Pilot Study Conducted by City of Clearwater is First in FL to Test Application of Chlorine Dioxide in Wastewater Disinfection

Part 1: City of Clearwater Explores Disinfection Alternatives to Adhere to New FDEP Effluent Rules

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In response to The Florida Department of Environmental Protection's (FDEP) tightening of the rules governing trihalomethane (THM) and disinfection by-product (DBP) in wastewater effluents, the City of Clearwater is evaluating disinfection alternatives to its existing gaseous chlorination treatment. The City has studied two different alternatives-chlorine dioxide and ultraviolet radiation (UV)-and is currently testing on-site generation of chlorine dioxide to augment chlorine disinfection. The six-month test, slated for completion in March, 2002, is the first in the State of Florida that tests the application of chlorine dioxide in wastewater disinfection.

The City of Clearwater recently obtained new operating permits for its three advanced wastewater treatment facilities: Marshall Street Advanced Pollution Control Facility (APCF), Northeast APCF, and East APCF. Operating under their current disinfection process, the facilities occasionally exceed the new THM limits, specifically those of dichlorobromomethane (22.0 (g/l) and chlorodibromomethane (34.0 (g/l). To reduce effluent THM levels and comply with the new regulations, the City has investigated alternative disinfection methods, including chlorine dioxide and ultraviolet (UV) radiation.

FDEP Reduces THM Limits, Effective 2002

THMs are organic contaminants produced when natural organic matter is present during the disinfection treatment process. The natural organic matter in the water reacts with chlorine to form THMs and other harmful by-products that have been linked with potential long-term health effects.

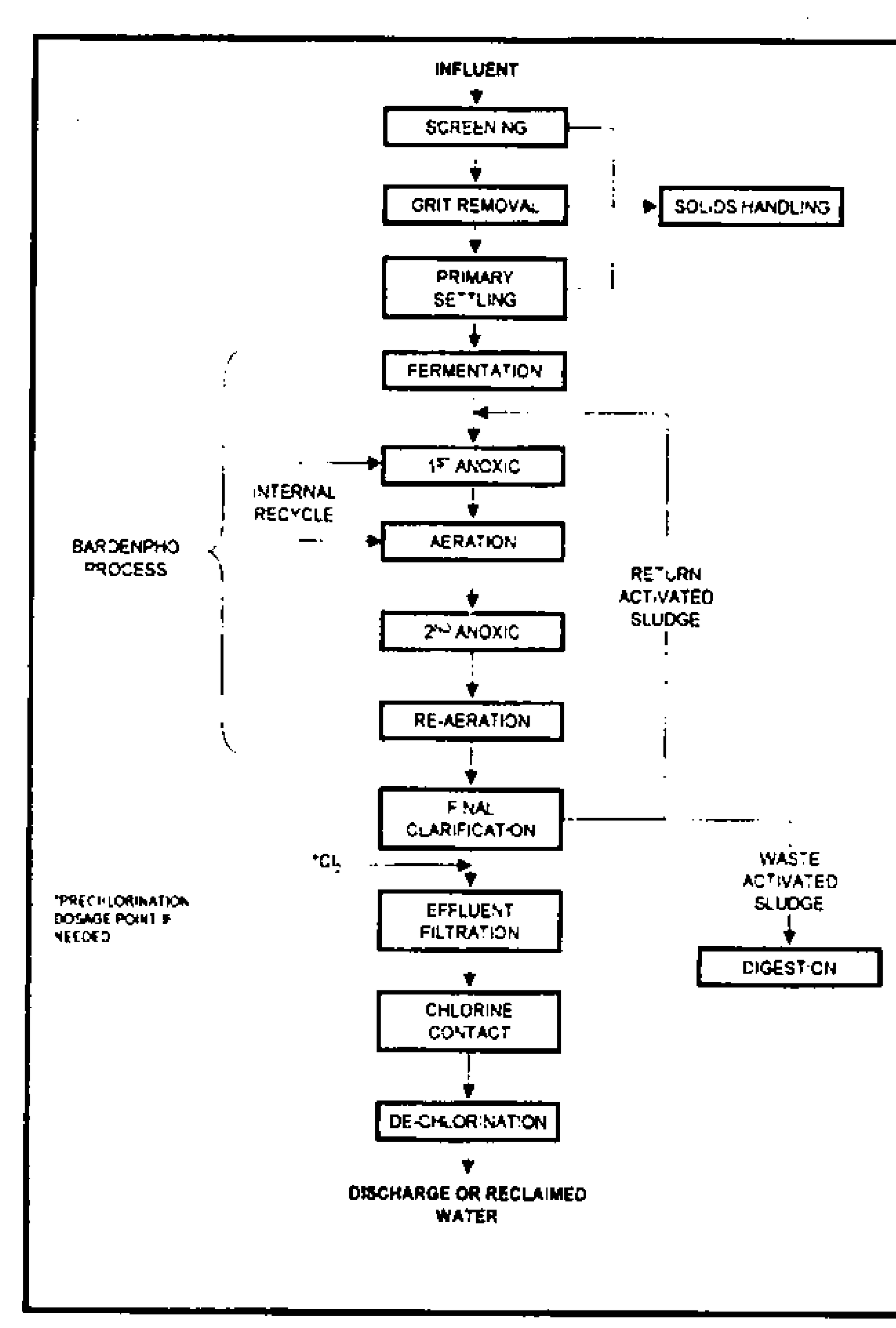
Because the THM formation is a natural reaction of free chlorine, it will continue to be a problem in this process as long as large amounts of chlorine are used. To effectively reduce the formation of the THM species, chlorine use in the disinfection process must be reduced or eliminated.

The stricter FDEP regulations on THMs and DBPs go into effect January 2002. In order to obtain new operating permits after that date, facilities must adhere to the new limits.

Plants Currently Use Gaseous Chlorine Disinfection

Clearwater's three wastewater treatment plants use gaseous chlorination and the five-stage Bardenpho(tm) process. A peaking factor of 2.0 times the average daily flow is common for the facilities during peak flows. All three facilities are capable of feeding 2,000 pounds per day (lbs/d) of chlorine. Each facility has an average design dosage of approximately 10 mg/l and a chlorine residual setpoint of 3.5 mg/l.

Process Diagram for City of Clearwater's Wastewater Treatment Facilities



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Process Diagram for City of Clearwater's Wastewater Treatment Facilities

At all three facilities, chlorine is delivered and stored in one ton steel cylinders. The cylinders are pressurized, so the chlorine is mainly in the liquid state with a gaseous headspace. The gaseous chlorine is drawn from the cylinder headspace, piped to the chlorinator, dosed into the returned reclaimed water stream, and piped to application points throughout the wastewater process stream.

The City has successfully completed all aspects of the required Risk Management Plan (RMP) and the Process Safety Management (PSM) Plan in order for the facilities to continue chlorine gas usage. The RMP and PSM were developed to insure that the facilities operate in a safe manner, and comply with applicable EPA and OSHA regulations relevant to accidental release prevention.

Clearwater Compares Chlorine Dioxide with UV Light

The City commissioned McKim & Creed to investigate alternatives to gaseous chlorination disinfection. McKim & Creed compared chlorine dioxide and UV radiation, and is currently working with Vopak USA, a chemical distribution company, to conduct a pilot study of the City's selected alternative.

The following is a brief comparison of the chlorine dioxide and UV radiation alternatives, as they relate to the Clearwater facilities.

Chlorine Dioxide

Background

Chlorine dioxide is a greenish yellow gas, with a distinct odor similar to that of chlorine. Because of its unstable nature, it must be generated on site, and water/wastewater applications usually produce and use it in aqueous solutions. Chlorine dioxide exists in aqueous solution as a dissolved gas, but is volatile and can be easily stripped from solution in water by passing air though the solution. Consequently, the chlorine dioxide concentration in solution is not stable when in an open vessel, and the solution strength can deteriorate rapidly.

When produced and handled properly, chlorine dioxide is an effective and powerful bacteriocide, disinfectant agent, and oxidizer. It penetrates the biological cell wall more effectively than chlorine and reacts with vital amino acids of the cell to kill microorganisms present in wastewater; therefore, it is a much stronger disinfectant than traditional chlorine gas.

The chemistry of chlorine dioxide is quite different from that of chlorine. Since chlorine dioxide exists as a free radical, it does not react by breaking carbon-carbon bonds; rather, it functions via an oxidation reaction instead of a chlorinating reaction. As a result, chlorine dioxide oxidizes natural organic matter constituents in a different manner than chlorine, which results in lower levels of chlorine or bromine substituted organic byproducts, including THMs.

Compared to chlorine, lower levels of chlorine dioxide can be used to produce the same effective inactivation of microbes. In addition, chlorine dioxide has been found to be active against pathogens resistant to chlorine.

On-Site Generation of Chlorine Dioxide

There are several routes for on-site generation of chlorine dioxide. Methods considered by the City of Clearwater included: 1) the reaction of sodium chlorate with an acid, and 2) the reaction of sodium chlorite with chlorine gas.

Safety of Chlorine Dioxide

As with any disinfectant chemical, if handled improperly, consumed internally, or absorbed or subjected to long-term exposure, chlorine dioxide can be toxic. Because of its instability, long stagnation of any vapors can result in an explosive decomposition.

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Cost of Using Chlorine Dioxide

McKim & Creed reviewed information from two separate suppliers of chlorine dioxide technology. One of the processes investigated uses two precursor chemicals, Purate and 78% sulfuric acid (H2SO4). Purate is a formulation of sodium chlorate (NaClO3) and hydrogen peroxide (H2O2). Using raw material costs for Purate and 78% sulfuric acid, the stoichiometry of the reaction results in a net cost of $2.34/lb of chlorine dioxide.

The other process we examined uses the two precursor chemicals, Akta Klor 25, which is a sodium chlorite (NaClO2) solution, and chlorine to produce chlorite (ClO2). The process chemistry generates a ClO2 cost of approximately $2.60/lb.

Another associated operating cost is dechlorination with ferrous chloride, if the continued use of sulfur dioxide is not feasible. Ferrous chloride may be more economical to use than sulfur dioxide, if high concentrations of ClO2 are being fed, resulting in a lot of residual chlorite that will need to be removed. The appropriate chemical can be decided during the pilot phase.

Based on the above cost information compared with local chlorine costs, a trade-off of 1 mg/l of ClO2 per 2.5 mg/l of chlorine will be more expensive than the original chlorination step. However, given the background chemistry of chlorine, the continued use of chlorine for disinfection in this process will not allow the City to comply with the recent THM limitations of the new operating permits. Some modification of the current chemistry is essential for the City to comply with the new limits. This modification may result in one of the two alternatives described below.

Alternative 1: Chlorine Replacement

The first alternative is for chlorine dioxide to completely replace chlorine. This would require a substantial investment and a long-term pilot process to determine the appropriate dosages, disinfection efficiency, toxicity, etc. The pilot study would have to be successfully conducted in small scale before it could be brought online at full-scale. Consequently, there would be a substantial time delay involved before any improvement in the existing effluent THM levels could be achieved.

Capital Costs - Chlorine Replacement

Equipment	Marshall St.	East Plant	Northeast Plant
Generators	$80,000	$80,000	$80,000
Storage Tank(s)	$50,000	$30,000	$50,000
Ferrous Feed System	$10,000	$6,000	$10,000
Associated Piping	$35,000	$20,000	$35,000
Building	$150,000	$100,000	$150,000
Chlorine Contact Chamber Cover	$88,000	$40,000	$165,000
Instrumentation	$25,000	$25,000	$25,000
Subtotal	**$438,000**	**$301,000**	**$515,000**
Pilot Test	$125,000	-	-
Total	**$563,000**	**$301,000**	**$515,000**

This price assumes a prefabricated modular building to house the generating equipment and precursor chemicals. Generator size is based on plant capacities, and process water and electricity would have to be provided to the building to create a motive source for the ClO2 generator output. All existing and proposed chlorine contact chambers are assumed sufficient for chlorine dioxide application, therefore, no new reactors are necessary.

Operating Costs - Chlorine Replacement

Parameter	Marshall St.	East Plant	Northeast Plant
Average Flow (mgd)	7	2.5	6
Lbs/d ClO2 (at 3 mg/l)	175	63	150
Annual ClO2 Cost	$150,000	$53,500	$128,200
Lbs/d FeCl2 (at 4.8 mg/l)	550	250	475
Annual FeCl2 Cost	$24,000	$11,000	$21,000
Total Annual Cost with FeCl2	**$174,000**	**$64,500**	**$149,200**

This table lists the operating costs for each Clearwater Wastewater Treatment Plant, based on the average flow rates and a chlorine dioxide dose estimated at 3 mg/l.

Alternative 2: Chlorine Supplementation

Instead of replacing the existing chlorine system entirely, another alternative would be to supplement chlorine with a small dosage of ClO2. Since ClO2 is equivalent to 2.5 mg/l of chlorine, a 1 mg/l dosage of ClO2, in addition to chlorine, would allow us to reduce the total chlorine used, reduce the amount of THM formed, and improve the basic disinfection process with only a minor increase in cost. The dose would most likely be applied ahead of the filters, and research has suggested that the successive application of chlorine at the contact chambers would react with any residual chlorite to reform chlorine dioxide, instead of reacting with organic matter to form THMs.

With this scenario, neither the populace nor environment would be at risk, and the added chlorine dioxide could immediately go to full-scale, thus achieving significant environmental improvement very quickly.

This concept has been discussed with the FDEP authorities in Tampa and they have indicated that permits could be obtained for such full-scale testing if the applied dosage of ClO2 never exceeds the approved drinking water concentration (1.4 mg/l).

The capital cost to do this for one plant is obviously much less than complete replacement. The equipment required for chlorine supplementation is similar to that needed for replacement, except the generators would be

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smaller, chlorine contact covers would not be necessary, and ferrous chloride would most likely not be required. However, dechlorination with sulfur dioxide might still be needed since residual chlorine could still be present in the effluent.

Capital Costs - Chlorine Supplementation

Equipment	Marshall St.	East Plant	Northeast Plant
Generators	$29,000	$34,000	$40,000
Storage Tank(s)	$40,000	$20,000	$40,000
Associated Piping	$35,000	$20,000	$35,000
Building	$150,000	$100,000	$150,000
Instrumentation	$25,000	$25,000	$25,000
Subtotal	**$279,000**	**$199,000**	**$290,000**
Pilot Test	$60,000	-	-
Total	**$339,000**	**$199,000**	**$290,000**

Operating Costs - Chlorine Supplementation

Parameter	Marshall St.	East Plant	Northeast Plant
Average Flow (mgd)	7	2.5	6
Lbs/d ClO2 (at 1 mg/l)	58	21	50
Annual ClO2 Cost	$50,000	$18,000	$43,000
Lbs/d Cl2 (at 3 mg/l)	175	63	150
Annual Cl2 Cost	$11,200	$4,000	$9,600
Lbs/day SO2 (at 1 mg/l)	58	21	50
Annual SO2 Cost	$7,500	$2,700	$6,400
Total Annual Cost with SO2	**$68,700**	**$24,700**	**$59,000**

Capital and Operating Costs - UV

Cost	Marshall St.	East Plant	Northeast Plant
Capital Cost*	$5.1 M	$3.8 M	$5.8 M
Operating Costs	$110,000	$ 60,000	$150,000

*Pilot testing included at Marshall Street

The main capital cost for UV is the system itself, while other associated costs would include standby power, reactor covers, and buildings. Most of the operating expenses come from required power and lamp replacements.

Ultraviolet (UV) Radiation

Background

Ultraviolet radiation disinfects wastewater by altering the genetic DNA material in cells so that the bacteria, viruses, and other microorganisms cannot reproduce. There is no chemical addition; therefore, it does not chemically alter water. Since no chlorine is involved in the process, it cannot react with natural organic matter found in the wastewater to form certain chlorinated or brominated organic compounds, including THMs.

The UV light used in the disinfection process is produced by lamps that operate in the germicidal energy range. As filtered effluent flows past the UV lamps, the suspended solids and microorganisms are exposed to a lethal dose of UV energy. The UV dose is measured as the product of UV intensity and the exposure time within the UV lamp array. Transmittance is defined as the percentage of UV light actually absorbed by the microorganisms. As the UV light passes through the wastewater medium, any suspended solids or tannic color absorb some of the energy and decrease the amount of light that actually reaches the microorganisms. A typical transmittance ranges from 60 to 75 percent. As the transmittance value of a characteristic wastewater goes down, more and more energy is required to achieve a kill, thus driving up the cost of the system.

The market has long debated which is the best lamp for disinfection. They all work to some extent, but as the flows to be disinfected get larger, the amount of energy to be transmitted gets very large. New technology in the marketplace has concentrated on either higher intensity, low pressure lamps, or medium pressure lamps. This study has considered both low pressure / high intensity and medium pressure lamps for cost purposes.

Safety

Although operation of a UV system is virtually chemical free (except for cleaning solutions), safety issues still exist. Specifically, personnel exposure to ultraviolet radiation is a concern. If not protected, workers can suffer severe burns and permanent eyesight damage.

Cost

Taking into account all of the complexities of UV, and because all three plants require high-level disinfection, McKim & Creed considered two options for the three Clearwater treatment plants: low pressure / high intensity lamps, and a medium pressure lamp. In every case, we assumed installation of the UV equipment into the existing chlorine contact channels.

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Comparison of Alternatives

Obviously, chlorine dioxide and UV differ widely in their impacts on the City and the local environment. Outright replacement of chlorine with either alternative will require substantial small scale pilot testing and impart significant delays into the schedule for resolving the compliance problems. FDEP will not allow either of these technologies to be implemented to replace chlorine without adequate test data to support the change. Both would be considered alternative disinfectants and both would need to be demonstrated on-site before they could be used to completely replace chlorine. The alternatives represent both a low capital and high capital cost approach, with fairly similar operating expenses.

From a capital cost standpoint, implementation of chlorine dioxide to replace chlorine is substantially less expensive than UV radiation. The chlorine dioxide route must still be viewed as experimental at this time, but it will have demonstrably lower up-front capital costs than UV. Operating expenses of the two technologies are similar. UV, however, qualifies as demonstrated technology to use for disinfection and THM control, with well-documented design guidelines with which to work.

Recommendations

Based on a careful comparison of the various parameters, and concentrating on a desire to reduce THM formation without compromising disinfection, McKim & Creed recommended that a pilot study of the low-level chlorine dioxide alternative be implemented at the Marshall Street facility. Specifically, McKim & Creed suggested the City utilize chlorine dioxide generation via acidification of sodium chlorate. This production method is an elemental chlorine-free technology; therefore, if the City were ever required to completely eliminate gaseous chlorine from their facilities, it could be achieved using this technology. Furthermore, it is less expensive than chlorine / chlorite generation.

The study began in September 2001, and will continue for six months. Vopak USA is providing the products, generator, technical support, and testing protocols. The generator system being used at the test site is manufactured by EKA Chemicals, a division of Akzo Nobel.

Says Jon Pena, manager of Vopak USA's specialty division of water and wastewater in Jacksonville, Florida, "To the best of my knowledge, this is the first study of its type to be conducted in Florida." Chlorine dioxide for secondary oxidation has been tested in drinking water, but is not commonly used for wastewater disinfection.

(The results of the study will be published after the testing is completed in March, 2002.)

Present Worth Cost Comparison

Alternative	Location Marshall St.	East	Northeast	Total
Replacement with ClO2				
Capital Cost*	$563,000	$301,000	$515,000	$1,379,000
Operating Costs	$174,000	$65,000	$150,000	
Operating Present Worth (10 yrs at 5%)	$1,343,582	$501,913	$1,158,260	$3,003,755
Total	$1,906,582	$802,913	$1,673,260	**$4.4 M**
Augmentation with ClO2				
Capital Cost*	$329,000	$199,000	$290,000	$818,000
Operating Costs		$69,000	$25,000	$59,000
Operating Present Worth (10 yrs at 5%)	$532,800	$193,043	$455,582	$1,181,425
Total	$861,800	$393,043	$745,582	**$2.0 M**
UV Light				
Capital Cost*	$5,100,000	$3,800,000	$5,800,000	$14,700,000
Operating Costs	$110,000	$60,000	$150,000	·
Operating Present Worth (10 yrs at 5%)	$849,391	$463,304	$1,158,260	$2,470,955
Total	$5,949,391	$4,263,304	$6,958,260	**$17.2 M**

*Pilot study cost included in Marshall St. capital cost

Capital and operating costs have been combined in a single present worth value for each plant, evaluated at 5% compound interest over a 10-year operating period.