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The Utility of Measuring Assimiliable Organic Carbon (AOC) as an Indicator of Biostability in Distribution Systems for Finished Water

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Abstract: The objective of this paper is to compare the applicability of assimilable organic carbon (AOC) or biodegradable dissolved organic carbon (BDOC) for quantifying biodegradable organic material (BOM) and biostability in distribution systems for a variety of finished waters. The study the data is derived from was part of an AWWARF and Tampa Bay Water tailored collaboration project to determine the effect of blending different waters on distribution system water quality. Seven different finished waters were produced from surface, ground, or brackish water on site and fed 18 independent pilot distribution systems (PDSs), either as single finished water or as a blend of several finished waters. AOC and BDOC have often been used as indicators of bacterial regrowth potential in distribution systems. In this study, AOC was the more useful assay of the two for the BOM concentrations observed in the PDSs. BDOC did not distinguish BOM while AOC did at the low BOM levels from many of the advanced treatments (e.g. RO, O^3/BAC). AOC in contrast allowed much more meaningful calculations of the consumption or production of AOC as the blends passed through the PDSs even for very low BOM blends. In addition, meaningful trends corresponding to changes in heterotrophic plate count (HPC) were observed for AOC but not for BDOC. Moreover, AOC stability was associated with waters produced from advanced membrane treatment.

Keywords: assimilable organic carbon (AOC), biodegradable dissolved organic carbon (BDOC), biodegradable organic matter (BOM), biostability, membrane treatment

Introduction

Organic nutrients in water impact the water quality of distribution systems by generating color, undesired taste, and odors.[1-4] Also, biodegradable organic matter (BOM) that is not removed during water treatment can result in growth of bacteria in distribution systems. Numerous methods have been developed to quantify the biodegradable fraction of organic matter in water. Two well-established methods are most often used to measure BOM levels in drinking water. The assimilable organic carbon (AOC) bioassay is based on the correspondence between the growths of one or two pure strains of organisms (commonly *Pseudomonas fluorescens* P17 and/or *Spirillum* NOX) with BOM levels. The biodegradable dissolved organic carbon (BDOC) assay consists of measuring the fraction of DOC that is biodegradable by a microflora of organisms, suspended or fixed on biological sand.

Volk *et al.*[5] have reported that BDOC has been related to biological stability of drinking water. Although when the entire body of literature is considered, this relationship is more consistent with AOC than BDOC.[6] Servais *et al.*[7] have associated biological stability with both AOC and BDOC and showed that AOC was a better indicator of BOM in low carbon finished waters (i.e., NF or RO permeate) while BDOC was useful in terms of predicting secondary residual stability.[8]

This study is part of an AWWARF and Tampa Bay Water tailored collaboration project to determine the effect of blending different water sources on distribution system water quality. AOC and BDOC bioassays were run to evaluate biostability of seven different source waters in pilot distribution systems (PDSs). Correlations between heterotrophic plate counts (HPCs) and both BDOC and AOC levels are investigated in this article.

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Materials and Methods

HPCs

Heterotrophic plate counts were performed by plate spreading on R2A agar incubated at 22°C for 7 d, according to Standard Method 9215B.[9] Results were expressed in colony-forming units per milliliter (cfu/m*l*). The procedure was performed entirely inside a laminar flow hood (model 62674, Envirco Corporation Albuquerque, NM, USA) equipped with a HEPA filter.

AOC

Assimilable organic carbon was measured using the rapid method of LeChevallier *et al.*[10] except that plate counts were used to enumerate bacteria rather than ATP fluorescence, in conjunction with Standard Methods 9217[9] and the method of Van der Kooij.[6] The procedure used a temperature of 25°C for sample incubation and is outlined in great detail in an article.[11] Quality control for the AOC bioassay was performed using blank controls, 100 μg/*l* sodium acetate standards, and duplicate samples. The 100 μg/*l* sodium acetate standards inoculated with P17 produced an average AOC of 93.80 ± 20.00 μg/*l* as acetate-C, while for NOX, they produced an average AOC of 77.20 ± 12.53 μg/*l*as acetate-C. Experimental yield values from acetate standards for P17 ($4.08 \pm 0.81 \times 10^6$ cfu/μg of acetate-C) and NOX ($9.26 \pm 1.50 \times 10^6$ cfu/μg of acetate-C) compared reasonably well with the literature values as specified in Standard Methods (4.1×10^6 and 1.2×10^7 cfu/μg of acetate-C for P17 and NOX, respectively). Literature yield values were used for the AOC calculations to conform to the Standard Method.[9] A significant correlation between the AOC concentration and the density of heterotrophic bacteria in distribution water supplies has already been reported.[6,12]

BDOC

The procedure for biodegradable dissolved organic carbon determination followed the technique using sand fixed bacteria.[11,13,14] In this method, there were two incubation flasks per sample plus two controls used in the BDOC method: sample flasks 1 and 2 (duplicates with 300 m*l* of sample each), activity control flask (300 m*l* of 2 mg/*l* sodium acetate solution), and inhibition control flask (300 ml of sample plus 3 m*l* of 200 mg/*l* sodium acetate stock solution). Approximately 100 ± 10 g of drained biological sand was placed in each incubation flask, and 300 m*l* of water/sample was poured into each incubation flask containing sand. The initial TOC of the water sample was measured and labeled as DOC_o. The sample flasks were then incubated at room temperature (22-25°C), and on days 3-6, the DOC concentration of each water sample was measured. The incubation continued until a minimum DOC value was reached. Volk *et al.*[5] determined values of 0.15 mg-C/*l* at 20°C and 0.30 mg-C/*l* at 15°C for achieving biological stability in distribution systems of Paris suburbs.

Experimental Set-up

University of Central Florida is conducting an AWWARF and Tampa Bay Water tailored collaboration project to determine the effect of blending different water qualities on distribution system water quality. Waters produced from seven different treatment systems (aeration (G1), softening (G2), blended softening (G3), blended NF (G4), CSF-O_3-BAC (S1), IMS (CSF-NF or S2) and high pressure RO are blended and distributed to 18 different pilot distribution systems (PDSs). The preceding acronyms are defined accordingly: G: ground water; S: surface water; NF; nanofiltration; CSF: coagulation-sedimentation-filtration; BAC: biological activated carbon; IMS: integrated membrane system; RO: reverse osmosis; LS: lime softening. G1, G2, G3, G4 and RO finished waters are produced from the same groundwater (Cypress Creek Water Treatment Plant, Polk County, Florida, USA). Salts are added in RO permeate to simulate typical finished water from a desalination process. The S1 and S2 finished waters are produced from the same surface water (Hillsborough River Water Treatment Plant, Hillsborough County, Florida, USA). The PDSs consist of combined PVC, galvanized, lined ductile iron and cast iron pipes taken from actual distribution systems and have a 5-day HRT.

Results and Discusstion

Experiments were conducted for about 9 months (from Dec 13th, 2001 to August 1st, 2002). The

Table 1. Average BDOC and AOC results for seven finished water sources

Water sources	AOCinf. μg-C/*l*	AOCeff. μg-C/*l*	Delta AOC μg-C/*l*	BDOCinf. mg-C/*l*	BDOCeff. mg-C/*l*	Delta BDOC mg-C/*l*
G1 - stripped	120	79	41	0.96	0.34	0.62
G2 - LS	94	130	-36	0.62	0.27	0.35
G3 - LS	119	121	-2	0.29	0.40	-0.11
G4 -NF	88	67	21	0.34	0.30	0.04
S1 - O^3/BAC	102	59	43	0.35	0.37	-0.02
S2 - NF	62	52	10	0.46	0.40	0.06
RO	50	46	4	0.27	0.13	0.14

G1: Aerated groundwater ; G2: Lime softened groundwater ; S1: Coagulated, settled and filtered surface water with post-ozonation treatment ; S2: Coagulated, settled and filtered surface water with nanofiltration treatment ; RO : Desalinated sea water ; G3: Lime softened blend of G1, S1 and RO ; G4: Nanofiltered blend of G1, S1 and RO.

samples were taken three times 2/12/01, 3/28/02, 5/16/06, 6/20/02, and 8/01/02, respectively from each influent and effluent sampling port located on each standpipe of 18 PDSs during the study. HPC was tested and the relationship between HPC and both BDOC and AOC has been investigated. During the experiments it was observed that the secondary chlorine residual in most lines was depleted, especially after February (data not shown).

Table 1 has shown that using influent BDOC, one would categorize G1 and G2 as having high BOM, and the other 5 finished waters as having a relatively lower BOM level. Using ΔBDOC, one would likewise categorize G1 and G2 as biologically unstable, while the other 5 finished waters had stable BDOC levels as the water passed through the PDS. With AOC influent and ΔAOC, we see the same trends as with BDOC for G1 and G2, which have high and unstable BOM levels regardless of which parameter is used. However, the other 5 finished waters can now be differentiated and fall into 3 separate categories. S2-NF and RO have both low BOM influent levels and stable BOM. G3-LS, G4-NF, and S1-O^3/BAC have BOM levels to G1 and G2, but G3-LS have high BOM but stable, while G4-NF and S1-O^3/BAC has high and unstable BOM. The main advantage of the AOC was in distinguishing the truly low and stable BOM waters (S2-NF and RO) from the other 5 waters, BDOC was unable to do this, probably because BDOC values were so low for these advanced treatments. Thus for advanced water treatment with respect to carbon/BOM removal,

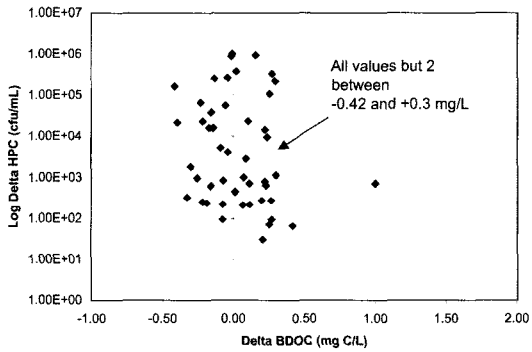

Fig. 1. Log Delta HPC vs Delta BDOC.

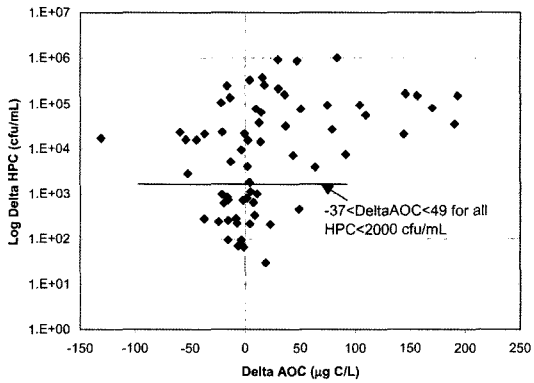

Fig. 2. Delta HPC vs Delta AOC.

AOC was more informative. It should be noted that increases in AOC have been observed before in warm distribution systems[11] which reflects biological activity (e.g. hydrolysis, fermentation, partial oxidation) just as AOC consumption does.

Using pooled PDS values for all blends and PDSs we can generate Fig. 1 and 2. Fig. 1 shows that ΔBDOC did not correlate to ΔHPC results (Fig. 1). All values of ΔBDOC ranged between −0.42 and +0.3 mg-C/*l* except 2 (Fig. 1), while HPC levels varied over 4 orders of magnitude. On the other hand, unstable AOC corresponded to high effluent HPC (Fig. 2). There were high ΔHPC values even when ΔAOC was low, but there was never a low HPC value when ΔAOC was high. Thus high ΔAOC implied a high ΔHPC. However, there were other factors that could cause a high ΔHPC even when ΔAOC was stable. Regardless of the other factors influencing, increased HPC number AOC was more informative than BDOC with respect to indicating possible problems with biological instability (e.g. increased HPC counts).

Conclusions

Unstable AOC (i.e. $-37 < \Delta AOC < 49$ μg C/*l*) always resulted in high increases in HPC however ΔBDOC did not correspond to HPC. Moreover, BDOC did not distinguish BOM while AOC did when advanced treatments needed to be differentiated (e.g. membranes). Among the seven lines fed by single water sources (produced from advanced treatments), after 8 months of study, most of them had BDOC levels that were too similar to allow meaningful differentiation. AOC in contrast allowed much more meaningful contrasts of influent levels, the consumption, and production of AOC as the blends passed through the PDS systems. Low influent AOCs and AOC stability were typically associated with waters produced from advanced membrane treatment. AOC was a more meaningful parameter for quantification of BOM than BDOC when the BOM levels were low entering a distribution system.

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