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Wastewater Disinfection in Enclosed Recirculation Systems with Electromagnetic Waves

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Wastewater Disinfection in Enclosed Recirculation Systems with Electromagnetic Waves

A Thesis

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DEDICATION

This thesis is dedicated to my loving family, Betilde, Rosa, Elizabeth, Manuel and Juan, specially my uncle Francisco for being my role model, for his support, encouragement and guidance in every step of the way.

To my classmates Grecia, Christopher and Sina, you will always be remembered.

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LIST OF UNITS

mg/L	Milligrams per Liter
ml	Milliliters
cfu	Colony Forming Unit
L/min	Liters per Minute
BOD_5	The Five-day Measure of the Biochemical Oxygen Demand
TSS	Total Suspended Solids
sec	Seconds
min	Minutes
L	Liters
cm	Centimeters
m	Meters
MGD	Million Gallons per Day
LPM	Liters per Minute
PSI	Pounds per Square Inch
$^{\circ}C$	Degrees Celsius

LIST OF ACRONYMS

EPA	Environmental Protection Agency
CWA	Clean Water Act
NPDES	National Pollutant Discharge Elimination System
DEQ	Department of Environmental Quality
LDEQ	Louisiana Department of Environmental Quality
BOD_5	The Five-day Measure of the Biochemical Oxygen Demand
TSS	Total Suspended Solids
E. coli	Escherichia coli
TCR	Total Coliform Rule
CDC	Center for Conventional Disease Control and Prevention
PVC	Polyvinyl Chlorine
CERM	Center for Energy Resource Management
USEPA	United States Environmental Protection Agency

ABSTRACT

Finding the most cost-effective and environmental friendly way to treat and disinfect wastewater has been raising concerns around the world. Failure in performing disinfection of wastewater before returning it to the environment could have terrible consequences to human health and the ecosystem. The risks associated to continue with current practices have led to the creation of stringent regulations.

In this research the HYDROPATH technology is tested while attaching a HydroFlow 60i unit to a reactor that works as a closed recirculation system. To determine the feasibility of the HydroFlow 60i unit as an alternative method to chlorine, the EPA method 1306 is used being Escherichia coli the unit of quantification. After performing several experiments modifying parameters such as conductivity and detention time, it was concluded that the HydroFlow 60i unit by itself would not able to replace current disinfection technologies, to meet EPA standards of E. coli removal.

Keywords: Wastewater, disinfection, effectiveness, reactor, parameters

1. INTRODUCTION

The increment in water pollution has been raising concerns around the world, as the human population grows the demand of natural resources increases. Although developed and developing countries have taken actions creating policies and regulations towards achieving a better usage of theses resources, in most undeveloped countries these regulations are inexistent or not enforced. As a result, it is common to find hazardous waste being discharged to water bodies and causing environmental and health issues. (Larsen et al, 1997)

Currently the most efficient and widely used way to disinfect wastewater before returning it to water bodies is the addition of chlorine. Chlorine has been proven to kill most viruses and bacteria that can affect nature and human health; also, it is the most cost-effective method currently available. However, the use of chlorine has its drawbacks, several environmental liabilities may occur if the use of chlorine is not controlled properly, transportation of chlorine through populated areas represents a high risk for public safety, and chlorine disinfection can produce carcinogenic byproducts. In addition, parasites such as cryptosporidium and giardia present in sewage effluent often survive conventional treatment processes using disinfectants such as chlorine. (USEPA, 1999)

Substituting chlorine as a disinfectant has been a case of study for many researchers around the world. A company called HYDROPATH founded by Dr. Daniel Stefanini and represented in the United States by HydroFlow USA, developed a technology for treating limescale deposits on the internal surfaces of pipelines and other water handling units. Also, HYDROPATH claims that this system is effective when treating water systems against bacteria and algae growth.

The purpose of this research is to determine the feasibility of using this technology as an alternative disinfection method for secondary wastewater effluents, more specifically its ability to remove Escherichia Coli. To be able to achieve this objective the HydroFlow 60i unit will be attached to a reactor built as a horizontal recirculation system that could hold up to 13.9 liters of secondary effluent, which will be run continuously for up to twelve hours.

2 LITERATURE REVIEW

2.1 Regulations and Permits

To perform any activity that involves water and wastewater treatment, usage, discharge and distribution there are regulations that must be complied, permits to be obtained and standards to follow. Some of them are locally enforced while others respond to federal legislations.

Water quality standards are the foundation of the water quality-based control program mandated by the Clean Water Act. Water Quality Standards define the goals for a water body by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water quality from pollutants. A water quality standard consists of four basic elements:

1. Designated uses of the water body (e.g., recreation, water supply, aquatic life, agriculture),
2. Water quality criteria to protect designated uses (numeric pollutant concentrations and narrative requirements),
3. An antidegradation policy to maintain and protect existing uses and high quality waters, and
4. General policies addressing implementation issues (e.g., low flows, variances, mixing zones).

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1972.

Under the CWA, EPA has implemented pollution control programs such as setting wastewater standards for industry. We have also set water quality standards for all contaminants in surface waters.

The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained.

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters. In most cases, the NPDES permit program is administered by authorized states. Since its introduction in 1972, the NPDES permit program is responsible for significant improvements to our Nation's water quality. (USEPA, 2012)

According to Title 33, Part IX, Subpart 1, in compliance with the regulations promulgated by the DEQ, the state shall hold public hearings at least once every three years to review applicable water quality standards and, as appropriate, modify and adopt standards. The revised standards will be reviewed in accordance with the state Administrative Procedure Act (R.S. 49:950 et seq.) and appropriate EPA procedures.

In Louisiana, the Louisiana Department of Environmental Quality has been running the NPDES program since 1996, which contains two sections of the LPDES; one is focused on industrial water permits and the other in municipal general water permit. The National Pollutant Discharge Elimination System Permit regulates wastewater treatment in Louisiana under the permit number LA0038091. This defines limits to which municipal wastewater has to be treated before discharging into the Mississippi River (Pulido, 2005).

The permit establishes limits for conventional and unconventional pollutants that should be monitored such as Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Fecal Coliforms, pH, Residual Chlorine and Visible Foam.

Table 1: NPDES permit summary (Cagle, 2012)

Parameter	Weekly	Monthly
BOD_5	45 mg/l	30 mg/l
TSS	45 mg/l	30 mg/l
Fecal Coliform	400 MPN/100 ml	200 MPN/100 ml
Escherichia Coli	235 cfu/100 ml (one dose)	200 MPN/100 ml (30 day rolling)
pH	Between 6 and 9	Between 6 and 9
Total Residual Chlorine	0.05 mg/l	0.05 mg/l
Other requirements	No floating solids or visible foam	No floating solids or visible foam

- **BOD_5:** The five-day measure of the biochemical oxygen demand.
- **Total Suspended Solids (TSS):** The amount of solid material suspended in water, commonly expressed as a concentration in terms of mg/L.
- **pH:** Measure of acidity of an aqueous solution.
- **Fecal Coliform:** A gram negative, non-spore-forming, rod-shaped bacteria found in the intestinal tract of warm-blooded animals.

2.2 Bacteria Types and Indicator Tests

Bacteria plays an important roll in wastewater treatment, some microbes are beneficial and even improve the quality of water performing degradation and stabilization of organic matter. On the other hand, wastewater may contain pathogens or pathogenic microorganism that could be a threat for human health.

Waterborne and water-related diseases are among the most serious threats for human health. The most common waterborne disease is diarrhea, caused by pathogens such as bacteria (Shigella dysenteriae, Escherichia Coli, Salmonella typhi and Campylobacter), viruses and parasites (Entamoeba histolytica) including protozoa (Giardia lamblia and Cryptosporidium), worms and rotifers usually spread by the fecal-oral route.

Shigella Dysenteriae: Any of the rod-shaped bacteria that make up the genus *Shigella*, which are normal inhabitants of the human intestinal tract and can cause dysentery, or shigellosis. Shigellae are gram-negative, non-spore-forming, stationary bacteria. *S. Dysenteriae*, spread by contaminated water and food, causes the most severe dysentery because of its potent toxin, but other species may also be dysentery agents.

Salmonella Typhi: Is a pathogen that lives in the lymphatic tissues of the small intestine, spleen, liver and bloodstream of infected humans. This pathogen is common in countries with poor sanitation systems representing a risk for public health. Infection of S. Typhi leads to development of typhoid and enteric fever. (Pollack, 2003)

Campylobacter: Campylobacteriosis is an infectious disease caused by bacteria of the genus Campylobacter. Campylobacter occasionally spreads to the bloodstream and causes a serious life-threatening infection. Campylobacter organisms are spiral-shaped bacteria that can cause disease in humans and animals. (CDC, 2013)

Entamoeba Histolytica: Is an anaerobic parasitic protozoan that infects the digestive tract of predominantly humans and other primates.

Giardia Lamblia: Also known as Giardia intestinalis or Giardia duodenalis, is a parasite often found in food or water that has been contaminated with feces. This parasite has an outer shell that protects it from chlorine disinfection and allows it to survive for long periods of time outside the body. (CDC, 2011)

Cryptosporidium: Its physical composition and characteristics are similar to the Giardia lamblia.

Escherichia Coli (E. Coli): Is one of several types of bacteria that normally inhabit the intestine of humans and animals. Some strains of *E. coli* are capable of causing disease under certain conditions when the immune system is compromised or disease may result from an environmental exposure. This bacterium has been used as a biological indicator since 1890. (Shanson, 1999)

Testing the water for each of these threats is impractical, therefore, water quality tests have been designed for indicator organism in order to measure its suitability for drinking, bathing and return to the environment. These indicator organism tests indicate whether or not fecal pollution has occurred and also detect the presence of microbial pathogens. Currently and complying with EPA Total Coliform Rule (TCR) total and fecal coliform as well as the enterocci-fecal streptocci are the indicators organisms used in the public health area.

The E. Coli, which was the bacteria type studied throughout this research, are present in the secondary effluent of wastewater, since their growth and lifespan depend on substrate which behaves as their energy source, E. Coli are removed by chlorination due to the impossibility to wait for the bacterium to naturally die off.

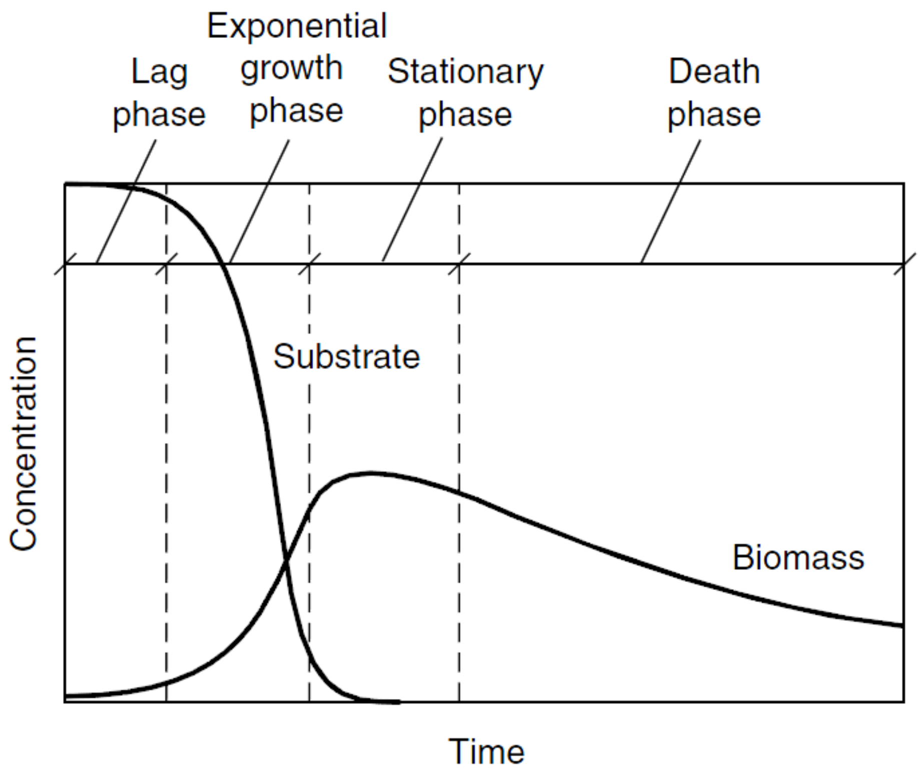

Figure 1: The general bacteria curve and the relationship between life cycle and substrate consumption with time. (Metcalf & Eddy, 2003)

2.3 Wastewater treatment processes

Wastewater treatment protects the environment and public health. Wastewater contains pollutants and microorganisms that are harmful to humans and wildlife. Therefore water must go trough a series of processes to assure that the final effluent complies with local and federal standards and regulations. The first step in wastewater treatment is to remove all sorts of solids contained in the wastewater, including plastics, rags, metals, branches among other types of the debris this process is called Screening. The main purpose of this process is to prevent clogging and damage to the equipment of the following processes. The flow continues to its second step entering into a grit chamber, which allows pieces of rock, bones, metal and any other material denser than organic matter to settle out the waste stream. The last step in primary treatment is sedimentation, which occurs in the primary clarifier, were coagulants and flocculants are often used to encourage the aggregation of particles. This process also reduces the BOD of the water.

Once solids and BOD are reduced, wastewater still has bacteria and pathogens that must be eliminated before returning it to the environment. Therefore, secondary treatment is applied. At first wastewater will be directed to the aeration tanks where oxygen is added to transform dead organic material in living organisms. Wastewater is then passed through a secondary clarifier where sedimentation occurs to create more bio-solid waste. The last step of secondary treatment is disinfection, which seeks to remove pathogen, and bacterium that could represent a threat to public health.

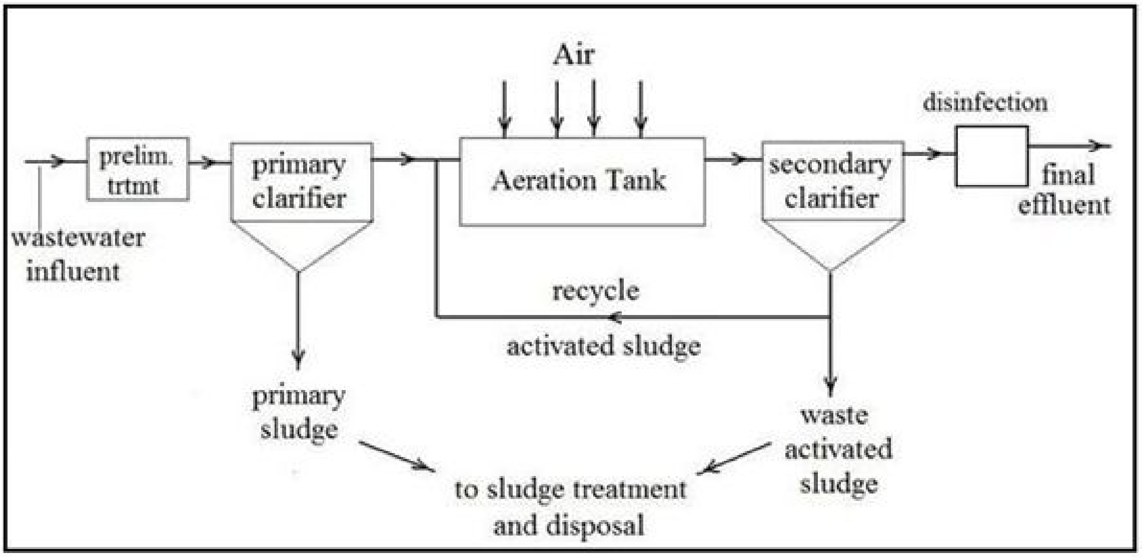

Figure 2. Wastewater Treatment Process flow diagram (Metcalf, 2003)

2.4 Wastewater Disinfection

In the past 15 to 20 years human exposure to wastewater in the environment has increased. Rise in the population and greater demand for water resources has deteriorated the quality of water. Therefore, wastewater must be disinfected to prevent transmission of infectious diseases. Since there is no perfect disinfectant, there are certain characteristics to look for when choosing the correct and most suitable disinfectant such as:

- Ability to destroy infectious agents under normal operation conditions
- Repercussion of its use to people and the environment
- Storage, shipping, handling, safety and ease of use.
- Absence of toxic residual that could cause cancer
- Affordability and operation and maintenance cost. (Solomon, Casey, Mackne, Lake, 1998)

2.4.1 Chlorination

Chlorine remains as the most widely used wastewater disinfectant in most countries including United States. It kills most bacteria, viruses, and other microorganisms that cause disease. Chlorine is introduced to wastewater in the different ways such as gas, hypochlorites (tablets, solutions, or powder), and other compounds (Solomon, Casey, Mackne, Lake, 1998).

Once chlorine is added to the wastewater, two reactions take place: hydrolysis and ionization.

Hydrolysis may be defined as:

$$\mathbf{Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-}$$

Where chlorine gas is mixed with water to form hypochlorus acid (HOCl).

Then hypochlorus acid is ionized to form a hypochlorite ion (OCl^-)

$$\mathbf{HOCl \rightarrow OCl^- + H}$$

The relative distribution between HOCl and OCl^- is very important because the killing of HOCl is up to 80 times more efficient than OCl^- (Metcalf, 2003).

2.4.2 Advantages Of Chlorination

There are several reasons why chlorination remains as the most used disinfection method:

- Chlorination is a fully developed technology.
- Most cost-effective method (Except when dechlorination is needed and fire code requirements must be met).
- Residual chlorine prolongs disinfection after initial treatment and also provides a measure of the effectiveness.
- Chlorine is reliable and effective against a wide spectrum of microorganisms.
- Flexible dosing enables greater control over disinfection since wastewater characteristics vary from time to time.
- Chlorine eliminates odors while disinfecting.

2.4.3 Disadvantages Of Chlorination

Although chlorine has a long history of being effective disinfectant, also has certain safety and health limitations such as:

- The chlorine residual, even at low concentrations, is toxic to aquatic life and may require dechlorination.
- All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling pose safety risks.
- Chlorine oxidizes organic matter in wastewater, sometimes creating com- pounds that could be harmful to humans and the environment.
- The chloride content of the wastewater is increased.
- Certain types of microorganisms have shown resistance to low doses of chlorine.
- The long-term effects of discharging dechlorinated compounds into the environment are unknown. (Solomon, 1998).

2.4.4 Dechlorination

Dechlorination is the process of removing combined and free residual chlorine residuals from water to reduce toxic residuals after chlorination and before being discharge to the environment. NPDES permits requires that the amount of residual chlorine in the discharged water to be "non-detectable", therefore, dechlorination must be applied. Currently there are a few chemicals commonly use to address this problem such as: Sodium bisulfate, sulfur dioxide, sodium metabisulfite and activated carbon.

Sulfur dioxide is the preferred option when removing residual chlorine from wastewater due to the high cost that activated carbon represents. This type of dechlorination dissolves the sulfur dioxide to form ionic sulfur in the S (IV) state, such as SO_3^{-2}. This causes a reduction of residual chlorine within minutes. However, too much sulfite addition can have environmental affects if it is not controlled, a decrease in pH, lowered dissolved oxygen and health and safety hazards are among the most common threats (Cagle, 2012)

The cost of dechlorination is strictly linked to the age of the wastewater treatment facility. Newer wastewater treatment plants, constructed after the NPDES were in place have lower cost associated to this process. On the other hand, old facilities have less efficient systems to control this issue. Therefore, new alternatives that meet environmental and operation standards is essential (Cagle, 2012).

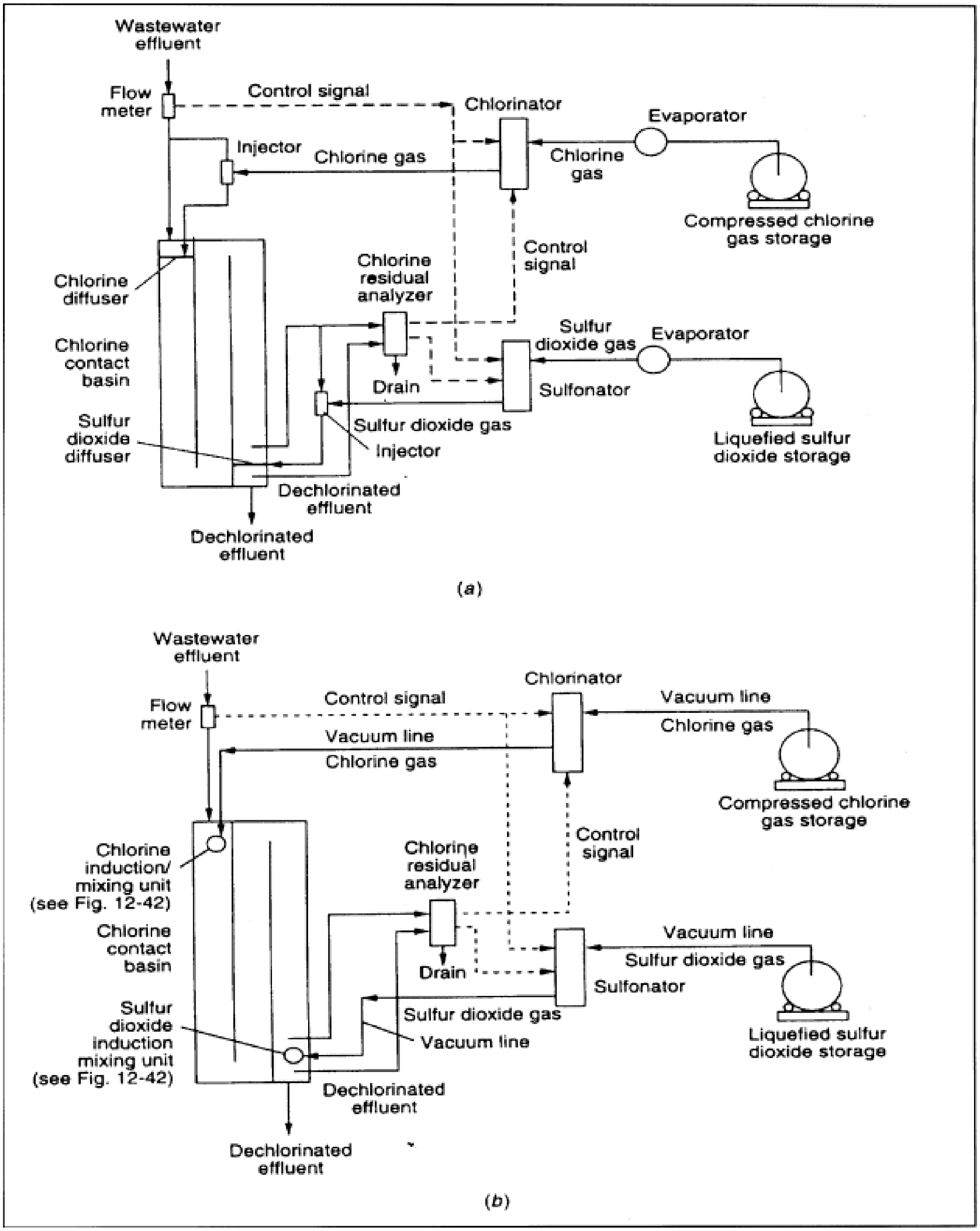

Figure 3. A compound-loop control system for chlorination with chlorine and dechlorination with sulfur dioxide (McGraw-Hill, 1998)

2.4.5 Disinfection Alternatives

The purpose of this research is to test the feasibility of alternative wastewater disinfection processes and technologies. There are other known methods to disinfect wastewater and reduce the dependency of chlorine that has been tested such as ozone disinfection, ultraviolet disinfection and electrolytic disinfection. However, these methods are not popularly used due to high cost of operation or because they do not reach the percent removal established by the EPA.

Table 2. Comparison of ideal and actual characteristics of commonly used disinfectants (Metcalf, 2003)

Characteristic	Chlorine	Sodium hypochlorite	Calcium hypochlorite	Chlorine dioxide	Ozone	UV radiation
Availability/ Cost	Low Cost	Moderately low cost	Moderately low cost	Moderately low cost	Moderately high cost	Moderately high cost
Deodorizing ability	High	Moderate	Moderate	High	High	Not applicable
Homogeneity	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Not applicable
Interaction with extraneous material	Oxidizes organic matter	Active oxidizer	Active oxidizer	High	Oxidizes organic matter	Absorbance of UV radiation
Noncorrosive and nonstaining	Highly corrosive	Corrosive	Highly corrosive	Highly corrosive	Highly corrosive	Not applicable
Nontoxic to higher forms of life	Highly toxic to higher life forms	Toxic	Toxic	Toxic	Toxic	Toxic
Penetration	High	High	High	High		Moderate
Safety concern	High	Moderate	Moderate	High		Low
Solubility	Moderately	High	High	High		Not applicable
Stability	Stable	Slightly unstable	Relatively stable	Unstable, must be generated as used	Unstable, must be generated as used	Not applicable
Toxicity to microorganisms	High	High	High	High	High	High
Toxicity at ambient temperatures	High	High	High	High	High	High

2.4.6 HYDROFLOW Technology

Testing the efficiency of the HydroFLOW is the case of study in this research. This technology was invented and developed over a decade ago by Daniel Stefani and commercialized in the United States by HydroFlow USA. The purpose of this invention was to reduce lime scale in plumbing systems in order to avoid the use of chemicals (hydroflow.com). To understand the way this technology works we should refer to Hydropath Distributor Training Document compiled by Dr. Denzil Rodriguez in 2012, which describes the science behind the HydroFlow signal.

2.4.6.1 The HydroFlow Signal

The signal that is used in all the HydroFlow units has a very distinctive and easily recognized form, although the details of its size and shape will vary depending on the particular application. The signal consists of high frequency oscillations that gradually die away (de- cay) and then repeat at varying intervals. Technically, this is referred to as an “exponentially decaying sine wave.” This form of the signal allows us to give the ions and particles in the water a relatively large “kick” (because of the initial peaks) without using too much power (because the peaks die away). The timing of the pulses changes, allowing the signal to treat all different plumbing systems (Rodrigues, 2012).

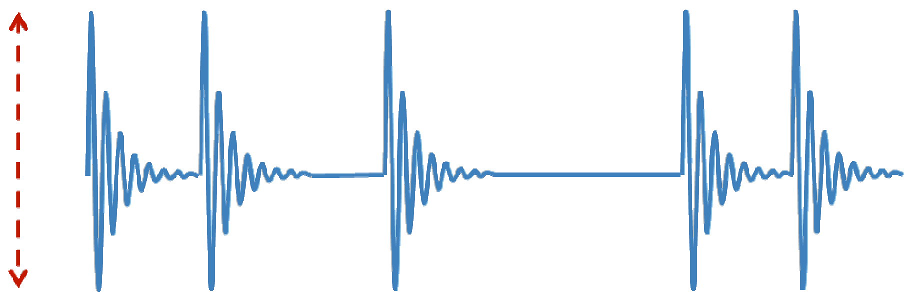

Figure 4. An example of a short section of the HydroFlow Signal. The red arrow indicates the “peak-to-peak voltage”. (Rodrigues, 2012)

2.4.6.2 The HydroFlow Unit as a Transformer

A transformer usually consists of two coils wrapped around a single ferrite core. Passing an AC (i.e. changing) current through the first (primary) coil creates a changing magnetic field which in turn induces an AC electric field in the second (secondary) coil. The ferrite, which is made of compressed iron powder, just helps channel the magnetic field. (Rodrigues, 2012)

It is important to note that an electric field is applied to the pipe (as opposed to a magnetic field) - this is what makes the technology so much more effective than magnet based conditioners. (Rodrigues, 2012)

We know that transformers work, and work very well, because we use them every day. Now, let us imagine that instead of many turns around the ferrite, the secondary coil is only a single turn. We can see that we still have a working transformer. Now imagine making the secondary coil longer and flatter and fill it with water and we see that we now have a method of inducing a current in a pipe. The pipe essentially acts as the secondary coil of a transformer, and this patented technique is one of the reasons why HydroFlow technology is so effective it uses a very efficient method of inducing the current in the pipe. (Rodrigues, 2012)

Figure 5. The HydroFlow (right) unit works as a transformer (left). (Rodriguez, 2012)

2.4.6.3 The Signal in the Water

The signal generated by the HydroFlow unit actually travels through the water. Following the transformer analogy, the water forms an additional secondary coil due to its conductivity; this allows the HydroFlow to transmit a signal regardless of the material the pipes are made of.

The signal travels both upstream and downstream close to the speed of light, that is way the HydroFlow unit has shown efficiency in still and moving water systems.

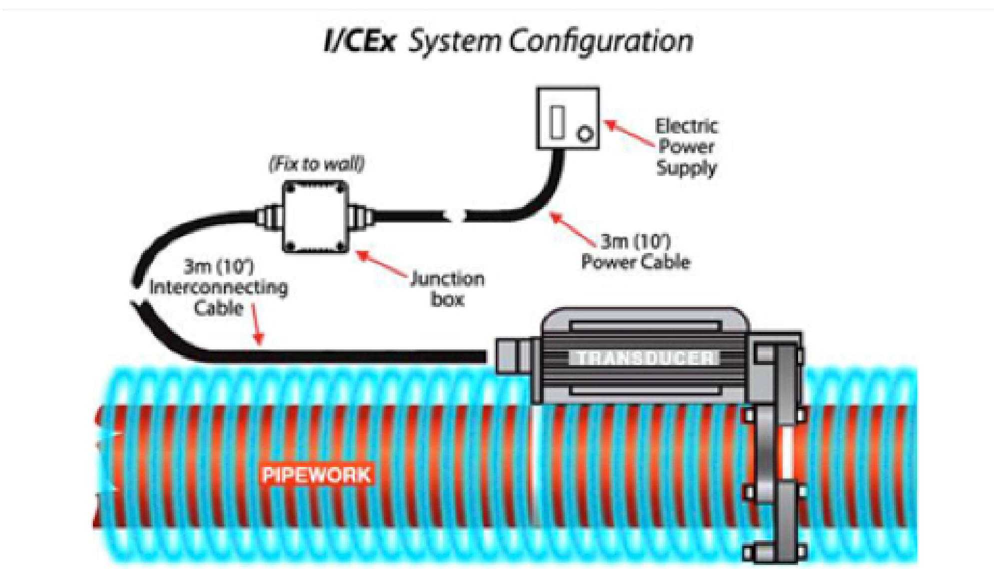

Figure 6. HydroFlow around the pipe, even if the ferrites are not in direct contact with water, the signal still propagates. (Hydroflow.com, 2013)

2.4.6.4 HydroFlow Technology and its effect in Bacteria

HydroFlow developers and manufacturers claim its application and efficiency when treating water to kill bacteria. The HydroFlow unit applies a charge (positive or negative) to particles and bacteria contained in the water (Fig. 6) passing through the ferrite ring. This charge will form a layer of pure water called “hydration layer” (Fig. 7) around the bacteria.

Osmosis forces (Fig. 8) water into the bacteria and/or algae, creating osmotic pressure, which ruptures the cell membrane and causes the cell to die Fig. 9).

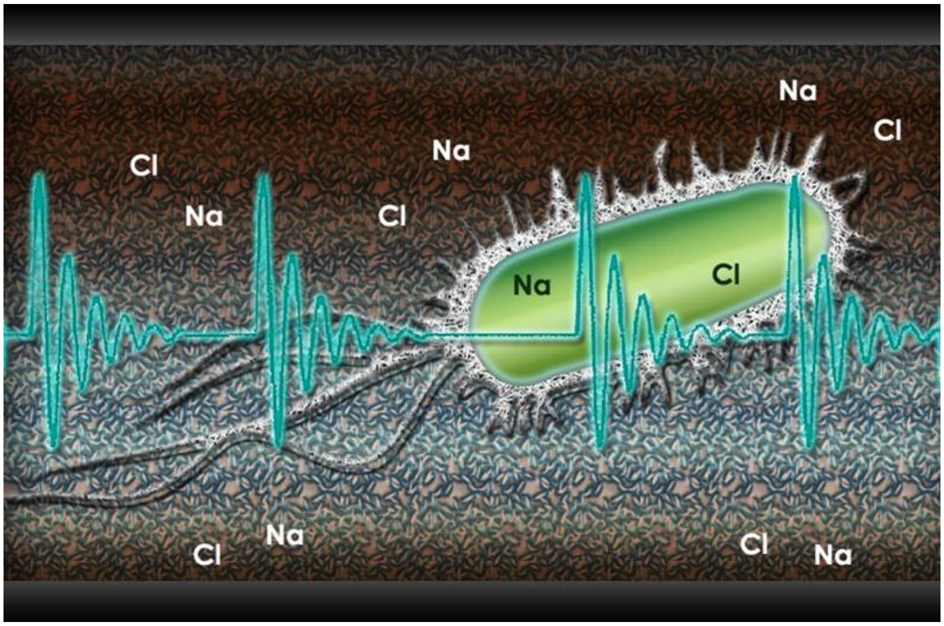

Figure 7. Bacterium passing through the HydroFlow signal (HydroFlow.com, 2013).

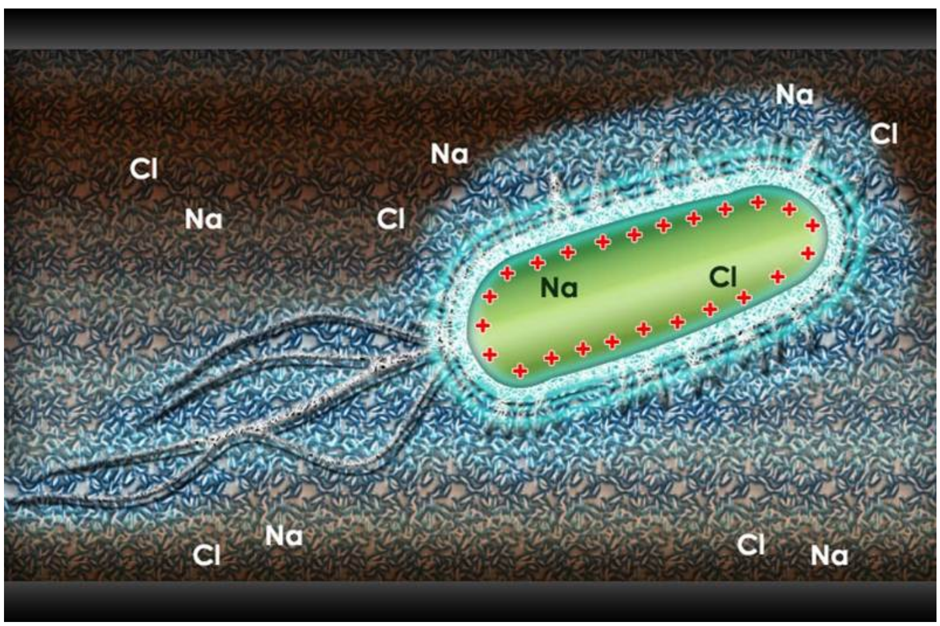

Figure 8. Water molecules being attracted to the charged bacterium (HydroFlow.com, 2013)

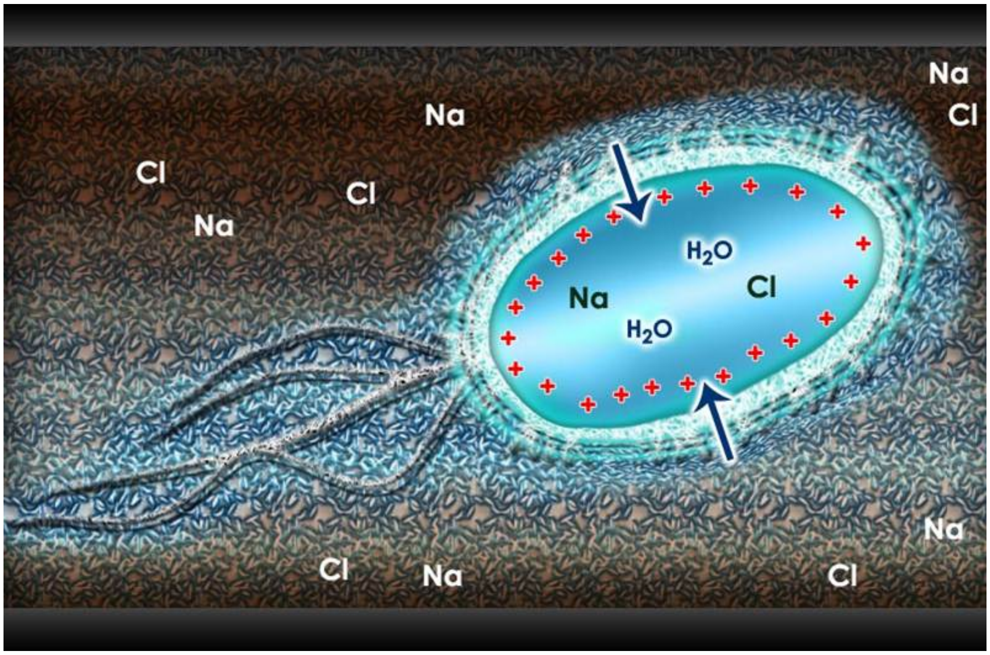

Figure 9. Osmosis draws pure water into the bacterium (HydroFlow.com, 2013)

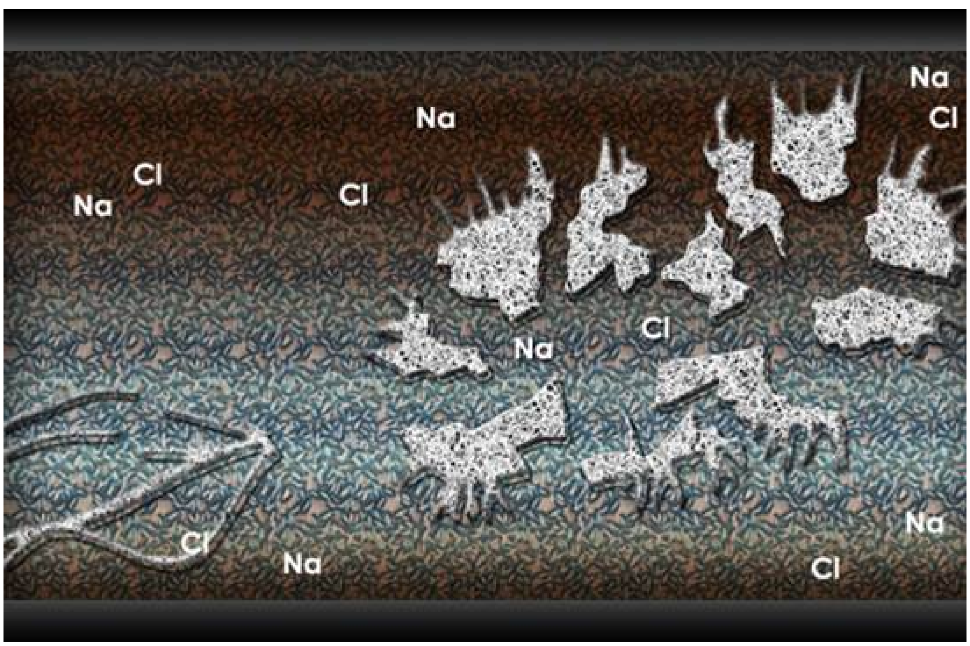

Figure 10. The osmotic pressure built inside the bacterium causes it to burst and die. (HydroFlow.com, 2013)

3. PREVIOUS RESEARCH CONDUCTED AT THE UNIVERSITY OF NEW ORLEANS

For the past three years and under the supervision and guidance of Dr. Enrique J. La Motta, the Civil and Environmental Engineering Department has been testing the feasibility of treating wastewater using the HydroFlow technology. Environmental concerns due to the use of chlorine as a disinfection method in the state of Louisiana and the efficiency in bacteria removal claimed by HydroFlow USA were the reasons why the HydroFlow unit was selected as a case of study.

3.1 Municipal Wastewater Disinfection with Electromagnetic Waves using Escherichia coli Concentration as Measurement of Quantification (Cagle, 2012)

Lauren Cagle designed a batch reactor in 2012, with the purpose of testing the E. coli removal efficiency using three different HydroFlow units.

Figure 11. Experimental Design of a batch reactor by Lauren Cagle (Cagle, 2012)

The reactor was made up of solid 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 straight PVC to reach the pump. The pump used in the system was an Utilitech irrigation pump (model #0313831). The pump's inlet and outlet were connected using an adaptor to a straight PVC pipe. A ball valve was located 15.24 cm above the pump outlet in order to regulate the flow through the system.

A turbine flow meter, 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. 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 (Cagle, 2012).

A heat exchanger constructed with copper tubing was placed inside the basin (Fig. 10). The copper was loosely twisted to about a 25.4 cm radius coil. 3⁄4 inch clear vinyl tubing was connected to the opening at both bottom and top of the copper coil and secured with a hose clamp. The clear vinyl tubing was connected to the faucet 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 clear vinyl tubing. The heat exchanger helped to keep the water cold and avoided killing the bacteria due to the increase in temperature caused by the pump. (Cagle, 2012)

Two HydroFlow units were tested using the reactor previously described, the first unit to be tested was the SpaKlear W63 (Fig. 11), according to the manufacturer this unit as designed for residential spas a hot tubs, it is also the unit that generates less amount of voltage out of the three tested during the course of this investigation. The second unit tested was the AquaKlear P60 (Fig. 11), which ended up being defective according to a representative from HydroFlow USA. For both units the general test procedure was the following:

- 5 gallons of wastewater were added to the basin.
- An 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. (Cagle, 2012)

Figure 12. SpaKlear W63 and AquaKlear P60 units (HydroFlow.com, 2013)

The third unit tested was the Industrial 60i, according to the manufacturer this unit is primarily design for industrial use, also it produces the highest voltage among the three units tested. However, the manufacturer claimed that this unit could remove bacteria after just one pass through the ferrites ring around the pipe, therefore changes were made to the original design, the heat exchanger was removed from the system as well as the recirculation pipes. For this unit, the general test procedure was modified as follows:

- 2.5 gallons of water was put into the sample basin
- An 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
- The 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)
- A 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. (Cagle, 2012)

Figure 13. Industrial 60i unit

According to the manufacturer, the 60i, an industrial grade unit, would require a single pass to kill the bacteria. Accordingly, the experimental procedure was modified so the water only passed through the unit one time and was then discarded. In the tests used with this set of experiments the starting colony counts were in the ranges of 375 000 E. coli/100 ml to 750 000 E. coli/100 ml. The first test showed a decrease in E. coli from the initial count to 0, and the second run showed a decrease from 600,000 E. coli/100 ml to 15,000 E. coli/100 ml. The tests that followed showed no decrease in E. coli concentration, with the average starting concentration of 500,000 E. coli/100 ml and average final concentration of 625,000 E. coli/100 ml. The sample water taken from June 14 had average initial bacteria concentration of 225,000 E. coli/100 ml, which was 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 170,000 E. coli/100 ml to 5,000 E. coli/100 ml, 225,000 E. coli/100 ml to 1 colony, and 270 000 E. coli/100 ml to 27 500 E. coli/100 ml; that is, a change of 99%, 97%, and 90% respectively. These results were not consistent with the following tests, in which 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. The average initial concentration of E. coli was about 195000 E. coli/100 ml and final average concentration was 182500 E. coli/100ml, with no data being an outlier in that average. The average variance between the initial and final concentrations is 15000 E. coli/100ml, which is equivalent to 6 colonies per plate (Cagle, 2012). These inconsistencies in the results led to further investigation performed by Christopher Blazo in between 2012 and 2013.

3.2 Wastewater Disinfection with HydroFlow Technology (Blazo, 2013)

Christopher Blazo designed two different reactors for his investigation; the first reactor was built and placed in the Marrero Wastewater Treatment plant (Fig. 13), with the purpose of testing the efficiency of the HydroFlow 60i unit when treating wastewater. The reactor consisted in a PVC pipe 10-m long, 50-mm diameter equipped with sampling ports at several points. Wastewater was withdrawn from secondary clarifier using a hose attached to a submersible pump connected to the inlet of the reactor. The flow was controlled using a ball valve and measured by a flow meter. A pipe was connected to the inlet system to remove the excess water from the reactor (Fig. 14). To ensure the pipe was full when water passed the HydroFLOW 60i unit, the unit was placed in a vertical pipe section. The sampling points were placed at the following distances from the unit: 3.42cm, 6.85cm, 17.12cm, 34.24cm, 102.72cm, 205.44cm, 410.88cm, 616.32cm, 821.76cm and 1027.3cm after the unit. A T-joint and a drain were used to build the sampling point. To elevate the pipe above ground level, several wooden planks were used. Finally, a pipe was connected to release the water from the system back to the clarifier trough. All the PVC pipes were connected to each other by using PVC glue. (Blazo, 2013)

Figure 14. Continuous flow reactor at the Marrero Wastewater Treatment Plant.

Figure 15. Pipe to remove excess of wastewater in the system.

The HydroFLOW 60i unit, and the flow meter were kept inside a storage box to protect them against the atmospheric elements. When the system was not used to take samples then the pump and other necessary components were kept inside the box and were locked. (Blazo, 2013)

Two tests were performed using the first reactor, the first one the wastewater flow was kept at 3.8 L/min for a total detention time of 5 minutes and three samples were collected at each sample point with contact times of 5 sec, 10 sec, 30 sec, 60 sec, 120 sec, 180 sec, 240 sec and 300 sec after passing through the HydroFlow unit. For the second test the flow was lowered 50% with respect of the first test to allow a detention time of 10 minutes, in this case samples were collected at 10 sec, 20 sec, 60 sec, 120 sec, 240 sec, 360 sec, 480 sec and 600 after passing through the HydroFlow unit. (Blazo, 2013)

The second reactor was a batch reactor built using a 0.6-m pipe of 50-mm diameter, supported by two pipe clamps attached to a wooden board. It was filled with 1.13 liters of wastewater that reached the 0.56-m mark of the pipe. A plastic seal was placed at the bottom of the pipe to hold the water in the system. Two holes were drilled in the bottom and one on the top of the reactor to connect a bellow pump and the air bubbling system to maintain a completely mixed solution and avoid settling that could affect the samples concentration. The bellow pump was from Gorman-Rupp having a highest rate of flow 2.48 L/min. The HydroFlow 60i unit was placed in the middle of the reactor and two sampling points were placed on top of it so that sample water can be collected after water passes the unit. Wastewater sample was collected from the secondary clarifier of Marrero Wastewater Treatment plant and was brought to the laboratory. The reactor was filled with the sample wastewater and was run using four different combinations: (Blazo, 2013).

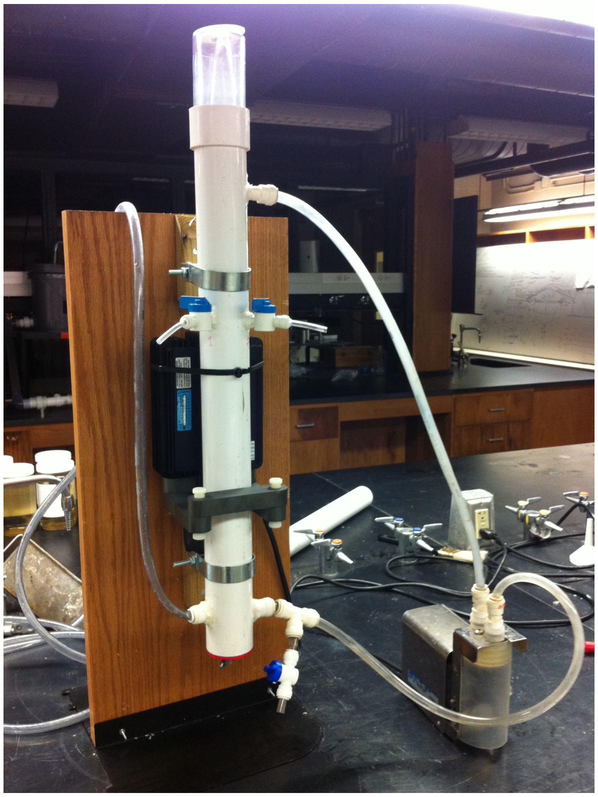

Figure 16. Batch reactor with air bubbling and recirculation.

- System 1 Air Bubbling ON | HydroFlow unit OFF | Bellow Pump OFF.
- System 2 Air Bubbling ON | HydroFlow unit ON | Bellow Pump OFF.
- System 3 Air Bubbling OFF | HydroFlow unit ON | Bellow Pump ON.
- System 4 Air Bubbling ON | HydroFlow unit ON | Bellow Pump ON.

In system 1 the finality was to verify that the air bubbling alone didn't have a negative effect in the bacteria that could compromise the outcome of the experiment. In effect the results obtained indicated that the bacteria concentration remained constant regardless the air bubbling.

In system 2, the results showed that with air bubbling and the HydroFlow unit turned on the removal efficiency achieved was 31.91% in 30 min, which increased up to 65.80% in 2 hours.

In system 3, with the HydroFlow unit and the bellow pump on, the results were almost the same as with the air bubbling, this might have happened due to insufficient recirculation which could have cause bacteria settling.

In system 4, with all the components of the reactors in the ON position, the efficiency obtained was up to 46.59% in 30 min and 68.61% in 2 hours.

These results were substantially better than the ones obtained by the previous investigation. However, they remained far from achieving the EPA standard of 200 coliform per 100 mL, which requires 99.999% coliform removal. Therefore a new closed loop reactor was design and built for the purpose of this investigation.

4. METHODOLOGY

4.1 Sampling Collection

Samples were collected from the Marrero Wastewater Treatment Plant, located at 6250 Lapalco Boulevard, Marrero, LA on the west bank of Jefferson Parish. Six gallons of secondary wastewater effluent were taken from the overflow trough after flowing over the weir and before entering the chlorine chamber from the secondary clarifier (Fig. 17) and storage in a plastic container for transportation. Due to the short lifespan of the E. Coli contained in the wastewater, new samples were collected and transported for each test to the lab located at the Center for Energy Resource Management (CERM) located at the Research Technology Park of the University of New Orleans, in New Orleans Louisiana.

Figure 17. The secondary clarifier at the Marrero Wastewater Treatment Plant.

Figure 18. Wastewater flowing over the weir.

4.2 Closed Recirculation System

The reactor was design and built in the Center for Energy Resource Management (CERM) located at the Research Technology Park of the University of New Orleans, in New Orleans Louisiana.

The closed recirculation system consists of an array of 11 pieces of 2-inch pipe, assorted as follows (Fig. 19):

- 1 piece of 7ft
- 1 piece of 2.5ft
- 5 pieces of 1ft
- 4 pieces of 2ft
- For a total 22.5ft

The HydroFlow 60i unit was placed one the left end of the reactor (Fig. 20). The wastewater flow was controlled by a Baldor Reliance pump Cat. No. IDNME3538 with adjustable speed drive connected to the reactor using 2ft of flexible ½ inch clear vinyl tubing. The reactor is equipped with 3 sampling points, the first one being located at 7.5ft mark, the second one at 15ft mark and the third one at 22.5ft mark. These points were placed after selecting a flow of 0.5 l/min and a detention time of ±15 minutes per pass to perform the experiment. However, the first run was not successful and the results were neglected, therefore new considerations were taken into account for the next test.

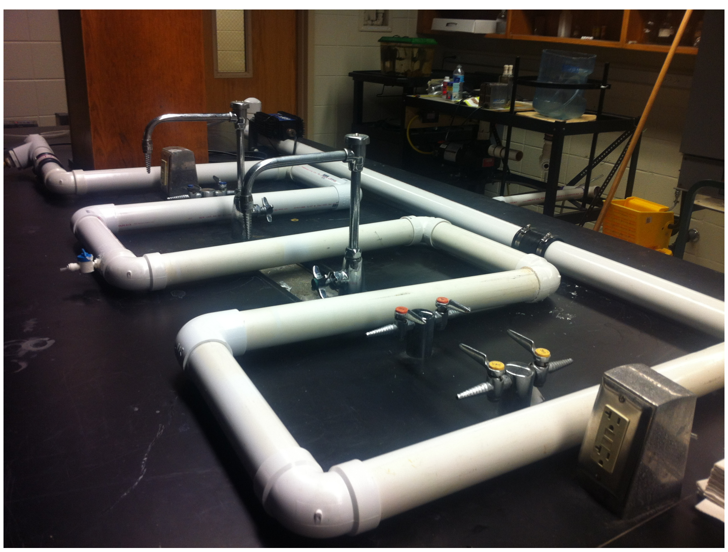

Figure 19. Closed Recirculation System

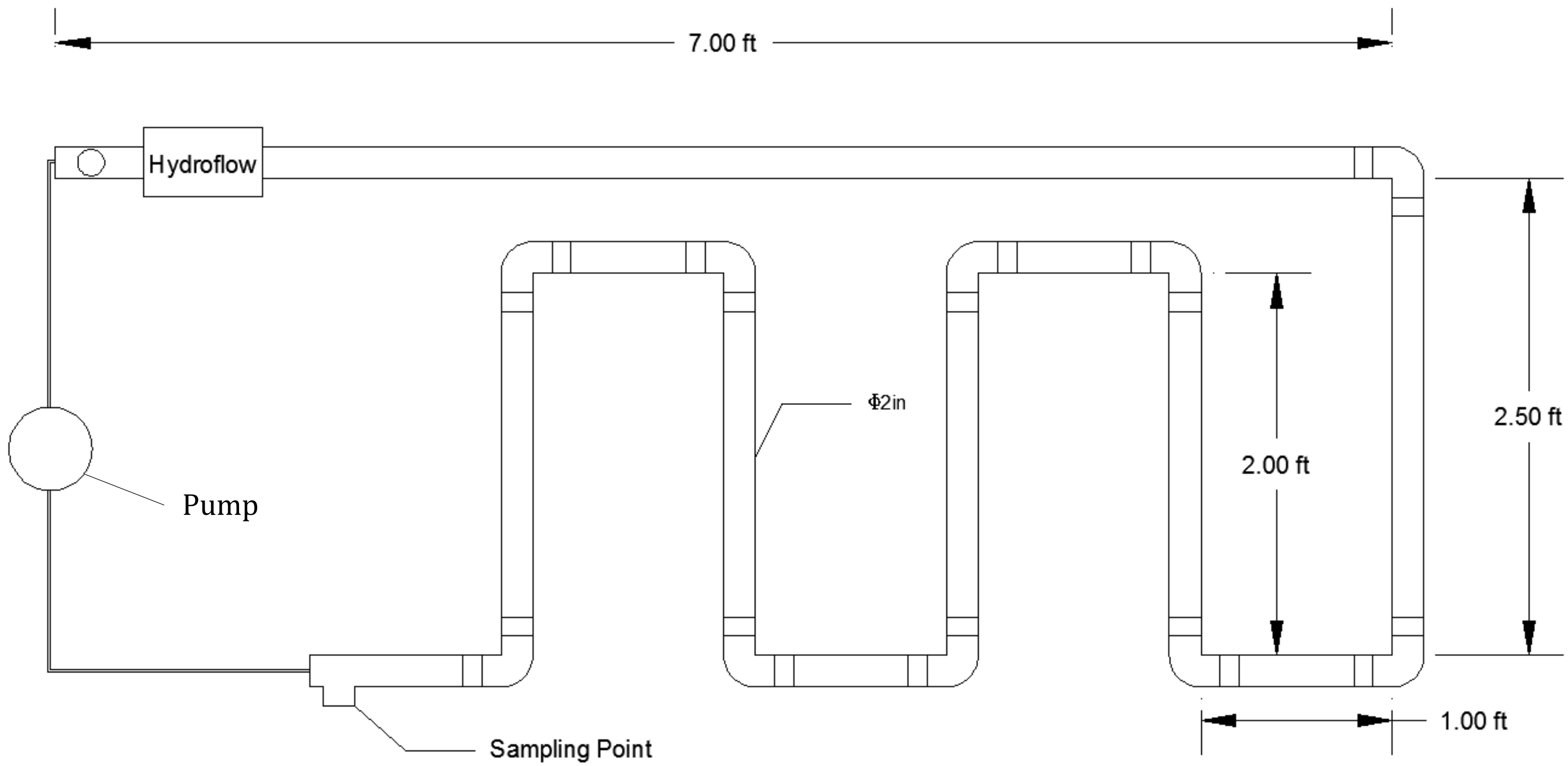

Figure 20. Closed Recirculation System Diagram

For the second run of experiments the water was previously mixed to avoid settling, also the flow was incremented to 1.0 l/min allowing 2 passes every 15 minutes. For this run, 5 samples were taken, the first one to measure initial concentration, the second one after 2 passes in 15 minutes, the third one after 4 passes in 30 minutes, the fourth one after 8 passes in 1 hour and the fifth one after 16 passes in 2 hr.

4.3 Quantification of Escherichia Coli

These samples were analyzed applying the "Method 1603: Escherichia coli (E. coli) in Water by Membrane Filtration Using Modified membrane-Thermotolerant Escherichia coli Agar (modified mTEC)" developed by the United States Environmental Protection Agency.

4.3.1 Modified mTEC agar preparation

Modified mTEC agar of 11.4g was added to 250ml of reagent-grade water, the solution was mixed thoroughly and place in a stirrer/hot plate in order to dissolve completely. The solution was later autoclaved at 121°C (15 PSI) for 15 minutes, and cooled in a 50°C waterbath; the pH was adjusted to 7.3 ± 0.2. With 1.0 N hydrochloric acid or 1.0 N sodium hydroxide. Then the medium poured into 9 × 50 mm culture dish to a 4-5 mm depth (approximately 4-6 mL), and was allowed to solidify to be stored in a refrigerator. (USEPA, 2009)

4.3.2 Test Procedure

1. The petri dish was marked with the sample identification.
2. A sterile membrane filter was placed on the filter base, grid side up, and the funnel was attached to the base so that the membrane filter is held between the funnel and the base.
3. 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 0.04 ml (40 microliters) was added to the DI water using a fresh, autoclaved pipette tip each time.
4. The sample was filtered, and the side of the funnel was rinsed with 20 mL of sterile buffered rinse water. Turn off the vacuum, and remove the funnel from the filter base.
5. Sterile forceps was used to aseptically remove the membrane filter from the filter base, and was rolled onto the modified mTEC agar to avoid the formation of bubbles between the membrane and the agar surface. The membrane was reseated if bubbles occurred.
6. The dish was closed, inverted, and incubated at 35°C ± 0.5°C for 2 ± 0.5 hours.
7. After a 2 ± 0.5 hour incubation at 35°C ± 0.5°C, the plates were transferred to Whirl-Pak® bags, the bags were sealed, and was submerged in a 44.5°C ± 0.2°C waterbath for 22 ± 2 hours.
8. After 22 ± 2 hours, the plates were removed from the waterbath; the number of red or magenta colonies were counted and recorded. (USEPA, 200228)

5. RESULTS

5.1 Trial Run 1

In the closed recirculation system, samples of wastewater were collected at 3 different sampling points in order to determine the effect of the HydroFlow technology in the variation of concentration of the E. Coli bacterium. The flow ran at a 1L/min to allow a detention time of 15 min. Due to inconsistencies in the results trial run 1 was not taken into account in the discussion of this investigation.

5.2 Trial Run 2

For the second run of experiments, the flow rate was lowered to 0.5 L/min to allow a higher detention time of 30 min, samples were taken from the last sampling point. The results are summarized in Table 3. It can be seen a significant reduction in the E. Coli concentration after 2 hours that reached an 83.5%. In figure 21 it can be appreciated graphic representation of the 100ml E. Coli concentration with respect to time.

Table 3. Removal efficiency of the HydroFlow unit 60i in a closed recirculation system (Trial Run 2)

Sampling Point	Time (min)	0.04 ml Count	Average Count	100 ml Count	% Removal
Influent	0	112	107.0	267500	0.0
		107			
		102			
1	15	63	69.0	172500	35.5
		75			
		69			
1	30	54	37.3	93333	65.1
		28			
		30			
1	60	30	32.7	81667	69.5
		32			
		36			
1	120	14	17.7	44167	83.5
		18			
		21			

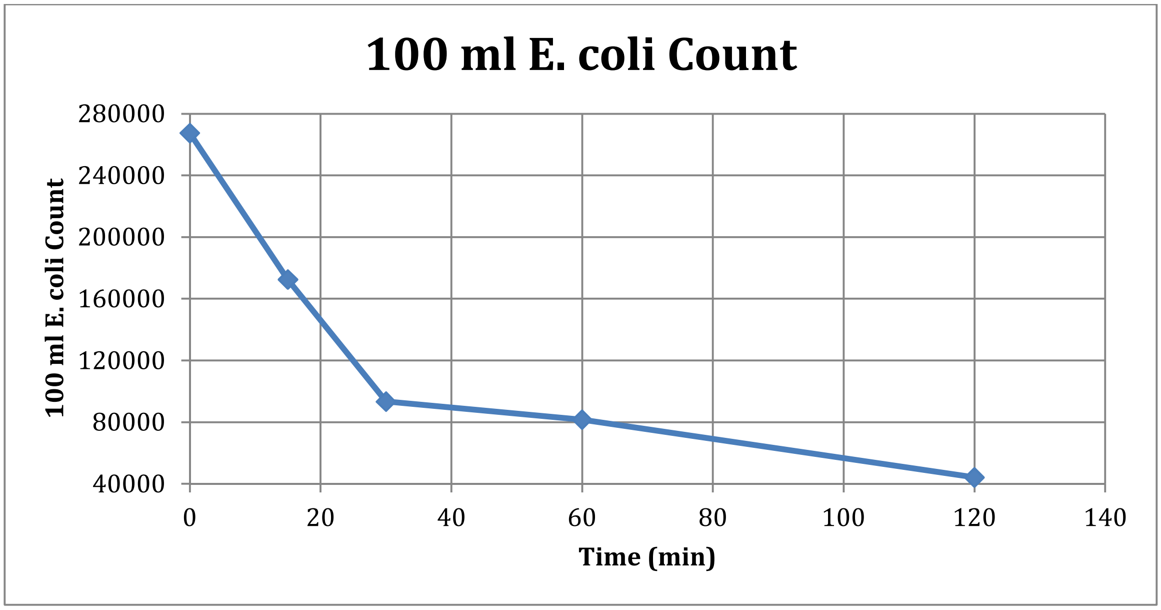

Figure 21. 100ml E. Coli count vs time (Trial Run 2)

5.3 Trial Run 3

In the third run of experiments, the flow rate was lowered to 0.25 L/min to allow one recirculation in a 60 min detention time, once more samples were taken from the last sampling point. The results are summarized in Table 4. A significant reduction in the E. Coli concentration can be observed after 2 hours reaching 85.8% removal efficiency. In figure 22 the graphic representation of the 100ml E. Coli concentration with respect to time is presented.

Table 4. Removal efficiency of the HydroFlow unit 60i in a closed recirculation system (Trial Run 3)

Sampling Point	Time(min)	0.04 ml Count	Average Count	100 ml Count	% Removal
Influent	0	124	124.7	311667	0.0
		132			
		118			
1	15	76	75.3	188333	39.6
		72			
		78			
1	30	60	40.3	100833	67.6
		30			
		31			
1	60	28	31.7	79167	74.6
		35			
		32			
1	120	17	17.7	44167	85.8
		15			
		21			

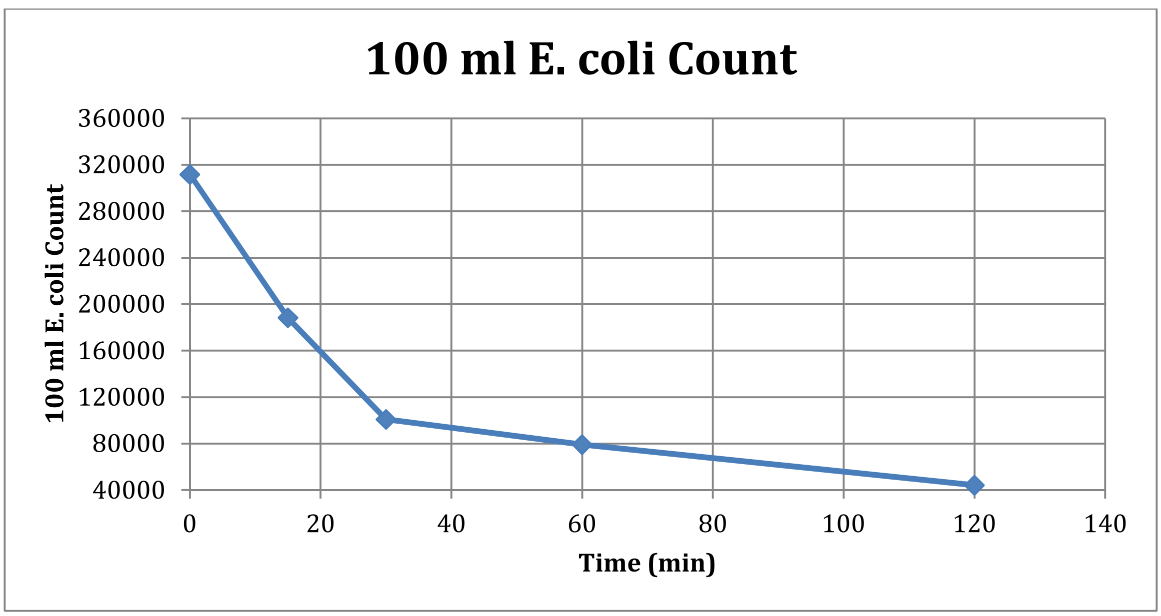

Figure 22. 100ml E. Coli count vs time (Trial Run 3)

5.4 Conductivity Test

Low conductivity in the system might decrease the efficiency of the process. In order to determine if the conductivity of the system was varying during the disinfection process a conductivity test was performed. The results are presented in Table 5. Figure 23 shows the graphic representation of the resulting conductivity values of the wastewater, not showing big variation in time.

Table 5. Conductivity of wastewater in time when exposed to the HydroFlow unit 60i in a closed recirculation system

Time (min)	Conductivity (µS/cm)
0	1138
30	1137
60	1149
90	1143
120	1140
150	1146
180	1144
210	1140
240	1139
270	1142

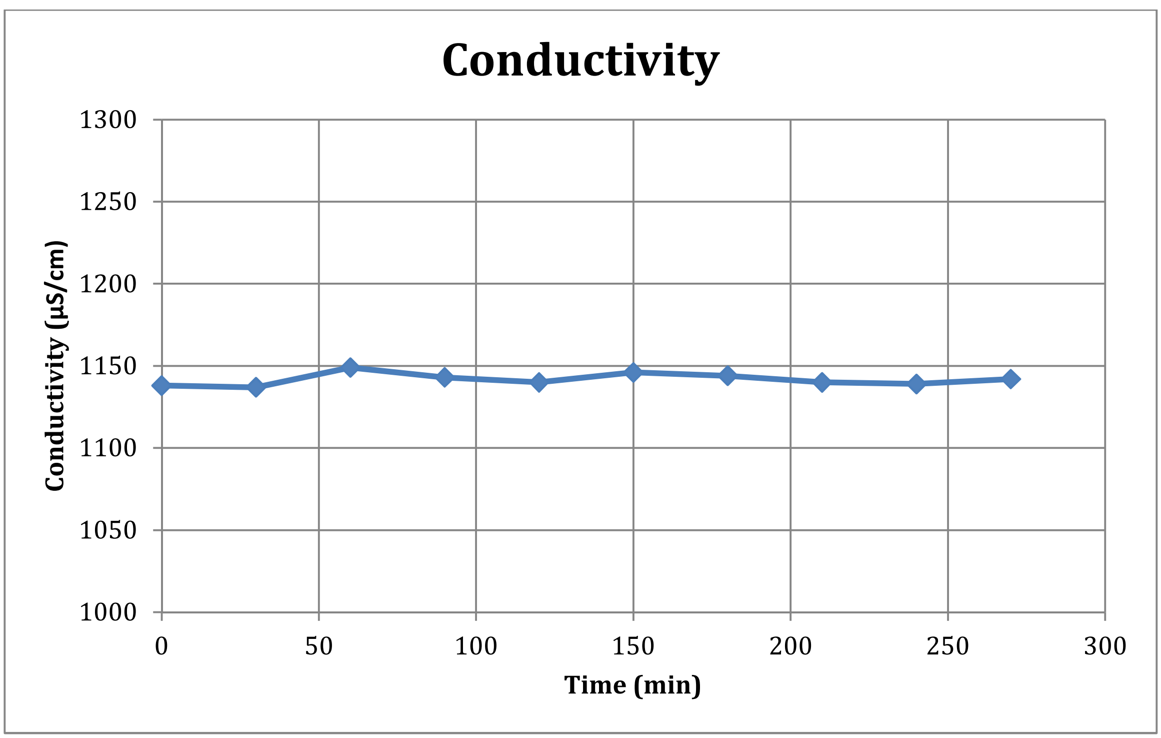

Figure 23. Conductivity of Wastewater vs time

5.5 Statistical Analysis

Based on the previous runs a statistical analysis was performed on the system. Linearizing the system by applying the natural log of the concentrations and plotting it against time the detention time needed to achieve the EPA maximum allowed fraction remaining of 200 coliform per 100 ml was found. The results obtained pointed to a detention time of 9 hours to obtain a removal efficiency of approximately 100%. The statistical analysis graphical representation is shown on Figure 24.

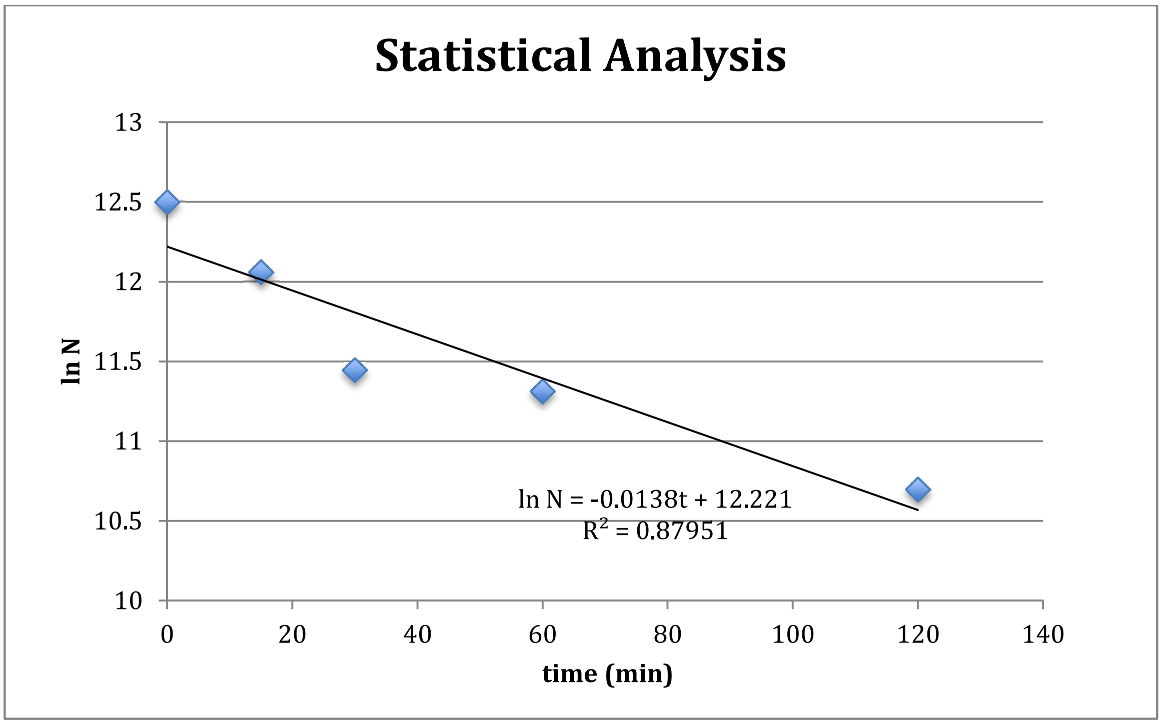

Figure 24. Statistical Analysis

5.6 Trial Run 4

Based on the statistical analysis detention time, this run was performed for 12 hours to ensure the detention time was achieved, and the flow rate was set back to 1 L/min since from previous results no significant change was observed when lowering the flow rate. Another important fact about this run is that one of the filters of the plant was out of service, this would lead to higher bacteria levels on the secondary effluents used for this investigation; therefore, the initial concentration was decreased from 0.04 ml to 0.02 ml count to avoid an exponential growth of colonies on the agar dishes which would result in uncountable number of colonies. The results are summarized in Table 6. The removal efficiency reached under these conditions was 70.81%. The graphic representation of the results obtained is shown on Figure 25.

Table 6. Removal efficiency of the HydroFlow unit 60i in a closed recirculation system (Trial Run 4)

Sampling Point	**Time(min)**	**0.02ml Count**	**Average Count**	**100 ml Count**	**% Removal**
		995			
1	0	1152	1051	5253333	0.0
		1005			
		508			
1	60	620	558	2788333	46.9
		545			
		418			
1	120	422	415	2076666	60.4
		406			
		382			
1	180	358	378	1890000	64.1
		394			
		408			
1	240	379	370	1848333	64.8
		322			
		398			
1	300	310	337	1683333	67.9
		302			
		345			
1	360		329	1642500	68.7
		312			
		375			
1	420		375	1875000	64.3
		398			
1	480	341	370	1847500	64.8
		312			
1	540	345	325	1626667	69.1
		319			
1	600	308	314	1567500	70.1
		319			

Table 6. Continuation of Removal efficiency of the HydroFlow unit 60i in a closed recirculation system (Trial Run 4)

		298			
1	660	306	294	1471667	71.9
		279			
		321			
1	720	295	306	1530000	70.8
		302			

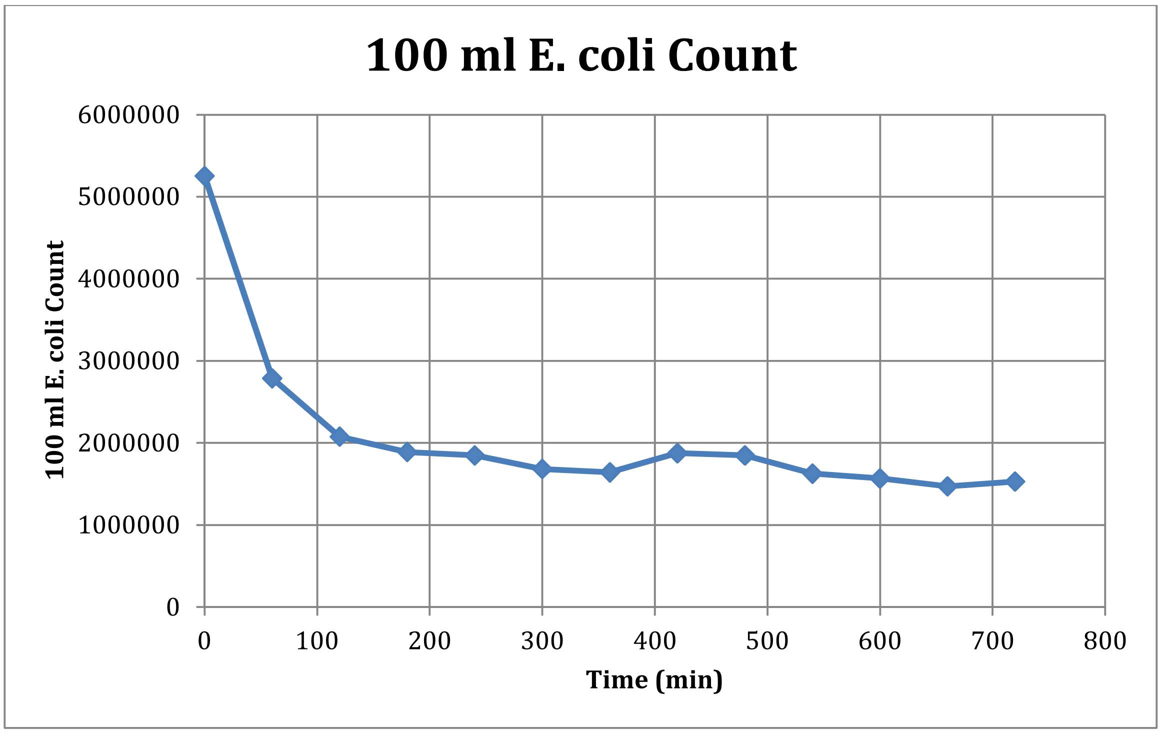

Figure 25. 100ml E. Coli count vs time (Trial Run 4)

5.7 Trial Run 5

Due to the low conductivity on the system, 3g/l MgSO were added to the system to increase the conductivity to the order of 4000μS/cm. Moreover, the initial concentration was once more decreased to 0.002ml due to higher than expected bacteria count in the previous trial, which could result in higher probability of systematic error. The results are presented in Table 7. The removal efficiency reached under these conditions was 83.19%. The graphic representation of the results is presented on Figure 26.

Table 7. Removal efficiency of the HydroFlow unit 60i in a closed recirculation system (Trial Run 5)

Sampling Point	Time(min)	0.002 ml Count	Average Count	100 ml Count	% Removal
		681			
1	0	538	610	30483333	0.0
		610			
		301			
1	60	358	293	14666667	51.8
		221			
		176			
1	120	196	186	9300000	69.4
		176			
1	180	200	188	9400000	69.2
		141			
1	240	139	135	6766667	77.8
		126			
		95			
1	300	92	95	4766667	84.4
		99			
		103			
1	420		104	5225000	82.9
		106			
		133			
1	540	108	130	6500000	78.7
		149			
		96			
1	660	109	103	5125000	83.2

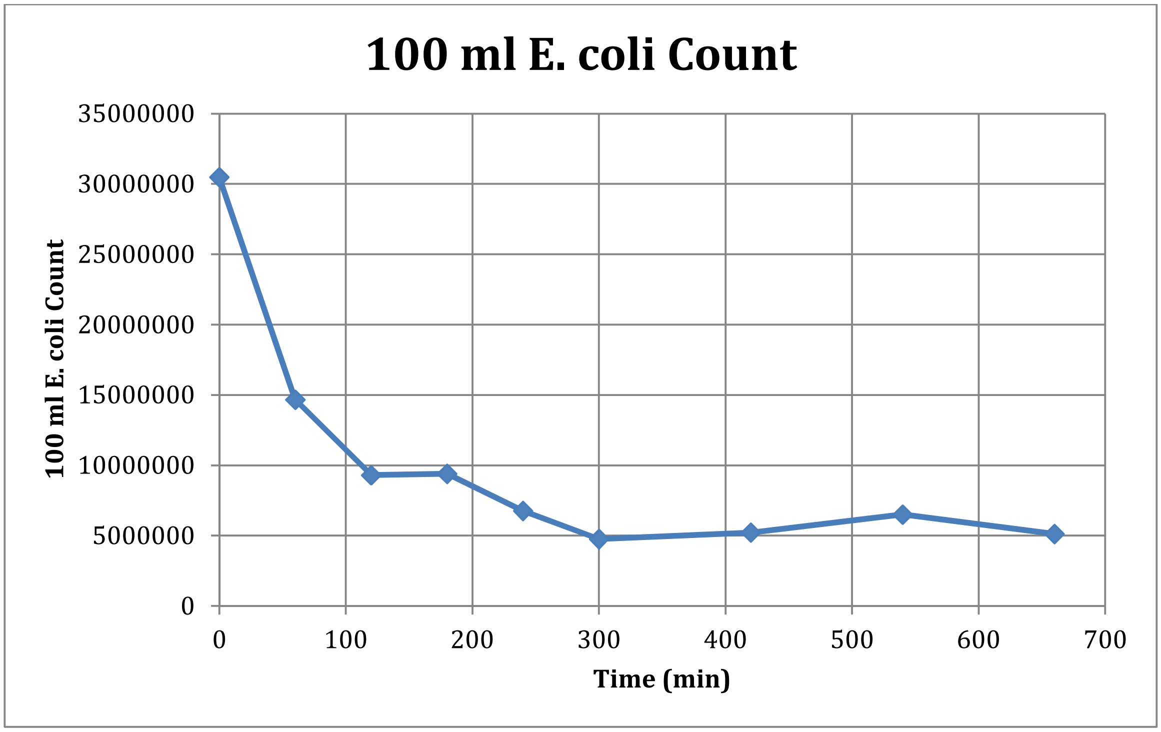

Figure 26. 100ml E. Coli count vs time (Trial Run 5)

6 DISCUSSIONS

The Hydropath technology has shown high efficiency when installed in cooling towers systems, by preventing limescale accumulation, removing existing limescale deposits and eradicating bacteria and algae growth.

Moreover, the Hydropath technology has been proven to be effective in other applications, such as swimming pools where water and energy can be saved by reducing backwash, decrease the amount of chlorine needed to disinfect as well as effectively prevent algae built up, eliminate odors and reduce scum lines. These results were also observed in fish farms and ornamental ponds.

Most of these applications, where the Hydropath technology has shown good results shared a common characteristic, namely, that the water volume to be treated remains constant for several days or varies slightly, which means that the water recirculates a large number of times within the system. However, that condition cannot be applied to the wastewater treatment process due to limitations related to the detention time, which cannot exceed more than 30 minutes.

Another consideration to be remarked is that HydroFlow claims to reduce the need of chlorine in about 60%, meaning that in some cases, where bacteria elimination is required, chlorination is still needed to achieve water quality standards and regulations.

Based on the results obtained in this research project, it can be stated that the HydroFlow 60i unit cannot be used to replace the chlorination process in the wastewater treatment as a disinfectant.

Many measures were taken to control and to assure reliable results. In every test run, all instruments and materials to be used were sterilized, in order to guarantee no contamination of the tested samples and avoid misleading results. DI water was tested before and after every test to control its quality in every step of the process. Also, a conductivity test was performed to determine whether or not it was a variable that might affect the performance of the HydroFlow 60i unit. Moreover, flask and filters were cured with a solution of ethanol at 10% to kill any bacteria remaining in the vacuum filtration system from previous samples and then washed out with DI water.

Based on previous applications of the HydroFlow technology, where the HydroFlow units claim to be effective, the reactor used for this research was built following the principles of a swimming pool, where a constant volume recirculates through the system several times The reactor worked as a closed recirculation system with a constant volume of 14 liters connected to an electronic controlled pump in order to maintain a constant flow, and a completely mixed system to avoid bacteria settling within the reactor.

One of the objectives of this research was to evaluate if the HydroFlow 60i unit was able to eliminate E. coli from secondary effluents. However, the results obtained were far from achieving EPA standards. Although, the HydroFlow 60i unit removed up to 83% of the bacteria during the first 5 hours, it was not possible to determine the causes for this behavior of the system, which was observed repeatedly in both previous (Blazo, 2013) and current research.

7 CONCLUSIONS

The feasibility of using the HydroFlow 60i unit to disinfect wastewater to substitute the chlorination process was evaluated in this research. To conduct this study, a closed recirculation system was employed, placing the HydroFlow 60i unit to the left of it and controlling the flow of wastewater with a Baldor Reliance pump Cat. No. IDNME3538. The reactor had 3 sampling points that were tested on the first run of the reactor, based on the results all the samples for the following runs were taken at the last sampling point located at 22.5ft mark. The parameter evaluated was the E. Coli concentration in time.

After running several experiment runs it can be stated that the HydroFlow 60i unit can remove bacteria from wastewater. However, it was unable to remove E. Coli to the required levels established by the EPA standards.

It was also found that increasing the conductivity of the water did not improve the performance of the HydroFlow 60i unit.

Based on this research, and on the results obtained in previous research performed at the University of New Orleans (Blazo, 2013 and Cagle, 2012), it can be concluded that the HydroFlow 60i unit is not a suitable option to replace the chlorination process in wastewater treatment.

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VITA

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During his Master's program, he has been working as a research assistant at the Department of Civil and Environmental Engineering of the University of New Orleans. The focus of his research has been wastewater disinfection with alternative methods for substituting chlorination.