THE FULL-SCALE STUDY ON PHOSPHORUS ADDITION TO BIOLOGICALLY ACTIVATED CARBON FILTERS

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Key words: phosphorus, biological activated carbon filter, natural organic matter

Introduction

Total organic carbon (TOC) in drinking water may cause formation of disinfection by-products and bacterial regrowth [1] that leads to water quality deterioration in distribution networks. Removal of TOC from drinking water at water treatment plant (WTP) is frequently accomplished with biologically activated carbon (BAC) filter. Surface of BAC filters is inhabited with naturally occurring microorganisms. During water filtration through BAC filters heterotrophic bacteria decompose biologically degradable portions of TOC, resulting in some 30%-50% of TOC reduction in drinking water.

More and more studies show that in areas with high amount of TOC in raw waters the limiting nutrient for bacteria growth in drinking water is phosphorus instead of main energy source – organic carbon [2-5]. This is most frequently observed in drinking waters treated with chemical coagulation. This could be because during coagulation phosphorus is more effectively removed than carbon [4, 6-7]. It was suggested that dosing of phosphorus ahead of BAC filters may be a potential strategy to improve removal efficiency of TOC. Earlier lab- or pilot-scale studies were not conclusive regarding effect of phosphorus on performance of BAC filters [7-9]. Here we report results from studies where effect of addition of phosphorus on removal efficiency of natural organic matters (NOM) during BAC were carried out in full-scale WTP. In this study phosphorus was dosed in one of the BAC filters at the WTP used for water supply of Riga (Latvia) during four month period.

Materials and methods

Study site

The study was carried out in the WTP of Riga city. The plant supplies drinking water to about 50% of the population of Riga (100 000 m^3/d). The treatment train includes primary ozonation, chemical coagulation with alum, sedimentation, rapid sand filtration, main ozonation, BAC filtration (activated carbon and anthracite filter media with depth of 2.3 m and filtration rate of 5 m/h) and disinfection with chlorine. Raw water is taken from river Daugava in which water contains high amount of humic substances.

Sampling procedure

100 ml water samples were taken from the raw water source (RW), from the mixing chamber (MC), after filtration (RF), after main ozonation (OZ), from BAC filters effluent (BAC) and from the clean water reservoir (DW). Samples of TOC, total phosphorus and orthophosphate were taken in eleven occasions during spring and summer. Samples of other chemical and microbiological analyses were taken every day during one month period in summer.

Glassware

Unless stated otherwise all glassware for chemical and microbiological analyses was prepared according to the Latvian Standard (LVS EN ISO 5667-3:1995) [10]. Glassware for TOC, total phosphorus and orthophosphate were first washed with detergent (Decon 90, Decon Laboratories Ltd., England), cleaned thoroughly with a 10 % solution of potassium dichromate in concentrated sulfuric acid and rinsed with hot tap water, then with 10 % nitric acid solution. Then, glassware were washed with hot tap water, air dried and covered with aluminum septum. Finally, the bottles were heated overnight at +250 ^{0}C [11].

Addition of phosphorus

Phosphorus was dosed as H_3PO_4 solution with a pump (Prominent Gamma/4, Germany) before one of the biofilter BAC (P).

The concentration of total phosphorus and orthophosphate was analyzed by an ammonium molybdate spectrometric method according to the Latvian Standard (LVS EN 1189:2000) [10]. The detection limit of this method is 0.009 and 0.003 mg l^{-1} respectively.

Analyses of TOC

The concentration of TOC was determined with a Shimadzu 5000 A TOC analyzer (Shimadzu Corporation, Japan).

Other chemical analyses

General chemical and microbiological analyses were determined according to the Latvian Standard [10]. Coliform bacteria number (CFUml^{-1}) was determined in 100 ml sample with membrane (Munktell Filter, Sweden) filtration method. Heterotrophic plate count (HPC) were determined with nutrient yeast agar (Sharlau Chemie S.A., Spain) after incubation at 22 ^{0}C for 3 days.

Statistical analyses

The effect of phosphorus addition to the TOC removal in BAC filter was tested with Wilcoxon's test for matched pairs [12].

Results

In total sampling was carried out in 20 occasions from different sampling points at WTP during period of six month. The concentration of TOC in raw water was 18.17 mg l^{-1} (Figure 1.). After chemical precipitation and filtration in rapid filters, the TOC concentration significantly decreased reaching values 5.95 mg l^{-1}. The following biofiltration did not change TOC considerably and in its concentration in drinking water was 5.15 mg l^{-1}.

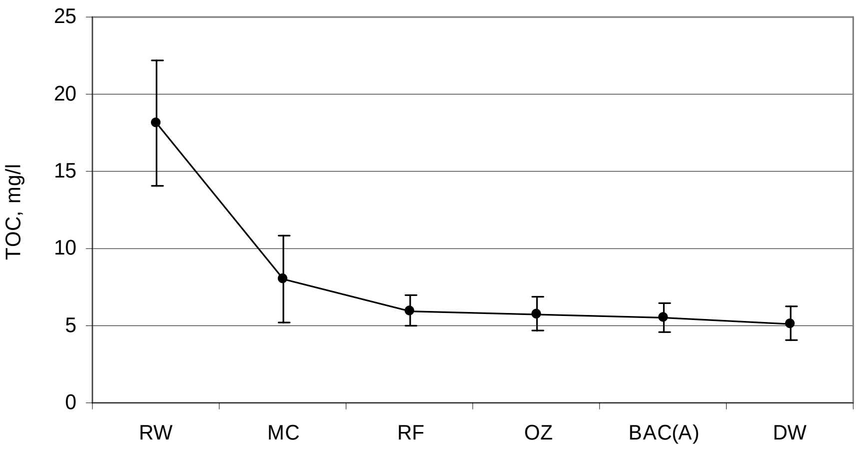

Figure 1. Changes of TOC during the water treatment process at the Daugava WTP in year 2004. Legends: RW, raw water, MC, mixing chamber, RF, outlet from rapid filters, OZ, outlet from ozonation chamber, BAC(A), outlet from biological filters, DW, drinking water.

The concentration of total phosphorus and orthophosphates in raw water is respectively 67 µg P-tot/l and 41 µg PO_4/l [6]. Phosphorus was effectively removed during chemical coagulation reaching levels of 6.5 µg l^{-1} before BAC filters. To satisfy optimal nutrient requirements (C:P=100:1) for bacteria growth in BAC filters the phosphorus dose was chosen as 50 µg PO_4^{3-}–P /l.

Results from analyses of water samples from effluent of BAC filters with and without addition of phosphorus showed that dosing of phosphorus did not change most of chemical and microbial parameters except for HPC and coliform numbers Table 2.

Table 2. Chemical and microbiological characteristics of effluent water from BAC filters

	BAC filter with addition of 50µg P/l			BAC filter without P addition		
Parameter	Mean value	SD	n	Mean value	SD	N
Dissolved O_2, mg l^{-1}	23,0	1,7	20	22,8	2,9	20
pH	6,71	0,08	19	6,63	0,14	19
UV abs, [254nm]	0,045	0,006	20	0,045	0,007	20
COD_{Mn}, mg l^{-1}	2,8	0,4	20	2,8	0,3	20
Temperature, ^oC	16	0,9	20	16	0,9	20
NH_4, mg l^{-1}	0,07	0,02	20	0,07*	0,02	18
NO_3, mg l^{-1}	2,0	0,3	10	2,0	0,3	10
Coliform organisms, CFU 100ml^{-1}	0,25	0,44	20	0,1	0,3	20
HPC, CFU ml^{-1}	2573	2817	20	265	223	20
Conductivity, µs cm^{-1}	258	53	5	295	98	10
P-tot, mg l^{-1}	0,008**	0,003	5	0,007***	0,003	10
PO_4, mg l^{-1}	0,006****	0,001	4	0,005*****	0,001	9
TOC, mg l^{-1}	5,13	0,31	5	5,52	0,91	11

Notes: * - 2 values under detection level
** - 2 values under detection level
***- 8 values under detection level
****- 3 values under detection level
*****- 7 values under detection level

UV abs, ultraviolet absorbance at 245 nm, COD_{Mn}, chemical ($KMnO_4$) oxygen demand, HPC, heterotrophic plate counts, TOC, total organic carbon

Although some 7 % improvement in removal of TOC in filter added with phosphorus was attained (Table 2) the difference between filters was not significant ($T \leq 0$, $p < 0.1$) (Figure 2.). Difference between other parameters charactering organic matter in water including UV and COD_{Mn} were also not affected by addition of phosphorus (Table 2). The number of heterotrophic bacteria in effluent of biofilter with extra phosphorus increased for 1-fold (Figure 2.). The mean values of bacteria number in effluent from biofilter with and without extra phosphorus were 2573±2817 CFU ml^{-1} and 265±223 CFU ml^{-1} respectively.

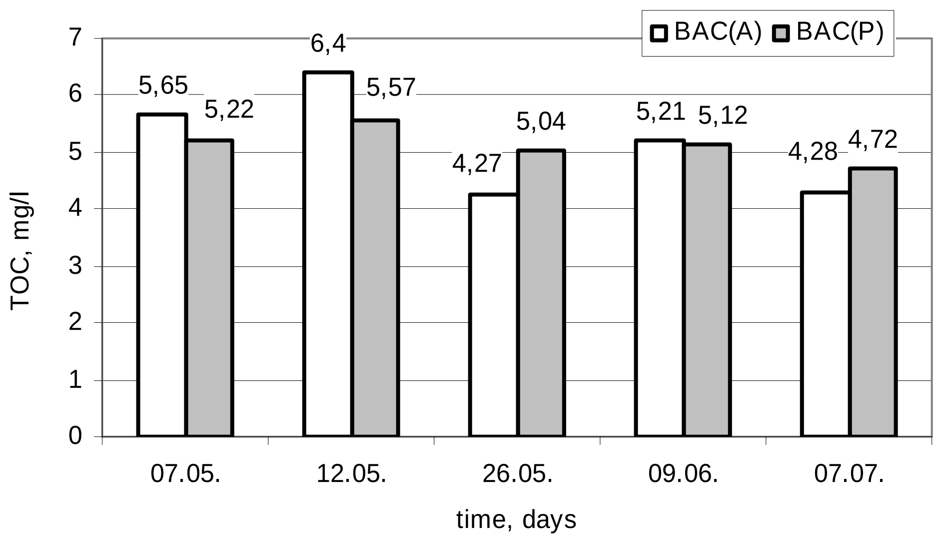

Figure 2. TOC in biofilters. Legends: BAC(A), outlet from biological filter without P addition, BAC(P), outlet from biological filter with addition of 50µg P/l.

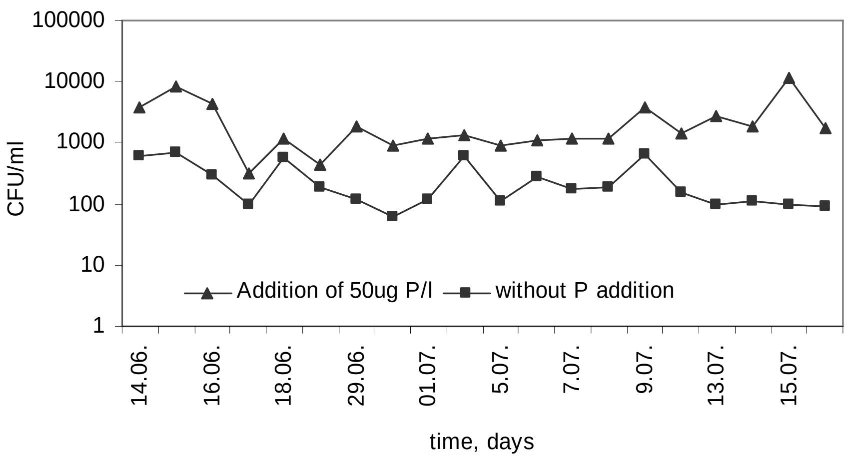

Figure 3. Heterotrophic bacteria counts in biofilters effluent with and without phosphorus addition.

Discussion

Ozonation before BAC filtration is a treatment step usually used for removal of TOC from waters after chemical coagulation. This study showed that removal efficiency of TOC during BAC filtration was significantly less than usually (30-50%) attained at this kind of water treatment systems.

The major factors affecting performances of BAC filters are contact time, temperature, characterization and concentration of influent NOM, filter media type, and backwashing strategy [13]. All these factors were optimal for BAC filters at Daugava WTP. The contact time (c.a. 30 min) and temperature (c.a. 16 ^{o}C) was sufficient to ensure significant bacterial activity, and according to calculation of mathematical model more 30% (<3.8 mg C/l) removal of TOC [14] should be reached in the filter. An optimal ration of O_3/TOC (1.0 mg/mg) for obtaining maximal biodegradable fraction of DOC [15] was also reached at the plant. Filter media used for BAC filters were mixture of anthracite and activated carbon, and therefore could not account for the low reduction of TOC during the treatment. As chorine was not used for backwashing of BAC filters at Daugava WTP it is not likely that backwash could have a negative impact on performances.
Earlier studies [6] have shown 100-fold decrease of microbiologically available phosphorus (MAP) during the coagulation rendering this element limiting for bacterial growth. Thus, shortage of MAP may result in low biological degradation of TOC in BAC filters. Yield of bacteria assimilable organic carbon increases after addition of inorganic nutrients [6], which confirms shortage of minerals in water. Nitrogen is not likely to be limiting since nitrogen containing substances significantly exceeded optimal nutrient requirement for bacteria.
In this study we examined if addition of phosphorus may increase performances of BAC filter for removal of TOC. Our results demonstrated that addition of phosphorus (50 µg P/l) to the BAC filters at the full-scale drinking water treatment plant (Daugava WTP) did not significantly affect TOC removal, however, it increased concentration of heterotrophic bacteria in the BAC effluent.
We suggest that a shortage of phosphorus is a reason for low removal efficiency of TOC during BAC filtration. The fact that additions of phosphorus significantly increased number of bacteria at the effluent confirmed this inorganic nutrient restricted bacterial activity in the biological filters.
The addition of phosphorus did not increase the phosphorus concentration in BAC filter effluent water. It is unclear whether all phosphorus was consumed by bacteria in filters or remained in the filter material. The reasons for bacterial washout from the filters and the fate of phosphorus during filtration requires further studies.
The results of this study agree with some [8] but disagree with other [7, 13] studies where dosing of phosphorus into biological filters was examined. This inconsistency should be examined in future. However, if it appears that retention of bacterial biomass is important issue we suggest that dosing of phosphorus could be practiced using biomembrane reactors.

Conclusions

Although phosphorus was a limiting nutrient for bacteria growth in waters investigated in this study addition of extra phosphorus (50 µg P/l) in to the biofilter of full-scale drinking WTP did not improve organic utilization measured as TOC, COD_{Mn} and UV absorbance. Values of average TOC for biofilter with extra phosphorus addition and without them were 5.13 and 5.52 mg l^{-1} respectively.

Addition of phosphorus promoted increase of HPC for 1-fold in biofilter effluent water. We suggest that addition of phosphorus increased detachment of bacteria from surface of BAC filter, therefore filters were not effective for removal of TOC.

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References

1. Camper A., Involvement of humic substances in regrowth // Int. Journ.Food.Microb. 92, 2004 – p.355-364.
2. Miettinen I.T.,Vartiainen T., Martikainen P.J., Phosphorus and bacterial growth in drinking water // Appl.Environ.Microbiol., 63 (8), 1997 – p.3242 –3245.
3. Sathasiavan A., Ohgaki S., Application of new bacterial regrowth potential method for water distribution systems-a clear evidence of phosphorus limitation //Water Res., 33, 1999 – p. 137-144.
4. Lehtola M.J., Miettinen I.T., Vartiainen T., Martikainen P.J., Changes in content of microbially available phosphorus, assimilable organic carbon and microbial growth potential during drinking water treatment processes // Water Res., 36 (15), 2002 – p.3681 –3690.
5. Polanska M., Huysman K., Van Keer C., Investigation of microbially available phosphorus (MAP) in femish drinking water // Water Res., 39 (11), 2005 – p.2267 –2272.
6. Juhna T. and Rubulis J., Problems of DOC removal during biological treatment of surface water with a high amount of humic substances // Water Sc. and Tech.: Water Supply, 4 (4), 2004 – p.183-187.
7. Nishijima W., Shoto E. and Okada M., Improvement of biodegradation of organic substance by addition of phosphorus in biological activated carbon // Water Sc. and Tech., 36 (12) 1997 – p. 251–257.
8. Yu X, Zhang X.J and Wang Z.S., Improving removal efficiency of organic matters by adding phosphorus in drinking water biofiltration treatment // Biomed. Environ., 16(1), 2003 – p.29-39.
9. Vahala R., Moramarco V., Niemi R. M., Rintala J., Laukkanen R., The Effects of Nutrients on Natural Organic Matter (NOM) Removal in Biological Activated Carbon (BAC) Filtration // Acta hydrochimica et hydrobiologica, 26(3), 1998 – p.196-199.
10. Latvijas Standarts / Internet - http://www.lvs.lv/Default.htm
11. Van der Kooij D., Visser A. and Hijnen W. A. M., Determination the concentration of easily assimilable organic carbon in drinking water // J. Am. Wat. Works Assn., 74, 1982 – p.540-545.
12. Fowler J., Cohen L., Jarvis P, Practical Statistics for Field Biology, 2th ed. // In: John Wiley&Sons Inc., USA, 2004 – p.259.
13. Urfer D., Huck P., Booth S.D.J., and Coffey B.M. Biological filtration for BOM and particle removal: A critical review. // J. Am. Wat. Works Assn. 89(12), 1997 – p. 83-98.
14. Laurent P., Prevost M., Cigana J., Niquette P., and Servais P., Biodegradable organic matter removal in biological filters: evaluation of CHABROL model. // Water Res., 33 (6), 1997 – p.1387-1398.
15. Siddiqui M., Amy G.L., and Murphy B.D., Ozone enhanced removal of natural organic matter from drinking water sources // Water Res., 31 (12), 1997 – p. 3098-3106.
16. Sang J., Zhang X., Li L., Wang Z., Improvement of organics removal by bio-ceramic filtration of raw water with addition of phosphorus // Water Res., 37, 2003 – p.4711–4718.

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Rubulis J. , Juhna T. Pētījums par fosfora pievienošanu biofiltros ūdens attīrīšanas iekārtā

Darbā apskatīta fosfora dozēšanas ietekme uz organisko vielu izdalīšanu bioloģiski aktīvās ogles filtros. Pētījums veikts ūdens attīrīšanas iekārtās, kurās mikroorganismu attīstību limitē fosfors. Organisko vielu izdalīšanu biofiltros mērījām nosakot kopējā organiskā oglekļa (TOC) koncentrāciju, ķīmiskā skābekļa patēriņu un ultraviolēto absorbciju. Mikroorganismu koncentrāciju biofiltru izplūdē noteicām mērot heterotrofo koloniju skaitu. TOC koncentrācija biofiltrā ar fosfora (50 µg P/l) dozēšanu bija 5.13 mg l^{-1} un filtrā bez dozēšanas 5.52 mg l^{-1}. HPC izplūdes ūdenī no biofiltra ar fosfora dozēšanu bija par vienu kārtu lielāks nekā filtrā bez fosfora dozēšanas jeb 2573 kolonijas veidojošās vienības ml^{-1} and 265 kvv ml^{-1}katrā. Pētījums parādīja, ka nebija ievērojamas statistiskas atšķirības organisko vielu izdalīšanai filtrā ar fosfora dozēšanu un filtrā bez dozēšanas.

Rubulis J, Juhna T. Study about phosphorus addition to the full-scale biologically activated carbon filters

The study examined how the removal of natural organic matter during water filtration through activated carbon filters is affected by the dosage of phosphorus. The experiment was performed in full-scale drinking water treatment plant. Organic matter utilization in biofilters was measured with total organic carbon, chemical oxygen demand and UV-absorbance. Microorganism concentration in water was measured using heterotrophic plate count. TOC concentrations in biofilters with extra phosphorus (50 µg P/l) addition and without them were 5.13 and 5.52 mg l^{-1} respectively. HPC in effluent waters for biofilter with phosphorus addition was for 1-fold higher, 2573 CFU ml^{-1} and 265 CFU ml^{-1} respectively. The study showed that NOM removal did not change significantly between biofilters with/without extra phosphorus addition.

Рубулис Я., Юхна Т. Влияние фосфора на очистку воды в биологических фильтрах с активированным углём.

Эксперимент проводился на станции очистки питьевой воды. В ходе эксперимента был исследован эффект влияния при добавлении фосфора, которое необходимо для удаления натуральных органических веществ в воде, во время фильтрации в биологичестких фильтрах с активированным углём, где развитие микроорганизмов лимитируется фосфором. Удаление органических веществ в биологичестких фильтрах измерялось как количеством общего органического углерода, так и окисляемостью перманганатной и ультрафиолетовой абсорбций.Содержание микроорганизмов измерялось количеством гетеротрофных бактерий. Концентрация общего органического углерода в биофильтре с добавлением фосфора составила 5.13 mg l^{-1} , а в биофильтре без добавления- 5.52 mg l^{-1}. При этом, количество гетеротрофных бактерий в воде отводимой из биофильтра с добавлением фосфора было на одну ступень выше, 2573 CFU ml^{-1} и, соответственно, 265 CFU ml^{-1}. Исследования показали, что существенной разницы, при удалении натуральных органических веществ в биофильтрах с добовлением фосфора и без него, не было.