Control of Water Quality Deterioration in Water Distribution Systems:

Part 4. Alternatives for Removal of Microbial Nutrients

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Summary

Part 1 of this series documented the widespread presence of methane in Illinois ground waters and assessed its effect on distributed drinking water quality. Evidence was presented for the stimulation of microbial growth by methane.

Part 2 reported on process evaluation studies of methane removal at the Normal, Illinois water treatment plant. Those results demonstrated that, without adequate aeration, methane penetrated through the plant into the distribution system.

Part 3 of this series detailed the results of pilot column aeration studies conducted at Normal. These studies evaluated the ability of alternative aeration procedures (tower aerators and diffused air aeration) to achieve more complete removal of methane and carbon dioxide.

Part 4, the final part of this series, presents a discussion of both the study results and alternatives for removing microbial nutrients from a groundwater supply containing methane.

Alternatives for Removal of Microbial Nutrients

Previous studies at the Normal water treatment plant have shown that control of excessive amounts of microbial growth and maintenance of a persistent disinfectant residual in the distribution system require reductions in the concentrations of the primary microbial nutrients, carbon and nitrogen. Methane may be removed by enhanced aeration and ammonium ion may be oxidized by breakpoint chlorination.

While unconventional, biological utilization of methane and nitrification of ammonium ion may be accomplished by placing a microbial support medium in the flume between the aerator and lime contactor. If feasible, this biological oxidation process might moderate the need for replacing or modifying the aerator. Also, biological nitrification would greatly reduce the amount of chlorine required to implement breakpoint chlorination.

Enhanced Aeration for Methane Removal

A significant portion of the total organic carbon (TOC) in Normal's well water is in the volatile form of methane. Pilot column studies have shown that methane can be effectively and economically removed by aeration. However, design information on the removal of methane from well water by commercial aerators is not available since methane is not currently recognized either as an abundant or undesirable constituent of ground water supplies.

The pilot column studies at the Normal water treatment plant indicate that methane might be effectively removed if the influent hydraulic loading on Normal's aerator was reduced to conventional design levels. Reduction in hydraulic loading would require the construction of an additional tray-type aerator or replacement of the existing aerator with a new aerator with a larger surface area. Although not critical at Normal because most of the plant is open to the atmosphere, dual units are often advisable so that one aerator can be bypassed for maintenance.

Tower Aerators

If tower aerators employing forced draft were constructed, there would be several additional operational costs and maintenance considerations. In addition to the blowers, a major operational cost would be the continuing, increased cost of pumping all influent water to the top of the towers.

Enclosed aerators also require access for cleaning. The contact medium or 'packing' used in aerators is subject to clogging from the accumulation of precipitated iron and manganese oxides as well as from gelatinous biological slime growths. If not readily accessible, these accumulations could result in substantial labor and material costs for removal, cleaning and periodic replacement of the contact medium.

Open, natural draft aerators, similar to Normal's existing aerator, are more easily inspected and maintained.

Tower Aerators, Willmar, Minnesota

Oxidation of Ammonium Ion by Chlorine

Studies were conducted at Normal to evaluate the potential for oxidation of ammonium ion by breakpoint chlorination. At molar ratios of chlorine to ammonia-N at and below 1:1, chlorine and ammonium ion react to produce NH_2Cl. The stoichiometric reaction can be shown as:

Cl_2 + NH_3 ——> **NH_2Cl** (monochloramine) + H^+ + Cl^-
71 g Cl + 14 g N

Since Normal plant water has an immediate chlorine demand of 3 gCl/m**3** and contains about 2.2 gN/m**3** of ammonium ion, the progressive addition of up to 3 + (2.2 x 5) g/m**3** of chlorine will theoretically convert all the ammonium ion present to NH_2Cl (monochloramine), if there are no side reactions.

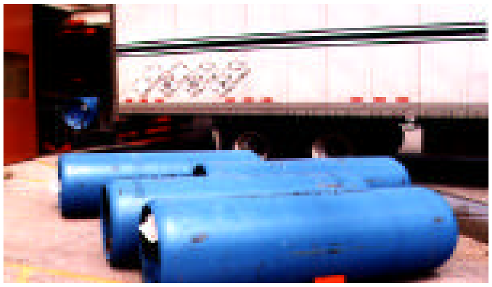
Chlorine additions beyond the 1:1 molar ratio begin to oxidize the ammonium ion to a variety of oxidized forms. If nitrogen is the predominate oxidation product, the stoichiometric reaction can be written as:

3 Cl_2 + 2 NH_3 ——> **N_2**(aq) + 6 H^+ + 6 Cl^-
213 g Cl + 28 g N

At a Cl_2:NH_3 molar ratio of 1.5:1, this reaction is theoretically complete; all the ammonium ion has been oxidized to nitrogen (N_2) and there is no longer any chloramine residual. This ideal reaction is complete at the minimum point corresponding to 3 + (2.2 x 7.6) gCl/m**3**. This point is referred to as the ‘breakpoint’. Chlorine additions beyond this point, if NO_3^- is not formed, will be present as ‘free’ or hypochlorous acid residuals.

From the breakpoint curve studies conducted, it appears that the reaction between chlorine and ammonium ion is rapid, almost immediate, in Normal well water. Approximately 22 gCl/m**3** are required to achieve ammonium ion oxidation and establish a hypochlorous acid residual.

While breakpoint chlorination is a viable option for controlling ammonium ion in the Normal water distribution system, the cost and labor for the purchase and handling of liquid chlorine is significantly increased. In addition, there is growing national concern for the hazards associated with handling and application of chlorine gas. The strategically central location of the Normal water works increases this concern.

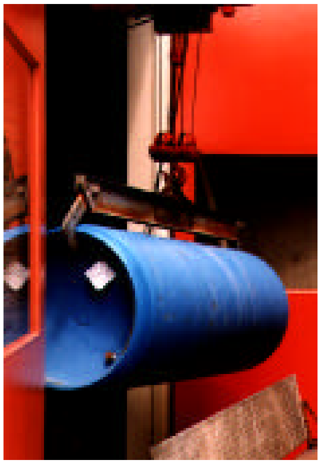


Supplier Unloading Chlorine Cylinders at Normal

Seasonal Application of Breakpoint Chlorination

Seasonal or periodic breakpoint chlorination may be an effective means for moderating the annual use of chlorine at Normal. If the maintenance of a hypochlorous acid residual is effective in eliminating microbial growths during a relatively short period (e.g., month) of application, it may be possible to reduce the application of chlorine substantially and return to more less costly chloramination for extended periods. The assumption is that the nitrifiers, inactivated by the hypochlorous acid residual, will not be capable of reestablishing themselves on the distribution system piping rapidly. The effectiveness of this strategy would be reflected in a persistent chloramine residual following breakpoint chlorination.

While this is an attractive alternative to continuous breakpoint chlorination, its effective application requires a significant distribution system monitoring effort to confirm the assumptions that nitrification and microbial growth remain under control and that persistent residuals are maintained. Regular monitoring during chloramination is required to determine when the repeat application of hypochlorous acid should be conducted.



Since the kinetics of microbial destruction in a distribution system by hypochlorous acid is not known, monitoring should be continually be conducted for oxygen depletion as an index of the degree of nitrification occurring.

Biological Oxidation of Ammonium Ion

An alternative approach to the removal of nutrients leading to microbial growth in the distribution system is to create conditions under which nutrient-consuming microbial growth will occur within the confines of the water treatment plant. If effective, biological processes would promote the conversion of methane and ammonium ion into bacterial cell mass which would, in turn, become attached or settled and removed before passing into the distribution system. To the extent that the biological growth took place within the plant, it would not take place in the distribution system.

Evaluations of Normal's water treatment plant have consistently provided evidence that biological processes are already removing microbial nutrients. Extensive microbial growth was observed on the plastic medium used in the aerators as well as within attached sediments along the bottom and side walls of the long flume which carries the aerated water to the lime softening contactor. These heavy accumulations are observed despite the application of chlorine at the aerator.

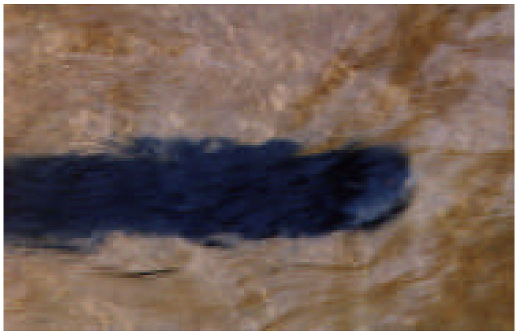
A simple approach to enhance the removal of microbial nutrients might involve the installation of contact medium (plastic balls, gravel, sheets, screens or sponges) within the existing flume to support biological accumulations. To promote growth kinetics, the application of chlorine at the aerator might be discontinued.

Where source waters contain ammonium ion, there may be other potential advantages to enhancing biological growth. Even a modest enhancement of nitrification during treatment might greatly reduce the dosage of chlorine required to reach breakpoint. In some cases, the need for breakpoint chlorination might be obviated if ammonium ion levels were reduced to less than 1 g N/m^3.

At Normal, potential disadvantages might include the need for diffused aeration in the recarbonation basin to restore oxygen consumed by the aerobic, nitrifying microorganisms. In addition, the lime softening sludge would continuously receive a comparatively small quantity of putrescible organic debris derived from the sloughing of microbial cell mass. This entrainment of this organic matter could lead to the creation of septic odors during sludge storage and disposal.

The microorganisms produced in the biological process would not be expected to be pathogens, but successors to the cells derived from Normal's ground water supplies. More important, the majority of these organisms would be produced (and removed) within the plant and not generated within the distribution system.

Finally, the potential for the generation of disinfection byproducts, such as the chlorinated hydrocarbons and haloacetic acids, should be markedly decreased if the application of high concentrations of chlorine could be avoided. If sufficient ammonium ion oxidation could be accomplished within existing treatment facilities, many water utilities should be able to continue to employ chloramination and minimize the formation of disinfection byproducts.



Accumulated Sediments on Bottom of Flume from Aerator to Lime Contactor
Brown (Oxygenated) Area is Oxidized Microzone of Iron Oxides and Aerobic Organisms
Dark Area was Scraped to Show Black (Anoxic), Septic-Smelling Organic Matter and Sulfides

Summary of Recommendations

Methane Removal

The pilot studies reported here indicate that a properly sized tray-type aerator can provide satisfactory removal of the methane dissolved in Normal's well water supply. In selecting an aerator, the ease of access for routine (semi-annual or annual) cleaning of the internal parts, including contact medium, should be considered. This is because both iron oxides and biological growths can be expected to accumulate on exposed interior parts and must be routinely cleaned to prevent aerator clogging and decreased aerator efficiency due to short-circuiting.

Performance requirements for a new aerator should include the reduction of methane to less than 1 g CH_4/m^3 in the aerator effluent. Since water treatment plant aerators are not currently specifically designed for methane removal, the degree of removal at the design flow rate should be determined before the aeration unit is placed in service.

Ammonium Ion Oxidation

Based on the breakpoint chlorination studies at Normal, the quantity of chlorine required for the complete oxidation of ammonium ion has been determined. Since the required amount of chlorine is substantially greater than that required for chloramination, the breakpoint procedure will only be applied periodically. The requisite frequency of the breakpoint procedure and the duration of its beneficial effects will be determined operationally based on a continuing, comprehensive distribution system monitoring program.