DEVELOPMENT OF A TRIHALOMETHANE CONTROL STRATEGY

Daniel S. Skalsky,[1] Randy E. Hildebran,[2] Carl S. Simmons[3]

AUTHORS: [1]Brown and Caldwell, 32 Perimeter Center East, Suite 120, Atlanta, GA 30346, [2]Olsen Associates, 2710 Wycliff Road, Suite 200, Raleigh, NC 27607, [3]Public Utilities Director, City of Raleigh, P.O. Box 590, Raleigh, NC 27602.

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INTRODUCTION

In 1974, Congress adopted the Safe Drinking Water Act (SDWA) which directed the U.S. Environmental Protection Agency (EPA) to develop national standards for drinking water quality. As a result of growing concern about the health effects of trace chemical compounds and other radionuclide and biological contaminants occasionally found in drinking water, the Safe Drinking Water Act was amended by Congress in 1986. With the current trend toward new and more stringent regulations, advanced water treatment technologies are being utilized with increasing frequency to meet the challenge of providing safe drinking water.

In recognition of the impact of the SDWA Amendments of 1986 and forthcoming drinking water requirements, the City of Raleigh, North Carolina has embarked on an aggressive study to ensure that future drinking water treatment goals are achieved. Brown and Caldwell has been working with the firm of Olsen Associates to prepare a master plan for the City of Raleigh's E.M. Johnson Water Treatment Plant (WTP). The objectives of the study are to:

- Conduct a review of the existing water treatment process, raw water and finished water quality and current regulatory trends, and to identify treatment processes that may be required in the future to meet recently adopted and anticipated water quality regulations;
- Prepare a master plan for the E.M. Johnson WTP that provides for the expansion of the treatment facilities to their ultimate capacity of 100 mgd, incorporates currently required changes in the treatment processes, and provides flexibility for future anticipated treatment processes; and
- Prepare preliminary cost estimates and recommendations for new facilities included in the master plan.

This paper focuses on the formation of trihalomethanes (THMs) and their control using a variety of treatment technologies. Trihalomethane concerns and control alternatives are discussed, and the strategy recommended for the E.M. Johnson WTP is presented.

TRIHALOMETHANE CONCERNS

The 1986 SDWA Amendments require EPA to promulgate new regulations for disinfection by-products. Regulations promulgated by EPA in 1979 established a maximum contaminant level (MCL) of 100 parts per billion (ppb) for total trihalomethanes (TTHMs); a group of chlorination by-products. Discussions with members of the Federal Drinking Water Advisory Commission indicate that these regulations may be revised to require lower THM limits by 1991.

During the period from January of 1981 to September of 1988, the average TTHM concentration measured in the distribution system of the E.M. Johnson WTP was approximately 90 ppb. This indicates that the current treatment practices have only a small margin of safety in meeting the current 100 ppb TTHM regulation. The plant will clearly have difficulty in meeting a reduced THM standard.

A review of plant operating records and raw water quality data indicated that the following water quality concerns also exist: (1) lead corrosion, (2) iron and manganese, and (3) filtration and disinfection performance. As is often the case, these concerns are not independent problems which can be resolved individually; they are interrelated. For example, iron and manganese problems may contribute to trihalomethane formation if prechlorination, which promotes THM formation, is used to control iron and manganese. Similarly, disinfection performance is enhanced by a longer contact time and higher chlorine dosage during chlorination, while these practices encourage THM formation.

TRIHALOMETHANE CONTROL OPTIONS

There are numerous approaches to the control of trihalomethanes including: (1) use of better quality raw water with fewer THM precursors, (2) removal of organic THM precursors, (3) removal of THMs following their formation, or (4) use of alternative disinfectants which do not form THMs (AWWA, 1982). Each general approach may in turn be subdivided into numerous specific options.

The effectiveness, advantages, and disadvantages of many options are specific to a given raw water and treatment facility. For example, powdered activated carbon (PAC) may be a viable option at a facility if PAC facilities already exist and the THM problem is intermittent. A summary of the control options considered in this study and the results of the screening analysis for the E.M. Johnson WTP are presented in Table 1. Three of the advanced treatment technologies which were considered in the screening analysis are described in greater detail in the following sections.

Alternative Preoxidants

Chemical oxidation processes are commonly used in water treatment to convert undesirable compounds to less objectionable compounds. Oxidation reactions involve either: (1) transfer of electrons, (2) transfer of hydrogen species other than protons, or (3) transfer of oxygen species other than oxides or hydroxides between compounds. Numerous oxidizing agents and catalysts exist. The most commonly

Table 1. Screening of Trihalomethane Control Options.

Control Option	Comments
Utilize higher quality raw water	No known feasible alternatives
Removal of precursors:	
* Conventional treatment optimization	
* Adsorption with PAC	Existing facilities
Adsorption with GAC	Relatively high cost
* Oxidation	
Ozonation	
Advanced oxidation processes	Still under development; a technology to watch
Chlorine dioxide	Health concerns regarding residuals
* Potassium permanganate	Relatively weak oxidant
Hydrogen peroxide	Lack of performance data
Removal of THMs:	
Oxidation	THMs difficult to oxidize
Aeration	Post disinfection required; THMs may form in system
Adsorption with GAC	Relatively high cost
Alternative disinfectants:	
* Chloramination	See text
Chlorine dioxide	Health concerns regarding residuals
Ozone	No residual
Bromine	Lack of experience
Iodine	Lack of large scale experience
Ultraviolet radiation	No residual

* Preferred Control Option.

utilized oxidant in water treatment is chlorine. Other oxidants used in water treatment include: (1) ozone, (2) chlorine dioxide, (3) potassium permanganate, (4) hydrogen peroxide, (5) bromine, and (6) oxygen or air. Although oxygen is an oxidant, aeration generally is not feasible for oxidizing THM precursors due to very slow reaction rates.

Strong oxidants are generally harmful substances by virtue of their oxidizing strength. In addition, some by-products of oxidation reactions may be harmful to human health, such as THMs. In general, the oxidant dosage should be minimized while maintaining the desired level of treatment to reduce by-product formation as well as oxidant costs. Due to the complexity of the oxidation reactions that may occur and the dependence of performance on raw water characteristics, site-specific testing is generally required. The following paragraphs briefly describe use of two advanced wastewater processes for the oxidation of trihalomethane precursors.

Preozonation. Ozone (O_3) is the strongest oxidizing agent currently applied as a water treatment. It is an unstable, allotropic form of oxygen (O_2). In general, ozone transfers an atom of oxygen to the compound being oxidized and degrades to elemental oxygen in the process. As a result, the by-products of ozone oxidation are oxygen and the oxidation by-products formed from the original compounds. The dosage range of ozone typically required for significant THM precursor oxidation is approximately 1.5 to 5.0 mg/l. This dosage level is far from that required for complete oxidation of ozone-consuming compounds, however. Due to the cost of ozone generation, dosages greater than about 5 mg/l are usually economically unattractive. In addition, higher dosages are generally not warranted since the partially oxidized ozonation by-products may be removed more effectively in subsequent treatment processes. In addition to THM precursor reduction, ozone is effective for improving taste and odor, oxidizing iron and manganese, improving flocculation, reducing color, enhancing adsorption, and predisinfection. Ozone's rapid degradation, however, does not permit the maintenance of an ozone residual. Consequently, a final disinfectant other than ozone is required to maintain a disinfectant residual in public water supplies.

Ozonation has been practiced for decades in Europe, while interest in the United States has generally been low due to the high cost of ozone relative to other disinfectants and oxidants, primarily chlorine. Interest in the United States has grown in recent years and large-scale facilities have been built in Los Angeles, California and in Hackensack, New Jersey. The effectiveness of preozonation depends upon raw water characteristics as well as the performance of subsequent conventional treatment processes. Pilot studies are necessary to determine the cost-effectiveness of preozonation for THM control on a particular raw water supply.

Although currently available ozonation systems are highly automated, considerable operator training is generally required due to the lack of experience of current plant staff with ozone generation and contractor technologies. Ozone plants require sophisticated control and monitoring of supply gas humidity, power consumption, ozone generator performance, and vented ozone scavenger systems, in addition to water quality and performance indicators such as total organic carbon and THM formation potential.

Advanced Oxidation Processes. Recent research has indicated that oxidation can be greatly enhanced by using two powerful oxidation processes together. Strategies being investigated for water treatment include combinations of the following processes: (1) ozone, (2) hydrogen peroxide, and (3) ultraviolet radiation. All of these processes, referred to as advanced oxidation processes, encourage the formation of the hydroxyl radical which is an even more powerful oxidant than ozone (Glaze et al., 1987).

Of these technologies, the combination of ozone and hydrogen peroxide (being termed "peroxone") has been the most thoroughly investigated to date. Peroxone appears to offer several distinct advantages over ozone alone. Specifically, a more rapid and more complete oxidation occurs due to enhanced formation of the hydroxyl radical. This phenomenon also appears to enhance the mass transfer of ozone into solution. Pilot studies indicate that peroxone may be less costly than ozone alone, due to the above factors (McGuire and Davis, 1988).

At the present time, advanced oxidation processes have not been tested in a full scale water treatment facility. Further, the potential adverse health impacts of their oxidation by-products have not been thoroughly investigated. However, they do hold considerable promise for the future and warrant continued attention as the technology develops particularly if: (1) regulations on THMs are tightened, (2) health concerns over by-products of advanced oxidation processes are resolved, and (3) apparent performance and cost benefits are verified on a large scale facility.

Disinfection Using Chloramines

Chloramines are a group of compounds formed by the reaction of free chlorine and ammonia in water. They are less effective disinfectants than free chlorine, particularly at low pH. However, they are relatively stable and persist in the distribution system much longer than free chlorine residuals. Chloramination has been used as the primary disinfectant for 70 years in Denver, Colorado and has recently been implemented at the Metropolitan Water District of Southern California, and at many other treatment facilities throughout the United States.

Chloramination, together with the elimination of prechlorination, can significantly reduce THMs in the distribution system if the process is well monitored and controlled. Eliminating prechlorination requires alternative methods for control of iron, manganese, biological growth, taste, and odor problems. Advantages of chloramination include: (1) considerable operating experience, (2) persistence of a disinfection residual, (3) ability to meet low THM requirements, and (4) the relatively low cost for conversion from chlorination to chloramination. The disadvantages of chloramination include: (1) lack of data on long-term health effects of chloramines, (2) toxicity to fish, (3) long contact time required for disinfection if used as a primary disinfectant, and (4) acute health effects for kidney dialysis patients.

In addition to the engineering aspects of converting to chloramination, an exhaustive public education program would be required. Key groups which would require special notification and education would include hospitals, kidney dialysis patients, pet stores, aquarium owners, and zoos. Point of use treatment to remove chloramines (i.e., granular activated carbon) would be required for customers adversely affected by chloramines.

TRIHALOMETHANE CONTROL STRATEGIES

Trihalomethane control is the most complex treatment issue facing the City of Raleigh at the E.M. Johnson WTP. Uncertainties exist in both the regulatory picture and the effectiveness of treatment technologies. Several alterative strategies were developed to accommodate this uncertainty. Combinations of treatment options were utilized to develop alternatives when individual treatment options could not reliably achieve treatment goals. A summary of the alternatives which were developed and their anticipated performance is presented in Table 2.

RECOMMENDATIONS

The trihalomethane control strategy developed for the E.M. Johnson WTP includes the following:

(1) Reduce or eliminate prechlorination through the use of alternative preoxidants such as potassium permanganate in the short-term and preozonation in the long-term. Although not fully tested, advanced oxidation process technology should be monitored as it developed.

(2) Improve waste solids handling facilities to reduce the recycling of iron and manganese which increases preoxidant demand.

(3) Conduct laboratory and pilot scale studies to assess the effectiveness of alternative preoxidants and PAC for precursor removal.

(4) Consider conversion to alternative disinfectant combinations such as: (a) ozone and chlorination, (b) ozone and chloramination, or (c) chlorine and chloramination.

Table 2. Probable Effectiveness of Trihalomethane Control Alternatives.

Alternative description	Achievable THM standard,[a] ppb 100	70	50	20
Alternative 1--Optimized existing conventional processes	Yes	No	No	No
Alternative 2--Alternative preoxidant, solids contact clarification with PAC[b]	Yes	Yes	No	No
Alternative 3--Alternative preoxidant and alternative disinfectant[b]	Yes	Yes	Yes	No
Alternative 4--Preozonation and alternative disinfectant	Yes	Yes	Yes	Yes
Alternative 5--Alternative preoxidant, solids contact clarification with PAC, alternative disinfectant[b]	Yes	Yes	Yes	No
Alternative 6--Preozonation, solids contact clarification with PAC	Yes	Yes	Yes	Yes

[a] The total trihalomethane standard is expressed as a moving annual average. To interpret this table following a change in the compliance calculation procedure, a relationship between the annual moving average and the new criterion would be required.

[b] "Alternative Preoxidant" refers to preoxidant other than ozone.

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