

Summer 8-2-2012

## Municipal Wastewater Disinfection with Electromagnetic Waves using Escherichia coli Concentration as Measurement of Quantification

Lauren M. Cagle  
*University of New Orleans*, [lcagle@uno.edu](mailto:lcagle@uno.edu)

Follow this and additional works at: <https://scholarworks.uno.edu/td>



Part of the [Environmental Engineering Commons](#)

---

### Recommended Citation

Cagle, Lauren M., "Municipal Wastewater Disinfection with Electromagnetic Waves using Escherichia coli Concentration as Measurement of Quantification" (2012). *University of New Orleans Theses and Dissertations*. 1500.

<https://scholarworks.uno.edu/td/1500>

This Thesis is protected by copyright and/or related rights. It has been brought to you by ScholarWorks@UNO with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Thesis has been accepted for inclusion in University of New Orleans Theses and Dissertations by an authorized administrator of ScholarWorks@UNO. For more information, please contact [scholarworks@uno.edu](mailto:scholarworks@uno.edu).

Municipal Wastewater Disinfection with Electromagnetic Waves using *Escherichia coli* Concentration as  
Measurement of Quantification

A Thesis

Submitted to the Graduate Faculty of the  
University of New Orleans  
In partial fulfillment of the  
Requirements for the degree of

Master of Science  
In  
Environmental Engineering

by

Lauren Cagle Carpenter

B.S. Louisiana State University, 2006

August 2012

### Acknowledgements:

I am extremely grateful to Dr. La Motta for all of his help and guidance throughout this process. His knowledge of this subject is remarkable, and I feel lucky to have had the opportunity to work with him. Most importantly I thank him for the courses I was a part of; succeeding in his classes reminded me of what I'm capable of and restored my confidence.

Dr. Kura was the first face I saw in the graduate department and has been there for me throughout my UNO experience. His classes taught me skills that I will forever be appreciative for, but, above all, I am thankful for his kind nature. He is always willing to go out of his way to help you be successful—and he'll smile while he does it.

Amanda Athey, you've rescued me too many times. I am sincerely grateful.

Finally, thanks to my family for all of your love and support.

## Table of Contents

List of Figures .....	iv
Abstract .....	v
Introduction .....	1
Literature Review .....	4
<b>Current Practices</b> .....	4
Discharge Requirements .....	5
<i>Escherichia coli</i> characteristics .....	5
Wastewater processes .....	7
Chlorination .....	8
Residual chlorine .....	8
Dechlorination .....	10
<b>Disinfection alternatives</b> .....	11
Ozonation .....	11
Ultraviolet (UV) disinfection .....	11
Electrolytic disinfection .....	12
Hydroflow technology .....	13
Marrero treatment plant specifics .....	17
Methods .....	19
Results .....	27
Discussion .....	34
Conclusion .....	37
References .....	38
Vita .....	40

## List of figures

**Table 1:** Overview of NPDES standards

**Table 2:** Overview of bacteria in secondary wastewater effluent

**Figure 1:** phases of bacteria concentration curve with respect to time

**Figure 2:** General diagram of wastewater treatment process

**Figure 3:** General diagram of wastewater treatment process

**Figure 4:** UV reactator diagram

**Figure 5:** Electolytic disinfection overview

**Figure 6:** Plan view of Marrero Municipal Wastewater Treatment plant

**Figure 7:** Hydroflow theory diagram

**Figure 8:** patent description of Hydroflow unit

**Figure 9:** Unit set up

**Figure 10:** Water passing through ferrite ring

**Figure 11:** Charge associated with microorganisms after passing through Hydroflow unit

**Figure 12:** Wastewater facilities secondary clarifier

**Figure 13:** photograph of heat exchanger used

**Figure 14:** photograph of functioning flow meter

**Figure 15:** photograph of Experimental Design setup used

**Figure 16:** EPA example of *E.coli* colonies on mTEC agar

**Figure 17:** Exploded view of vacuum filtration

**Figure 18:** photograph of vacuum filtration set up used

**Figure 19:** W63 model tested

**Figure 20:** P60 model tested

**Figure 21:** 60i model tested

**Figure 22:** Graph of bacteria curve of *E.coli* from Marrero secondary effluent

**Table 3:** Data summary of bacteria curve of *E.coli* from Marrero secondary effluent

**Figure 23:** Graph of control run through design system

**Table 4:** Data summary of *E.coli* concentration of control run of secondary effluent

**Figure 24:** Graph of W63 unit run through design system

**Table 5:** Data summary of *E.coli* concentration of W63 run of secondary effluent

**Figure 25:** Graph of P60 run through design system

**Table 6:** Data summary of *E.coli* concentration of control run of secondary effluent

**Figure 26:** Percent difference found after one pass with the P60i unit

## Abstract

Wastewater treatment is essential to protecting the environment and human welfare. Although chlorination is widely used, the environmental and health concerns associated with chlorine are growing. Treatment facilities are implementing alternative technologies, though the cost and efficiency associated with these practices leave much room in the wastewater field for innovation.

HydroPath Technologies Limited introduced a piece of equipment that uses the properties of a transformer to pass an alternating electric current through the pipe and into the contents of the channel. Hydroflow claims that the charged microorganisms react with the oppositely charged water molecule to force osmosis and kill the cell. Disinfection capabilities of three Hydroflow models with varying voltages are tested using municipal wastewater from the secondary clarifier using *Escherichia coli* concentration as the unit for quantification. After testing the results surrounding these experiments cannot support the hypothesis that the Hydroflow technology could replace chlorination for municipal wastewater disinfection.

**Keywords:** Wastewater, wastewater treatment, wastewater disinfection, alternatives chlorination methods, Municipal wastewater, Hydroflow, disinfection with electromagnetic waves, Marrero Municipal Wastewater Treatment plant

## **Introduction**

Water is a resource that is fundamental to human life, which makes taking action to protect the resource on the forefront of research. Treated wastewater effluent is a possible source that can pollute receiving water bodies and cause contamination. It is often discharged into larger bodies of water that are used in people's everyday lives. Assuring that water is processed effectively to protect human health is essential as well as the general environmental concerns that come with introducing a foreign pollution source. (Metcalf, 2003).

The Federal Water Pollution Control Act of 1948 was the first major U.S. law to address water pollution. Since then regulations on water discharge have gradually become stricter. The Clean Water Act in 2003 originally instituted guidelines with a focus on human safety. Years later in 1987, the act evolved into a concrete set of rules and consequences that set up accountability for discharge, not only on grounds of human health but also waters that were used recreationally. Today there are both national and state standards that wastewater discharge must meet (AWWA, 1995). As technology advances, so does the ability to get an accurate speciation of wastewater. Knowing the level of treatment necessary to protect public health is essential in wastewater studies, and it is this new information along with ever-changing regulations depicting air, sludge processing, and discharge standards that drive wastewater system engineering and design (Metcalf, 2003).

Chlorination has been the major method of disinfection in past years. It kills the pathogens in wastewater after it has been treated for particulates and oxygen demanding wastes. Although chlorine is effective and inexpensive it does not come without drawbacks (Pulido, 2005). As the pathogen concentration of the water increases the amount of chlorine necessary for disinfection also increases. Using the chlorine in the concentrations that are needed for removal of higher amounts of organics creates byproducts that are often carcinogenic in nature. Disinfection of organic matter with chlorine results in the halogenated organic compounds, these byproducts produced by chlorination came to the forefront of water research in the 1970's. Trihalomethanes were the first byproducts identified in drinking water, followed by a slew of others in varying concentrations, with Dichloroacetonitrile and dichloroacetic acid proving to be potent carcinogens(des.nh.gov,2006)

The effects of residual chlorine in wastewater effluent do not end there, they also can have negative effects on fish and other aquatic life. In many situations treated wastewater is clearly known to cause

interruptions in the physical, chemical and biological parameters of discharge stream locations (Peterson, 2005).

It has been known for decades that residual chlorine from treated wastewaters have ecological impacts on the bodies of water that it is discharged into. The byproducts formed are persistent, potentially toxic, and bioaccumulative. Residual chlorine could persist at levels that are toxic for aquatic life for significant distances from the point of discharge. In freshwater the chlorine tolerance is as little as .002milligrams/liter for fish (EPA Victoria, 2002).

The chemical characteristics of chlorine make it handling it a challenge. The Occupational Safety and Health Adminsitration (OSHA) has exposure limits of workers that handle chlorine due to its reactive nature. Chlorine in concentrations of 50 ppm is dangerous to a workers health, and it is fatal in high concentrations, even in brief exposures. In conditions where chlorine concentration is 15ppm workers have experienced throat irritation (OSHA, 2012).

This causes necessary changes in permit requirements and safety concerns associated with the chemical (Peterson, 2005). It is due to this that facilities are seeking other methods of disinfection that are safer then chlorination techniques. Newer facilities are implementing alternative methods such pressure driven membrane filtration, ozonation, and, most commonly, UV radiation. These new technologies open up health and environmental effects of their own, and are often expensive and not as effective as the chlorination used in the past (Metcalf, 2003). This gap in availability of an ideal process leaves the industry open for effective innovations. This research will seek to test the validity of a possible innovation in the field of wastewater disinfection engineering.

Hydropath Technologies Limited introduced a piece of equipment that uses the properties of a transformer to pass an alternating electric current through the pipe and into the contents of the channel. Hydroflow claims that the charged microorganisms react with the oppositely charged water molecule to force osmosis and kill the cell. The claims made by Hydropath Technology Limited are on a theoretical basis with little or no testing to validate or discredit them besides preliminary lab results show a decrease in *E. coli* and legionella concentration with contact time of 1 hour.



Concerns with the validity of these statements stem upon the voltage that would be needed by the core element to charge the water to have an effect.

The general properties of a transformer voltage are:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

Where :  $V_s$  is the voltage of the secondary winding

$V_p$  is the voltage of the primary winding

$N_s$  is the number of turns in the primary winding

$N_p$  is the number of turns in the secondary winding

In a transformer the voltage that is passed into the secondary coil, or the pipe in the Hydroflow system, is directly related to the number of turns it makes around the conductor (the ferrite ring.) It does not seem possible for the single “loose coil” provided by the pipe to get the voltage needed to destroy bacteria. In the Hydroflow design, The low current that would be passed to the pipe would not be powerful enough to fully charge the pipe contents to facilitate cell destruction by osmotic pressure gradients. Therefore, although the Hydroflow unit may be successful for other uses, it would not produce the voltage needed to disinfect wastewater.

## Literature review

### Discharge Regulations

There are regulations associated with the discharge of any pollutants into the waters of Louisiana by LAC 33:Chapter IX under the Louisiana Pollutant Discharge Elimination System (LPDES) program. The Louisiana Department of Environmental Quality (LDEQ) has been in control of the NPDES program since August 1996 and consists of two LPDES sections: industrial water permits and municipal general water permits (LDEQ, 2012). Wastewater treatment in Louisiana is regulated by the National Pollutant Discharge Elimination System Permit number LA0038091. This defines limits to which municipal wastewater has to be treated before discharging into the Mississippi River (Pulido,2005). The clean water act required every state to define the water quality standards for discharge, and then have them approved by the EPA. Water quality standards are based on the classification of how the water is used, a numeric and narrative criteria for water standards, and an anti-degradation policy for future protection. The parameters for the states standards rely on three main ideals. They are expected to represent the following:

- 1) include provisions for reporting and maintaining the chemical physical and biological integrity of state waters
- 2) provide water quality protection and propagation of fish, wildlife, and recreation in the water
- 3) consider the use and value of State waters for public water supplies

States are expected to review water standards every three years. The permit places limits on Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Fecal Coliforms, pH, Residual Chlorine, and visible foam and are summarized in Table 1. In the NPDES permit *Escherichia coli* (*E.coli*) concentration is specifically identified to be monitored. The regulations stipulate that water samples must be taken from the effluent four times in a month to ensure the concentration is in compliance. (NPDES, 2010).

Table 1: NPDES permit summary

Parameter	Weekly	Monthly
BOD5	45 mg/l	30 mg/l
TSS	45 mg/l	30 mg/l
Fecal Coliform	400 MPN/100ml	200 MPN/100ml
Escherichia coli	235 cfu/100ml (one dose)	126cfu/100ml (30 day rolling)
pH	Between 6 and 9	Between 6 and 9
Total Residual Chlorine	.05 mg/l	.05 mg/l
Other requirements	No floating solids or visible foam	No floating solids or visible foam

Table 1: A summary of the wastewater effluent standards as described in the National Pollution Discharge Elimination System (NPDES) permit [NPDES, 2010].

### ***Escherichia coli* Characteristics**

*Escherichia coli* (*E.coli*) is a fecal coliform that is often used as the standard in permit limits. The limits are based on what could cause illness to people. In wastewater permitting the U.S. Environmental Protection Agency (USEPA) and the National Pollution Discharge Elimination System (NPDES) cite *E.coli* monitoring as a way to “best serve public health.” Because *E.coli* are found in the intestines of warm blooded animals, they are indicators of fecal contamination, though it is not always the case.

Quantifying *E.coli* in wastewater proves more beneficial to public health than other fecal coliforms.

*E.coli* is well studied and can be enumerated fairly accurately. It has been proven to be an indicator of the presence of other microorganisms as well. For instance, when there are high quantities of bacteria that are detrimental to public health, the concentration of *E.coli* also rises (Elmund, 1999). *E.coli* was used as the indicator to quantify disinfection in this research.

There are many different types of *Escherichia coli* (*E.coli*) both harmless and pathogenic strains. It belongs to the taxonomic family, *Enterobacteriaceae*. It is a gram-negative, rod shaped bacterium that does not produce spores. As a facultative anaerobe, it has both a respiratory and fermentative type of metabolism. Although *E.coli* can thrive in a wide range of conditions, its ideal growth conditions are warm, wet, dark places with a pH of between 6-8 and temperature of 37 degrees Celsius (98.6 degrees Fahrenheit), making the human body a perfect environment for their growth. *E. coli* is often associated with food borne illnesses, but most strains of *E.coli* are harmless to humans. Common bacteria found in

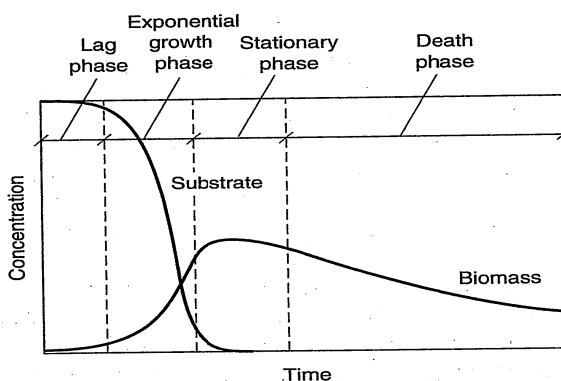
secondary effluent of treated wastewater and the illnesses associated with them are summarized below [USEPA, 1997].

Table 2:

Pathogen		Disease or Type of infection	Indicative levels of pathogens	Infectious dose
Bacteria	<i>Shigella</i> spp.	Dysentery	$10^4 - 10^6$ organisms/100mL	180
	<i>Salmonella</i> sp.	Typhoid and gastroenteritis		$10^4 - 10^6$
	<i>Escherichia coli</i> (enteropathogenic)	Gastroenteritis		$10^6 - 10^{10}$
	<i>Campylobacter</i> spp.	Gastroenteritis		$10^3 - 10^7$
	<i>Vibrio</i> spp.	Cholera		
	<i>Mycobacterium</i> spp.	Johne's disease (cattle, sheep, goats)		

**Table 2:** Types of microorganisms found in secondary effluent from a wastewater treatment facility and the illnesses associated with them. [EPA Victoria, 2002]

*E.coli* that are present in the secondary effluent of wastewater are removed by chlorination, because of the length of time that would be needed for the organisms to die off naturally. Bacterial growth and death are generally determined by substrate availability and other environmental limitations. In a batch reactor a certain concentration of substrate is available to the bacteria and as it runs out the bacteria begin to die off.

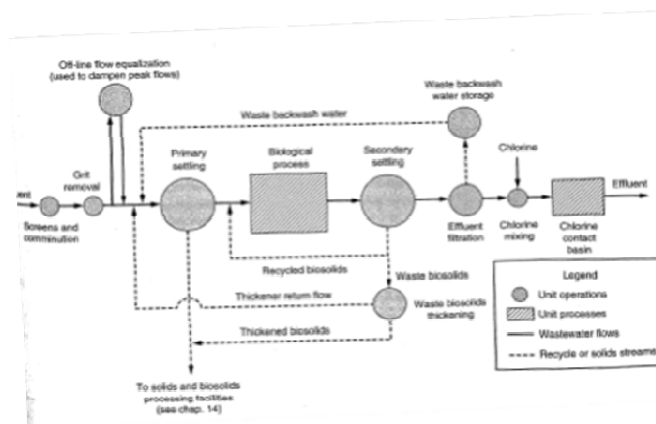


**Figure 1:** The general bacteria curve associated with cell death. The span is broken into lag phase, exponential growth phase, stationary phase and death phase. These stages are linked to substrate uptake [Metcalf, 2003]

The diagram above shows the bacteria curve. The lag phase occurs when the biomass is first added and the organisms are getting adjusted to the environmental conditions, such as pH temperature or salinity. The exponential growth phase occurs when the bacteria are replicating. At this point, substrate, nutrients or space, have not become a limiting factor, but it is affected by temperature. Stationary phase occurs when cell growth is balanced by cell death. Eventually, the substrate begins to be a limiting factor and cell death is occurring faster than any cell growth the death phase takes place (Metcalf, 2003)

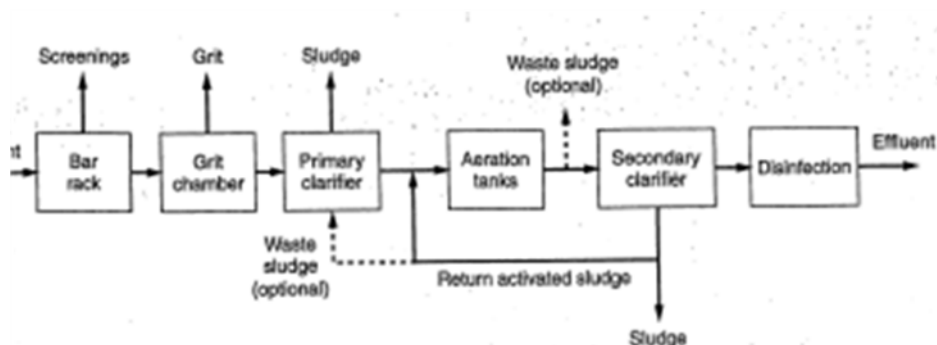
## Wastewater Processes

Wastewater treatment is a necessary process to everyday life. The general purpose is to remove organics from the water to be discharged back into locations that the water will be used in other daily capacities. The process overview in municipal wastewater treatment facilities starts with screening, which is the process of removing any large (coarse) solids that include sticks, rags, and large debris. The effluent moves to the fine screening and micro screening phases, here smaller particles and floatable algae are removed respectively (Bermudez, 2003). Water may go to an equalizer tank to level flow rates and mass loading of suspended solids and BOD. The flow continues to the grit chamber then to the primary clarifier where sedimentation occurs; any solids that are settled out go to their own processing facilities. Clarifiers are also referred to as settling basins or sedimentation basins (EPA Biological processes follow in the aerator where oxygen is added to facilitate the transformation of dead organic matter into living organisms. Secondary settling then takes place, creating more waste bio-solids. The effluent is then disinfected by the addition of chlorine. After the water flows through the chlorine contact basin it is discharged (Metcalf, 2003)



**Figure 2:** General overview of wastewater treatment processes. [Metcalf, 2003]

Microorganisms play an important role in wastewater treatment. They are used to remove dissolved and particulate carbonaceous BOD and stabilize the organic matter. The organic matter is oxidized into simple end products by these microorganisms in the presence of other needed nutrients, such as oxygen ammonia and phosphate. The equation is represented below:



**Figure 3:** Metcalf and Eddy diagram showing the overall wastewater treatment process [Metcalf,2003]

The diagram above shows suspended growth aerobic bacterial treatment processes are used in municipal treatment processes. The activated sludge is the process of using an activated mass of microorganisms to stabilize waste in the presence of oxygen. In the aeration tank the suspended mass, called mixed liquor suspended solids (MLSS) or mix liquor volatile suspended solids (MLVSS) comes in contact with the influent waste water. In the clarifier the microbial suspension is separated from the water and is thickened, once settled it is referred to as activated sludge due to the concentration of live microorganisms. After the clarification step 99% of the suspended solids have been removed. After the organics are removed disinfection takes place, the most common type of disinfection is chlorination.

### Chlorination

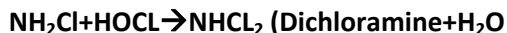
Chlorine dissolves in water and reacts to form hypochlorous acid then hypochlorites. These “free chlorine” compounds interact with the organics in the wastewater and form chlorinated organic compounds. Hydrolysis is the reaction in which hypochlorous acid is formed when chlorine gas and water react.



Hypochlorous acid is then ionized to form a hypochlorite ion  $\text{OCl}^-$



Hypochlorite and hypochlorous acid are called “free” chlorine when they are found in water. HOCl is up to 80 times more efficient at disinfection than hypochlorite. Hypochlorous acid is a proficient oxidizer and will react with ammonia found in wastewater in the following way:



The chlorine in this form is referred to as “combined available chlorine.” Chlorine also oxidizes other wastewater components, such as hydrogen sulfide, ferrous iron, and thiosulfates, and is affected by pH, temperature, and contact time. The amount of chlorine added is key to complete disinfection. It is often used in municipal waste treatment plants to reduce the number of bacteria. Fecal coliforms are used to determine wastewater disinfection (Metcalf, 2003).

### Residual Chlorine

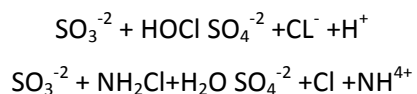
Disinfection of organic matter with chlorine results in the halogenated organic compounds, including Trihalomethanes, Dichloroacetic acid, and Dichloroacetonitrile such as chloroform, haloacetates, and chlorophenols. Trihalomethanes are a family of organic compounds named as derivatives of methane and are suspected carcinogens (USEPA, 1999).

The halogenated disinfection byproducts produced by chlorination came to the forefront of water research in the 1970's. Trihalomethanes were the first byproduct identified in drinking water, followed by a slew of others in varying concentrations, with Dichloroacetonitrile and dichloroacetic acid proving to be “potent carcinogen(s).” Trihalomethanes include chloroform ( $\text{CHCl}_3$ ) Dibromochloromethane  $\text{CHBr}_2\text{Cl}$  and Bromoform  $\text{CHBr}_3$ .

The EPA defines residual chlorine as the amount of free or available chlorine remaining after a given contact time under specified conditions. Total residual chlorine is also stipulated to be monitored in the NPDES permit regulations to a monthly average concentration of less than .05 mg/l and no more than 8.19 micrograms/l daily. This sample is expected to be taken and tested 5 times a week (NPDES, 2011).

## Dechlorination

NPDES permits requires the amount of residual chlorine that can be discharged to be “non-detectable,” which proposes the problem of de-chlorinating the effluent. There are few viable ways to accomplish this with respect to wastewater disinfection; carbon adsorption and dechlorination with sulfur dioxide. Because carbon adsorption is costly, the process of dechlorination using sulfur dioxide or sulfite salts, to remove the residual chlorine from effluent is more common. In this type of dechlorination the sulfur dioxide or sulfur salts dissolve to form ionic sulfur in the S(IV) state, such as  $\text{SO}_3^{-2}$ . This ion reacts with the chlorine rapidly, and reduces chlorine concentration in minutes.



Sulfur dioxide and chlorine generally react at a one to one ratio, but obtaining that ratio is critical and not easily controlled. Too much sulfite addition can have environmental affects separate from those that are caused by residual chlorine. Excess sulfite can lead to a decrease in pH or lowered dissolved oxygen content, due to the formation of sulfate. In addition, sulfur dioxide that is used in the process is a corrosive gas that has health and safety hazards associated with it.

Reliable monitoring for the small level of residual chlorine that is produced is a challenge. Measuring it amperometrically is currently used, but is sometimes inadequate at low concentrations. Feed-back control systems are used when one hundred percent chlorine removal is not needed. The analyzer measures the residual chlorine after the sulfur dioxide is added. Based on the residual chlorine concentration present, the sulfur dosage is increased or decreased. This does not result in a “zero level” amount of chlorine in the effluent, because there is a short lag time associated with the sulfur addition. To combat this lag time, facilities that need to regulate to have no chlorine in the effluent adopted a “forward-feed” system, where the residual chlorine is measured before the sulfur dose. The amount of sulfur added is then determined by the exact one to one ratio needed for chlorine removal(USEPA, 1999).

The costs associated with dechlorination are dependent mainly on when the facility was constructed. Newer wastewater treatment plants that were built after the NPDES were in place have lower costs associated with this process. Generally, older plants that added these controls in response to stricter limit have less efficient problematic systems. Finding alternatives ways to meet environmental or



operational standards is essential; replacing chlorination altogether is one way to eliminate the need for dechlorination processes (USEPA, 1999).

### **Disinfection Alternatives:**

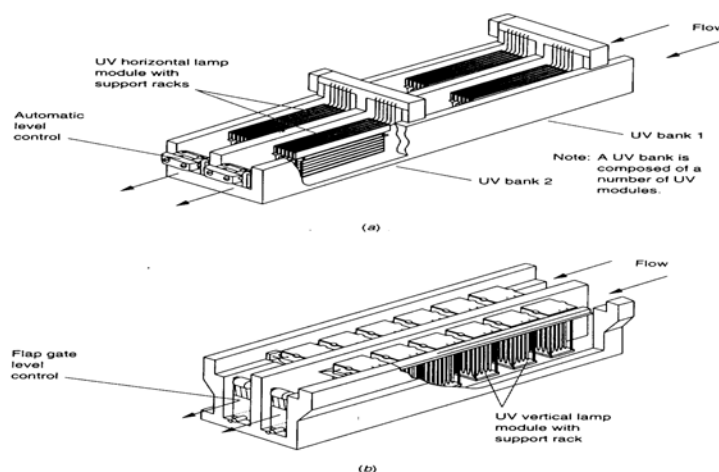
#### ***Ozone Disinfection***

Ozonation is an effective method of disinfection, although the costs associated with it make it undesirable in the United States. Ozone is one method of disinfection that is used for secondary effluent of municipal wastewater treatment plants. It disinfects by using an alternating current of 6 to 20 kilovolts across a “dielectric discharge gap” in the presence of oxygen gas. The charge causes oxygen molecules ( $O_2$ ) to dissociate and recombine to form ozone ( $O_3$ ). The ozone produced, a powerful oxidant, destroys bacteria in three different ways. The ozone in the water causes breakage in the cell wall and stops the cells ability to separate it from its surroundings causing cell destruction. In the process of ozonation the radical byproducts, hydroperoxide ( $HO_2$ ) free radicals and hydroxyl ( $OH^\cdot$ ), are produced. Radicals are a disinfecting agent because the cell wall degrades (lysis) due to oxidation of the protoplasm or nuclear fluid. Finally the ozone can cause damage to the cells DNA itself. The characteristics of the bacteria present are a major factor of disinfection efficiency by ozone, detention time and ozone concentration also play a role(USEPA, 1999).

#### ***Ultraviolet Disinfection***

Disinfection with ultraviolet radiation is a method of disinfection that has taken the place of chlorination in wastewater facilities, including in Louisiana. ([www.crowley.la.com/DEPwater.html](http://www.crowley.la.com/DEPwater.html)) Passing electricity through a mercury cloud creates the UV radiation that is used in the process. A schematic of a two different UV contact reactors used in waste water disinfection is shown in figure 4. The energy enters the cell, damages its DNA and RNA, and prevents reproduction. It is also affected by the strength of the radiation and detention time. Particles farther away from the lamp are exposed to a lower intensity of UV radiation; these low doses are sometimes not powerful enough to kill organisms in the water stream. Process plants must monitor the water flow carefully to maintain ideal conditions. In wastewater treatment contact reactors with submerged UV lamps are most common; in this scenario no flap gates and weirs are used to obtain the desired the flowrates. Higher concentrations of total suspended solids (TSS) can also have an effect on disinfection efficiency. UV disinfection increases with increasing colloid concentration, because the UV radiation is absorbed by the colloidal solids and block the bacteria from the light. This occurs in water with TSS levels of 30 mg/L cause low pressure UV lamps to become less

effective. Although UV radiation has some drawbacks, it is not only considered a viable alternative to chlorination but in some ways superior to it. The average detention time with UV disinfection is less than with chlorination, which affects the amount of space and time the process facilities needs to be functional. The fact that it is a physical process instead of a chemical removes the hazards of transporting chemicals that are used in chlorination and the environmental effects associated with residual chlorine(USEPA, 2000).



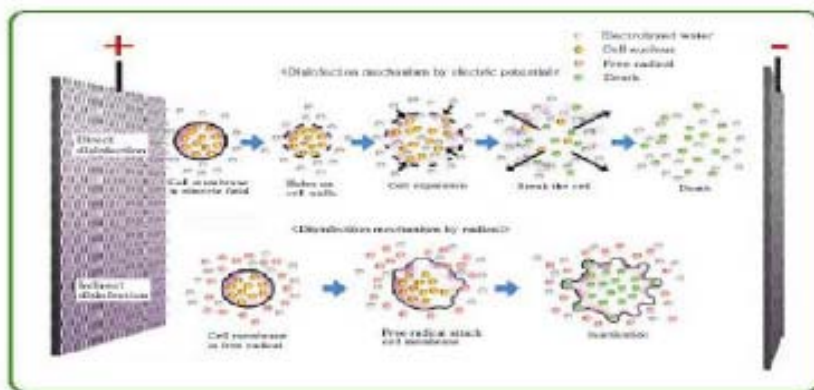
**Figure 4:** A schematic of a two different UV contact reactors used in waste water disinfection [EPA,2000]

### ***Electrolytic Disinfection***

Electrolytic disinfection is a process of water disinfection that utilizes an electric current to inactivate microorganisms. Developed in the 1980's, it has been accepted as an effective alternative to chlorination. (La Motta, ) In this process the electric potential that is created between a positively charged cathode and negatively charged anode are used to damage the cell membrane and inactivate the cell shown in figure 5. The electrolysis with water creates free radicals, such as hydroxyl, hydroperoxyl, superoxide, hydrogen peroxide, ozone, and hypochlorite ions. The oxidation potential of these radicals cause them to react quickly and efficiently with organics present. The radicals are generated at the anode; where the acidic pH also causes protein coagulation and high oxidation reduction potential affects metabolic inhibition. Concurrently at the cathode the cells ability to move inorganic particles through the membrane is affected by the basic conditions of pH10 to 11. The extremely negative environment causes the cell membrane to degrade.

Electrolytic disinfection can occur directly or indirectly in wastewater. Direct electrolytic disinfection uses the electric potential to create holes in the cell wall, which disrupts the osmotic pressure and

allows water to flow in. Indirect disinfection relies on the radicals produced in electrolysis to interact with the cell membrane to facilitate cell inactivation. These two methods work simultaneously to not only damage the cell membrane, but also degrade cytoplasm, inactivates enzymatic activity in the cell and disrupt the balance of osmotic pressure (Kim,2007).



**Figure 5:** In the process of Electrolytic disinfection the electric potential that is created between a positively charge cathode and negatively charged anode are used to damage the cell membrane and inactivate the cell. (Kim,2007)

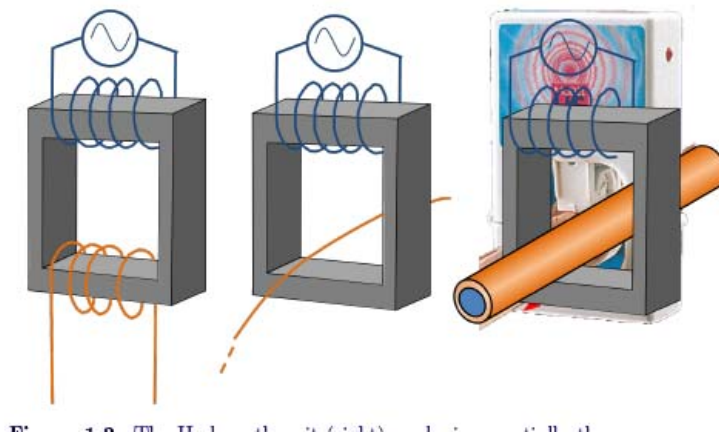
Water disinfection with electrolysis has been shown to eliminate more than 90% of *Escherichia coli* in lab experiments (Kim,2007) when compared to the *E.coli* not exposed to electricity.

### Hydroflow Technology

The purpose of the research described herein is to test the feasibility of alternative wastewater disinfection methods. The proposed method is meant to reduce wastewater treatment facilities dependency on chlorine.

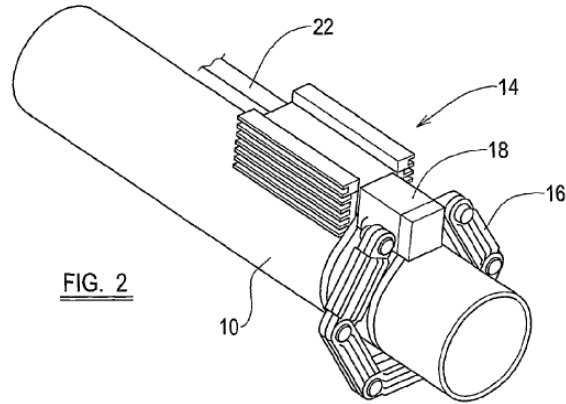
A technology from the company HYDROFLOW USA manufactured by Hydroflow Holding Limited, introduced a system that claims to manipulate electromagnetic fields to disinfect water. The unit, invented by Daniel Stefani (patent application no. US2008/0185328 AL), was designed over a decade ago with the purpose of reducing lime scale in plumbing systems without the use of chemicals(hydroflow.com). The device, referred to as the Hydroflow unit, is described as an” apparatus for treating fluid in a conduit. The Hydroflow unit uses varying frequency of signals referred to as “exponentially decay sine waves” to prevent bacterial growth. An electric field is applied to the pipe

using a transformer. In contrast to standard transformers, the Hydroflow unit substitutes the pipe as the second coil. The AC current is passed through one coil wrapped around a ferrite core made of compressed iron, which facilitates the conductivity of the magnetic field, and is transmitted to the pipe itself in place of the second coil. The pipe and its contents conduct the signal, assuming there is dissolved ions (patent, 2005). The figure below, figure 7, describes the approach. The figure to the left shows a transformer with E. coil around the ferrite. The second picture unwraps the coil to a “single turn” and the picture to the right substitutes a conduit with fluid for the single turn coil. The picture to the right is the proposed methodology of how the Hydroflow unit generally works.



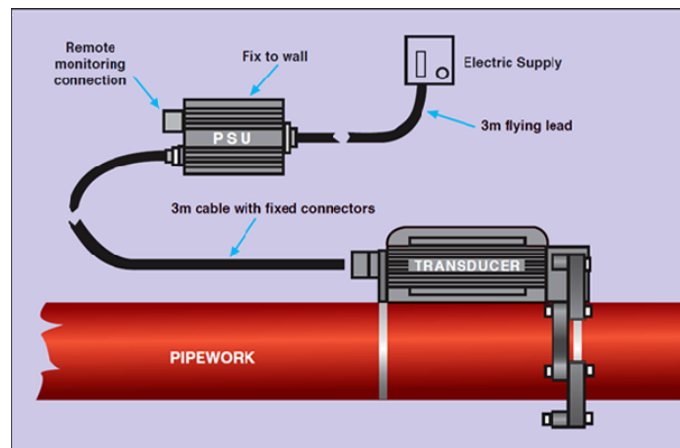
**Figure7:** The Hydroflow unit uses the same principles used in transformers to apply an electric field to the conduit as a single turn coil [Rodriques 2012].

The figure below, figure 8, is the diagram of a Hydroflow unit showing the ferrite rings around the pipe, the core element, and the signal generator. The Hydroflow unit uses this general technology to solve many issues associated with water systems. The process is expected to kill bacteria in the conduit and cause flocculation of any suspended solids. The singular coil used in the electrical signal process is located inside the housing of the unit (Rodriques, 2012). The generator creates a radio frequency signal that is wired to the core element and coil. These signals could be any appropriate wave form including sinusoidal or square waves. The application of these signals stemming from the core forms an electric field that propagates into the water of the pipe. The electrical current alternates from positive to negative voltages, causing the water to be positive or negatively charged, respectively. It is this charge that causing the osmotic effects associated with the process (Patent, 2005).



**Figure 8:** Diagram of the unit from the Hydroflow patent. This shows the ferrite ring around the conduit, the core element, and the charge generator. [Patent, 2005]

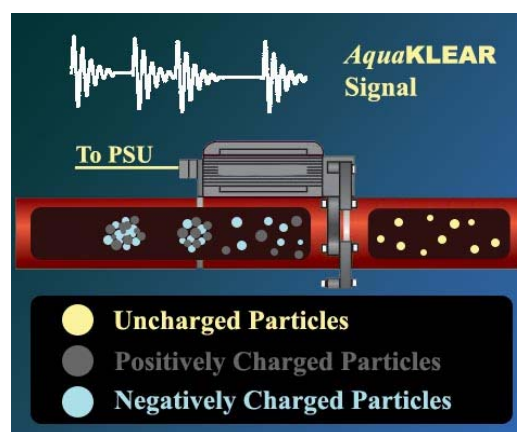
Figure 9 shown below is the full schematic of the Hydroflow technology. Emphasizes how the ferrites fit around the pipe, not directly in contact with the pip contents. The transducer or core element, representing the primary coil, sits on top of the pipe with the ferrite attached to it directly. The power supply unit is connected to the transducer by a wire and plugged into an average wall outlet or surge protector



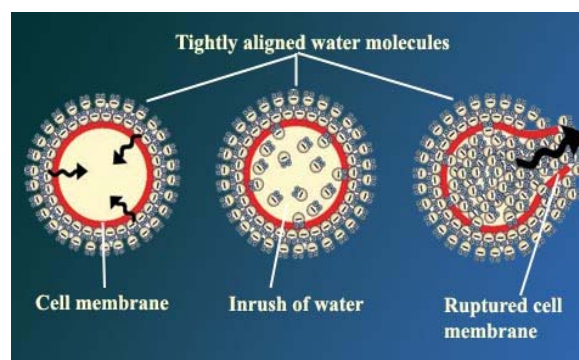
**Figure 9:** The ferrites fit around the pipe, not directly in contact with the pip contents. The transducer or core element, representing the primary coil, sits on top of the pipe with the ferrite attached to it directly. [Hydroflow USA, n.d]

The water passing through the ferrite ring of the Hydroflow unit will acquire a charge Shown in figure 10. As the field shifts from positive to negative the microorganisms will take on that respective charge. The charged microorganism will attract the oppositely charged water molecule. The differences in

charges form a gradient that force osmosis and the cell is inundated with water and cannot continue life functions according to the inventor of this technology. The Hydroflow unit uses the electrical charge to induce osmosis, causing an influx of water into the cell and increasing the pressure inside the cell. EPA defines osmosis as the passage of a liquid from a weak solution to a more concentration solution across a semi permeable membrane. The membrane allows the passage of the water, but not the solutes. The Hydroflow unit applies a charge to the bacteria as they pass through the ferrite ring. The charge induced mimics a concentration gradient which causes osmotic pressure to move the surrounding fluid into the cell shown in figure 11((Rodriques, 2012)



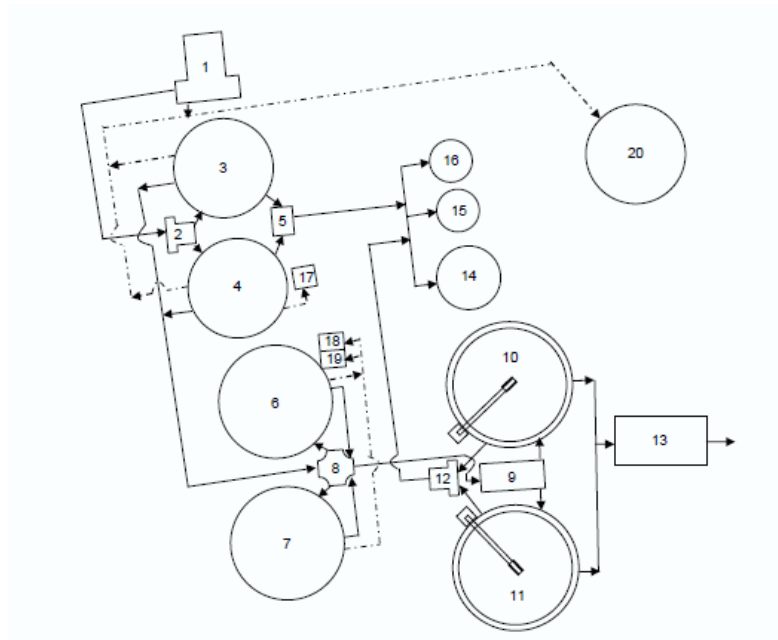
**Figure 10:** The water passing through the ferrite ring of the Hydroflow unit will acquire a charge. The charged particles mix with the oppositely charged water to cause cell destruction (powertechipc, n.d.)



**Figure11 :** The water and microorganisms that pass through the unit get a charge. The opposite charges of the water and microorganism force the cell to take in water osmotically. Shown is a cell with a negative charge with the positive side of the water molecules surrounding it. If the charge of the cell was positive it would attract the negative side of the water molecules.[Rodriques, 2012]

## Marrero Municipal Wastewater Treatment

Secondary effluent was obtained from the Marrero Municipal Wastewater Treatment Plant located at 6250 Lapalco Boulevard, Marrero, Louisiana and is part of the Department of Sewerage of Jefferson Parish. The original facility consists of the following treatment units: pre-chlorination, two mechanic bar screens and one manual bar screen, two grit chambers, two primary settling tanks, two trickling filters, two aeration basins. Two secondary clarifiers, two chlorine contact chambers, three aerobic sludge digesters, and two belt presses used in the process of sludge dewatering (Bermudez, 2003). The Marrero treatment plant is similar to many other municipal treatment plants throughout the United States. The wastewater travels through a coarse screen to remove larger solids then flows into the grit chamber then splitter box. The effluent then flows to the primary clarifier where up to 70 percent of the TSS and 40 percent of the BOD can be settled out. While the sludge is moved to aerobic digestion, the clarified liquid goes to the secondary treatment stage. The figure 6 below shows the plan view of the wastewater treatment plan in Marrero.



**Figure 6:** Plan view of the Marrero Wastewater plant. The figure shows: 1)headworks, 2) Primary flow splitter structure 3, 4 primary clarifiers, 5 primary sludge pumping station 6,7) trickling filter 8)recirculation pump 9) solids contact tank 10,11) secondary clarifier 12) Secondary sludge pumping station 13 chlorine contact tank 14,15,16) aerobic digester 17, 18,19) chemical scrubber 20) biofilter [Bermudez, 2003]

In 2007, a new expansion of the treatment plant provided relief to the overloaded plant. The most significant difference between the new and old aerobic biological reactors at the Marrero plant is the absence of primary clarifiers in the new section of the plant. After the splitter box, the degrittied sewage goes directly to two parallel plug-flow aeration basins, both of which discharge into a single final clarifier. This final clarifier is a circular tank with a diameter of 36.6 m (120 ft), which works independently from the old units. The capacity of the new addition is 615.1 m<sup>3</sup>/h (3.9 MGD).



## Methodology

Samples were collected from Marrero wastewater treatment plant located at 6250 Lapalco Blvd Marrero, LA on the west bank of Jefferson Parish. The samples were taken from the overflow trough of the original secondary clarifier before going to the chlorine contact chamber. The *E.coli* in the sample has a short lifespan, so new samples were taken before each experiment. The water was pumped out of the clarifier trench using a small pump and discharged into a five gallon, plastic Kentwood bottle. The Marrero secondary clarifier are shown below in Figure 12. The sample was transported to the lab of the Center for Energy Resource Management (CERM) building located on the University of New Orleans Campus. The pump used in this process was a Utilitech, nonsubmersible utility pump, model number 0040506. The voltage was 115, a current of 1.8 amps, frequency of 60 Hz and an impeller speed of 6500 rpm.



**Figure 12:** The secondary clarifier of the Marrero Wastewater Treatment Plant. The samples were pumped from the trough that the water spills into after flowing over the weir.

### Batch Reactor Design:

Components of Reactor Design:

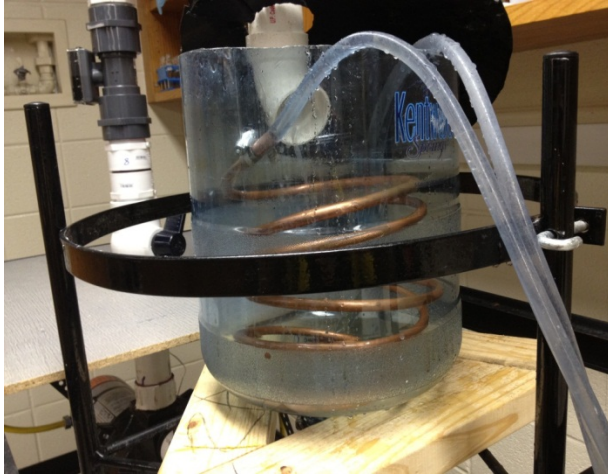
- Schedule 40 Straight PVC total, 2inch (5.08 cm) diameter
- 2 Schedule 40 PVC elbows (2inch (5.08 cm) diameter)
- Schedule 40 PVC ball valve (2 inch (5.08 cm) diameter)
- Schedule 40 PVC T-Joint
- Schedule 40 PVC adaptors
  - 2 @ 1.5 to 2 inch (3.81 to 5.08 cm) into pump
  - 2 @ 2inch male threaded to 2 inch (5.08 cm ) female (for flowmeter attachment)
  - 1 @ 2inch to ¾ inch (5.08 to 2.86 cm) (for spigot drainage connection)
- Utilitech Pump (model #0313831)
- GPI Flowmeter (model # TM200-N)
- Basin -15 gallon (56.78 L) plastic, then altered to a 5 gallon (18.93 L) Kentwood bottle
- Rubber coupling sleeve
- PVC glue
- Heat exchanger

- 4.572 meters of ¾ inch (2.86 cm) copper
- rubber tubing connecting to facet
- 2 metal hoseclamps (2.86 cm)

The reactor was made up of opaque white schedule 40 polyvinylchloride (PVC) pipe connected by PVC couples and elbows. The inner pipe diameter measured 5.25 cm .391 cm inside diameter. All of the PVC was attached to each other using PVC glue. The 4 inch in length PVC was attached to the basin of the unit by a rubber sleeve to ensure no leakage and connected to a 5.08 cm PVC T. One side of the T was connected to the straight PVC that went to the pump, and the other opening of the T was attached to a copper spigot that was attached to the hose. This was used to gravity drain the system between tests and could be closed to divert water through the system. When the drain spigot was closed the water would go through .914 meters of straight PVC to reach the pump. The pump used in the system was a Utilitech irrigation pump (model #0313831). Its design specifications indicated 181.70 Liters per minute with a 4.57 meter head; our system only had about a .9144 meter head. The inlet and outlet were 3.81 cm inner diameter, therefore an adaptor must be used. The pump's inlet and outlet were connected by the adaptor to a straight, 5.08cm diameter PVC pipe. A ball valve was located 15.24 cms above the pump outlet. This was there to regulate the flow through the system. A turbine flow meter , shown in figure 13 with PVC housing material manufactured by GPI (model # TM200-N) was used. The flow range of the device was (75.7 LPM to 757.1 LPM) 20 to 200 GPM with +/- 3% accuracy. Its length is 19.81 cm and fitting size was 5.08 cm flow meter was located six inches above the valve outlet and was connected to PVC by 5.08 cm adaptors. Approximately 6 inches after the outlet of the flow meter the PVC was connected to a 5.08cm elbow and a straight piece of .9144 meter PVC, which connected to another PVC and elbow combination. The system was designed to be a recycle batch reactor, so the water would discharge back into the basin. In the original design the basin was a 56.78 L, white plastic container that was held in place by a metal frame. This design was later altered to a 5 gallon inverted Kentwood bottle, due to temperature control issues.

A heat exchanger was located inside the 18.92 L basin, shown in figure14 It was constructed from 4.57 meter of 3/4inch copper tubing. The copper was loosely twisted to about a 25.4 cm radius coil. ¾ inch rubber tubing was slipped over the opening at the top and the bottom of the copper coil and secured with a hose clamp. The rubber tubing was connected to the facet where tap water would pass through the coil then exit through the rubber tubing on the outlet, which ran through handle of the Kentwood bottle. After the tap water passed through the heat exchanger it would discharge through the rubber

tubing and go into the drain. There was no mixing of the water from the heat exchanger with the sample in the basin. The reactor is shown in figure 15.



**Figure 13:** Heat exchanger to regulate temperature



**Figure 14:** Flow meter measuring 67.54gpm

#### **Hydropath Tests Methodology:**



**Figure 15:** Experimental Design with basin, pump, flowmeter, and unit in place. The design was altered to accommodate temperature changes associated with longer runtimes

#### **Test procedure for *E.coli* Characteristics.**

The natural reduction of *E.coli* concentration with respect to time within the design system was found. This step was done to gather information about how the *E.coli* in the secondary effluent would behave in the parameters of this experiment and to be able to account for any naturally occurring cell death.

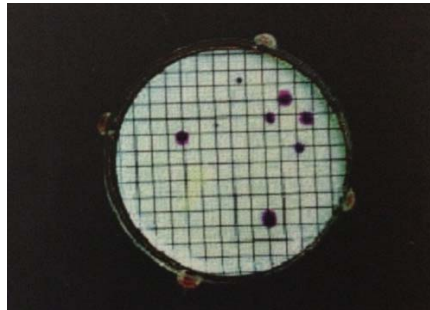
Five gallons of the secondary effluent that was taken from the wastewater treatment plant was poured into the basin of the design system. A 2 mL sample from the wastewater was taken in a 10 mL glass test tube to get the initial *E.coli* concentration. The heat exchanger and pump were turned on and the ball valve was adjusted to regulate flow at 70 gallons per minute. The temperature was watched closely and recorded as the motor of the pump conveyed heat to the water going through the system. Fresh 10 mL glass test tubes were used to collect 2 mL samples from the system effluent in 5 hour intervals. After the sample was collected it would be analyzed using vacuum filtration as described in USEPA Method 1603: *Escherichia coli* (*E.coli*) in Water by Membrane Filtration Using Modified membrane-Thermotolerant *Escherichia coli* Agar (modified mTEC.)

#### ***Quantification of E.coli by Membrane Filtration Procedure***

Quantification of the *E.coli* present was done by using USEPA Method 1603: *Escherichia coli* (*E.coli*) in Water by Membrane Filtration Using Modified membrane-Thermotolerant *Escherichia coli* Agar (modified mTEC.)

Prior to performing the filtration, the mTEC agar was made and plated, assuring it was the correct pH and sterile. The petri dish was marked and a sterile membrane filter was opened and placed, with the grid side up, onto the filter base using sterile tweezers. The funnel was placed onto the filtration system and the clamp was placed on. A volume of 200 mL of DI water was measured and poured into the funnel of the filtration system. The wastewater sample was shaken vigorously then .04 mL (40 microliters) was added to the DI water using a fresh, autoclaved pipette tip each time. The vacuum was turned on and the water with sample passed through the membrane filter and into the discharge flask below. When the entirety of the sample was processed about 20 mL of DI water was used to rinse the sides of the funnel; this ensured all the bacteria was processed to the membrane. This gave the total volume of DI water used to be 220 mL. The funnel was removed and the filter was removed from the filter base, using sterile forceps, and placed onto the mTEC agar plate. The plate was then inverted and relocated to an incubator set to 35 degrees Celsius for 2 hours. When the incubation was complete the sample was placed into a Whirl-Pak bag, inverted, and submerged in a waterbath for 22-24 hours. The colonies that

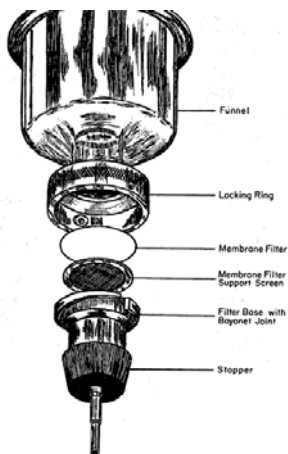
formed were counted from the grid paper using a stereoscopic microscope. The *E.coli* colonies appeared as a magenta color due to the mTEC agar. Counting rules were observed from USEPA microbiology methods manual, part ii section C, 3.5 (EPA, 2002).



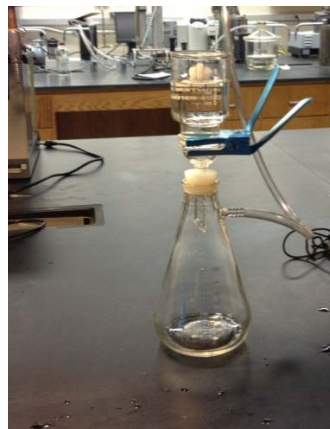
**Figure 16:** EPA example of a mTEC agar with magenta *E.coli* colonies present.[EPA,2002]

After the colonies on the filter were counted, the concentration of *E.coli* in the samples was estimated to the amount per 100 milliliter of sample. This was done by dividing the number of colonies counted divided by the volume of the sample that was filtered in milliliters, then multiply by 100. The equation is shown below:

$$\frac{E.coli}{100ml} = \frac{\text{Number of } E.coli \text{ colonies}}{\text{Volume of sample filtered}} \times 100$$



**Figure17:** Exploded view of Vacuum filtration apparatus used in EPA method



**Figure 18:** Vacuum Filtration set up

## Test Procedures:

### **W63 Unit**

According to HYDROFLOW USA, the W63 is a technology developed by Daniel Stfanini that was designed for residential spas and hot tubs; it fits pipe sizes ranging from 5mm (1/4") to 63mm (2 1/2"). It is approximately 2.3 inches (60 mm) in length .78 inches wide (20mm) and 2 inches (50mm) in height. According to HYDROFLOW USA it is the unit that produces the least amount of voltage tested.



**Figure 19:** The W64 unit manufactured by HYDROFLOW USA utilizes the lowest voltage of the models tested.

Five gallons of water was poured into the basin of the design system and flow was added heat exchanger. An initial 2mL water sample was taken in a 10 mL glass test tube. The Hydropath unit was turned on and verified by the glowing red and green light. The pump was turned on, giving the flow through the system an average of 70 gallons per minute. The total volume of wastewater was recycled through the system for an hour and 2 mL samples were taken in 15 minute intervals, at t=0, t=15 minutes, t=30 minutes, t=45 minutes, and t=60 minutes (final concentration.) The samples were taken from the discharge of the pipe as the water left the PVC and entered the basin. After the sample was collected it would be analyzed using the vacuum filtration as described in EPA Method 1603: *Escherichia coli* (E. coli) in Water by Membrane Filtration Using Modified membrane-Thermotolerant *Escherichia coli* Agar(modified mTEC.)As the control, this procedure was duplicated using the same methodology without the hydro flow unit activated.

Between tests the system was cleaned with tap water to flush out any residual bacteria from the pump, basin, and pipe system. This was done by adding about 5 gallons of tap water to the basin and letting the water run through the system for approximately 5 minutes at 70 gallons per minute, before the water was discharged.

General Test procedure for W63 and P60 unit:

- 5 gallons of wastewater was put into the basin

- initial 2mL sample was taken in a 10 mL glass test tube
- The Hydropath unit was activated and the green and red lights were observed
- Flow was initiated to the heat exchanger
- The pump was turned on at a flow rate of 70 gallons per minute
- Water was recycled continuously for an hour
- ~2mL sample was taken as the water discharged through the outlet of the system
  - Time=0 minutes (initial)
  - Time=15 minutes
  - Time=30 minutes
  - Time=45 minutes
  - Time=60 minutes (final)
- The temperature was monitored every 5minutes to ensure constant temperature
- The samples taken were analyzed using vacuum filtration method outlined in USEPA method 1603.
- System design was flushed with tap water between test runs

**P60 unit (possibly defective):**

The P60 unit has two main parts, the transducer and the power supply unit. The transducer is 9.8 inches (250mm) in length, 2.8 inches (72mm) in height, and 5.4 inches (138mm) wide. The power supply rating is 87-240 VAC/47-63 Hz. The maximum and minimum input current is 89 mA and 31 mA, respectively. The transducer weight is 8.8 lbs (4kg), and it was attached to the top of the PVC in the experimental design using the stainless steel ties provided. The four ferrite bars were assembled and fastened around the PVC pipe and through the opening in the retaining cage of the housing of the core element using the hexagon nuts specified. The unit was placed on the upper most PVC of the design system, following the flowmeter. The water would flow in the pipe about 4 inches (10.16 cm) before being discharged back into the basin. After the unit was secured to the pipe the power supply unit was connected to the transducer (core element housing). When activated the green power supply light and red activated signal induction light both were visibly glowing.

It should be noted that after the tests with this unit were complete a representative from HYDROFLOW-USA visited the lab and used an oscilloscope to measure the voltage of the unit. Based on his knowledge of the unit's specification he deemed the unit defective.

Tests using this unit were completed in an identical manner to the procedure used for the W63 unit.



**Figure 20:** The P60 unit manufactured by HYDROFLOW USA. [hydroflowcandada, n.d.)

**60i unit.**

The 60i unit (Figure 21) is unit designed for industrial use. HYDROFLOW USA claims that this unit produces a higher voltage than any other products previously tested. It is similar is size and weight to the P60 unit formerly described with a transducer of 9.8 inches (250mm) in length, 2.8 inches (72mm) in height, and 5.4 inches (138mm) wide. The power supply rating is 87-240 VAC/47-63 Hz. The maximum and minimum input current is 89 mA and 31 mA, respectively. The transducer weight is 8.8 lbs (4kg.)



**Figure 21:** The 60i unit manufactured by HYDROFLOW USA utilizes the highest voltage of the models tested.

After speaking with the manufacturer, the procedure that was used with the W63 and P60 units was modified. Based on the manufacturer's recommendation the experiment was altered to not recycle the water. The sample volume was only allowed to pass through the unit one time. In this procedure the heat exchanger was not necessary and it was removed from the system design.

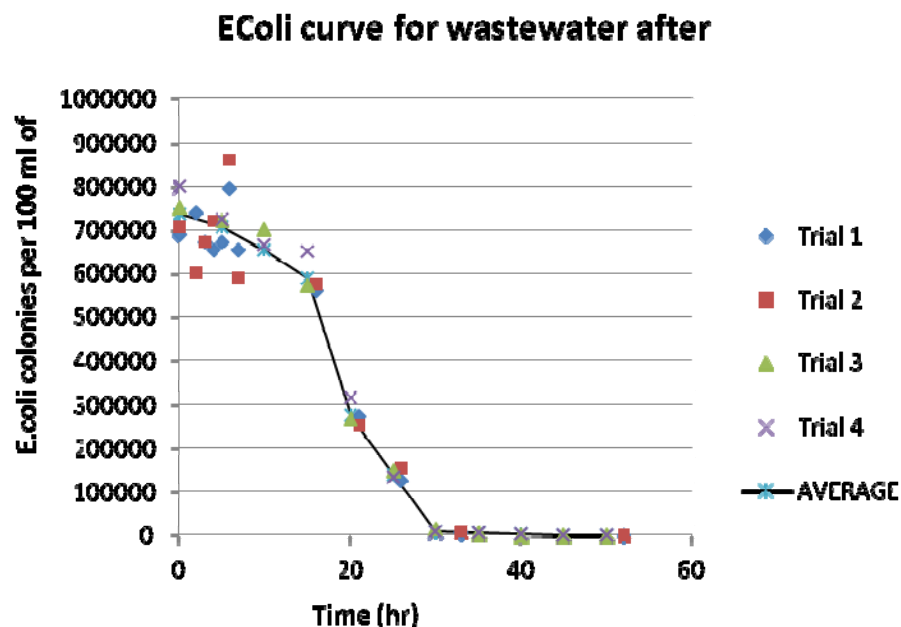
Modified procedure:

- 2.5 gallons of water was put into the sample basin
- initial 2mL sample was taken in a 10 mL glass test tube
- The Hydropath unit was activated and the green and red lights were observed
- pump was turned on (the flow was decreased to 26.6 gallons per minute)
- sample water discharged into a separate basin ( water was not recycled)
- ~2mL sample was taken as the water discharged through the outlet of the system.
- the discharged water was then discarded
- The samples taken were analyzed using vacuum filtration method outlined in USEPA method 1603.



### Results:

The bacteria die off curve of the *E.coli* from the Jefferson Parish municipal wastewater treatment plant was found first. The secondary effluent was taken from the secondary clarifier before chlorination and the concentration of *E.coli* per 100ml of sample was found by running it through the system with the manipulated variable of time. The average concentration of *E.coli* in the final effluent was 736250 per 100 ml. The first 5 hours saw a decrease of about 4%, which is fairly insignificant. After 10 hours there was an average of 11% decrease. The average concentration of *E.coli* decreased with increasing time, but there was a sharp decline at 20 hours, from 589375 *E.coli*/100ml to 276250 *E.coli*/100ml, and a 62% decrease from the initial amount. The amount of viable bacteria continued to decline, and after 40 hours 100% of the *E.coli* in the sample were nonliving. The summary of the results are shown in Table 3 and are graphed in Figure 22.

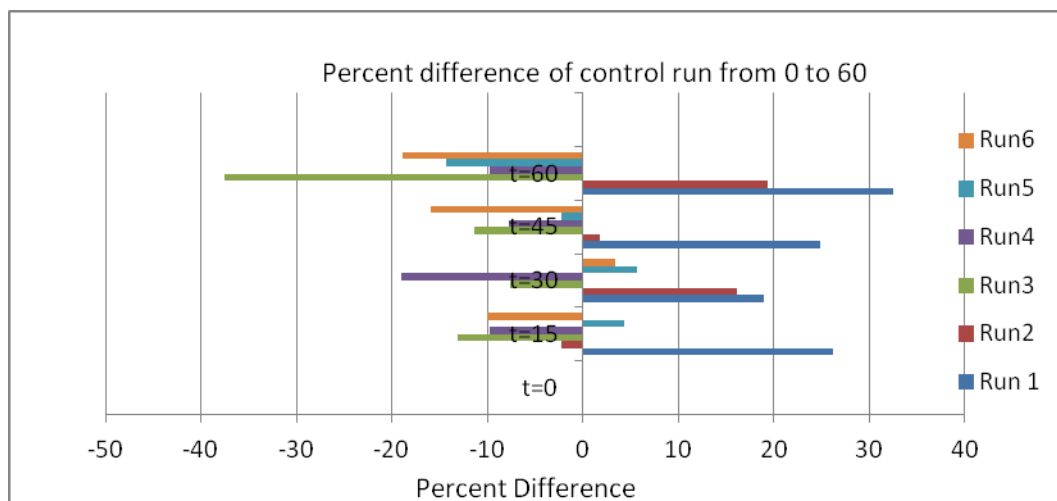


**Figure 22** The bacterial curve was done to quantify the average length of time it takes for the *E.coli* to use any remaining substrate in the wastewater and die. After four trials the *E.coli* found in the water could live about 40 hours in the conditions of the system. After 20 hours half the bacteria died going from an average concentration of 736250/100 ml to 0. After 40 hours there was no *E.coli* present.

Summary:						
Time (hr)	Dilution	Trial 1	Trial 2	Trial 3	Trial 4	AVERAGE
0	.04/250	690000	705000	750000	800000	736250
5	.04/250	670000		720000	725000	705000
10	.04/250	655000	590000	700000	665000	652500
15	.04/250	560000	575000	572500	650000	589375
20	.04/250	272500	250000	267500	315000	276250
25	.04/250	125000	155000	150000	135000	141250
30	.04/250	5000	7500	12500	7500	8125
35	.04/250			5000	5000	5000
40	.04/250	0	0	0	2500	625
45	.04/250	0	0	0	0	0
52	.04/250	0	0	0	0	0

**Table 3:** The effluent from the secondary clarifier was run through the system to identify the death rate of the *E.coli*. The sample went from an average of concentration of 736250 *E.coli* /100ml to 0 at over 40 hours of runtime. This timeframe is based on substrate usage. This time is associated with substrate usage.

In the runs with no unit attached, the control runs, there was no clear change in the number of *E.coli*/100ml in the first hour. Of the six runs the initial *E.coli* concentration was between 332500 *E.coli*/100ml and 675000 *E.coli*/100ml, after an hour the concentrations were between 342500 *E.coli*/100ml and 837500 *E.coli*/100ml. The data showed an average differential from t=0 to t=60 to be a 2083 *E.coli*/100ml, which is not substantial or definitive. Generally, the runs showed no significant change in *E.coli* concentration. The results are summarized in Table 4 and the percent difference is shown in Figure 23 below.

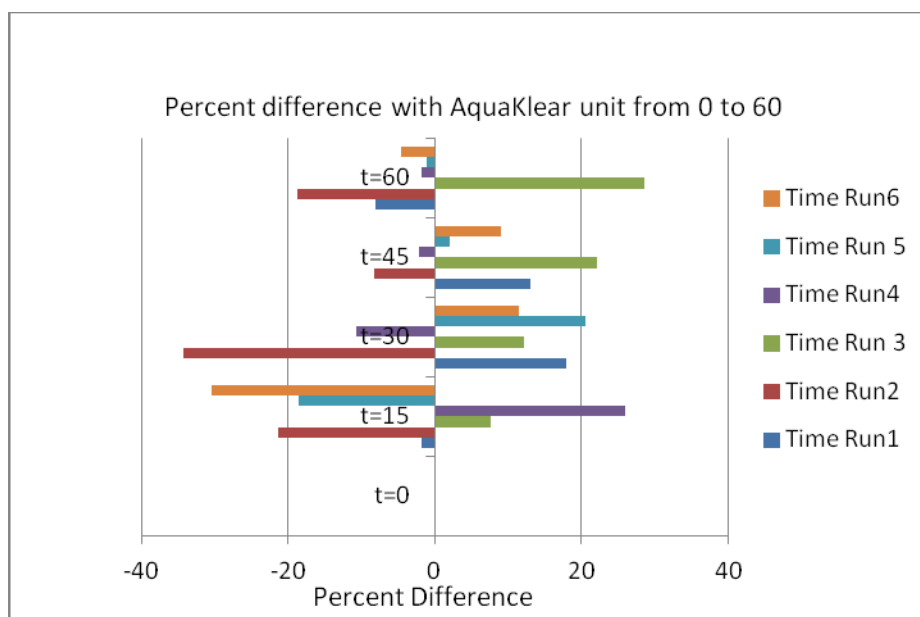


**Figure 23:** The control runs showed no trend in with respect to runtime using 15 minute increments up to an hour.

Control			2/28/2012	28-Feb	23-Feb	23-Feb	8-Mar	8-Mar	
Time (min)	Dilution	Flow	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	
0	04/220	66.6	515000	675000	592500	487500	332500	422500	
15	. 04/220	67.86	697500	660000	515000	440000	347500	380000	
30	. 04/220	66.86	635000	805000	547500	395000	352500	437500	
45	. 04/220	67.74	685000	687500	525000	450000	325000	355000	
60	04/220	66	762500	837500	370000	440000	285000	342500	average difference
Differential			247500	162500	-222500	-47500	-47500	-80000	

**Table 4:** As a control the waste water was run through the system with no unit present. The water was tested for *E.coli* before the system was turned on then again every 15 minutes up to an hour. The average difference between the number of colonies present initially and after the system was running for 2 hours is 0.833

The W63 unit did not show any difference in number of colonies of *E.coli* from the initial to final pass through the units. About 15 gallons of water was pumped through the system at a rate of about 70 gallons per minute. At a two hour detention time the waste water was passing through the unit about 560 times during the runtime. There was no clear change in the amount of *E.coli*/100ml from the initial to after one hour in the system. Of the six runs the initial *E.coli* concentration was between 402500 *E.coli*/100ml and 817500 *E.coli*/100ml, after an hour the concentrations were between 370000 *E.coli*/100ml and 802500 *E.coli*/100ml. The data showed an average differential from t=0 to t=60 to be a 15416 *E.coli*/100ml, which is not definitive. Generally, the runs showed no significant change in *E.coli* concentration. The results are summarized in Table 5 and the percent difference is shown in Figure 24 below.

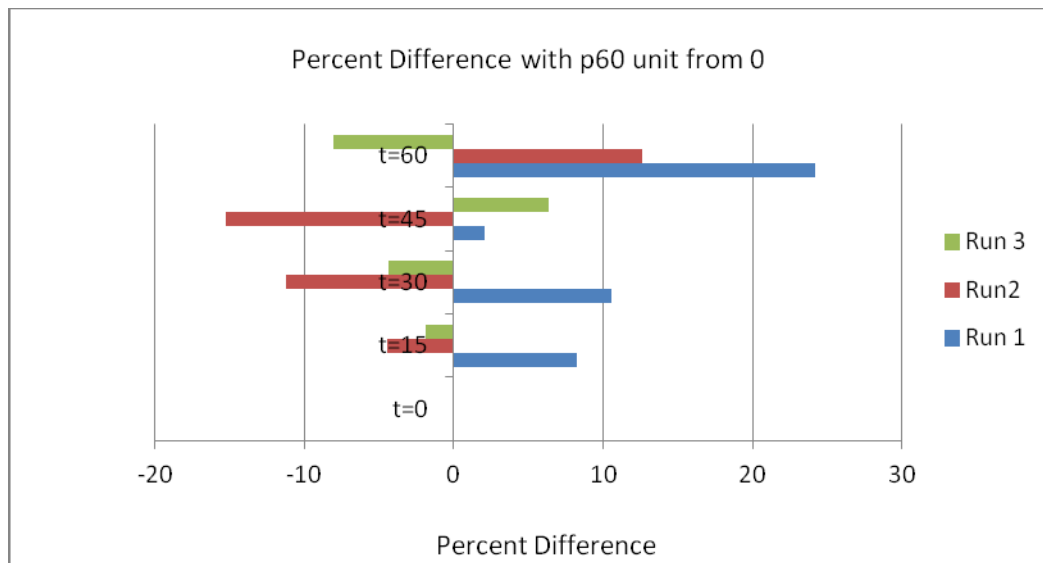


**Figure 24:** The W63 runs showed no trend in with respect to runtime using 15 minute increments up to an hour.

Time (min)	Dilution	Flow	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	
0	.04/220	26.6	402500	480000	670000	817500	630000	655000	
15	.04/220	24.86	395000	377500	725000	1105000	512500	455000	
30	.04/220	24.86	490000	315000	762500	730000	792500	740000	
45	.04/220	24.74	462500	440000	860000	800000	642500	720000	
60	.04/220	25.6	370000	390000	937500	802500	622500	625000	average differential
			-32500	-90000	267500	-15000	-7500	-30000	15416.67

**Table 5:** Six tests were done using the W63 unit. Wastewater samples were taken initially then in 15 minute increments up to 60 minutes. The differential between the amounts of *E.coli* present initially verses what was present after 60 minutes with the unit in service was 6.33.

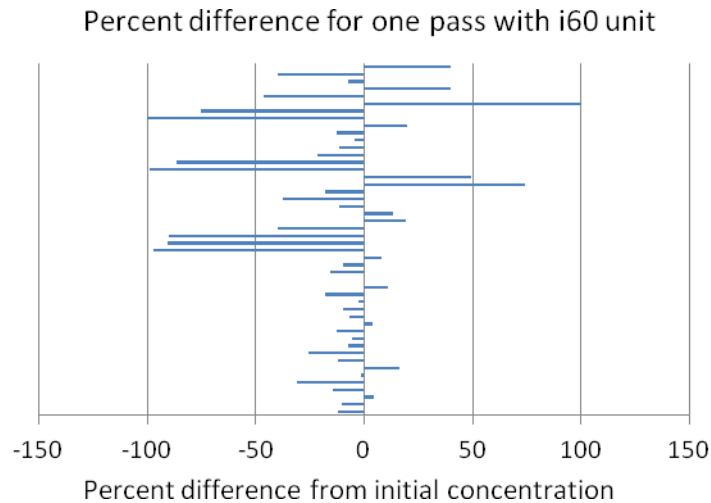
Similar tests were run using the P60 unit. Again there was no clear change in the amount of *E.coli*/100ml from the initial to after one hour in the system. Of the three runs the initial *E.coli* concentration was between 405000 *E.coli*/100ml and 360000 *E.coli*/100ml, after an hour the concentrations were between 372500 *E.coli*/100ml and 475000 *E.coli*/100ml. The data showed an average differential from t=0 to t=60 to be a 46666 *E.coli*/100ml. There is no clear trend one way on how the P60 unit would affect the bacteria in the system. The results are summarized in Table 6 and the percent difference is shown in Figure 25 below.



**Figure 25:** The P60 runs showed no trend in with respect to runtime using 15 minute increments up to an hour.

Time (min)	Dilution	Flow	8-Mar	8-Mar	10-Mar	
			Trial 1	Trial 2	Trial 3	
0	.04/220	69.36	360000	397500	405000	
15	.04/220	71	392500	380000	397500	
30	.04/220	69.5	402500	357500	387500	
45	.04/220	70.2	367500	345000	432500	
60	.04/220	70	475000	455000	372500	average differential
			115000	57500	-32500	46666.67

**Table 6:** Three tests were done using the P60 unit. Wastewater samples were taken initially then in 15 minute increments up to 60 minutes. The differential between the amount of *E.coli* present initial verses what was present after 60 minutes with the unit in service was 46666.67 of *E.coli*/ 100ml sample



**Figure26:** Percent difference of initial and final *E.coli* concentration after one pass though the P60i unit

Many adjustments were made to ensure the experiment was controlled. It was noted that after 2 hours with the pump running the water temperature increased 15 degrees from 25 degrees Celsius to 40 degrees Celsius. A heat exchanger, made of a copper coil, was added to the design set up. The coil had a steady stream of cold water passing though that did not mix with the control water. The control volume was also reduced to 20 L increase the heat exchanger efficiency. With the heat exchanger in use the temperature of the water was controlled to a 2-degree range.

The 60i, an industrial grade unit, was guaranteed by the manufacturer to kill *E.coli* with one pass through the unit. The procedure was altered so the water only passed through the unit one time and was then discarded, therefore the heat exchanger was not being used. The first test with new unit was of concern, because the concentrations of *E.coli* initial samples were particularly low. This could be due to many factors, one of which is the temperature and length of time it was stored before it could be processed. In the tests used with this set of experiments the starting colony counts were in the ranges of 375000 *E.coli*/100 ml to 750000 *E.coli*/100 ml. The first test showed a decrease in *E.coli* from *E.coli*/100 ml to 0, and the second run showed a decrease from 600000 *E.coli*/100 ml to 15000 *E.coli*/100 ml. The tests that followed showed no decrease in *E.coli* concentration, with the average starting concentration of 500000 *E.coli*/100 ml and average final concentration of 625000 *E.coli*/100 ml. The sample water taken from June 14 had an average initial bacteria concentration of 225000 *E.coli*/100 ml, which is more usual to the concentrations observed in previous experiments with this dilution. Of the valid 18 runs the

first 5 showed a change in the initial to final *E.coli* concentrations. The first three runs went from 170000 *E.coli*/100 ml to 5000 *E.coli*/100 ml, 225000 *E.coli*/100 ml to 1 colony, and 270000 *E.coli*/100 ml to 27500 *E.coli*/100 ml; a change of 99%, 97%, and 90% respectively. These results were not consistent with the following tests where there was no trend in *E.coli* reduction. The trends observed at the start of the experiment resulted in an alteration of the procedure. The Hydroflow unit was turned on at the beginning of the tests and left running throughout the duration of the following tests. It was predicted that leaving the unit running while there was no flow through the pipe could be affecting the effectiveness of the unit to destroy the bacteria. In the third set of tests, the unit was turned off when the pump was not running to ensure the Hydroflow unit was at optimal conditions. The average initial concentration of *E.coli* was about 195000 *E.coli*/100 ml and final average concentration was 182500 *E.coli*/100 ml, with no data being an outlier in that average. The average variance between the initial and final concentrations is 15000 *E.coli*/100 ml which is equivalent to 6 colonies per plate.

## Discussion

The purpose of this research was to test a particular method of wastewater disinfection as an alternative to chlorination. The conclusions drawn from this research shows that results obtained cannot support the hypothesis that the Hydroflow technology could replace chlorination for municipal wastewater disinfection.

Many steps were taken to ensure that this experiment was as controlled as possible. One action taken to assure this was finding the general characteristics of the life expectancy of bacteria present in secondary effluent and to show consistencies in the design system itself. The general bacteria die off curve demonstrated that without the addition of substrate *E.coli* strand in the secondary effluent of the Marrero wastewater plant has a viability of approximately 40 hours. This length of time was found to show that without application of the electromagnetic fields originated by the Hydroflow unit the bacteria would live in the time frame that was used in the experiment. Generally if any bacterial death occurred it would not be due to normal cell death conditions. At this point there should be little to no substrate in the water because it has already gone through the process to remove BOD and suspended solids. Running the unit for longer than 40 minutes became an issue with respect to temperature. The motor of the pump caused a significant increase in water temperature after a time greater than an hour, increasing by 15 degrees Celsius. The results of that test were discarded and a heat exchanger was added to the system (Barlett, 1996). This kept the temperature steady at a range of about 2 degrees Celsius, eliminating the temperature differential and keeping the system controlled. The lag in cell death could have to do with the living cells using the dead cells as a food source and extending the life. When measuring the average cell life with no substrate it is expected to see a slight increase in cell population, then a gradual decline when the substrate is used up. Because the water used was secondary effluent after settling with very little substrate present, there was no increase in initial cell concentration.

A control test was run to eliminate any possibility that the design system itself caused an effect on the results. The system was set up the same way the tests with the units functioning would be run. This tests the effects of the basin, pipe-structure, flow rate, pump, and heat exchanger on the *E.coli* concentration. The time frame of one hour was chosen to represent conditions of a waste water treatment plant. At a flow rate of 70 gallons per minute (5.3L/s) with a basin of 5 gallons (18.93L), the average sample passed through the ferrite ring about 840 times. Recirculation of that magnitude is not



considered practical, even if the technology were successful. A detention time of an hour in a functioning facility is generally not used in treatment plant practices.

The results of the control run did not show any change in bacteria concentration from  $t=0$  to  $t=60$  minutes. The tests were first done with the W63 unit. This is the least powerful unit tested, with respect to voltage, of the units manufactured by Hydroflow Technologies Limited. The unit was placed before and after the pump, to see if the location affected the success rate.

As the tests were expected to show bacteria populations decline in as little as one pass, the original test was run taking samples in two minute increments. Because there was very little difference in the 2 minute data intervals, the data was ultimately reported in 15 minute groups. All runs showed *E.coli* was present in every sample with no general trend of concentration to run time. The W63 unit did not show any change in bacteria concentration within the one- hour run.

The P60, a more powerful unit with respect to voltage was tested in the same procedure. The positive results of the tests were sporadic, but there was no clear trend to show that the unit had an effect on *E.coli* concentration. Later, the manufacturer demonstrated that the unit used for these tests was defective, because it provided only 10% of the voltage it was supposed to generate (24 V).

After discussions with the technical contacts at Hydropath Technologies Limited the procedure was altered to simulate the way it is intended to be used. A newer more powerful unit, the Industrial 60i, was provided for testing. This unit was tested with an oscilloscope to ensure that it was putting out the required voltage. The company expected 99% removal efficiency with one pass, therefore the procedure was altered to prove this claim. The wastewater passed through the system and unit one time and was discharged into a container that was then discarded. The result for the first two tests showed a nearly 100% efficiency. On the fifth run the unit was ineffective. The test that followed showed the same pattern; in the first two runs the bacteria were removed with <75% efficiency, and then they not removed at all. The trend seemed to be that the machine was more effective upon startup. This could have been due to a deficiency in the unit causing it to lose effectiveness or a problem with the system itself. The last set of runs the Hydroflow unit was powered down then turned back on before the sample was run. This was done to ensure that every run would get the “startup” conditions that appear to be effective in previous test runs. This change in the experimental design did not obtain the desired

results. The concentration of *E.coli* in wastewater did not change in any of the runs. Of the 45 viable runs, 8 had a removal efficiency of over 75 percent. Although this does not eliminate the possibility of effectiveness, it also does not show with certainty that the unit can be used as a water disinfectant.

## **Conclusions**

Based on the results from the series of tests described herein, none of the Hydroflow units could be recommended as an alternative to wastewater chlorination. The data collected in this research do not allow supporting the claim that the Hydropath technology can be used as a substitute for wastewater chlorination.

Throughout this research there was an omnipresent question of what timeframe the Hydroflow unit needed to be successful at bacteria removal. It has been hypothesized that a possible reason for the negative results surrounding these tests were due to the detention time of the water in the system after passing through the unit. The idea is that the charge would be stronger in the water if it is in the pipe than out of the time. Therefore increasing the time the water has in the conduit after accepting the voltage may affect how effective the unit is in bacteria removal. An alteration in the experimental design that changes the length of pipe after the ferrites of the unit, increasing the residence time before discharge of the sample, would be beneficial. Also, to make future research more thorough, an oscilloscope should be used to measure the voltage in the water upstream and downstream of the Hydroflow unit. This would be useful to see how much energy was actually transmitted to the water, and would that transmission be enough to destroy bacteria. Also, results from this would give a better classification of the power difference of the Hydroflow models tested.

### References:

- Aieta, E., Berg, J., Roberts, P., & Cooper, R. (1980). Comparison of Chlorine Dioxide and Chlorine in Wastewater Disinfection. *Water Pollution Control Federation* , 52(4), 810-822.
- Allen, L., Pasley, S., & Pierce, M. (1952). Some Factors Affecting the Viability of Faecal Bacteria in Water. *Journal of General Microbiology*. 7, 36-44.
- Bartlett, D. (1996).The Fundamentals of Heat Exchangers. *The Industrial Physicist, American Institute of Physics* .12(96).18-21.
- Bermudez,V. (2003). *Biofiltration for Control of H<sub>2</sub>S from Wastewater Treatment Plant Gases*.(Master Degree Thesis). University of New Orleans, New Orleans, LA.
- Bordner, R., & Winter, B. (1978). Microbial Methods of Monitoring the Environment Water and Wastes. *Environmental Monitoring and Support Laboratory Office of Research and Development* . Retrieved from www.usepa.gov
- Decamp,O., & Warren, A. (2000). Investigation of *Escherichia coli* Removal in Various Designs of Subsurface Flow Wetlands used for Wastewater Treatment. *Ecological Engineering*. 14. 293-299.
- Elmund, G., Allen, M., & Rice, E. (1999) .Comparison of *Escherichia coli*, Total Coliform, and Fecal Coliform Populations as Indicators of Wasteware treatment Efficiency. *Water Environmental Research*.71(3). 332-339.
- Environmental Protection Agency- Victoria. (2002).*Disinfection of Treated Wastewater*. Guidelines for Environmental Management.
- Karr, J., Heidinge, R., & Helmer,E. (1985). Effects of Chlorine and Ammonia from Wastewater Treatment Facilities on Biotic Integrity. *Journal water pollution control federation*. (579). 912-915.
- Kim, E., Shin, K., Kang, J., Pak, D., Lee, K., Lee, I., Rhie, K. (2007). Consideration on the Environmental Acceptability and Biological Effectiveness of the Electrochemical Disinfection System for Ballast Water Manangement. *Oceans 2006-Asia Pacific*
- Kovarova-Kovar, K., & Egli, T.(1998). Growth Kinetics of Suspended Microbial Cells: From Single Substrate-Controlled Growth to Mixed- Substrate Kinetics. *Microbiology and Molecular Biology Review*. 62.646-666.
- Metcalf and Eddy. (2003) *Wastewater Engineering. Treatment, Disposal*. New York, NY:McGraw Hill.
- Monarca, S., Feretti, D., Collivignarelli, C., Guzzella, L., Zerbini, I., Bertanza, G., & Pedrazzani, R; (1999). The Influence of Different Disinfectants on Mutagenicty and Toxicity of Urban Wastewater. *Water Research*.34(17).4261-4269.
- Patent Description (2005)Hydroflow Technologies Limited patent application no. US2008/0185328 AL

- Peterson, M. (2005). *ElectroDisinfection of Municipal Wastewater Effluent*. (Master Degree Thesis). University of New Orleans, New Orleans, LA.
- Pulido, M. (2005). *Evaluation of an Electro-disinfection Technology as an Alternative to Chlorination of Municipal Wastewater Effluents*. (Master Degree Thesis). University of New Orleans, New Orleans, LA.
- Rodrigues, D. (2012) Hydroflow Technology, Hydroflow Distributor Training Document
- Shehata, T., & Marr, A. (1971). Effect of Nutrient Concentration on the Growth of *Escherichia coli* *Journal of Bacteriology*.17. 210-216.
- United States Environmental Protection Agency. (1999). *Wastewater Technology Factsheet: Ultraviolet Disinfection*.
- United States Environmental Protection Agency. (1999). *Wastewater Technology Factsheet: Chlorine Disinfection*
- United States Environmental Protection Agency. (2000). *Wastewater Technology Factsheet: Dechlorination*
- United States Environmental Protection Agency. (1999). *Wastewater Technology Factsheet: Ozone Disinfection*
- United States Environmental Protection Agency. (1991). *Dictionary of Technical and Legal Terms Related to Drinking Water*. Retrieved from:
- United States Environmental Protection Agency. (2010). *NPDES Permit Writing Manual*. Office of Wastewater Management. Retrieved from [http://www.epa.gov/npdes/pubs/chapt\\_05.pdf](http://www.epa.gov/npdes/pubs/chapt_05.pdf)
- United States Environmental Protection Agency. (2002) *Method 1103.1: Escherichia coli in Water by Membrane Filtration Using Membrane-Thermotolerant Escherichia coli Agar(mTEC)*
- United States Environmental Protection Agency. (2002) *Method 1603: Escherichia coli in Water by Membrane Filtration Using Modified Membrane-Thermotolerant Escherichia coli Agar(mTEC)* .

### **Vita**

Lauren Cagle Carpenter was born in Metairie, Louisiana. After completing high school in 2002, she entered Louisiana State University in Baton Rouge. She received a Bachelor of Science in Biology in 2006. Upon graduation she taught biology and physical science at De La Salle High School in New Orleans then at Grace King High School in Metairie. In 2008 she enrolled at the University of New Orleans with engineering fundamentals coursework, and was accepted into the Environmental Engineering graduate program in 2011.

As a graduate student she her research on the environmental impacts of the B.P oil spill was published in Environmental Management, a magazine for the Air and Waste Management Association. She completed her research under the guidance of Dr. Enrique LaMotta. This thesis was typed by the author.