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Analysis of the Properties and Particle Size Distribution of Spent Filter Backwash Water from Groundwater Treatment at Various Stages of Filters Washing

In Poland, water supply for villages and small towns is provided mainly from groundwater resources. In spite of good physicochemical and bacteriological properties for groundwater, in most cases it is required to remove iron and manganese, which influences the applied treatment technologies. The processes of potable water treatment result in the emergence of certain by-products, i.e. technological wastewater (mainly spent filter backwash water) and sediments that contain the pollutants removed from water. The study presents the results of the Authors' tests of particle size and quantity distribution in spent filter backwash water from the groundwater treatment plant in Kąty Wrocławskie. The paper also contains an analysis of the changeability of iron and manganese content and turbidity in different phases of filter backwashing (initial backwashing, air backwashing, second backwashing). The research consisted of four series of tests conducted during the period from July 2013 to May 2014. Spent filter backwash water samples were collected during backwashing of two filters. Test results have shown that the quality of spent filter backwash water changed on subsequent stages of backwashing. Suspension particles of a size ranging from 10÷20 µm accounted for the highest volume percentage share in the analysed samples of spent filter backwash water from both filters, while the quantitative distribution of particles of the given diameters was heterogeneous and it depended on the stage of filter backwashing.

Keywords: **water treatment plant, spent filter backwash water, laser granulometer, laser diffraction, groundwater**

Introduction

Water supply systems use both surface waters and ground waters. It is estimated that approx. 70% of groundwater intakes in Poland take water that requires iron removal and 55% - water that requires manganese removal [1, 2]. The selection of potable water treatment technology depends on the type and nature of existing contaminants [3].

The emergence of spent filter backwash water from the backwashing of iron and manganese removal filters and of sediments is an integral part of the groundwater treatment process. The amount and composition of the emerging backwash water may differ and they depend on the amount of the treated water, the degree of its contamination, the type and dosage of applied chemical substances and on the degree of contaminant removal [4, 5].

The composition of spent filter backwash water from iron and manganese removal filters of collected groundwater is significantly different from the composition of backwash water emerging as a result of backwashing filters for surface water treatment. Spent filter backwash water from groundwater treatment plants contains a high amount of suspensions, composed mainly of amorphous, strongly hydrated iron and manganese oxides and hydroxides. According to research conducted by Sozański [6] on 22 stations, their share in mass accounted for 70÷80%, while the share of organic substances did not exceed 20%. Spent filter backwash water from groundwater treatment plants usually does not contain heterotrophic bacteria, although the presence of autotrophic ferric, manganese and nitrifying bacteria is often noted [7].

The size of particles constituting a suspension may be easily identified for spherical particles, by stating their diameter. However, in practice, most commonly encountered particles have varied shapes that diverge from the model spherical shape and their sizes may adopt a wide range of values. In order to characterise particles that constitute so-called polydisperse suspensions, which exist, among others, in spent filter backwash water in water treatment facilities, the notion "mean diameter of a set of particles" was introduced. These diameters may be determined directly, basing on particle size distribution or indirectly, basing on the parameters of log normal distribution. The diameter D(1,0) is the number-length mean diameter, D(2,0) is the number-surface mean diameter, while D(3,0) is the number-volume mean diameter. The first two types of diameters are used in the studies on catalysers [8]. The Sauter mean diameter D(3,2), i.e. the surface area moment mean diameter, is most commonly used in engineering measurements and analyses, i.e.: characteristics of dust, particles that create clouds [9] and in calculations for fluidised bed boilers [10]. On the other hand, the D(4,3) diameter is used for the identification of grain size distribution in fine coal and ground metal ores [11, 12]. Knowledge about the size of particles that create suspensions in water and wastewater is becoming increasingly commonly used for the selection of water treatment technology and planning wastewater treatment processes.

Currently, several methods are used to determine the size of diameters of particles that create the given suspension. Each of them has both advantages and disadvantages and can be applied to a specific range of particle sizes [11]. The most important currently used approaches include optical methods based on the measurement of scattering of a light beam passing through the given medium. These methods include, among others, the method based on laser light diffraction used by particle size distribution analyser, also known as laser granulometer or laser diffractometer.

The objective of the study was to determine the usability of information obtained from laser granulometer to determine the properties and particle size distribution of particles that create the polydisperse suspension of spent filter backwash water that emerges as a result of the backwashing of iron and manganese removal filters at the groundwater treatment plant in Kąty Wrocławskie. Additionally, the sizes and properties of suspension particles in spent filter backwash water collected from filter backwashing were compared. The paper also contains an analysis of the changeability of iron and manganese content and turbidity in different phases of filter backwashing.

1. Methodology

The analysis of particle size distribution in spent filter backwash water was conducted with use of Mastersizer 2000 laser granulometer, manufactured by Malvern Ltd., with a particle size measurement range from 0.02 to 2000 μm. Tests were conducted at the Geotechnical Laboratory of the Wroclaw University of Environmental and Life Sciences. The content of iron and manganese in backwash water samples was also measured and the turbidity of water was determined. Selected quality indicators of collected spent filter backwash water samples were analysed at the Faculty Water and Wastewater Technology Laboratory of the Wroclaw University of Environmental and Life Sciences.

Samples were collected during the backwashing of filters at the groundwater treatment plant in Kąty Wrocławskie. The groundwater intake in Kąty Wrocławskie uses approved operational resources from tertiary formations. Water may be collected from the maximum depth up to 91.5 below ground level, from five wells. Raw water has a slightly alkaline pH (7.2) and hardness ca. 130 mg $CaCO_3/dm^3$. Additionally, it is characterised by increased iron content, up to 1.2 mg Fe/dm^3 and manganese content up to 0.3 mg Mn/dm^3, and by a specific smell. The water does not raise any microbiological concerns, so it is disinfected only periodically, for prophylactic purposes. The technological system adopted by the groundwater treatment plant guarantees that all contaminants will be removed from raw water to achieve the desired standard values. The plant employs a two-stage water pumping system. Raw water is directed to a water-air mixer, where it is aerated with use of compressed air. Then it is subject to filtration in four filters, at the rate of 8 m/h. Filters are backwashed automatically, with air supplied by a blower and treated water supplied by the backwashing pump. Spent filter backwash water is directed to the settling tank, and then, after clearing (after at least 2 hours of settling), the supernatant is discharged to a nearby ditch. After pumping, sediments that gather in the settling tank are removed to a wastewater treatment plant located nearby [13].

Spent filter backwash water samples were collected during the backwashing of filters No. 3 and 4 at the groundwater treatment plant in Kąty Wrocławskie, during the period from July 2013 to May 2014. Filter backwashing lasted a total of 20 minutes and it took place as follows:

1) Initial backwashing - 5 minutes,
2) Air backwashing - 5 minutes,
3) Second backwashing - 10 minutes.

Samples were collected at 2-minute intervals, i.e. after 2, 4, 6, 8, 10, 12, 14, 16 and 18 minutes from the start of backwashing. On the first sample collection day, i.e. 05.07.2013, no samples were collected after 10 minutes as the amount of backwash water was too low to conduct laboratory tests. In the two first series of sample collection (5.07.2013 and 7.11.2013) filter backwashing took place in mid-filtration cycle, while in the subsequent series (14.02.2014 and 8.05.2014) - after the completion of a full cycle.

2. Results and discussion

Pursuant to the obtained research results it was determined that the content of iron in the backwash water from backwashing of filter No. 3 fell into the range 18.86÷207.84 mg Fe/dm^3,while manganese content in the backwash water from the same filter ranged from 0.25÷1.13 mg Mn/dm^3. The iron and manganese content in the backwash water from backwashing filter No. 4 was similar and fell, respectively, into the ranges: 11.48÷202.90 mg Fe/dm^3 and 0.17÷1.29 mg Mn/dm^3 (Table 1).The lowest iron content was determined in the backwash water on 7.11.2013. This resulted from the fact that on that day, the backwashing of filters did not take place after a whole day of filtration, as in the subsequent two series of collecting samples. The highest manganese content was found in spent filter backwash water samples collected on 7.11.2013. The conducted analyses have shown that the quality of spent filter backwash water changed on different stages of backwashing. The highest iron and manganese content in spent filter backwash water in all test series from each filter occurred after the 10th minute of backwashing, i.e. after the end of air wash and starting the actual wash. Particles of sediment raised by air were removed during the actual water wash, which is why the lowest quality of backwash water was obtained just after the start of this phase.

Table 2 contains turbidity values for selected spent filter backwash water samples from the backwashing of filters No. 3 and 4 on 14.02.2014 and 08.05.2014. Turbidity for samples of the 14.02.2014 fell into the range of 150÷1038 NTU, while for samples from backwashing collected on 08.05.2014 it fell into the range 40÷988 NTU. Similarly as in the case of iron and manganese, the highest turbidity was noted after the 10th minute of backwashing, i.e. after the air wash has ended and the water wash of the sediment began.

Particle size distribution results for the suspension at specific sample collection intervals are presented in Figures 1 and 2. They allowed us to observe that in samples collected during the backwashing of filter No. 3 on 05.07.2013 and 07.11.2013, particles of substitution diameters ranging from 10÷100 μm accounted for the highest share in the volume (approx. 60%). On the other days, in most of the spent filter backwash water samples the highest volume percentage share (from approx. 48 to approx. 56%) was noted for particles of diameters ranging from 1÷10 μm. The particle size range was subject to changes during the backwashing process. Spent filter backwash water collected in the first minutes of backwashing contained mainly particles of substitution diameters close to 100 μm. However, the volume share of smaller particles, of diameters ranging from 1÷10 μm increased with the duration of backwashing. The percentage share in the total volume of suspension particles contained in spent filter backwash water from filter No. 4 was similar to that in filter No. 3.

Table 1. **Iron and manganese content in spent filter backwash water samples from filters 3 and 4 of the Water Treatment plant in Kąty Wrocławskie on 7.11.2013, 14.02.2014 and 08.05.2014**

Spent filter backwash water sample; backwashing time	Sample collection date	Filter 3		Filter 4	
		Iron content mg Fe/dm^3	Manganese content mg Mn/dm^3	Iron content mg Fe/dm^3	Manganese content mg Mn/dm^3
2 minutes	7.11.2013	18.86	0.28	11.48	0.17
6 minutes		18.10	0.41	13.41	0.26
10 minutes		54.07	1.13	57.39	1.29
14 minutes		23.63	1.04	23.30	1.08
18 minutes		6.27	0.32	7.59	0.37
2 minutes	14.02.2014	23.99	0.27	45.51	0.21
6 minutes		207.84	0.39	134.63	0.25
10 minutes		175.30	0.55	202.90	1.00
14 minutes		57.00	0.85	82.23	0.82
18 minutes		30.97	0.30	31.25	0.27
2 minutes	08.05.2014	7.12	0.25	96.67	0.40
6 minutes		54.80	0.37	110.4	0.49
10 minutes		192.61	0.92	159.68	0.96
14 minutes		59.21	0.76	50.46	0.69
18 minutes		20.92	0.36	20.23	0.26

Table 2. **Turbidity of spent filter backwash water in filters 3 and 4 of the Water Treatment plant in Kąty Wrocławskie on 14.02.2014 and 08.05.2014**

Spent filter backwash water sample; backwashing time	Sample collection date	Turbidity, NTU	
		Filter 3	Filter 4
2 minutes	14.02.2014	181	150
6 minutes		367	690
10 minutes		1038	803
14 minutes		456	276
18 minutes		189	184
2 minutes	08.05.2014	40	52
6 minutes		275	412
10 minutes		988	950
14 minutes		318	285
18 minutes		148	123

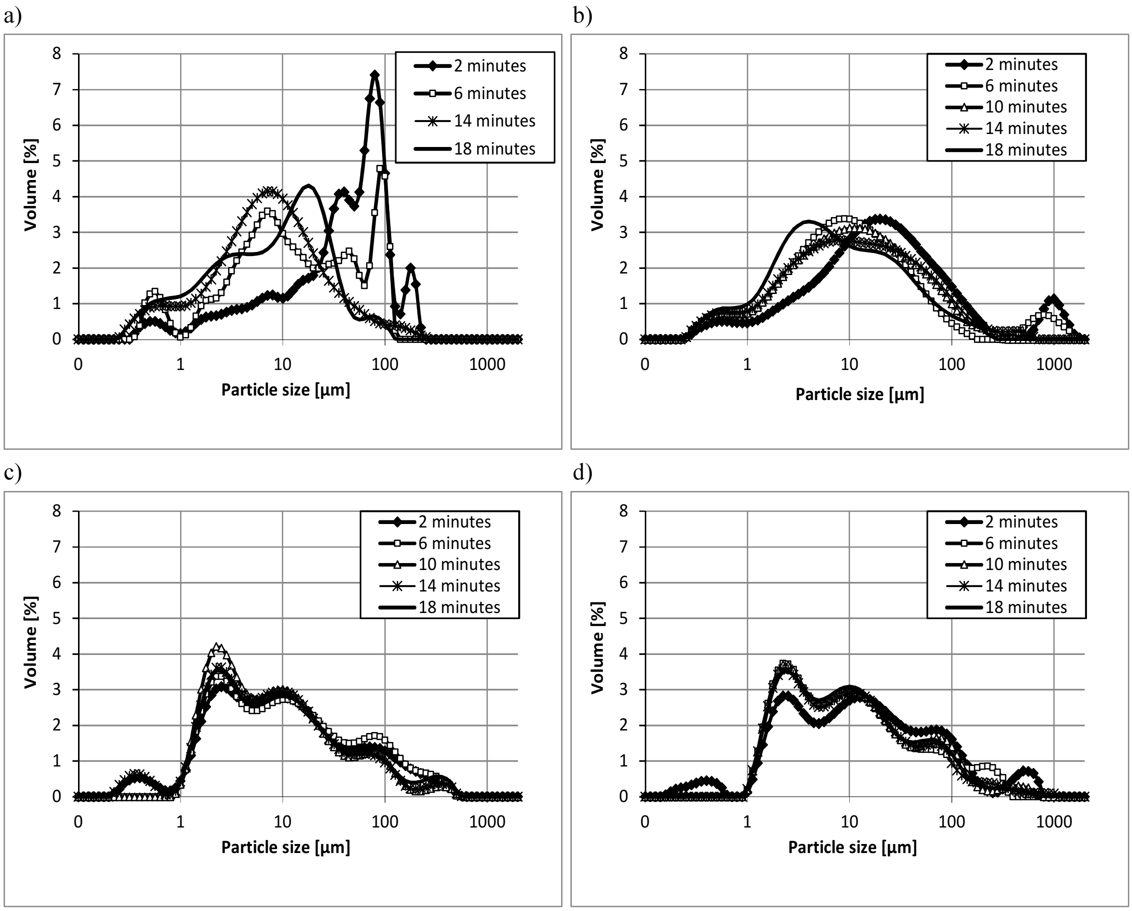

Fig. 1. Percentage share of particles of the diameter d_i in the total volume of suspension particles present in spent filter backwash water from backwashing filter No. 3 of the Water Treatment Plant in Kąty Wrocławskie on: a) 05.07.2013, b) 07.11.2013, c) 14.02.2014, d) 08.05.2014

Figures 3 and 4 show the results of particle size distribution tests in the quantitative aspect, for spent filter backwash water from selected stages of backwashing of both filters for all test series. The results demonstrate that in the first two test series both for filter 3 and 4 particles of a diameter ranging from 0.4÷0.6 µm accounted for the highest percentage share. In the other series, the results differed noticeably depending on the backwashing stage of the given filter. On the 14.02.2014, during the initial wash (up to 5 min) and from the 14th minute until the end of the backwashing process, particles of a diameter of 0.1÷1 µm dominated in quantitative terms, while on the other stages the dominant fraction consisted of particles of a diameter close to 10 µm. Spent filter backwash water samples from the last analysed series showed differences in the percentage content of particles in the total amount of suspension only during the initial washing. On the subsequent stages, the percentage share was more stable.

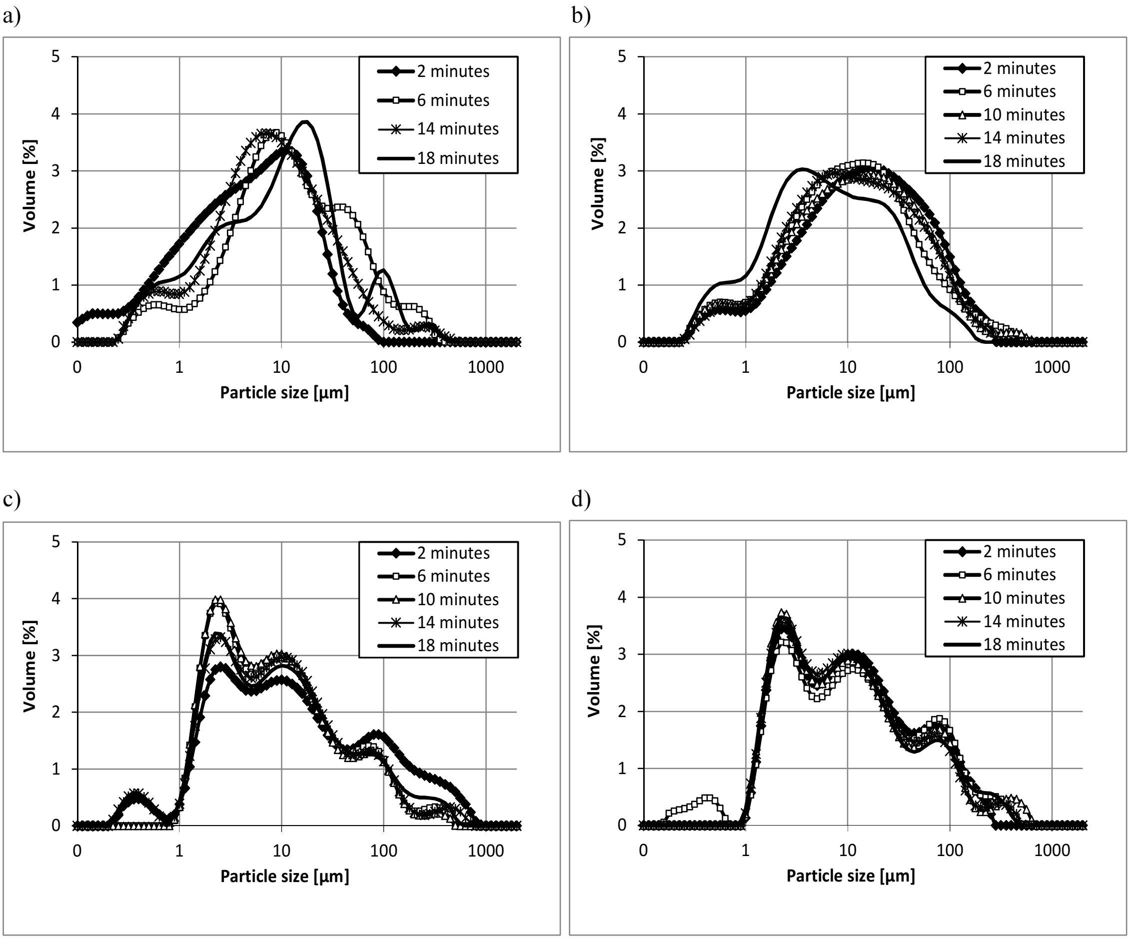

Fig. 2. Percentage share of particles of the diameter d_i in the total volume of suspension particles present in spent filter backwash water from backwashing filter No. 4 of the Water Treatment Plant in Kąty Wrocławskie on: a) 05.07.2013, b) 07.11.2013, c) 14.02.2014, d) 08.05.2014

Mean diameter values of particle sets calculated by means of Mastersizer's software as the function of changes in the volume of suspension particles contained in the backwash water from backwashing of filters 3 and 4 for selected test series are presented in tables 3 and 4. In all spent filter backwash water samples the value of the mean diameter D(1,0) was lower than 2 µm, and in the samples collected during filter backwashing in mid-filtration cycle (Table 3) it was lower than 0.715 µm. The size of this diameter provides information about the sizes of particles that are dominant in the polydisperse suspension. The mean diameter D(3,2) is a measure of the active surface of particles that create such suspension. The active surface of particles increases along with the decrease in the D(3,2) diameter, enhancing their efficiency in catalysing chemical processes. In all the analysed spent filter backwash water samples, the mean diameter D(3,2) was lower than 10 µm. These results confirm the high adsorption capacity of suspension particles contained in the analysed backwash water and their ability to catalyse chemical reactions. In approx. 94% of the analysed samples, the mean diameter D(4,3), calculated basing on the volume and mass, was lower than 50 µm, while in over 11% of the samples it was lower than 20 µm.

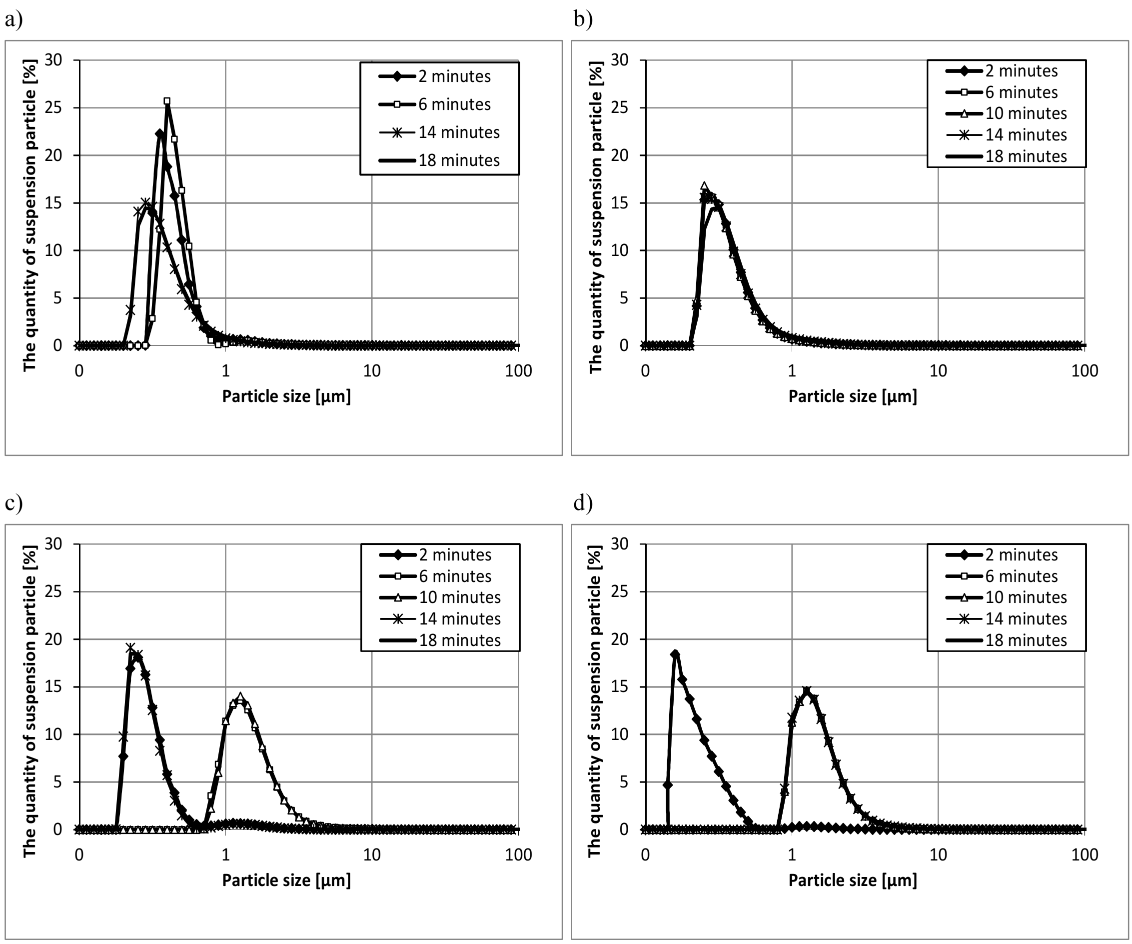

Fig. 3. Percentage share of particles of the diameter d_i in the total quantity of suspension particles present in spent filter backwash water from backwashing filter No. 3 of the Water Treatment Plant in Kąty Wrocławskie on: a) 05.07.2013, b) 07.11.2013, c) 14.02.2014, d) 08.05.2014

Table 3. **Mean diameters D(1,0), D(2,0), D(3,0), D(3,2) and D(4,3) determined pursuant to the function of changes in the volume of suspension particles V(d_i) in the spent filter backwash water from backwashing filters 3 and 4 of the Water Treatment Plant in Kąty Wrocławskie on 5.07.2013 and 7.11.2013**

Spent filter backwash water sample; backwashing time	Sample collection date	Mean particle diameters, μm - Filter No. 3					Mean particle diameters, μm - Filter No. 4				
		D(1,0)	D(2,0)	D(3,0)	D(3,2)	D(4,3)	D(1,0)	D(2,0)	D(3,0)	D(3,2)	D(4,3)
2 minutes	5.07.2013	0.576	0.748	1.670	8.317	57.387	0.496	0.665	1.324	5.254	36.956
4 minutes		0.597	0.739	1.343	4.431	40.278	0.506	0.703	1.367	5.172	26.864
6 minutes		0.602	0.768	1.407	4.719	34.362	0.493	0.658	1.230	4.300	29.505
8 minutes		0.603	0.763	1.285	3.643	14.296	0.493	0.662	1.213	4.063	20.587
12 minutes		0.539	0.718	1.217	3.492	14.722	0.504	0.650	1.101	3.159	25.065
14 minutes		0.505	0.656	1.106	3.141	18.256	0.498	0.649	1.109	3.242	17.310
16 minutes		0.553	0.714	1.251	3.848	24.229	0.520	0.666	1.390	6.058	135.953
18 minutes		0.516	0.652	1.081	2.969	14.709	0.518	0.655	1.104	3.128	22.108
2 minutes	7.11.2013	0.492	0.656	1.290	4.987	30.958	0.495	0.661	1.262	4.606	32.064
4 minutes		0.510	0.703	1.329	4.760	27.026	0.486	0.643	1.181	3.989	27.464
6 minutes		0.497	0.653	1.136	3.434	17.292	0.495	0.652	1.184	3.905	32.519
8 minutes		0.493	0.637	1.034	2.726	11.761	0.491	0.644	1.141	3.589	49.286
10 minutes		0.490	0.642	1.158	3.767	25.719	0.488	0.642	1.180	3.988	31.006
12 minutes		0.512	0.693	1.270	4.270	25.700	0.518	0.697	1.275	4.256	29.475
14 minutes		0.500	0.651	1.161	3.692	32.467	0.528	0.713	1.295	4.265	31.456
16 minutes		0.526	0.699	1.219	3.713	22.243	0.529	0.701	1.225	3.740	29.574
18 minutes		0.533	0.695	1.151	3.156	19.181	0.504	0.642	1.065	2.927	21.372

Table 4. **Mean diameters D(1,0), D(2,0), D(3,0), D(3,2) and D(4,3) determined pursuant to the function of changes in the volume of suspension particles $V(d_i)$ in the spent filter backwash water from backwashing filters 3 and 4 of the Water Treatment Plant in Kąty Wrocławskie on 14.02.2014 and 8.05.2014**

Spent filter backwash water sample; backwashing time	Sample collection date	Mean particle diameters, μm - Filter No. 3					Mean particle diameters, μm - Filter No. 4				
		D(1,0)	D(2,0)	D(3,0)	D(3,2)	D(4,3)	D(1,0)	D(2,0)	D(3,0)	D(3,2)	D(4,3)
2 minutes	14.02.2014	0.450	0.653	1.201	4.067	34.703	0.427	0.600	1.125	3.960	48.261
4 minutes		0.459	0.673	1.231	4.128	32.686	0.477	0.715	1.354	4.858	32.398
6 minutes		1.857	2.137	2.930	5.509	39.381	1.877	2.140	2.822	4.908	27.989
8 minutes		1.887	2.142	2.809	4.831	30.274	1.857	2.110	2.737	4.603	23.688
12 minutes		1.869	2.121	2.746	4.600	24.398	1.872	2.136	2.789	4.759	24.799
14 minutes		1.851	2.121	2.792	4.834	29.254	1.870	2.153	2.853	5.010	27.526
16 minutes		0.409	0.570	1.019	3.259	26.429	0.414	0.580	1.057	3.513	32.460
18 minutes		0.415	0.579	1.040	3.347	34.032	0.415	0.582	1.054	3.455	26.801
2 minutes		0.418	0.583	1.043	3.334	29.077	0.415	0.581	1.054	3.479	32.735
4 minutes	8.05.5014	0.309	0.442	0.916	3.941	79.496	1.971	2.262	3.052	5.556	27.951
6 minutes		1.965	2.242	2.975	5.237	26.910	1.969	2.257	3.037	5.498	32.118
8 minutes		1.937	2.209	2.939	5.203	31.976	0.310	0.461	0.930	3.786	37.581
10 minutes		1.918	2.179	2.883	5.051	31.910	1.900	2.164	2.903	5.223	35.633
12 minutes		1.934	2.205	2.937	5.210	32.648	1.924	2.190	2.924	5.213	36.567
14 minutes		1.933	2.205	2.925	5.146	28.855	0.287	0.409	0.828	3.398	58.124
16 minutes		1.925	2.200	2.951	5.309	39.954	1.932	2.213	2.951	5.244	30.626
18 minutes		1.861	2.128	2.821	4.957	30.241	1.888	2.165	2.905	5.232	32.889
2 minutes		1.917	2.200	2.948	5.293	31.532	1.873	2.144	2.863	5.104	29.855

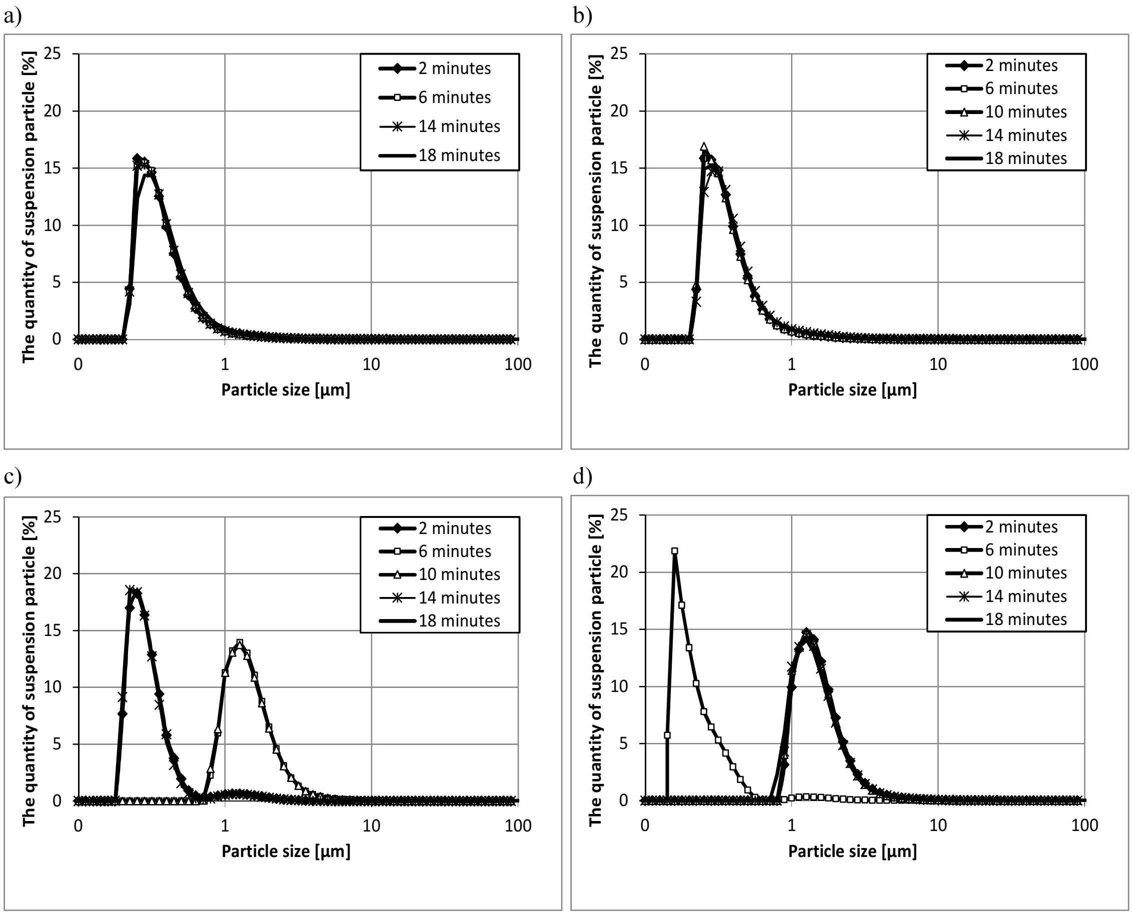

Fig. 4. Percentage share of particles of the diameter d_i in the total quantity of suspension particles present in spent filter backwash water from backwashing filter No. 4 of the Water Treatment Plant in Kąty Wrocławskie on: a) 05.07.2013, b) 07.11.2013, c) 14.02.2014, d) 08.05.2014

Conclusions

The obtained research results allow us to draw the following final conclusions:

1. The quality of spent filter backwash water depended on the stage of filter backwashing. The highest turbidity and the highest iron and manganese content in spent filter backwash water were determined after the 10^{th} minute of backwashing, i.e. after the end of air backwashing and starting the second backwashing.
2. The analysis of particle size distribution in suspensions with use of laser granulometer ensured high reproducibility of the obtained results. Moreover, it also allowed for the identification of the size and quantity of the particles constituting the suspension.

3. Suspension particles of a size ranging from 10÷20 μm accounted for the highest volume percentage share in the analysed samples of spent filter backwash water. The quantitative distribution of particles of the given diameters was heterogeneous and it depended on the stage of filter backwashing.
4. Backwash water collected in the first minutes of backwashing contained mainly particles of substitution diameters close to 100 μm, and the volume share of smaller particles, ranging from 1÷10 μm, increased with the duration of backwashing.
5. In all the analysed spent filter backwash water samples the mean diameter D(3,2) was lower than 10 μm. Suspensions contained in the analysed spent filter backwash water were characterised by a high adsorption capacity and ability to catalyse chemical reactions.
6. In most of the analysed spent filter backwash water samples the mean diameter D(4,3) was higher than 20 μm. In quantitative terms, in samples collected in mid-filtration cycle, particles smaller than 1 μm, classified as micro-suspensions, were dominant.
7. Lower iron contents were found in samples collected during the backwashing of filters in mid-filtration cycle than in samples collected after the completion of the full filtration cycle. The length of the filtration cycle did not influence the properties of particles constituting the backwash water suspension.

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Badania właściwości i rozkładów wielkości cząstek zawiesin w popłuczynach w różnych czasach trwania cykli filtracji

W Polsce w celu zaopatrzenia w wodę wsi i małych miasteczek ujmowane są przede wszystkim zasoby wód podziemnych. Pomimo dobrych właściwości fizyczno-chemicznych i bakteriologicznych wykazywanych przez wody podziemne większość z nich wymaga odżelaziania i odmanganiania, co ma wpływ na technologie ich uzdatniania. Podczas procesów uzdatniania wody przeznaczonej do spożycia przez ludzi powstają produkty uboczne, tj. ścieki technologiczne (głównie popłuczyny) oraz osady, w których zawarte są zanieczyszczenia usuwane z wody. W pracy przedstawiono wyniki własnych badań rozkładów wielkości i ilości cząstek zawiesin w popłuczynach ze stacji uzdatniania wód podziemnych w Kątach Wrocławskich. W artykule przeanalizowano również zmienność zawartości żelaza, manganu oraz mętności w różnych fazach płukania filtrów (płukanie wstępne wodą, płukanie powietrzem, płukanie właściwe wodą). Badania obejmowały cztery serie badawcze w okresie od lipca 2013 roku do maja 2014 roku. Próbki popłuczyn były pobierane podczas płukania dwóch filtrów. Wyniki badań wykazały, że jakość popłuczyn ulegała zmianie w kolejnych etapach płukania. Największy udział procentowy cząstek w badanych próbkach popłuczyn z płukania obydwu filtrów w ujęciu objętościowym stanowiły cząstki zawiesin o wielkościach z zakresu 10÷20 µm. Natomiast rozkład ilościowy cząstek o danych średnicach był niejednorodny i zależał od etapu płukania filtrów.

Słowa kluczowe: **stacja uzdatniania wody, popłuczyny, granulometr laserowy, dyfrakcja laserowa, wody podziemne**