

**Morton Treatment Plant Process Performance Evaluations:
The Removal of Microbial Nutrients**



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Chronology of Project Initiation and Water System Study Activities

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H₂O'C engineers met with water utility and city officials to discuss a proposed distribution system study and observe Morton's distribution system flushing program. Based on these discussions, H₂O'C prepared a proposal for a comprehensive water treatment and distribution system study.

The proposal and a summary report of the site visit were submitted on October 28, 1999. On November 2, 1999, the Village of Morton Board of Trustees authorized H₂O'C to proceed with the proposed study to determine the origin of taste-and-odor complaints and make recommendations for remediation. Consumer complaints had focused on strong, septic odors in the water at the tap. In response, the Morton Water Department continued to undertake an extensive main flushing program.

November 1-5, 1999 – Phase 1 of Treatment Plant and Distribution System Study

During the week of November 1-5, studies were initiated at the three Morton water plants and distribution system. Records of plant operational data for the past year were reviewed. Chlorine persistence studies were initiated using plant finished water samples. A program of plant and distribution system total organic carbon (TOC) monitoring was arranged with samples to be sent to PDC Laboratories in Peoria for analysis. Micrographs were made of the organisms found in finished water and sediments from the main flushing program. The presence of bacterial growth was confirmed.

Data was also obtained on chlorine and dissolved oxygen residuals in distribution system samples. In some instances, chlorine and dissolved oxygen were severely depleted. However, Morton's flushing program appeared to restore measurable levels of both indicators, particularly, at remote distribution system locations.

A meeting was held with Morton's distribution system manager, Lon Barksdall, to determine distribution system travel times and the locales of consumer complaints as part of an effort to establish an expanded distribution system monitoring protocol.

December 6-10, 1999 – Phase 2 of Treatment Plant and Distribution System Study

TOC: In the intervening month between plant site visits, a revised plant performance study plan was prepared based on the initial analytical data obtained and reviewed. TOC analysis had shown that a substantial amount of natural organic matter (NOM) is present in Morton's well water. Repeat studies to determine the specific influences of dissolved organic matter on *chlorine persistence* were indicated.

CH₄: Continued monitoring within Morton's three treatment plants had shown that, at times, dissolved methane removals were incomplete. More detailed studies of the factors affecting methane removal were indicated. In addition to enhanced methane stripping, improved carbon dioxide removal (to pH 7.8) and oxygen absorption (to saturation) during aeration are also desired.

NH₄⁺: Plant operational data had indicated that ammonium ion removals were variable and possibly related to the exhaustion of cation exchange capacity. As a result, studies of the performance of several cation exchangers throughout an exhaustion cycle were proposed. Increased monitoring for ammonium ion and the reduction of volume throughput on specific exchangers prior to regeneration will likely be required.

KMnO₄: In addition to studies of the required dosage of permanganate for manganese oxidation, studies were undertaken to determine the quantity of permanganate required to consume accumulated

organic deposits on greensand filter medium. This dosage would be applied as part of filter treatment during backwash. These studies were indicated by previous observations of total oxygen depletion as water passed through several filters at Plant #1. The loss of oxygen indicated the prior consumption of permanganate by reaction with accumulated organic matter on the greensand medium.

Columns: On learning that Morton is in the process of adding another filter to Plant #3 to increase filtration capacity, column studies were proposed to evaluate the comparative effectiveness of iron and manganese removal on aged (used) greensand, virgin greensand and silica sand. These studies allowed visualization of the filtration process as well as an assessment of the effectiveness of backwashing at different backwash rates. Silica sand was included in the comparison because it is far less costly than the proprietary greensand.

Breakpoint Chlorination:

A special study was conducted to determine the chlorine dose-response, commonly called the *breakpoint* curve. This data is necessary if ammonium ion removal is to be based on oxidation by chlorine (breakpoint chlorination) rather than cation exchange.

Preliminary Study Results

Disinfectant Persistence

Even in clean glass bottles, representing *clean* pipe, in the laboratory, disinfectant (chloramine) residuals are rapidly lost in the finished water effluents from all three of Morton's treatment plants. Contact with encrusted deposits in distribution system piping (*dirty* pipe) would make these residuals disappear even more rapidly. The loss of bacteriostatic disinfectant residuals makes microbial regrowth possible. The rapid depletion of Morton's disinfectant residual is a major problem that must be brought under control if microbial regrowth in the distribution system is to be controlled.

Other plant evaluation studies related to incomplete methane, ammonium ion and manganese removals that may require operational changes or plant process upgrades.

Results of Disinfectant Persistence Studies

Chlorine residuals were measured in finished waters from each of the three treatment plants. Thereafter, each of the waters was dosed with an additional 5 mg Cl/l so that chlorine depletion studies could be conducted over several days.

Whereas a small fraction of the chlorine residual, averaging 0.2 mg Cl/l, consistently appeared as 'free' chlorine, most of the disinfectant residual was combined (chloramine). Within 24 hours, one-half to three-quarters of the residuals were consumed by reducing agents in the finished waters. At room temperature, an average of 80 percent of the initial chlorine residual was progressively lost within two days (48 hours).

These results indicate that chlorine cannot be expected to persist in Morton's distributed water. The data also raised questions as to what constituents in the well water exert the chlorine demand.

Based on previous studies, in the absence of dissolved reducing agents, chloramine residuals would be expected to persist for hundreds of hours in clean (non-reactive) bottles. Still, chloramine residuals may be rapidly depleted where water is in contact with accumulated deposits on distribution system pipe surfaces.

In this instance, the results of the Morton study suggest that significant quantities of *dissolved* organic reducing agents in Morton's ground water are also reacting to consume the residuals even in the absence of contact with distribution system piping.

Possible Formation of Chlorinated Organic Amines

Chlorine persistence studies initiated over 20 days earlier by Morton water department laboratory staff still showed evidence of stable, titrable disinfectant residuals. These results were inconsistent with the observations of rapid chloramine depletion. It was hypothesized that these seemingly persistent residuals are artifacts that result from the reaction of chlorine with organic amines in the source water. Chlorinated organic amine compounds have been reported to be persistent in their ability to appear as a disinfectant residual. However, they are ineffective in causing inactivation of microorganisms.

In summary, the studies conducted indicate that it is the dissolved natural organic matter in Morton's well water that is reacting to consume the disinfectant residuals. In addition, a small portion of the chlorinated byproduct formed appears as a persistent, but false, disinfectant residual.

Testing of Hypothesis

Effect of Removal of Organic Substances on Chlorine Persistence

These hypotheses were tested using a locally purchased Culligan Model FF100 granular activated carbon (GAC) adsorber. The GAC adsorber was attached to the faucet in the treatment plant shop area. Plant #2 finished water that had been trickled through the adsorber at a rate of approximately one gallon per hour (and was thereby dechlorinated) was then dosed with chlorine to test chlorine persistence. As a control, Plant #2 finished water from the laboratory was treated with a similar dose of chlorine.

The removal of organic substances by the GAC adsorber reduced the natural yellow-brown color of the Morton finished water significantly. Thereafter, the chloramine formed in the GAC-treated water was found to persist far longer than previously observed. Of 4 mg Cl/l initially present, approximately 3 mg Cl/l remained after 40 hours. More than half the residual remained after six days.

The clear implication of this result is that the removal of naturally-occurring, colored organic substances is required, as a minimum, if Morton is to sustain a disinfectant residual in the distribution system.

Effect of Removal of Ammonium Ion on Chlorine Persistence

A parallel study was conducted using water that had passed through the cation exchange unit of Plant #2. The effluent from this unit contained only 0.18 mg N/l of ammonium ion. While not as dramatic as the effect of removal of organic matter, chloramine persistence increased significantly. Approximately, ¼ of the applied chlorine remained after 6 days.

This experimental result is counter to what would normally be expected. The removal of ammonium ion results in the formation of a disinfectant residual that is, primarily, hypochlorous acid ('free' chlorine). The reactions of hypochlorous acid are known to be more rapid than those of chloramine. However, at Morton, the opposite is evident. As a result, it appears that the removal of both organic matter and most of the ammonium ion will produce plant finished water capable of maintaining its disinfectant residual.

Thereafter, it is still necessary to maintain this residual in the distribution system in contact with previously deposited residues and accumulated microbial cell mass.

Iron and Manganese Removal

Daily analysis for iron in the filtered and finished waters from all plants indicates that iron is nearly completely removed at all times. However, manganese appears in the plant effluent on occasion. This may be due to:

- A slow rate of manganese precipitation and aggregation into a filterable floc.
- The periodic passage of potassium permanganate due to accidental overdose.
- Peptization of hydrous manganese oxides precipitates ($MnO_2 \cdot nH_2O$) by organic substances present.

Studies were conducted using grab samples of the influents and filter effluents of all three of Morton's plants. Manganese ranged from 0.4 to 0.9 mg Mn/l in the filter influents and from 0.02 to 0.09 mg Mn/l in the filter effluents.

Filter #2 of Plant #2 was found to be passing manganese in quantities (0.09 mg Mn/l) that caused staining of the 0.45µm membrane filter used to separate the particulate and dissolved manganese in the plant effluent. Since most of the manganese (0.07 mg Mn/l) passing through the filters was in particulate form, it appeared that the problem was that of physical removal by the filter medium rather than chemical oxidation and precipitation. This indicates that modifications of the filtration protocol will be required for those filters that are not currently removing the precipitated manganese oxides effectively.

Permanganate Demand

Studies were conducted to determine the dosage of potassium permanganate required for complete oxidation of the iron and manganese in the influent to the greensand filter units.

During the month of November 1999, the following average amounts of potassium permanganate were applied at the three plants:

- Plant #1: 2.21 mg KMnO_4/l
- Plant #2: 2.21 mg KMnO_4/l
- Plant #3: 1.16 mg KMnO_4/l

The plant personnel judges the appropriate dosage of potassium permanganate based on the pink tinge of the water as it leaves the filter units. They then reduce the permanganate application slightly so as to eliminate the pink color from the filter effluent. This plant operational procedure appears to be an effective means by which to judge the chemical requirements for meeting the permanganate demand.

To determine the amount of potassium permanganate required to oxidize accumulated organic matter during backwash, a portion of the greensand medium was removed from an operating filter. The medium was treated with various dosages of potassium permanganate ranging from 0.3 to 10 g KMnO_4 per kg greensand. The resulting slurry was mixed for one to three hours and the decolorization of potassium permanganate observed.

From the study results, it is estimated that treatment of the greensand filter medium during backwash would require 2.5 g KMnO_4 per kg greensand and a contact period of 24 hours. This procedure would be indicated if dissolved oxygen was found so be severely depleted in the filter effluent that ferrous, manganous and sulfide ions were being formed at the end of filter runs.

Determination of the Breakpoint Chlorination Curve

Large dosages of chlorine are routinely applied following aeration at the three Morton plants. Much of this chlorine has been consumed by the time the water is filtered. As a result, additional chlorine is applied for post-chlorination.

Since it was believed that the chlorine was primarily consumed in the oxidation of ammonium ion, studies were conducted to establish the breakpoint chlorination curve for Morton's well water. This curve is a strong function of ammonium ion concentration. Ammonium ion concentrations of 3 mg N/l would consume in excess of 25 mg Cl/l to establish chlorine residuals beyond the breakpoint. Therefore, reductions in the amount of ammonium ion in the water being treated results in significant reductions in the amount of chlorine required to establish a residual.

The breakpoint curve was established for aerated water from Well #10 serving Plant #3. At the time, the ammonium ion concentration was measured at 2.4 mg N/l. Within 15 minutes, the ammonium ion was completely oxidized by the addition of 25 mg Cl/l. A free chlorine residual of 2 mg Cl/l was obtained with the addition of 29 mg Cl/l.

As a result of these studies, it was recommended that the dosage of chlorine applied during dechlorination be sharply reduced and post-chlorination take advantage of the ammonium ion removal achieved by the cation exchangers. This recommendation has been adopted. Plant superintendent, Lon Stalter reports that chlorine use has since decreased substantially while finished water chlorine residuals have been maintained or increased.

For the near future, it is recommended that approximately 75 percent of Morton's water be treated by cation exchange to reduce ammonium ion concentrations to less than 1mg N/l. This will result in chemical savings for chlorine shipment, storage and application and increased costs for salt (NaCl) for regeneration. Only minimal amounts of chlorine, 0 to 3 mg Cl/l to meet immediate chlorine demands, are specifically required for prechlorination. Unless reducing conditions, indicated by oxygen depletion, are found to occur in the filters, virtually no chlorine is required in the filter effluents. Oxidizing conditions in the filters should be maintained through the use of potassium permanganate.

Depending upon the ammonium ion concentration in the blended water following cation exchange and mixing, post-chlorination with 5 to 10 mg Cl/l should result in a combined chlorine residual. Higher chlorine dosages would be expected to result in a free (hypochlorous acid) residual that would promote the formation of disinfection by-products during distribution.

Recommendations for Control of Microbial Growths in the Morton Water Distribution System

Short-Term Strategy

- Periodic flushing and cleaning of mains is required to dislodge accumulated sediments and increase bactericidal disinfectant residuals at dead ends and points of stagnation.
- The turnover of water stored in elevated storage tanks is required to limit retention times and minimize increases in water temperature during distribution.

Treatment Process Modifications

The primary objective of modifying the present treatment process is to increase the stability of the chloramine residuals in the plant finished waters. More persistent residuals would permit lower chlorine dosages at the treatment plant.

Removal of Ammonium Ion prior to Chlorination

Based on the present study results with respect to the oxidation of ammonium ion by chlorine, beginning December 1999, the Morton Water Department markedly reduced the amount of chlorine applied prior to filtration (pre-chlorination). Currently, chlorine is primarily being applied following the removal of the bulk of the ammonium ion by the cation exchangers (post-chlorination). This practice has resulted in a reduced chlorine demand and has permitted significant reductions in the total use of chlorine. Reportedly, this has also resulted in a somewhat more stable residual.

Removal of Organic Matter

However, to produce a plant finished water which will sustain a chloramine residual throughout the distribution system, it will be necessary to remove a portion of the naturally-occurring organic matter in Morton's well water.

The purgeable or volatile portion of the total organic carbon, including methane, can be removed by improved aeration. Enhanced methane removal can be achieved either by reducing the hydraulic loading on the aerators or by providing additional aeration capacity. In the long-term, the latter is preferable in order to provide for system growth and the need for increased water production. Whatever other future treatment modifications are necessary, the removal of dissolved gases will be required at all plant sites.

The oxidation or removal of the non-purgeable (dissolved) organic carbon, such as the colored humic substances, will require the adoption of an additional treatment process. For the present laboratory-scale investigation, a block of granular activated carbon (GAC) was used to remove a portion of the colored organic matter present in the well water. As indicated, adsorption on GAC produced water that was decolorized and sustained a chloramine residual for several days.

However, other treatment alternatives might include oxidation by ozone or hydrogen peroxide, the application of powdered activated carbon or adsorption on a proprietary anion exchange resin. The latter process has recently been placed in service in Washington, Illinois.

Biological Prefilter to Remove Microbial Nutrients

Potentially, the most economic alternative for removal of the biologically assimilable portion of the organic matter in Morton's well water is the *biological prefilter*. Installation of a biological contact medium following aeration would facilitate the growth of aerobic microorganisms capable of using the biodegradable organic matter present as a substrate (food source). The occurrence and growth of these organisms prior to removal by filtration would preclude their growth in the distribution system.

Specific Operational Recommendations

- Monitor distribution system water quality monthly according to the attached monitoring protocol.
- Map distribution system locations where taste-and-odor complaints are received.
- Flush mains in affected areas whenever chlorine and oxygen are depleted.
- Draw down water levels in elevated storage tanks so that average retention times are less than three days.
- Reduce the hydraulic loadings on the aerators to less than 20 gallons per minute per square foot.
- Monitor the effluents from the aerators to maintain pH > 7.8; oxygen > 90 percent saturation; and methane < 1 mg CH₄/l.
- If necessary to achieve operational guidelines, provide supplemental aeration using surface or diffused aeration.
- Filter 250 milliliter aliquots of greensand filter effluent through 0.45 μm membranes to visually check for complete removal of manganese oxides.
- Monitor effluents from all cation exchangers immediately preceding regeneration to ensure consistent and complete removal of ammonium ion throughout exchange cycle.
- Increase proportion of plant flow through softeners to 75 percent or greater to reduce ammonium ion to less than 1 mg N/l.