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EVALUATION OF EFFECTIVENESS TECHNOLOGICAL PROCESS OF WATER PURIFICATION EXEMPLIFIED ON MODERNIZED WATER TREATMENT PLANT AT OTOCZNA

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Abstract

The article presents the work of the Water Treatment Plant in the town of Otoczna, located in the Wielkopolska province, before and after the modernization of the technological line. It includes the quality characteristics of the raw water and treated water with particular emphasis on changes in the quality indicators in the period 2002 - 2012 in relation to the physicochemical parameters: the content of total iron and total manganese, the ammonium ion as well as organoleptic parameters(colour and turbidity). The efficiency of technological processes was analysed, including the processes of bed start up with chalcedonic sand to remove total iron and manganese and ammonium ion. Based on the survey, it was found that the applied modernization helped solve the problem of water quality, especially the removal of excessive concentrations of iron, manganese and ammonium nitrogen from groundwater.

It has been shown that one year after modernization of the technological line there was a high reduction degree of most parameters, respectively for the general iron content - 99%, general manganese - 93% ammonia - 93%, turbidity - 94%. It has been proved, that chalcedonic turned out to be better filter material than quartz sand previously used till 2008. The studies have confirmed that the stage of modernization was soon followed by bed start-up for removing general iron from the groundwater. The stage of manganese removal required more time, about eight months for bed start-up. Furthermore, the

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technological modernization contributed to the improvement of the efficiency of the nitrification process.

Keywords: groundwater and treated water, iron and manganese removal process, the physicochemical and organoleptic parameters of drinking water

1. INTRODUCTION

Water as a source of life was included in the definition of food and must comply with sanitary requirements specified in the Regulation of the Minister of Health from 29th of March 2007 (The Journal of Laws of the Republic of Poland No. 61, item. 417) [12]. Groundwater is an important source of drinking water. However, like other elements of the natural environment, it is exposed to the influence of anthropogenic factors [17]. Therefore, it must be under special protection and systematic monitoring of quality. Groundwater usage values are much higher than surface waters due to the more favourable chemical and microbiological characteristics. In this context the positive factor is lack of pathogenic bacteria and viruses as well as toxic pollution. Groundwater at the same time has favourable and stable physicochemical properties. Despite the many advantages, only a small fraction of groundwater is suitable for direct use without treatment. A vast majority of groundwater requires iron and manganese removal. Therefore, these processes play a key role in water treatment technology [13].

The technology of groundwater treatment is in most cases simple. Iron does not usually create major problems and can easily be removed by using a conventional aeration and filtration system. In spite of this process iron may be present in drinking water also as a result of using ferric coagulants or due to corrosion of steel and cast iron water pipes. The problem is more complex when not only iron is present but also other additives such as manganese. Iron oxide and manganese oxide have a particularly negative impact, because they form porous and unstable coatings, which may cause pitting as well as homogeneous corrosion. The destruction of water system by corrosion exposes water companies to serious losses resulting from the necessity of network renovation and also from the increase of the water flow resistance [5].

According to Kuś et al. [6], meeting the requirements concerning content of iron, turbidity and colour of the water is a very difficult task to achieve while operating in heavily corroded pipelines.

Despite years of research, the problem of efficient purification of groundwater from excessive contents of iron, manganese and ammonia nitrogen still exists. New efficient and cost-effective methods of removing these contaminants from water are still a subject of research. [3].

The main purpose of this study was to determine the effectiveness of iron, manganese and ammonium ions removal in the selected Water Treatment Plant in the Wielkopolska province before and after modernization. The effectiveness of water treatment was evaluated based on the removal degree of the individual physicochemical and organoleptic parameter of water quality.

2. SUBJECT AND METHOD OF RESEARCH

2.1. Subject of research

The subject of research was raw and treated water in a municipal water intake plant located in the north - eastern part of the village Otoczna in the municipality of Września in the Wielkopolska province. This plant supplies drinking water and water for economic purposes for the residents of the villages of Otoczna, Sędziwojewo, Stanisławowo, Gutowo Wilekie, Kleparz, Grzybowo, Wódki, Sobiesiernie, Węgierki, Gonice and Goniczki.

The average output of the water intake in the period 2003 - 2008 was maintained in the range from 87.6 to more than 95.5 thousand m^3 a $year^{-1}$.

In the period from April 2008 to March 2010, the water treatment plant was out of service because of the modernization works. The plant started to work again in April 2010.

In the period 2002 - 2007 before the stage of modernization, the technological system included:

- raw water intake with the existing deep-water wells (maximum water intake about 40.0 $m^3 \cdot h^{-1}$),
- pressure aeration with compressed air supplied to the screen-adjacent aerators (four pressure aerators with a diameter of DN 600 for each filter),
- pressure filters with a diameter of 1400 mm (4 pieces) filled with sand bed with a height of about 1.1 m.

The technological line described had low efficiency in the technological process of raw water aeration in screen-adjacent aerators. Therefore, there was poor oxygenation of water, resulting in a deficit of oxygen which was insufficient to meet the stoichiometric requirements for the oxidation of iron, manganese and ammonium ion. Furthermore, devices were in a very poor condition as a result of the progressive corrosion. Therefore, it was necessary to modernize the system to make it possible to implement new modernized solutions.

After the process of modernization (May 2008 - March 2010), the new technological line of groundwater treatment was based on the following devices:

- deep wells (pumping station level I) (maximum water intake also 40.0 m^3 h^{-1}),

- aeration cascade (open aeration),
- reaction chamber of aerated water,
- interoperational pumping station (pumping station level II),
- system of parallel connected three pressure filters with a diameter of 1400 mm, filled with chalcedonic layer of 1.8 m height, with average speed of filtration 13 $m^3 \cdot h^{-1}$,
- tanks of clean water,
- pumping station level III.

2.2. Method of research

A physicochemical analysis of water was performed at "Laboratorium Analiz Wody i Ścieków Przedsiębiorstwa i Kanalizacji we Wrześni Sp. z o.o". In 2008 the laboratory was accredited by the Polish Centre for Accreditation -Certificate No.AB984, which means that the existing management system complies with the requirements of the PN-EN ISO/IEC 17025:2005 [11]. Laboratory has the authorization of the Province District Inspector in Września in accordance with paragraph 6 of the Regulation of the Minister of Health from 29 March 2007 [12] on the quality of water intended for human consumption. This authorization qualifies them to perform water analysis within the range of supervisory and review monitoring (the Journal of Laws of the Republic of Poland No. 61, item. 417 with subsequent amendments).The range of analytical determinations in this study included the following parameters:

- total iron,
- total manganese,
- ammonium ion,
- colour,
- turbidity.

The determination of these parameters was performed by standardized methods and procedures based on Merck and Hach Lange tests.
The determination of the total iron content was performed in accordance with the test procedure based on the Merck test, catalogue number: 1.14761.0001.
The determination of the total manganese content was performed in accordance with the test procedure based on the Hach Lange test, catalogue number: LCW032. The determination of ammonium ion was performed in accordance with the test procedure based on the Merck test, catalogue number: 1.14752.0001. The determination of colour was performed according to the standard PN-EN ISO7887:2002 [9]. The determination of turbidity was performed according to the standard PN-EN ISO 7027:2003 [10].

The samples of raw and treated water from the water intake in the village of Otoczna were collected once a week. The data presented in this study are means of 48 replications.

3. RESULTS AND DISCUSSION

The essential factors causing corrosion are low alkalinity, a high oxygen content resulting from the presence of strong oxidizers in water such as chlorine and ozone, as well as an increased level of sulphates and chlorides. In the present study, regardless of the modernization stage, the reaction of the drinking water analysed was very stable and ranged from 7.4 to 7.8.

However, the fundamental drivers of the water supply system corrosion phenomena are compounds of iron and manganese, leading to the accumulation of oxide deposits.

Total iron in the ground water may be present in a wide range of concentrations, from trace amounts up to about 30 mg L^{-1} [13].

According to the data in Table 1, the amount of iron in the raw water during the period 2002 to 2007 was in the required range because it varied from 1.301 to 2.464 mg L^{-1}, which was a 2.0 times difference. After the modernization of the station, the concentration level of metal in the water was slightly reduced and varied from 1.100 (2010) to 1.201 (2012) mg L^{-1}

Table 1. Average values of parameters for ground water (raw) in the municipal water intake in the village of Otoczna during the period 2002 to 2012

Years	Colour	Turbidity	Iron	Manganese	Ammonium
	[mgPt·L^{-1}]	[NTU]	[mg·L^{-1}]		
2002	56.9	3.56	1.425	0.301	0.851
2003	101.4	6.88	2.464	0.582	0.787
2004	34.9	2.41	1.605	0.357	0.857
2005	36.1	2.34	1.990	0.385	0.928
2006	58.1	4.44	1.301	0.285	0.681
2007	22.7	1.10	1.380	0.317	0.852
2008	Modernization of the water treatment plant - lack of water intake				
2009					
2010	15.8	5.48	1.100	0.302	0.889
2011	25.2	6.72	1.130	0.269	0.913
2012	26.4	1.82	1.201	0.247	0.902

At the water treatment plant, the process of removing total iron and manganese from ground water after the modernization was performed in the oxidation deposits with activated chalcedonic sand. Grains of these deposits were covered with permanent coatings of Fe_2O_3 in the iron removal area and MnO_2 in the manganese removal area. The production of these oxides was the essence of deferrization and manganese removal processes. The water treatment processes performed at the station in Otoczna up to 2007 contributed to the removal of iron by 67% (2006) to 97% (2007). This eventually resulted in at tenfold reduction of metal which varied from 0.042 (2007) to 0.428 mg·L^{-1} (2006) (Table 2). According to Kowal and Świderska-Bróż [5] at concentrations above 0.3 mg Fe ·L^{-1} , there is no detectable taste in water, but such concentration may cause a different colour and turbidity of water also an excessive iron content in the water creates favourable conditions for the growth of iron bacteria, which derive energy from the oxidation of ferrous ion and form greasy deposits covering the water pipes [18].

Table 2. Average values of parameters for treated water in the municipal water intake in the village of Otoczna during the period 2002 to 2012

Years	Colour	Turbidity	Iron	Manganese	Ammonium
	[mgPt·L^{-1}]	[NTU]	[mg·L^{-1}]		
2002	14.2	0.62	0.055	0.154	0.156
2003	24.8	1.28	0.130	0.141	0.363
2004	17.4	1.22	0.138	0.103	0.271
2005	20.0	1.12	0.228	0.108	0.221
2006	33.6	0.51	0.428	0.080	0.131
2007	16.6	0.30	0.042	0.081	0.209
2008	Modernization of the water treatment plant - lack of water intake				
2009					
2010	16.0	<0.20**	<0.020**	0.138	0.189
2011	12.4	<0.20**	<0.020**	<0.020**	<0.064**
2012	15.3	<0.20**	<0.020**	<0.020**	<0.064**
Standard for drinking water *	15.0	1.0	0.2	0.05	0.5

*) Regulation of the Minister of Health from 29th of March 2007 on the quality of water intended for human consumption (The Journal of Laws of the Republic of Poland, No. 61, item. 417, with subsequent amendments)

**) result under the scope of accreditation for the determined test method

When these quoted values are compared with values acceptable according to the Regulation of the Minister of Health (the Journal of Laws of the Republic of

Poland, No. 61, item. 417) [12] on the amount of iron in the drinking water (0.2 mg·L^{-1}), the result is unsatisfactory.
However, the modernization improved significantly the quality of water in terms of this parameter. This resulted in a stable amount of total iron below 0.02 mg ·L^{-1} and a high - 99% reduction of this element (Table 2). The positive results of the improved quality of treated water after the modernization of the plant are shown in the Figure 1. Analysing this phenomenon on a monthly basis, it is can be seen that before the modernization process of the technological system, the average content of total iron ranged from 0.024 to 0.067 mg·L^{-1}, with the highest values in March and April. The analysis of the treated water in the newly modernized plant made it possible to achieve the concentration of this parameter below the limit of 0.02 mg·L^{-1}. The highest content of total iron in treated water after the modernization was recorded in February and March, 0.018 and 0.014 mg·L^{-1} respectively. In the other months of 2010, the amount of this metal remained at a very low level of 0.006 mg·L^{-1}.

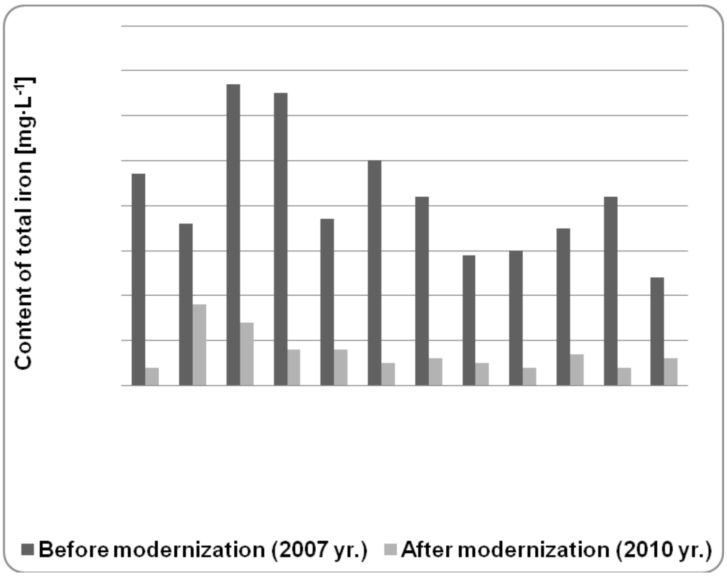

Fig. 1. Average content of total iron [mg·L^{-1}] in treated water before and after the modernization of the water treatment plant on a monthly basis.

According to Sozański and Dymaczewski [13] the concentration of total manganese in extracted waters is more than tenfold lower than the concentration of total iron. The data presented in Table 1 do not reflect such a trend. In the analysed water intake the quantitative difference between total iron and manganese was fourfold. Regardless of this aspect, the amount of total manganese in the raw water during the period 2002 - 2007 ranged from 0.285 - 0.582 mg·L^{-1}, which was a 2.0 times difference (Table 1). The modernization process contributed to the stabilization of the level of concentration of metal in the range of 0.247 to 0.302 mg·L^{-1} (Table 1). Water treatment before the modernization resulted in a reduction of manganese by 49 - 76%, corresponding to concentrations of 0.080 (2006) to 0.154 (2002) mg·L^{-1} (Table 2). In the view of the acceptable standards for drinking water (Journal of Laws of the Republic of Poland, No. 61, item. 417) [12] these values exceeded the above standards by 1.5 - 3.0 times. The manganese level above 0.1 mg·L^{-1} [5] is usually tolerated by consumers of water. However, as the quoted authors emphasize, concentrations exceeding 0.1 mg·L^{-1} manganese lead to dirty sanitation and laundry, and also cause an undesirable flavour of beverages. Furthermore, some microorganisms accumulate in the cells of manganese, which creates problems with the taste, odour and turbidity of water supplied by the water distribution system [1].

The modernization of the plant significantly improved water quality by reducing the value of this parameter. According to the data in Table 2, since 2011 the total manganese concentration in treated water remained below 0.02 mg·L^{-1}, which was associated with the reduction of total manganese on the level of 93%. The changes in the quantity of total manganese on a monthly basis in the year before and after the modernization are presented in Figure 2. According to the presented data, before modernization the general manganese content ranged from 0.041 to 0.144 mg·L^{-11}, with the highest quantities in July and September. However, the optimization of the manganese removing process after the modernization was reached only after eight months' start-up of the filter material by creating natural coating of manganese oxides on chalcedonic sand grains. From January to September 2010 the monthly average content of total manganese in treated water was 0.211 mg·L^{-1} (Figure 2), which exceeded the acceptable concentration level more than four times. As of February 2010, a gradual decline of this parameter was observed, and finally in September the content of that pollutant in treated water was reduced to a level below the scope of accreditation for the determined test method, i.e. 0.02 mg·L^{-1}.

On the basis of the authors' own research as well as in the light of reports of Weber and Szambelańczyk [15, 16] it appears that chalcedonic is a better filter material than previously used quartz sand. According to Jeż-Walkowiak et al. [2] chalcedonic should be regarded as a material of great potential for use in sanitary engineering as filtering material with high efficiency for removing iron compounds during water treatment. This material has no significant adsorption or catalytic properties. Therefore, effective manganese removal on chalcedonic deposit can occur only after the natural start-up of material, when the grains get covered with a coating of manganese oxides [7, 8].

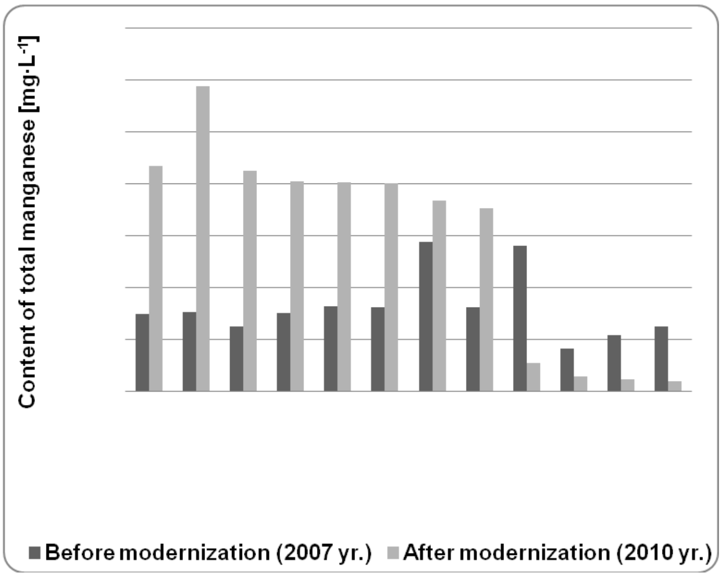

Fig. 2. Average content of total manganese [mg·L^{-1}] in treated water before and after the modernization of the water treatment plant on a monthly basis

The quality control of treated water also includes the monitoring of the ammonium content. According to Zięba [19], it is caused by the negative impact of this compound on the effectiveness of chlorine disinfection, causing formation of nitrite, difficulties in manganese removal, reduction of oxygen, creating an undesirable smell and taste of the water and the deterioration of the bacteriological composition of the water in the system. On the basis of the authors' own research (Table 1 and 2) and a study conducted by Michel [8] it appears that chalcedonic is also a good material to successfully remove ammonium from raw water in the process of nitrification.

The content of ammonium in raw water during the period 2002 - 2012 was on a quite stable level of 0.681 to 0.852 mg·L^{-1} with the average of 0.851 mg·L^{-1} during the years of the research (Table 1). The process of modernization of the plant did not differentiated substantially the level of ammonium, because the values ranged from 0.889 (2010) to 0.913 (2011) mg·L^{-1} (Table 1). However, in light of the reports by Sozański and Dymaczewski [13] about possible concentration of ammonium ions in water from traces to 9.5 mg·L^{-1}, these values can be considered as positive only if the data in Table 2 are both taken into consideration. It appears that the reduction of ammonium in treated water extracted during the period 2002 - 2007 was small, in the range of 32 - 82%.

As a consequence, the amount of ammonium was varied from 0.131 to 0.363 mg·L^{-1}. The modernization process contributed positively to the quality of treated water, because since 2011 there was a significant reduction (by about 93%) of the content of this parameter resulting in a concentration below 0.064 mg·L^{-1}, which was in accordance with the acceptable concentration for drinking water (Journal of Laws of the Republic of Poland, No. 61, item. 417) [12].

Figure 3 shows the detailed quantitative fluctuation of ammonium in 2007 and 2010 on monthly basis. The data prove that the replacement of quartz by chalcedonic sand contributed to the reduction of the ammonium concentration, although the result was not visible right away, because the greatest value of this parameter was observed in January (0.877 mg·L^{-1}) and March (0.875 mg·L^{-1}). It can be assumed that the increased ammonium content was caused by the incomplete chalcedonic bed start up after the modernization, as well as the low water temperature during these months. According to Kowal [4], the efficiency of nitrification leading to the reduction of ammonia in treated water can be increased by a high water temperature, a narrow ratio of Cl_2:NH_4, and a long period of the flow of water in the system. During the other months of 2010, the average content of ammonium in the treated water was 0.053 mg·L^{-1}.

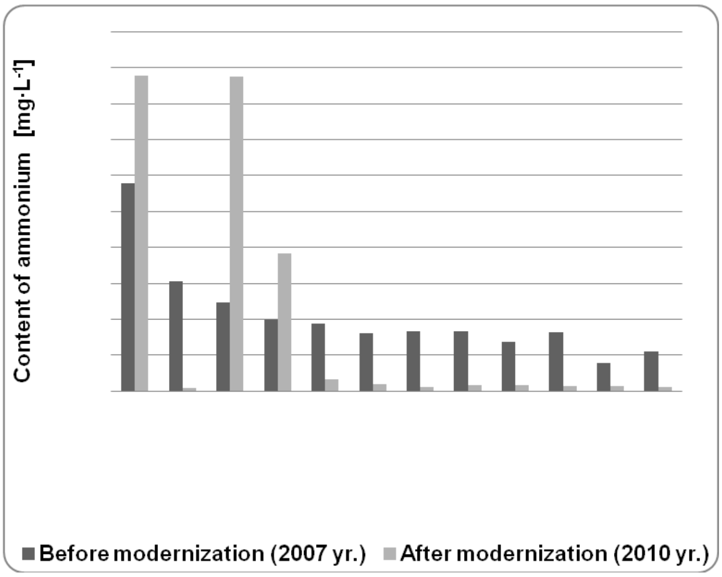

Fig. 3. Average content of ammonium [mg·L^{-1}] in treated water before and after the modernization of the water treatment plant on a monthly basis

For customers the most important factors in assessing the quality of water are organoleptic indicators, such as colour and turbidity. According to Sozański and Huck [14] they are closely related by cause and effect systems with many other technological issues. The colour is usually caused by the presence of coloured organic substances, which are associated with the humus fraction of the soil.

This indicator depends on the content of iron and other metals, which can be natural ingredients of water or products of corrosion. This statement was confirmed in the conducted research. A simple correlation analysis (data not presented) shows that the colour was in 82% determined by the total iron content. However, the colour of raw water was in 58% determined by total iron and in 60% by total manganese. According to tabular data, the colour of raw water varied within a wide range of values from 22.7 (2007) to 101.4 (2003) mgPt $\cdot L^{-1}$, which was a 4.5 times difference. The modernization of the water treatment plant contributed to the reduction of this parameter, which varied from 15.8 (2010) to 26.4 (2012) mgPt$\cdot L^{-1}$ (Table 1). In light of the reports by Dymaczewski and Sozański [13] the colour parameters indicated above should be considered as typical, because according to them this parameter can vary from 0 - 170 mgPt$\cdot L^{-1}$. Regardless of this, the degree of colour reduction in treated water during the period 2002 - 2007 ranging from 27 to 76% should be regarded as negative (Table 2). The implemented modernization process of the station improved the quality of treated water only by a small degree from this point of view. According to the data in Table 2, the colour value ranged from 12.4 (2011) to 16.0 (2010) mgPt$\cdot L^{-1}$, so it exceeded the value which is acceptable by the Regulation of the Minister of Health. As a consequence, there was a small reduction of this component ranged from 42 to 50%. As previously mentioned, the aesthetic perception of treated water is strictly correlated with turbidity. A large value of this pollutant facilitates the growth of microorganisms in water, increases the chlorine demand for disinfection and reduces its effectiveness. A value higher than 5 NTU is detectable by consumers. However, during disinfection, it is desired to have less than 1 NTU turbidity [13]. Moreover, the above authors observed that this parameter can take values in a wide range of 0 to 155 NTU, the same as in the case of the colour. In our study, in the analysed samples of raw water during the period 2002 - 2007 this parameter was fluctuating, taking values in the range of 1.10 NTU to 6.88 NTU, which was a 6 times difference (Table 1). The modernization process of the station did not have a crucial effect on changing this parameter in raw water. As shown in Table 1, the turbidity in 2010, 2011 and 2012 was 5.48, 6.72 and 1.82 NTU respectively. Analysing the effect of water treatment in the station, there was a reduction of turbidity by 52 - 89% (2002-2007). The discussed parameter varied from 0.30 to 1.28 NTU during this period of time (Table 2). The modernization contributed to positive changes in turbidity, because as shown in Table 2, the reduction of this organoleptic index was on the level of 90 - 97% (in the years 2010-2012). At the same time the estimated value was less than 0.20 NTU, which was in line with the standards acceptable by the Regulation of the Minister of Health on the quality of water intended for human consumption (Table 2).

4. CONCLUSIONS

The effectiveness of the newly modernized water treatment station should be considered as high, what was reflected in complying with the required limits acceptable by the Regulation of the Minister of Health. One year after the modernization of the technological line there was a high reduction degree of most parameters for the total iron content - 99%, total manganese - 93% ammonium - 93% and turbidity - 94% respectively. On the basis of this study it can be concluded, that chalcedonic turned out to be a better filter material than quartz sand used previously in 2008. At the same time, the stage of modernization was followed by the start-up of deposits to remove total iron from the groundwater. On the other hand, the stage of manganese removal required more time, about eight months for chalcedonic bed start-up. Furthermore, the technological modernization contributed to the improvement of the efficiency of the nitrification process, which is as important for water treatment as the process of iron and manganese removal.

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OCENA EFEKTYWNOŚCI PROCESÓW TECHNOLOGICZNYCH UZDATNIANIA WODY NA PRZYKŁADZIE ZMODERNIZOWANEJ STACJI W OTOCZNEJ

Streszczenie

Artykuł prezentuje pracę Stacji Uzdatniania Wody w miejscowości Otoczna w województwie wielkopolskim przed i po modernizacji ciągu technologicznego. Zawarto w nim charakterystykę jakości wody surowej oraz uzdatnionej ze szczególnym uwzględnieniem zmian jakości wskaźników w latach 2002 - 2012 w odniesieniu do barwy, mętności, żelaza, manganu oraz jonu amonowego. Zanalizowano efektywność procesów technologicznych w tym przebieg procesów wpracowania złóż z piaskiem chalcedonitowym do usuwania żelaza ogólnego, manganu i jonu amonowego. Na podstawie przeprowadzonych badań stwierdzono, że zastosowana modernizacja pozwoliła rozwiązać problem poprawy jakości wody, a zwłaszcza usuwania nadmiernych stężeń związków żelaza, manganu oraz azotu amonowego z ujmowanej wody podziemnej.

Wykazano, że rok po modernizacji ciągu technologicznego osiągnięto wysoki stopień redukcji większości parametrów wynoszący odpowiednio dla zawartości żelaza ogólnego - 99 %, manganu ogólnego - 93 %, amoniaku - 93 %, mętności - 94 %. Udowodniono, że zastosowany w filtrach chalcedonit okazał się lepszym materiałem filtracyjnym niż stosowany do 2008r. piasek kwarcowy. Badania potwierdziły, że najszybciej po etapie modernizacji doszło do wpracowania złoża w etap usuwania żelaza ogólnego z wody podziemnej. Etap odmanganiania wymagał dłuższego około ośmiomiesięcznego czasu wpracowania się złóż. Ponadto zmodernizowanie stacji uzdatniania wpłynęło na poprawę efektywności procesu nitryfikacji.

Słowa kluczowe: woda podziemna i oczyszczona, usuwanie żelaza i manganu, fizyko-chemiczne i organoleptyczne parametry wody do picia

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