Comparison of Chlorine Delivery Systems for Palm Beach County

Leisha L. Pica, Francis E. Duran, Glenn Dunkelberger, and Robert Eskuchen

The most hazardous and potentially dangerous on-site chemical system in water and wastewater treatment plants is typically chlorination. There have been numerous accounts over the years of plant operators being injured and neighboring residents having to be evacuated because of chlorine leaks. Alternate chlorine delivery systems have been proposed in Palm Beach County to minimize the danger associated with chlorine gas storage and use.

This article compares and contrasts two alternative types of chlorine delivery systems—commercially purchased, high concentration sodium hypochlorite, and low concentration sodium hypochlorite generated on site from salt—with the traditional chlorine gas system.

Existing Installation Experience

Chlorine is the most widely used disinfection chemical in the water treatment industry. Chlorination equipment uses an established technology with many installations and a history of reliable performance. The commercial sodium hypochlorite system also uses established technologies, although the number of installations are limited due to the high cost of the chemical. The sodium hypochlorite generation system uses an established technology, although not widely used in the water treatment industry. The number of large systems (>500 ppd) installed is limited, although there are several scheduled to be installed in Florida soon.

Traditional Chlorine Gas System

New chlorine gas systems have several safety features to minimize risks: gas containers are stored in an enclosed facility equipped with a gas scrubber system, all equipment is kept in an enclosed area connected to an automatic emergency ventilation system, and all operational activities—connection and disconnection of containers from the chlorine withdrawal piping manifold and loading and unloading of containers from delivery trucks—must be performed by at least two operators wearing safety equipment.

But, even with these safety features, there remain activities that pose safety risks. The delivery truck typically must pass through residential and light commercial areas, which can be endangered if the truck is involved in an accident. It is not uncommon that small amounts of chlorine gas are released into the atmosphere during the connection and disconnection of chlorine containers from the piping manifold. Using liquid withdrawal instead of gas withdrawal increases the risk of a larger spill if the connection is not made properly. Although a leak from a poor connection would not present a danger to the areas surrounding the facility because of the emergency gas scrubber system, it would certainly present a danger to the operators performing the task.

On-Site Sodium Hypochlorite Generation System

The main bulk material for the generation of on-site sodium hypochlorite is salt, which is stored in fiberglass brinemakers specially designed to store and dissolve the salt to form a saturated brine. The brine is passed through a bag filter and pumped from the brinemakers to the cell assemblies, which generate low concentration (0.8%) sodium hypochlorite. The sodium hypochlorite solution is stored in fiberglass daytanks and pumped from them to the injection points.

Normal operational requirements for this type of system, such as checking instruments, receiving bulk salt, acid washing of the cell assemblies, and cleaning of the brinemaker tanks, is minimal.

Depending on the quality of the salt used in the system, sludge may build up in the bottom of the brinemaker. Removing that sludge can take up to two days and requires that the brinemaker be completely empty of salt.

Except for a small amount of muriatic acid, the sodium hypochlorite generation system uses no hazardous chemicals. If proper operating procedures are followed, plant operators do not face major dangers. A potential buildup of hydrogen gas in the daytanks is handled with the use of redundant dilution blowers.

Commercial Sodium Hypochlorite System

Commercial sodium hypochlorite (10%-12%) is purchased and delivered by truck to Palm Beach County's WTP No. 8 site. It is stored in two fiberglass bulk storage tanks and pumped by chemical feed pumps to injection points. Normal day-to-day operational requirements are minimal. One major operational factor is that high concentration sodium hypochlorite loses strength if stored for long periods of time. Factors affecting the rate of decay include the solution's concentration and temperature.

Since commercial sodium hypochlorite is very corrosive, efforts must be taken to minimize spills. There is also significant wear on feed pumps. As with the sodium hypochlorite generation system, plant operators do not face major dangers if proper operating procedures are followed. Surrounding areas also are not threatened by a leak of high concentration sodium hypochlorite.

Cost Comparison Of Chlorine Delivery Systems

Table 1 summarizes the difference in capital cost, operating cost, and total amortized capital and operating cost per 1,000 gallons produced and per year for the proposed construction of a 2,500 pound per day (ppd) chlorine system. All capital costs are in 1996 dollars and operating costs are based on current chemical and electricity costs and on normal WTP chlorine dose (18.5 ppm).

Given the life cycle costs for both systems, the chlorine gas system would cost approximately $16,000 less per year than the sodium hypochlorite generation system. The life-cycle costs of the commercial sodium hypochlorite system is considerably higher than the other two systems.

Table 1. Summary of Cost Comparison

	Traditional Chlorine Gas	Sodium Hypochlorite Generation	Commercial Sodium Hypochlorite
Capital Cost [a]	$ 1,155,000	$ 1,500,000	$100,000
Operating Cost, $/1000 gal	$0.031	$0.031	$0.165
Operating plus Amortized Capital, $/1000 gal(b)	$0.046	$0.050	$0.182
Operating plus Amortized Capital, $/year [b][c]	$179,000	$195,000	$709,000

(a) Accuracy of the capital cost estimate for both systems is plus thirty, minus fifteen percent (+30%, -15%).
(b) Capital costs amortized at 6 percent over a 30 year period.
(c) The costs per year are based on a yearly water production equivalent to two-thirds of maximum plant capacity.

Capital Costs

The capital costs for the chlorine gas system, based on equipment quotes from the equipment manufacturer and recently-bid chlorine system projects, include all new equipment, a new 4,200-square-foot building, and a fully enclosed truck unloading area.

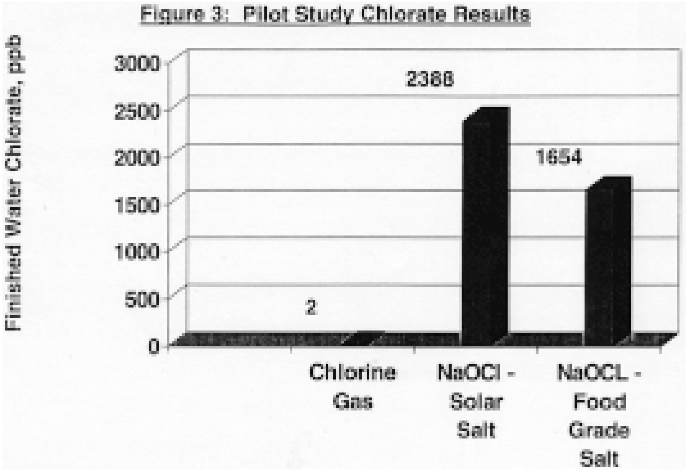
The proposed sodium hypochlorite generation system capital costs include three 1,250-ppd generation cell assembly units, plus tanks, pumps, and piping, containment areas for the brinemakers, brine daytanks, and sodium hypochlorite daytanks, and a 1,500 square foot building to house the generation cell assembly units and acid cleaning system.

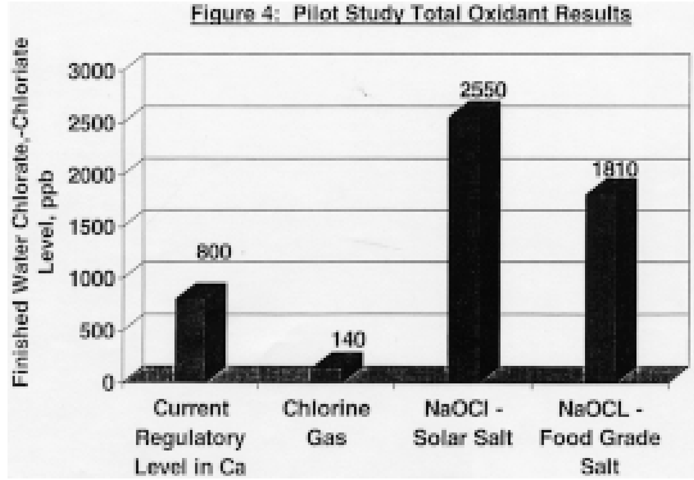
The capital costs for the commercial sodium hypochlorite system are the lowest of the three systems. This system also has the least amount of equipment, having only two tanks and two feed pumps even at future WTP expansion.

Operating Costs

The major operating cost for the chlorine system is that of chlorine containers. One concern about the chlorine gas system is the increase in chlorine gas price over the last five years. Two years ago, the price of chlorine was $214 per ton container; now it is $404.50. According to chlorine price quotes in the *Chemical Marketing Reporter*, chlorine prices increased an average of 70 percent between 1991 and 1995.

For the sodium hypochlorite generation system, the major operating costs are salt and electricity. The system requires 3.2 pounds of salt and 2.3 kilowatt-hours of electricity per pound of chlorine generated. The price of salt, though varying with quality, has remained essentially the same over the last five years according to the *Chemical Marketing Reporter*. The price is approximately $0.029 per pound for lower quality salt and $0.05 per pound for higher quality salt. Use of lower quality salt will cause more sludge accumulation in the brinemaker tanks and increase the frequency





of acid cleaning of the cell assemblies. The price of electricity was assumed to be between $0.045 and $0.050 per kilowatt-hour.

The major cost for the commercial sodium hypochlorite system is the cost of the sodium hypochlorite, which drives the life-cycle costs of the system considerably higher than the other two systems. The operating cost per pound of chlorine is nearly five times higher than using chlorine gas or sodium hypochlorite generation.

Pilot Testing

A pilot test was performed of the on-site sodium hypochlorite system to investigate and develop potential methods for reducing the anticipated high levels of disinfection by-products in the finished water while still providing superior disinfection. Specifically, the formation of chlorate, chlorite, and bromate were of concern.

The pilot test was performed with a standard Sanilec B-100 sodium hypochlorite generation unit with a chlorine production capacity of 100 pounds per day. The unit produced a low concentration (0.7 to 0.8 percent) sodium hypochlorite solution. Chlorine dosages ranged from 20 to 30 mg/l, with the majority of chlorine added to the raw water and the remaining amount added to the softened and ozonated water prior to filtration. Prior to the test runs, samples were collected to measure the levels of bromate, chlorate, and chlorite in the finished water as treated by the current disinfection practice (chlorine gas). Samples from the raw water, softened water, ozonated water, and filtered water were analyzed for the same parameters.

Six tests were run. The first four tests used a crude solar salt as a raw material; the last two used a higher-quality food grade salt.

Water Quality Results

The primary water quality concern with on-site sodium hypochlorite generation is increased levels of bromate, chlorite, and chlorate in the finished water. Figure 1 presents the average results for finished water bromate levels for the test runs. Bromate is expected to be regulated during Stage 1 of the DBP Rule at a level of 10 µg/l. As indicated in Figure 1, the use of sodium hypochlorite generated with solar salt will cause the finished water bromate level to substantially exceed the proposed regulatory level. The use of food grade salt produced a finished-water bromate level that was one-tenth of the proposed regulatory limit.

Figure 2 presents the average results for finished water chlorite levels for all test runs. Chlorite is expected to be regulated during Stage 1 of the DBP Rule at a level of 1,000 µg/l. As indicated on Figure 2, the use of the sodium hypochlorite generation will slightly increase the finished water chlorite level as compared to chlorine gas. There was no significant difference between the use of solar salt and food grade; the use of either salt allowed the finished water chlorite level to be well below the proposed regulatory limit.

Figure 3 presents the average results for finished water chlorate levels for all test runs. It is anticipated that chlorate will be regulated during Stage 2 of the DBP Rule. Some states already regulate chlorate levels in drinking water. As indicated in Figure 3, generated sodium hypochlorite will considerably increase the level of chlorate in the finished water as compared to current disinfection practice. The use of food grade salt reduced the finished water chlorate level by over 30 percent as compared to solar salt.

One method by which chlorate can be regulated is in combination with chlorine dioxide and chlorite levels, a total oxidant maximum contaminant level. This approach is used in California, which has set a maximum containment level of 800 µg/l for the sum of chlorine dioxide, chlorate, and chlorite concentrations in finished water. For this application, there is no chlorine dioxide, though the finished water levels of chlorate during the pilot study were high enough to cause concern if chlorate and chlorite are regulated together.

Figure 4 presents the average results for the sum of finished water chlorate and chlorite levels for all test runs. Sodium hypochlorite generation will significantly increase the level of chloratechlorite in the finished water as compared to chlorine gas. The use of food grade salt produced a 29 percent reduction in the finished water chlorate-chlorite level compared to the use of solar salt. The level obtained by using the food grade salt was still greater than the regulatory limit used in California.

Conclusions

Either system can be expected to provide reliable, effective disinfection. The chlorine gas system has a lower capital cost than the sodium hypochlorite generation system, but not less than the commercial sodium hypochlorite system. Despite the higher capital cost, the life-cycle costs for the sodium hypochlorite generation system and the chlorine gas system are similar, with a difference of less than $0.005 per 1,000 gallons. This difference will cease if the price of chlorine increases. The life-cycle costs for the commercial sodium hypochlorite system are considerably higher than the other two types of systems.

Either sodium hypochlorite system will provide a safer system for operating personnel and surrounding areas of the WTP.

The pilot study results indicate that at higher chlorine dosages, the level of finished water disinfection by-products, especially bromate, chlorate, and chlorite, increase significantly when using generated sodium hypochlorite instead of chlorine gas. Other studies using commercial sodium hypochlorite indicate that high levels of chlorite and chlorate can be found in finished water at high chlorine doses. The use of food grade salt will reduce the disinfection byproducts, especially bromate, and will also reduce the maintenance associated with sludge buildup in the brinemaking tanks.

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Automation for Unattended Water Treatment Plant Operations

Orlando Utilities Commission's Water Project 2000 Multi-Plant, Systemwide Modernization

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The Orlando Utilities Commission (OUC) provides water and electric service to nearly 90,000 residential and more than 10,000 commercial and industrial accounts within a 244-square-mile service area including the city of Orlando and portions of Orange County. OUC operates eleven water treatment plants, all of which are unattended. The plants receive water from 34 deep wells and deliver water through a distribution system of almost 1,500 miles of pipe.

Treatment capacity is currently 167 MGD and is projected to be 224 MGD upon completion of OUC's Water Project 2000 (WP 2000) program. Under this program, a Facility Automation and Information Management (FAIM) system is being implemented to support the WP 2000 treatment system infrastructure modernization. Projects included in Water Project 2000 include a new ozonation-based treatment plant that began operation in January 1997, the FAIM project (the initial phase has been completed), upgrades of three of the existing treatment plants to incorporate ozone treatment, a second new treatment plant, conversion of additional plants to ozone treatment by the year 2000, and miscellaneous improvements.

System Evolution

Since the 1950s, OUC's water system has featured unattended operation of multiple water treatment plants and distribution facilities using Supervisory Control and Data Acquisition (SCADA) systems. The SCADA system has allowed OUC to treat water with fewer operators compared to fully staffed plants. While operating reliably, the most recent SCADA system installed in the mid-1980s was becoming obsolete and was replaced with the FAIM system.

In 1994, OUC faced complex choices in defining the future operation of its water system. OUC desired ozone as a core treatment technology to minimize chlorine usage and improve water taste. While a new treatment plant incorporating ozone disinfection was being designed, Water Project 2000 was about to commence. To meet its goals within the planned time frame, OUC decided to implement the FAIM project to allow continued remote operation of the existing, converted, and new treatment plants.

The SCADA system was replaced in early 1997 with the implementation of the FAIM system, and is being integrated with multiple treatment plant upgrade projects executed by engineer/contractors using the engineer-procure-construction management (EPCM) delivery method for plant improvements and the design-build delivery method for new construction.

The various project delivery mechanisms considered by OUC along with the evaluation are discussed in the paper "Integrated Project Delivery—Is it Time for IPD?" presented at the 1996 American Water Works Association Engineering and Construction Conference[1].

Evolution of FAIM Systems

Before upgrading or replacing the SCADA system, OUC wanted to understand the advances in SCADA and information management systems and how these advances could help meet the following five OUC's goals for the FAIM system:

1. Using the most current technology, design and implement an information and control system that will enhance and extend OUC's proven capability for unattended water treatment plant operations beyond the year 2000.
2. Eliminate the need to staff an operations control center on a 24-hour basis, and free operators to "roam" the system.
3. Provide the capability to automatically satisfy total water system demand with the most economic choice of pumps and treatment.
4. Using existing networking capabilities, provide control and information system access to users throughout OUC.
5. Integrate all O&M informational needs into a graphics-based system using commercially available products.

About a year before the establishment of Water Project 2000, OUC began its planning with a SCADA upgrade study. As a result of this six-step decision process, OUC moved quickly to incorporate goals for the FAIM system into Water Project 2000. The study recommended converting the existing minicomputer-based remote control system to a fully automated control system featuring a distributed open architecture using programmable logic controllers (PLCs), Windows-based operator workstations, information integration with OUC's existing information systems, and a high-speed communication network using fiber optics, frame relay and T1 telecommunications services, and 900-megahertz multi-address system and spread spectrum radio. A facility information management (FIM) system was also recommended to provide electronic access to operations and maintenance (O&M) documentation.

The FAIM system will implement a wide area network allowing OUC's operators to monitor and control the OUC system from virtually any location within the system. Figure 1 depicts the resulting systemwide integration of the FAIM system. Figure 2 depicts the generic criteria for a plant monitoring and control system.

Project Coordination

Keys to success included coordinating the implementation of the FAIM system with the other infrastructure projects and clearly defining the responsibilities for each party involved in the projects. A conventional control system project delivery was unrealistic because, for each plant project, construction and startup activities would occur almost simultaneously with different design engineers and contractors. The design of all plants needed to be consistent to allow OUC's operators to deal with the simultaneous operation of multiple treatment plants.

OUC established the following projects for implementation under Water Project 2000:

- Criteria Development—The purpose of this effort was to define criteria for the design and construction of instrumentation and controls in each treatment plant and to establish coordination responsibilities. These criteria were used to set up contracts for design and construction of each treatment plant.
- Operations Center SCADA Conversion—The purpose of this

project was to upgrade the SCADA system to the new FAIM system in coordination with commissioning of the new Southwest Water Treatment Plant (WTP), the first Water Project 2000 plant, in January 1997.
- Individual Plant Projects—The design and construction of four treatment plants are currently under way with additional projects scheduled.
- Ozone System Procurement—Ozone equipment was purchased for each of the above four plants. The procurement includes PLCs and their application software programming for control of the ozone generator equipment.
- Treatment Plant FAIM Implementation—The implementation includes various coordination responsibilities with each of the other projects as discussed in the following text.

Contractual responsibilities were defined for each plant project in Water Project 2000 and for each project element associated with the FAIM system on the basis of the integrated delivery approaches selected by OUC.

Operations Center Conversion Project

The purpose of the Operations Center Conversion Project was to replace the previous proprietary SCADA system before the more highly automated plant controls were implemented as plants were built or upgraded. The previous SCADA system provided the operator with the ability to monitor plant discharge pressures, flows, operations, and alarms and to manually and remotely operate well pumps and high service pumps and associated chemical treatment systems from the Operations Center. It also allowed the operator to monitor levels in the (¨evated storage tanks, and to turn high service pumps on and off in manual mode.

The previous SCADA system consisted of dual processors, computer terminal consoles with color graphic displays, alarm and report printers, magnetic tape drives, video copier, and programmer's console. The system provided real time monitoring, remote manual control, alarming, data acquisition, and historical data recall and reporting. The total system signal inputs and outputs (I/O) consisted of 620 discrete inputs and outputs, 200 analog inputs, and nine analog outputs. Data acquisition and control was provided by remote telemetry units (RTUs) communicating over leased telephone lines with 900 MHz band multiple address system radios for backup telemetry. The existing plant controls were standardized and consisted of control panels with RTUs and microprocessors for communication with the central minicomputer system and the local hard-wired plant controls.

The Operations Center Conversion Project was accomplished by replacing the minicomputer system with a personal computer based system, converting the RTUs' proprietary communications protocol to MODBUS protocol, and interfacing to the RTUs using existing telemetry. As plants are built or upgraded, high speed frame relay communications will be implemented, and a wide area network will link the treatment plants, allowing plants to be operated from any location in the system. New plants will be added to the FAIM system upon commissioning. As existing plants are upgraded, their RTUs will be converted to PLCs, and PC-based operator machine interface workstations will be added at each plant.

The initial implementation of the FIM system was also part of the Operations Center conversion project. The FIM provides "web browser" technology for searching O&M documentation and is linked to the FAIM system to provide rapid access to online documentation. OUC is converting existing paper documentation. As plants are built or modified, record documentation will be submitted electronically for inclusion in the FIM.

Individual Plant Projects

Coordination of individual plant design and construction projects with the FAIM system project was essential to meeting OUC's goals for the overall program. Automation and control of individual plants needed to be standardized throughout the system to allow for effective and efficient operation by OUC's staff, and documentation needed to be consistent to allow O&M problems to be diagnosed rapidly. A criteria package was developed to establish the basis for contracts with each plant's designer-builder and to define coordination requirements among OUC, the FAIM designer, and the ozone system supplier. The FAIM element of the criteria package defined responsibilities for design development, control logic development, application software programming, design and record documentation, procurement of owner-furnished equipment, testing coordination, and implementation.

Coordination of application software development and FAIM equipment procurement and integration, testing, and commissioning are key elements of each plant project as shown in Figure 3.

In addition to the criteria package, a standard operating procedure was developed by the FAIM designer, in conjunction with OUC, to help coordinate the controls between the plant design, the ozone systems, and the FAIM system, and to define equipment sequencing and reaction to various equipment, power, and communications failure modes to be implemented in the plant controls.

Ozone Systems

The ozone system supplier is providing equipment for each project under a contract with OUC. The ozone system equipment includes PLCs compatible with the FAIM system for monitoring and controlling individual ozone equipment, such as ozone generators or ozone destruct units. The individual plant designer has the responsibility of integrating the ozone equipment into the overall plant design including sequencing and capacity demand controls.

Conclusion

The implementation of the FAIM system is allowing a smooth upgrade of the existing control and information system while the physical plant infrastructure is modernized under Water Project 2000. In addition, the FAIM system provides complete water system interconnectivity using a high speed wide area network. This will allow OUC to operate the FAIM system from any location within the water system and to integrate data gathered from operating plants with other OUC information management resources. This interconnectivity augments OUC's responsiveness to water treatment issues and helps ensure continued safe delivery of water.

The FAIM system allows OUC to continue its long history of unstaffed plant operations even as plant automation and complexity increases. In addition, it provides the basis for future automation and information management enhancements for plant and distribution system operations, thus providing OUC rate payers the continued benefit of efficient, cost-effective service.

References

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