ALTERNATIVE DISINFECTION TECHNOLOGY DEMONSTRATES ADVANTAGES FOR WET WEATHER APPLICATIONS – A PILOT STUDY OF POWDERED BROMINE TECHNOLOGY

Peter E. Moffa*, Daniel P. Davis*, Chris Somerlot*, Dan Sharek**, Brian Gresser***, Tom Smith***

* Brown and Caldwell
5710 Commons Park
East Syracuse, New York

** Hatch Mott McDonald
Gateway View Plaza, 1600 West Carson Street
Pittsburgh, Pennsylvania

*** City of Akron
Akron, Ohio

ABSTRACT

A bromine disinfection technology currently utilized in Japan for Combined Sewer Overflow (CSO) disinfection was piloted by the City of Akron, Ohio. Bromochlorodimethylhydantoin (BCDMH) is a biocide in powdered form that, when dissolved in water, hydrolyzes to hypobromous acid, hypochlorous acid (the active biocides) and Dimethylhydantoin. This unique combination in active biocides can yield similar or better bacteria reductions in less time and with lower disinfection byproducts compared with a similar dose of sodium hypochlorite.

The City of Akron expressed interest in this technology in anticipation of wet weather application of high-rate disinfection that would require intermittent operation and storage of chemicals between such operations. Consequently, Hatch Mott McDonald / Brown and Caldwell were hired to demonstrate this technology using a pilot facility at the Akron Water Pollution Control Station (WPCS).

KEYWORDS

Disinfection, Bromine, Chlorine, CSO, High-rate treatment

INTRODUCTION

A new technology for high-rate disinfection has been examined under wet weather conditions in Akron, Ohio. The technology, developed by EBARA of Tokyo, Japan, has been successfully implemented at a number of sites in Japan for treatment of wet weather discharges, but has not yet been implemented in the United States. The technology uses a compound known as Bromochlorodimethylhydantoin (BCDMH) that contains both chlorine and bromine oxidants. As reported by EBARA, BCDMH achieves better bacteria kills than a comparable dose of chlorine, and is stored in powdered form with negligible degradation of oxidation strength over time. These combined factors represent a disinfection technology ideally suited for intermittent treatment of wastewater, such as CSO abatement.
BCDMH disinfects with a combination of hypobromous acid (HOBr) and hypochlorous acid (HOCl) (shown in Figure 1), which are powerful oxidizing agents. Previous studies done in Japan have shown that necessary contact times to achieve three log kills of fecal coliform can be less than 5 minutes.

According to the manufacturer BCDMH is a highly stable powder, which allows it to be stored over one year without a decrease in effectiveness. Conversely, other chemicals such as sodium hypochlorite (NaOCl) and chlorine dioxide (ClO₂) decay at a rapid rate such that on-site generation in combination with storage and periodic replacement is often recommended.

**Literature Review**

The BCDMH compound, as illustrated in Figure 1, breaks down with water to form DMH, HOBr, and HOCl. HOBr usually breaks down into dibromamine in wastewater. Studies have shown that bromine is not as germinically effective as equivalent amount of chlorine halogen, (henceforth called chlorine equivalent), in sewage; this is speculated to be due to the fact that the bromine, as a more powerful halogen, is lost in side reactions with organic matter (White, 1999). However, tests conducted using bromine disinfection following chlorine disinfection have shown that better germinidal kills are obtained than by using chlorine alone, as the chlorine serves to meet the halogen demand, and bromine is available for oxidation to provide the kills.

Except for studies done by the manufacturer in Japan, there is relatively little information on the chemistry and germicidal effectiveness that apply to wet weather applications.

**Figure 1 - BCDMH Oxidation Process**

Disinfection byproducts from bromine appear to be less toxic than similar compounds formed in disinfection by chlorination, likely because bromamines are less stable than chloramines. However, while bromine residuals typically die away within minutes, organobromamines can be formed in the presence of organic nitrogen, which will persist for hours.

The process by which BCDMH solution is made is relatively uncomplicated. With the EBARA system, BCDMH powder is liquefied as needed by being fed through a dissolution mixer with clean water to form the solution, after which it is injected into the wastewater. BCDMH facilities are more compact than other high-rate disinfection technologies due to the relatively smaller storage needed for the powder. Consequently, BCDMH disinfection may be an excellent
candidate for satellite facilities where equipment may be intermittently operated and available space is limited, such as a wet weather CSO treatment facility.

BCDMH is currently not used in the United States for the purposes of disinfecting wastewater, but is used in several other industries, including the pool and hot-tub industry. As such, the compound is produced in the United States and is generally available, although the current domestic production capacity is unknown.

**Existing Installations and Manufacturers.** Currently, facilities using BCDMH for disinfection of wastewater have been implemented only in Japan. These facilities have been designed to inject the BCDMH solution directly into the wastewater flow, without a plug-flow disinfection chamber or high-rate mixers. Therefore, these facilities rely on in-stream turbidity to provide mixing. This type of facility has a very small footprint, and given the stability of the powder, needs minimal maintenance. A typical facility is shown in Figure 2.

![Figure 2 - Typical Full-Scale BCDMH Unit](image)

EBARA is the only known company which produces BCDMH for the wastewater industry. Moreover, EBARA has manufacturing facilities in the United States.
Testing Methodology

Pilot testing of BCDMH was conducted at the City of Akron WPCS and utilized a full-scale BCDMH unit provided by EBARA. The pilot unit was setup to produce a batch of solution that was fed to a 250 gpm side-stream of waste-water through a full-scale ½ HP induction mixer and then into a plug flow contact chamber with a 5 minute residence time. A schematic showing the setup of the pilot operation is shown in Figure 3.

The pilot testing consisted of four test events: three wet weather test events on primary influent and one test with effluent from a Compressed Media Filtration pilot unit. The three wet weather test events were completed in October and November of 2005 and offer a variety of different wet weather conditions. Flows at the Akron WPCS vary from 80 MGD in dry weather and accepts up to 250 MGD during peak wet weather events. Flows in excess of 110 MGD (when the plant’s secondary treatment process is bypassed) are considered wet weather. The wet weather events captured were during plant flows varying from 130 MGD to 230 MGD. One test was completed during dry weather using the effluent from a compressed media filtration unit also being piloted on-site, to determine the advantages of filtration prior to disinfection with BCDMH.

During each of the tests, three different dosages of BCDMH were run through the pilot contact chamber, namely, 3, 6, and 12 mg/L (as chlorine equivalent) to be able to develop kill-dose relationships. Additionally, bench-scale testing was conducted to compare NaOCl and BCDMH effectiveness.

Fecal coliform, *Escherichia coli*, and *Enterococcus* were selected as indicator species representative of kill effectiveness. As identified in the 1986 EPA Ambient Water Quality Criteria for Bacteria, *Escherichia coli* and *Enterococcus* have been chosen to be suitable indicators for measuring pathogen concentrations.

Total Organic Carbon (TOC), Chemical Oxygen Demand (COD), Total Residual Chlorine (TRC), and Total Suspended Solids (TSS) were measured to provide background data on the strength of the wastewater. Additionally, temperature, pH, and Dissolved Oxygen (DO) were monitored during the testing.
Figure 3 - Schematic of Pilot Setup

Existing Primary Tanks

Influent → 40 mgd avg. dry-weather flow (28,000 gpm) → Effluent

Return drain to primary effluent ~ 5 gpm

250 gpm pump

BCDMH Unit

1000 mg/L

Secondary Effluent

Feed water (21 psi)

40 gpm

FM

BCDMH Mixer Tank

250 gpm

Contact Chamber (12” pipe) with sample ports at 3 & 5 min

FM = Flow Meter

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RESULTS

Bacteria Reductions

The results from the pilot and bench scale tests using BCDMH show similar results.

Pilot Testing. Results showing geometrically averaged kill-dose relationships in Figure 4 through Figure 6 include range bars to indicate the full range of individual test results. The reductions in bacteria measured during the pilot tests varied from 1.5 log reduction to 3.8, as shown in Table 1. There was more variation in bacteria reduction across different dosages than between the two different contact times tested (3 and 5 minutes). This variation can be seen in Table 1 and Figure 4 through Figure 6. These dose-kill curves show that most of the reduction (knee of the curve) occurs during the first 3 minutes.

Bench-Scale Testing. The results from the bench-scale testing of BCDMH show trends in reductions of fecal coliform similar to those seen in the pilot-scale testing. The dose-kill curves for these bench-scale tests are shown in Figure 7. These curves show that the kill rate for NaOCl is generally more linear than BCDMH; greater contact time produces proportionally greater bacteria reductions. Figure 7A and 7B illustrate the bench-scale results run by EBARA staff and Akron staff respectively. Whereas Figure 7A represents a single test event from the primary influent, Figure 7B represents an average of the three wet weather test events. The BCDMH data in Figure 7A is consistent with the data in Figure 7B, and both sets of results are consistent with the pilot results. However, while the NaOCl results depicted in Figure 7A are consistent with other data on CSO, the NaOCl results depicted in Figure 7B are not; kills shown for the higher dose of 10 mg/L are greater than 4.5 log reduction. Data from previous studies show on the order of 3 log reductions at this concentration (WERF 2005, CDM/Brown and Caldwell, 2001). The results in Figure 7B are atypical and not consistent with previous results.

Table 1 - Reduction (Kills) of Bacteria Indicators

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Initial Concentration (CFU/100mL)</th>
<th>Dose: 3mg/L</th>
<th>Dose: 6mg/L</th>
<th>Dose: 12mg/L</th>
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<tr>
<td></td>
<td></td>
<td>Log Reduction</td>
<td>Log Reduction</td>
<td>Log Reduction</td>
</tr>
<tr>
<td>Fecal coliform</td>
<td>1.9E+06</td>
<td>2.4</td>
<td>3.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>1.0E+06</td>
<td>1.6</td>
<td>2.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Enterococcus</td>
<td>2.0E+05</td>
<td>0.9</td>
<td>1.5</td>
<td>2.8</td>
</tr>
</tbody>
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<td>1.5</td>
<td>2.0</td>
<td>3.3</td>
</tr>
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</table>
Figure 4 - Fecal Counts in BCDMH Pilot

- 3 mg/L (as chlorine)
- 6 mg/L (as chlorine)
- 12 mg/L (as chlorine)
Figure 5 - *E. coli* Counts in BCDMH Pilot

![Graph showing the number of cfu/100mL over minutes for different chlorine concentrations (3 mg/L, 6 mg/L, 12 mg/L as chlorine). The y-axis represents the number of cfu/100mL, and the x-axis represents minutes. The graph includes error bars for the measurements.](image-url)
Figure 6 - *Enterro* Counts in BCDMH Pilot

![Graph showing *Enterro* counts over time for different chlorine concentrations (3 mg/L, 6 mg/L, 12 mg/L) with time in minutes on the x-axis and cfu/100mL on the y-axis.](image-url)

- **3 mg/L (as chlorine)**
- **6 mg/L (as chlorine)**
- **12 mg/L (as chlorine)**
Figure 7 - Comparison between BCDMH and NaOCl

A: Fecal Coliform Kills from Bench Scale Tests: Performed by EBARA

B: Fecal Coliform Count from Bench Scale Tests: Performed by Akron
Disinfection Byproducts

Haloacetic acids and trihalomethanes were measured in the samples from the pilot testing.

Figure 8 shows the results averaged from the three wet weather tests. Trihalomethanes did not exceed levels established as acceptable by the USEPA. However, haloacetic acids produced from 12 mg/L after five minutes of contact did exceed USEPA allowable limits for concentration in drinking water by 40 percent. While effluent from satellite CSO facilities may not be expected to reach drinking water standard limits, due to dilution that could be provided by receiving waters, these limits serve as a point of reference for this investigation. From the curve produced by these results, it appears a maximum dose of 9 mg/L will prevent this exceedance, but more testing will be necessary to substantiate this conclusion.

Figure 8 - Disinfection Byproducts Generated by BCDMH
Toxicity

The Acute Whole Effluent Toxicity test results are reported as percentage of sample required to kill 50 percent of the test specimens (LC50). Therefore, when the background samples (dosages of 0 mg/L) are reported to be 100 percent, the undiluted sample produced a 50% or less mortality rate in the test organisms. If the result was 50 percent, this would mean that a sample diluted in half would kill 50 percent of the test organisms. Therefore, a result of 100% indicates a sample is minimally toxic, and lower values indicate more toxic samples.

The average toxicity for the three wet weather test events for each toxicity are shown in Figure 9. There was some toxic effect on Daphnia from the BCDMH, but the toxicity did not increase for this species with increasing dose of BCDMH. For the Fathead Minnow there appears to be little effect.

These acute toxicity tests were done on samples directly from the effluent of the pilot, and do not reflect dilution from the receiving water. Therefore it can be assumed that actual toxicity in receiving water will be less.

Figure 9 - Average Toxicity Results
Coupled with Compressed Media Filtration

The results from testing the effectiveness of BCDMH and NaOCl following treatment by compressed media filtration shows that BCDMH is much more effective than NaOCl, and achieves a 4-log reduction in fecal coliform after only 3 minutes. This can be attributed to the reduction in demanding material since research shows that bromine is more reactive on such material than chlorine, or it can be attributed to increased bacteria exposure to the active biocides as there is less solids to harbor bacteria. A plot of the comparison of reductions in fecal coliform from BCDMH and NaOCl is shown in Figure 10.

Figure 10 - Comparison of Fecal Coliform Reduction Following Compressed Media Filtration

Operations

The pilot unit was run for two hours to test reliability of the dissolution and injection equipment to produce a constant strength solution. Samples were taken every 20 minutes. The results show that the dissolution and injection equipment produced consistent strength. Longer term trials are required to test reliability of the equipment.
CONCLUSIONS

Disinfection Effectiveness

BCDMH proved to be an effective disinfectant which achieves comparable kills to NaOCl over a shorter period of time. This can reduce the size of a contact chamber for disinfection treatment at the selected peak design flow. This difference can be significant for large combined sewer treatment systems.

The USEPA criterion for haloacetic acids was exceeded only at the higher dose of 12 mg/L. A receiving water dilution of 40% would result in acceptable levels.

There was some observed acute toxicity from the pilot unit. Additional testing would be required to establish the variability of influent characteristics and their impact on chronic and acute toxicity before full scale implementation.

Results from testing BCDMH following compressed media filtration show that BCDMH is more effective than NaOCl at reducing fecal coliform where such treatment is provided. More testing is needed to verify these results on other bacteria indicators.

Comparison to Sodium Hypochlorite

Cost. A typical high-rate disinfection facility requires the following equipment:

- A contact chamber sized to treat the peak flow for at least 5 minutes
- High-rate induction mixers for chlorination and dechlorination
- Feed pumps and equipment
- Tankage (or hopper) for storage of chemicals
- Miscellaneous piping, control, and safety items

A facility that uses BCDMH will need all of the same equipment listed above with the exception of tankage to store chemicals. In addition, it will need a dissolution and injection unit (which has a hopper to store the powder). However, the increased cost from the BCDMH equipment represents only 7 percent of the total capital cost of an average facility, based on data from previous studies. See Table 2 for a breakdown of costs for equipment and chemical usage for units sized for several of Akron’s proposed facilities.
Table 2 - BCDMH Chemical and Equipment Costs

<table>
<thead>
<tr>
<th>Hydraulic Parameters</th>
<th>CSO 33</th>
<th>CSO 36</th>
<th>CSO 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of Overflow (avg. annual)</td>
<td>MG</td>
<td>1.5</td>
<td>7.8</td>
</tr>
<tr>
<td>Peak Rack Treatment rate</td>
<td>MGD</td>
<td>3.6</td>
<td>22.6</td>
</tr>
<tr>
<td>Average BCDMH Dosage(^a,(^b))</td>
<td>mg/L</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Maximum Possible BCDMH Dosage(^a)</td>
<td>mg/L</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BCDMH Injection Equipment</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate of BCDMH (at max dosage)</td>
<td>lbs per min</td>
<td>10.7</td>
<td>67.4</td>
</tr>
<tr>
<td>BCDMH Injection Equipment Cost US$</td>
<td></td>
<td>80,000</td>
<td>168,000</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>BCDMH Powder</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BCDMH Chemical consumption(^c)</td>
<td>ton per year</td>
<td>0.09</td>
<td>0.46</td>
</tr>
<tr>
<td>BCDMH Chemical Cost US$ per year</td>
<td></td>
<td>400</td>
<td>2,300</td>
</tr>
</tbody>
</table>

\(^a\): As chlorine  
\(^b\): Based on variable dosing over period of CSO event  
\(^c\): BCDMH is 56% active halogen agent (by weight)  
\(^d\): Cost is premised on manufacturing in USA and not guaranteed.

The major advantage in using BCDMH is the savings in the contact chamber. The BCDMH using high-rate induction mixers can effectively disinfect within three minutes whereas NaOCl typically requires five minutes. Inasmuch as the contact chamber represents over 90 percent of the capital cost, this represents a savings of three-fifths x 90 percent or 54 percent. The cost difference in all other equipment is within 10 percent and is essentially the same.

**Operation and Maintenance.** Operational differences are more difficult to identify since the BCDMH equipment has been operated for a limited period of time at a small scale at the Akron WPCS as opposed to NaOCl facilities that have a long history of operations at large scale facilities. Safety requirements for NaOCl are subject to the regulatory requirements of bulk handling and storage above 185 gallons of liquid stored. The requirements for storing powdered BCDMH are not known at this time. Handling and risk exposure are seemingly less for the BCDMH but there is a greater need for operational experience. Equipment maintenance would appear to be more for the BCDMH owing to the number of distinct operating units but this too requires greater operational input. Table 3 shows a comparison of the relative O&M labor required for a facility using BCDMH versus NaOCl which reflects the input from Akron Operations staff.

The pilot unit was run using air from plant air supply, which is dried using a desiccant. Further large-scale testing is necessary to understand what the effects of long-term storage will be regarding caking of the BCDMH powder in the hopper. Also, a better understanding of the units currently in operation in Japan would give greater insight into air supply requirements, such as drying and heating. Similarly, knowledge of enclosure requirements (type of building, heating) based on existing installations would be valuable.
Table 3 - O&M Labor Comparison

<table>
<thead>
<tr>
<th>Operations</th>
<th>NaOCL</th>
<th>BCDMH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Requirements</td>
<td>stipulated</td>
<td>not known</td>
</tr>
<tr>
<td>Handling</td>
<td>more</td>
<td>less*</td>
</tr>
<tr>
<td>Risk Exposure</td>
<td>more</td>
<td>less*</td>
</tr>
<tr>
<td>Equipment Maintenance</td>
<td>less</td>
<td>more*</td>
</tr>
</tbody>
</table>

* = limited experience

RECOMMENDATIONS

Given the effectiveness of BCDMH at comparable costs to NaOCl, it is recommended that full-scale facilities be operated side by side with NaOCl facilities at an existing CSO over a year to confirm operational advantages.

For greatest assurance of disinfection effectiveness, the full-scale pilot should follow preliminary treatment such as storage or vortex separation, and should include high-rate induction mixing.

This full-scale testing should include additional testing to determine the optimum dosage. Such testing should be conducted under a quality control and assurance program that complies with USEPA QAPP standards for research model development and application projects (USEPA 1991).
ACKNOWLEDGEMENTS

Thanks go to Akron WPCS Staff at the plant and in the lab, for their high level of professionalism. Without their significant investment in time and interest, above and beyond what was expected, this pilot test would not have been successful.

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