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Effect of sedimentation time on the granulometric composition of suspended solids in the backwash water from biological activated carbon filters

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Abstract. The paper presents the results of analyzes of the granulometric composition of suspended solids in backwash water from biological activated carbon (BAC) filters and its changes during sedimentation. Backwash water samples were taken during backwashing of two pilot filters after different filtration time. It was found that regardless of the concentration of suspended solids in the collected backwash water, particle sizes vs. their percentage volume contributions for all samples were similar. Particle sizes were in the range of 2–100 μm. However, the two-hour sedimentation for most of the samples proved to be effective (total suspended solids removal up to 93%), which is caused by self-coagulation of the sample.

1 Introduction

Biologically active filters are used in water treatment technology to remove organic compounds. They have been shown to be very effective in removing biodegradable organic matter and also many troublesome organic compounds such as: polyaromatic hydrocarbons (PAHs), phenols, detergents [1], pharmaceuticals, personal care products and endocrine disrupting chemicals [2–4], disinfectant byproducts [5, 6]. Reduction of organic compounds concentration in treated water, cause lowering the doses of disinfectants and contributes to the improvement of the quality of treated water (lower concentrations of disinfection by-products). In addition, as a result of biofiltration, the biological stability of water in the water supply network increases [7–12].

The granular activated carbon bed (GAC) after the initial period of work lasting from 2 to 4 months becomes biologically active (BAC) [13–15]. This activation is caused by the development of biofilm consisted of bacteria and protozoa initially present in influent water [16]. In the initial period of the filter operation, adsorption dominates, but after biological

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activation biodegradation is the main process. Heterotrophic bacteria use the oxygen contained in water to oxidize organic compounds to carbon dioxide. Part of organic compounds is assimilated by microorganisms and used to build new cells. As a result, the mass of the biofilm contained in the bed increases during the filtration cycle. The consequence of this is the bed clogging and the increase of hydraulic losses, as well as the risk of separation and leakage of fragments of the biofilm, which negatively affects the quality of the filtrate [17]. In order to ensure high efficiency of filters, it is necessary to control the biofiltration process by skillful periodical bed backwashing. Backwashing is accomplished by passing water or a mixture of water and/or air in an up-flow manner through the BAC filters [18, 19].

BAC filter runs last from several days [20–22] up to 40 days [23]. Their length is mainly influenced by the content of organic compounds in the influent water, temperature, dissolved oxygen concentration and filtration velocity. The first three parameters affect the growth rate of microorganisms, while the hydraulic conditions of the filtration process determine the structure and thickness of the biofilm, and hence its susceptibility to peeling and its diffusion properties.

The backwash water is discharged to the clarifiers in which suspended solids are separated in the sedimentation process. The clarified water, meeting the required criteria, can be drained to sewer system or drainage ditches. It could be also further purified and return to the water treatment system.

The effectiveness of separation of suspended solids in sedimentation process used for backwash water purification is affected mainly by the size of the contaminant particles. The article presents the results of analyses of the granulometric composition of suspended solids in backwash water from BAC filters and its changes during sedimentation.

2 Methodology

Biofiltration studies were carried out on a pilot scale on a two physical models of BAC filters operated since April 2015 in the Institute of Environmental Engineering at the Poznan University of Technology. The filtration columns differed with regard to the method of the filter bed activation [24] and the microorganisms found there [25]. In the filter No. 1, the microorganisms residing in the filter bed came from the water passing through the filter i.e. from the network water. The filter bed of the filter No. 2 was inoculated with the backwash water from carbon filters operated in a selected water treatment plant. The experimental stand and the quality of inflowing water are described in details by authors in other publications [24–27].

The BAC filters were backwashed according to the schedule established during the experiment. This article presents the results of analysis of backwash water taken from both BAC filter columns for two different duration of filtration runs. Table 1 presents information about filtration cycles ended with backwashing, which was the source of examined backwash water.

Table 1. Information about filtration runs.

Filtration column	Backwashing date	Backwashing number	Filtration time (d)	Filtration velocity (m/h)
No. 1	16.03.2017	1	273	5.06
	11.05.2017	2	55	5.06
No. 2	23.03.2017	1	279	5.06
	18.05.2017	2	55	5.06

Backwashing, after each filtration run, was performed in the same way. The beds were backwashed for 17 minutes with tap water at an intensity of 300 L/h, ensuring an expansion of approx. 30%. All backwash water in an amount of 85.0 L was collected. For the sedimentation tests an averaged sample of 5.5 L was used. The sedimentation tests were carried out in a cylindrical tank with a diameter of 17.00 cm and an active height of 24.25 cm. After mixing, immediately after pouring into the tank, the initial sample of backwash water was taken (0 min). Next samples were taken from a depth of 2 cm below the water level in the tank after a given sedimentation time lasting from 0 to 300 min. In all samples turbidity was determined (Turb 550 IR, WTW). In the sample taken at the beginning and after 120 min of sedimentation concentration of total suspended solids (TSS) and COD_{KMnO4} (potassium permanganate acidic method) was also examined. In samples taken at the beginning and after 20, 45, 90, 120 and 300 min particle size distributions were determined using a Mastersizer 2000 instrument (Malvern Instruments Ltd.), which enables measurements of particle diameters in the range 0.02–2000 μm, based on dynamic light scattering method. The instrument has two laser beams – red with λ = 633 nm and blue with λ = 466 nm. The measurements were performed using a wet unit (Hydro 2000G) in which an appropriate quantity of the sample was dispersed in a water medium. After establishing the instrument background, appropriate measurements were performed.

3 Results and interpretation

The tests showed that the length of the filtration cycle had a decisive influence on the quality of backwashings (Table 2). This is related to an increase in biomass due to the removal of organic compounds in BAC filter. The amount of biomass (suspended matter) washed out from both filters after runs lasting about 270 days is comparable (Table 2), as is the amount of COD_{KMnO4} removed from the treated water, equal 136.3 and 121.0 g COD_{KMnO4} for filter No. 1 and 2, respectively. COD_{KMnO4} removed from water was calculated in an approximate way on the basis of grab samples taken from the inflow and outflow from the filters during filtration time.

Table 2. Quality of backwashings from filter No. 1 and No. 2.

Filtration column	Backwashing number	TSS (mg/L)	Turbidity (NTU)	COD_{KMnO4} (mg O_2/L)
No. 1	1	292	242.5	49
	2	63	139.0	16
No. 2	1	288	330.5	44
	2	25	60.3	16

In the case of cycles lasting 55 d, the amount of biomass washed out from the filter No. 1 is proportionally 5 times smaller than in the longer cycle, while for the filter No. 2 it is definitely smaller. At the same time, less organic compounds were removed in the filter No. 1 (13.7 g COD_{KMnO4}) than in the filter No. 2 (28.0 g COD_{KMnO4}) during filtration time. This confirms greater biological activity in the filter No. 2 found by Mądrecka et al. [26].

Biofilm washed out from the bed is the main carrier of pollutants in the backwashings from BAC filters. Higher concentrations of suspended solids caused higher turbidity and COD_{KMnO4}. However, for the same concentrations of TSS in both filters, different turbidity was noted. Turbidity is a parameter, which depends directly not only to TSS concentration but also to the pollutant particle size in the sample. A suspension consisting of small particles produces more turbidity than a suspension with the same concentration consisting of large particles. It is assumed that the content in the sample of particles smaller than 5 μm has a significant effect on turbidity [28]. The temperature and pH of the backwashings were

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dependent on the parameters of the used water and were 15.2–17.5°C and 7.46–7.72, respectively.

Turbidity, due to the simplicity and speed of determination, has been used to determine the changes in the quality of backwashings during sedimentation (Fig. 1). The turbidity was reduced by 55–67% in 120 min, further extension of the sedimentation time slightly improved the effect of clarification of backwashings.

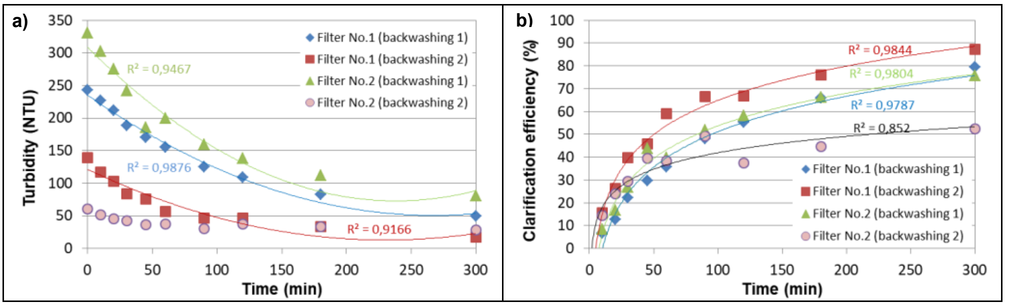

Fig. 1. Changes of backwash water turbidity (a) and clarification efficiency (b) during sedimentation.

The removal efficiency of the TSS concentration and COD_{KMnO4} was determined only for sedimentation lasting 120 min (Fig. 2a–b). It should be noted that despite similar turbidity reduction efficiency, the efficiency of suspension removal varied from 20 to 93%. The reduction of COD_{KMnO4} was not proportional to the removal of turbidity or TSS concentration. Perhaps this is due to the fact that some of the organic compounds came from the biomass of the suspension-forming bacterial cells and some are adsorbed on the flocs of the suspension.

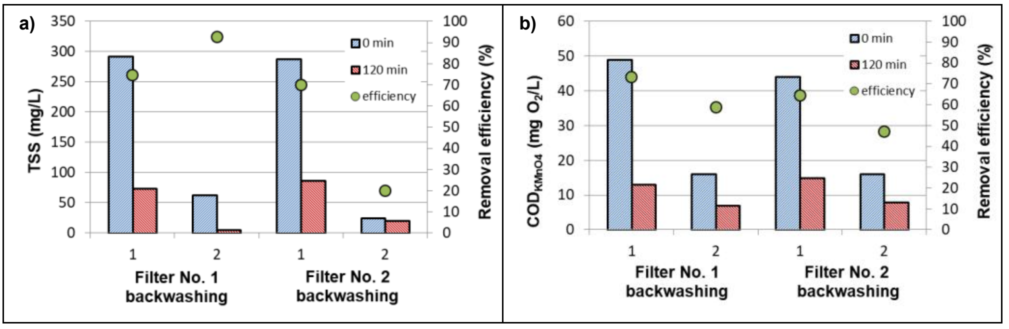

Fig. 2. Reduction of backwash water TSS concentration (a) and COD_{KMnO4} (b) after 2 h sedimentation.

Regardless of the concentration of suspended solids in the collected backwash water, particle sizes vs. their percentage volume contributions for all four samples were quite similar (Fig. 3). Mean particle diameter was in the range of 20.75–25.72 µm (Table 3 and 4). Histograms were symmetrical with one dominant peak, that shows the most dominant particles diameter. It was approximately equal mean diameter. More than 95% of particles were particles in the range of 2–100 µm. These are sizes corresponding to the size of the bacteria. These particles are hardly sedimentable. Only in the backwashings from the filter No. 1 larger particles appeared. In result parameter D [4.3] (volume weighted mean diameter [29]) of particles in backwash water from filter No. 1 was higher than from filter No. 2, equal 43.99–45.04 µm and 25.21–29.16 µm respectively. The granulometric composition of suspended solids in the backwash water from BAC filters and from iron and manganese removal filters is similar [30]. This suggests that the technology used for the treatment of both kinds of backwashings could be similar.

During sedimentation larger particles fall down and only smaller particles remain in the backwashings (diameter d (0.5) decreases over time). At the same time, self-coagulation occurs and larger flocs appear in the water.

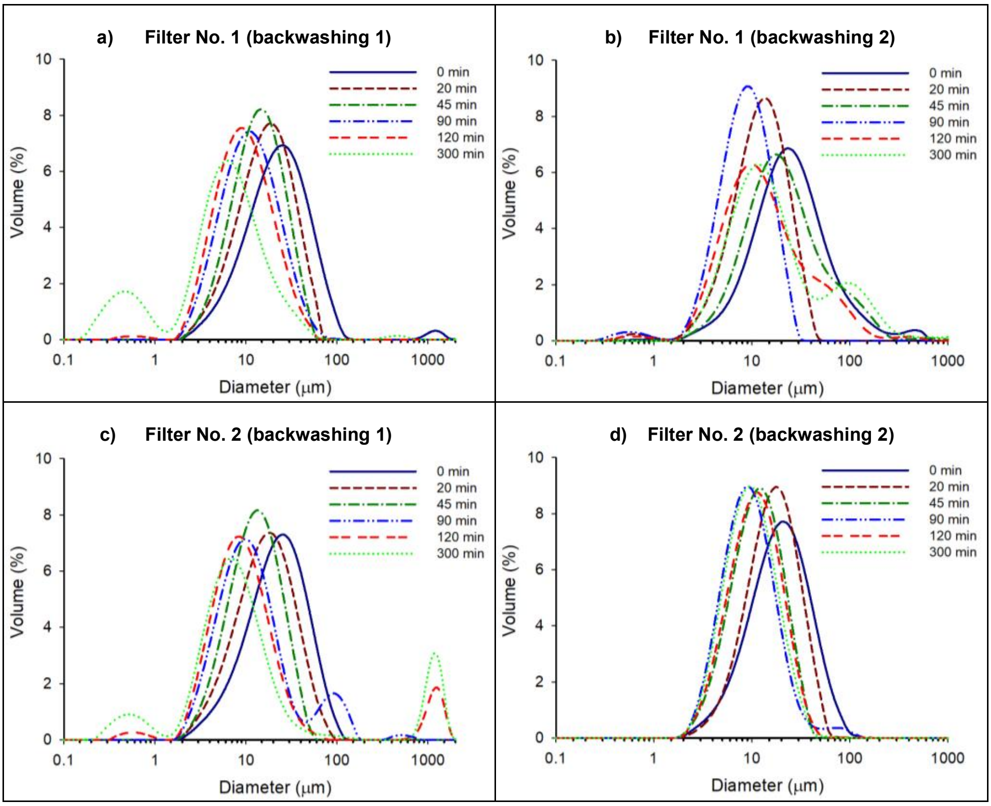

Fig. 3. Particle size distributions vs. their percentage volume contributions in backwash water after selected sedimentation time: a–b) backwash water from filter No. 1, c–d) backwash water from filter No. 2.

Table 3. Changes of dispersive parameters in backwash water from filter No.1 during sedimentation.

Sedimentation time (min)	**Backwashing number**	**Diameter (μm)**			
		D [4.3]	d (0.1)	d (0.5)	d (0.9)
0	1	45.037	8.140	24.409	62.555
20		21.237	6.669	17.967	40.833
45		17.323	6.101	14.750	32.455
90		15.014	4.716	11.741	29.465
120		12.772	4.115	9.974	25.267
300		11.706	0.581	6.289	19.700
0	2	43.987	8.921	25.723	82.441
20		14.989	5.270	13.185	27.502
45		39.418	7.628	21.265	84.704
90		10.299	4.016	9.123	18.520
120		26.251	4.677	12.935	59.509
300		49.148	5.611	15.552	118.110

Table 4. Changes of dispersive parameters in backwash water from filter No. 2 during sedimentation.

Sedimentation time (min)	Backwashing number	Diameter (µm)			
		D [4.3]	d (0.1)	d (0.5)	d (0.9)
0	1	29.155	8.088	23.991	57.531
20		21.683	6.356	17.670	42.578
45		15.915	5.558	13.514	29.889
90		25.341	4.537	11.430	62.422
120		107.343	3.906	9.758	35.232
300		163.183	2.602	8.266	1021.682
0	2	25.209	7.754	20.749	48.659
20		20.225	7.637	17.730	36.545
45		13.895	5.366	12.160	25.057
90		13.013	4.668	9.899	22.234
120		13.662	5.157	11.606	24.678
300		12.241	4.816	10.304	22.243

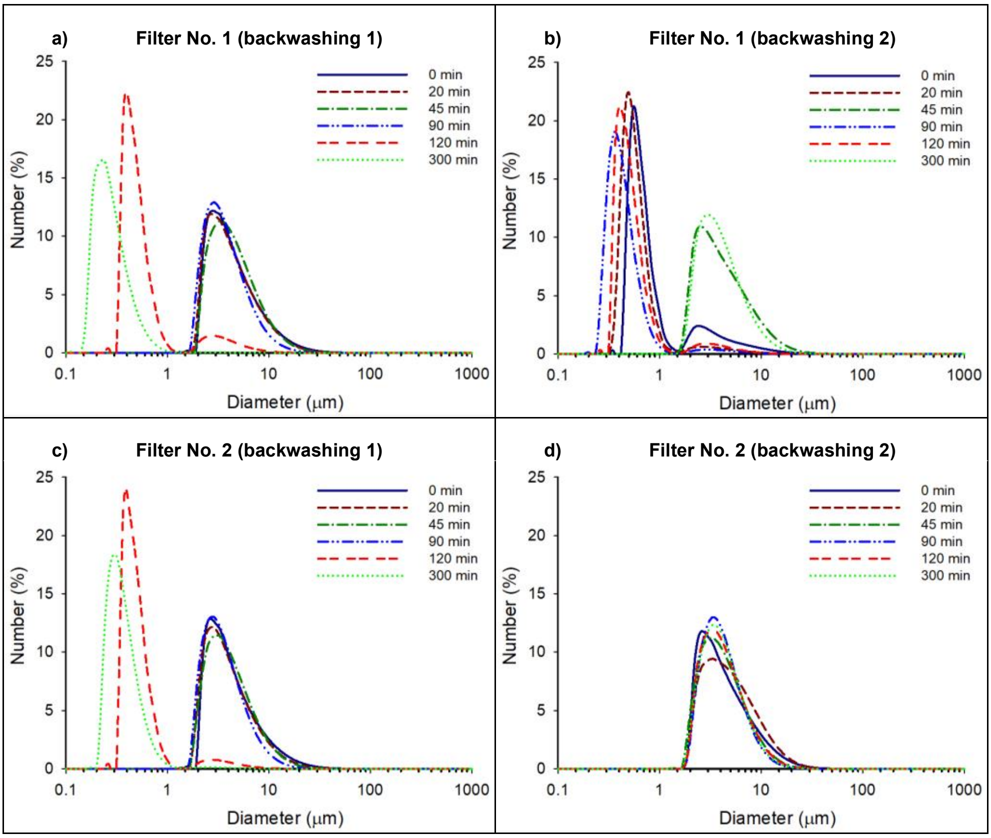

Fig. 4. Particle size distributions vs. their percentage number in backwash water after selected sedimentation time: a–b) backwash water from filter No. 1, c–d) backwash water from filter No. 2.

Fig. 4 shows measured particle sizes vs. their percentage number in backwash water. In collected backwash water quantitatively dominate particles in the range 2–10 µm, except the second backwashing of filter No.1 when most of the particles had a diameter in the range 0.4–1.0 µm. The suspensions contained in the backwashing sediment quite well. In the case of backwashing after more than 270 days of filtration, after 120 minutes of sedimentation, mainly small particles with a diameters of < 1 μm remain in the liquid. After analysis of samples from second backwashing of filter No. 1, it can be concluded that particles form agglomerates, which then fall off. This fact is confirmed by periodical increase of the numerical proportion of larger particles. In case of the second backwashings of filter No. 2, no significant changes in the particles number in the range of 2–10 μm were found. This also coincides with the slight removal of turbidity and suspended solids from the analyzed sample. Low initial concentration of suspensions in the sample is not conducive to self-coagulation and consequently worsen the effect of sedimentation.

4 Summary

The quality of backwash water from BAC filters depends mainly on the quality of the treated water, the filtration velocity and the length of filtration cycle, and consequently on the amount of removed organic matter load. The main contamination present in them is a suspension consisting of fragments of biofilms removed from the bed. Along with lengthening the filtration cycle, while maintaining the other filtration and backwashing parameters, the quality of the backwash water deteriorates. It was found that for backwashings characterized by the amount of TSS in the range of 25–292 mg/L, turbidity equal to 60–330 NTU and COD_{KMnO4} 16–44 mg O_2/L, the granulometric composition was quite similar. Most of particles diameters were in the range of 2–100 μm. Mean particle diameter was in the range of 20.75–25.72 μm. The two-hour sedimentation, however, was effective in eliminating the turbidity (up to 67%), TSS (up to 93%) and COD_{KMnO4} (up to 73%) in most samples. Process was encouraged by self-coagulation of suspended particles. For one sample with a low initial concentration of suspended solids, no self-coagulation was observed, and as a consequence, sedimentation efficiency was low.

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