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Magnetic Field Usage Supported Filtration Through Different Filter Materials

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Abstract: Currently, methods of water purification and aqueous solutions leading to effective reduction of introduced chemical compounds into water purification systems have become the subject of research. Physical methods have become an alternative, because by subjecting water and aqueous solutions to UV (ultraviolet) radiation or magnetic fields (MF), either ultrasonic or electric, it is possible to influence the change of structure, which results in changes in the properties of water and aqueous solutions. This paper attempts to verify the influence of a weak magnetic field on the removal of iron and manganese compounds in the filtration process on gravel of 1–2 mm granulation, sand of 0.4–0.8 mm granulation, activated alumina and activated carbon. The conducted research proved that MF has a significant influence on the effectiveness of iron and manganese removal from water in the case of alumina, while in the filtration process through other filter materials the effect of MF was small.

Keywords: magnetic field; water treatment; filtration; iron; manganese

1. Introduction

The influence of magnetic fields (MF) as a physical factor on liquids is a subject dealt with by researchers in many scientific centers. New applications of this process are still being sought after. It is believed that changes in the properties of water, aqueous solutions and suspensions caused by the magnetic field are related to, among others, changes in the molecular structure of a liquid as well as polarization and ordering of molecules, along with the change in the charge of these molecules. Magnetic fluid treatment can be used in numerous processes related to environmental engineering, Magnetic fields influence the competitiveness of intra- and intermolecular hydrogen bonds, which results in the weakening of large structures and in the creation of small structures with stronger hydrogen bonds within water clusters [1–8]. The results obtained by the Toledo research team [8] showed that viscosity, surface tension and evaporation enthalpy increased in water affected by magnetic fields. The increase in these physical parameters causes molecular interactions and thus changes in the chemical properties of water [8]. These factors may affect the effectiveness of water treatment contaminated by heavy metals. In particular, if the viscosity of the purified solution increases, the removal of its components can also be increased [1–8].

There are many ways to magnetize water, in which different magnetic field induction values are used, obtained by means of permanent magnets or electromagnets. The impact of the magnetic field on water is wide and diverse. The literature describes many types of magnetic field effects on water, aqueous solutions and suspensions. The most frequently mentioned include [3]: changes in conductivity, surface tension and pH under the influence of an MF [4–6]; changes in the viscosity of aqueous solutions [7,8]; changes in water evaporation rate [9,10]; effect on the precipitation of calcium sulfate(VI) [11,12]; effect of the field on calcium carbonate precipitation [13–16]; the so-called

magnetic memory effect [15–17]; change of corrosion rate of steel treated with magnetic-conditioned water [18]; improvement in the development and rate of germination of seedlings and elongation of roots of some plants (e.g., narrow-leafed lupine, ground cucumber, coriander) using magnetized water for irrigation [19,20]; and an MF can also affect the biodiversity of organisms in activated sludge biocenosis [21,22].

If an MF is used, no by-products are created. It may contribute to water protection, protection of the natural environment and protection of human health by limiting the applicability of chemicals. Other advantages of magnetic field application as a unit process in water technology and pipe systems are: ease of use; low costs associated with operating the device; the method does not require the use of chemicals and energy; and application can take place without technical supervision [1].

While analyzing collected examples of the confirmed effect of the magnetic field on the properties of water and aqueous solutions, it was decided to use a weak magnetic field to support the filtration process, which aims at removing iron and manganese compounds from water. This paper attempts to verify the influence of a weak magnetic field on the removal of iron and manganese compounds during the filtration process on gravel with a granulation of 1–2 mm, sand with a grain size of 0.4–0.8 mm, activated alumina and active carbon.

2. Materials and Methods

The experiment was carried out on a laboratory scale, in which the research station consisted of eight separation funnels. The volume of a single separation funnel was 1 dm^3, the height 24 cm, and the diameter 12 cm. Individual separation funnels were grouped in pairs and filled with the same filtration bed, i.e., separation funnels No. 1 and 2 with gravel with a granulation of 1–2 mm, separation funnels No. 3 and 4 with quartz sand with a grain size of 0.4–0.8 mm, separation funnels No. 5 and 6 with activated alumina with a grain size of 3–5 mm, separation funnels No. 7 and 8 with active carbon with a granulation of 1–2 mm. In each pair of separation funnels, one was intended for control samples (without MF), while the other was for magnetized samples. The weight of individual filtration materials in the control and magnetized sample separation funnels was 750 g/dm^3.

The studies were carried out for one-component model solutions of iron and manganese. Distilled water was used to prepare the solutions, which allowed us to eliminate the influence of other factors. It was used with the addition of a pure standard iron or manganese solution, because the goal of experiments was to investigate the effect of an MF on the efficiency of removing only iron or manganese. The natural water matrix could interfere with the determination of the MF impact. In addition, the natural water matrix contained many admixtures and impurities, including calcium and magnesium, mineral and organic suspension. Natural water also contains many anions (NO_2^-, NO_3^-, Cl^-, SO_4^{2-}, HCO_3^- etc.) and cations (NH_4^+, Na^+, K^+ etc.). A mineral suspension, which is a natural water pollution, apart from silica, consists of heavy metals and inorganic salt ions, e.g., nitrates (V), sulphates (VI). A magnetic field influences the hydration of ions contained in water [10], which may cause the precipitation of heavy metals salts, including iron and manganese. Knez and Pohar [23] proved the influence of MF on the acceleration of Ca and Mg precipitation. Additionally, MF influences the coagulation of organic suspension. When removing organic matter, iron and manganese adsorbed on organic agglomerates are removed. The direct effect of the magnetic field on iron and manganese would be impossible to determine if natural water was used for the experiment. Since MF affects most of the above-mentioned components, distilled water was used as a matrix in the studies, which allowed us to determine the effect of an MF only on the changes of Fe and Mn concentrations.

The samples were prepared by adding to distilled water a concentrated Trace-CERT® iron standard solution, 1000 mg/dm^3 Fe and a concentrated TraceCERT® manganese standard solution, 1000 mg/dm^3 Mn by Sigma-Aldrich. A series of Fe solutions at concentrations were prepared: 1; 2; 5; 10 mg/dm^3 and a series of Mn solutions with concentrations of 0.1; 0.2; 0.5; 10 mg/dm^3. The samples prepared in this way were subjected to a magnetic field. For the magnetization process, permanent ferrite magnets with magnetic induction size equal to B = 118 mT were used. They were used to encapsulate a water

tank made of PET (polyethylene terephthalate) material conducting magnetic field. The measurement of magnetic induction was performed with the use of an HGS-10A teslometer. The magnetic induction measured through the bottle wall was 57 mT and the magnetization time was 10 min. The control tests were not exposed to a magnetic field. The solutions were then filtered through deposits filled with activated alumina and sand, gravel, activated carbon. The pH of the samples was not corrected. Differences in pH were related to the addition of an individual metal standard solution. In the future, the authors plan to use natural water with a pH value of drinking water. Figure 1 shows the process of preparing samples of model water for filtration and the filtration process.

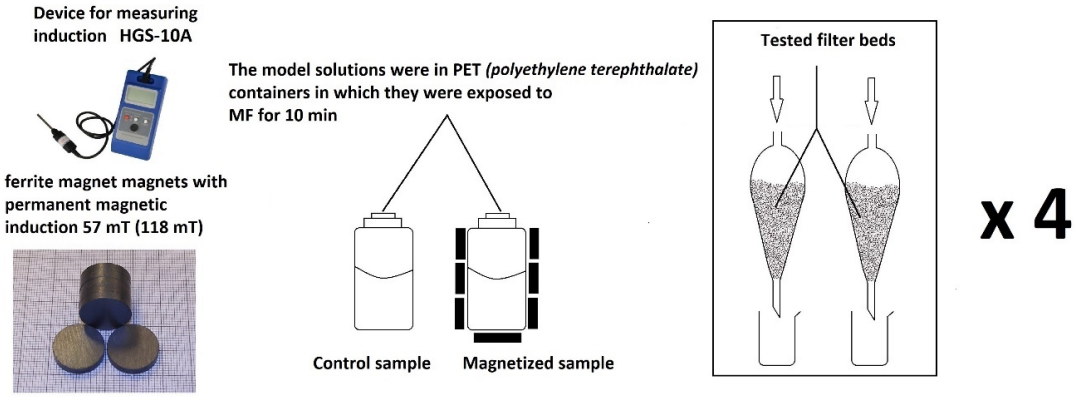

Figure 1. Diagram of the process of control and magnetized samples preparation.

The concentration of iron and manganese in the model solution and samples after filtration process on individual filtration materials was determined by atomic absorption with flame atomization using a Thermo Scientific iCE3500 atomic absorption spectrometer with deuterium background correction. For the determination of each of the elements, their standard solutions were prepared in flasks with a capacity of 50 cm^3 enabling to plot a standard curve consisting of 3 measuring points each. The reference sample was distilled water. Table 1 shows the limit of detection and limit of quantification of heavy metals, characterized by a spectrometer iCE 3500 [13]. In parallel, the matrix reference material TMDA 54,5 was analyzed to verify the correctness of the method (Table 2).

Table 1. The instrumental detection limits (IDL) and instrumental quantification limits (IQL) for the spectrometer iCE 3500 (g/dm^3) [24].

	IDL (mg/dm^3)	IQL (mg/dm^3)
Fe	0.0043	0.050
Mn	0.0016	0.020

Table 2. Comparison of measured and certified concentrations in TMDA 54,5 (mg/dm^3).

	TMDA 54,5		AAS		Dev *
	Concentration (mg/dm^3)	±SD (mg/dm^3)	Concentration (mg/dm^3)	±SD (mg/dm^3)	(%)
Fe	0.383	0.0325	0.377	0.042	−1.57
Mn	0.287	0.0219	0.276	0.019	−3.83

* relative difference between measured and certified concentration: 100%·(cm−cc)/cc.

Following the magnetic field assisted filtration process and in control samples, in addition to the iron and manganese concentration, values of pH, electrolytic conductivity and redox potential were also measured using the WTW Ino-Lab® Multi 9430 multiparameter meter. The experiment was performed in three replicates. Table 1 shows the average values of iron and manganese concentrations in samples

of filtered solutions by individual filtration materials, i.e., in control samples and in magnetized samples. The efficiency of iron and manganese removal as a result of filtration was also calculated according to Equation (1).

$$R = \frac{C_o - C_k}{C_o} * 100\% \quad (1)$$

C_o—initial concentration, mg/dm^3,
C_k—final concentration after filtration by Al_2O_3, mg/dm^3.

3. Results and Discussion

Filtration belongs to the group of the most commonly used unit processes. It is applied in water and sewage-sedimentary circuits in purification stations for drinking, boiler, cooling or pool water as well as in industrial plants treating the post-production sewage with a high content of some elements, e.g., Cd, Cu, Fe, Mn, Hg, As, Co, Ni etc. [1,25–28]. Progressive technical and technological development allows for its continuous improvement while searching for non-chemical assistive methods (e.g., magnetic field or sonification). Such synergy will allow us to meet the increasing requirements for water quality, taking into account the economic aspect translating into a reduction in financial output and energy saving.

For the first time, a magnetic field in water treatment was applied in the second half of the 20th century by the Belgian inventor Theo Vermeiren, who in 1953 patented a device using a magnetic field to protect heating installations against boiler stones [8]. Since then, magnetizers and electro-magnetizers have been widely used in heating technology. Their main advantage is the fact that the MF they generate affects the crystallization of $CaCO_3$ by delaying its precipitation. It also triggers the "memory effect", which means that the anti-scale properties of calcium carbonate in the installation persist for some time from exposure to the magnetic field [29,30]. Another example of the use of MF in water treatment is the use of magnets to increase water saturation with oxygen. Magnetized water, absorbs its paramagnetic oxygen molecules during contact with the atmosphere, which results in an increase in oxygen concentration in the liquid [31]. The authors of the present work have therefore put forward a thesis that this may improve the efficiency of iron and manganese removal in inorganic compounds.

The removal of iron and manganese from water can be carried out by many conventional methods. In general, the essence of iron removal is the oxidation of Fe(II) ions to Fe(III) and the removal of precipitated $Fe(OH)_3$ sediments from the treated water by sedimentation and filtration. De-manganation however, consists of the oxidation of Mn(II) ions to Mn(IV) and precipitation in the form of MnO_2 sediments [25]. The method used to remove these metals from water is determined by the form in which they occur in the treated water. If iron is bound as $Fe(HCO_3)_2$, a simple water treatment system is used: aeration, sedimentation, rapid filtration and final disinfection. If the iron is also in the form of $FeSO_4$, then the alkalization process should be included in the system to ensure neutralization of H_2SO_4 formed during the hydrolysis of $FeSO_4$. If iron is present in water in combination with organic compounds, aeration, sedimentation and filtration are ineffective. Coagulation or chemical oxidation is usually required to remove such iron forms [25,32]. The Mn(II) ions present in the water are more persistent and do not hydrolyze as easily as iron salts. The effective oxidation of manganese occurs only at pH = 9.5 [32]. Oxidation is accompanied by a decrease in pH due to the release of hydrogen ions. The required high pH of the Mn(II) oxidation reaction with water-soluble oxygen explains the insufficient effect of water demanganization in the classical purification system sufficient for iron oxidation, i.e., aeration and filtration. The use of water aeration at pH <9.5 does not ensure the oxidation of manganese, it only allows the deacidification of water. Without increasing the pH value required for effective oxidation of Mn(II) to Mn(IV), stronger oxidants such as ozone can be used instead of oxygen. When removing iron and manganese compounds from water, the following phenomena are used: low solubility of iron and manganese hydroxides, hydrolysis and oxidation of mineral connections of iron ions in water as a result of aeration of water and catalytic effects of iron and manganese oxides and hydroxides [32]. Removal of iron and manganese compounds from water can be carried out in one-stage filtration on multilayer deposits or in two-stage filtration on single-stage

deposits. After the initial aeration of the water, only iron compounds can be oxidized to Fe(III) and precipitated as $Fe(OH)_3$, which are retained on filters. Effective removal of manganese is only possible with a suitable catalytic medium, which is either chemically activated or treated [32]. In the global literature [25,26,32] filter media used during iron removal and de-manganation can be divided into inactive, catalytic and oxidative media, such as:

- worked out natural quartz masses, covered with a stable coating of iron and manganese oxides, formed from iron and manganese compounds removed from water during the filtration process,
- natural manganese ores—depending on the origin from 60 to 95% MnO_2,
- deposits that are pre-activated at the production, covered with iron and manganese oxides according to patented technologies, e.g., with grains industrially coated with manganese dioxide (MnO_2) coatings.

The authors of the present work have experience in experiments on water filtration and iron and manganese removal from water and have undertaken research on a new process, which may improve the efficiency of Fe and Mn removal by traditional methods. Therefore, tests were carried out to determine the effect of a magnetic field on the filtration process by the most commonly used filtration materials such as sand, gravel, aluminum oxide and activated carbon. The goal of the experiments on water magnetization was not iron nor manganese oxidizing. According to Toledo and others [8], an MF affects the ordering of water molecules. The experiment aimed to check indirect influence of water molecules order. The visible results were water purification and the efficiency increase of water filtration with various materials. In the future, tests are planned with different water magnetization times.

The obtained results of iron and manganese removal, changes in redox potential, pH and electrolytic conductivity in the MF assisted filtration process are presented in Tables 3 and 4.

After analyzing the iron concentrations (Table 3) in modeled water samples with an initial concentration of 0.95 mg/dm^3 filtered by individual filtering materials, it was found that only in the case of samples filtered by activated alumina was the Fe concentration in samples subjected to MF lower than in the control sample. Calculated efficiency of iron removal in this bed was from about 20% in control samples up to 30% (Figure 2) in magnetized samples. In contrast, filtration efficiency for other tested filter materials, at the same initial iron concentration, ranged from about 89% for quartz sand to 93% for activated carbon. For these substances, no effect of the magnetic field on the filtration efficiency was recorded. Skoczko et al. [25] also investigated the efficiency of iron removal on various filter beds. In their research, the highest efficiency of iron removal was achieved for the GreenSandPlus deposit (from 82.59% to 97.61%). Quartz sand proved to be the least effective, allowing removal from only 25.67% to 45.39% [25].

Considering another series of tests with an initial concentration of iron of about 2 mg/dm^3, a similar trend was observed as in the previous series. The effect of the MF was observed only in the filtration process realized with activated alumina. The effectiveness of iron removal on this material in the case of samples subjected to MF amounted to 33.5% and in control samples, 47%. In another series, the concentration of iron in raw water was about 5 mg/dm^3. This time, the effect of MF on the iron removal effect on all tested filter materials was noticed. The greatest impact was observed in the case of the Al_2O_3 deposit. The difference between the magnetized and control sample was 14%. For other filtration materials, the effect of the MF was negligible. The difference between concentration of Fe in filtered water in MF samples and controls was from 0.5% to 3%. In the last research series, raw model water was prepared with an iron concentration of about 10 mg/dm^3. This time, a noticeable effect of the magnetic field during filtration process on all tested materials was achieved. However, in the case of quartz sand, gravel and activated carbon, as in the previous series, it was small. The difference in the effectiveness of Fe removal ranged from 1.8% for quartz sand to 5.2% for gravel. In the activated carbon filtration process, the difference in Fe removal efficiency was calculated at around 3% in favor of samples treated with MF. Studies on the use of MF were also conducted by Xiao et al. [33]. They tested the influence of a magnetic field on the adsorption process associated with filtration on

active sorption materials. They used a weak magnetic field to increase the efficiency of removing the Orange II dye during the adsorption process on metallic iron. Chen et al. [34] found that a weak magnetic field accelerates the removal of chloroacetamide with zero-valent iron in drinking water. Tireli et al. [35] proved that an MF supported the change in the sorption capacity of magnetic clay by increasing the adsorption of the dye, methylene blue. Changes in the course of Langmuir's isotherm were observed [35].

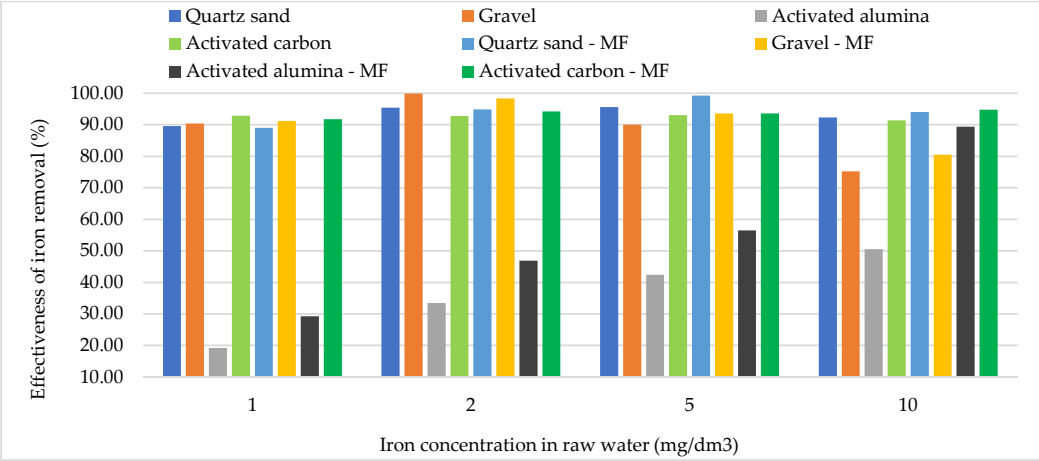

Figure 2. Graph of the dependence of the iron removal efficiency on initial concentration in raw water.

There are several theories explaining the action of a magnetic field and its effect on changing water properties. Baker and Jude divided them into four categories [29]: impact on intramolecular interactions (e.g., change of electronic configuration), influence of pollutants (released as a result of the magnetic field), effects on extramolecular interactions (e.g., changes in water interactions with ions), impact on phenomena occurring at the interface. Due to these above, while conducting model tests upon the effect of MF on the water filtration process by selected filtration materials, the redox potential, pH and electrolytic conductivity in water samples before and during the process were also measured. Redox potential in raw water before the filtration process ranged from −23.1 to 305.1 mV, while in the control samples after the process, depending on the initial iron concentration, it ranged from −21.1 to 369 mV. In samples under the influence of an MF, no significant differences were observed in comparison to the control samples. The pH in samples tested in each series before the filtration process ranged from about 3.80 to 7.81. Lower pH was observed in series with higher initial iron concentration, i.e., 5 and 10 mg/dm^3. The reason was larger volume of the standard solution added, which was acidified. After the filtration process on activated alumina, an increase in pH was observed in control samples as well as in samples treated with an MF. This can be explained by the amphoteric nature of this material. During the contact of water with Al_2O_3, hydroxides form on its surface, which raise the pH of the water flowing through the filter bed [28], which confirms the theory of Baker and Jude [29].

As part of the research, experiments were carried out, in which the one-component solution was a model water containing manganese. In the first series, the initial concentration of manganese was about 0.1 mg/dm^3. A slight influence of MF was noted for filtration through Al_2O_3 and gravel (Table 4). In the case of filtration through quartz sand and activated carbon, the concentration of Mn in magnetized water was higher than in the control sample. In the subsequent series, model water was used, in which the concentration of manganese was about 0.2 mg/dm^3 and then no effect of MF on the filtration efficiency was observed. Then, model water with a manganese concentration of about 0.5 mg/dm^3 was tested. This time, the efficiency of manganese removal from water during the filtration process through sand and gravel increased and the highest one, in the case of aluminum oxide, was found. In the case of activated carbon, the manganese removal efficiency was again lower in the samples of magnetized water than in the control samples without the influence of MF.

Table 3. Obtained results comparison for samples including Fe.

Parameter	Raw Water	Quartz Sand		Gravel		Activated Alumina		Activated Carbon	
Sample		**CS**	**MF**	**CS**	**MF**	**CS**	**MF**	**CS**	**MF**
1 mg/dm^3									
Conc. (mg/dm^3)	0.95	0.099 ± 0.001	0.104 ± 0.001	0.091 ± 0.001	0.093 ± 0.002	0.767 ± 0.066	0.672 ± 0.022	0.067 ± 0.009	0.079 ± 0.004
Redox (mV)	305.1	237.8	183	224.5	243	111.5	102	88	16
pH	7.81	8.28	8.75	8.07	8.09	9.4	9.55	10.06	9.45
Conductivity (µS/cm)	18	52.1	54.9	32.9	44.8	239	205	1298	1080
2 mg/dm^3									
Conc. (mg/dm^3)	1.92	0.089 ± 0.017	0.098 ± 0.036	0.002 ± 0.0009	0.031 ± 0.003	1.278 ± 0.18	1.0193 ± 0.26	0.138 ± 0.05	0.111 ± 0.07
Redox (mV)	−23.1	−26.2	−5.2	132.4	5.6	−36.1	27	−21.1	−5
pH	7.38	8.41	8.91	6.31	7.16	9.7	10.25	10.75	10.22
Conductivity (µS/cm)	53.1	61.4	61.4	81.5	86.2	364	296	1550	1293
5 mg/dm^3									
Conc. (mg/dm^3)	4.89	0.216 ± 0.08	0.037 ± 0.07	0.487 ± 0.065	0.313 ± 0.026	2.813 ± 0.028	2.128 ± 0.105	0.3385 ± 0.005	0.312 ± 0.006
Redox (mV)	265.1	282	268.6	369	334.7	45.8	31.2	−18.7	−12
pH	5.56	5.44	6.19	4.38	4.72	9.78	9.8	10.51	9.81
Conductivity (µS/cm)	105.3	175.6	167.3	272	237	3222	341	1261	988
10 mg/dm^3									
Conc. (mg/dm^3)	9.45	0.726 ± 0.051	0.559 ± 0.072	2.337 ± 0.097	1.843 ± 0.084	4.676 ± 0.092	1.001 ± 0.19	0.810 ± 0.035	0.494 ± 0.031
Redox (mV)	167.9	200.7	388	558.6	463.3	63.9	59.9	10.4	37.7
pH	3.80	3.77	4.46	3.39	3.55	9.32	9.59	10.04	8.68
Conductivity (µS/cm)	563	647	452	844	742	409	368	1041	752

CS—control sample, MF—water sample subjected to magnetic field.

Table 4. Summary of results for samples containing manganese.

Parameter	Raw water	Quartz Sand		Gravel		Activated Alumina		Activated Carbon	
Type of Sample		**CS**	**MF**	**CS**	**MF**	**CS**	**MF**	**CS**	**MF**
0.1 mg/dm^3									
Conc. (mg/dm^3)	0.0841	0.0087 ± 0.001	0.0111 ± 0.003	0.013 ± 0.003	0.012 ± 0.003	0.009 ± 0.002	0.0084 ± 0.003	0.0063 ± 0.001	0.0069 ± 0.001
Redox (mV)	309.9	215	160.7	269.7	234.7	86.6	83.4	57.4	117
pH	6.71	8.04	9.03	7.11	7.49	9.42	9.33	10.08	8.66
Conductivity (µS/cm)	14	5.4	7.3	8.1	7.1	211	221	735	405
0.2 mg/dm^3									
Conc. (mg/dm^3)	0.174	0.0124 ± 0.003	0.0135 ± 0.004	0.023 ± 0.003	0.023 ± 0.004	0.0066 ± 0.002	0.00819 ± 0.002	0.0072 ± 0.003	0.0127 ± 0.002
Redox (mV)	260.2	202.8	161.9	255.3	209.8	62.1	56.1	82.1	50.9
pH	5.35	8.25	8.64	6.9	7.9	9.69	9.88	10.15	9.45
Conductivity (µS/cm)	26	9.8	11.6	11.8	10.7	206	201	845	359
0.5 mg/dm^3									
Conc. (mg/dm^3)	0.4636	0.0544 ± 0.021	0.052 ± 0.025	0.123 ± 0.046	0.085 ± 0.01	0.034 ± 0.003	0.0273 ± 0.004	0.004 ± 0.001	0.0049 ± 0.001
Redox (mV)	220.1	317.9	240.2	364.7	326.6	50.1	47.5	90.2	87.8
pH	6.9	6.81	7.36	5.17	5.92	9.38	9.29	9.98	9.35
Conductivity (µS/cm)	63.6	22.2	21.7	29.6	19.4	168.4	178.5	503	294
1 mg/dm^3									
Conc. (mg/dm^3)	0.8934	0.1958 ± 0.037	0.1889 ± 0.031	0.289 ± 0.046	0.2613 ± 0.034	0.0859 ± 0.043	0.0581 ± 0.015	0.0061 ± 0.001	0.0048 ± 0.001
Redox (mV)	229.2	257.9	208.9	389.3	368.4	62.7	45.6	64.4	107.5
pH	6.52	8.05	8.68	5.33	6.44	9.84	10.1	9.92	9.11
Conductivity (µS/cm)	132.1	44.3	45.5	67	51.3	172.3	182	480	263

CS—control sample, MF—magnetic field sample.

Research on the removal of metals using filter material and magnetic field was also conducted by the research group Gonzalez [36]. They used model Cu and Zn solutions. They used two different materials as adsorbents: activated carbon made of bituminous coal and activated carbon from bone. Magnetic characteristics of these materials have shown that activated carbon from bituminous coal is a ferromagnetic material, while bone carbon is a paramagnetic material. In the case of both adsorbents, no additional modifications have been made to change or improve their magnetic properties. Obtained adsorption results depended on the magnetic nature of both the adsorbent and the adsorbate. It was found that due to its ferromagnetism, activated carbon was working better under the influence of external magnetic field. There was an increase in the adsorption capacity by 63% for Cd^{2+} and 15% for Zn^{2+} [36]. The difference in the removal efficiency of metals in our own research and Gonzalez studies [36] is due to the time of water magnetization. Gonzalez applied a magnetic field throughout the whole experiment duration, while the authors of this work only applied a magnetic field for a period of 10 min when water was in the raw water reservoir.

In the last series of tests, as part of the work carried out, tests were conducted with a manganese model solution at a concentration of approximately 1 mg/dm^3. On the basis of calculations, higher efficiency of Mn removal in samples treated with MF during the filtration process through sand, Al_2O_3 and activated carbon was found. The difference in the manganese removal efficiency between the MF and control water on individual filter beds (Figure 3) ranged from 0.8% for sand, 3.1% for aluminum oxide and 0.1% for active carbon. Baker and Jude [29] also studied the influence of magnetic field on the removal of selected impurities from waters using aluminum oxide. It should be noted that manganese removal is more effective at higher pH values and adequate oxygen saturation [26,28]. The amphoteric character of Al_2O_3, due to formation of $Al(OH)_3$ particles on its surface, allows local elevation of water reaction and precipitation of Mn in the form of MnO_2. On the other hand, the use of MF increases the saturation of water with oxygen necessary for the oxidation reaction of Mn(II) to Mn(IV). Filter materials such as quartz sand or gravel are chemically inert, thus their impact on physical and chemical properties of water through the use of a magnetic field did not increase the efficiency of iron and manganese ions

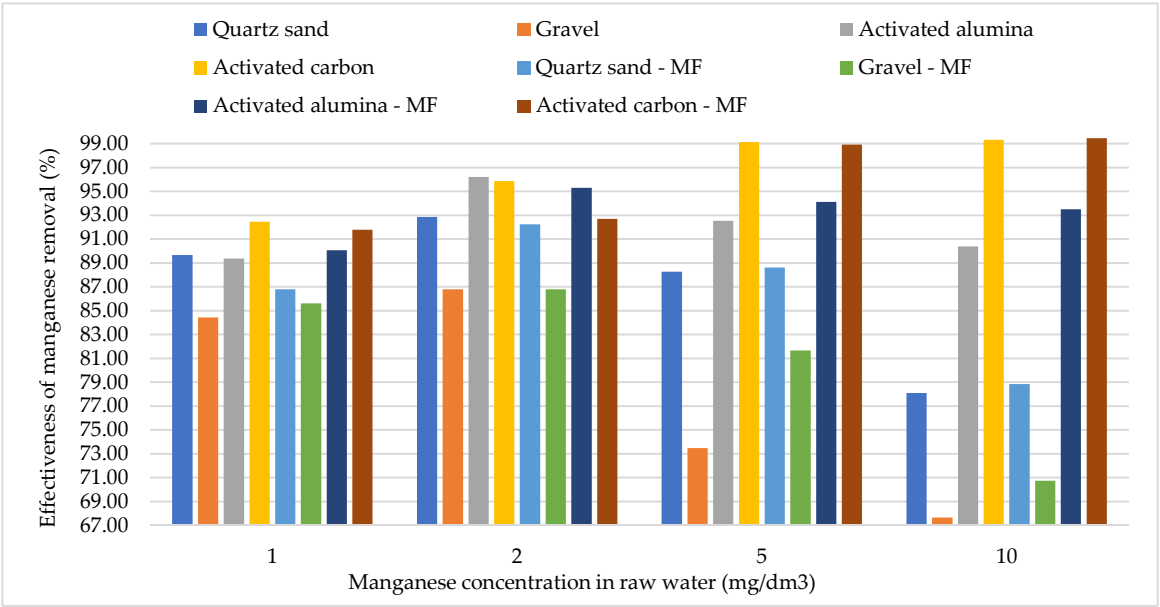

Figure 3. Dependence of the manganese removal efficiency on initial concentration in raw water.

After analyzing the MF-assisted filtration process, besides the manganese concentration, the following parameters were also studied: redox potential, pH and electrolytic conductivity. The obtained averaged results are presented in Table 2. Redox potential before the filtration process

ranged from 220.1 to 309.9 mV. In the control samples after the sand bed filtration process, the redox potential was higher for Mn concentrations in raw water of approximately 0.5 and 1 mg/dm^3. In the first and second series, at a concentration of manganese about 0.1 and 0.2 mg/dm^3, its value was lower for filtered water, both in the control sample and the MF treated one. After the filtration process on gravel in the first two test series, at a concentration of 0.1 and 0.2 mg/dm^3 manganese, redox potential was lower in the control samples than in the model samples before the filtration process. However, in the two remaining series during filtration on the same bed, the redox potential was higher by more than 100 mV in the MF samples than in the model samples before the process. In the case of samples filtered by activated alumina and active carbon in all research series, redox potential was lower than in the pre-process samples. In the case of magnetized samples filtered through this deposit, similar trends were observed.

The pH value in the tested samples of manganese solutions before the filtration process ranged from about 5.35 to 6.71. High pH variability was observed in samples subjected to magnetic field and control samples for all test series in the filtration process on each of the analyzed filtration materials. The highest increase in pH in the magnetized and control samples was found in the case of filtration through activated alumina, which was caused by the same amphoteric effect as in the case of iron samples.

The electrolytic conductivity in water containing Mn prior to the filtration process ranged from 14.0 to 132.1 μS/cm. During the research, the highest increase in conductivity was recorded both in samples treated with MF and control samples in the filtration process on activated carbon.

Toledo and others [8] indicated that the external magnetic field affects the number of hydrogen bonds, the structure of liquid water and the diffusion coefficient of water molecules among themselves. They performed research and calculations based on measurements of enthalpy, viscosity, surface tension, which proved that MF significantly affects the breaking of hydrogen bonds. Competition between intra- and intermolecular hydrogen bonds weakens large structures and creates small structures with stronger hydrogen bonds within water clusters. Experiments have shown that viscosity, surface tension and evaporation enthalpy increased in water under the influence of magnetic fields. The increase of water viscosity under the influence of magnetic fields was explained on the basis of the formation of a stronger hydrogen bond inside smaller water clusters [27,37]. An increase in water evaporation enthalpy was also observed in earlier studies by Nakagawa and coworkers [38]. Using the experience of the above mentioned researchers, a magnetic field was applied to improve the efficiency of iron and manganese removal from water in the filtration process through water magnetization, which according to the above mentioned researchers caused an increase in viscosity, surface tension and evaporation enthalpy, and these properties affect the sorption of iron and manganese on the filtration bed.

The available scientific literature describes numerous, various types of magnetic field effects on water and its dissolved components. The most frequently mentioned include: the impact on the precipitation of calcium carbonate crystals, both as to their type and place of precipitation (mainly aragonite as a form of calcium carbonate crystallization), effect on the precipitation of calcium sulphate (VI) [8,27,37], changes in pH over time, preservation of the above properties for a specified time (up to 200 h) also known as magnetic memory, reduction of the surface tension of water, change in the corrosion rate of steel. There were no reports regarding the influence of magnetic field on the removal of iron and manganese from water, hence attempts were made to assess the effect of magnetic field on the effect of removing these elements from water during the filtration process on various fillings. Based on the research carried out upon the application of a magnetic field supporting the process, it was found that an MF has an impact on improving the efficiency of the filtration process. A clearer effect was observed in the filtration on activated alumina and quartz sand. The obtained results confirm the thesis that MF can support the filtration process, especially since it does not increase the amount of introduced chemical compounds to water treatment systems or to the environment.

4. Conclusions

1. Among the tested filtration materials, i.e., quartz sand, gravel, activated alumina and active carbon, the material most susceptible to MF influence turned out to be activated alumina, which allowed us to increase the removal efficiency of tested pollutants by about 1–3% compared to processes without the application of an MF
2. From among all analyzed filtration masses used to remove iron from the raw model water, the best effect of Fe removal was obtained for filtration on quartz sand and gravel. The effect of the MF was best observed in the removal of iron in the filtration process on activated alumina.
3. The most effective filter beds in manganese removal from the model raw water were activated carbon and aluminum oxide. In the case of manganese removal during the filtration process on quartz sand and gravel, a decrease in efficiency was observed along with an increase in the concentration of manganese in raw water from 0.2 mg/dm^3 to 0.5 mg/dm^3 and up to 1 mg/dm^3.
4. The magnetic field can support the filtration process, especially since it does not increase the number of chemical compounds introduced into water treatment systems or the environment. Experiments on the impact of MF on water purification processes should be continued in order to thoroughly investigate the impact.

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