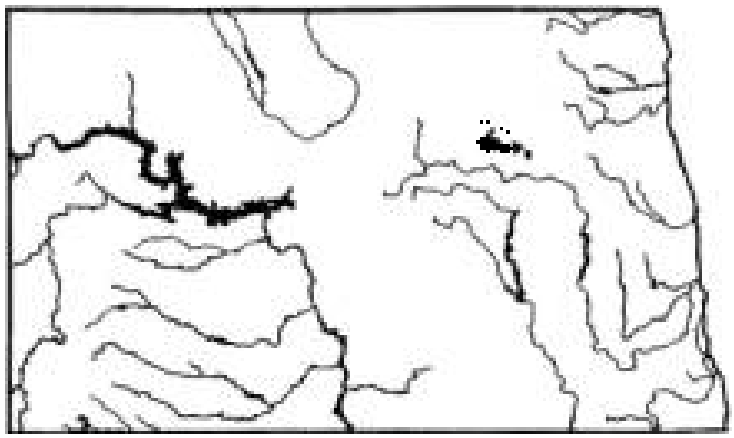

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ABSTRACT

The microbial regrowth potential of water from different stages of the treatment trains and distribution systems of the cities of Moorhead, Minnesota and Fargo, North Dakota was studied. Assimilable organic carbon (AOC) and biodegradable dissolved organic carbon (BDOC) were the key indicators used to justify the regrowth potential. Dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UV_{254}), and specific ultraviolet absorbance (SUVA) were complimentary parameters examined. Water samples collected bi-weekly for the entire year of 2004 from the two water systems were analyzed for the five parameters. Raw water for both systems was high in AOC and BDOC concentrations. Both treatment systems removed substantial amounts of AOC and BDOC but the levels in their finished water were still well above the threshold concentrations for possible microbial regrowth. However, there was no significant reduction in AOC and BDOC in both distribution systems as the levels in the finished water and tap water were comparable throughout the year. The values of the other three parameters (DOC, UV_{254}, and SUVA) tended to support the AOC and BDOC results. Based on these observations, there should be minimal or no microbial regrowth in the Moorhead and Fargo distribution systems.

Background

In recent years, water quality scientists and engineers have emphasized on the biodegradability of dissolved organic matter in both raw and treated waters. This is because the biodegradable organic matter (BOM) in treated water can induce the growth or regrowth of microorganisms in the distribution system of drinking water. Residual BOM is usually the most important limiting factor responsible for bacterial regrowth in the water distribution system (Rittmann and Snoeyink, 1984). One of the most effective methods in controlling the bacterial growth in the distribution system is to limit the amount of BOM required for the growth of heterotrophic bacteria in treated water (Servais *et al.*, 1993). Water containing BOM less than a minimum concentration that supports the bacterial growth is usually biologically stable.

Biodegradable dissolved organic carbon (BDOC) has been used as one of the parameters for quantifying the amount of BOM in water. Servais *et al*. (1989) defined BDOC as the fraction of dissolved organic carbon (DOC), which can be metabolized by bacteria within a period of time. The BDOC test measures the reduction of DOC in a water sample, which is exposed to microorganisms in a period of time (Servais *et al.*, 1987 and 1989). The first BDOC measurement was introduced by Servais *et al*. (1987). It was developed as a batch procedure. A mixed microbial culture from the same environment as the sample was used as an inoculum. Incubation occurred in the dark at 20 ± 0.5°C for a period of 10 to 30 days and BDOC was the difference between the initial and final DOCs.

The first BDOC procedure was used specifically for testing the quality of raw water and for designing and monitoring, and optimizing operating conditions of biological activated carbon (ozonation + granular activated carbon) systems. Occasionally, it was used to examine the BDOC removal of other treatment processes such as coagulation and filtration. Interest in BDOC of finished water started to grow when BDOC was linked to the microbial proliferation in the distribution systems. As a result, BDOC is a widely used parameter in the drinking water field.

An alternative to the BDOC procedure called assimilable organic carbon (AOC), was invented by van der Kooij *et al*. (1982). AOC is the portion of the organic carbon that can be synthesized to cellular material by a single bacterial strain. In the AOC determination method, a preheated water sample is seeded with a pure strain of *Pseudomonas fluorescens* P17. The sample is incubated at 15°C, and bacterial growth is monitored daily by colony counts (spread plate techniques) until the maximum growth is reached. The incubation period (the number of days to reach the maximum yield) can be from 3 to 30 days depending on the type of the water sample. By concurrently determining the growth yield of bacteria in solutions of known acetate concentration, the maximum growth can be converted into AOC and expressed as μg of acetate-C equivalents/L.

van der Kooij (1987) and van der Kooij *et al*. (1989) included a *Spirillum* strain, NOX, into the AOC procedure as an alternative seed or a dual strain seed due to the inability of *Pseudomonas fluorescens* P17 to metabolize oxalic acid, which is one of the products frequently formed during ozonation. Unlike BDOC, AOC only accounts for the organic carbon used for cell synthesis. Since the AOC test measures cell growth of a single or dual strain, the test does not guarantee that all the assimilable carbon is measured. The inoculum may not be capable of metabolizing all

contaminants. Therefore, the reported AOC value is normally less than the reported BDOC value for the same sample. The AOC method has been widely adopted when the regrowth is a concern. One of the three threshold criteria proved useful in predicting coliform occurrences is AOC concentrations in plant effluent > 100 µg/L (Volk and LeChevallier, 2000).

BDOC has also been related to the regrowth of microorganisms. High BDOC in finished water indicates poor quality and a potential of microbial multiplication. Maintaining free chlorine residual to prevent the regrowth along the distribution system is a common solution; however, a large amount of chlorine is required. Also, chlorine residual cannot completely inactivate fixed bacteria (Le Chevallier *et al.*, 1988). Controlling microbial dynamics by limiting available substrate (BDOC) is a new and interesting approach (Rittmann and Snoeyink, 1984, Huck, 1990, and Servais *et al*., 1993). Biologically stable water should contain less than 0.15 mg of BDOC/L. At this threshold level, microbial12.3 0 Td[ )]

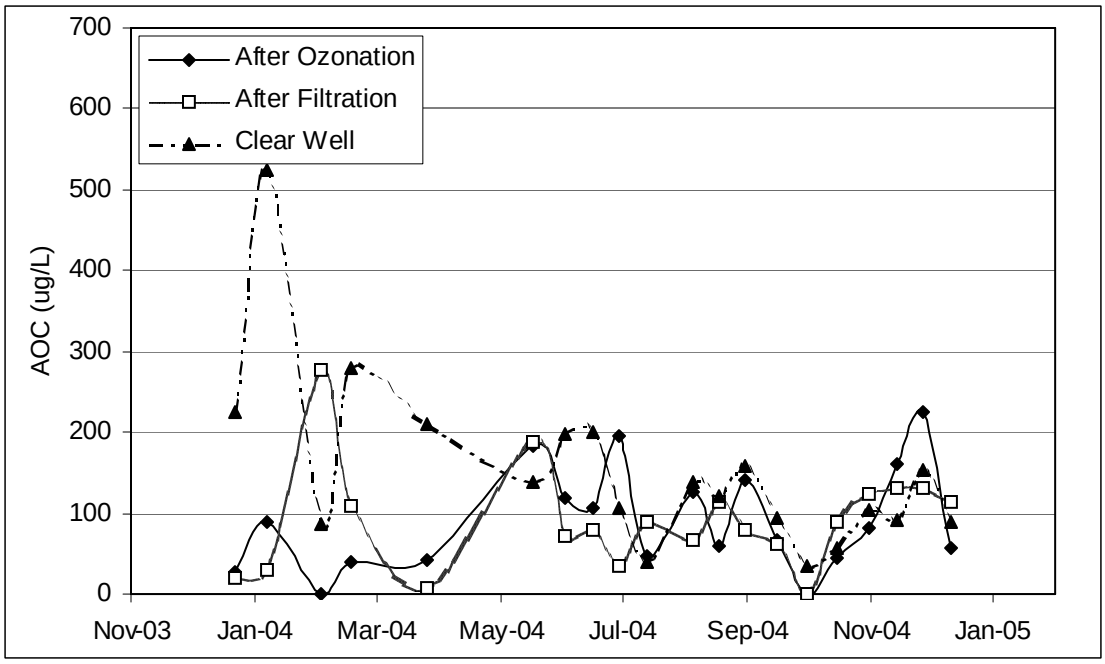

Figure 30. AOC of after ozonation, filtration, and clear well samples from the Fargo Water Treatment Plant.

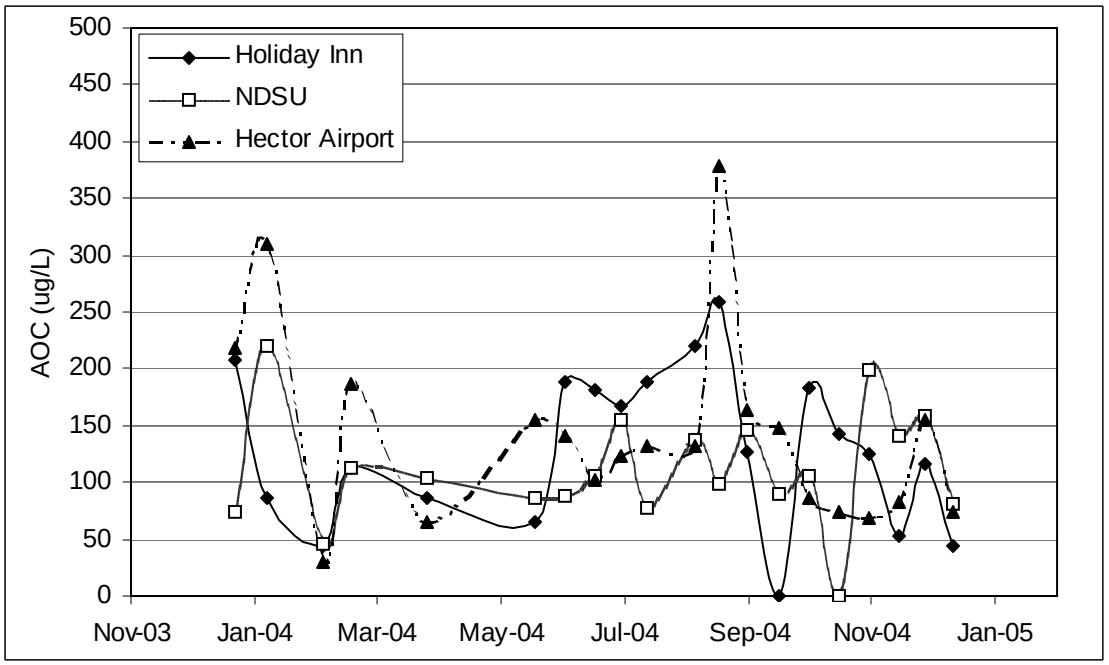

Figure 31. AOC of samples from the Fargo distribution network.

Conclusions

The microbial regrowth potential through the Moorhead and Fargo water systems were investigated using BDOC and AOC as the main indicators. DOC, UV_{254}, and SUVA of the water samples collected bi-weekly from the two systems were also determined. The sampling occurred for the entire year of 2004. For the Moorhead water system, BDOC in the Red river raw water was high. Softening was very effective in reducing BDOC significantly. Ozone enhanced BDOC but filtration removed only some of the increases (not down to the levels in softened samples). Chlorination slightly increased BDOC, which remained relatively unchanged in distribution system. AOC was not detected in all after softening samples. This observation is not explainable. Other than that, the AOC results were inconsistent and therefore were not as useful as the BDOC results. The results of the other three parameters supported the BDOC results. The results for the Fargo system were similar to those for the Moorhead system. The rapid mixing and sedimentation processes at the Fargo plant had very minimal effects on BDOC and AOC. The finished water of the Fargo plant had higher regrowth potential (BDOC) than that of the Moorhead plant.

The filters at the two plants tended to be more biologically active during the Summer and Fall months. The finished waters of the Moorhead and Fargo systems had high regrowth potential evidenced by their BDOC and AOC concentrations, which were very much higher than the threshold levels. However, BDOC and AOC at comparable levels to those in finished waters were observed in all tap water samples regardless of season. Since BDOC and AOC were not depleting, it was likely that no actual significant regrowth in the distribution systems took place.

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