JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(6), 50–54
https://doi.org/10.12911/22998993/137674
ISSN 2299–8993, License CC-BY 4.0

Received: 2021.04.15
Accepted: 2021.05.15
Published: 2021.06.01

Efficient Manganese Removal in Fast Contact Filters with Continuous Bed Rinsing

Agnieszka Cydzik-Kwiatkowka[1*], Paweł Kozicki[1], Dawid Nosek[1]

[1] University of Warmia and Mazury in Olsztyn, Department of Environmental Biotechnology, Słoneczna 45g, 10-709 Olsztyn, Poland

* Corresponding author's e-mail: dawid.nosek@uwm.edu.pl

ABSTRACT

There is a need to implement high-efficiency solutions for groundwater treatment, especially in the context of manganese compounds removal. This study analyzed the impact of a water treatment plant modernization to a technology of fast contact filters with continuous bed rinsing. On the basis of basic indicators of water pollution, such as iron, manganese, turbidity, color, and nitrogen compounds, the raw water collected from the groundwater intake and the water treated after the filtration process were characterized. A comparison of the efficiency of water treatment installation before and after modernization indicated that there was a significant improvement in the quality of treated water, especially in terms of manganese removal.

Keywords: water treatment, manganese removal, contact filters, continuous bed rinsing

INTRODUCTION

The technical and technological solutions for water treatment have to dynamically meet the increasing requirements for water quality. Currently, there are many innovative technological solutions, for the treatment of both groundwater and surface waters. The self-cleaning suction sieves used for the treatment of surface waters or new filter solutions for deep wells used for the treatment of groundwater constitute the examples [Gromiec et al. 2014]. Significant progress has been made with water treatment devices used in particular for filtration, demineralization, coagulation, sorption and physical disinfection with UV rays.

Two examples of the most modern water treatment technologies are certainly membrane technologies, supported by aquaprions and nanotechnologies [Gromiec et al., 2014]. Ultrafiltration removes not only manganese and iron compounds but also dangerous bacteria and colloids that are retained on the membrane. However, the use of membrane water treatment technologies may not be economically viable. Therefore, for the treatment of water for domestic and economic purposes, both traditional technologies based on filtration through a gravel-sand bed and modern membrane separation technologies can be used [Makowska and Krause 2017].

The water from underground intakes is usually the cleanest. Water treatment does not require the use of complicated methods and consists of three main stages: aeration, filtering on a filter bed (a layer of gravel and sand), and disinfection. The expectations for the filtration process relate to both the efficiency of the process and its stability. The main disadvantage of filtration with fast filters is the change in the quality of treated water during the operational cycle of a filter. The poor quality of treated water at the beginning of the filtration process is related to the phenomenon of Mn and Fe oxides accumulation in the filter bed [Toczyłowska, 2005]. With the passage of the cycle, the filter beds display a decrease in porosity, which decreases the number of suspensions in the bed and causes water quality to deteriorate. One solution to this problem is the use of a technology based on gravity contact filters working in a pressure system with the filter bed rinsed continuously during the working cycle. Such filter operation allows for the treatment of surface waters or a contact/surface coagulation process, as well as for iron and manganese removal from underground water [Toczyłowska, 2005].

The legal system of the European Union does not specify the provisions for recirculating water after its use for rinsing the filter bed (hereafter, referred to as following water) by returning this following water to the treatment technological line. In the United States, in contrast, there are specific legal provisions for this process. The amount of following water produced as a result of rinsing the filter bed in traditional filters ranges from 2% to 8% of the raw water volume. The following water may constitute an additional stream of water supplying the technological line of water treatment, if it is disinfected to prevent the growth of psychrophilic bacteria, which is particularly important in the summer months. The reuse of following water is a method of protecting natural water resources in the event of unfavorable weather phenomena, e.g., a drought lasting several months [Zimoch, Lasocka-Gomuła, 2015].

The aim of the study was to evaluate the effect of modernization of an existing water treatment plant using technology based on fast contact filters with continuous bed rinsing.

MATERIALS AND METHODS

The research was carried out on the water intake in Mirów, which is based on groundwater resources from three aquifers of Pleistocene formations [Water and Law Operations, 2009]. The water permit is maximum hour flow 300.0 m^3/h and the average daily flow 5,300.0 m^3/d (decision of the Przasnysz Staroste no. ROŚ.6223 / 13–1 / 09/2010 of 11/01/2010, Hydrogeological Expertise, 2014).

Before the modernization, water treatment was based on aeration, followed by a two-stage filtration through iron removal filters (8 units) and manganese removal filters (8 units). Closed filters with a diameter of 2400 mm, area of 4.38 m^2, bed grain size 0.5–1.2 mm, filter layer height of 1 m and a maximum filtration velocity of 15 m^3/h were used. After filtration, the treated water was chlorinated. After modernization, the first stage of the technological line consists of contact tanks (each 36 m^3), ensuring the contact of air with water before filtration. Raw water is fed to the first contact tank (ZKT1). The top of this tank is aerated by three automatic mixers. Raw water flows from the top down through the ZKT1 tank, and then it flows from the bottom up in the second contact tank (ZKT2), owing to which it is aerated. In order to increase the efficiency of the oxidation process, the $KMnO_4$ solution with a concentration of 2% is added to the ZKT2. Water with precipitated iron and manganese compounds is introduced to six DynaSand vertical contact filters [type DS5000AD-STD, Balter and Feldthusten, 2013]. The filters are operated at water flow velocity of 9.5 m/h and each has a filtration area of 5 m^2. The water flows through an inlet pipe and down to the distribution grate located at the foot of the cylindrical part of the tank. From there, the water is treated in a countercurrent flow in a moving filter bed with a height of about 2 m. A sand bed with a grain diameter of 0.71 ÷ 1.25 mm retains a layer of oxidized and coagulated iron and manganese compounds on its surface. In the filters, gravity water flow is forced by the difference in the water level in filters and contact tanks.

In the center of the filter, vertically in the guide pipe, there is a Mamut pump. The compressed air fed to the Mamut pump lifts the contaminated bed with water from the conical, bottom part of the filter to the labyrinth washer in the upper part of the tank. In the pump, turbulence causes initial separation of contaminants from the bed grains. The contaminated sand is fed into a wash maze and washed in a small volume of filtrate. The cleaned grains of the bed are reused in the filtration process. PRAESTOL 2540 TR coagulant is continuously dosed to the following water in a concentration of 0.05% (ABT User's Manual, 2005) to increase the efficiency of pollutant removal. About 90% of the following water is returned to the system. The filtered water is deaerated in the deaeration tank. If necessary, disinfection of water can be carried out with sodium hypochlorite or UV lamps (400 J/m^2).

In the research, iron, manganese, nitrates(III), nitrates(V) and ammonium nitrogen concentrations as well water turbidity and pH in raw water and water after treatment were determined (PN-ISO 6332:2001, PN-92/C-04590/03, PN-EN 26777:1999, PN-82/C-04576.08, PN-ISO 7150–1:2002, PN-EN ISO 7027–1:2016–09, PN-EN ISO 10523:2012, respectively). The results were statistically analyzed in the Statistica 13.1 (StatSoft) software package, with $p < 0.05$ using the Student's t-test. The measurement data from 2003 (before modernization) and 2017 and 2018 (after modernization) were compared.

RESULTS AND DISCUSSION

Contamination indicators in raw and treated water before and after modernization are summarized in Table 1.

The average efficiency of iron removal from water in the technology with two-stage filtration was 96.53 ± 4.25%, which was significantly lower than the iron removal efficiency in the currently used technology (by nearly 2%) (Tab. 1). The efficiency of total iron removal after modernization was stable: in 2018, a minimal reduction in the efficiency of iron removal from water to about 96.0% was observed only three times (Fig. 1b). Before the modernization, the iron removal stability was much lower and the iron removal efficiency periodically dropped as low as 69.9% (Fig. 1a).

The effectiveness of manganese removal before modernization averaged 49.18 ± 16.0%, which was significantly lower than after modernization (by nearly 36%) (Tab. 1). The lowest manganese removal efficiency was recorded in May 2003 (18.2%) and the highest (94.3%) in August 2003 (Fig 1a). The average manganese removal efficiency after modernization was 85.07 ± 2.66% with a minimum in September 2018 (76.6%) and a maximum in May 2018 (90.6%) (Fig. 1b). The effectiveness of manganese removal did not decrease in winter periods. For comparison, in the water treatment plant in Słupsk that treats underground water in a technological line based on fast filters (www.wodociagi.slupsk.pl), the average efficiency of manganese removal is 76.1%, i.e., about 9% lower than in the modernized line at the plant in Mirów. The removal of iron and manganese from waters on slow sand filters has been reported to range from 90 to 95%; however, this has been achieved with raw water of fairly good quality [Marsidi et al. 2018]. Hasan et al. [2013] used BAF (Biological Aerated Filters) for the treatment of simulated drinking water, and found that Mn^{2+} oxidation occurred simultaneously with ammonia nitrogen removal, but the key was to ensure an appropriate concentration of dissolved oxygen. Mn^{2+} at a concentration of 5.9 mg/L was removed with 99.1% efficiency when the aeration rate was 0.3 L/min. Increasing the aeration rate to a range from 0.6 to 2.0 L/min raised the concentration of Mn^{2+} in the treated water.

The effectiveness of water treatment depends on the type of filter bed material. Skoczko et al. [2015] compared the effectiveness of water removal and manganese removal under laboratory conditions using filters with beds made of manganese zeolite, amorphous quartz activated with MnO_2 sand, zeolite and natural crystalline aluminosilicate. The best results were observed with manganese zeolite, which removed 82.5–97.05% of the iron. Manganese removal was not so effective. Guo et al. [2017] treated groundwater on the filters filled to a height of 1.5 m with quartz sand. A lack of manganese in the bed filling was compensated for by dosing potassium permanganate, which allowed the bed start-up time to be shortened below 30 days. MeOx dosing enabled stable removal of ammonia and manganese, and MeOx showed high oxidation activity at a water temperature of 6.6°C. Those authors showed that chemical catalytic oxidation, rather than biological degradation, played an important role in removing ammonium and manganese from

Tab. 1. Contamination indicators in raw and treated water before and after modernization

	before modernization			after modernization		
	raw water	treated water	efficiency	raw water	treated water	efficiency
	mg/L		%	mg/L		%
Fe	1.99 ± 0.31 (n=98)	0.07 ± 0.07 (n=98)	96.53 ± 4.25	2.13 ± 0.19 (n=188)	0.04 ± 0.01 (n=188)	98.26± 0.34
Mn	0.23 ± 0.02 (n=98)	0.12 ± 0.04 (n=98)	49.18 ± 16.0	0.22 ± 0.02 (n=188)	0.03 ± 0.01 (n=188)	85.07 ± 2.66
Turbidity (NTU)	12.00 ± 2.29 (n=23)	0.77 ± 0.26 (n=23)	93.49 ± 2.02	5.71± 2.50 (n=188)	0.77 ± 0.26 (n=188)	92.62 ± 4.55
NO_3	0.58 ± 0.49 (n=9)	0.74 ± 0.43 (n=9)	-	0.27 ± 0.1 (n=20)	0.89 ± 0.36 (n=20)	-
NH_4	0.92 ± 0.22 (n=9)	0.24 ± 0.35 (n=9)	80.44 ± 22.46	0.64 ± 0.18 (n=20)	0.17 ± 0.08 (n=20)	72.59 ± 13.05
pH	-	-	-	7.5 ± 0.1 (n=20)	7.6 ± 0.06 (n=20)	-

– not calculated/not measured

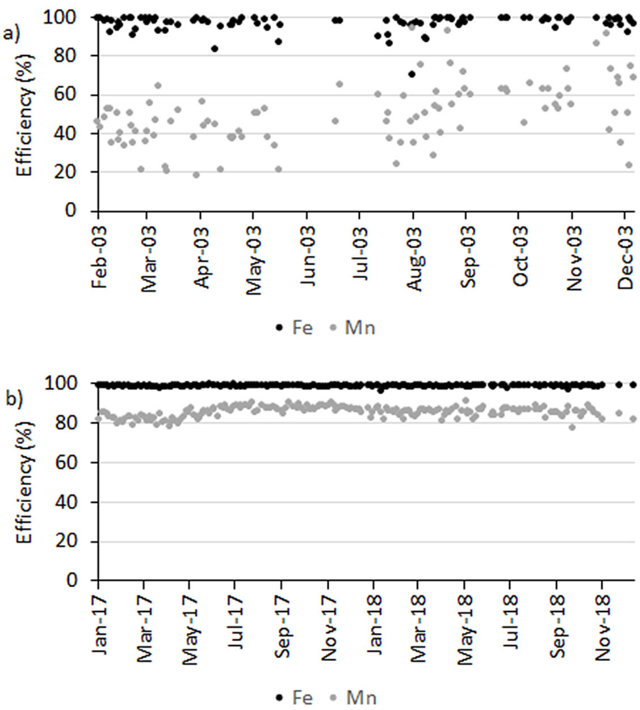

Fig. 1. Efficiency of iron and manganese removal a) before modernization and b) after modernization.

groundwater. The results obtained in the modernized plant in Mirów are comparable to the results observed at a water treatment plant in the Zoological Garden in Poznań. In the zoological garden, the treatment line consisted of a water-air mixer, two filters and UV lamps. Filters for one-stage filtration were filled with active material, consisting of GreenSand and anthracite, placed on a gravel bed [Granops, 2005]. Apart from air, potassium permanganate was also dosed to the water to improve the iron and manganese removal. Disinfection was carried out with UV lamps, mainly due to the animals' sensitivity to chlorine compounds. The iron removal efficiency was 97.3%, while the manganese removal efficiency was 88.9%. The use of the GreenSand catalytic bed enabled simple and effective treatment [Granops, 2005].

The efficiency of turbidity removal was high both before and after modernization, averaging 93.49 ± 2.02 and 92.6 ± 4.5%, respectively (Tab. 1). A similar water treatment technology (DynaSand contact filters) has been successfully implemented in Nowy Sącz. After modernization, the efficiency of pollutant removal improved significantly. The turbidity index in 90% of the samples in the analyzed period was not more than 0.55 NTU. The iron removal process on pressure filters before modernization was unstable and the iron removal efficiency varied from 29% to 96%, with an average of 62%. After modernization to the DynaSand filter technology, the average iron removal efficiency increased to 95.8% [Bergel, Kudlik, 2011].

The water treatment technology at the facility in Mirów is not fully adapted for the removal of ammonia and its derivatives. The content of nitrates(V) in the purified water was higher than that in the raw water (by 0.27 ± 0.10 mg/L) and averaged 0.89 ± 0.36 mg/L. In the presented research, a significant increase in the concentration of nitrates(V) and (III) in the treated water was observed after the disinfection of the treatment line (data not shown), which destroyed the bacterial microbiota on the filter bed grains. After disinfection, it took a month for the indicators to return to their normal values. In the studies by Liu et al. [2017] on the use of BAF technology on a pilot scale for river water treatment, the efficiency of nitrogen compounds removal was highly dependent on the process temperature. In summer, the nitrate(III) removal efficiency was the highest (97.9%), while a drop in temperature below 7°C resulted in an increase in nitrate(III) concentration during water treatment. The temperature also influenced the removal of ammoniacal nitrogen, which reached a minimum (77.5%) in winter. In the present studies, the average efficiency of ammoniacal nitrogen removal was lower (up to 72.6%), but there was no influence of temperature on the process and the treated water met the required value.

CONCLUSIONS

The use of modern, properly selected water treatment technologies allows the requirements for the quality of treated water to be met. After modernization, water treatment at the plant in Mirów, which was based on contact filters with continuous rinsing of the bed, was very stable. The modernization significantly improved the efficiency of water treatment. The efficiency of manganese removal averaged 85.1% (an improvement of about 36%), while the average efficiency of iron removal was 98.3%.

REFERENCES

1. Barter P., Feldthusen M. 2013. Ultra low P consens. Nordic Water Hydro International. Manchester, UK.
2. Bergel T., Kudlik K. 2011. Fizyczno-chemiczna i bakteriologiczna skuteczność filtrów DynaSand w zakładzie oczyszczania wody zaopatrującym Nowy Sącz. Ochrona Środowiska, 33(4), 57–61. (in Polish)
3. 3.. Granops M. 2005. Wysokosprawne metody usuwania żelaza i manganu z wody w stacjach wodociągowych na terenach niezurbanizowanych. Katedra Budownictwa i Geodezji SGGW, Warszawa. (in Polish)
4. Gromiec M., Rowiński P., Sadurski A., Zalewski M. 2014. Zagrożenia związane z jakością wody. Nauka, 1, 99–122. (in Polish)
5. Guo Y., Huang T., Wen G., Cao X. 2017. The simultaneous removal of ammonium and manganese from groundwater by iron-manganese co-oxide filter film: The role of chemical catalytic oxidation for ammonium removal. Chemical Engineering Journal, 308, 322–329.
6. Hasan H.A., Abdullah S.R.S., Kamarudin S.K., Kofli N.T., Anuar N. 2013. Simultaneous NH_4^+, N^- and Mn_2^+ removal from drinking water using a biological aerated filter system: Effects of different aeration rates. Separation and Purification Technology, 118, 547–556.
7. Liu H., Zhu L., Tia, X., Yin Y. 2017. Seasonal variation of bacterial community in biological aerated filter for ammonia removal in drinking water treatment. Water Research, 123, 668–677.
8. Makowska M., Krauze J. 2017. Filtration or separation–comparative cost analysis for underground water treatment system. Acta Scientiarum Polonorum. Formatio Circumiectus, 16(4), 155.
9. Marsidi N., Hasan H.A., Abdullah S.R.S. 2018. A review of biological aerated filters for iron and manganese ions removal in water treatment. Journal of Water Process Engineering, 23, 1–12.
10. Operat wodnoprawny na pobór wód podziemnych z ujęcia wody Mirów 2009. Biuro Studiów Ocen Strategicznych „EKOL-EKON" s.c., Ostrołęka. (in Polish)
11. Skoczko I., Szatyłowicz E. 2018. Usuwanie związków żelaza i manganu w procesie filtracji wspomaganej polem magnetycznym na piasku i aktywnym tlenku glinu. Rocznik Ochrona Środowiska, 20. (in Polish)
12. Toczyłowska B. 2005. Skuteczność usuwania zawiesin w złożach filtrów DynaSand i Dynamik. Ochrona Środowiska, 27(3), 51–54. (in Polish)
13. Zimoch I., Lasocka-Gomuła I. 2015. Możliwa skuteczność technologiczna recyrkulacji wód popłucznych w układzie oczyszczania wód podziemnych w stacji „Mosina" koło Ochrona Środowiska, 37(3), 49–55. (in Polish)
14. www.wodociagi.slupsk.pl (access 15.10.2019).