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Performance of ozonation/biofiltration for disinfection by-products control on eutrophicated water source, Turkey

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ABSTRACT

Ozone and biofiltration columns were used to evaluate the removal efficiency of natural organic matter and to reduce chlorinated disinfection by-product (DBP) formation for eutrophicated water. Firstly, the effects of ozone dosage and then the column contact time and support material type together with ozonation and biofiltration processes on the control of DBPs were investigated. Porsuk river water, which is a eutrophicated water source, had been polluted by industrial, agricultural, and domestic wastewater in Eskisehir, Turkey. The empty bed contact time (EBCT) and support material type are significant parameters in both the operation and design for the biologically activated filter after ozonation. Sand, zeolite, and granular activated carbon (GAC) were used as biofilter support materials. The GAC had the best results in the using as a biofilter material for all observed parameters when it was compared with the other materials, sand, and zeolite. The eutrophicated water source extensively contained chlorophyll-a and hydrophilic NOM species that could not be easily removed by classical treatment methods. Ozonation and biofiltration are good alternatives. By increasing the ozone dosage for the eutrophicated water source, the formation potentials of THM and HAA could be reduced significantly when ozone and biofilter were applied together. At 1.1 mg O_3/mg TOC ozone dosage, UV_{254}, DOC, the formation potential of THM and HAA removals reached 53%, 81%, 73%, and 53% at 30 min EBCT.

Keywords: Algae; Disinfection by-products; Eutrophicated water source; Haloacetic acid (HAA); Natural organic matter (NOM); Porsuk water; Trihalomethane (THM)

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1. Introduction

Disinfection is an important issue for a secure water supply. Chlorine and ozone are the most common disinfectants or oxidants for the control of pathogenic microbes, so they are used for the prevention of outbreaks of waterborne diseases. The oxidants react with natural organic matter (NOM) in source waters, and disinfection by-products (DBP) are formed in drinking waters. The nature and source of the NOM and its concentrations affect DBP formations. In general, natural water resources have NOM that has an extensive and complex structure. There are different types of NOM inlets to the water media; by means of breaking down the terrestrial plants that come from land areas and the by-products of bacteria, algae, and aquatic plants in aquatic areas [1,2]. This complexity significantly affects many sides, such as water treatment process selection (coagulation, oxidation, adsorption, membrane separation etc.) or their operational issues, disinfectant types, and biological stability [3]. NOM is a major precursor of DBPs and comprises humic substances (HSs) that include humic acids and fulvic acids, which are hydrophobic in structure. and about 50–65% of the total organic matter, and the rest of the fraction is non-humic substances (NHSs), which are more hydrophilic in structure, such as amino acids, amino

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sugars, peptides and proteins, hydroxyl acid groups, and polysaccharides. [4].

In the pre- and post-disinfection steps, chlorine reacts with the NOM in the water source, and this causes the formation of trihalomethanes (THM) and haloacetic acids (HAA), which are the most well-known chlorinated disinfection by-products. They are considered to have human and animal carcinogenic, mutagenic, and teratogenic health effects [5–10]. Therefore, these DPBs have been limited by regulation worldwide and in Turkey [11–13].

Algae pollution has become an important concern because it negatively affects both drinking water quality and water treatment processes. Currently, many cities' water resources (lakes and rivers) are affected to different degrees by algal pollution. Highly agricultural activities, domestic wastewater discharges from cities, and industrial effluents, which cause high algae pollution, have become important concerns because they negatively affect both drinking water quality and water treatment processes by causing high nutrient influents to surface waters and the algae content of the water resources to rise excessively, especially in hot regions [9,14–17]. Algal organic matter shows more hydrophilic and less aromatic carbon content and more organic nitrogen (org-N) content. Generally, its specific ultraviolet (UV) absorbance (SUVA) values are lower than 2 L/mg m and its heterogeneity is higher [18,19]. High-productivity lakes and reservoirs are affected by the critically extracellular products of algae and often characterize the more significant part of the concentration of the total organic carbon of reservoirs or lakes. In small or low-productivity lakes and reservoirs, the NOM often comprises organics that come from terrestrial areas [17].

Conventional water treatment processes (coagulation, flocculation, sedimentation, sand filtration, and disinfection) can only effectively remove particles and a limited part of NOM components that are mostly a higher molecular weight [8,20–22]. On the other hand, the concentration of the hydrophilic fraction also increases due to excessive algae growth and anthropogenic pollutants, such as synthetic organics (SOs), which have lower molecular weight and are more hydrophilic. For this reason, the elimination of them from the water source is a more serious problem using the coagulation process [17,23]. The concentration of chlorophyll-a is proportional to the concentration of DOC, which is shown by analytical investigations [17,24].

Since the classical coagulation process has a limited effect in removing carboxylic acids, amino acids, proteins, carbohydrates, and algal toxins, all of which have low hydrophobicity, DBP cannot be reduced as required. Therefore, some additions or changes in the treatment procedure are needed among the available technologies. Application of ozonation and biofiltration together is an alternative method for the control of DBP precursors to achieve better water quality [25,26].

Ozone is a very effective disinfectant to inactivate microorganisms, such as protozoa (Giardia cysts, Cryptosporidium parvum oocysts), which are very resistant to chlorination. It can easily degrade many refractory organics and micropollutants by reacting with electron-rich moieties (carbon–carbon double bonds and aromatic alcohols) and can improve the degradation of NOM [27–29]. On the other hand, the biofiltration process is a necessity because some fractions of DOC can be converted to easily biodegradable DOC during ozonation, which can cause bacterial regrowth in the distribution system. To reduce the concentration of disinfection by-product precursors and the potential for bacterial regrowth in the distribution system, ozonation/biofiltration can be applied [30–32]. Biofiltration is an effective process for eliminating both hydrophilic and hydrophobic, specifically amines, aliphatic aldehydes, phenols, pharmaceuticals, pesticides, algae metabolites, and algal toxins. In addition, it helps to remove some inorganics, such as iron, manganese, inorganic nitrogen, and phosphorus species [33–40].

This study aim was to firstly control the formation potential of the DBPs of Porsuk Water, which is a highly eutrophicated water resource in Turkey, by the application of ozone and a subsequent biofiltration process. In addition, the different filter media and empty bed contact time (EBCT) influences under varying ozone dosages applications were evaluated on the removal of DOC, UV254 and formation potential of THM and HAA.

2. Materials and methods

2.1. Source water

Porsuk water (PW) is the main drinking water resource of Eskisehir City, Turkey. The average values of the PW characteristics were as follows in the experiments (the average and the standard deviations in the parentheses of the parameters). The dissolved organic carbon (DOC) and total organic carbon (TOC) were 4.37 (0.65) mg/L and 5.10 (1.06) mg/L, respectively. The total alkalinity, total phosphorus, and chlorophyll-a of the raw PW were 258.86 (21.69) mg/L, 0.980 (0.260) mg/L, and 7.820 (4.150) mg/m^3, respectively. The pH was in the range of 7.8–8.1.

Before coming to Eskisehir, Porsuk River is polluted by industrial point discharges, which are Nitrogen Fertilizer Factory and Magnesite Factory, and the domestic wastewaters of the city of Kutahya, which are all located upstream of the river. In addition, other pollution sources are land-based non-point sources from agricultural areas. Since high concentrations of nitrogen and phosphorus enter the river and reservoir, the water in the river and reservoir has a high eutrophication level [41,42].

The SUVA$_{254}$ value (UV$_{254}$ absorbance divided by the DOC concentration) of the PW was 1.89 L/mg m, which is lower than 2 L/mg m in humic content [10,43].

2.2. Materials

The bulk density of GAC was about 510–530 kg/m^3 with a particle size range of 0.5–2.5 mm, BET surface area of 900–1,000 m^2/g (Lurgi-Hydroffin 30), and uniformity coefficient lower than 1.5. Bigadic zeolite was used with a particle size range of 1.0–2.0 mm with a surface area of 22–28.40 m^2/g and specific gravity of 2.30. The other material was quartz sand with a particle size range of 1.0–2.0 mm (a surface area of 0.22 m^2/g) and a 1.5 kg/m^3 bulk density with an effective size of 0.85–0.95 mm and uniformity coefficient of around 1.25–1.5.

2.3. Experimental set-up

Experiments were conducted to research the biofiltration performance by varying the empty bed contact time (EBCT) and microorganism growth material after applying ozonation on PW. Different O_3/TOC ratios were applied by using an ozone generator (Ozone-Safe). Pure oxygen gas was used to produce ozone that was introduced to the reactor by a porous glass diffuser at the bottom with a constant gas flow (5.0 L/h). Before starting ozonation, the ozone generator was kept working for a minimum of 15 min to stabilize ozone production. Twenty-five liters of PW were ozonated in a stainless steel reactor and then kept in a feeding tank. The ozone dose was determined by monitoring the gas phase ozone before and after the reactor using a 2% potassium iodide (KI) solution method [44]. The residual ozone in the water was also determined by a UV spectrophotometer. All experiments were done at room temperature (20–22°C). Ozonation was performed by applying different ozone doses from 0.6 to 5.0 mgO_3/mg TOC. Two serial connected biofiltration column which was feed ozonated PW by peristaltic pump, and hydraulic loading rate was of 0.6 m^3/m^2 h and operated in the up-flow mode. The diameter and height of each column were 2.5 and 25.0 cm, respectively. The bench scale columns had 15.0 cm of filter media and were operated at 15 and 30 min EBCT. Sand, zeolite, and granular activated carbon (GAC) materials were filled as different growth filter media and worked as three parallel experimental set ups (Fig. 1). The microorganism growth was established on the filter materials through the process of feeding with Eskisehir tap water over a period of 8 months [45]. Samples were taken after the first column effluent that represents 15 min EBCT and the second column (together with the first column) effluent at 30 min EBCT.

2.4. Analytical procedures

The results were evaluated by measuring UV_{254}, the specific ultraviolet absorbance (SUVA) at 254 nm, the formation potential of THM, and haloacetic acid (HAA) according to the procedures described in Standard Methods and EPA methods. pH measurements were taken with a WTW-pH meter. UV_{254} and VIS_{400} absorbance measurements were performed in accordance with Standard Methods 5910 B [46] by using a Hach-Lange DR 5000 UV/Vis spectrophotometer at a wavelength of 254 nm with 1 cm quartz cell. After collecting the samples, they were firstly filtered through a pre-washed 0.45-µm membrane filter to remove turbidity.

DOC was analyzed according to the high-temperature combustion method in accordance with 5310 B [47] after filtration through a 0.45-µm membrane filter performed using a Shimadzu TOC-5000 analyzer (Shimadzu, Corp., Japan) equipped with an autosampler.

THM (chloroform, bromodichloromethane, dibromochloromethane, and bromoform) concentrations were determined with liquid–liquid extraction method according to EPA Methods 551.1. [48]. Five haloacetic acid species (monochloro-, dichloro-, trichloro-, monobromo-, and dibromo- acetic acid) were reported as HAA in µg/L and were determined with the liquid–liquid extraction method (acidic methanol etherification) according to EPA Methods 552 [49]. THM and HAA Calibration standards were prepared by using the standard mixture procured from AccuStandard, USA. The THM and HAA samples were measured by gas chromatography (Agilent-6890 Series) with a micro electron capture detector and auto sampler. The detection limits for the THM and HAA species were about 0.5–1.5 µg/L.

The samples were chlorinated prior to the THM and HAA analyses. Chlorination was conducted in head-space-free 111 mL amber vials with Teflon-lined screw caps. HCl,

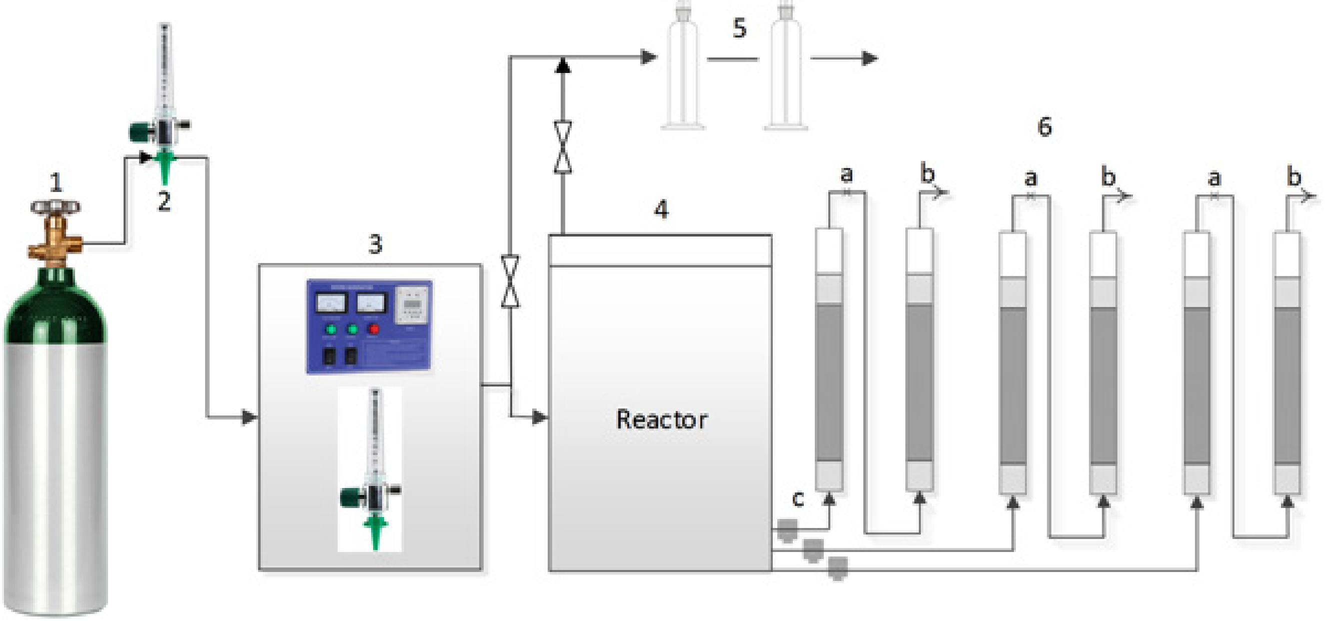

Fig. 1. Ozonation/Biofiltration experimental setup, 1) Oxygen source, 2) Flowmeter, 3) Ozone generator, 4) Reactor, 5) KI solutions, 6) Biofiltration columns.

NaOH, and phosphate buffer solutions were used to adjust the pH of the samples. The appropriate chlorine dosage based on preliminary demand tests on raw water samples was determined for Cl_2:DOC ratios to be 3, and then they were incubated in a dark room for 7 d at 25°C. The same chlorine doses were applied to each sample after the ozonation-biofiltration process. Residual chlorine was removed in the sample bottle using sodium sulfite solution [50]. Then, the THM and HAA species were analyzed (analytical methods are given in detail by Akcay et al. [45]).

3. Results

3.1. Ozone

By applying ozone to the water sample, the organic matter structure changed and transformed the molecular weight from higher to lower, the aromatic structure from hydrophobic to hydrophilic, and increased the polarity. In the literature, it is expressed that the process can reform non-biodegradable organics to biodegradable organics, decrease the DBPs, and obviously increase the biological activity after [29,30,51,52]. The ozonation of raw PW experiments showed that the average UV_{254} absorbance value was about 0.15 cm^{-1} at the start, and as the ozone dose increased, the UV_{254} absorbance of the ozonated water decreased and reached an almost steady value of about 0.06 cm^{-1}. Fig. 2 shows the levels of SUVA and formation potential of THM and HAA at several transferred ozone dosages for PW.

UV absorbance, $SUVA_{254}$, and DOC are the most used surrogate parameters. Researchers have concluded that simple and reliable relationships between the change in the UV absorbance of NOM after chlorination and the formation of chlorinated by-products exist [10,53–55]. The formation of the THM values of PW had a similar trend to the SUVA values. At 1.1 and 2.1 mg O_3/mg TOC transferred ozone dosage, the percentage reductions of the formation of THM were 15% and 35%. The SUVA value reductions were 22% and 42% at 1.1 and 2.1 mg O_3/mg TOC, respectively. PW has a low SUVA value, and Hua and Reckhow (2013) found the average percentage removal of SUVA of 45% after ozonation for low-SUVA waters [56]. Molecular ozone reacts readily with carbon–carbon double bonds and NOM moieties with high electron density, so aromatic compounds degrade smaller compounds when considering UV_{254}, which changes by 18% and 36% at 1.1 and 2.1 mgO_3/mg TOC. The formation of THMs could be primarily induced by a hydrophobic fraction of DOC and controlled with a reduction of the aromatic concentration and activity of the major precursor by ozonation. Kim and Yu [8] expressed that THMs were mainly influenced by the hydrophobic fraction, while that of HAAs depended more on the hydrophilic fraction. The THM formation potential was reduced after ozonation, which was attributed to the change from hydrophobic NOM to hydrophilic NOM. There were no changes in TOC removal after ozonation, but the UV reductions were significantly reduced. Therefore, this was shown by a reduction in SUVA values.

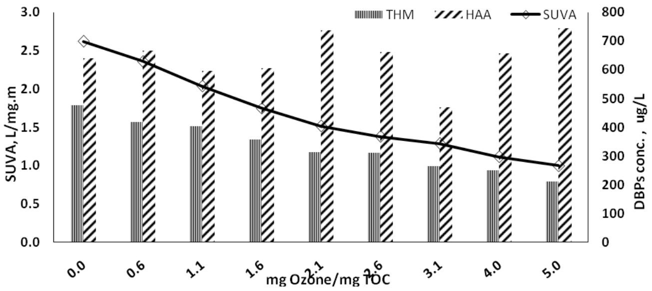

Fig. 2. SUVA and formation potentials of THM, and HAA at different ozone dosage of PW.

The THM reduction was attributed to the structural modification of the NOM. Ozonation increases the hydrophilic fraction; furthermore, the formation of HAA precursor sites was not effectively reduced by the ozonation. Hua and Reckhow expressed that NOM is a more important precursor to DBP formation for low-SUVA water sources and ozone is not effective in terminating the DBP precursors and is likely to considerably increase the formation potentials of certain DBPs, such as DHAAs, in low-SUVA waters. Ozone oxidizes NOM and changes in the NOM reactivity with chlorine and bromine [56]. Some research about low-humic-content natural waters in the literature expressed that SUVA tends to be a weak indicator of the reactivity of the derived DOC [4,8,43].

3.2. Ozone and biofiltration

Ozonation improves the biodegradability of dissolved organics; therefore, after ozonation, through the biofiltration process, the usage can be obtained for biologically stable water to improve water quality in terms of DOC and DBPs [57]. The reductions of the UV absorbance at 254 that characterize unsaturated carbon bonds that include aromatic compounds, which are generally recalcitrant organics for biodegradation, ozone can alter the these compounds to more simple products, such as aldehydes (formaldehyde, acetaldehyde, glyoxal, and methylglyoxal) and carboxylic acids (formic, acetic, glyoxylic, pyruvic, and ketomalonic acids) that they are more easily transferred to the cell membrane and can hit by metabolic enzymes [30,33,58].

If microorganisms grow by allowing heterotrophic bacteria attachments in the filter unit, it is converted to biofilters and biodegradable DOC is utilized as a carbon source for energy production [59]. DOC removal is affected according to the NOM structure changes by ozone dosage and biofilter operational parameters (EBCT, filter media). Generally, rapid filters are operated in a biologically active mode as a form of biofiltration. In the process, filter media choices and bed residence time are important because of the major cost effects and effectiveness. In this study, the performance of biofilters with different support materials was obtained after 0.6, 1.1, and 2.1 mg O_3/mg TOC ozone dosage. The feeding water of the biofilter columns was used as 1.1 mg O_3/mg TOC ozonated raw PW, and each column's effluent DOC values are seen in Fig. 3.

The ozonation and biofiltration processes together had DOC removal capacity, whereas ozonation could not be performed alone. In the ozonation step, DOC was not able to mineralize anymore to CO_2 in this ozone dosage, but could only be turned into more biodegradable forms. By

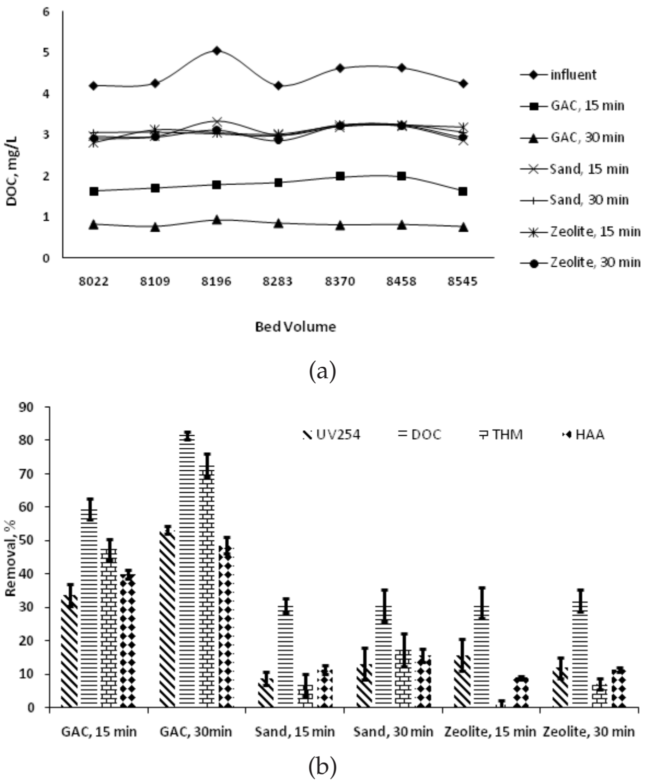

Fig. 3. a) DOC influent and effluent values of biofilters after ozonated PW after steady state, b) ozonation and biofilter performances for different biofilter media (1.1 mg O_3/mg TOC and EBCT 15–30 min).

observing the UV_{254} reductions, the degeneration of complex organics could be determined, as discussed before. At the 1.1 mgO_3/mg TOC ozone dose, the UV_{254} absorbance was reduced by about 18%. In particular, the biodegradable part of the DOC could be removed effectively in all biofiltration columns made of sand and zeolite about 30% at the 15 and 30 min contact times. It was obvious that the GAC media had some of the best removal powers of 60% and 82% at the 15 and 30 min contact times.

3.2.1. Effect of filter media

Mostly, anthracite and sand are used in rapid filtration media and are non-adsorptive media, but can be converted to biofilters. GAC is a good adsorbent and is generally used due to its specification in water treatment works. For long time operation without regeneration, GAC acts as a biologically activated filter. In this case, the GAC has a role of both a biofilm support material and partly adsorptive specification.

Before the column experiments, biofilm was grown to all the support materials, sand, zeolite, and GAC, for almost 11 months with feeding tap water (8 months) and then raw PW (3 months). Then, the columns were called biofilters because of the microorganism growth. The UV_{254} values and DOC concentrations in the effluent of the biofilter columns were always lower than those in the influent for PW. The effluent water of the biofilter columns reflects that the fluctuation of influent water considering DOC does not depend on the media type. The media type affects the removal of DOC performance. Sand is an inert material and has no adsorption capacity for DOC.

The type of biofilter media can be an important factor that affects the biomass accumulation and growth pattern in the biofilters. A researcher showed that biofilm accumulation in the GAC filters was higher than sand [60]. GAC had higher pore size distribution than others, and sand was an inactive material for adsorption for DOC. The natural Bigadic Clinoptilolite, which is kind of zeolite, gave very similar results to sand in the DOC removal of PW in the usage of biofilter media. The adsorption capacity of natural zeolite depends on the structure and chemical composition of both natural zeolite and natural organic matter [61]. On the other hand, sand and natural zeolite are the lowest-cost materials for filters.

The application of the biofiltration process after ozonation had a positive effect on both the formation potential of DBPs (THM and HAA) and DOC removal. Biofiltration had a dramatic decline in DBP formation potentials in all the column effluents, especially for HAA. In considering only the ozonation process, HAA formation potentials could not be reduced for PW that had low SUVA.

The GAC biofilter was more effective than the sand and zeolite biofilters in the removal of UV_{254} and DOC, as seen in Fig. 4. Ozonation and adsorption increased the GAC biofilter. Some parts of organics, such as those that are not easily biodegradable, could be adsorbed in the biologically regenerated GAC surface site, and then organisms could use them later [62]. The average DOC removals in the GAC biofilter compared with those in the sand and zeolite biofilters were 59%, 31%, and 31%, respectively for 15 min EBCT with the application of 1.1 mgO_3/mgTOC ozone dosage. For the 30 min EBCT, DOC removal ratios were 81%, 31%, and 32% for the GAC, sand, and zeolite biofilters, respectively, at the same ozone dosage. It was observed that in the GAC biofilter, the effluent was always higher than that of the sand and zeolite biofilter effluent.

3.2.2. Effect of contact time

EBCT is a significant parameter for both design and operation for the removal of organics within biological filters [63]. It is supposed that biotransformation was the main mechanism in the sand and zeolite biofiltration columns, while the GAC biofilter underwent an extra adsorption reaction in addition to biotransformation and higher porous media. Therefore, there was a big difference in the removal percentage of UV_{254} and DOC and the formation potential of THM and HAA, and GAC always had higher values than the other filter material, as seen in Fig. 4. It is thought that regenerated sites can use adsorption and caused this important difference. Even if the sand and zeolite biofilter column contact time was increased from 15 to 30 min, there was no effect on DOC removal. Columns that had 15 min and 30 min contact times had 76 cm^3 and 152-cm^3-bed volumes (BV), respectively. This means 30 min gives extra support material. The biological activity of the sand and zeolite material had an effect on the DOC removal values, but it almost remained constant at 31% at the 1.1 mgO_3/mgTOC ozone dosage (Fig. 4b). Even though EBCT was increased from 15 to 30 min, there was no increase in DOC removal. In the first of the two columns with a 15-min EBCT, the colonized organisms easily consumed biodegradable organics (or rapid BDOC) from influent water, but the second column with a 30-min EBCT was not able to have the desired rapid BDOC; therefore, no additional removal was observed at the second biofilter column for PW.

Increasing EBCT from 15 min to 30 min did not cause big differences. In addition, the removal of DOC and formation of DBPs (THM and HAA) almost reached a steady position after 15 min EBCT while considering 30 min for the sand and zeolite media. After 15 min, the remaining organics were probably recalcitrant organic molecules, as seen in Figs. 4c and 4d. Some research supports these findings, and EBCT (15 min), which was short, can achieve a decrease in DOC rapidly because easily biodegradable organics can be consumed effortlessly in a short time, but at the latter period (between 15–30 min), a very small decrease was observed due to the absence of easily degradable organics [30,59,64]. GAC can remove some of the recalcitrant organics by adsorption using biodegraded sites and therefore could be more successful at removing both DOC and DPB in the case of an increase to 30 EBCT min.

3.2.3. Effect of ozone dosage

Different ozone dosage applications (0.6, 1.1, and 2.2 mg O_3/mg TOC) of PW after the biofiltration experimental results can be seen for different support media in Fig. 4. By increasing the ozone dosage from 0.6 to 2.2 mg O_3/mg TOC, both the UV_{254} and DOC removal efficiencies gradually increased the biofilter column effluents for 15 and 30 min EBCTs (Figs. 4a and 4b). The UV_{254} values could be decreased by 18% only by ozonation and by 29% and 50% by ozone and GAC biofiltration at 15 and 30 min EBCT, respectively. It can be deduced that the effects of the biofilter alone were 11% and 32% after ozonation from Fig. 4a. According to the DOC changes between the ozone and together with the ozone and GAC biofiltration results, the percentage reductions were very significant. Only ozone could not reduce any DOC values, but the ozone with GAC biofilter DOC reductions were 52 and 78% at 15 and 30 min EBCT, respectively, as shown in Fig. 4b.

It was observed that increasing the ozone dosage in the GAC biofiltration column had a much greater effect at 15 min EBCT than 30 min. On the other hand, at the 0.6 mg O_3/mg TOC ozone dosage with 30 min of EBCT application, fulfilled result, such as 78% DOC removal. When the sand and zeolite biofiltration columns did not have differences from increasing EBCT, but by ozone, dosage increases made a slight positive increase. It could be concluded that 2.2 mg O_3/mg TOC and 15 min EBCT were more appropriate for the application for sand and zeolite media. The best reductions of the formation potential of both THM and HAA were detected at the 2.2 mg O_3/mg TOC ozone dosage and 30 min EBCT as 81% and 60%, respectively, from the effluent of the GAC biofilter column, as seen in Figs. 4c and 4d.

On the other hand, the sand biofilter column reduction efficiencies for the formation potential of THM and HAA were observed as relatively small as about 29% and 17%,

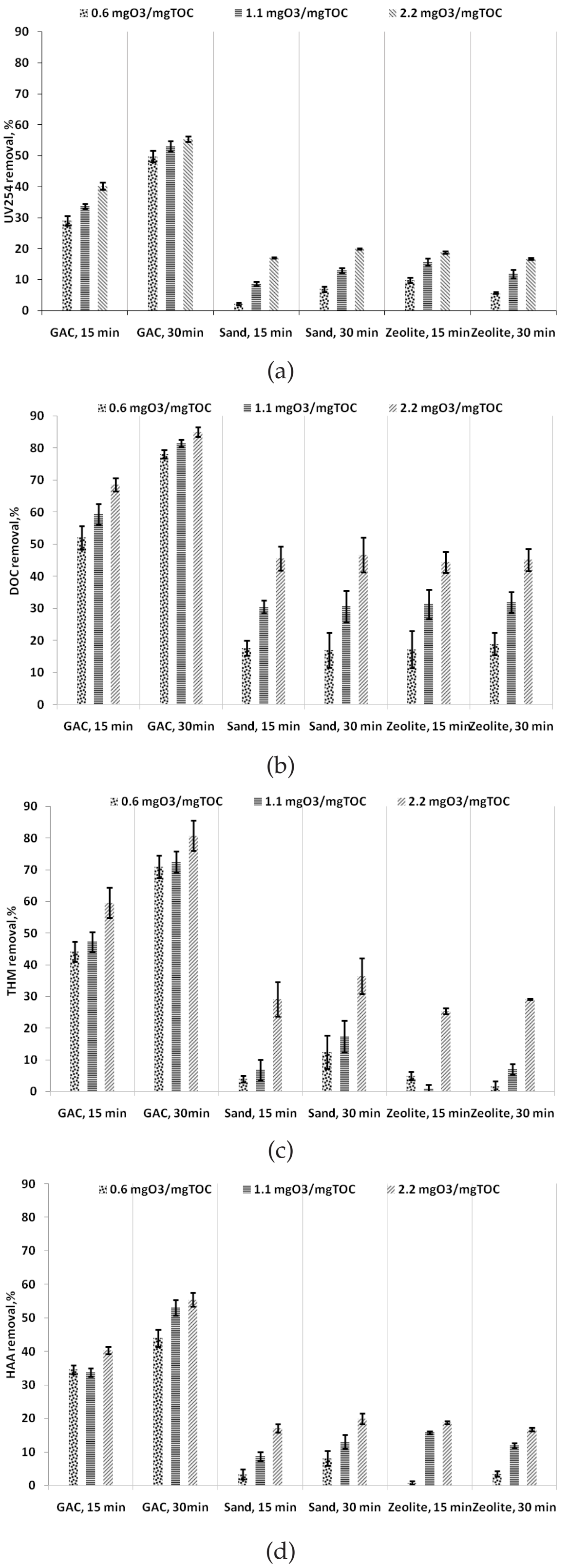

Fig. 4. Average biofilter performances after different ozone dosages: a) Removal percentage of UV_{254}, b) Removal percentage of DOC, c) Removal percentage of THM formation potential, d) Removal percentage of HAA formation potential (average values of 6 datasets).

respectively, and 25% and 30% for zeolite. Increasing the ozone dosage from 0.6 to 2.2 mg O_3/mg TOC assisted in predominantly reducing the HAA formation potential rather than the THM formation potential. Ozonation caused NOM to lower the molecular weight of hydrophilic compounds, and they could be adsorbed more easily by activated carbon and readily biodegradable afterward. Consequently, together with ozone and the GAC column, this is a promising process for removing hydrophilic NOM, which is the main HAAs precursor, before final disinfection [8,51].

4. Conclusions

Ozone dosages, contact time, and support material type effects were investigated by the application of ozonation followed by biologically activated filtration for a eutrophicated water resource. Eutrophication or chlorophyll-a has a positive effect on the rise of the hydrophilic part of the DOC, and classic water treatment options, such as coagulation or enhanced coagulation, could not remove the DOC and make the water safe regarding DPBs.

In biofilter design and operation for water treatment purposes, EBCT and support material type are important parameters. Sand, zeolite, and GAC materials were used as biofilm support materials. The GAC had the best results when used as a biofilter material for all observed parameters when it was compared to the other materials, sand and zeolite, and it had an external surface on the macrospores for both bacterial growth and adsorption sites. In addition, the bacterial activity on the surface had a positive effect, such as the bioregeneration of the adsorption sites. Contact time is a critical parameter for the transport of the organics into the cell and for adsorption. 15 min EBCT was sufficient for the sand and zeolite filter materials, but GAC material made a significant difference. By increasing EBCT from 15 min to 30 min, the DOC removal and indirect THM and HAA formation potential removal values were increased when ozone and the biofilter were applied together for a eutrophicated water source.

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