pH; 3) Eh; 4) bendrosios ir divalentės geležies koncentracijos;
 - 5) mangano koncentracijos; 6) amonio jonų koncentracijos; 7) ištirpusio deguonies koncentracija; 8) cheminis deguonies suvartojimas (ChDS_{Cr}); 9) gelžbakterių skaičius (kolonijas formuojančių vienetų).
- iškoštame vandenyje ir iš įvairaus košiančiojo užpildo klodų gylio paimtame vandenyje: 1) bendrosios geležies koncentracijos; 2) mangano koncentracijos;

- 3) amonio jonų koncentracijos; 4) pH; 5) Eh; 6) ištirpusio deguonies koncentracija; 7) gelzbakterių skaičius kolonijas formuojančiais vienetais (k.f.v.).
- košiančiojo užpildo iš įvairaus gylio klodų mėginiuose: 1) cheminis deguonies suvartojimas (ChDS_{Cr}); 2) gelzbakterių skaičius (k.f.v.); 3) manganą oksiduojančių vienaląsčių gelzbakterių tankis dumble (ląst./l).

Statistiniam duomenų patikimumui nustatyti naudotasi Stjudento variacinės statistikos metodu. Geležies, amonio jonų bei mangano koncentracijų kitimas vandenyje, jam skverbiantis į vis gilesnius koštuvų užpildų sluoksnius aprašytas matematinėmis lygtimis naudojant *Mapple* programų paketą. Šios lygtys palygintos su iki šiol naudotomis panašioms procesams aprašyti. Ištyrus geležies, amonio bei mangano šalinimo išnatūralaus požeminio vandens procesą bakteriologiniu aspektu, gelzbakterių veikla buvo intensyvinama tiekiant dirbtinai paruoštą (turintį didesnes geležies bei mangano koncentracijas) vandenį. Šių tyrimų pagrindu padarytos išvados ir pateiktos rekomendacijos.

PAGRINDINĖS IŠVADOS

1. Laboratoriniais tyrimais gamybinio bei eksperimentinių geriamojo vandens ruošimo koštuvų kvarcinio smėlio užpildų apnašose aptikti mikroorganizmai, morfologiniais požymiais atitinkantys mokslinėje literatūroje aprašytas *Gallionella*-, *Sphaerotilus*-, *Leptothrix*-, *Crenothrix*- bei *Siderocapsa*- genčių gelzbakteres.
2. Koštuvų kvarcinio smėlio užpildų apnašų mėginiuose esantys mikroorganizmai buvo išauginti selektyvioje terpėje ir suskaičiuoti. Bakterijų išaugimas specialiose terpėse bei jų dažymasis, kaip aprašyta metodikoje, patvirtina faktą, jog tai gelzbakterės.
3. Matematiškai daugianariais aprašytas Fe, Mn bei NH_4^+ koncentracijų kitimas eksperimentinių koštuvų charakteringuose taškuose (1-6 čiaupų gylyje), pateiktos formulės bei grafikai, iš kurių matyti, kad minėtų medžiagų koncentracijos košiamajame vandenyje didėjant užpildo gyliui mažėja pagal polinomines priklausomybes ($R^2 \approx 0,98$).
4. Nustatytas gelzbakterių skaičiaus (biomasės) pasiskirstymas gamybinio bei eksperimentinių koštuvų užpildų gylyje (jas auginant selektyvioje terpėje ir pagal ChDS rodiklį (mgO_2/g_u)), kuris įtakoja biologinio geležies bei mangano oksidavimo intensyvumą. Gelzbakterių skaičius mažėja didėjant košiančiojo užpildo gyliui ir mažėjant geležies, mangano bei amonio jonų koncentracijoms pagal polinomines priklausomybes ($R^2 \approx 0,98$), košiant natūralų aeruotą vandenį ir šis skaičius kinta pagal eksponentines priklausomybes ($R^2 = 0,9513$, kai košimo greitis $v = 15\text{m/h}$ ir $R^2 = 0,9946$, kai $v = 10\text{m/h}$), košiant dirbtinai paruoštą vandenį.
5. Eksperimentiniais tyrimais nustatyta, kad Vilniaus m. Virių, Pečiukų, Nemenčinės, Karveliškių bei Kirtimų vandenviečių vanduo (kurio analitės artimos daugeliui Lietuvos vandenviečių) yra tinkamas fiziniam – biologiniam geležies bei mangano šalinimui, jame natūraliai yra gelzbakterių. Požeminį vandenį, kurio savybės panašios į tirtojo Antavilių vandens gerinimo įrenginiuose bei Kirtimų vandentiekio mazge, galima išvalyti nuo geležies bei mangano priemaišų iki higienos normos HN 24:2003 reikalavimų vienalaipsniu košimu vien fiziniais – biologiniais procesais pagrįsta technologija.
6. Fizinis – biologinis amonio jonų bei mangano šalinimas iš vandens iki higienos normos HN 24:2003 reikalavimų įmanomas tik subrendus koštuvų užpildams. Jų brandimas trunka apie du mėnesius.

7. Rekomenduojamas technologinis režimas fiziniam – biologiniam geležies bei mangano šalinimui vienalaipsniu košimu iš vandens būtų: vandens košimo greitis -- 10, 15 m/h, koštuvų užpildų plovimas žaliu vandeniu 15 min $\approx$ 10 l/s/m² intensyvumu, prieš tai prapūtus oru $\approx$ 30 l/s/m² intensyvumu, koštuvai turi būti užpildyti kvarciniu smėliu ($d_{\min} = 0,71$ mm, $d_{\max} = 2,0$ mm, užpildo gylis $\geq$ 1600 mm), į koštuvus žalias vanduo turi būti tiekiamas po aeravimo, kai jame ištirpusio deguonies koncentracija $\approx$ 5,0 mg/l, vandens pH $\geq$ 7,5, temperatūra – 8-10°C. Košiamajame vandenyje neturi būti daug organinių medžiagų ($\text{ChDS} \leq 15 \text{ mgO}_2/\text{l}$), jo savybės (ir cheminė sudėtis: Fe, Mn, NH_4^+ ir kt. koncentracija, parodyta 4.1 lentelėje) turi būti artimos tirtajam vandeniui.
8. Rekomenduojama geležies, amonio jonų bei mangano šalinimo iš požeminio vandens technologija įvertinant Lietuvos sąlygas (tirtose vandenvietėse) yra perspektyvesnė už šių priemonių šalinimo technologijas (aprašytas eilėje mokslinės literatūros šaltinių) tuo, kad šiuo atveju minėtos priemonės pašalinamos iš vandens iki higienos normos reikalavimų vienalaipsniu košimu. Jų šalinimui nereikia atskirų dviejų ar trijų etapų bei papildomo aeravimo, kas leidžia sutaupyti lėšas.

Short description about the author

1981 – 1984: undergraduate studies at Zooengineering Faculty of Lithuanian Veterinary Academy, Bachelor of Engineer Sciences (Zooengineering).

1998 – 2000: graduate studies at Water Supply and Management Department of Vilnius Gediminas Technical University, Master of Environmental Engineering.

2000 – 2004: post-graduate studies at Water Supply and Management Department of Vilnius Gediminas Technical University, post-graduate student of Technical Sciences, Environmental Engineering and Landscape Management – 04.

Aušra Mažeikienė

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