Electrocution: Solution for the Removal of Escherichia coli from Wastewater

Yanice A. Cesáreo Díaz
Civil Engineering
Roger Malaver, PhD.
Civil & Environmental Engineering
Polytechnic University of Puerto Rico

Abstract — *This project consists proving that there is present an alternative disinfection procedure to remove pathogen indicator bacterium in wastewater. Escherichia coli is removed from the Caguas Regional Wastewater Treatment Plant after wastewater passes the secondary clarifier and filtered. The alternative disinfection procedure is Electrocution.*

The basis of this project consists on the movement of electrons when applying Direct Current (DC) to the bacteria Escherichia coli, producing an alteration in the cell nucleus which results in the removal of the bacteria. A typical electrocution in a convict person depends on its density (mass per unit volume), independently if the living cell is a multi-cellular or unicellular form. Therefore, voltage, amperage, and exposition time should be different for humans and bacteria Escherichia coli. To produce an environmentally-safe wastewater stream (treated effluent), the treatment method should comply with U.S. EPA removal efficiency of 99.99% (log-4) of Escherichia coli.

Key Terms — *Electrocution, Escherichia coli, Log-4, Wastewater.*

OBJECTIVE

This innovative project could be the new change of disinfection in the industry, using an alternative method called Electrocution to substitute Chlorination and UV. In order to prove this hypothesis, a quantitative method is used to count the colonies of the bacteria Escherichia coli and use different materials at different time of contact (Tc) to identify which one maximizes the process.

The goal in this study is to produce an environmentally-safe fluid wastewater stream (treated effluent), that complies with the United States Environmental Protection Agency (U.S. EPA) regulations and the National Pollutant Discharge Elimination (NPDES) Permit of 99.99% (log-4) of removal efficiency for bacteria Escherichia coli.

This Project is distinguished to sight an innovative method of disinfection, in order to possibly change the leading industry of environmental design for future construction and major renovations.

INTRODUCTION

Water is essential to live in our planet. The demand for clean water is a requirement in the U.S. and its territories. Human activities have been threatening our water resources for years and it is the main reason why the Clean Water Act (CWA) of 1972 was created to establish limits and goals for pollutants discharged in our waters. The CWA regulates surface waters quality standards necessary to protect the marine life and maintain the water quality for human use and recreation. The CWA established the NPDES permits for regulating point sources of pollution.

Escherichia coli is not considered a health threat under the EPA regulations, but it is used as an indicator of potentially harmful bacteria. Coliforms are naturally present in the environment; as well as feces; fecal coliforms and Escherichia coli only come from human and animal fecal waste [1].

Treatment Techniques are required processes intended to reduce the level of a contaminant in drinking or waste waters. The Maximum Residual Disinfectant Level (MRDL) is the highest level of a disinfectant allowed. The addition of a disinfectant is necessary for the control of microbial contaminants, allowing margins of safety for public health goals. Using the best available treatment technology and taking cost into consideration, the Maximum Contaminant Level (MCL), is the highest level of a contaminant allowed in drinking water. Current methods for the elimination of bacteria and pathogens used by the Puerto Rico Aqueduct and Sewer Authority (PRASA) for quality treatment in wastewater include: Chlorination and Ultraviolet (UV) Disinfection. The wastewater used in this project was obtained from the effluent of the filters of the Caguas Regional Wastewater Treatment Plant (CRWWTP). The treatment processes at the CRWWTP consist of a primary treatment (mechanical sewage screening and primary clarification); a secondary advance treatment, Biological Nutrient Removal (BNR); and a tertiary treatment, final clarification, filtration, chlorination and UV disinfection process). The CRWWTP treatment capacity ranges from 12 to 24 million gallons per day (MGD), with a daily average of 13.64 MGD in 2010-2011. The CRWWTP collects wastewater from domestic and industrial users, from the municipalities: Caguas, San Lorenzo, Juncos, and Aguas Buenas. At the time of the project samples were taken, the plant effluent discharge average concentrations for Escherichia coli complied with the NPDES permit No. PR0025976, requirements.

This proposed method is capable to eliminate the found levels of bacterium of Escherichia coli in wastewater and can be eliminated using a different type of disinfection method, Electrocution. The method consists of applying Direct Current (DC) to the bacteria Escherichia coli with different electrical charges to prove the valid hypothesis of this project. As discussed in the objective, this innovative project could be the new change of disinfection in the industry, using an alternative method called Electrocution to substitute Chlorination and UV. In order to prove this hypothesis, a quantitative method is used to count the colonies of the bacteria Escherichia coli and use different materials at different time of contact (Tc) to identify which one maximizes the process.

BACKGROUND

Bacteria are simple, colorless, one-celled organisms that use soluble food and are capable of self-reproduction. Bacteria sizes range from approximately 0.5 to 5 micrometers and therefore are only visible in a microscope. Bacteria are a large domain of prokaryotic microorganisms and are present in most habitats on Earth [2].

There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a milliliter of fresh water; in all, there are approximately five billion bacteria on Earth, forming a biomass that exceeds that of all plants and animals [3].

Microorganisms have an intense metabolic activity to adapt to the environment. Bacteria reproduction occurs by binary fission, in which cells are divided into two new cells and so on. This occurs every 15 to 30 minutes in an ideal environment, which consists of abundant food, oxygen, and other nutrients. One of the most common bacteria found in sanitary waters is Escherichia coli [4].

Waterborne Disease

Water-borne diseases are any illness caused by drinking water contaminated by human or animal feces, which contain pathogenic microorganisms. Effective disease control in wastewater treatment plants is in compliance when monitored by a NPDES Permit.

The proportion of drinking water outbreaks associated with surface water increased from 11.8% during 1997-1998 to 17.9% in 1999-2000 [5].

In some people, particularly children under 5 years and the elderly, infections can also cause a complication called hemolytic uremic syndrome, in which the red blood cells are destroyed causing the kidneys to fail. About 2%-7% of infections lead to this complication. In the U.S., the hemolytic uremic syndrome death rate is 3%-5% [6]. The trustworthiness of Escherichia coli indicates the presence of pathogens. Furthermore, it has been proved that Escherichia coli can be killed or inactivated in our water and wastewater treatment plants by using two methods approved by PRASA: Chlorination and UV.

Escherichia coli: Cell Physiology

Physiologically, Escherichia coli is versatile and well-adapted. Escherichia coli have no growth factor requirements, and metabolically it can transform glucose into all of the macromolecular components that make up the cell. The bacterium can grow in the presence or absence of oxygen (O_2). Under anaerobic conditions it will grow by means of fermentation, producing characteristic "mixed acids and gas" as end products. However, it can also grow by means of anaerobic respiration, since it is able to utilize nitrate (NO_3) and nitrite (NO_2) as final electron acceptors for respiratory electron transport processes. In part, this adapts Escherichia coli to its intestinal (anaerobic) and its extra intestinal (aerobic or anaerobic) habitats.

Escherichia coli can respond to environmental indicators such as chemicals, pH, and temperature in a number of very remarkable ways considering it is a unicellular organism. For example, it can sense the presence or absence of chemicals and gases in its environment and move towards or away from these.

Therefore, the microbiological quality of water is based on testing for nonpathogenic indicator organism, the coliform group [4].

Escherichia coli can cause death in immune-compromised individuals, the very young, and the elderly due to dehydration [7].

In average, about 50 millions coliform per gram reside in human and warm-blooded animals. Untreated domestic wastewater generally contains more than 3 million coliforms per 100 ml [4].

In 1974, Congress approved and established the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime, with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water. EPA sets MCLGs based on the best available science to prevent potential health problems [8].

A treatment technique is an enforceable procedure or level of technological performance which public water systems must follow to ensure control of a contaminant. States may set a more stringent MCL or treatment technique level for pathogens and indicators in drinking water than EPA [8].

Water Quality

A wastewater system is subject to triggering source water monitoring if it does not provide reliable treatment to achieve compliance of at least 99.99% (log-4) inactivation or removal of viruses. Based on the Total Coliform Rule (TCR), if a water treatment system receives notice of a total coliform positive distribution system on a sample collected, it must take a source water sample within 24 hours. The system does not have to take a source water sample if the state can determine that the positive sample was due to an issue in the distribution system and not at the source. If any initial triggered source water sample is a fecal indicator-positive, the system must collect an additional five repeat source water samples over the next 24 hours for each of the sites that was initially fecal indicator-positive. [9]. For those systems that already treat drinking water to reliably achieve at least 99.99 % (log-4) inactivation or removal of viruses, the rule requires regular compliance monitoring to ensure that the treatment technology installed is reliably removing contaminants [9].

Electrocution: Fundaments of Experiment

Electrocution is a type of electric shock that can end life, independently if it is a multi-cellular (e.g. humans) or unicellular form (e.g. Escherichia coli).

Actual convicted criminals to death penalty electrocution method is an initial eight-second application of 2,450 volts administered, followed by a one-second pause, then a 22-second application at 480 volts. After a 20-second break, the cycle is repeated three more times at an alternating current (A/C) of eight amps [10].

The voltage necessary for electrocution depends on how the current moves through the body and Tc. Ohm's law states that the current drawn depends on the resistance of the body. The resistance of human skin varies from each person, under dry conditions; the resistance offered by the human body may be as high as 100,000 Ohms. Wet or broken skin may drop the body's resistance to 1,000 Ohms, adding that high-voltage electrical energy quickly breaks down human skin, reducing the human body's resistance to 500 Ohms [11].

The usage, for a typical electrocution, in a human depends on its density (mass per unit volume), this is the starting point of the theory. Therefore, voltage, amperage, and Tc should be different in these two living forms (human vs. Escherichia coli). Human is about four times denser than Escherichia coli, in equal conditions. Table 1 includes a summary of the ratios between humans and Escherichia coli.

Table 1
Comparative Ratio for Escherichia coli vs. Humans

Characteristic	Escherichia coli	Ratio	Human
Height (h) (average)	$3x10^{-6}$ m	1 : 5.83×10^{5}	1.75 m
Weight (wt) (average)	$1x10^{-12}$ g	1 : 7.5×10^{16}	75,000 g
Volume (v)	$4.2x10^{-18}$ m^3	1 : 1.87 x 10^{16}	$0.0789m^3$
Density (d)	238.95 kg⁄m^3	1 : 4	950 kg⁄m^3

For this investigation project, it is very important when using electrocution as a disinfection method, to understand its characteristics of the bacteria this include: height, weight, volume and density, to prove the trustworthiness of this method. Actual method of electrocution in humans should be used as a comparison, to understand the Tc needed to exterminate the Escherichia coli in a controlled environment.

LAB-SCALE OF EXPERIMENT

Corrosion Resistant Alloys (CRA) are essential for providing long term resistance to corrosion for many production environments. The components of a CRA include safety critical elements, pipelines, valves, and heat exchangers among others. There are many CRAs to select from, and they can be characterized by their resistance to specific environments [12].

Module System

When using different types of metallic materials submerge in the wastewater, amperage can be amplified because water works as an electrolyte (water electric conductivity) for the E.R. H2O.

There is a benefit for using electric shock as a novel stimulus. Without involvement of extreme rising heat, and as a function of field strength, one could then study the biological effects of electric shock directly [13].

Each Module is described below; this includes the construction configuration, materials, and sizing which provide a better understanding of its structure:

- Module #1: Thirteen feet of Stainless Steel cable T 304 with a 1/16 inches diameter, enrolled and separated by 3/4-inch, on acrylic plate with a width of 2-½ inches with a length of 1ft -7 inches (19 inches). This element is anchored in a 4- inch diameter Polyvinyl Chloride (PVC) cap with two stainless steel bolts, with a length and diameter of 5¼ inches and ¼ inches, respectively. DC is applied through a battery to their negative and positive on each bolt. Each battery has 12 volts. If more batteries are needed, these are installed in series. Wastewater interacts with the Stainless Steel cable and passes through the treatment process. Refer to Figure 1.

- Module #2: Rounded hallow Copper with a 2½inches diameter and a length of 1ft-7inches (19 inches), working as the positive charge (cathode). The inner solid cylinder is made of the Stainless Steel Type 304 with a ¾-inch diameter and a length of 1 ft-6 inches (18 inches) working as the negative charge (anode), installed in the center of the rounded hallow Copper cylinder. This element is anchored in a 4-inch diameter PVC cap with two stainless steel bolts, with a length and diameter of 5¼" and ¼-inch, respectively. DC is applied through a battery negative and positive on each bolt. Each battery has 12 volts. If more batteries are needed, these are installed in series. Water passes inside the module interacting with the wastewater and both materials. Neoprene seal of ¾-inch is added to stop the interaction of the wastewater with the water in the electrocution process. The copper cylinder has two holes of 1-inch to let water pass through the treatment process. Refer to Figure 2.

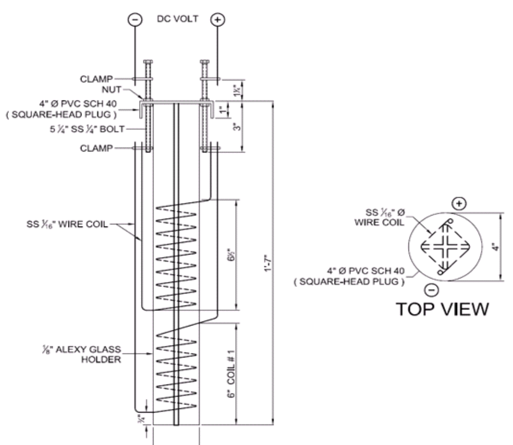


Figure 1

Module #1 of Escherichia coli Removal from Wastewater

- Module #3: Hallow square Stainless Steel Type 304 with a width of 2½ inches and a length of 1 ft-7 inches (19 inches), working as the positive charge (cathode). The inner solid cylinder is made of the Stainless Steel Type 304 with a ¾-inch diameter and a length of 1 ft-3½ inches (15½ inches) working as the negative charge (anode), installed in the center of the rounded hallow Stainless Steel Type 304 cylinder. This element is anchored in a 4 inch diameter PVC cap with two stainless steel bolts, with a length and diameter of 3½inches and ¼ inch, respectively. Direct current (DC) is applied through a battery negative and positive on each port. Each battery has 12 volts. If more batteries are needed, these are installed in series. Water passes inside the module interacting with the wastewater and both materials. Neoprene seal of ¾" inches is added to stop the interaction of the wastewater with the water in the electrocution treatment process. The hallow square has two holes of 1 inch to let water pass through the process; see Figure 3.

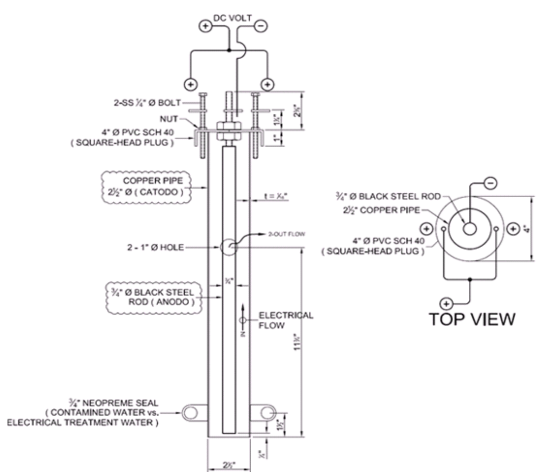


Figure 2

Module #2 of Escherichia coli Removal from Wastewater

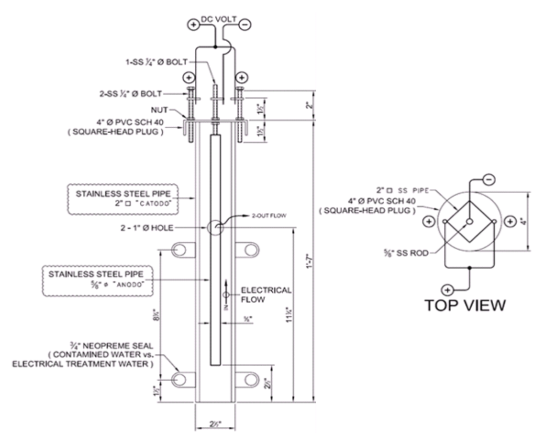


Figure 3

Module #3 of Escherichia coli Removal from Wastewater

Lab-Scale Design

In this study, a prototype of the system with various modules of the E.R. H2O is constructed. The main material for the system is PVC, shaped as a "U" where the system, works as gravity-feed water batch supply. The system can incorporate three gallons of wastewater in a single feed-batch. The inlet zone of wastewater is a reservoir tank with a diameter and height of 8 inches and 5¼ inches, respectively. This is attached to a 4 inch diameter PVC tube with a height of 6¾ inches. Wastewater will travel through another restrainer from 4 inches diameter to a 2 inch diameter, within a length of 1 ft-10½ inches (center to center). Along this 2 inch diameter tube, there is an open ball gate, which restrain a wastewater bypass. Along this tube there is no slope required to feed the E.R H2O Module, mentioned previously, this system works by gravity. The hydraulic head can be measured in a column of water using a standpipe piezometer by measuring the height of the water surface in the tube relative to a common datum. The effluent enters the PVC tube with a diameter and height of 4 inches and 19 inches.

Water passes through E.R. H2O module and is treated with the disinfection process using electrocution. The module is anchored in a 4 inch diameter PVC cap with two stainless steel bolts. DC is applied through a battery negative (anode) and positive (cathode) on each bolt. Module is connected to a battery, either 12 or 24 volts, which provides the necessary current for the electrocution of the bacteria Escherichia coli. If more batteries are needed, these are installed in series. Components connected in series are connected along a single path, so the same current flows through all of the components. In a series circuit, the current flow through each of the components is the same, and the voltage across the components is the sum of the voltages across each component.

Several samples can be collected after the Tc is applied to the module, (water and electricity). Samples are collected by opening the ball gate.

For cleaning and draining the lab-scale device, it is needed to open the ball gate on the lower part of the apparatus.

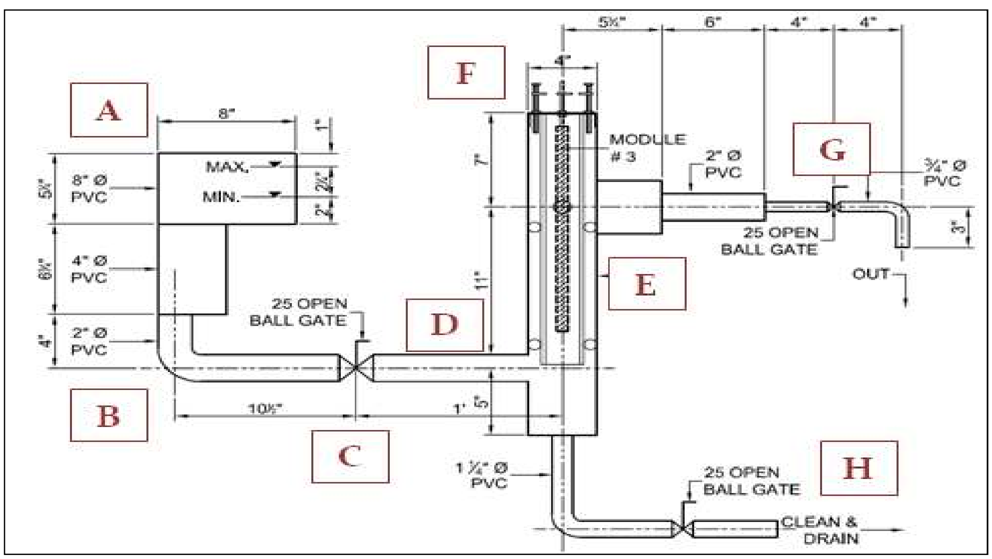


Figure 4
Lab-Scale apparatus design for Escherichia coli Removal from Wastewater

System Operation

CRWWTP wastewater samples are collected during the morning, between the hours of 7:00-9:00 am. Based on historical information during this time frame, the plant receives the highest concentrations of contaminants. The six gallons of wastewater are preserved in ice within a temperature oscillating between 5-15°C, until the procedure.

The operation procedure is as follows. First, the unit is cleaned with three gallons of water. Wastewater is poured into the reservoir tank and passes through the system {A}. It is left for five (5) minutes; this is a form of sterilization. Wastewater enters the reservoir tank and passes through a reduced pipe {B} and its release when the escape valve #1 is open {C}. Wastewater enters the reservoir tank and passes through a reduced pipe {D}, arriving to the nucleus of the project {E}. In the nucleus of the project the module is inside {E}, in which the wastewater gets into contact with the E.R. H2O for further treatment. Batteries are connected, positive and negative, to the bolts in which DC is passed to the module {F}. Battery voltage and amperage is verified in the field.

Wastewater passes inside the module and reside for fifteen minutes or more, to make sure Escherichia coli is completely electrocuted. Treated wastewater samples are collected when valve #2 is open {G}. Cleaning and drainage valves are located in the lower part of the equipment {H}. Refer to Figure 4. Samples are preserved in ice until during transportation to the PRASA Central Laboratory in Caguas.

METHODS – WATER SAMPLING LABORATORY ANALYSIS

Water samples are analyzed using IDEXX's laboratory products for coliform and Escherichia coli. Tests are conducted following U.S.EPA Standard Methods for Examination of Water and Wastewater approved tests, which provides results in less than 24 hours for drinking and source waters. Colilert® and Quanti-Tray® are easy to use, rapid and accurate for analysis results. Colilert® uses the patented Defined Substrate Technology® to simultaneously detect total coliforms and Escherichia coli. Two nutrient-indicators, *ONPG* and *MUG*, are the major sources of carbon in Colilert® and can be metabolized by the coliform enzyme *β-galactosidase* and β-*glucuronidase*. As coliforms grow in Colilert, they use *β-galactosidase* to metabolize *ONPG* and change it from colorless to yellow. Escherichia coli use *β-glucuronidase* to metabolize *MUG* and create fluorescence which can be seen within a UV light. Quanti-Tray® provides counts to 200/100 mL without dilutions and detects a single viable coliform or Escherichia coli per sample [14].

If counts of Escherichia coli surpass the count of 200/100 ml, dilutions are required and do not affect the integrity of the sample. Sample should be preserved at temperature 2-30°C and away from light [14].

Using Colilert® and Quanti-Tray® is as simple as adding the reagent, Colilert®, to the sample, then pouring into Quanti-Tray®. Then, the sample is sealed and placed in an incubator for 24 hours. If Quanty-Tray turns yellow/fluorescent means that there is a presence of Escherichia coli [14].

EXPERIMENTAL RESULTS

For experiment purposes, two batteries in series of 12 volts each were used, for a total of 24 Volts. The bacterium Escherichia coli was treated by exposing the wastewater to different Tc until a removal efficiency of 99.99% (log-4) of disinfection was achieved. The voltage, current, and Tc used to eliminate bacteria Escherichia coli *was* 25 volts, 20 amps, and 15 minutes, respectively.

Several electrocution experiments were conducted with different metal materials, Tc, voltage and amperage. The Tc should be a minimum of fifteen minutes. It was proved that with the adequate material, E.R. H2O complies with the EPA disinfection requirements of 99.99% (log-4) for Escherichia coli. Sixteen samples were collected, analyzed, and validated by the CRWWTP and PRASA Central Laboratory located in Caguas. Experimental data was collected and summarized in a table. Sample data collected includes: date and time of the process, the Tc, voltage and amperage, pH, residual chlorine, and Escherichia coli colonies. For the purpose of this project, wastewater samples were collected at different points as follows:

- Sampling Point #1: Wastewater sample collected from CRWWTP after passing the filters. Wastewater sample was preserved in ice.
- Sampling Point #2: Wastewater sample collected from CRWWTP after passing the filters and the E.R. H2O process. Wastewater sample was preserved in ice.
- Sampling Point #3: Wastewater sample collected from CRWWTP after passing the filters and the E.R. H2O process. Wastewater sample was not preserved in ice.

DATA ANALYSIS

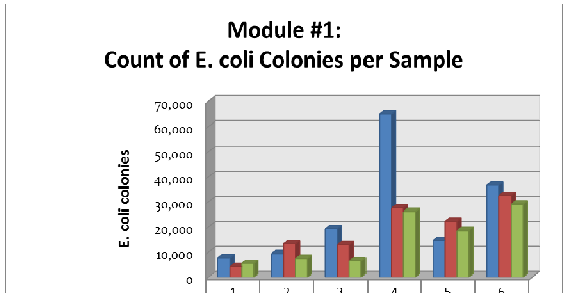
Escherichia coli is fragile and can be removed from wastewater using electricity. The estimated Voltage, Current and Tc computation considered necessary to remove bacteria Escherichia coli (24 volt, 20 amp and 15 minutes, respectively) were used as a comparison with human species as an accurate result for the project theory. Two batteries in series of 12 volts each, for a total of 24 volts, with a current of 20 amps (both field data values), a minimum Tc of 15 minutes, and using the materials described in Model #3, a 99.99% (log-4) removal efficiency was achieved. E.R. H2O is an effective means of removal for Escherichia coli.

Electrocution can be accomplished using the appropriate materials, voltage, current and contact time.

Graphical data included in Figures 5, 6, and 7 provides a visual illustration for each module.

Module #1 was used for a period of six days. Day one (09-19-2011) E.R. H2O used a Tc of approximately 2 minutes, with a low voltage and current of 7.5V and 5A, respectively, resulting in a 44.49% removal of the bacteria. Day 2 (02-20-2011) had the same parameters as Day 1, resulting in a 42.87% removal. Because there was no significant change in the disinfection process between days 1 and 2, the voltage, current and Tc applied were increased for Day 3. For Days 3 and 4 (09-26-2011 and 09-27-2011), voltage, current, and the contact time were 12V, 9A, and 15minutes, respectively. Higher electrocution was anticipated for Days 3 and 4 which resulted in 32.42% and 57.54% removal of Escherichia coli, respectively. Day 5 (09-28-2011) was intended to intensify the voltage and the current to 24V and 18A respectively, but reduced the Tc to five minutes. Unfortunately, the battery did not operated efficiently on day 5 because the battery was damage and voltage values were altered. Therefore, Escherichia coli multiplied and doubled its colonies for the initial sampling point #1. On Day 6 (09-29-2011) the battery was recharged and the sample for day five had the same parameters as Day 4, but the bacteria removal efficiency was very low, 10.92%. The battery was replaced for a new one.

All the removal efficiencies presented are based on the removal value from sampling point #1 versus #2.



	1	2	3	4	5	6
E. coli colonies for Sampling point #1	7,710	9,330	19,180	64,880	14,670	36,540
E. coli colonies for Sampling point #2	4,280	13,330	12,960	27,550	22,240	32,550
E. coli colonies for Sampling point #3	5,540	7,540	6,570	26,130	18,500	29,090

Figure 5

Count of Escherichia coli Colonies per Sample for Module #1

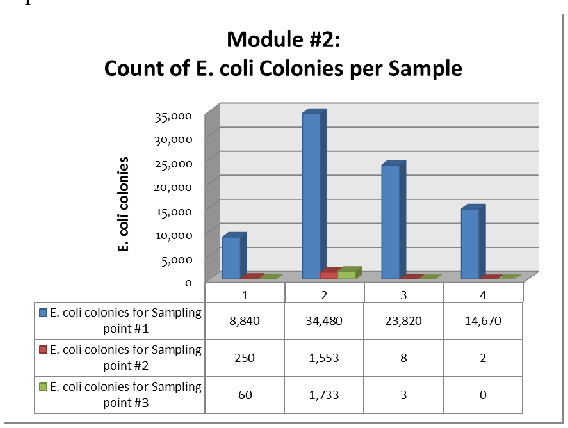
Module #1 did not transmitted the required electricity to electrocute the Escherichia coli and therefore did not achieve the disinfection of 99.99% (log-4) to comply with EPA requirements, even when Escherichia coli was exposed for Tc of fifteen minutes.

The material was change as per Module #2 description and used for subsequent experiments. Figure 6 includes a summary of the analysis of the experimental data.

Module #2 was used for a period of four days. Day 7 and 8 (10-03-2011 and 10-10-2011), a voltage, current and Tc of 24V, 18A, and 5 minutes, respectively was used, resulting in a 77.04% and

82.43% removal of the Escherichia coli within these two days. Removal of Escherichia coli increased, but not enough to achieve EPA requirements. Therefore, on Day 9 and 10 (10-11-2011 and 10-13-2011) the same voltage and current as Day 7 and 8 was maintained, but Tc was increased to fifteen minutes. Higher levels of electrocution were expected and an increase on the removal of the bacteria occurred; 99.97% and 99.99% removal for Day 9 and 10, respectively. All removal efficiencies presented are based on the elimination value form sampling point #1 versus #2.

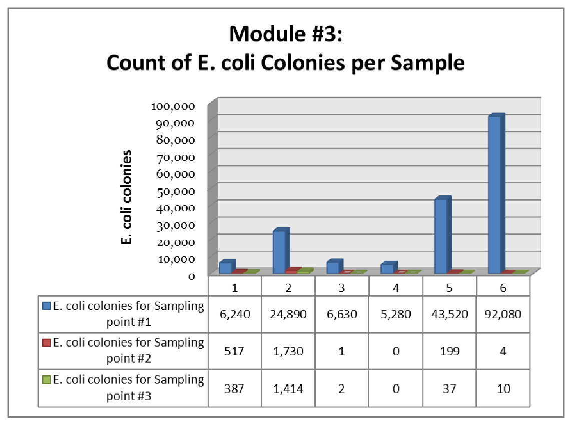
Module #2 achieved disinfection of 99.99% (log-4) required by EPA, but produced Copper sulfate which is very toxic to aquatic life. Further field studies have been conducted by the EPA and results showed that direct application of copper sulfate to water may cause a significant decrease in populations of aquatic invertebrates, plants, fish, and microorganisms. After Day 10, the third phase of the investigation, the material was changed as described in Module #3 for subsequent experiments. Figure 7 includes a summary of the analysis of the experimental data.



	1	2	3	4
E. coli colonies for Sampling point #1	8,840	34,480	23,820	14,670
E. coli colonies for Sampling point #2	250	1,553	8	2
E. coli colonies for Sampling point #3	60	1,733	3	0

Figure 6
Count of Escherichia coli Colonies per Sample for Module #2

Module #3 was used for a period of six days. E.R. H2O on Day 11 (10-17-2011) used a voltage, current and Tc of 24V, 20A and 10 minutes, respectively, resulting in a 91.71 % removal of the bacteria. Day 12 (10-18-2011) had the same parameters as Day 11, resulting in a 93.05% removal. Because it was noticed that Tc of ten minutes made a significant removal of the bacteria, investigational procedure maintains the same voltage and current parameters but with a change in Tc to fifteen minutes. During Day 13, 14, 15, and 16 (10-19-2011; 10-24-2011; 10-26-2011; and 10-27-2011) the voltage and the current, 24V and 20A respectively, were maintained but the Tc was increased over fifteen minutes. Electrocution was accomplished resulting in bacteria removal of 99.98%, 100.00%, 99.54% and 100.00% for Day 13, 14, 15, and 16, respectively. The removal efficiencies observed for the last four days of the investigation, presented a successful pattern of electrocution to sustain the theory of 24V, 20A, and Tc≥15 min making Escherichia coli vulnerable to electricity. Module #3 was successfully, using the voltage, current, and contact time of 24 volt, 20 Amp and 15 minutes (minimum) respectively, to achieve disinfection of 99.99% (log-4) as required by EPA regulations.



	1	2	3	4	5	6
E. coli colonies for Sampling point #1	6,240	24,890	6,630	5,280	43,520	92,080
E. coli colonies for Sampling point #2	517	1,730	1	0	199	4
E. coli colonies for Sampling point #3	387	1,414	2	0	37	10

Figure 7
Count of Escherichia coli Colonies per Sample for Module #3

CONCLUSION

Elimination of Escherichia coli, used in PRASA as a standard to identify the presence of pathogens, is vital to fulfill Water Quality Standard Regulations by U.S. EPA and meeting water-quality standards established in the NPDES Permit.

People should always seek to improve or create treatment processes for wastewater to provide quality, economic and safer water to our country.

Using Electrocution for Escherichia coli, was a great example to prove the theory. In conclusion:

- Tc should be more than fifteen minutes, and should oscillate approximately between 15 to 20 minutes.
- Stainless steel series T 300 are very resistance to corrosion and staining. Stainless steel can be cleaned and sterilized.
- Module #1 (cable of stainless steel type 304) was not a feasible material because it did not transmit enough electricity to electrocute the bacteria and did not achieve the disinfection of 99.99% (log-4) required by EPA, even when the bacteria was exposed to Tc equal to 15 minutes.
- Module #2 achieve disinfection of 99.99% (log-4) required by EPA, but produced Copper sulfate which is very toxic to aquatic life. Direct application of copper sulfate to water may cause a significant decrease in populations of aquatic invertebrates, plants and fish.
- Module #3 was successful, using the voltage, current, and contact time of 24 volt, 20 Amp and 15 minutes respectively, to achieve the disinfection of 99.99% (log-4) required by EPA.
- Escherichia coli could be successfully electrocuted if exposed to 24V, 20A and Tc oscillating from 15 to 20 minutes, resulting in disinfection of 99.99% (log-4) required by EPA.
- If the project is considered in a bigger scale, E.R. H2O can be designed and operated using solar panels, batteries, or other “green” alternatives to help conserve energy and help to build a healthier environment.

ACKNOWLEDGMENT

Thanks to my father, Eng. Cesáreo Martínez; my mother, Sra. Mayra A. Díaz Yambó; my sister, Marleane A. Cesáreo Díaz; my aunt, Lic. Marilyn Díaz Yambó; CRWWTP, ETAG, PRASA Central Laboratory Team, my friends Eng. Benny Albarrán, Eng. Mónica M. Quiñones and God! Thanks to all for helping me to get started my dream project!

REFERENCES

[1] U.S. EPA. Water: Drinking Water Contaminants. 30 Sept.2011<http://water.epa.gov/drink/contaminants/index.cfm#1>

[2] Hammer, Mark J. and Mark J. Jr, Water and Wastewater Technology, 4th Edition, 2001

[3] Fredrickson JK, Zachara JM, Balkwill DL et al. (2004). "Geomicrobiology of high-level nuclear waste-contaminated vadose sediments at the Hanford site, Washington state".

[4] Carrillo, Leonor, Microbiología Agrícola, Vida y muerte de los microorganismos, Capitulo 2, 2003.

[5] Lee, H. Sherline; Levy, Deborah A.; Craun, Gunter F.; Beach, Michael J.; Calderon, Rebecca L.; U.S. EPA Division of Parasitic Diseases National Center for Infectious Diseases, CDC, Surveillance for Waterborne-Disease Outbreaks United States, 1999-2000, 8 Nov., 2002.

[6] U.S. EPA. Water: Ground Water Rule. 07 Oct. 2011 <http://water.epa.gov/drink/contaminants/basicinformation/ecoli.cfm>

[7] Todr, Kenneth, Microbiology PhD, Todar’s Online Textbook of Bacteriology <http://textbookofbacteriology.net/e.coli.html>

[8] U.S. EPA. Water: Basic Information about Regulated Drinking Water Contaminants. 29 Sept. 2011 <http://water.epa.gov/drink/contaminants/basicinformation/pathogens.cfm>

[9] U.S. EPA. Water: Ground Water Rule. 07 Oct. 2011 <http://water.epa.gov/lawsregs/rulesregs/sdwa/gwr/basicinformation.cfm>

[10] Christen, AG; Christen, AG Christen JA. (November 2000). "Alfred P. Southwick, MDS, DDS: dental practitioner, educator and originator of electrical executions". Journal of the History of Dentistry 48 (3): 115–45. PMID 11806253

[11] U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health: A Summary of NIOSH Surveillance and Investigating Findings, “Worker Deaths by Electrocution”, Publication No. 98-131, 1998.

[12] Nickel Institute. Nickel Metal-The Facts. 2011 <http://www.nickelinstitute.org/en/NickelUseInSociety/AboutNickel/NickelMetaltheFacts.aspx>

[13] W Shi, M J Lentz, and J Adler; Department of Biochemistry, College of Agricultural and Life Sciences, University of Wisconsin-Madison, “Behavioral responses of Escherichia coli to changes in temperature caused by electric shock”,

[14] IDEXX Laboratories, 2011. <www.idexx.com/>