

Report as of FY2008 for 2008KY118B: "Inventory and assessment of combined sewer overflow discharges within Kentucky communities"

Publications

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Report Follows

Inventory and Assessment of Combined Sewer Overflow Discharges within Kentucky Communities

Problem and Research Objectives

Wet weather flows (WWFs) consist of combined sewer overflows (CSOs), sanitary sewer overflows (SSOs) and storm water discharges from municipal separate storm sewer systems (MS4s). Each of these types of WWFs can cause water quality violations in surface waters, exceeding water quality standards designed to protect human health and aquatic life in receiving waters. Nationwide, approximately \$50.6 billion dollars will be needed to reach an 85% reduction in CSOs by volume and approximately \$4 billion will be needed to address the reduction of SSOs (EPA, 2004). In the state of Kentucky, 17 communities have been mandated by the Kentucky Department of Environmental Protection and the US EPA to address their WWFs. The three largest sewer districts, Louisville, Northern Sanitation District 1, and Lexington are facing estimated costs of \$500 million, \$880 million and \$300 million, respectively, to bring their WWFs into compliance with the Clean Water Act.

While traditional technologies exist to address WWFs, they are often cost prohibitive to the rate payers of the individual communities faced with the responsibility of compliance. Many of the current technologies can yield toxic by-products. In areas of older infrastructure, space for facilities to treat overflows is often limited if available at all. As such, more cost effective technologies requiring less space and producing less harmful by-products are currently being explored. One possibility is alternative high-rate disinfection using peracetic acid (PAA). The decomposition of peracetic acid results in only the non-toxic by-products oxygen, carbon dioxide and water. The disinfection reaction occurs in a short contact time and with a high kill rate. Thus, this technology can prove effective where space is limited, but it is also extremely environmentally sound. The objective of this research is twofold; 1) to determine the effectiveness of PAA as a disinfectant for WWFs and 2) to determine the cost of implementing PAA as a high-rate disinfectant in comparison to traditional technologies.

Methodology

The CSO Control Policy indicates that CSOs should receive a minimum of: 1) “Primary clarification (removal of floatables and settleable solids may be achieved by any combination of treatment technologies or methods that are shown to be equivalent to primary clarification.)”; 2) “Solids and floatables disposal”; and 3) “Disinfection of effluent, if necessary, to meet water quality standards, protect designated uses and protect human health, including removal of harmful disinfection chemical residuals, where necessary.” Since it is apparent that CSO discharges will require primary clarification and solids and floatables removal prior to disinfection, the WWFs investigated in this research were also assumed to have equivalent preliminary treatment prior to the disinfection process. The source of simulated WWFs used in

experimentation was the primary effluent of the Lexington, Kentucky Town Branch Wastewater Treatment Plant that had received both primary clarification and solids and floatable removal. The water quality was varied to simulate a representative range of WWFs including 1) dilute storm water, 2) moderate strength combined sewer overflow water, and 3) concentrated sanitary sewer overflow water by using different dilution factors with the same primary effluent.

Once the primary effluent sample was collected and the simulated WWF was generated, the initial concentration of E coli., ammonia, total phosphorus, total suspended solids, chemical oxygen demand, pH, specific electric conductance and dissolved oxygen were monitored and recorded prior to treatment. These parameters are commonly monitored at permitted facilities that have discharge limits for the treated water and each of these parameters may affect the efficiency of the disinfectant.

In order to determine the effectiveness of PAA as a disinfectant, each of the simulated WWFs was treated with nine different combinations of PAA dose (mg/l) and contact time (minutes). In addition, replicate data were secured for statistical analysis and for quality control and assurance (each treatment done in triplicate at least three times on varying water qualities). Based on the range of water quality being investigated and some preliminary bench testing, PAA doses of 5, 10 and 15 mg/l appeared to be strong enough to meet water quality standards. In addition, contact times of 2, 5 and 10 minutes were used since traditional technologies are commonly designed for 15 minute contact times. Shorter contact times are desired as they translate into cost savings by reducing the size (capital costs) of disinfectant contact tanks and making disinfection more feasible in areas with limited space. The remaining E coli. concentration was monitored for each treated sample at the end of each contact time to determine the difference between the initial and final concentration (the total kill) for each treatment. The process by which data were collected to analyze the performance of PAA as a disinfectant is shown in Figure 1.

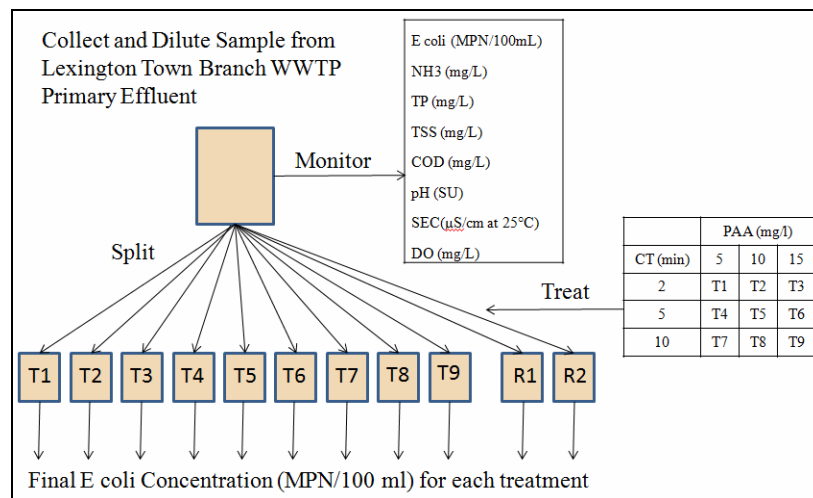


Figure 1. Data Generation Process to Determine the Efficacy of PAA as a Disinfectant

A mathematical relationship can be developed such that the performance of the disinfection system can be modeled given the initial concentration of E coli., the concentrations of other possible influential parameters, the final concentration of E coli., the dose of PAA applied, and the contact time. Given any water quality (within the range modeled), the dose, the contact time, and the final E coli concentration can be determined and likewise the attainment of water quality standards can be determined. To date, this system has been modeled with multivariate regression analysis using *SAS* (a proprietary statistical analysis package). However, genetic algorithm fixed set function analysis will also eventually be used to generate a model of the PAA disinfection system. In the end, a comparison of the genetic algorithm function and the multivariate regression equation will be conducted to determine which model is more accurate. This evaluation will be based on the calibration and validation results.

Non-linear constrained optimization will be performed on the superior numeric model as determined above. The optimized system model should yield, given a specific initial water quality, the most cost effective combination of disinfectant (PAA dose) and capital costs (based on contact time) over the anticipated life of the facility that will consistently meet water quality standards. In order to predict the optimal combination of PAA dose and contact time, the Shuffle Complex Method of optimization will be used. In the end, this information will indicate the cost of this technology to meet water quality standards and to determine if it is cost competitive with traditional technologies. If it is determined that this technology is more expensive than traditional technologies, the modeling techniques can also be used to determine what the cost of this technology (particularly the chemical costs) needs to be to compete with the traditional but larger and less environmentally sound technologies.

Principal Findings and Significance

The efficiency of the PAA was measured using E coli. concentrations that were considered strong, medium and weak WWFs. The strong WWFs ranged from approximately 1,500,000 MPN/100 ml to 1,000,000 MPN/100 ml. Moderate WWFs were considered those flows with E coli. concentrations less than 1,000,000 MPN/100 ml but greater than 100,000 MPN/100 ml. Finally, weak WWFs were those with concentrations less than 100,000 MPN/100 ml. For each strength, the combinations of contact time (i.e. 2, 5 and 10 minutes) and PAA concentration (i.e. 5, 10, and 15 mg/L) were evaluated.

Figure 2 presents the performance curves for varying strengths of WWFs. A concentration of 1,000 cols/100 ml is met with 10 - 15 mg/l of PAA in two to five minutes. In addition, the primary water quality standard of 130 col/100 ml is met with 15 mg/l PAA up to a concentration of 1,500,000 MPN/100 ml and with 10 mg/l PAA up to 1,000,000 MPN/100 ml within five minutes. One thing to note from each of these figures is that the majority of kill occurs in the first 5 minutes (regardless of the initial concentration) using either the 10 or 15 mg/l PAA dosages.

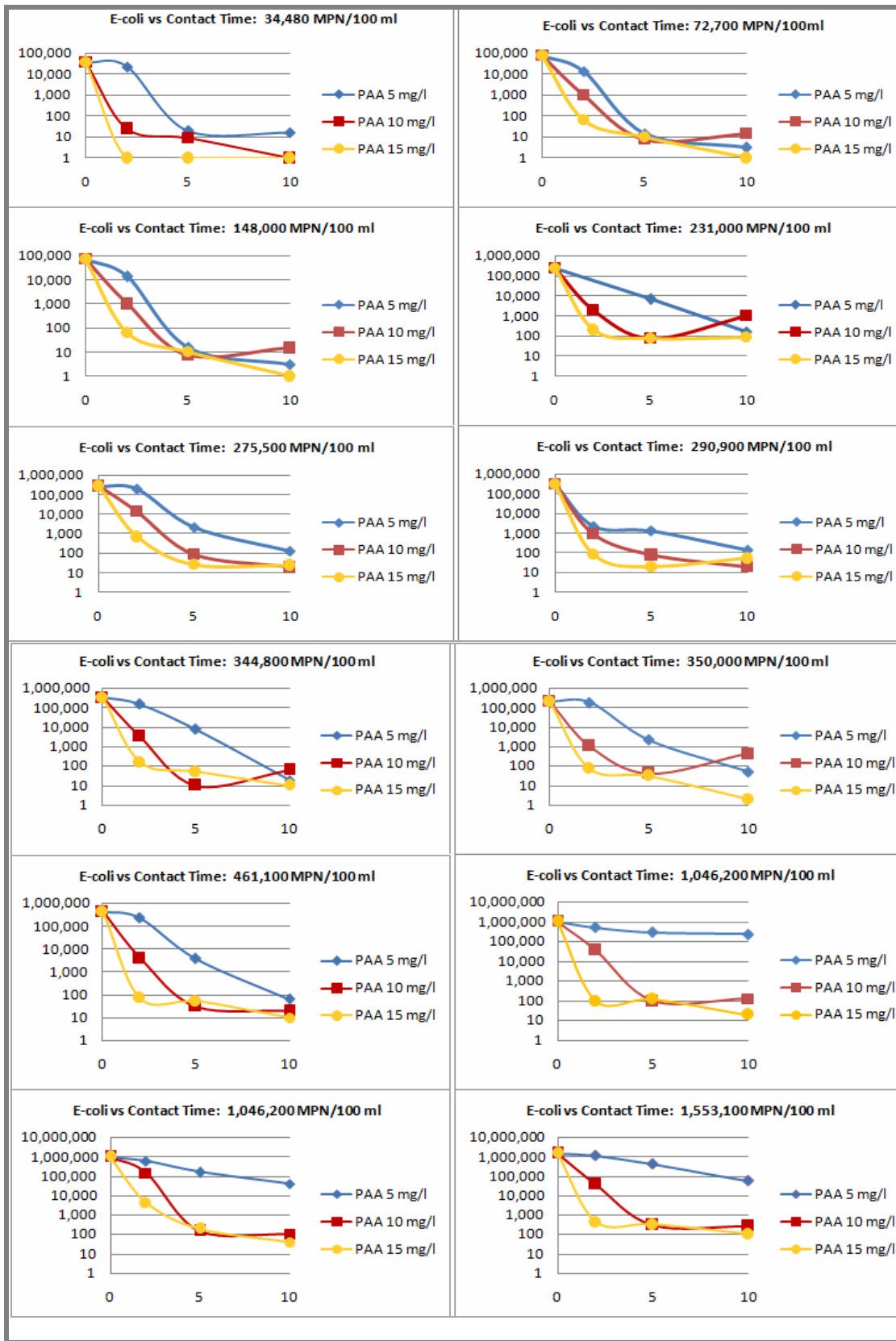


Figure 2. Performance Curves for the Disinfection of E coli with PAA

For moderate WWFs, the primary water quality standard for E coli. of 130 cols/100 ml is met consistently with the 10 and 15 mg/l doses and achieved or very closely approached with 5 mg/l. With a contact time of 2 minutes, this water quality standard is met with the 15 mg/l dose and again the majority of the disinfection occurs within the first 5 minutes (if not the first two) with the higher dosages. If a 10 minute contact time is desired such that less PAA is used, it appears that a dose of 5 mg/l or slightly higher would achieve primary water quality standards. All doses applied to moderate strength WWFs achieved concentrations less than 1,000 cols/100 ml. As with the moderate strength WWF results, weak WWF tests resulted in the three doses achieving primary water quality standards with the majority of the disinfection occurring within the first 5 minutes of treatment.

Based on the data generated for the performance curves and the water quality parameters monitored, multivariate regression analysis was performed on a number of statistics with the most closely identified distributions as follows:

- Normal Distribution
Percent Kill Rate = $\frac{\text{Initial Concentration} - \text{Final Concentration}}{\text{Initial Concentration}} \times 100$
- Negative Binomial Distribution
Total Kill = $\text{Log}(\text{Initial Concentration} - \text{Final Concentration})$
- Logistic Distribution
Kill Rate = $\frac{\text{Initial Concentration} - \text{Final Concentration}}{\text{Initial Concentration}}$

Using the percent kill rate, which closely approximated a normal distribution, the best fit model yielded Equation 1. The multivariate regression modeling of this statistic resulted in a better fit without the influence of the additional water quality parameters. However, it did not yield a model with an acceptable level of performance.

$$(\text{EO}-\text{EF})/\text{EO} \times 100 = (65.025 + 1.874 \times \text{PAA} + 1.729 \times \text{CT}) \quad \text{Eq. 1}$$

Total kill was found to closely mimic a negative binomial distribution which when limited to positive values yields a Poisson distribution (as is commonly found in bacteriological data). The multivariate regression analysis again yielded an equation that resulted in a better fit without additional parameters. Equation 2 is the best fit equation based on total kill with a negative binomial distribution. Again, this model does not meet an acceptable level of performance.

$$\text{EO}-\text{EF} = e^{(-4.1434 + 1.0958 \times \text{Log}(\text{EO}) + 0.0234 \times \text{PAA} + 0.0205 \times \text{CT})} \quad \text{Eq. 2}$$

Finally, kill rate was analyzed as logistically distributed (rather than normally distributed as with percent kill rate). Equation 3 resulted from this analysis and yielded an acceptable r-squared value of 0.71. The model of this statistic resulted in a better fit when all water quality

parameters were taken into consideration. Thus, this multivariate function accounts in part, for the influence of the other water quality parameters.

$$(EO-EF)/EO = 1/[1+e^{-(-17.8373+(0.5691)PAA+(0.4252)CT+(0.3421)NH_3+(0.4815)pH+(0.00358)SEC+(0.1609)TP+(0.00791)TSS-(0.0401)COD-(0.0176)DO)}] \quad \text{Eq. 3}$$

It appears that PAA is an appropriate disinfectant for WWFs with harmless byproducts and shorter contact times than traditional disinfection technologies. Potential cost savings are apparent although they have not yet been fully quantified. It has been estimated that 30% of capital costs for traditional technologies is for de-chlorination. Thus a 30% reduction in capital costs for disinfection systems can be realized with PAA while meeting water quality standards. In addition, due to the speed of the disinfection reaction, the remaining 70% of capital costs for disinfection can be further reduced by perhaps 1/3 to 2/3 because disinfection can be done in 1/3 or 2/3 of the contact time. Based on preliminary results, it appears that PAA will be highly cost competitive from a capital cost perspective. Upon finalization of the modeling and cost optimization (which will include both capital and chemical costs) a determination of cost competitiveness for the entire system will be completed.

References

- USEPA. 2004. Office of Water. *Report to Congress Impacts and Control of CSOs and SSOs*. EPA 833-R-04-001. Electronic source: http://cfpub.epa.gov/npdes/cso/cpolicy_report2004.cfm
- USEPA. 2002. Office of Research and Development. *Cost of Urban Stormwater Control*. Cincinnati, OH. EPA 600-R-02-021.
- USEPA. 1999. Office of Water. *Combined sewer overflow technology fact sheet: alternative disinfection methods*. Washington, DC, USA. [EPA 832-F-99-033].
- USEPA. 1993. Office of Research and Development. *Combined Sewer Overflow Control*. Washington, DC, USA. [EPA 625-R-93-007]