OZONATION & OTHER UNIT TREATMENT PROCESSES USING PACKAGE PLANT TECHNOLOGY

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ABSTRACT

The Atkins Reservoir, located in Amherst, Massachusetts is a typical New England surface supply with regards to turbidity, color, corrosivity, etc., but seasonably produces poor taste and odor quality. This paper focuses on the use of package plant technologies which have been configured and integrated into the Town's new 1.5 MGD filtration plant which effectively satisfies current drinking water quality standards as well as produces an excellent flavor and odor quality water.

Three manufacturers' package systems have been incorporated to provide for ozonation, clarification/filtration, and granular activated carbon adsorption (GAC), all integrated with associated chemical metering systems via a PLC/PC central SCADA link. This paper details the aspects of design, construction and start-up associated with combining multiple package systems. In addition, some background design criteria and water quality data are presented. An innovative process application available using these package systems is the ability to apply ozonation and GAC in series to promote a biologically activated carbon adsorber.

INTRODUCTION

The Town of Amherst, Massachusetts is predominantly a residential community with a character largely dominated by 5 college campuses in the area. Three of these are within the Town's boundary and are served directly by the water system. Amherst has a year round residential population of 20,000± people and a school season peak population of 35,000±.

The Town water system is supplied by two reservoir systems and four groundwater wells. The subject of this paper is the newly constructed 1.5 MGD Atkins Reservoir Filtration Plant.

The Atkins Reservoir Filtration Plant was planned under the guidance of an Ad Hoc Citizens' Advisory Committee working in conjunction with the Department of Public Works, and Tighe & Bond, Inc., the Town's Engineering Consultant.

The Citizens' Advisory Committee recognized that the taste and odor quality of the Atkins Reservoir supply was of most concern to the residents of North Amherst and the University of Massachusetts campus which receive most of the water supplied from the Atkins Reservoir source. The selected water treatment objectives of the Committee were as follows:

1. Provide the best possible odor and flavor quality to Amherst water customers.
2. Meet Federal/State water quality standards.
3. Plan for anticipated future water quality standards.

Using this guidance the treatment plant's process configuration was developed to include a number of unit treatment processes in a flexible arrangement. Further, an innovative utilization of manufacturers' package systems was selected to provide an economical means of constructing the extensive process configuration.

PLANT PROCESS

Treatment unit processes included in the plant design are shown schematically on Figure 1 and include the following:

- Raw Water Ozonation
- Clarification/Filtration
- Post-Filtration Ozonation
- Granular Activated Carbon (GAC) Adsorption
- Chlorine Contact/Chloramine Formation
- Corrosion Control
- Fluoridation

The Amherst Department of Public Works strives to operate each of its supply sources as economically as possible while producing high quality water. Seasonal variations in both source quality and customer usage require adjustments in the configuration of the supply sources and treatment. For this reason the Atkins Reservoir WTP has been designed with flexibility to allow for several treatment configurations to be operator selected. During seasons of high quality raw water the plant may be configured to provide only clarification/filtration, corrosion control, chlorination for primary CT disinfection and chloramination for secondary disinfection. To this "basic" treatment configuration ozonation may be added to the raw water and/or to the filtered water, and post-filtration GAC adsorption may be added, with or without ozonation.

In general the more advanced treatment processes of ozonation and GAC adsorption have been included for the following purposes:

Ozonation

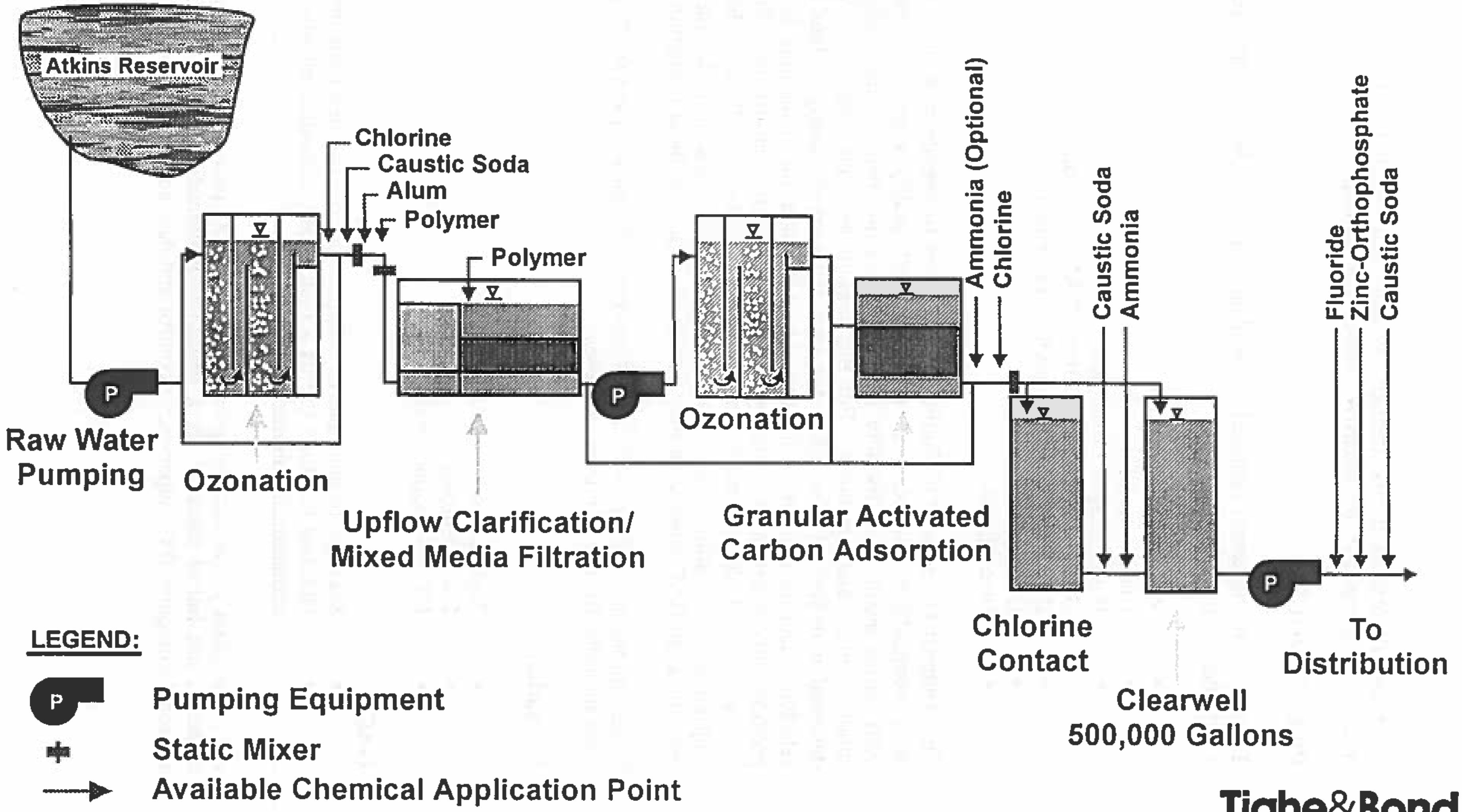
- Taste and odor oxidation
- Color removal
- CT disinfection credits

GAC

- Seasonal backup and/or enhancement of taste and odor improvement
- Optional full time use as a biologically activated adsorber for TOC and ozonation by-products removal.

All of the plant's treatment equipment, including both package and custom built-in-place systems, are linked together via a central programmable logic controller (PLC) and personal computer (PC) supervisory control and data acquisition system (SCADA).

FIGURE 1
PROCESS FLOW SCHEMATIC



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PACKAGE TREATMENT SYSTEMS

The Atkins Reservoir WTP includes the use of 3 treatment processes which were constructed as manufacturer or vendor package systems. These are as follows:

- Ozone Production
- Clarification/Filtration
- Granular Activated Carbon Adsorption

The package systems were integrated with built-in-place systems to provide the overall treatment plant process configuration. Built-in-place systems include the following:

- Ozone contactor basins
- Chemical handling and metering systems
- Central SCADA system
- Chlorine reaction and clearwell basins

INNOVATIVE OZONATION/GAC PACKAGE TECHNOLOGY APPLICATION

The most innovative aspect of the plant's configuration is the ability to utilize one of the two ozone contactors after the clarification/filtration process and before the GAC adsorption plant's process. Ozonation prior to GAC adsorption will encourage the growth of attached bacteria on the surface of the GAC media. This process is known as biologically activated carbon (BAC).

BAC is now used at many plants throughout Europe and is gaining interest within the United States as a treatment process to remove natural organic matter (NOM) which includes disinfection by-product (DBP) precursors. Additionally, BAC has recently been demonstrated to be effective in removing various ozonation by-products.

Ozonation converts some of the NOM to assimilable organic carbon (AOC) which is in a form that is more readily used as a food source by the attached bacteria. The formation of AOC from TOC encourages the microorganisms which attach themselves to the GAC within the contactor, to remove the AOC through natural bio-assimilation. This allows the GAC to remove biodegradable substrates through means other than adsorption. The resulting product water has a reduced NOM content (reduced TOC), typically contains fewer DBP precursors, and usually has a reduced disinfectant demand allowing for stable, persistent disinfectant residuals throughout the distribution system.

The Atkins Reservoir WTP was designed to allow 3 different process configurations with regards to the GAC-system:

1. No GAC adsorption (by-pass)

2. Conventional GAC adsorption on a seasonal basis.

3. Biologically activated GAC on a continuous basis.

It is expected that the initial few years of plant operation will generally utilize process configurations 1 or 2 and the GAC contactors will be placed into service only during late summer and fall months as conventional GAC adsorption contactors for taste and odor removal. However, as more emphasis is placed on disinfectants and disinfection by-products (D-DBPs) in the future, the plant may convert to full-time biologically activated GAC.

It should be noted that the original construction of the plant does not include a source of non-chlorinated backwash water for the GAC system. Using chlorinated or chloraminated water for backwashing is likely to disturb bio-activity in the adsorber for a period of time. The BAC process will be applied to filtered water which typically has a turbidity of less than <0.1 NTU, therefore it is expected that backwashing of the BAC will be infrequent and perhaps only once or twice per year. Nonetheless, the periodic disturbance of the BAC process due to backwashing with chloraminated water may not be a desirable operating condition.

If necessary, future consideration may be given to dechlorinating the backwash supply to the GAC system by injecting sodium bisulfite into the flow of backwash water using one of the existing chemical metering systems at the plant. This is not currently a common practice in water treatment and must be subjected to further analysis and testing prior to implementation.

DESIGN CONSIDERATIONS

The overall concepts which controlled design and construction of the plant were as follows:

1. Maximize use of manufacturer or vendor package systems with a well defined envelope of responsibility.

2. Provide a central PLC/PC SCADA link between all systems for one-station operator monitoring and control of the entire plant.

3. Where appropriate, specify various customized features into manufacturer or vendor package systems to provide important plant operation and control features.

4. Design an automated plant which can be staffed one shift per day and monitored from off-site when not staffed.

Although the plant maximizes the use of package systems, the plans and specifications developed for project bidding and construction include important details to accomplish the system integration, desired quality, and "customized" system features. In addition, minimum performance requirement specifications with a performance bond provision were included in the contract documents for both the ozone production and clarification/filtration systems.

In general the specifications for each package system included the following:

- Minimum experience provisions (3 similar systems in operation for 2 years)
- Envelope of responsibility definition
- Applicable design criteria
- Listing of major components and minimum requirements
- All materials of construction of concern
- Maximum "footprint" dimensions
- Manufacturer's startup assistance requirements
- Manufacturer's performance testing requirements
- Manufacturer's operator training requirements
- Central PLC/PC SCADA system compatibility requirements

The most difficult aspect of designing, constructing and de-bugging the initial operation of the plant was accomplishing the PLC/PC link between all systems. Currently, there is no standard or universal format for the operation of PLCs. Each PLC manufacturer has developed a somewhat unique computer "language" and one manufacturer's PLC cannot necessarily communicate with another manufacturer's PLC without interfacing computer hardware, software and special programming. This inter-system PLC/PC link difficulty was handled as follows:

1. The specifications detailed the hardware and software for the central plant PLC/PC system.

2. The specifications for each package system required that the package system vendor be responsible for all hardware, software and programming necessary for each system's PLC to effectively link with the central plant PLC/PC system.

This worked out well as an effective way to electronically link all systems to a single-station control, but required much coordination during construction and substantial system startup time. From a design viewpoint the only other practical alternative is to provide one overall plant PLC and "hard-wire" all of the systems to this one PLC. The software and programming then becomes the entire responsibility of the PLC vendor and removes the operation and control features of each package system from the package manufacturer's envelope of responsibility. This is not a desirable approach because each package system vendor should maintain responsibility for the critical operation and control feature of the package system. The Atkins Reservoir WTP project demonstrates that each package system may include its own PLC control system while effectively linking with a central PLC/PC system.

PACKAGE SYSTEM CUSTOM FEATURES

Each of the manufacturer or vendor package systems include various custom design features which allow for achieving what was considered to be important operation and/or control benefits. These are as follows:

Ozone Production System

- Substantial instrumentation monitoring
- Internal PLC control
- Communication link with plant SCADA

Clarification/Filtration System

- Coagulant control option using a streaming current detector
- Filter-to-waste piping, valves, and controls
- Motorized automated valves in lieu of pneumatic valve operators
- Stainless steel slotted underdrain for air/water backwashing of filter media
- Internal PLC control
- Communication link with plant SCADA

Granular Activated Carbon Contactor System

- Filter-to-waste piping, valves, and controls
- Stainless steel slotted underdrains for air/water backwashing of media
- Automation directly via plant SCADA

PLC/PC Monitoring & Control System

- Links all WTP equipment systems
- Provides overall plant treatment system automation, and single station monitoring and control
- Provides both on-site and off-site monitoring and control
- Allows adjustment of operating parameters
- Provides hard-copy record of important events
- Computerizes report forms

CONSTRUCTION CONSIDERATIONS

It has long been recognized that package systems typically reduce the complexity of construction, reduce construction time, and generally are an economical means of construction. These traits certainly hold true for the complex arrangement of package systems incorporated into the Atkins Reservoir WTP.

Nonetheless, several engineering tasks remain as important for package systems as they are for built-in-place systems. These are summarized as follows:

1. The detailed review of shop drawings is critical to ensuring overall compliance with the contract documents, and also important for achieving each of the specific customized features.

2. Construction trades such as electrical, piping, and mechanical systems must be supplied with adequate layout and detail by the package system manufacturer to allow for construction of "connections" to the package system in an orderly and desirable manner. Often substantial coordination efforts are required by the Engineer to avoid unacceptable construction arrangements.

3. Package system manufacturers typically need reminders throughout construction of the "project specific" features of the system. The tendency is to supply what is included in the typical "standard" package system.

4. Compatibility of all finish coating systems is important and requires careful coordination throughout construction, starting with the shop drawing stage. Most manufacturers package systems are factory painted, but often require either touchup or finish coatings after installation. Again, the tendency is for manufacturer's to supply what typically is provided, which may not be compatible with intended finish coatings.

5. Successfully accomplishing the necessary PLC/PC links requires substantial communication between the package system vendors, the central SCADA system vendor, and the Electrical Sub-Contractor. The Engineer must insist that this communication takes place in a timely manner. System electronic inter-communication problems must be identified as early as possible and resolutions developed in a timely manner.

START-UP CONSIDERATIONS

The initial start-up and operation of any treatment facility requires a "de-bugging" and testing phase. Package systems are no different, but the start-up is somewhat simplified because of the clearly defined envelope of responsibility.

For the Atkins Reservoir WTP the process complexity, degree of automation, and configuration flexibility resulted in the PLC/PC SCADA link being the most time consuming aspect of the start-up process. It is necessary to step-by-step check and verify every line of programming to ensure that process control is correct, and that alarms and alarm responses perform as intended. This responsibility lies with the PLC/PC monitoring and control system vendor, but must include witnessing by the Engineer. Additionally, fine tuning a complex control system requires many operating and control details which must be developed by an interactive process between the system vendor, Engineer, and Owner.

The start-up process is often constrained by various pieces of construction which may be incomplete or inoperative, but in general the sequence must be as follows:

- Package system vendors must verify the functionality of each system component.
- Package system vendors must verify the functionality of the system's internal control system.
- Package system vendors in conjunction with the SCADA system vendor must verify PLC/PC link functionality.

Once the plant has been verified to function correctly each system should be performance tested to demonstrate compliance with the contract documents. Performance testing should be witnessed by either the Engineer or plant operator.

CONSTRUCTION COST

It is difficult to directly compare the cost of various water treatment plants due to the many variables of construction. For informational purposes the construction cost of the Atkins WTP, broken down by major treatment and pertinent features, is provided. It is believed that the overall $5,000,000 construction cost represents an economical price for achieving all of the treatment unit processes, automation, and configuration flexibility which is included, particularly when site constraints are considered.

A few project specific features which affected the cost are summarized as follows:

- Difficult site topography and geology which required large quantities of earth moving and ledge excavation.
- Site size and topography constraints which required a below grade reinforced concrete clearwell storage basin, and a relatively long access roadway.
- Town Committee decision to provide a building exterior architecture incorporating barnboard siding and an asphalt shingled roof for aesthetic appearance purposes.
- Site constraints which required both raw and finished water pumping.

The project's construction cost was as follows:

Site Work and Yard Piping	$ 750,000
Ozonation System (Including Contactors)	$ 400,000
Trident® Clarification/Filtration System	$ 700,000
GAC System	$ 200,000
Chemical Metering Systems	$ 200,000
Pumping Equipment	$ 150,000
Instrumentation and Control System	$ 200,000
Building Structure, Misc. Equipment, Mechanical Systems, Concrete Tankage, etc.	$2,400,000
Total Construction Cost	**$5,000,000**

WATER QUALITY "SNAPSHOT"

Atkins Reservoir Raw Water Quality - A summary of basic raw water quality data from the Atkins Reservoir is presented in Table 1. As shown, the Atkins Reservoir exhibits low turbidity, low pH, low alkalinity and hardness and moderate color and organic content (TOC and THMFP). The Atkins Reservoir's water quality is typical of many reservoir systems in New England.

The reservoir has been known to suffer from moderate phytoplankton counts in the summer months. Laboratory analyses during periods of algae blooms have identified high counts of diatoms including Synedia and Tabellaria as well as high counts of Dinobryon and Peridinium. These algae along with other species are believed to be the source of taste and odor complaints of the consumers in Amherst's system that are served by the Atkins source.

TABLE 1
ATKINS RESERVOIR RAW WATER QUALITY

Parameter	Minimum	Maximum	Average
Temperature (°C)	3°C	22°C	11°C
Turbidity (NTU)	0.2	2.2	0.4
Color (Pt-Co)	10	30	20
DOC (mg/L)	1.8	6.0	2.9
pH	4.8	7.8	5.8
Alkalinity (mg/L as $CaCO_3$)	0.5	6.1	2
Hardness (mg/L as $CaCO_3$)	4	12	8
Calcium	1.2	1.9	1.4
Iron (mg/L)	<0.03	0.58	0.25
Manganese (mg/L)	<0.01	0.05	0.02
7-day THMFP (ug/L)	102	213	140
Phytoplankton (no./ml)	6.2	1879	100

Atkins Reservoir WTP Finished Water Quality - Table 2 shows typical raw and finished water quality data since the plant commenced full-time operation in February 1994.

TABLE 2
WTP RAW AND FINISHED WATER QUALITY

Parameter	Average Quality	
	Raw Water	Finished Water
Turbidity	0.5	0.07
Color	15	1
Odor	None Detected	None Detected
pH	5.5	9.2

Historical Trihalomethane Data - Figure 2 shows the average distribution system trihalomethane (THM) concentrations from 1986 to the present. The data are generally the average of 8 distribution system sample points. The data are not entirely representative of the Atkins source, since Amherst's supply includes another surface water source (filtered) as well as four groundwater wells. Of note is the decrease in average distribution system THMs which occurred in 1990 due to the switch to chloramines for secondary disinfection.

Distribution System Haloacetic Acids Data - The forthcoming Disinfectants / Disinfection By-Products Rule (D/DBPR) will regulate, for the first time, a group of halogenated disinfection by-products called Haloacetic Acids. A maximum contaminant level (MCL) of 60 ug/L will be proposed for a group of 5 haloacetic acids (HAA_5). In addition, the D/DBPR will propose a more stringent MCL for total trihalomethanes (TTHMs) of 80 ug/L.

As shown on Figure 2 and discussed above, it is anticipated that Amherst will easily meet the forthcoming Phase 1 MCL for TTHMs. Given the levels of TTHMs in the Amherst distribution system and the distribution system water pH (8.5-9.0) it is anticipated that Amherst will also be in compliance with the future HAA_5 MCL.

In order to begin to assess the levels of HAA_5 in Amherst's distribution system, water quality samples were collected from 5 of Amherst's TTHM distribution system sampling points and analyzed for HAA_5. The results are presented on Table 3. As shown, the average HAA_5 concentration in Amherst system at the time of the sampling was 33 ug/L. It is interesting to note that the two highest HAA_5 concentrations were detected at Amherst's other surface water treatment plant (the Centennial WTP) and a location in the distribution system not too far downstream of the Centennial WTP (Pickering Plumbing). The HAA_5 concentration of the Atkins Reservoir WTP finished water was 36 ug/L.

Based on this data, it is believed that Amherst will be in compliance with the D/DBPR Phase 1 MCL for HAA_5, however optimization of treatment at the Town's Centennial WTP may be required in order to meet a future, more stringent Phase 2 D/DPBR MCL for HAA_5.

TABLE 3
DISTRIBUTION SYSTEM HAA_5 DATA

Sampling Location	HAA_5 (ug/L)
Atkins Reservoir WTP Finished Water	36
Daisy's Restaurant	21
North Fire Station	23
Centennial WTP Finished Water	57
Pickering Plumbing Co.	63
Average	33

TTHM and HAA_5 Precursor Removal - TTHM formation potential (TTHMFP) and HAA_5 formation potential (HAA_5FP) tests were conducted at several steps throughout the Atkins Reservoir WTP plant process to profile the removal of TTHM and HAA_5 precursors by the plant. In addition, UV_{254} and dissolved organic carbon (DOC) measurements were taken at the same locations. The results of these analyses are summarized in Table 4.

As shown, the Atkins Reservoir WTP removed 39% of the TTHM precursors, 54% of the HAA_5 precursors, and 10% of the DOC of the raw water. At the time the samples were collected, the plant was operating with pre-ozonation; post-Trident ozonation and the GAC contactors were not in use. Also, the plant utilized a cationic polymer for coagulation at a pH of 6.0. It is interesting to note that a significant portion of the TTHMFP and HAA_5FP reduction occurred through ozonation, prior to coagulation and filtration.

Water Quality Summary - The Atkins Reservoir WTP has been on-line for approximately four months. Thus far, the plant has demonstrated its ability to produce a high quality treated water, meeting all regulatory requirements and treatment performance goals. In particular, color removal has been exceptional, greatly enhancing the treated water's aesthetic appearance. Further, it is anticipated that as regulatory standards continue to change, including the development of more stringent disinfection by-product regulations, the treatment process flexibility designed into the plant, using manufacturers' packaged equipment systems, will enable the plant to satisfy the future requirements.

FIGURE 2

Amherst Massachusetts

Distribution System Total Trihalomethanes

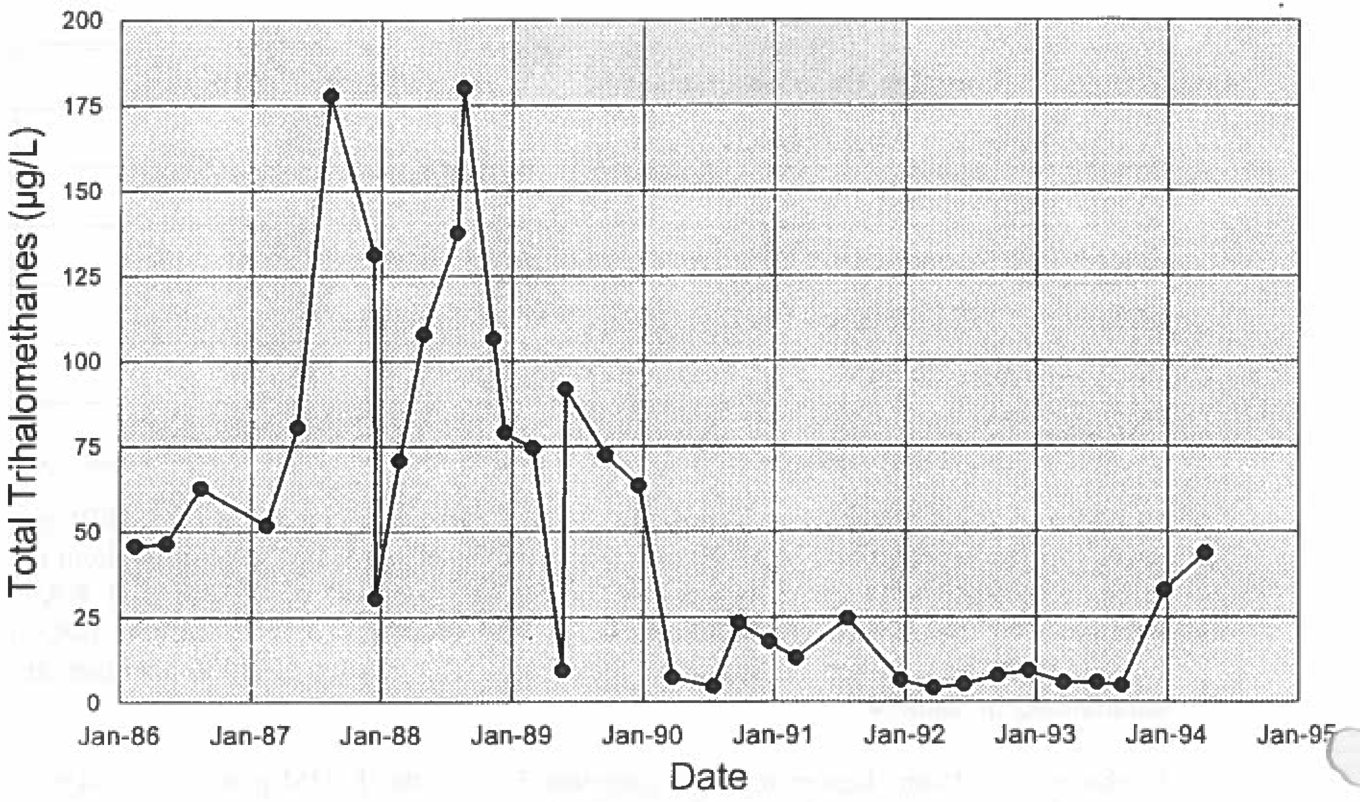

TABLE 4
TTHM AND HAA_5 PRECURSOR REMOVAL THROUGH ATKINS RESERVOIR WTP

Sample Location	UV_{254}		DOC		TTHMFP[1]		HAA_5FP[1]	
	(cm^{-1})	% Rem	mg/L	% Rem	ug/L	% Rem	ug/L	% Rem
Raw Water	0.064	--	2.99	--	170	--	248	--
Ozone Contactor Effluent	0.030	53%	3.03	(1%)	119.6	29%	137	45%
Filtered Water	0.022	66%	2.68	10%	104	39%	115	54%

Notes: [1] TTHMFP and HAA_5FP tests based on 3-day incubation periods at 25°C at pH 7.0 with 20 ug/L applied chlorine dosage.

SUMMARY

In summary, advanced water treatment processes can be combined into a flexible, functional, and economical process configuration using package plant technology. Selected treated water goals including a high degree of taste and odor improvement, DBP control, and excellent turbidity and color removal may be achieved. Also, the overall facility can be effectively automated to allow for operator staffing only one shift per day. Accomplishing these goals requires careful integration of individual systems and close attention to details throughout design, construction and initial start-up.

Throughout the design, construction, and start-up project phases, the successful utilization of package systems requires special considerations, different from more traditional built-in-place systems. These are summarized as follows:

Design - Must establish adequate details to ensure desired performance, quality, operating and maintenance characteristics, etc. with a minimum experience provision as a pre-requisite. In most cases performance guarantees are appropriate.

Construction - Extensive coordination of many project participants (vendors/contractors) is necessary to achieve adequate and professional end results.

Start-up - Meticulous verification of both package system controls and central PLC/PC links is essential. Performance testing is advisable and should be witnessed by the Engineer or Owner.