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Application of jug filters for the treatment of model well water

Ewa Puszczało, Anna Marszałek*, Gabriela Kamińska

Silesian University of Technology, Department of Water and Wastewater Engineering, Konarskiego 18, 44-100 Gliwice, Poland, email: anna.marszalek@polsl.pl (A. Marszałek)

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ABSTRACT

This study evaluates the performance of treatment of model well water by means of home water filtration with overflow filters. Treatment efficiency was determined by measuring physicochemical parameters such as water hardness, conductivity, and iron, manganese and endosulfan concentration. The microbiological performance of the jug filter was also assessed. Model well water was prepared by spiking iron, manganese and endosulfan to tap water. Daily filtration of 5 L water batches was performed for a period of 1 month. Test samples of the filtered water were taken twice a week, and each filter was tested 3 times. Depending on the water filter, manganese and iron were reduced by 50%–70% and 96%, respectively. Removal of endosulfan reached the maximum level of 90%. Disease-producing bacteria (Coliform bacteria, *Escherichia coli*) were not detected in the filtration period of 4 weeks. Filters stored in the refrigerator revealed better microbiological performance, as the multiplication of bacteria was lower than for filters stored under ambient conditions. The disadvantage of the filtration processes was a reduction of the filtration flow rate.

Keywords: Iron; Manganese; Pesticides; Well water; Jug filters; Drinking water

1. Introduction

Groundwater plays a crucial role in the world's freshwater resources. Specifically, groundwater accounts for 26% of global renewable freshwater resources [1]. The water purity is highly dependent on the water source, precipitation, inland surface water, and subsurface geochemical processes. Groundwater contains liquefied mineral ions, which often deteriorate the overall water quality and limit its potential applications for various reasons. As a result, groundwater quality must be adequately tested in order to confirm its suitable applications [1–3]. Well water, which is sensitive to both natural and anthropogenic pollutants, plays an important role as drinking water for many countries worldwide. In most cases, the quality assessment and monitoring of well water are performed according to standard physicochemical or microbiological parameters [4].

The high concentrations of iron and manganese are among the primary problems found in groundwater, although various methods have been developed for their removal including filtration, adsorption, and membrane processes [5–9]. Currently, the most frequently used option is sorption on granular substrates [6]. While the presence of iron and manganese in drinking water is not harmful to the human body, higher concentrations result in discoloration, stains, cloudiness, and taste problems. Excessive iron and manganese ions can also produce an accumulation of iron oxide or manganese dioxide in pipes. Dalai et al. [10] developed low-cost methods for iron and manganese removal from groundwater using rice husk-based activated carbon and sugarcane-based activated carbon. This study reported 100% removal of both iron and manganese following single passes through either filter material [6]. In another study, Jusoh et al. [9] successfully removed iron and manganese from the water via adsorption using

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* Corresponding author.

granulated activated carbon (GAC), although GAC was found to have a higher adsorption capacity for Fe(II) compared with Mn(II). This can be related to the adsorbates' characteristics in terms of electronegativity, ionic radius, and the number of functional surface groups on the activated carbon that interact with both Fe(II) and Mn(II) [9].

Other groundwater pollutants include pesticides introduced by agriculture and livestock farming. Recently, the concentration of pesticides increase due to overuse in agriculture. Groundwater contamination sources include also intensive localized use of fertilizers and plant protection products, improper storage of mineral fertilizers, and removal sites for expired pesticides. In fact, it has been estimated that <0.1% of the pesticides applied to crops reach the target pest; the rest enters the environment, contaminating soil, air and water bodies [11]. Consequently, the increase in the concentration of nitrogen compound, chloride, bicarbonate, sodium, and potassium is observed in groundwater. However, other unintentional events may also lead to groundwater contamination. For example, leaks and ruptures of pipelines and sewage systems, technological installation failures, damage to tanks containing hazardous substances, inadequate preparation of solutions, and washing of spraying equipment in unsuitable conditions have all been traced to groundwater contamination [11–13]. Additionally, small fires in rural areas have also resulted in the pollution of shallow groundwater contained in wells.

All mentioned aspects result in the improper quality of private well water. What's worse, there are not any recommended criteria and standards for wells. Individual well's owners are responsible for the quality of their water. Using well water as drinking water is popular in many countries. For example, private wells were used by more than 13 million households in the United States in 2017 [14].

The quality of well water can be improved by using home water filtration with overflow filters.

The producers of jug filters guarantee an improvement of water quality by removing color, hardness, chlorine and even traces of pesticides. They also specify the time of using single water filters to maintain the good quality of water. Our previous study showed that after half of the recommended time the water filters were nonutility for removal of calcium and magnesium from tap water [15]. Therefore, determination of the performance of jug filtration for improvement of well water is especially important as this water is not regularly tested and its safety is challenging.

Therefore, the aim of this study was to evaluate the jug filtration performance for the removal of iron, manganese and endosulfan, as these pollutants can exist in well water at different concentrations. Three types of overflow filters, which are generally available on the domestic market, were tested. The effectiveness of the filters was assessed on the basis of the measurement of physicochemical parameters (i.e., water hardness and conductivity) and concentration of iron, manganese and endosulfan. Endosulfan was chosen to represent potential pesticide groups owing to its high logK_{ow} factor, which makes it a strong candidate for large volume soil accumulation and subsequent groundwater contaminants [16]. This research was conducted using model well water where iron, manganese and endosulfan, were spiked to the tap water.

2. Material and methods

2.1. Model well water

Model well water was prepared by adding iron and manganese in the form of $FeCl_2 \cdot 6H_2O$ and $MnSO_4 \cdot H_2O$ salts and endosulfan stock solution to the tap water collected from the kitchen in a university building. The concentration of iron, manganese and endosulfan was 1.5 mg Fe/L, 1.5 mg Mn/L and 1.0 mg/L, respectively. Endosulfan stock solution was prepared by dissolving the analytical standard in methanol. Model well water was used as feed water in this study. The physicochemical characteristics of the model well water are given in Table 1.

2.2. Filters jug filtration

Filter jugs were operated according to the standard procedure where the lid is removed and water simple poured inside. The container tapers downwards, allowing water to flow freely through the filter. After passing through the cartridge, water flows into the empty chamber and does not mix with raw water. The time of the filtration process itself takes about 5–10 min. In every universal water jug filter cartridge, the refill is composed of two filter layers. According to the manufacturer information, the first layer, active carbon microbeads made from coconut shells, removes chlorine, phenols, detergents, and some heavy metals (e.g., lead, mercury, and nickel) from water. The second part of the filter cartridge is filled with an ion exchange resin that removes magnesium and calcium ions responsible for water hardness. For filter jugs with a volume of 2.0 L, 5 L of water were filtered every day for a period of 1 month. Test samples were taken twice a week. Each filter was tested 3 times. Three types of overflow filters, which are generally available on the domestic market, were tested. The tested filters came from three different companies. They were characterized by the same filling but had a different structure and filtration speed. Each filter can filter 150 L of water according to the manufacturers' recommendations.

2.3. Water quality analysis and microbiological assessment

Color measurements were performed using ultraviolet-visible spectroscopy (UV-Vis) with a UV-Vis Spectroquant® Pharo 300 (Merck, Kenilworth, NJ, USA). Manganese and

Table 1
Physicochemical characteristics of model water

Parameter	Value
pH	6.60
Conductivity, μS/cm	822
UV_{254}, m^{-1}	0.01
Total hardness, mg$CaCO_3$/L	360
Total hardness, mval/L	7.0
Manganese, mg/L	1.5
Iron, mg/L	1.5
Endosulfan, mg/L	1.0

iron ions were determined spectrophotometrically with Merck test kits. The absorbance was measured at 254 nm using a UV-Vis Cecil 1000 (Analytik Jena AG Company, Jena, Germany). The pH and conductivity were monitored using a multifunctional analyzer CX-461 (Elmetron, Zabrze, Poland). Water hardness was measured using the ethylenediaminetetraacetic acid method. Microbiological analysis, including coliform bacteria, the total number of microorganisms at 22°C ± 2°C and 36°C ± 2°C, *E. coli*, was conducted by an external accredited lab according to ISO methods.

The concentration of endosulfan was measured with a gas chromatograph (GC; 6500GC System GC-FID, Yl Instrument Co. Ltd., Hogye-dong, Anyang, Korea). The instrument was equipped with a 30 m × 0.25 mm inner diameter SLB®-5ms fused silica capillary column of 0.25 µm film thickness (Sigma-Aldrich, Poznań, Poland). Helium 5.0 was used as the carrier gas. Chromatographic separation of micropollutants was performed by temperature program of the column oven for all substances (80°C–320°C). The injector temperature was set at 240°C. Prior to analysis, compounds were extracted from samples by means of solid-phase extraction with C18 bed (Supelco), according to a previously developed method [16].

3. Results and discussion

3.1. Removal of hardness and conductivity of model well water

To assess the efficiency of jug filters, the reduction of hardness and conductivity of model well water was monitored (Figs. 1 and 2). As shown in Fig. 1, the total hardness decreased by 46% (Filter A and B) and 48% (Filter C) for the first 20 L of filtered water. During further filtration, the reduction of this parameter decreased significantly. After filtration of 40 L, the hardness was reduced by only 27.9% (Filter A and B) and 23% (Filter C), and, after 150 L, this further decreased to 13% (Filter A and B) and 5% (Filter C). When analyzing the conductivity, a decrease was also observed during the filtration process. The initially measured conductivity in model feed water was 820–880 µS/cm. After filtration of 20 L, the conductivity decreased to 700–750 µS/cm. However, after filtering of 140 L water, the measured conductivity returned to an initial value.

3.2. Removal of manganese and iron from model well water

In order to improve the aesthetic quality of drinking water in terms of color, smell, and taste while simultaneously reducing the total hardness, many households use at least one water softening product (e.g., water softener or tablet softeners) [17]. In addition to the aforementioned basic physicochemical properties, higher concentrations of iron and manganese ions may occur in surface and groundwater sources, including deep well water [18]. According to the regulation of the Minister of Health, the amount of iron and manganese in drinking water cannot exceed 0.2 mg Fe/L and 0.05 mg Mn/L, respectively [19]. High concentrations of iron and manganese in drinking water produce both aesthetic and operational problems such as bad taste and color, stains, and sediment in the water system. Although the presence of manganese in drinking water for concentrations below 500 µg/L has no harmful effect on human health, concentrations exceeding 100 µg/L are undesirable for customers due to the subsequent contamination of laundry and plumbing equipment [20]. The high levels of iron and manganese found in groundwater necessitate the development of local, inexpensive purification techniques. Various methods are available for iron and manganese removal from water.

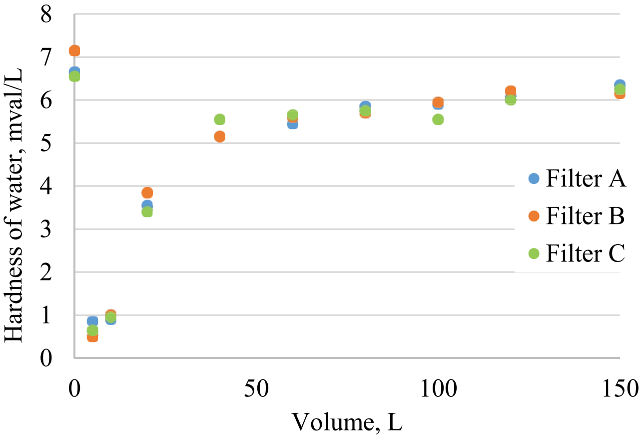

Fig. 1. Change in the hardness during the model well water filtration process.

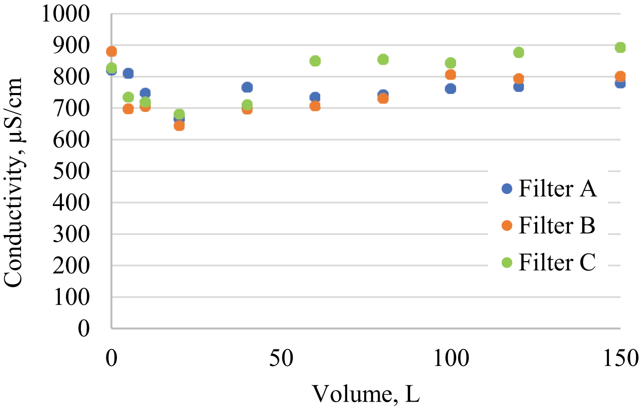

Fig. 2. Change in conductivity during the model well water filtration process.

The effectiveness of filter jugs in the removal of excessive iron and manganese ions is presented in Figs. 3 and 4. After filtering of 100 L water, the average concentration of manganese was reduced to 0.8, 0.4, and 0.5 mg/L for Filter A, B, and C, respectively. Despite a high decrease in manganese concentration (from 1.5 to 0.4–0.8 mg Mn/L), its concentration was on average 10 times higher than recommended [19]. For larger filtered volumes, a gradual decrease in the manganese ion adsorption process and a subsequent increase in manganese concentration in the filtrate were observed. The results also indicated a high efficiency of Fe removal. The average Fe concentration after filtering 100 L of water was 0.05, 0.00, and 0.1 mg/L for Filters A, B, and C, respectively. No leaching was observed in the case of iron, likely due to iron ions being trapped

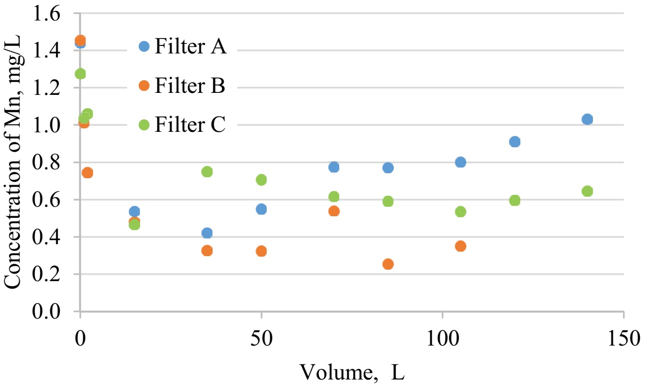

Fig. 3. Change in the value of the manganese concentration during the filtration process.

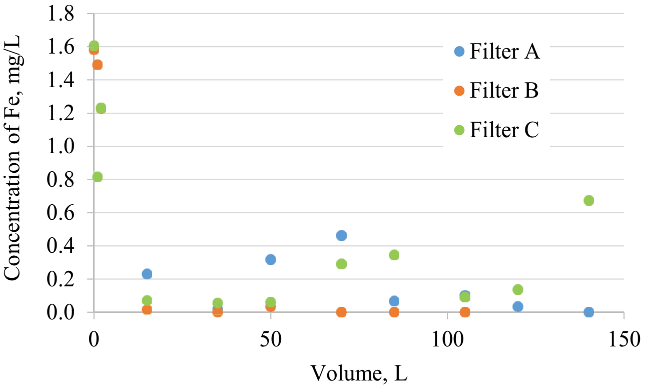

Fig. 4. Change in the value of the iron concentration during the filtration process.

by filter clogging. The concentration of iron in filtered water did not exceed the standard values for the quality of drinking water according to the regulation of the Minister of Health [19].

During the filtration process, a decrease in efficiency was observed. The initial flow averaged 4 L/min for triplicate tests. However, after filtering 100 L of the prepared water containing manganese and iron, the flow was reduced to 2.5, 0.6, and 3.7 L/min for Filter A, B, and C, respectively.

3.3. Removal of pesticides

Herbicides, fungicides, and insecticides are commonly used pesticides for agricultural crop protection. The frequent intense use of these pesticides allows them to easily penetrate into deep soil layers and aquifers. Regular consumption of water contaminated with pesticides can lead to negative health effects that can take years to show symptoms. Sjerps et al. [23] detected 15 out of 24 tested pesticides in surface and groundwater monitoring studies in the Netherlands, seven of which occurred at concentrations above the water quality standard. The concentration of pesticides in drinking water cannot exceed 0.1 µg/L [19].

Figs. 5a–c shows the degree of endosulfan removal by jug filters of three different companies. For the first 50 L

Table 2
Microbiological analysis of water

Parameter	Values								
	Model well water	Water after filtration in jugs stored at room temperature				Water after filtration in jugs stored in the refrigerator			
		1 week	2 week	3 week	4 week	1 week	2 week	3 week	4 week
Coliform bacteria , CFU/100 mL	0	0	0	0	0	0	0	0	0
Escherichia coli , CFU/100 mL	0	0	0	0	0	0	0	0	0
Total number of microorganisms at 22°C ± 2°C after 72 h, CFU/1 mL	8 ± [4; 17]	84 ± [30; 66]	163 ± [120; 220]	>300	>300	15 ± [9; 22]	45 ± [30; 66]	150 ± [110; 180]	>300
Total number of microorganisms at 36°C ± 2°C after 72 h, CFU/1 mL	–	5 ± [0; 8]	11 ± [6; 21]	>300	>300	0	2 ± [0; 4]	10 ± [2; 17]	155 ± [112; 190]

Notes: The number after the symbol ± represents the expanded uncertainty calculated for the coverage factor $k = 2$, which corresponds to a confidence interval of approximately 95%. For microbiology, the confidence interval of the obtained result was given in accordance with PKN-ISO/TS 19036:2011;
The value given does not take into account the uncertainty associated with sampling;
The sign ">" indicates that the test result is above the laboratory's upper measuring range.

of filtered water, over 90% of endosulfan was removed, although this dropped to an average of 75% for higher volumes of filtered model well water. From the high removal efficiency of endosulfan, it is clear that jug filters have the potential to remove the pesticide from well water. However, in the studied case, the initial concentration of endosulfan was very high (1 mg/L) and even 90% removal efficiency did not decrease the concentration of endosulfan for the acceptable level [19]. The high removal efficiency of endosulfan was probably a consequence of its adsorption by active carbon in the first layer of refill. Endosulfan as a compound with logK_{ow} value higher >2 exhibits a high affinity for adsorption and can be easily removed by typical adsorbents. Activated carbon has been routinely reported as a strong pesticide removal agent capable of removing 14 of the most common and popularized pesticides [21,22]. Jusoh et al. similarly measured high pesticide removal (i.e., 71.4% and 82.9% for palm shell activated carbon and coconut shell activated carbon, respectively) in aqueous solutions [24].

3.4. Microbiological analysis of water

Polish legislation [25] regulates water quality for human consumption using a specific set of standards, which include the complete lack of *Escherichia coli* and Enterococci and other similar regulations regarding coliform bacteria and the total number of microorganisms. The number of microorganisms in the water is determined by culturing at a temperature of 36°C ± 2°C and/or 22°C ± 2°C to test mesophilic and psychrophilic bacteria, respectively. Most psychrophilic bacteria cannot grow at 37°C, making them relatively harmless to humans. Microbiological analysis of the model well water revealed it to be free from mesophilic bacteria contamination. However, after two weeks of filter operation, jugs stored at room temperature showed multiplication of these bacteria in the amount of 11 ± (6; 21) CFU/1 mL. The results of the microbiological analysis of filtered water from 1–4 weeks of jug filters operation are presented in Table 2. It is clear that in the whole filtration period, disease-producing bacteria (Coliform bacteria, *Escherichia coli*) were not detected. The total number of microorganisms (22°C ± 2°C after 72 h and 36°C ± 2°C after 72 h) increased gradually during 4 weeks of filtration.

Pitcher filter manufacturers recommend following proper storage methods (i.e., cold and shaded place or refrigerator) to maintain good water properties in terms of physicochemical and bacteriological conditions. According to the Regulation of the Minister of Health, the number of microorganisms growing at 22°C and 37°C should not exceed 100 CFU/mL and 20 CFU/mL, respectively.

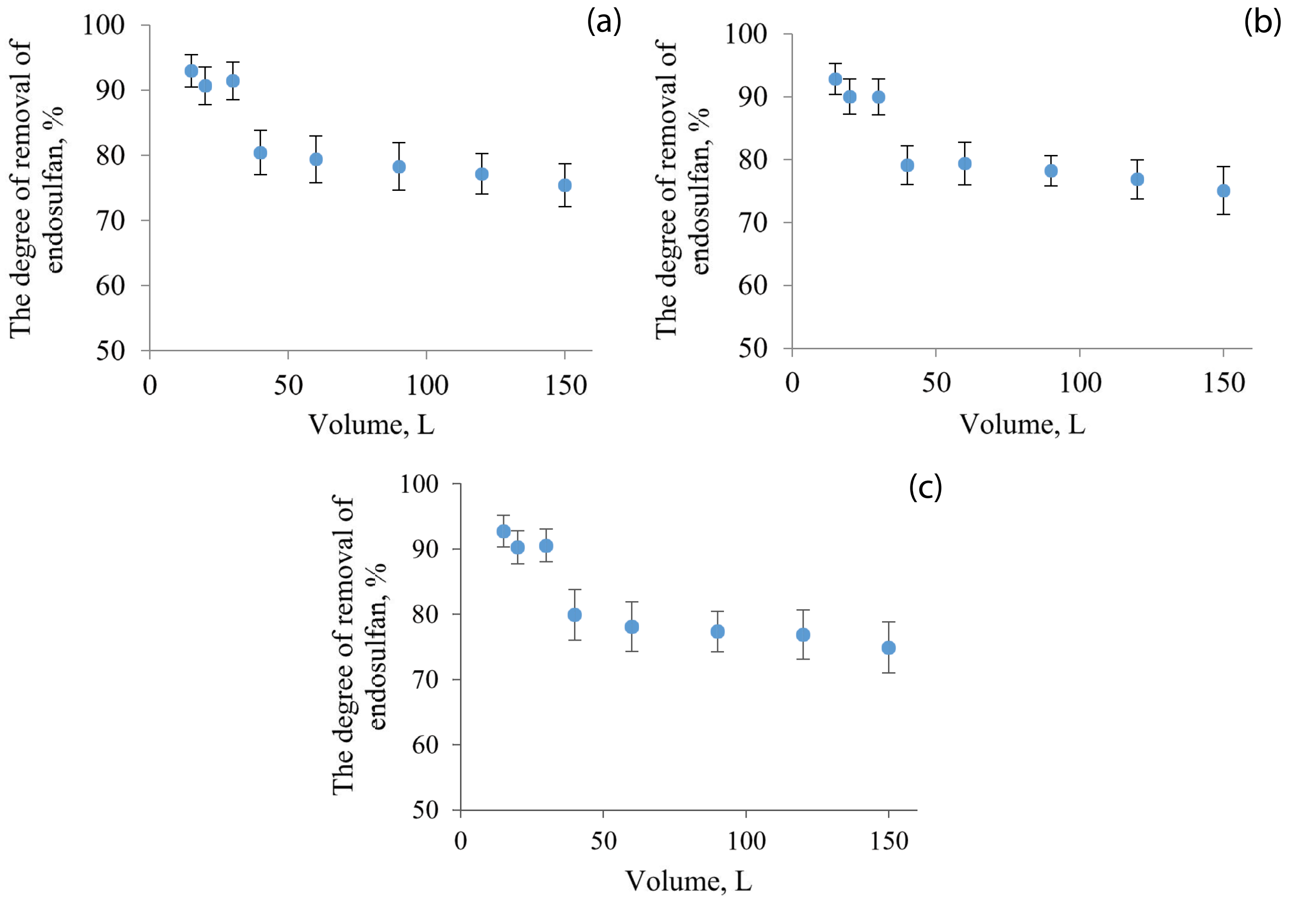

Fig. 5. Removal of endosulfan in the filtration process using (a) Filter A, (b) Filter B, and (c) Filter C.

However, our research shows that the number of psychrophilic bacteria in the samples from filters stored at room temperature after 2 weeks of use were higher than the permissible norms and amounted to 163 ± (120; 220). Based on these results, the filter should be replaced after 2 weeks of use at room temperature at the most. For filtered water in jugs stored in a refrigerator, a smaller number of these microorganisms were measured (i.e., 45 ± (30; 66) CFU/1 mL). Lawton et al. [25] similarly conducted research on the usefulness of home water filters as a way to reduce human exposure to microcystins, which may be periodically present in drinking water sources. Their study showed that home water filters can be used to reduce the amount of live cyanobacterial cells and microcystins in tap water.

4. Summary

Filter jug manufacturers ensure that active carbon microbeads retain chlorine and other odor-deteriorating substances, provide cleaner and safer water, and reduce the presence of trace contaminants such as selected herbicides, pesticides, and pharmaceuticals. The ion exchange beads in these filters soften water and reduce heavy metal concentrations such as lead and copper. Little to no information is provided regarding iron and manganese removal.

Overall, this study shows that jug filters can improve the quality of well water by reducing conductivity, hardness and concentration of iron, manganese and endosulfan. However, to obtain drinking water from highly contaminated well water, jug filtration is not efficient due to exceeding the acceptable concentration of manganese and endosulfan. More specifically, the following conclusions can be withdrawn from the experimental part:

- The overflow filters reduce the water hardness value to 1 mval/L.
- Water hardness returned to its initial value after filtering 150 L of model well water.
- Jug filters showed the high removal efficiency of iron and manganese. After filtering 100 L of water, the concentration of iron was acceptable (i.e., 0.0, 0.05 and 0.1 mg Fe/L for Filters B, A, C, respectively) according to the regulation of the Ministry of Health. However, the manganese concentration in filtered water was in the range of 0.4–0.8 mg Mn/L, which was 10 times higher than recommended.
- The removal efficiency of endosulfan reached 90% and then dropped to 75% after filtering 150 L of water. Despite, the high removal efficiency of endosulfan, its concentration in filtered water exceeds the acceptable level of 0.1 μg/L.
- Filters stored in the refrigerator revealed better microbiological performance, as the multiplication of bacteria was lower than for filters stored under ambient conditions.
- After two weeks of operation of filters, the number of bacteria exceeds the permissible level.
- Disease-producing bacteria (Coliform bacteria, *Escherichia coli*) were not detected in the whole filtration period.
- Reduction of flow rate decreased gradually in the whole filtration period.

Acknowledgments

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