# *Wastewater Disinfectant Technologies a Comparative Review of the Benefits and Disadvantages of the Implementation of Peracetic Acid versus Chlorine*

*Roberto C. Ramos Torrens*
*Master of Engineering in Civil Engineering*
*Christian A. Villalta Calderón, PhD.*
*Civil and Environmental Engineering Department*
*Polytechnic University of Puerto Rico*

***Abstract*** — *Disinfection in wastewater treatment plants is an essential part of the daily process. It can be said that the majority of municipal wastewater treatment plants utilize chlorine in gas or liquid as their primary method for treating their daily water flow. Recently, studies to analyze various alternative disinfectant products have been carried out. This work presents a review analysis of the disinfection efficiency and the advantages and disadvantages of implementing peracetic acid as the main source of disinfection in a wastewater effluent. It also presents the first and only municipal wastewater treatment plant in Puerto Rico to implement peracetic acid as its main effluent disinfection chemical. The investigative review has concluded that peracetic acid is an effective disinfectant in treating municipal wastewaters. Given the various advantages like safety, economic and operational improvements it can be said that the use of peracetic acid as a disinfectant is a validated alternative to the traditional use of chlorine.*

***Key Terms*** — *Alternative Disinfectants, Disinfection, Peracetic Acid, Wastewater.*

## INTRODUCTION

As of today there are many alternative techniques for wastewater disinfection that can be used individually or in combination. Some of these traditional disinfection alternatives include chlorine compounds (gas and liquid), chlorine dioxide, ultraviolet (UV), and ozone. Recently there's been a movement towards finding new viable technics of disinfection for wastewater effluents. Just recently the environmental protection agency (EPA) published the acceptance of peracetic acid (PAA) also known as peroxyacetic acid. Chlorine gas is still globally the most common disinfectant used due to its low cost and high volume manufacturers, however the awareness of harmful disinfection by-products or DBP's (e.g. trihalomethanes) which are potentially mutagenic and/or carcinogenic [3], have sparkled a recent movement to find a new disinfection chemical capable of complying with regulatory measures and eliminating the production of dangerous DBP's which are a health hazard. The importance of treating and ensuring the safety of the wastewater effluent with a disinfectant capable of removing bacteria and not production DBP's is that the wastewater industry is moving towards the reuse of this vital and scarce resource. Wastewater industry is implementing studies and regulatory parameters to reuse the effluent water for farming irrigation and other activities which in the past wasn't practiced but increase of global population, industries and the ever changing climate has obligated to foresee this alternative of reuse treated water. As stated before the product that's been considered is peracetic acid (PAA), which has strong oxidizing properties due to the series of reactions that take place during decomposition leading to the formation of acetic acid, oxygen and hydrogen peroxide. It has already been used as a disinfectant in the food and pharmaceutical industries, and more recently in health environments. Peracetic acid has been proposed as a disinfectant for urban sewage either alone [2], [4], [5], [6], [7] or in combination with ultraviolet irradiation [8]. This combination is been implemented in Puerto Rico's municipal waste water treatment plant in Caguas.

## JUSTIFICATION

The everyday more restrictive parameters to which waste water is being measured. Existing traditional disinfection technics, the inquietude to improve the standard of operation and to introduce a practice that can be utilized as a viable alternative in Puerto Rico's waste water treatment industry, induced the motivation to present the methodology used in this research.

Peracetic acid (PAA) is currently used in various countries in Europe like Italy (see Figure 1) and recently has been tested and approved for use in St. Augustine wastewater plant in Florida which can be the model to become a common practice in some of the states of the United States of America. Puerto Rico can be part of this group if more pilot cases of peracetic acid are conducted and recommended to be used in the wastewater practice by the federal and the local agencies.

**Figure 1**
**Nosedo WWTP, Milan Italy**

## LITERATURE REVIEW

Wastewater treatment is the science that encompasses the treatment of the used waters such as municipal and industry. The typical configuration for a wastewater treatment plant is based on physical and chemical processes, biological treatment, clarification, sedimentation, and disinfection (see Figure 2).

Wastewater treatment plants can be secondary or tertiary depending of the treatment goals it wants to achieve but the one process for which every wastewater treatment plant has to have is the disinfection part. Disinfection is the part of the treatment, usually the last step in the wastewater treatment process, that ensures the bacteria, viruses and coliforms are eliminated.

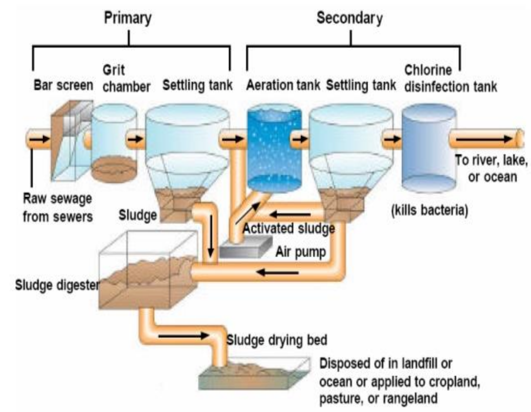


**Figure 2**
**Wastewater Treatment Plant**

For years the chosen technic has been chlorine in gas form under pressure and delivered in ton tanks or cylinders. Since the early 1900s chlorine has been used as a wastewater disinfectant been the favorite among industries to treat their wastewater until Rook [1] discovered the production of several harmful disinfection by products (DBPs) in chlorinated water. Since then the wastewater industry has been studying disinfectant alternatives such as ozone, UV, PAA, and Hydrogen Peroxide (HP) to substitute chlorine treated wastewater. Currently chlorine is proven to be the main source for causing several harmful disinfection by products (DBPs). Chlorine is relatively cheap because of its high demand and various local producers. The advantages of disinfecting with chlorine is that it is proven effective in destroying pathogenic organisms, its cost effectiveness against any other disinfectant alternative and its flexible dosage and residual control. Some of the disadvantages in using chlorine as a disinfectant are: high residuals dosages can be harmful to aquatic life, it requires dechlorination prior to discharge, produces harmful disinfection byproducts DBPs, such as trihalomethanes, it requires to meet OSHA and other rigorous safety standards and protocols.

On the other hand peracetic acid (PAA), also known as peroxyacetic acid has been used for a long time in the food, health paper and pulp industries as an effective disinfectant. Europe countries, especially Italy, have demonstrated its capabilities as a disinfectant for wastewater effluent because of its similar disinfection abilities to chlorine, without producing any harmful DBPs [9]. Peracetic acid is formed by the combination and reaction of acetic acid and hydrogen peroxide giving the following chemical **Equation 1**: [1]

$$CH3COOH + H2O2 \rightarrow CH3COOOH + H2O \qquad (1)$$

Advantages in using peracetic acid (PAA) is the lack of production of harmful disinfecting by products (DBPs), minimal dependency to pH, no dechlorination for high residuals, safe handling and storage and low capital operation and maintenance cost. Some of the disadvantages are no high residual concentrations, high production cost, because of the lack of few local manufacturers.

Studies showed that peracetic acid dosage depends on wastewater bacterial quantity and contact time. Typical dosages vary from 0.50 to 2 mg/L of PAA on secondary effluent, 5-10 mg/L of PAA in enhanced primary and 10-20 mg/L of PAA in raw wastewater. For contact times the typical times were 10 to 30 minutes. The majority of the peracetic acid (PAA) reacted within the first 10 minutes of contact with wastewater.

When costs are discussed some pilot studies found that peracetic acid (PAA) treatment could reduce chemical volume up to 90 percent and was 10 percent less expensive than a chlorination/dechlorination system.

## METHODOLOGY

The following information explains methodology used in this research. First several papers were reviewed in order to obtain the academic studies performed. In base of what has been done with the peracetid acid (PAA) actual study cases were selected to compare the findings. Peracetic acid was tested in various scenarios with the following parameters in mind: pH, total suspende solids (TSS), contact time, E.coli removal, total coliform removal and dosages.

Costs and safety advantages are part of the final assessment based on the case studies findings.

## CASE STUDIES

### ST. AUGUSTINE WWTP [10]

Two case studies were selected in order to demonstrate the disinfecting capabilities of peracetic acid when compared to chlorination. The first one was performed in St. Augustine wastewater treatment plant in Florida (see Figure 3).

**Figure 3**
**St. Augustine WWTP, Florida**

Wastewater treatment plants are required to disinfect effluent prior to discharge in order to destroy any pathogenic organisms present in the water in order to guarantee public health safety. Chlorine has been the principal disinfection method in the wastewater industry, despite the fact that disinfection with chlorine produces chlorinated disinfection byproducts (DBPs), including trihalomethanes (TTHMs), that are toxic to aquatic life. In recent years, many municipalities have been required to install dechlorination systems in order to address the disinfection by products (DBPs) problem. The major concern for every wastewater treatment plant is the fact of upgrading an existing plant with a dechlorination process which implies high capital cost and operational complexity. When the study case began, the 2.7 million-gallon-per-day (MGD) wastewater treatment plant in St.Augustine, Florida had a working chlorination/dechlorination disinfection system. Because of the various concerns mentioned before the plant administration started seeking for alternative disinfection processess that did not generate DBPs, was cost effective, and was simple to operate. The plant investigated disinfection options such as ozone and ultraviolet disinfection, but peracetic acid (PAA) disinfection was deemed the most attractive option because the plant's existing contact chamber could be used for the PAA technology. By having the option of reusing existing infrastructure it gave an extra incentive because of the large capital cost savings to the municipality. After successful bench-scale testing with PAA, a full-scale demonstration test was conducted to evaluate the performance of the PAA disinfection system compared to the existing chlorination/dechlorination system, based on several evaluation criteria: disinfection performances, aquatic toxicity, disinfection byproducts and chemical consumption/sustainability.

### Peracetic Acid (PAA) used in Trial

The chemical chosen is a proprietary 15-percent peracetic acid formulation that is approved by the U.S. Environmental Protection Agency for wastewater disinfection, EPA Reg. No. 65402-8. It was provided with the information that when the peracetic acid (PAA) reacted it broke down into the non-harmful products: water, oxygen, and acetic acid (vinegar).

### St. Augustine WWTP Disinfection Layout

The St. Augustine Wastewater Treatment Plant has two identical disinfection contact tanks. Each tank receives 50 percent of the 2.7-MGD plant flow. The peracetic acid (PAA) disinfection system consisting of a storage tank, a dispensing system or pump skid, and a (PAA) residual monitor to treat the first contact tank which treated the 50 percent of the entering wastewater. For the second contact tank the existing chlorination/dechlorination system continued its normal operation treating the other 50 percent of the wastewater entering. The plant's flow data, pathogen counts, chemical dosage rates, and residual data were recorded during the trial.

### Trial Tests Results Analysis

Both wastewater disinfectants, peracetic acid (PAA) and chlorine, performances were based on the removal efficiency of *enterococci* and *fecal coliform* (FC). Effluent "grab" samples from both disinfection tanks were performed several times during the week. The Enterococci bacteria tests showed that an average concentration or dosage of 1.5 parts per million (ppm) of peracetic acid (PAA) reduced the *enterococci* count between 1 and 6 CFU/100mL, this result was well below the plant's discharge limit of 35 CFU/100mL. The applied average chlorine dose was 7 ppm and it gave similar *enterococci bacteria removal* results. Only to one result came at 29 CFU/100mL. The results demonstrated that the plants dosage of peracetic acid could be a lot less than that of chlorine and still remove efficiently the *enterococci* bacteria. This reduction in chemical consumption can result in an economic improvement.

The other parameter tested was that of fecal Coliforms (FC) or total coliforms as is demonstrated in other studies. When the study started the registered plant's discharge permitted limit for total coliforms was 200 CFU/100mL. Results showed that peracetic acid (PAA) treatment performance was almost identical to the results of the chlorination/dechlorination treatment. Reported data showed that an average dosage of 1.5 ppm of peracetic acid (PAA) gave similar disinfection performance to an average chlorine dosage of 7 ppm, and that both disinfection processes were effective in keeping total coliform count below the permitted discharge limit.

### Water Toxicity Tests Performed

Water toxicity can produce severe adverse effects on the biological ecosystem by damaging its infrastructure and causing death to marine life in the body of water were wastewater effluent is discharged. The criteria used for water toxicity testing are mortality and reproduction rate. For this tests *Mysidopsis bahia* (mysid shrimp) and *Menidia beryllina* (tidewater silverside) were the species chosen for both the acute and the chronic toxicity testing. During the trial, testing for acute and chronic toxicity at dilution levels ranging from 0 percent (control) to 100 percent effluent. The first set utilized treated effluent from the chlorination/dechlorination process (see Table1).

**Table 1**
**Toxicity Results from Chlorination/Dechlorination**

| | *M. bahia* | | *M. beryllina* | |
|---|---|---|---|---|
| % | Survival | Growth | Survival | Growth |
| Control | 97.5 | 0.390 | 100 | 2.096 |
| 6.25 | 85 | 0.375 | 97.5 | 1.986 |
| 12.5 | 97.5 | 0.415 | 97.5 | 2.333 |
| 25 | 90 | 0.372 | 100 | 2.226 |
| 50 | 77.5 | 0.414 | 100 | 2.562 |
| 100 | 82.5 | 0.377 | 97.5 | 2.506 |

The second set utilized the PAA-treated effluent (see Table 2).

**Table 2**
**Toxicity Results from PAA**

| | *M. bahia* | | *M. beryllina* | |
|---|---|---|---|---|
| % | Survival | Growth | Survival | Growth |
| Control | 92.5 | 0.353 | 100 | 2.374 |
| 6.25 | 90 | 0.383 | 100 | 2.487 |
| 12.5 | 95 | 0.380 | 100 | 2.491 |
| 25 | 95 | 0.396 | 100 | 2.426 |
| 50 | 90 | 0.377 | 100 | 2.563 |
| 100 | 97.5 | 0.358 | 97.5 | 2.337 |

The toxicity results show a higher survival rate for the M. bahia and the M. beryllina in the PAA treated effluent when compared to the chlorination/dechlorination treated effluent. The growth rate results for both disinfection systems were comparable. The overall trend showed that PAA was slightly less toxic to aquatic life than chlorination/dechlorination.

### Disinfection by Products (DBPs) Tests Results

Disinfection by products (DBPs) are chemicals formed as a result of the reaction between the disinfectant added to the water and any naturally occurring organic material present in the wastewater. The U.S. Environmental Protection Agency has established discharge effluent limits for disinfection by products (DBPs). Untreated effluent grab samples were taken from the plant’s side stream and tested for disinfection by products (DBPs) once chlorine was added (chlorine start), after disinfection was completed (chlorine end), and after the dechlorinating agent was added (after dechlorination). Total trihalomethanes (TTHMs) concentration was found to be 194.19ug/L after disinfection. After the dechlorinating agent was added, TTHMs concentration decreased to 170.70ug/L, suggesting that the dechlorinating agent had only a limited capability of reducing TTHMs concentrations. Results showed that there were virtually no TTHMs generated by the PAA disinfection process. Currently one of the major problems many wastewater treatment plants are facing is that they are not complying with the disinfection by products limits. This study analysis demonstrated that a conversion to peracetic acid as their disinfectant can probably eliminate the disinfectant by products problem.

### Chemical Consumption

The plant’s monitoring system data showed that the average chemical usage for chlorination/dechlorination system was 235 gallons per day, while the PAA system used only 23 gallons per day of chemical to meet the same disinfection requirements. This confirms the economic savings in chemical consumption giving peracetic acid another edge against chlorine systems. Plant operators observed that the PAA treatment was easier to adjust and maintain dosing in response to rapid changes in plant flow rate, compared to the chlorine system. This may be attributed to the lower PAA chemical feed rate compared to that of chlorine. Field studies have demonstrated that changes in wastewater characteristics can impact the dosage of PAA required for effective pathogen control.

## CAGUAS MUNICIPAL WWTP

The Caguas WWTP is the largest wastewater plant in the Puerto Rico Aqueduct and Sewer Authority's Eastern Region. Situated approximately 22 miles south of San Juan, Caguas has a population of 141,000 people which produce an average daily flow rate of 13 million gallons per day (MGD). The Caguas WWTP is an advance treatment plant that just recently started implementing peracetic acid (PAA) as their main disinfection chemical (see figure 4).

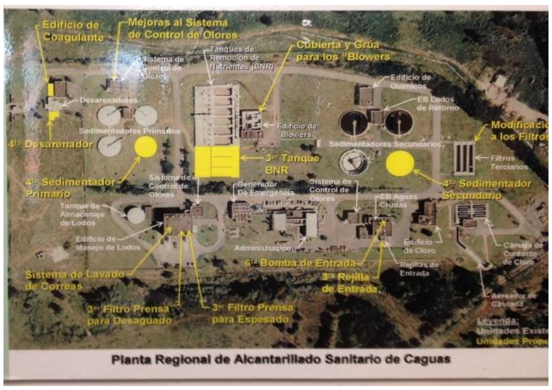


**Figure 4**
**Caguas Municipal WWTP, Puerto Rico**

A 12 percent base peracetic acid (PAA) product was chosen for the full scale trial which started between March 27th and April 7th of 2011. A total of seven different peracetic acid (PAA) doses were used, these were (3.51, 2.75, 2.5, 1.8, 1.25, 0.8 and 0.625 ppm). The trial began at the Caguas municipal wastewater treatment plant which is a typical tertiary treatment activated sludge wastewater treatment plant. In the plant the water passes though bar screens, degritters, primary clarifiers, aerated sludge basins, final clarifiers, tertiary filters, a disinfection basin, a UV disinfection unit followed by some "aeration stairs" before exiting in a long pipe to the Bairoa River which leads to the source of one of the largest drinking water plants on the island, the Sergio Cuevas Filtration Plant, which provides 100 MGD of drinking water. Ultimately this receiving body becomes a drinking water source for the island. The disinfection basin consists of 4 parallel channels with a capacity of 85,738 gallons each with a total capacity of 338,952 gallons. At a maximum flow rate of 24MGD this gives a minimum retention time of 21 minutes. The Caguas wastewater treatment plant processes approximately 11 million gallons of wastewater per during dry conditions. During the trial the flows ranged from 9.2 – 20.2 MGD with an average of 13 – 14 MGD. The wastewater from the Caguas treatment plant is typically very clean with very low total suspended solids.

## EQUIPMENT AND SAMPLING LOCATIONS

Peracetic acid (PAA) was dosed through one dose point in the common channel after the tertiary filters inside the tertiary filter building (see Figure 5).

**Figure 5**
**Peracetic Acid Injection Point**

This point was just upstream of the underground pipe leading to the disinfection chamber and was adjacent to an overflow from one of the tertiary filters which provided good mixing. The pumps used were motor driven positive displacement diaphragm pumps (Figure 6).

The selected pumps allowed an automaticly controlled flow of the chemical, this guaranteed and keep a constant peracetic acid (PAA) dose to the effluent.

**Figure 6**
**Peracetic Acid Pumps Skid**

At each sampling point, three to four grab style samples were taken. The samples were taken at these locations: Sample point "A" – After the tertiary filters and before the PAA injection, Sample point "B" – After the disinfection chamber in an open channel approximately 40 feet upstream of the UV unit, Sample point "C" – After the UV unit at the bottom of the aeration stairs. Sample point "C" is currently the location of Caguas' NPDES compliance sampling point.

The other sample points taken were: B1, B2, B3, & B4 which represented the beginning of one of the four parallel disinfection chambers. B5 is in the common channel leading to the chambers. Currently the permit limit for total coliforms is 4000 CFU / 100ml and the permit limit for fecal coliforms is 200 CFU / 100ml. Bacteriological tests came back with positive results having removed bacteria to lower quantities than the permit allowed. The tests also showed that the combination of peracetic acid (PAA) and ultraviolet radiation worked in favor of the disinfection effect.

## CASE STUDIES ST. AUGUSTINE WWTP AND CAGUAS MUNICIPAL WWTP RESULTS COMPARISON

After presenting both the St. Augustine wastewater and the Caguas Municipal wastewater case studies there can be said that they yielded similar and positive results. First of all on both case studies peracetic acid (PAA) achieved the desired removal of bacteria in comparison to the chlorine removal. Secondly on both studies it can be demonstrated that the doses were peracetic acid (PAA) achieved satisfactory bacteria removal was much lower than that of chlorine dosage. Another parameter that can be demonstrated is that no harmfull disinfectant by products (DBP's) were created at any dosage amount of peracetic acid (PAA).

## CONCLUSIONS AND FUTURE WORK

As shown in this review there are many advantages for the implementation of peracetic acid (PAA) as the main wastewater effluent disinfectant. Even though peracetic acid (PAA) dosages are dependant of the waste water quality it can be said that and economic advantage can be achieved, but the major advantage of applying peracetic acid is the elimination of disinfection by products (DBPs) caused primarily by a chlorination/dechlorination disinfection system. Future work shall be done in the different scenerios of the various wastewater plants inside the Puerto Rico Aqueduct and Sewre authority to implement the many benefits a peracetic acid (PAA) disinfection system can bring.

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