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Biofiltration for Control of H2S from Wastewater Treatment Plant Gases

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BIOFILTRATION FOR CONTROL OF H_2S FROM WASTEWATER TREATMENT PLANT GASES

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τ	Residence Time
θ	Porosity of media
a	Interfacial area
A	Surface area
Amp	Ampere
APC	Air Pollution Control
BF	Biofilter
CAA	Clean Air Act
C_G	Contaminant concentration in the air phase
Cg_i	H_2S inlet gas concentration
Cg_o	H_2S outlet gas concentration
C_L	Contaminant concentration in the bulk water
C_L^*	Contaminant concentration in equilibrium with local air concentration
CO_2	Carbon dioxide
EC	Elimination capacity
EBRT	Empty bed residence time
ft	Foot
g	Gram

g/m^3h	Grams per cubic meters hour
h	Hours
H	Henry's Law constant of proportionality
H^+	Hydrogen
HDPE	High density polyethylene
H_2O	Water
Hp	Horse power
H_2S	Hydrogen sulfide
H_2SO_4	Sulfuric acid
Hz	Hertz
in	Inches
K_L	Liquid film coefficient
K_La	Overall transfer coefficient
m	Meter
m^3/h	Cubic meter per hour
MACT	Maximum Achievable Control Technology
NSPS	New Source Performance Standards
POTWs	Publicly Owned Treatment Works
PVC	Polyvinyl chloride
Q	Air stream flow
RE	Removal efficiency
RPM	Revolutions per minute
s	Second

S^{2-}	Sulfur
SO_4^{2-}	Sulfate
SSSA	Soil Science Society of America
t	Time
V_f	Volume of biofilter
VOCs	Volatile organic compounds
WWTP	Wastewater treatment plants

ABSTRACT

A low-cost and efficient methodology was used to test the performance of a biofilter removing gaseous hydrogen sulfide generated in the headworks and a primary clarifier of a local Wastewater Treatment Plant. The contaminated gas stream is distributed upward through 1,718 m^3 of filter material. With a flow rate varying between 3,503.0 m^3/h and 4,587.3 m^3/h and hydrogen sulfide inlet concentrations between 0.8 and 146 ppm, hydrogen sulfide was efficiently eliminated by the wood bark biofilter. The removal efficiencies ranged from 97.5% to 99.9%. The mean water content of the filter material was determined to be 67.1%. The excess water existing in the unit and long residence times may have provided the appropriate conditions for a high hydrogen sulfide removal.

1. INTRODUCTION

Wastewater Treatment Plants (WWTP) are the most popular way for treatment of the water carrying waste removed from commercial and industrial establishments, institutions, residences, together with surface water, ground water, and stormwater. They have been a concern since the early 1970s because of increasing health and environmental effects (Porter et al., 1986). Biological conversion processes under anaerobic conditions occurring in the wastewater are responsible for the decomposition of the organic matter that produces the gases causing air quality impacts (Bertucci et al., 1994).

Wastewater treatment operations have the potential to release pollutants to the atmosphere. Under the Clean Air Act (CAA), New Source Performance Standards (NSPS) require the states adopt and enforce regulations for controlling emissions to the atmosphere from wastewater treatment plants. Under these guidelines, Publicly Owned Treatment Works (POTWs) must establish the Maximum Achievable Control Technology (MACT) standards.

To control and manage the emission of pollutants to the environment, traditional air pollution control technologies for pollutant gases, such as adsorption and combustion have been used (Wani et al., 1998). However, in the case of treatment of diluted waste gas streams these traditional methods are

relatively less effective, more expensive, and wasteful in terms of energy consumption (Allen et al., 1992).

A suitable alternative air pollution control technology is biofiltration. This method utilizes two simultaneous processes of adsorption and bioconversion to continuously treat contaminants in a flowing waste gas stream. The gaseous pollutants are absorbed into a moist surface biofilm layer and adsorbed onto the surfaces of the biofilter stationary bed material (Williams and Miller, 1992). Microorganisms attached to the bed material oxidize the absorbed/adsorbed gases and renew the treatment capacity of the bed material (Devinny, 1999).

This approach has been successfully applied to a wide range of industrial and public sector sources for the abatement of odors. This technology is an established control method involving high volume/low concentration of odor causing compounds (Deshusses et al., 1995). Biofiltration for control of pollutants in waste gases is a relatively unknown and little explored control technology in the United States (Yonghua et al., 1994). However, biofilters are increasingly being used by wastewater treatment plants as deodorizing filters because they minimize the generation of a second waste stream and their low operating and maintenance costs (Togashi et al., 1986).

Odors from WWTP have represented more of a public nuisance than a community health hazard. Trace compounds present in complex mixtures such as wastewater gas have been responsible for some of the malodors associated with wastewater treatment operations. These important odorants sometimes reported in wastewater gas include ammonia, methyl amine, trimethyl amine,

chlorine, hydrogen sulfide, and organosulfur compounds (Metcalf and Eddy, 2003).

Hydrogen sulfide is colorless, irritating, toxic, corrosive, smelly substance with a very low odor threshold. It is the odor encountered most commonly in wastewater management facilities (Metcalf and Eddy, 2003). This gas is the principal cause of odor nuisance, and is usually present at concentrations up to 300 ppm in the POTWs (Iranpour et al., 2001). The amount of this odor compound liberated in wastewater treatment depends upon a variety of factors: nature and organic content of the wastewater, amount of oxygen present, temperature, and the wastewater treatment facility where it is produced.

Biofilters have a proven track record for controlling H_2S emissions. Studies of these units at laboratory, pilot, and full scale have been intensified in the last 20 years. Removal efficiencies around 99% have been reached due to the high biodegradability of this gas (Leson and Winer, 1991).

The study of hydrogen sulfide elimination appeared to provide a great scope for developing an understanding of biofiltration processes. Van Langenhove et al. (1986) published the result of H_2S removal with a wood bark biofilter. During 70 days they insisted on over 95% removal efficiencies and provided useful information about the pressure drop and media water content relationship. Allen et al. (1992) showed the removal efficiencies of H_2S by changing the loading rate at different detention times in two laboratory scale and one full scale biofilters. During long term operation they studied the water content and deterioration of media characteristic effects on removal. Two years later,

Allen et al. extended their studies in the laboratory scale biofilters. This time, the study included the effects of compost acidity, compost sulfate content, and temperature on removal efficiency. Researchers such as Wani et al. (1999), Cha et al. (1999), Chung et al. (2000), Kim et al. (2002), and Li et al. (2003) studied the removal of hydrogen sulfide in a mixture of odorous gases, which provided a greater understanding of multicomponent removal in a biofilter.

1.1. Objectives and Scope

The main objective of this research is to understand the effectiveness of a full scale biofilter in treating odors produced in municipal wastewater treatment facilities through the literature and field observations at a local municipal wastewater treatment facility.

The specific objectives of this research project are the following:

- Understand the effectiveness of biofilters in treating odors from municipal wastewater treatment facilities through the literature review.
- Evaluate the full scale biofilter implemented for treatment of odors at the Marrero Wastewater Treatment Plant.
- Develop a low-cost and efficient methodology to test the performance of the biofilter at the Marrero Wastewater Treatment Plant.
- Perform field tests to evaluate H_2S removal efficiency of a full scale biofilter using the identified testing methodology.
- Develop an operation and maintenance testing protocol for the Marrero Wastewater Treatment Plant operators.

This research project was carried out at the Marrero Municipal Wastewater Treatment Plant in Marrero, Jefferson Parish, Louisiana. The biofilter consists of a cylindrical concrete vessel that is half-buried in the ground within the facility area. It was designed to remove the easy degradable compounds such as H_2S and other odorous compounds.

The results of the literature review, the evaluation of the full scale biofilter, and the development of an efficient testing methodology will be used to assist in the operation and maintenance of the biofilter at the Marrero Wastewater Treatment Plant.

2. LITERATURE REVIEW

2.1. Historical Review of Biofiltration

Biofiltration is a relatively new pollution control technology. It was first used for the treatment of wastewater from chemical manufacturing facilities, solid waste processing plants, composting operations, rendering plants, etc. (Wani et al., 1997). Today, with the growing industry sectors, biofiltration has found a wide range of applications.

The first proposition to use biological methods to treat odorous compounds was as early as 1923 when Bach used a biologically active biofilter to control emissions of H_2S from a wastewater treatment plant. However, it was in the mid-fifties that this method was first applied for the treatment of odorous compounds in low concentrations. In 1959, a soil bed was installed in Germany at a sewage treatment plant in Nuremberg, for the control of odors from an incoming sewer main (Devinny, 1999).

In the 1960's, people started using biofiltration for the treatment of gaseous pollutants. Research was intensified in West Germany and in the US. In the 1970's, biofiltration to clean the air was widely and successfully used in West Germany (Wani et al., 1997). Since the 1980's biofiltration is increasingly

used in Germany and in the Netherlands to control Volatile Organic Compounds (VOCs) and air toxics emitted from industrial facilities (Tonga et al., 1994).

Now biofiltration is a well established Air Pollution Control (APC) technology in several European countries where this technology is widely used in controlling odor and both organic and inorganic air toxic pollutants (Wani et al., 1997). Control of VOCs from a variety of industrial and public sector sources such as chemical manufacturing, industrial waste treatment plants, residential wastewater treatment plants, waste oil recycling facilities, composting facilities, and coating operations is one of the widest applicabilities of this technology (Devinny, 1999). Biofilters are used to efficiently control inorganic toxics like H_2S emitted from such facilities as refineries and pulping processes; NH_3 emissions from fertilizer plants; odors from sanitary landfills, composting facilities, the sugar industry, distilleries, breweries; and organics like benzene, formaldehyde, and methylene chloride.

Through its short history, biofiltration has found high acceptance and a wide range of applicabilities. The advancements in the technology have focused on better control of operational conditions and a detailed understanding of kinetics and removal mechanisms. This air pollution control technology has great potential, and further research in the field will provide the concrete scientific principles to become a theoretical practice.

2.2. The Biofiltration Process

Biofiltration is a biological process that uses microorganisms to remove undesirable components from industrial waste gases. Waste gases are forced though filter material on which microorganisms are immobilized. After absorption in the filter material, microorganisms break down the organic compounds (or inorganic compounds) into harmless products such as carbon dioxide, mineral salts, acids, water, and more microorganism cells (Wani et al., 1998). The biological oxidation performed by microorganisms can be written as follows:

Equation 1

$$\text{Organic Pollutant} + \text{Oxygen} \rightarrow CO_2 + H_2O + \text{Heat} + \text{Biomass}$$

This process is catalyzed enzymatically (Yang et al., 1994). The reaction, which can take place at a wide range of temperatures becomes inhibited at low temperatures. The balance between biomass and carbon dioxide production is not constant and heat is generated due to the transformation (Devinny, 1999).

The mechanisms carried out in a biofiltration process are complex and have a predominant action on the pollutant removal according to the age of the biofilter. When starting up a biofilter, a large elimination capacity is observed, resulting mostly from adsorption effects. Over a period of time, the outlet concentration of the contaminant and the elimination capacity decline, depending on the contaminant concentration and the adsorptive capacity of the medium (Devinny, 1999). Finally, the outlet concentration again declines as microbiological activity on the filter material rises. This is called the acclimation

time. A low loading is recommended to be used allowing the biofilm to develop in the first week or so. Devinny (1999) suggests it to be 20% to 50% of the design flow rate.

After this initial period of low loading, the flow can be increased stepwise over short periods of time (1 to 2 days) until the design flow is achieved (Devinny, 1999). An initial reduction in removal followed by an increase to stabilize elimination capacity should occur. The flow can be raised until obtaining the elimination capacity that meets the regulatory requirements of the operating permit (Porter et al., 1994). Constant operational conditions of the biofilter are difficult to keep during its operation after acclimation time. The performance of a particular biofilter on a particular waste gas can not be predicted. Figure 1 shows the adsorption and biodegradation characteristics during biofilter startup.

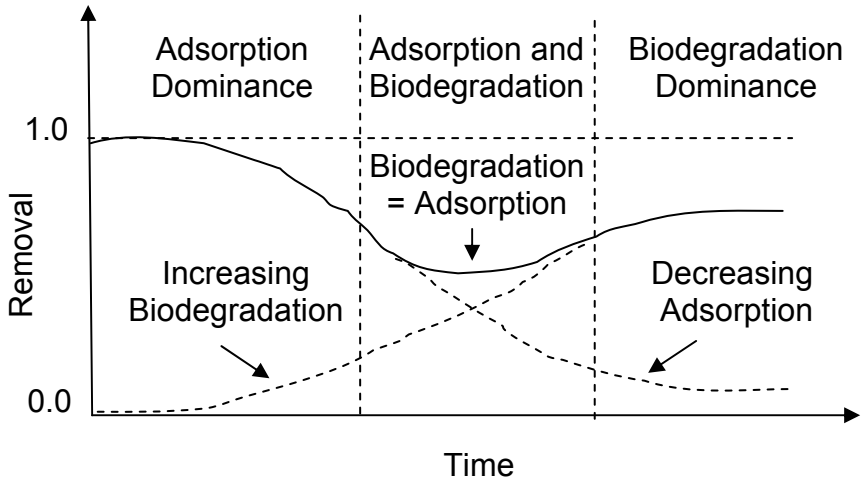

Figure 1. Adsorption and Biodegradation during Biofilter Startup (From Webster, T.S., *Control of air emissions from publicly owned treatment works using biological filtration*, Ph.D. thesis, The University of Southern California, Los Angeles, 1996.)

Testing and data collection are required during the operation of a biofilter. It is important for the operator to identify and understand the operational parameter effects on the mechanisms that limit efficiency. Under optimum conditions and without replacement of the biofilter media, these systems have the potential to run for a number of years and the pollutants are fully biodegraded.

Each of the sequential steps and the related mechanisms in the biofiltration process are explained in detail throughout the next sections for a better understanding of biofilter operation.

2.2.1. Phases of Biofiltration

The first phase to be carried out in a biofiltration process is the mass transfer of the pollutant from the air stream to the water phase on the media surface. Once the air comes into contact with the media, the transfer occurs from regions of high concentration in the air to regions of low concentrations in the water. This movement occurs according to Henry's Law where the concentration in the water will be proportional to that in the air:

Equation 2

$$C_G = HC_L$$

where:

C_G= Concentration of the contaminant in the air phase (g/L_{air}),

C_L = Equilibrium concentration of the contaminant in the water phase (g/L_{water}),

H = Henry's Law constant of proportionality ((g/L_{water})/ (g/L_{air})).

Henry's constant are almost all well below 1, making the contaminants hydrophilic and the biofilters workable. This means that for any volume within a biofilter, more contaminant is likely to be in the water than in the air. This characteristic contributes to retardation of the contaminant as the air moves through the biofilter (Devinny, 1999).

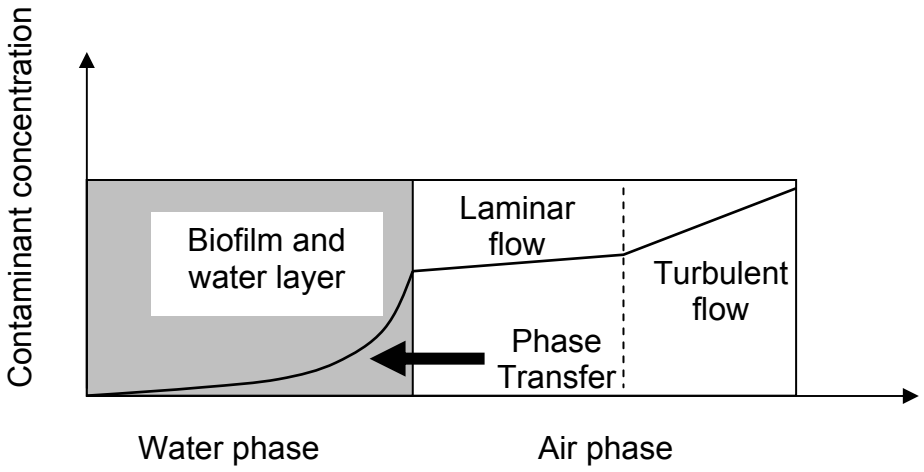

Figure 2. Biofilter Model for Gas Transfer (From Devinny, 1999)

In a biofilter, the pollutant mass transfer has been modeled into 3 steps as is shown in Figure 2. The air flows in a turbulent regime into the biofilter and the pollutant moves by advection and turbulent diffusion. The air flow becomes laminar near the air-water interface. Thus the contaminants experience a slower mechanism of transportation in its molecular diffusion. However, due to the rapid air flow used in biofilters, the laminar layer is kept thin, not constituting a limiting factor in this step. The mass transfer from the air to the water is presumed to occur at a rate that is proportional to the degree to which the concentration in the

water is below the equilibrium value (Devinny, 1999). According to the two film theory, the interface mass transfer rate can be calculated using the overall mass transfer coefficients and the bulk concentration of the contaminant in the liquid, as follows:

Equation 3

$$\frac{dC_L}{dt} = k_L a(C_L^{\ *} - C_L)$$

where:

C_L = Concentration of contaminant in the bulk water,

C_L^* = Contaminant concentration in equilibrium with local air concentration,

k_La = Overall transfer coefficient,

K_L = Liquid film coefficient, and

a = Interfacial area.

The water and biofilm together are considered to be one layer which is between the solid and the gas. The biofilm is a relatively uniform layer of cells embedded with a polysaccharide gel produced by the microorganisms where the diffusion of the contaminant is very slow. The concentration is higher near the surface of the water layer while the bottom concentration may be depleted due to the biodegradation of the contaminant through the layer.

Adsorption phenomena in biofilters are poorly understood. The phase of biofiltration referent to the adsorption or dissolution of the contaminant involves several complex mechanisms. Contaminant molecules may be dissolved in the water, but they may also be adsorbed on the surface of the medium, or collected

at the surface of the water (Devinny, 1999). Contaminants can also be found in large pores and be available for biodegradation, while those in pores too small for microorganisms may not be. The objective of biofilter design is to achieve the maximum possible concentration of contaminant in the forms that are available for biodegradation.

The last phase of biofiltration is the biodegradation and transformation of the contaminants. This phase is limited by one or a combination of factors such as insufficient inorganic nutrients, oxygen, microorganisms, substrate concentrations, and diffusional barriers. Degradation rates are limited by diffusion phenomena rather than by biological activity (Devinny, 1999).

Aerobic degradation predominates in biofilters. The low concentration of contaminants in the air stream does not deplete the oxygen available in air even when they oxidize completely. Anaerobic conditions may occur beneath the aerobic biofilm and within remote pores in the support medium where the diffusion of oxygen is limited. A cause for replacement of biofilter media is the generation of anaerobic generated compounds such as sulfides, mercaptans, ammonia, carboxylic acids, and other odorous and toxic gases. Products of denitrification and reductive dehalogenation processes found in biofilters have been reported by some investigators proving the partial anaerobic operation of this technology.

2.2.2. Product and Heat Generation

Organic and inorganic compounds in biofilters are transformed by microorganisms into more simple compounds such as carbon dioxide, water, sulfate, or nitrate. Depending on the level of biodegradability, compounds could be transformed into intermediate products that pass to another organism to also be transformed. Different transformations in several microbial species can be performed before obtaining the dominant product of biodegradation.

Some of the carbon content in the contaminant is incorporated into the biomass for its growth. Part of the biomass will disappear from the biofilter as some organisms die and are consumed by other organisms and as small quantities escape with the air or leachate.

Chemical elements are neither destroyed nor created in biofilters while compounds are transformed. Thus, a measurement of the biomass accumulation or by-products can be calculated if some carbon entering the biofilter is coming out (Devinny, 1999). However, a steady state condition of the biomass is important to maintain in order to avoid its accumulation and posterior clogging the biofilter.

The transformation or biodegradation of contaminants in a biofilter generates heat. Microorganisms convert the chemical energy to heat energy. The amount of heat generated depends on the biodegradability level of the contaminant.

In a biofilter that is not at steady state, some of the energy released by biodegradation will contribute to increase its temperature. If the biofilter is at

steady state, the temperatures of the medium and the vessel will not change. Experiments have shown heat loss to its surrounding due to the difference of the temperature inside and outside the biofilter. These losses can be minimized by careful insulation of the biofilter. In large biofilters where the exterior surface to volume ratio is small, heat transfer through the walls may be negligible (Devinny, 1999).

Higher humidity and temperature in the outlet air are two forms of the biologically generated heat. The temperature of the air as it passes through the biofilter increases and evaporation of the water content will occur because the water content of warmer air is higher. Also, heat is required to bring the humidity of the outlet air to 100% in the common cases that the inlet air enters the biofilter with less relative humidity.

Heat balance can give an independent estimate for the rate of biomass accumulation in the biofilter. The amount of energy consumed in warming the flow can be calculated using the heat capacity of the air. The sum of the heat of evaporation and the heat required for warming is the amount of biodegradation heat generated. This can be compared with the heat of combustion of the compound being treated to determine how much of the contaminant is being degraded. The difference between the amount being degraded and the amount represented by CO_2 release from the biofilter gives an indication of how much carbon is being incorporated into the biomass (Medina et al, 1995).

2.3. Factors and Operational Parameters of a Biofilter

The success of a biofilter is to have the proper biodegradation of the contaminant that allows high removal efficiencies. For degradation, microbes in biofilters require an organic energy source, such as VOCs in the air stream or compost as media, adequate moisture, mineral nutrients, oxygen, and a convenient temperature range. To provide these requirements to microorganisms, factors and operational parameters in the biofilter must be controlled.

2.3.1. Biofilter Media

2.3.1.1. Water Content

Although biofilters can be operated stably for years, one of the most important and troublesome operating parameters is maintaining the proper water content in the bed material (Van Lith et al., 1990). In biofilters the bed material is not normally saturated and does not have a free-flowing water phase. Therefore, the water content is difficult to determine or adjust reliably on-line.

Both physical and biological processes of the system are affected by the water content. Excessive water leads to elevated pressure drops as water displaces air in the void spaces, thereby restricting the flow of air. Excessive water can also cause the bed material to compact increasing the pressure drop (Gostomski et al., 1997). High pressure drops imply increments in the operating and equipment costs for pumping the gas stream. Higher water content means more dissolved contaminants, more opportunity for decomposition, and more

rapid and effective treatment. However, high water content can also cause diffusional limitations in the bed for compounds with low water solubility (Gostomski et al., 1997).

Low water content can reduce the microbial degradation capacity of the bed material because water serves as the medium where dissolved contaminants diffuse toward the microbial cell to be depleted. Drying can also cause cracking and by-pass flow in the reactor, thereby decreasing the overall performance (Gostomski et al., 1997).

Water content in a biofilter is controlled by direct irrigation or by the humidity of the incoming air stream. The need for a humidification chamber before the biofilter depends on the inlet gas stream temperature, relative humidity, and filter bed temperature. The operator should have an accurate control of the incoming air humidity because a 1% relative humidity drop will cause a reduction of 10% or more of the media moisture depending on its physical characteristics (Van Lith and Lesson, 1996). A complex set of factors that affects the water content of the media, such as the type of media and its water holding capacity, its porosity, air flow direction, the rate of biodegradation of the incoming contaminant, or the characteristic metabolic heat produced, etc. (Devinny, 1999). Measurement of moisture in the media must be performed until the value that provides the higher removal efficiency in the actual operation mode is reached.

The optimum moisture content for biofilters is not well established. However, moisture content over which BFs are typically operated is

approximately 50% of the field capacity. With compost bed material, optimum values range from 20% to 65% of water by weight (Devinny, 1999). Frachetti et al. (1992) performed a full scale biofilter survey and found that a moisture content of 40% to 70% was the most desirable in the facilities owning the biofilters. Wood bark is considered to be a good reservoir of water that makes the control of moisture content easy. Other media such as peat or perlite, which are light porous materials, have not presented a good performance as a medium because of the relative difficulty of controlling the bed moisture.

2.3.1.2. Nutrient Content

In general, inorganic nutrients are supplied in granules or sprayed as solution onto the medium during initial preparation only. However, in some cases these nutrients are added subsequently on a regular basis during operation. High nitrogen, phosphorous, potassium, and sulfate content as well as trace elements are required for the establishment of a vigorous microbial activity.

Compost and other media with organic content have the advantage that the nutrients are present in the medium. As degradation takes place, compounds and elements are released in the approximate proportions appropriate for cell growth. However, the rate of degradation can be higher than the rate of cell growth; in this case, the rate of nutrient release can be a limiting factor to consider when deciding the pollutant load (Devinny, 1999).

2.3.1.3. pH

For the greatest spectrum of bacterial activity, a pH near neutral values is required. The usual pH value for packing materials is 6 to 8. Although, in some cases as when treating sulfur compounds, a pH as low as 2 to 4 has been observed without an important loss of pollutant removal performance.

Different biofilters may have different pH values, depending on the contaminant being treated and the characteristics of the microbial ecosystem. Microorganisms are generally affected by changes in pH. Although, they adapt to slow changes in pH values and the tolerant species of the new conditions replace those which do not.

The pH in a biofilter may also change during operation. Profiles with depth may reveal which parts of the biofilter are more active. Generally, acid pH values are found near the inlet of the biofilter where more biological activity occurs and neutral pH values are found in the center sections (Devinny, 1999). Many of the pollutant biotransformations in the biofilter generate acid final products or intermediates when treating pollutants such as VOCs. In this case of treatment of acidifying gases, acidity accumulates and the pH falls. Using a biofilter medium with the ability of resisting pH changes, property known as buffer capacity, the acidity effects in the biofilter can be controlled. The removal or neutralization of the acids is required when using an inorganic media or a media with a low buffer capacity. A base can be added at intervals with the irrigation water. For biofilters subject to low levels of acidification, it may be sufficient to have materials such as limestone or oyster shells included in the medium. As

the medium ages, the basic materials are gradually exhausted and a new addition will be needed. In some cases, a wash of the biofilter medium with a high irrigation flow of water is enough to remove the acidifying compounds from the unit.

The leachate pH should also be measured. It is an indicator of the condition near the bottom of the biofilter. For up-flow biofilters, it indicates what is happening at the inlet (Devinny, 1999).

2.3.2. Temperature

Temperature has an important role in a biofilter. In general, biofilters tend to operate effectively in the mesophilic temperature range (20 to 45°C) where most diverse microbial communities thrive. Temperature has a great effect on the kinetics of the microbial degradation. The rates of reaction and diffusion of the contaminant are increased with the rising of temperature. For this reason, it is important to supply the waste gas at a temperature close to the mesophilic range as possible. For industrial processes that produce waste gases far exceeding the mesophilic range, gases must be cooled. However, effective removal has been seen at low temperatures (5 to 16°C) (Devinny, 1999). The temperature of the incoming air stream of the biofilter, in most cases, is controlled by regulating the temperature of the humidification chamber when it is available.

2.3.3. Air Flow Direction

In most applications of enclosed biofilters, downward air flow has proven superior to up-flow (Devinny, 1999). The advantage of the down-flow biofilter is that it improves moisture control. Drying of the biofilter starts generally in the inlet side as a result of both unsaturated air stream and production of metabolic heat concentrated at the inlet side. For this mode of operation, moisture can be efficiently controlled by additional water supply provided as a spray on the top of the bed where it is more needed. The down-flow mode allows better drainage, particularly at the bottom of the bed.

In the up-flow mode, drying occurs at the bottom of the biofilter where it is difficult to provide additional moisture. However, there are some cases in which up-flow is beneficial. Such a case is the treatment of reduced sulfur compounds, such as those produced in wastewater treatment plants. In this case, sulfuric acid is generated as a consequence of biodegradation. This causes the pH to decrease, particularly near the inlet where the biological activity is concentrated. The excessive pH drop is detrimental for pollutant removal. In this case, an up-flow might be preferred because the acidic end products are then easily washed out without leaching through the entire bed. An additional lower irrigation system usually is used for biofilters treating acidic gases.

2.3.4. Residence Time

The residence time is the actual time a parcel of air will remain in the biofilter. Poor removal efficiencies can be obtained as a result of a low residence

time. In the case herein, a more prolonged residence time must be provided to obtain adequate adsorption and biodegradation rates of the contaminant.

The residence time can be controlled by adjusting the flow rate fed to the biofilter. For treatment of odors, authors of numerous papers have recommended a residence time of at least 25 seconds. However, a wide range of time has been used by biofilters. The value of the residence time for a particular biofilter is a function of the biodegradability of the particular contaminant being removed. Equation 4 allows the calculation of the true residence time.

Equation 4

$$\tau = \frac{V_f \times \theta}{Q}$$

where:

τ: is the residence time (s),

V_f: is the filter bed volume (m^3),

Q: is the gas flow rate (m^3/s), and

Θ: is the porosity of the media expressed as the volume of void space per volume of filter material.

2.3.5. Empty Bed Residence Time (EBRT)

Also called empty bed contact time, EBRT is defined as the volume of the BF divided by the air flow rate. The EBRT overestimates the actual treatment time. Contact time is shortened by a reduction of the volume within which air flows that causes the medium. Equation 5 shows the EBRT calculation:

Equation 5

$$EBRT = \frac{V_f}{Q}$$

2.3.6. Surface, Volumetric, and Mass Loading Rates

Any of the three definitions presented below, shows the unit of pollutant introduced to a biofilter per unit of volume, filter material, or a filter dimension characteristic per unit time.

- Surface loading rate: the volume of gas being treated per unit of filter area in a unit of time (m/s). The surface loading can be calculated by Equation 6.

Equation 6

$$Surface\_loading = \frac{Q}{A}$$

- Volumetric loading rate: the volume of gas being treated per unit of filter volume in a unit of time (s^{-1}). Equation 7 can be used to calculate this parameter.

Equation 7

$$Volumetric\_loading = \frac{Q}{V_f}$$

- Mass loading rate: the inlet mass of contaminant present in the gas being treated per unit of filter volume in a unit of time ($g/m^3.s$). An easy way to calculate the mass loading is shown in Equation 8.

Equation 8

$$Mass\_loading = \frac{Q \times Cg_i}{V_f}$$

where:

A = Biofilter area (m^2), and

Cg_i = Inlet gas concentration (g/m^3).

2.3.7. Gas Flow Rate

The flow rate is defined as the volume of gas being treated per unit of time. Low air flow rates pumped provide more time for the contaminants to diffuse and be oxidized in the biofilm. In this case, higher removal efficiencies are obtained and emissions to the environment are minimized.

2.3.8. Removal Efficiency

The Removal Efficiency (RE) is an operating parameter used to judge the success of a biofilter in terms of bioconversion of a contaminant. It is defined as the fraction of the contaminant removed by the biofilter.

Equation 9

$$RE = \left(\frac{Cg_i - Cg_o}{Cg_i} \right) \times 100$$

where:

Cg_o = Outlet gas concentration (g/m^3).

2.3.9. Elimination Capacity

The maximum loading capacity of the bed is the maximum amount of contaminant that the optimal microbial population can consume, without inhibition of activity (Allen et al., 1992). The Elimination Capacity (EC) is the mass of contaminant degraded per unit of volume of filter in a unit of time ($g/m^3.s$).

Equation 10

$$EC = \frac{(Cg_i - Cg_o) \times Q}{V_f}$$

or

Equation 11

$$EC = Volumetric\_loading \times RE$$

EC is always less or equal than the mass loading rate. EC is equal to the mass load under low load conditions. In this case, the RE is 100%. When the load on the system is increased, a point is reached where the overall EC is exceeded by the mass loading rate, and efficiencies less than 100% are generated. This point is typically called the critical load or critical elimination capacity. Figure 3 illustrates how the EC is affected by the load in a biofilter.

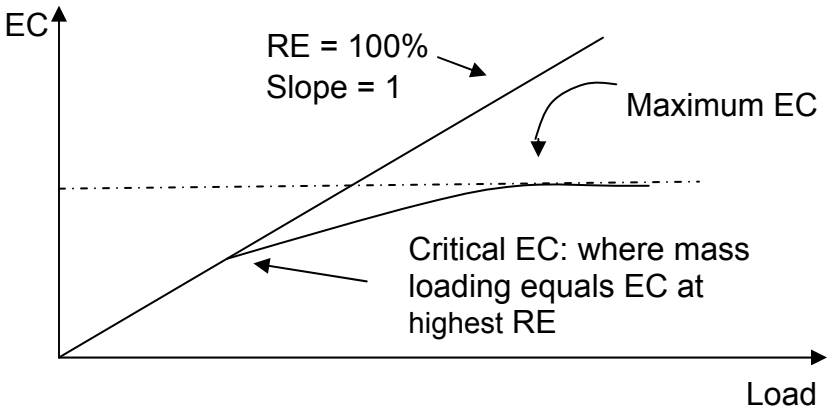

Figure 3. Typical Elimination Capacity vs. Load Curve (From Devinny, 1999)

2.3.10. Pressure Drop

The head losses are obtained due to interferences with the passage of the air stream. Thus, the pressure drop becomes a function of a vacuum or pressure head across the humidifier, air distribution system length and geometries, diameter of ducting, filter bed material and porosity, biomass build, and any other in-line devices. The pressure drop across the biofilter media can be increased significantly because of clogging caused by excessive microbial growth, compaction, and water retention.

2.4. Biofiltration for Hydrogen Sulfide Removal from Wastewater Treatment Plant Gases

Several elements and compounds are found in wastewater including organic matter such as proteins, amino acids, carbohydrates, sulfites, sulfates, organic nitrogen, different forms of phosphorus, calcium magnesium, sodium, potassium, carbonates, bicarbonates, hydroxides, etc. (Metcalf and Eddy, 2003).

The organic material constitutes a source of food for microorganisms. Generally, under anaerobic conditions, the microorganisms degrade these energy sources and odorous compounds are formed.

Organic and inorganic forms of sulfur, mercaptans, ammonia, amines, and organic fatty acids are identified as the most offensive odor-causing compounds associated with the treatment of wastewater and sludge in WWTPs (Walker, 1991). These compounds are typically released from the wastewater or sludge by heat, aeration, and digestion (Metcalf and Eddy, 2003). The odors vary by the type of residual wastewater processed and the method of processing. An example is hydrogen sulfide and other sulfur-containing gases produced by anaerobic digestion of primary wastewater residuals.

Wastewater processors are faced with odors during any of the wastewater treatment processes, including digestion, dewatering, conveying, storage, and truck loading of sludge. These nuisance odors can have detrimental effects on aesthetics, property values, and the quality of life in communities subjected to them. Due the numerous complaints that are received from these communities, the use of biofilters in WWTPs for control of odor nuisances has increased in the last few years.

The most commonly reported odorous compound in the off-gases of wastewater treatment plats is H_2S. The following generalized reactions are typical for the generation of H_2S from wastewater.

Equation 12

$$Organic\_matter + SO_4^{2-} \xrightarrow{bacteria} S^{2-} + H_2O + CO_2$$

Equation 13

$$S^{2-} + 2H^{+} \rightarrow H_2S$$

2.4.1. H_2S Characteristics

Hydrogen sulfide is a weak acid heavier than air that tends to be located a few feet above the source where it is generated (Walker, 1991). This hydro-soluble gas is colorless, corrosive, and very flammable.

Hydrogen sulfide has a very low recognition odor threshold of 0.0047 ppm (WES/ASCE, 1995) and a rotten-egg smell. It is easy to detect at low concentrations, but at higher concentrations it paralyses the sense of smell. This chemical does not meet the toxicity criteria but is considered a chemical of concern. Hydrogen sulfide is classified as a chemical asphyxiant. It immediately interacts chemically with the hemoglobin of blood to block oxygen from being carried to the vital organs and tissues of the body. Figure 4 presents the hydrogen sulfide toxicity spectrum and human effects with concentration.

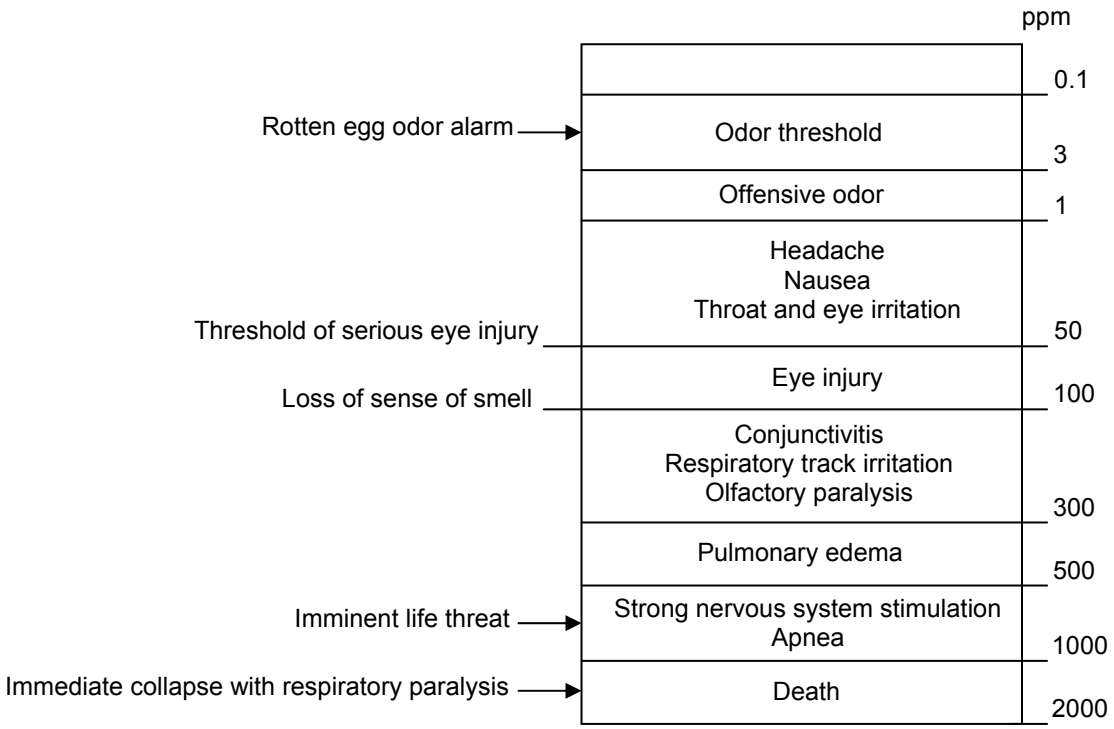

Figure 4. Hydrogen Sulfide Toxicity Spectrum (After EPA *Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants*, EPA/625/1-85/018, 1985)

2.4.2. H_2S Biodegradation

Contrary to the regular biofilters used for control of other contaminants, biofilters controlling H_2S are operated at low values of pH. Under aerobic conditions, H_2S can be oxidized by many species of microorganisms. As a result of the oxidation performed by these microorganisms, sulfuric acid is produced. The biological reaction of oxidation can be expressed as follows:

Equation 14

$$H_2S + 2O_2 \rightarrow H_2SO_4$$

Partial oxidation of H_2S and formation of sulfates and elemental sulfur is caused by the accumulation of sulfuric acid in the media. Yang et al. (1999) studied the performance of a biofilter treating odorous air from a WWTP. They observed the accumulated solids on the media and recommended the substitution of the media in no more than 3 to 5 years. This solid phase of sulfur compounds is deposited on the surface of the media and changes the media characteristics. The combined result is a reduction of the organic media surface available for attachment of microorganisms and low pH levels due to the acid produced. Some investigators have found a substantial reduction in treatment efficiency. Usually the low pH problem is countered by the addition of buffering materials to the medium, or of a base contained in the irrigation water.

A large number of bacteria can be found to inhabit the filter material in BFs treating WWTP gases. They include genera of the chemolithotrophic bacteria including ammonia-oxidizing bacteria (*Nitrosomonas*), hydrogen sulfide-oxidizing bacteria (*Thiobacillus*), genera of heterotrophic bacteria including methane oxidizing bacteria (*Methylomonas*), cresol-degrading bacteria (*Pseudomonas*), and other hetrotrophic bacteria using carbon compounds as energy sources (Chung et al., 1997).

The typical microorganisms found in the low pH biofilters are the thiobacillus thiooxidans which are not inhibited until pH falls below 1 (Devinny, 1999). H_2S is oxidized rapidly and production of exopolysaccharides is not performed by these organisms. Thiobacillus are autotrophic organisms. It means that their organic matter is made by fixing carbon dioxide. Thus, even though

there is a high removal of H_2S and a low pH of 1, the BF is less susceptible to clogging by an overgrown biofilm. Thiobacillus are accompanied by acidophilic heterotrophs. The waste products (fatty acids) produced by thiobacillus are consumed by these microorganisms. Organic compounds in the air stream are also consumed by the heterotrophbs so that a low pH biofilter can treat more than just H_2S (Devinny, 1999).

The solubility of H_2S in water is high, and biodegradation rates are rapid, making the biofiltration an effective treatment process. Low pH biofilters have the advantage of an easy pH control and solid salts removal. The acid produced can be washed away with an excess of irrigation water, producing some leachate. However, in biofilters at pH 7, where the acid concentration is low, substantial amounts of water are required to remove the acid produced by the same H_2S load (Devinny, 1999).

3. EXPERIMENTAL SETUP AND DESIGN

3.1. Introduction

The experimental program was designed and implemented to develop a better understanding of the role of a biological process in the removal of hydrogen sulfide from the air stream produced in WWTP. The program was developed and carried out in a biofilter (BF) located in the Marrero Municipal Wastewater Treatment Plant, 6250 Lapalco Boulevard, Marrero, Louisiana. The Marrero Wastewater Treatment Plant is a division of the Department of Sewerage of Jefferson Parish, LA.

The Marrero Wastewater Treatment Plant treats the municipal waters of the city of Marrero and the central portion of the west bank of the Mississippi River. The Marrero plant has the following units for the treatment of wastewater: pre-chlorination, two mechanical bar screens and one manual bar screen, two covered aerated grit chambers, two covered primary settling tanks, two covered 4-in. rock trickling filters, two aeration basins, two secondary clarifiers, two chlorine contact chambers, three aerobic sludge digesters, and two belt presses for sludge dewatering. For the treatment of the gas streams produced in some of the units named above, the Marrero plant also uses three chemical scrubbers

and a BF. Brief explanations of the wastewater treating units releasing the odors removed by the BF are referenced next.

The Headworks: include the influent channel, the bar screens, and aerated grit chambers. They are equipped with grit pumps, sand/water separators, a belt conveyor, and air blowers. Wastewater passes through a coarse screen where large and stringy material is removed. Next, wastewater flows into grit removal chambers where air is introduced to scour the organic materials from the grit/sand before the grit/sand settles down to the bottom of the chamber. The settled grit/sand is pumped by a grit pump to a sand/water separator. Grit/sand and screened material are delivered by belt conveyors to the same containers which are trucked to another location for disposal. Effluent from the grit chamber then flows to a box that divides the stream to the two primary clarifiers.

The Primary Clarifiers: treatment in these tanks allows for settling and flotation of solids and organic materials. Scrapers move the settled solids (sludge) to sumps at the center of the tank. From there the sludge is pumped to aerobic digesters for the production of volatile fatty acids required for biological treatment. The remaining clarified liquid, containing mostly dissolved materials, flows to the secondary treatment stage. Scum floating on the surface is removed by a skimmer and sent to digesters for treatment.

A plan view of the wastewater treatment units and the location of the BF in the Marrero plant are shown in Figure 5.

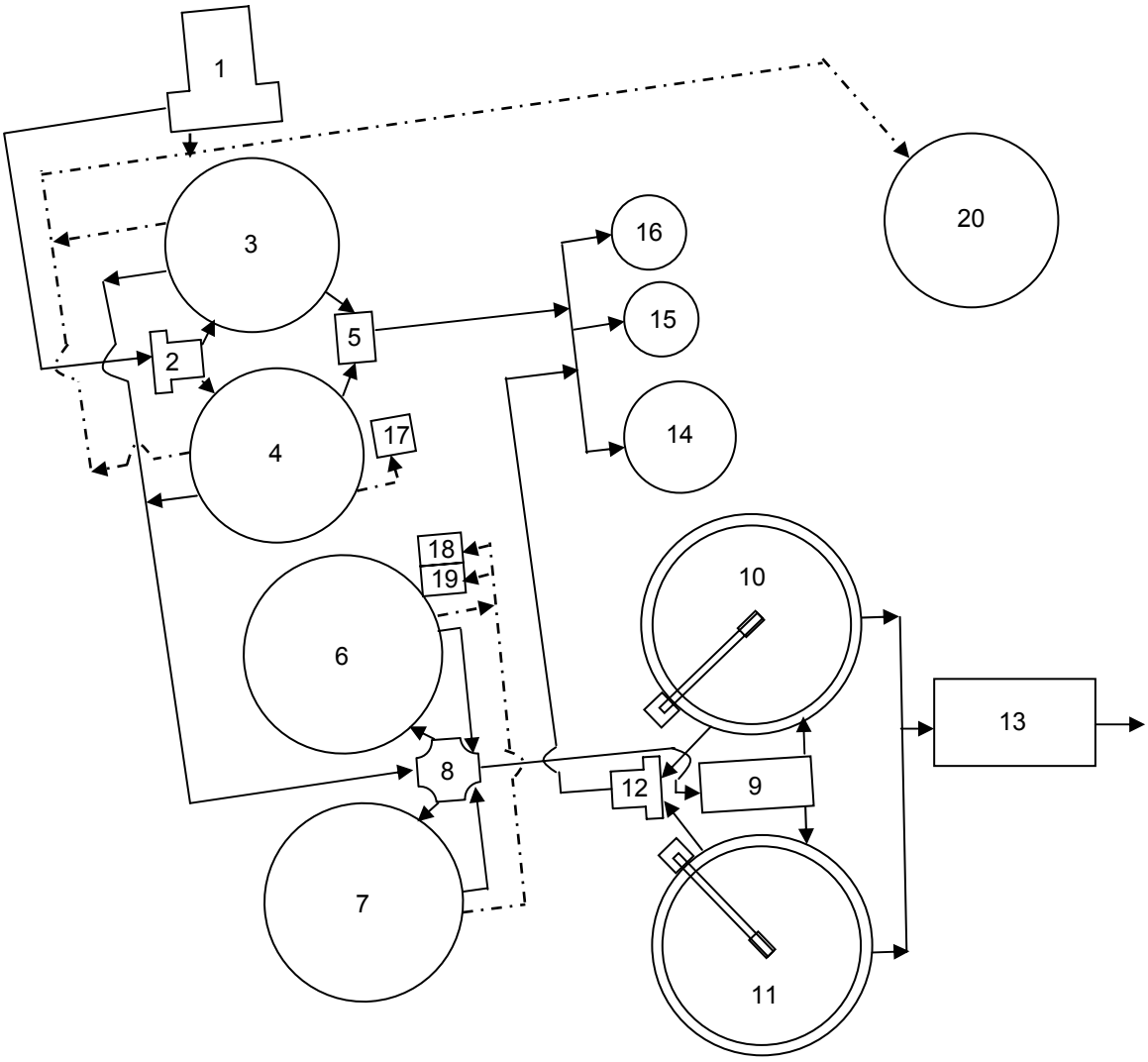

Figure 5. Plan View of Treatment Units in Marrero Wastewater Treatment Plant

The units of treatment shown in Figure 5 are: (1) Headworks, (2) Primary flow splitter structure, (3) Primary clarifier, (4) Primary clarifier, (5) Primary sludge pumping station, (6) Trickling filter, (7) Trickling filter, (8) Trickling filter recirculation pump station, (9) Solids contact tank, (10) Secondary clarifier, (11) Secondary clarifier, (12) Secondary sludge pumping station, (13) Chlorine contact tank, (14) Aerobic digester, (15) Aerobic digester, (16) Aerobic digester,

(17) Chemical Scrubber, (18) Chemical Scrubber, (19) Chemical Scrubber, and (20) Biofilter.

3.2. Biofilter Description

The odorous gases produced in the headworks and in the effluent radial overflow weir space of the two primary settling tanks are removed in the BF. The BF was specifically designed and implemented in 1998 for the removal of the hydrogen sulfide and other odorous traces. The design was made upon an existing concrete vessel which was used years before as the vessel of a trickling filter for treatment of wastewater. Modifications and additions to the trickling filter concrete structure were carried out for a functional design of the biofilter vessel structure.

Each system conforming to the BF is described in detail for a better understanding of the individual importance of each one of them in the operation of the unit.

3.2.1. Biofilter Vessel System

The bioreactor is a 98-ft. diameter cylindrical vessel constructed of heavy concrete as was required for the trickling filter design years before. The depth of the vessel varies for draining purposes of the leachate. The triangular shaped bottom is sloped gradually from the vessel perimeter to where the central leachate collection pipe is located, forming a trench which crosses the BF. The

system has a maximum depth of 7-ft. 30-in. in the trench and a minimum 7-ft. depth in the vessel perimeter.

The entire bottom slab and sump of the vessel are coated with a liner as shown in Figure 6. The high density polyethylene liner is used to prevent moisture penetration to the concrete structure and avoid reduction of its strength. The sump is a concrete box added to one side of the vessel structure for collection of the leachate. The underdrain sump will be explained in detail next as a part of the leachate collection system.

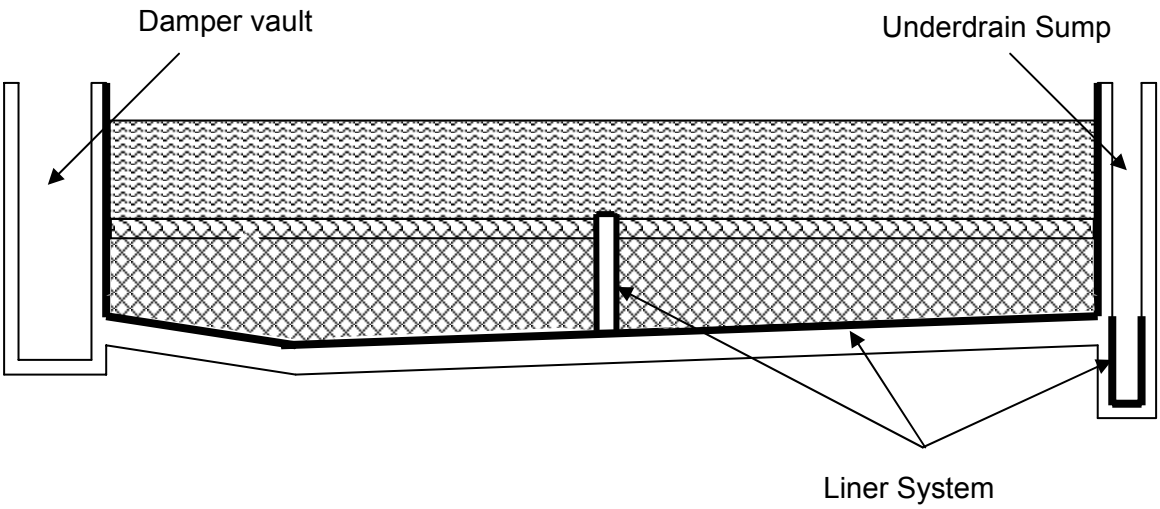

Figure 6. Biofilter Vessel and Liner Systems

A brick wall divides the vessel into two identical left and right sides. This wall is made of 8-in. concrete blocks and provides the anchors to prevent floating of the air piping.

A part of the BF cylindrical vessel is occupied by the damper vault. This box is 31-ft. long, 6-ft. wide and 9-ft. deep. Connections of the main pipes of the

air distribution system, two pitot tubes for air flow measurement, and the main valves and piping of the humidification system are accessible by operators in the damper vault. Figure 7 graphically illustrates the plan view of the vessel structure.

3.2.2. Air Distribution System

Air is drawn from headworks and primary clarifiers by two blowers. The forced draft system is used to distribute the contaminated air upward through the filter material. Hoods and the unburied fragment of the 30-in. ducting from headworks and primary clarifiers to the BF are constructed of fiberglass reinforced with corrosion resistant, epoxy vinyl ester resin. The buried polypropylene ducting is sloped until it reaches the air distribution zone level at the bottom of the BF. The air distribution zone consists of a 30-in. layer of 4-in. diameter rocks topped by a 6-in. layer of ¾-in. diameter rocks. The smaller diameter rocks and a coarse geotextile fabric spread on its top prevent media fines from migrating into the air distribution zone. Once in the BF vessel, the main ducting is divided into two perpendicular 24-in. polypropylene pipes. 8-in. polypropylene pipes spaced 4-ft. are connected perpendicularly to the two 24-in. polypropylene pipes. These 8-in. polypropylene pipes distribute the air through the circular area of the BF. Openings at these pipes are placed farther apart to make the flow uniform and with higher pressure. The air containing the odorous gases then flows through the rocks in the distribution zone, the layer of ¾-in.

rocks, and the media. Details of the air distribution system are also shown in Figure 7.

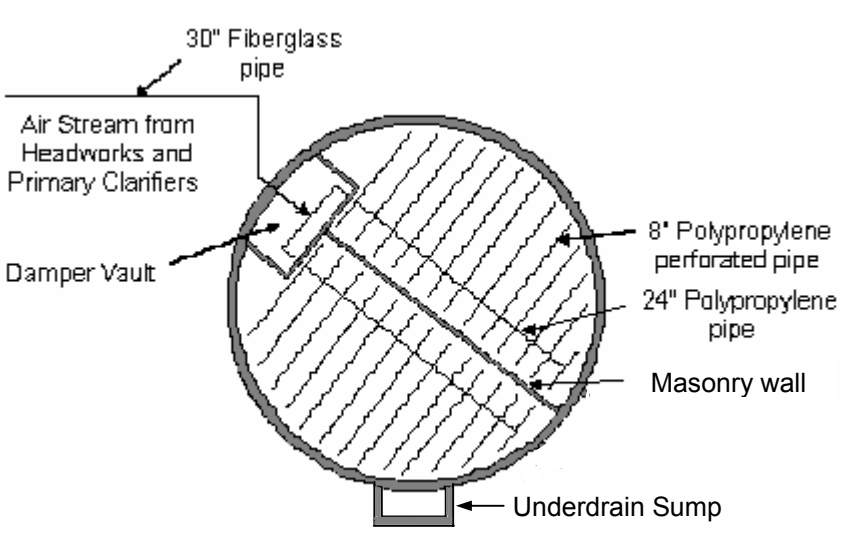

Figure 7. Biofilter Vessel and Air Distribution Systems Plan View

3.2.3. Media System

Wood bark is used as the media for this BF. The common particle sizes are 1 to 3-in. It occupies 36-in. depth. The organic material has enough nutrient supply for the indigenous microbial population. Because hydrogen sulfide is an acidic forming contaminant, initial preparation of the wood bark required the addition of sea shells to neutralize the acid. The buffer capacity of the media is a function of the hydrogen sulfide loading and is expected to diminish with time, requiring further material removal and caustic recharging. The shell content in the media is not reported by designers.

The time for removal and substitution with new media recommended by designers was seven years. In general, wood bark is considered to have

sufficient surface area and air pore spaces for adsorption of the contaminants and attachment of microorganisms, good retaining moisture capacity, and low shrinking potential. Figure 8 illustrates the aforementioned media system and the rock layers filling the BF.

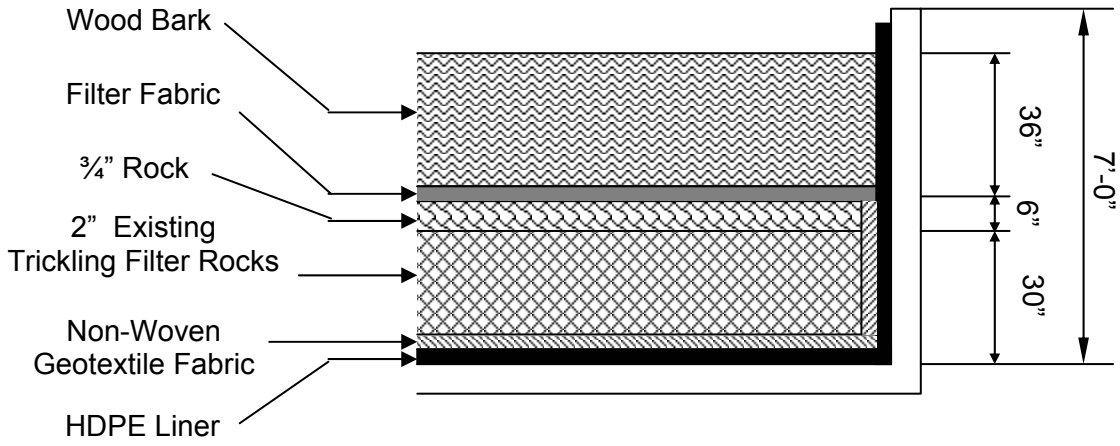

Figure 8. Schematic of the Media System in the Biofilter

3.2.4. Moisture Control System

A humidification system and an automatic irrigation system are used to provide moisture to the bed material. Controlled by a timer, the irrigation system uses four sprinklers to spray potable water over the entire surface of the media. Water is pumped through two ½ -in. diameter steel pipes. A transition to PVC piping is performed once steel pipes reach the BF vessel to prevent corrosion of steel. Then water flows inside the PVC piping whose route inside the BF is located along the masonry wall 12-in. below the top of the ¾ -in. stone cap. Finally, water is delivered to each pressure compensated sprinkler head. For 10 minutes the surface is irrigated by two of the sprinklers, alternating with the other

two every half an hour continuously. The sprinklers are located in the central area of the BF. The total volume of water irrigated every hour is not provided in the design information.

Before the incoming air stream reaches the reactor, it is humidified. In the damper vault, a spray humidification device is placed inside the 30-in. diameter main pipe. It consists of three ½ -in. diameter pipes with ball valves (control valves) which end in 1/8-in. diameter helix nozzles. The three pipes are introduced perpendicularly into the main pipe and are spaced 4-in. from each other. The central nozzle meets the interior center of the 30-in. pipe. Water is sprayed in the form of fine water drops and a relative humidity near 100% of the air stream is achieved.

3.2.5. Leachate Collection System

The BF is supposed to operate with a stationary water phase. However, drainage has occurred every day since its installation. Excess water in the media is presented usually when irrigation is overdone, when condensation from the input air is heavy, or when there is rain on the open BF. The leachate collection system was designed to collect this excess water and discharge it to the influent wastewater of the plant for treatment.

Liquid is moved downward through the media, geotextile fabric, and the two layers of rocks under the force of gravity. Six aligned 8-in diameter orifices at the bottom liner are crossed by the liquid. These orifices are met by six 8-in diameter hub strainers of 1-in. diameter openings. The strainers cover 8-in.

vertical pipes connected in a “T” to an 8-in. diameter pipe. This pipe is open to the atmosphere at both ends and is located inside a concrete encasement. The concrete encasement is a rectangular box aligned along the vertex of the bottom of the BF. The dimensions are 2-ft. wide, 96-ft. long, and from 2-ft. high in one end and 2-ft. and 6-in. high at the opposite end. The maximum height is reached at the underdrain sump end. The other end of the pipe empties into a small concrete box located next to the concrete vessel. The box has a drilled opening to prevent an increase in the pressure. In this way, the leachate flows by gravity inside the pipe. Empty spaces in the encasement were filled with concrete. The leachate drained falls into the underdrain sump where it is collected. Finally, by level control, the liquid is automatically pumped to headworks. Figures 9 and 10 show the cross and plan views of the leachate collection system of the BF.

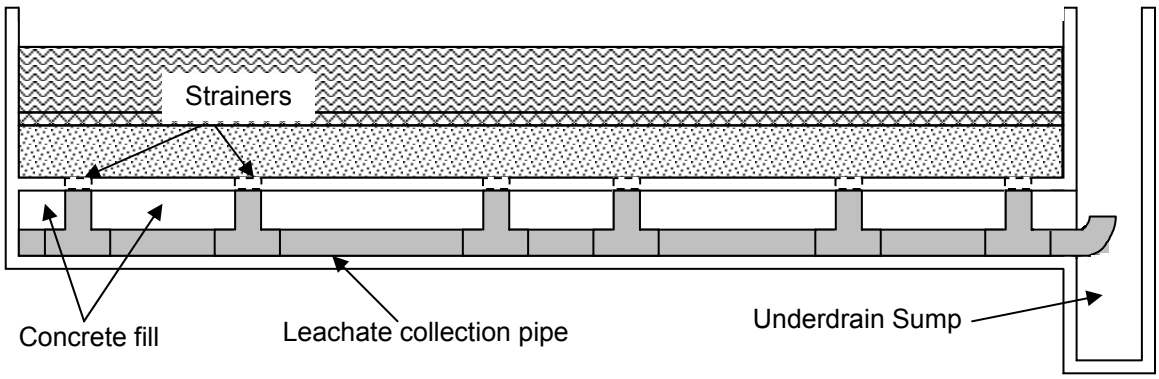

Figure 9. Leachate Collection System Cross View

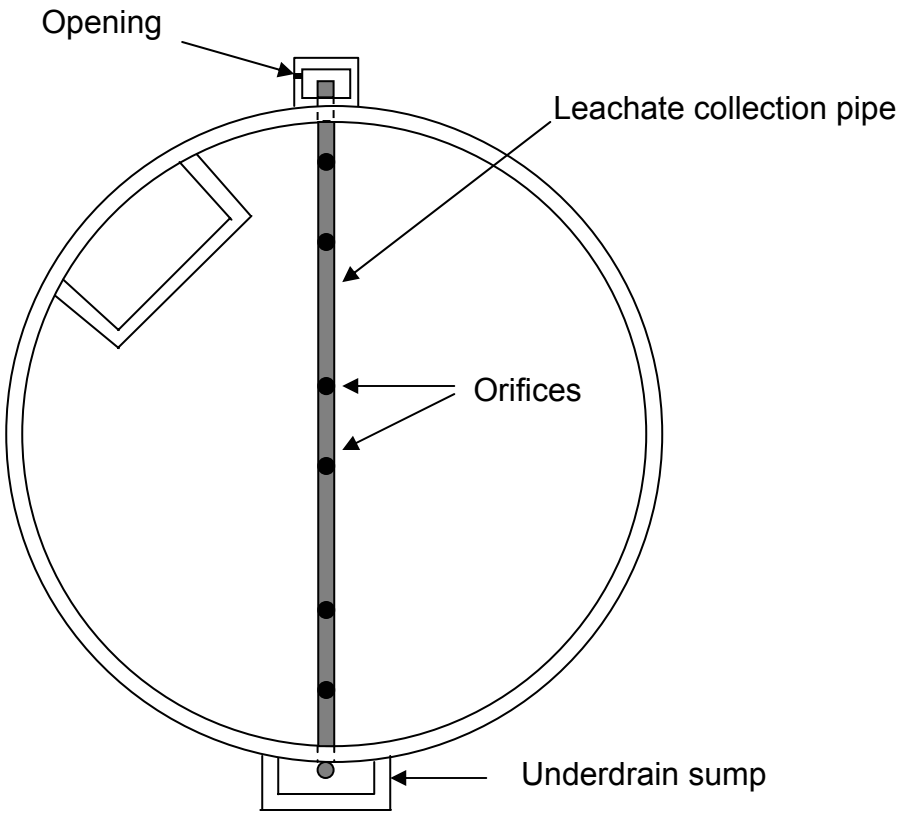

Figure 10. Leachate Collection System Plan View

3.2.6. Electrical System

Electrical equipment used for operating the BF requires 460-volt alternating current. This type of power source is available in the WWT facility. Two blowers are used to extract the waste gases from the headworks and the two primary clarifiers. The manufacturer (Reliance Electric) ensures a 91% efficiency of the equipment. Other specifications of the blowers are provided in Table 1. Demand of electricity consumed by the blowers is increased due to the pressure drop in geometries of headworks and primary clarifiers, ducting, and the

media in the BF. However, the large portion of this demand is a function of porosity, moisture content, and structure of the filter bed.

Two identical centrifugal pumps from the Ingersoll Dresser Pumps manufacturer are used to send the leachate to headworks and discharge it into the raw water stream. Specifications of these pumps are shown in Table 1.

Energy consumption of the BF is not constant in time. Due to exposition of the BF to non-controlled ambient conditions, the consumption of electricity is increased on rainy days and during the fall when ambient temperatures are low and activity of microorganisms is reduced.

Table 1. Electrical Equipment Specifications

Equipment	Quantity	Voltage (VAC)	Current (Amp)	RPM	Motor size (Hp)	Frequency (Hz)
Blower	2	230/460	47.0/23.5	1760	20	60
Centrifugal Pump	2	230/460	13.0/6.5	1730	5	-

3.2.7. Control System

The BF consists of two control systems. Both of them were constructed by the consulting company responsible for the BF design. Control of the irrigation of media and humidification of the inlet air are performed by the moisture control system, which is equipped with a control panel where the length of time that the irrigation discharges water onto the media can be set up and controlled. The in-line flow devices that are used for this purpose are: two rotameters, two gate valves, four globe valves (control valves), and a by-pass

arrangement for alternation of the sprinklers. The flow of water used to humidify the incoming waste gas is also regulated by this system. A rotameter, a globe valve, and three ball valves (control valves) provide a constant flow of water to be sprayed at any time.

A level control system is used for control of the volume of leachate in the underdrain sump. The control panel of the system is located a few feet apart from the underdrain sump. The system has two indications: high level and low level. An alarm warning high level is turned on if it is reached by the leachate inside the underdrain sump. The level control system consists of two devices called float switches inside the underdrain sump, one for each indication, which have ON and OFF positions. Once the level of leachate reaches the floats, they obtain the ON position and pumps start suctioning the leachate and pumping it to headworks.

3.3. Sampling, Monitoring, and Analysis

The sampling, monitoring, and analysis program performed for evaluation of the BF was initiated in September 2003 and lasted through October 2003.

3.3.1. Sampling

Sample collection of the leachate of the BF was carried out three days a week, typically in the morning through the afternoon. Data collection of the leachate pH was impossible to perform from mid-September to mid-October due to problems with the electrode of the pH meter.

The leachate of the biofilter was placed into 1-L. glass bottles (one bottle for each sample). After their collection, the liquid samples were immediately taken to the Marrero Wastewater Treatment Plant laboratory to be analyzed. All tests were duplicated.

Draeger tubes were used to measure the H_2S concentration in the inlet stream and outlet stream of the BF. The H_2S concentration measurement was performed every hour from 7:00AM to 2:00PM three days a week and was accompanied with measurements of the ambient temperature, inlet air stream temperature, and inlet air stream velocity.

Biofilter media was extracted from six sampling points and collection was carried out once a week. The media samples were placed in a 1-L. glass bottle (one bottle for each sampling point). The media test analysis was performed in the UNO Environmental Laboratory at the Research and Technology Park the same day the media samples were collected.

3.2.1.1. Sampling Points

The gas sampling points in the biofilter were located in the surface area of the BF for the outlet air stream and one in the pipe of the inlet air stream. The sampling port in the inlet air stream pipe is a 1-in. hole. A rubber stopper was used to cover the hole when sampling was not taking place. The five sampling ports in the outlet air stream are pipes of 6-in. diameter and 1-ft. long. Pipes were used to provide the Draeger tubes protection from the wind. In this way,

prevention of dispersion of gases leaving the BF was assured at the points of measurement.

Media sampling points were distributed on the surface of the biofilter. The surface area of the BF was divided into six smaller circular areas. Media samples were taken from different points inside these circular areas at a depth range of 6 to 10-in. Figure 11 demonstrates the location of the BF sampling points of the air streams and the media.

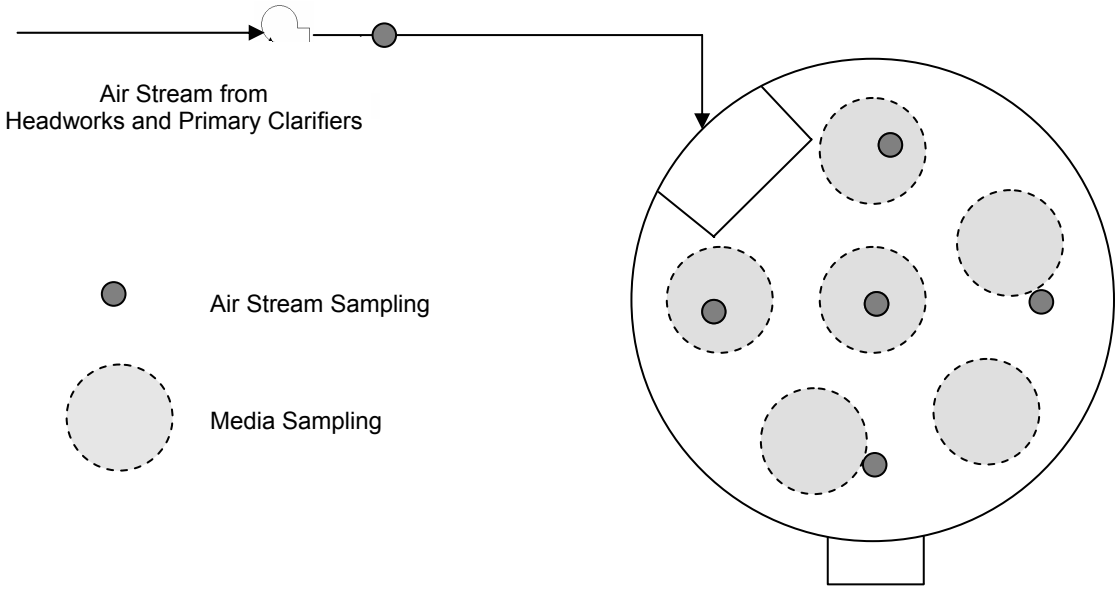

Figure 11. Sampling Port Distribution of the Biofilter

Leachate sampling points were located in the outlet pipe of the leachate and in the vessel collecting the leachate (underdrain sump). These two points were selected due to the great difference in the leachate pH. Figure 12 shows the collection points for the leachate produced by the BF.

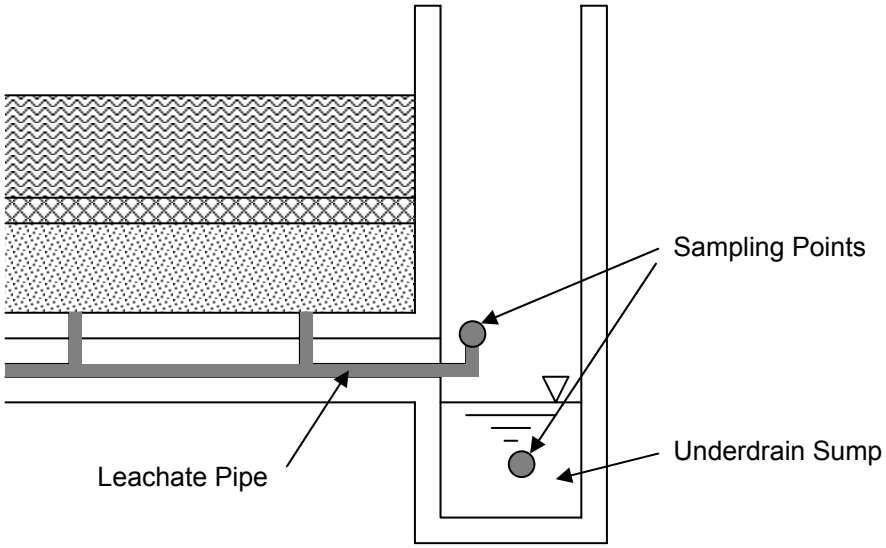

Figure 12. Leachate Collection Points of the Biofilter

3.3.2. Laboratory Analysis and Measured Parameters

The concentration of H_2S, ambient and flow temperatures, flow velocity, media and leachate pH, and media water moisture and porosity were measured. The analytical procedures are mentioned below.

3.3.2.1. Measurement of Concentration of H_2S

The concentration of hydrogen sulfide present in the air streams studied was monitored with the use of Draeger tubes, which are glass vials filled with a chemical reagent that reacts to a specific chemical or family of chemicals. A calibrated 100 ml sample of air is drawn through the tube with the Draeger Accuro Pump. If the targeted chemical (H_2S) is present, the reagent in the tube changes color instantaneously and the concentration of the contaminant is read

directly from the calibrated scale by assessing the length of the discoloration. The tubes are capable of detecting low concentration ranges such as 0.1 to 4 ppm volume and high concentration ranges such as 2% to 40%. Draeger tubes offer a +/- 10% standard deviation on the results.

3.3.2.2. Measurement of Air Velocity

The velocity of the air flow sent from the headworks and the two primary clarifiers to the BF was measured with a digital anemometer (TSI Incorporated model 8345) every hour in parallel with the H_2S concentration measurement. The flow of incoming air to the BF was calculated following the instruction of the manufacturer of the anemometer.

3.3.2.3. Measurement of Temperature

Ambient air temperature and air stream temperature were measured with the anemometer.

3.3.2.4. Measurement of Leachate pH

The pH was measured with a pH meter (Corning Pinnacle model 540). An electrode was introduced into the volumetric flask containing the liquid sample. The equipment was previously calibrated following the recommendations given by the manufacturer.

3.3.2.5. Measurement of Media pH

The pH of the media was measured using two different methods. Both methods were performed in the laboratory. The first method consisted of the saturation of 5-g. of media with distilled water. The pH of the sample was then measured using the pH paper in contact with the sample.

Due to the imprecision and high standard deviation offered by the first method, a second method was used for comparison of results. The method is a modification of the Soil Science Society of America (SSSA) 12-2.6.5. A 10-g. of sample previously dried at 104°C for 24 hours was placed into a 250-ml. glass beaker, and 20ml. of distilled water was added. The sample was then stirred for 30 min. and the pH was determined using a calibrated pH meter (Orion model 420).

3.3.2.6. Measurement of Media Moisture Content

The water content of wood bark samples was tested in the laboratory. Moisture content was determined by measuring the weight loss after oven drying at 104°C for 24 to 48 hours. Media samples were weighted and placed in a crucible. After being dried in the oven, the sample and crucible were removed from the oven, cooled in a desiccator, and weighted again. All values are reported as a percentage of wet weight of wood bark (g. H_2O/100-g. wet wood bark).

Equation 15

$$\%Moisture = \frac{P_2 - P_1}{P_2} \times 100$$

where:

P_1= dry medium sample weight, and

P_2= wet medium sample weight.

3.3.2.7. Measurement of Media Porosity

This measurement provides an idea of how empty space is available for air to flow through the media. The porosity of media was calculated by water displacement in a graduated cylinder. An undisturbed volume of media was placed at the bottom of the cylinder. The total volume occupied by the media in the cylinder was recorded as V_1. A known volume of water V_2 was added to the graduated cylinder, and immediately the new volume was recorded as V_3. The wet bed porosity was calculated as follows:

Equation 16

$$\%Porosity = \frac{V_1 + V_2 - V_3}{V_1} \times 100$$

where:

$V_1 + V_2 - V_3$ = volume occupied by the empty spaces in the sample volume, and

V_1 = volume occupied by the sample.

4. RESULTS AND DISCUSSION

Analysis of the experimental data reveals a clear picture of the removal of hydrogen sulfide in the full scale BF. Despite interferences to measure some of the parameters, results supporting the satisfactory performance of the BF were obtained. This chapter contains a description and discussion of the results obtained from testing the BF treating H_2S generated in a WWTP. The investigation addressed a) the effectiveness in treating odors from municipal wastewater treatment facilities, b) the evaluation of a full scale biofilter implemented for treating H_2S, and c) the development of a low-cost and efficient methodology to test the performance of the BF at the Marrero Wastewater Treatment Plant.

4.1. Hydrogen Sulfide Removal in the Biofilter

The Marrero Wastewater Treatment Plant implemented the operation of the BF in 1998. Nearly five years have elapsed without system interruptions. No evaluation of the system has been performed so far and this is the first evaluation.

In this experiment, hydrogen sulfide concentrations were measured at the inlet and outlet of the BF using a colorimetric method. Inlet concentrations of H_2S

varied significantly during the testing period. Even when duplicating the measurement during short intervals of time (seconds), different concentrations were found. Despite this fact, no problems associated with the measurement of the inlet concentrations of H_2S were present. However, measurement of the outlet concentration of H_2S was not always successful due to the minimum detection value offered by the Draeger tubes (0.02 ppm). Every time the outlet concentration was under the limit of detection, the limiting value was taken as the concentration of H_2S at the outlet of the BF for the estimation of the corresponding removal efficiency (RE).

The raw data (H_2S inlet and outlet concentrations) were used to calculate the removal efficiencies in the BF. The H_2S inlet and outlet concentrations and the H_2S removal efficiencies are shown in Table 2. This table shows that for those values of H_2S inlet concentration ranging closer to the limit of detection, the resultant RE is lower than for high values of concentration. These RE values are not considered to be proper because they were calculated with a non-measured value of outlet concentration. True H_2S removal efficiencies were calculated only when a measurement of the H_2S outlet concentration was obtained.

Table 2. Results from the H_2S Inlet and Outlet Concentrations Measurement.

Date-Time	Inlet Concentration (ppm)	Outlet Concentration (ppm)	Removal Efficiency (%)
9/3/2003 - 7:00 AM	14.3	0.020	99.86
8:00 AM	8.2	0.020	99.76
9/4/2003 - 7:00 AM	16.2	0.020	99.88
9:00 AM	8.2	0.020	99.76
10:00 AM	10.5	0.020	99.81
11:00 AM	7.5	0.020	99.73
12:00 PM	9.0	0.020	99.78

(Table 2 continued)

Date-Time	Inlet Concentration (ppm)	Outlet Concentration (ppm)	Removal Efficiency (%)
9/5/2003 - 7:00 AM	13.3	0.020	99.85
9/8/2003 - 7:00 AM	15.4	0.020	99.87
9/9/2003 - 7:00 AM	20.5	0.020	99.90
8:00 AM	14.5	0.020	99.86
9:00 AM	11.0	0.020	99.82
10:00 AM	5.8	0.020	99.66
11:00 AM	3.5	0.020	99.43
12:00 PM	2.7	0.020	99.26
1:00 PM	7.0	0.020	99.71
9/11/2003 - 7:00 AM	4.0	0.020	99.50
8:00 AM	3.0	0.020	99.33
9:00 AM	0.8	0.020	97.50
10:00 AM	2.3	0.020	99.13
11:00 AM	1.7	0.020	98.82
12:00 PM	1.9	0.020	98.95
9/16/2003 - 7:00 AM	3.1	0.020	99.34
8:00 AM	2.4	0.020	99.15
9:00 AM	1.4	0.020	98.52
10:00 AM	2.5	0.020	99.18
11:00 AM	2.4	0.020	99.17
12:00 PM	2.3	0.020	99.13
1:00 PM	0.9	0.020	97.78
9/18/2003 - 7:00 AM	1.4	0.020	98.57
8:00 AM	3.2	0.020	99.38
9:00 AM	1.3	0.020	98.46
10:00 AM	1.4	0.020	98.57
11:00 AM	2.6	0.020	99.23
9/23/2003 - 7:00 AM	8.4	0.020	99.76
8:00 AM	6.2	0.020	99.68
9:00 AM	6.0	0.020	99.67
10:00 AM	4.7	0.020	99.57
11:00 AM	5.8	0.020	99.65
12:00 PM	4.7	0.020	99.57
1:00 PM	3.4	0.020	99.41
2:00 PM	3.1	0.020	99.36
9/25/2003 - 7:00 AM	2.5	0.020	99.18
8:00 AM	2.1	0.020	99.05
9:00 AM	1.6	0.020	98.71
10:00 AM	1.4	0.020	98.57
11:00 AM	1.2	0.020	98.26
12:00 PM	1.3	0.020	98.46
10/2/2003 - 7:00 AM	3.3	0.020	99.39
8:00 AM	2.6	0.020	99.23
9:00 AM	0.9	0.020	97.78
10:00 AM	2.0	0.020	99.00

(Table 2 continued)

Date-Time	Inlet Concentration (ppm)	Outlet Concentration (ppm)	Removal Efficiency (%)
11:00 AM	2.0	0.020	99.00
12:00 PM	2.1	0.020	99.05
10/6/2003 - 7:00 AM	3.4	0.020	99.40
8:00 AM	2.6	0.020	99.23
9:00 AM	1.6	0.020	98.71
10:00 AM	2.6	0.020	99.22
11:00 AM	2.3	0.020	99.11
12:00 PM	1.1	0.020	98.18
10/8/2003 - 7:00 AM	1.3	0.020	98.46
8:00 AM	1.5	0.020	98.62
9:00 AM	1.4	0.020	98.57
10/9/2003 - 7:00 AM	38.0	0.020	99.95
8:00 AM	21.0	0.020	99.91
9:00 AM	20.5	0.020	99.90
10:00 AM	19.0	0.020	99.89
11:00 AM	16.5	0.020	99.88
12:00 PM	24.5	0.020	99.92
10/15/2003 - 7:00 AM	69.5	0.020	99.97
8:00 AM	77.5	0.020	99.97
9:00 AM	65.0	0.020	99.97
10:00 AM	80.0	0.020	99.98
11:00 AM	98.0	0.020	99.98
12:00 PM	86.0	0.028	99.97
1:00 PM	75.0	0.020	99.97
2:00 PM	74.5	0.012	99.98
10/16/2003 - 7:00 AM	60.5	0.020	99.97
10/21/2003 - 7:00 AM	146.0	0.020	99.99
8:00 AM	125.0	0.046	99.96
9:00 AM	123.0	0.040	99.97
10:00 AM	86.5	0.026	99.97
11:00 AM	72.0	0.020	99.97
12:00 PM	62.0	0.020	99.97
1:00 PM	70.0	0.020	99.97

From the table, two periods can be highlighted based on the H_2S inlet concentration. Low concentrations of H_2S entering the BF are observed from 9/3/2003 to 10/9/2003 and high concentrations from 10/15/2003 to 10/21/2003. During the experiment, the mean H_2S RE was 99.37% at H_2S inlet concentrations fluctuated between 0.8 and 146 ppm. The mean H_2S outlet

concentration was 0.021 ppm. The mean inlet and outlet concentrations and its corresponding removal efficiencies are located in Table 3.

Table 3. Summary of Performance of Biofilter

Period	H_2S Inlet Concentration (ppm)	H_2S Outlet Concentration (ppm)	H_2S Removal Efficiency (%)	
			Mean ± STD	Range
Entire	21.2 ± 33.6	0.021 ± 0.004	99.37 ± 0.60	99.50 - 99.99
Low Concentrations	6.2 ± 7.1	0.020 ± 0.000	99.23 ± 0.59	97.50 - 99.95
High Concentrations	85.7 ± 25.0	0.021 ± 0.008	99.97 ± 0.01	99.96 - 99.99

The results demonstrate that the easily biodegradable H_2S can be effectively removed by passing the air waste stream through a wood bark biofilter of 1,718 m^3 of bed volume. The BF showed consistently high removal performance during the entire two months of operation. For more details, the continuous operation of the BF H_2S inlet and outlet concentrations and the resultant removal efficiencies were plotted. The results can be observed for each day in Appendix B.

The values of all raw data including the inlet and outlet concentrations of H_2S, inlet gas stream velocity, ambient air temperature, and inlet gas stream temperature collected during the evaluation period are presented in Appendix A.

Measurements and tests performed for collection of data were carried out during the late summer and beginning of the fall of 2003. During this period, ambient air temperatures were found to vary from 59.6 to 93.3°F, and gas stream temperatures varied from 76.4 to 100.9°F.

The long term performance of hydrogen sulfide removal in the full scale BF is shown in Figure 13. During the length of this study, odor removal efficiencies were found to be between 97.5% and 99.99%.

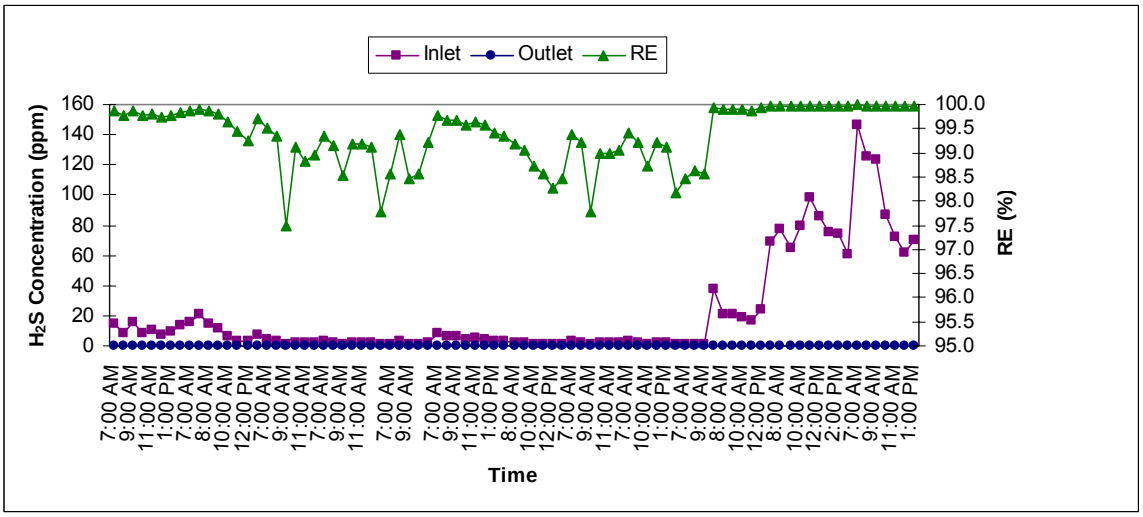

Figure 13 Long Term Performance of Biofilter

4.1.1. Air Flow Effect on H_2S Removal Efficiency

An important parameter on the performance of the BF regarding H_2S removal might be the air flow rate, which varied from a minimum of 3,503.0 m^3/h to a maximum of 4,587.3 m^3/h during the testing period. Additionally, the H_2S inlet concentration was not constant either. Figure 14 presents a plot of a lack of correlation between the two variables. The values of air flow for the complete testing period are shown in Appendix C.

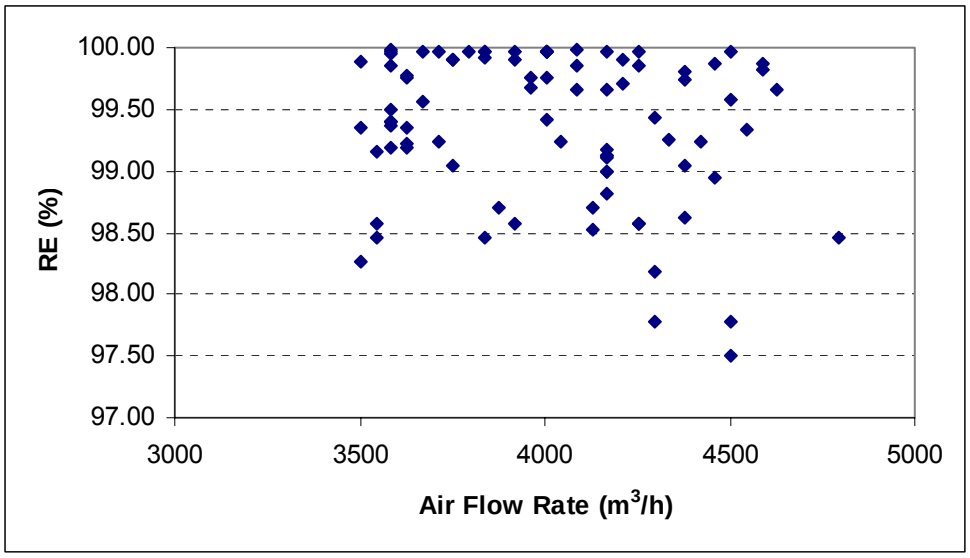

Figure 14. H_2S Removal Efficiency and Air Flow Rate

4.1.2. Mass Load Effect on H_2S Outlet Concentration

Due to differences in the H_2S concentration at the inlet of the BF, it was possible to group the results into two categories for the analysis of H_2S outlet concentration and mass loading rate. The first group corresponds to the results obtained for the low inlet concentration period and the second group corresponds to the high inlet concentration period. The values of the mass loading rate can be viewed in Appendix C.

In conflict with the results reported by several researchers, Figure 15 indicates no effect on H_2S outlet concentration with increased mass load. It is important to recognize that the outlet concentration measurement is limited by the limit of detection (0.02 ppm).

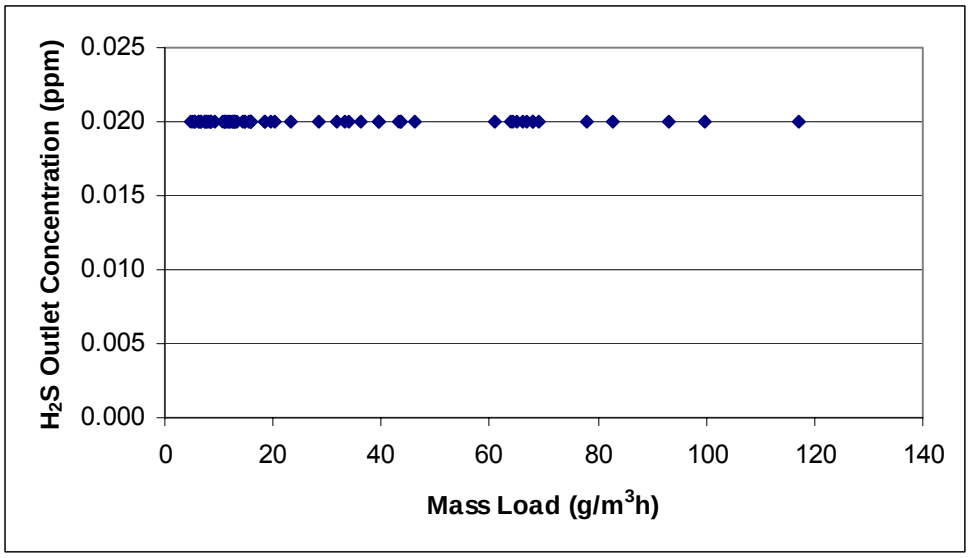

Figure 15. Hydrogen Sulfide Outlet Concentration and Mass Load at Low Inlet Concentrations

Figure 16 presents the variation of the H_2S outlet concentrations caused by the variation of the loading rate at the high concentration period. Nearly complete removals of hydrogen sulfide (> 99.96%) were achieved. Results in this case show lack of correlation between the H_2S outlet concentration and the mass load.

A better approach to view the dependency of the H_2S outlet concentration on the loading rate is presented in Figure 17. The H_2S outlet concentration was observed to reduce with increased loading rate during the period in which the outlet concentrations were above the limit of detection (0.02 ppm). However, the range of outlet concentrations in this graph is very small and the standard deviation (+/- 10%) offered by the method of its measurement is high; these two disadvantages give Figure 17 no validity for analysis.

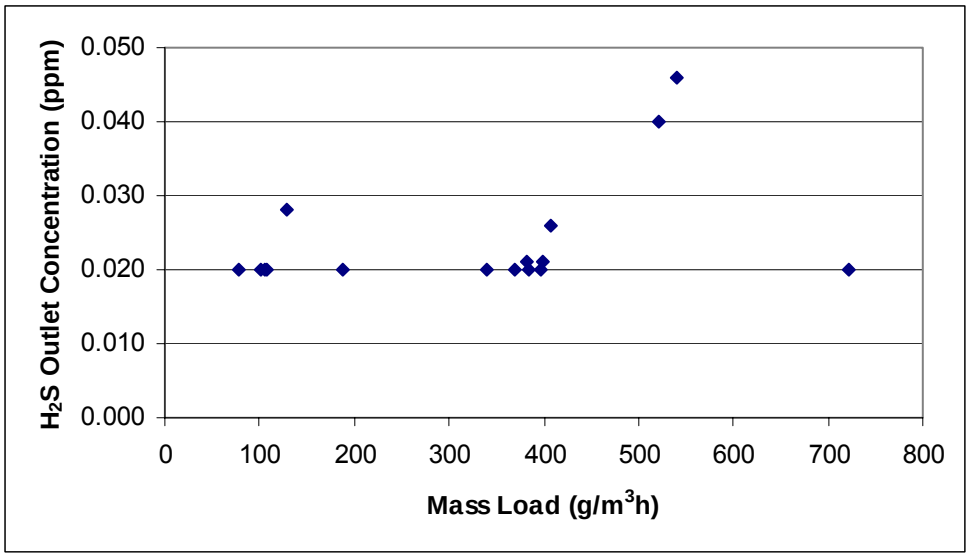

Figure 16. Hydrogen Sulfide Outlet Concentration and Mass Load at High Inlet Concentrations

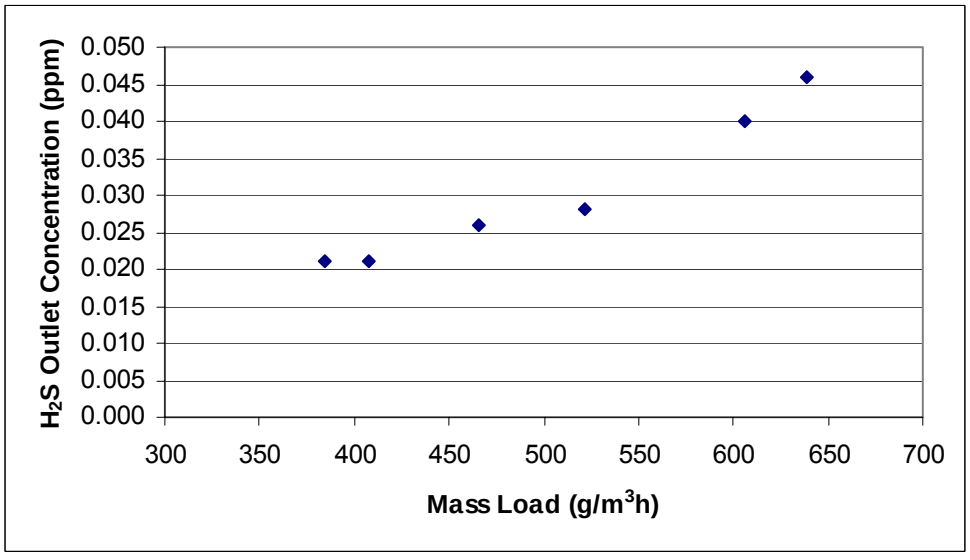

Figure 17. Hydrogen Sulfide Outlet Concentration and Mass Load for H_2S Outlet Concentration above the Limit of Detection

4.1.3. Empty Bed Residence Time Effect on H_2S Removal Efficiency

The H_2S RE and empty bed residence time (EBRT) results are graphically illustrated in Figure 18. The EBRT ranges from a minimum of 1,290 seconds to a maximum of 1,766 seconds. The values of the EBRT obtained can be viewed in Appendix C.

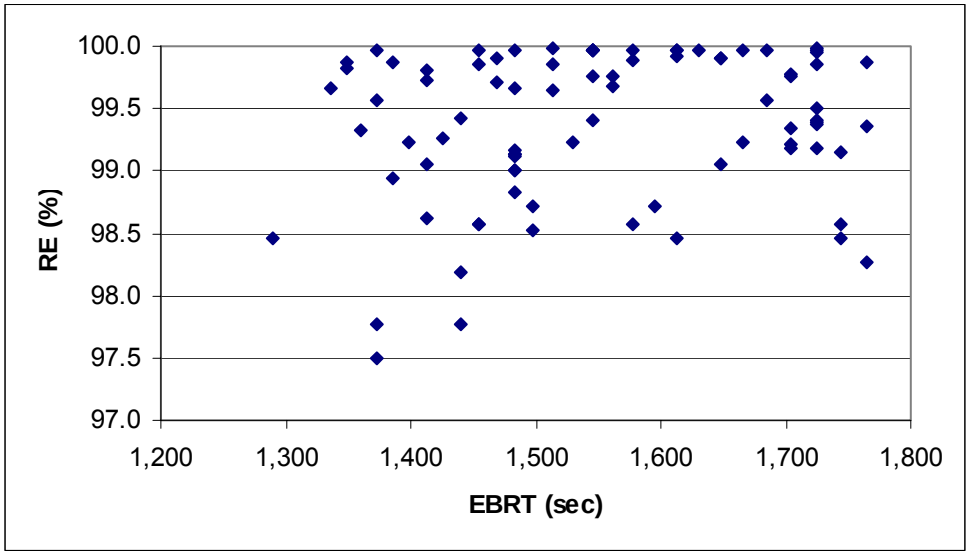

Figure 18. H_2S Removal Efficiency and EBRT

The results reported in the above figure with respect to EBRT show a non-uniform behavior of the RE. The EBRTs obtained are very high. An average of 1,552 seconds (25 minutes, 52 seconds) was calculated. This value is more than ten times higher than the values of EBRT recommended for treatment of H_2S. Chung et al. (1996) have treated H_2S in a biofilter using Thiobacillus thioparus as inoculum and reported H_2S removal efficiency of greater than 98% with an empty bed residence time of 28 seconds. Allen et al. (1992) reported an

EBRT of 88 seconds and removal efficiencies over 99% when studying the removal of H_2S in a full scale compost BF treating odors from a WWTP during the summer of 1988.

4.2. Media Characterization

Characterization tests were performed on filter material. Values for the percent moisture, wet porosity, and pH were determined. Appendix D includes the results of the characterization tests. Table 4 shows the mean and standard deviation of these parameters in the total surface area of the BF and in its central area.

Table 4. Characterization Parameters of Biofilter Media

Location of Measurement	Moisture (%)	pH (pH paper)	pH (pH meter)	Media Porosity
Total area	67.12 ± 10.33	4.29 ± 0.36	4.02 ± 0.07	0.063
Central area	76.21 ± 7.64	4.10 ± 0.32	3.94 ± 0.04	-
Adjacent to central area	65.30 ± 9.87	4.16 ± 0.37	4.04 ± 0.06	-

4.2.1. Moisture Content

The results reported in this section illustrate high values of moisture content especially in the central area of the BF. This phenomenon may be explained by the fact that the irrigation system was observed to irrigate more water in the central area than in the areas closest to the vessel perimeter.

Biofilters are typically operated with a range of water content around 50% of the media capacity for good water and heat balances within the unit. Van Langenhove et al. (1986) studied the elimination of H_2S in a wood bark biofilter

and found that the optimum water content was 65%. Compared to these values, the results reported are high. However, results of RE obtained show that microbial activity in the BF has not been reduced by the excess water in the bed.

4.2.2. pH

Acidification of the media was found. A phenomenon expected is the final product of biodegradation of hydrogen sulfide. Sulfuric acid (H_2SO_4) accumulates in the media because there is no transformation that consumes the acid. In spite of the fallen pH to low values, the removal efficiencies reported in the previous section indicate that microbial activity has not been inhibited. The average pH in the media reported is 4.02. However, lower values of pH were always observed in the central portion of the filter where a mean pH of 3.94 was measured. The pH of the latter was probably due to more microbial activity in the central area. In addition, the high values of moisture content in this area help the dissolution of H_2S, providing more opportunity for decomposition.

4.2.3. Porosity

The fraction of void volume available for the air stream to flow within the media resulted in 0.063. This value of wet bed porosity is very low, indicating that the energy required for moving the air through the filter bed at the required flow rate is high. The higher the porosity, the higher the pressure drops and the lower the air velocities.

Reduction in media porosity may be the result of several factors such as particulate accumulation, water content, reduction of particle size of organic media, mineralization of the organic media, and compaction. Personnel of the facility have observed that media depth reduced about 1.5-ft. in 5 years. This means a reduction of 18.2% in the media volume as a consequence of compaction. The low porosity of media has reduced the space for the air stream to flow and media surface area available for the oxygen to be in contact with the biofilm. The high values of removal efficiencies in the BF reveal that despite this oxygen limitation, and due to the prolonged retention time of the BF, biodegradation of H_2S is not being affected.

In addition, porosity may have reduced due to the acidification of the media. The accumulation of sulfurs has increased the small particle content in the media. Thus, measures should be taken to remove the accumulated small particles periodically. Otherwise, the pressure drop will continue increasing and the air velocity decreasing, which will lead to enhanced energy consumption. Allen et al. (1992) found 35% removal of accumulated acidity and sulfur content by applying periodic washings. However, the effect on pH was small.

4.2.4. Leachate pH

Leachate samples were collected from the underdrain sump and were analyzed. After one week, leachate leaving the drain pipe was also collected and analyzed. This warm liquid was found to be very acidic in comparison with the

leachate collected in the underdrain sump. Table 5 shows the results of pH measurements at these two collection points.

Table 5. Leachate pH

Location of Sample Point	pH
Drain pipe	3.26 ± 0.56
Underdrain sump	6.93 ± 0.49

The results indicate one more time the formation of sulfuric acid within the media. The mean pH value obtained was 3.26. Comparisons of this result with the pH of the media (4.02) reflect that the accumulation of sulfuric acid may be drained away throughout the media continuously in a way that amounts of acid in the leachate are greater than those in the media.

The leachate drained from the drain pipe continuously fell into the underdrain sump. In this leachate collection box, the pH found was around neutral values. The reason for this radical change in pH from one sampling point to the other could not be established and is beyond the scope of this research project.

Finally, Table 6 shows the values of leachate pH in the periods of high inlet concentration and low inlet concentration of H_2S. During the period of high inlet concentration of H_2S, the values of the leachate pH were observed to be higher than those for the period of low inlet concentration. This confirms that, at low loading rates, the potential for acidification of the filter material is lower than with higher loading conditions. The values of leachate pH can be viewed in Appendix D.

Table 6. Leachate pH during H_2S Inlet Concentration Periods

Period/pH	**Location of Sample Point**	
	Drain Pipe	Underdrain sump
High Inlet Concentration	3.19 ± 0.62	6.70 ± 0.47
Low Inlet Concentration	3.48 ± 0.24	7.31 ± 0.19

5. CONCLUSIONS AND RECOMMENDATIONS

The following summarizes the conclusions derived from the research conducted under this project:

- The biofiltration process was found to be an effective treatment method for the removal of H_2S concentrations present in wastewater treatment facilities.
- The biofilter in the Marrero Wastewater Treatment Plant has been observed to be an effective, durable, and inexpensive technology for the treatment of H_2S emissions from headworks and primary clarifiers.
- The biofilter can achieve removal efficiencies greater than 97.5% for the treatment of H_2S in inlet concentrations ranging from 0.8 to 146 ppm.
- Despite the low bed porosity, the high value of residence time in the biofilter ensures high removal efficiencies for the H_2S emissions.
- As a result of the implemented irrigation type and the excess water in the media, drainage of sulfuric acid in the BF has provided beneficial conditions for the activity of microorganisms.
- Proper biofilter operation requires a good understanding of the microbial requirements and controlling factors.

The following summarizes the recommendations to the Marrero Wastewater Treatment Plant:

- Substitute the media every 3 to 4 years and change the actual media as soon as possible. The media to be used can be wood bark with the same characteristics of the one being used. The substitution of the media will improve the bed porosity, thus reducing the resistance to air flow. This, in turn, will result in better blower performance and a reduction in energy costs.
- Add the air streams from the trickling filters to the influent piping system to the biofilter for removal of H_2S and other organic compounds generated in these units. H_2S concentrations in the trickling filters were measured (mean = 0.8 ppm) and were found to be lower than those from headworks and primary clarifiers. The existing biofilter has enough removal capacity for the additional air flow. This expansion will eliminate the costs of chemical feed, operation, and maintenance of the chemical scrubbers that actually remove H_2S emissions from the trickling filters.
- Evaluate and provide maintenance to the biofilter in the Marrero Wastewater Treatment Plant. These activities can be carried out following the recommendations presented in the Manual of System Operation and Maintenance prepared and provided to the facility as a result of this research. This manual is presented in Appendix G.

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APPENDIX A

H_2S Inlet Concentrations, H_2S Outlet Concentrations, Air Stream Velocities, Ambient Air Temperatures, and Gas Stream Temperatures during the evaluation period

Date	Time	Inlet (ppm)	Outlet (ppm)	V (ft/min)	T Stream (˚F)	T Amb. (˚F)
9/3/2003	7:00 AM	14.3	0.02	490	98.1	90.0
	8:00 AM	8.2	0.02	475	95.2	79.0
9/4/2003	9:00 AM	16.2	0.02	550	94.7	84.1
	10:00 AM	8.2	0.02	435	98.7	93.3
	11:00 AM	10.5	0.02	525	100.2	97.1
	12:00 PM	7.5	0.02	525	100.8	92.7
	1:00 PM	9.0	0.02	435	100.7	93.1
9/5/2003	7:00 AM	13.3	0.02	430	93.7	77.0
9/8/2003	7:00 AM	15.4	0.02	535	90.9	76.0
9/9/2003	7:00 AM	20.5	0.02	505	90.3	73.5
	8:00 AM	14.5	0.02	510	94.1	90.3
	9:00 AM	11.0	0.02	550	93.0	83.0
	10:00 AM	5.8	0.02	555	94.4	84.0
	11:00 AM	3.5	0.02	515	93.9	83.4
	12:00 PM	2.7	0.02	520	92.7	82.0
	1:00 PM	7.0	0.02	505	93.4	81.9
9/11/2003	7:00 AM	4.0	0.02	430	90.8	75.0
	8:00 AM	3.0	0.02	545	91.8	81.0
	9:00 AM	0.8	0.02	540	94.0	85.4
	10:00 AM	2.3	0.02	500	96.3	87.1
	11:00 AM	1.7	0.02	500	99.8	90.0
	12:00 PM	1.9	0.02	535	99.4	88.9
9/16/2003	7:00 AM	3.1	0.02	435	99.2	82.6
	8:00 AM	2.4	0.02	425	90.6	83.7
	9:00 AM	1.4	0.02	495	92.7	81.8
	10:00 AM	2.5	0.02	435	95.0	81.5
	11:00 AM	2.4	0.02	500	97.1	86.6
	12:00 PM	2.3	0.02	500	96.3	87.1
	1:00 PM	0.9	0.02	515	99.4	87.5
9/18/2003	7:00 AM	1.4	0.02	425	99.8	86.7
	8:00 AM	3.2	0.02	430	86.0	75.1
	9:00 AM	1.3	0.02	575	94.6	82.3
	10:00 AM	1.4	0.02	510	99.8	89.6
	11:00 AM	2.6	0.02	445	100.9	92.7
9/23/2003	7:00 AM	8.4	0.02	480	85.7	69.0
	8:00 AM	6.2	0.02	475	90.0	73.1
	9:00 AM	6.0	0.02	500	87.7	74.3
	10:00 AM	4.7	0.02	440	91.1	80.4
	11:00 AM	5.8	0.02	490	92.0	80.0
	12:00 PM	4.7	0.02	540	93.4	81.3
	1:00 PM	3.4	0.02	480	89.9	82.0
	2:00 PM	3.1	0.02	420	93.8	86.1
9/25/2003	8:00 AM	2.5	0.02	430	94.3	82.6
	9:00 AM	2.1	0.02	450	94.0	82.9
	10:00 AM	1.6	0.02	465	94.1	83.1
	11:00 AM	1.4	0.02	470	96.1	83.4

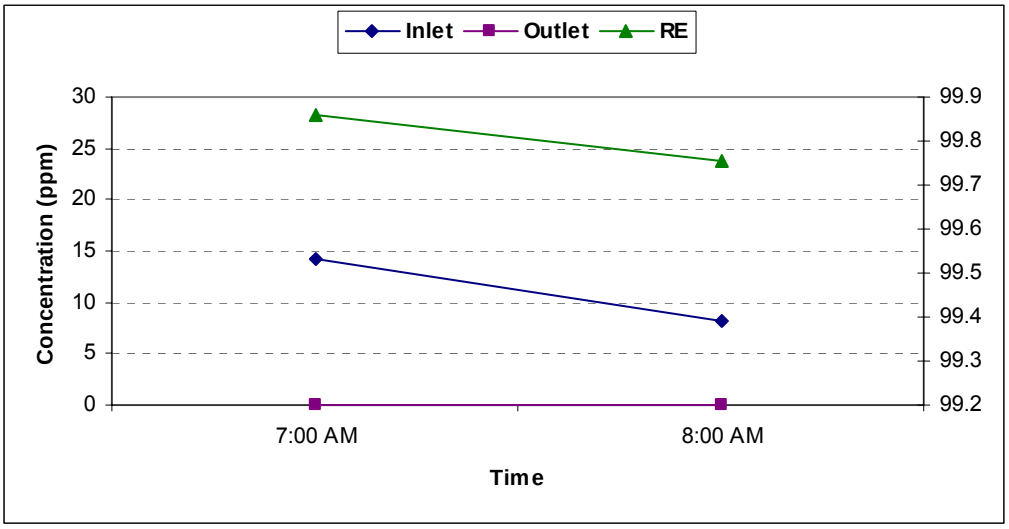
(table continued)

Date	Time	Inlet (ppm)	Outlet (ppm)	V (ft/min)	T Stream (˚F)	T Amb. (˚F)
	12:00 PM	1.2	0.02	420	97.5	84.3
	1:00 PM	1.3	0.02	460	98.6	83.5
10/2/2003	7:00 AM	3.3	0.02	430	99.2	86.0
	8:00 AM	2.6	0.02	530	91.8	81.0
	9:00 AM	0.9	0.02	540	94.0	85.4
	10:00 AM	2.0	0.02	500	96.3	87.1
	11:00 AM	2.0	0.02	500	99.8	90.0
	12:00 PM	2.1	0.02	525	99.4	88.9
10/6/2003	9:00 AM	3.4	0.02	430	99.2	82.6
	10:00 AM	2.6	0.02	485	90.6	73.7
	11:00 AM	1.6	0.02	495	92.7	71.8
	12:00 PM	2.6	0.02	435	95.0	81.5
	1:00 PM	2.3	0.02	500	97.1	86.6
	2:00 PM	1.1	0.02	515	99.4	87.5
10/8/2003	7:00 AM	1.3	0.02	425	99.8	86.7
	8:00 AM	1.5	0.02	525	94.6	82.3
	9:00 AM	1.4	0.02	510	99.8	89.6
10/9/2003	7:00 AM	38.0	0.02	430	84.0	72.6
	8:00 AM	21.0	0.02	450	84.0	72.9
	9:00 AM	20.5	0.02	450	84.1	73.1
	10:00 AM	19.0	0.02	470	86.3	73.4
	11:00 AM	16.5	0.02	420	87.7	74.0
	12:00 PM	24.5	0.02	460	88.6	73.5
10/15/2003	7:00 AM	69.5	0.02	480	85.7	69.0
	8:00 AM	77.5	0.02	455	90.0	73.1
	9:00 AM	65.0	0.02	500	87.7	74.3
	10:00 AM	80.0	0.02	440	91.1	80.4
	11:00 AM	98.0	0.02	490	92.0	80.0
	12:00 PM	86.0	0.028	540	93.4	81.3
	1:00 PM	75.0	0.021	480	89.9	82.0
	2:00 PM	74.5	0.021	460	93.8	86.1
10/16/2003	7:00 AM	60.5	0.02	480	76.4	59.6
10/21/2003	7:00 AM	146.0	0.02	430	83.3	67.3
	8:00 AM	125.0	0.046	445	84.3	73.1
	9:00 AM	123.0	0.04	430	85.0	74.0
	10:00 AM	86.5	0.026	470	84.7	76.5
	11:00 AM	72.0	0.02	460	91.0	85.1
	12:00 PM	62.0	0.02	480	94.4	84.7
	1:00 PM	70.0	0.02	510	94.7	88.8

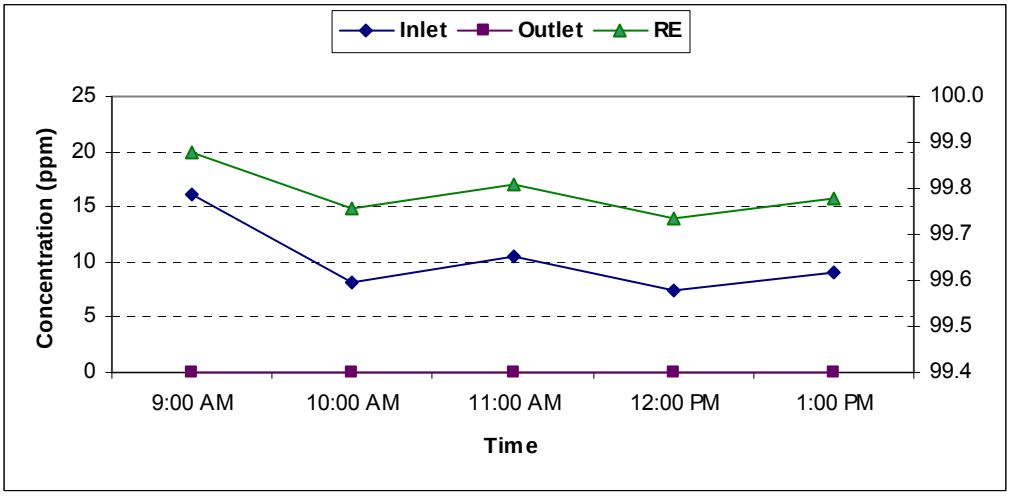
APPENDIX B

H_2S Inlet Concentrations, H_2S Outlet Concentrations, and Removal Efficiencies in continuous operation of the Biofilter

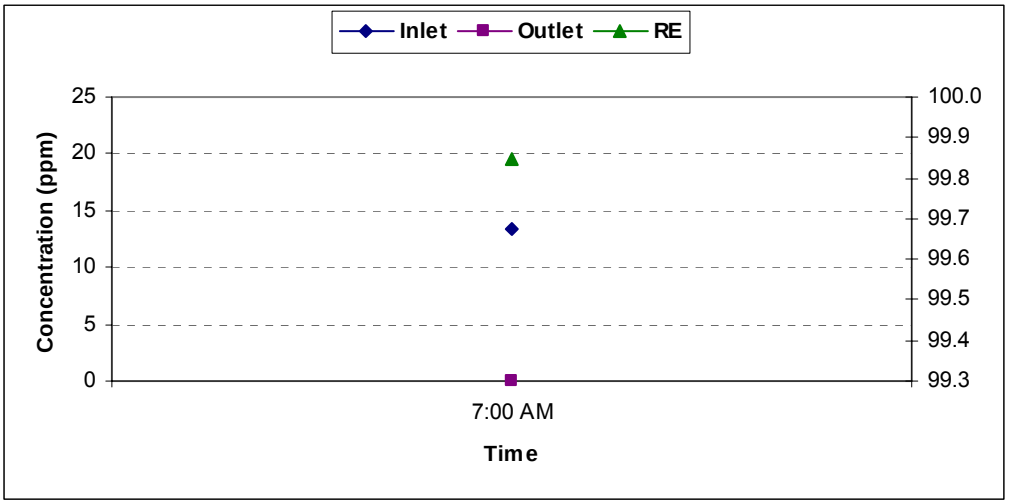
9/3/2003



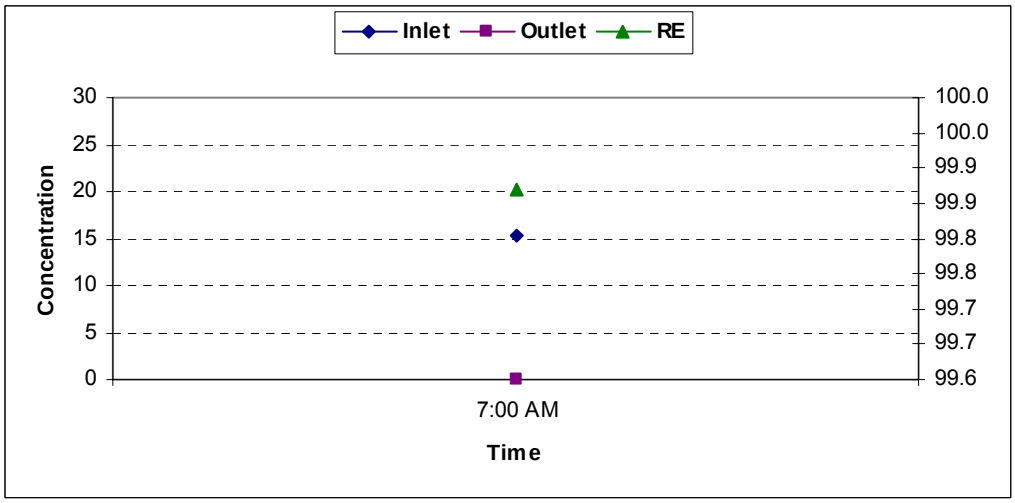
9/4/2003



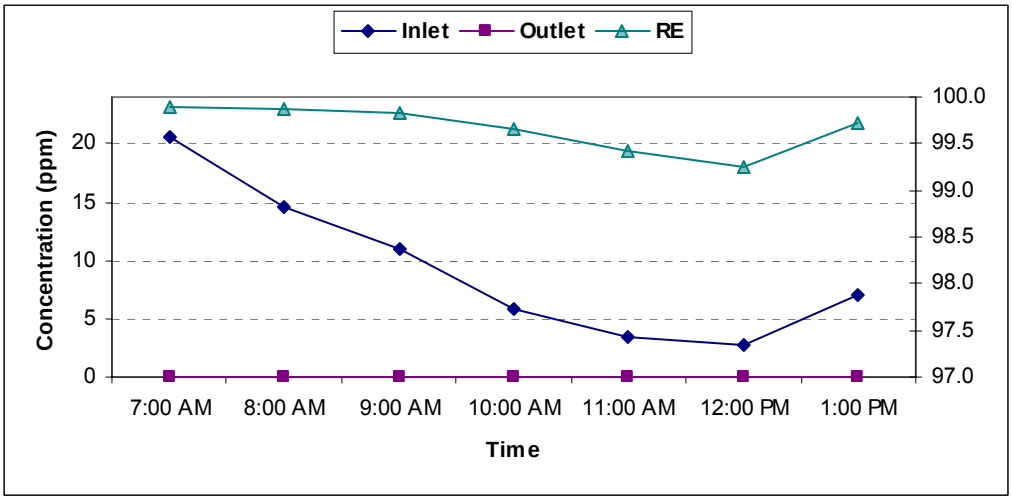
9/5/2003



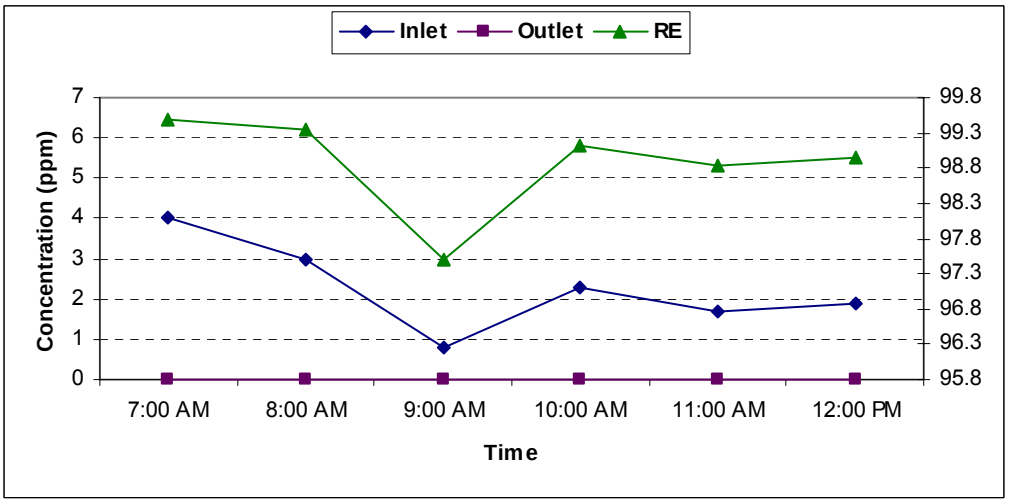
9/8/2003



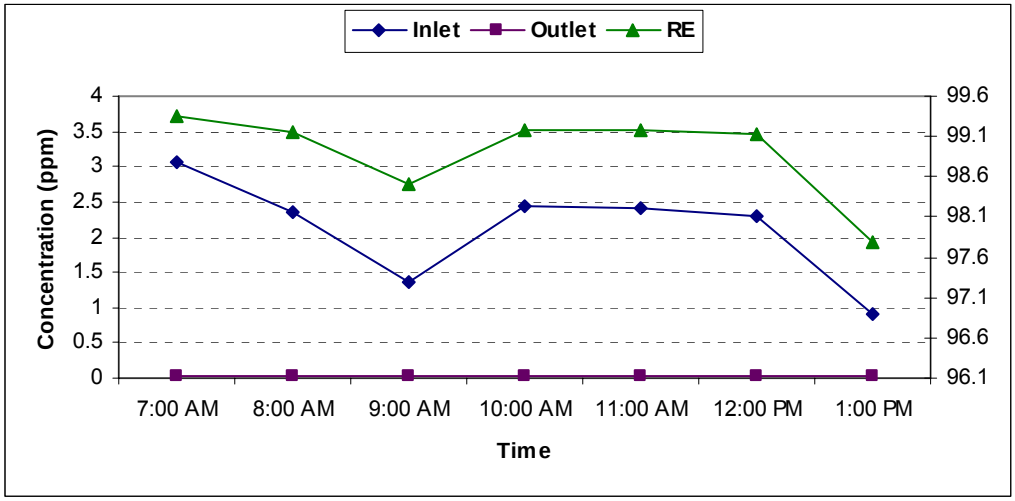
9/9/2003



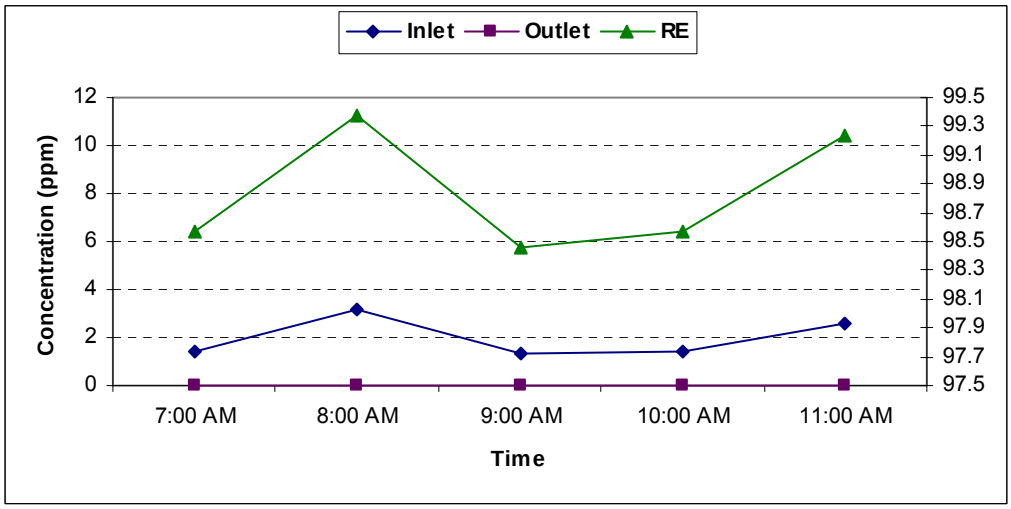
9/11/2003



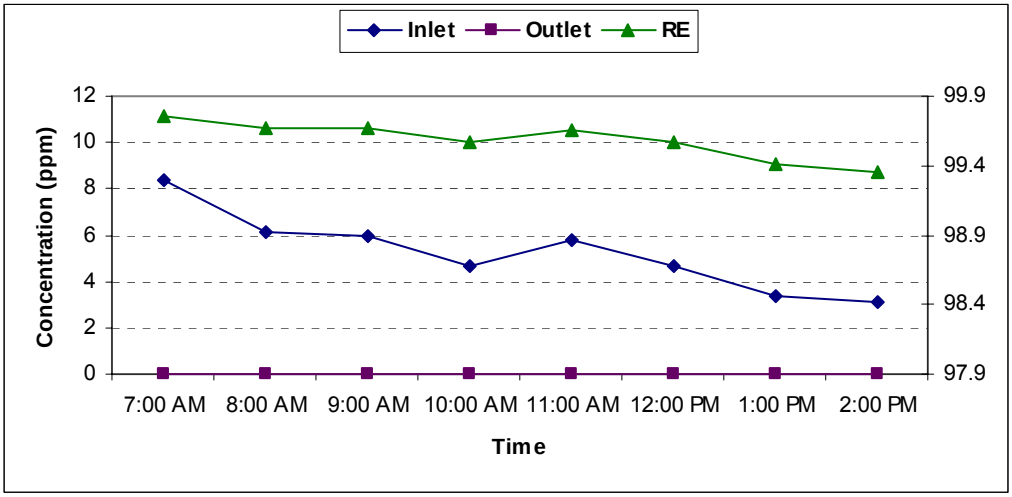
9/16/2003



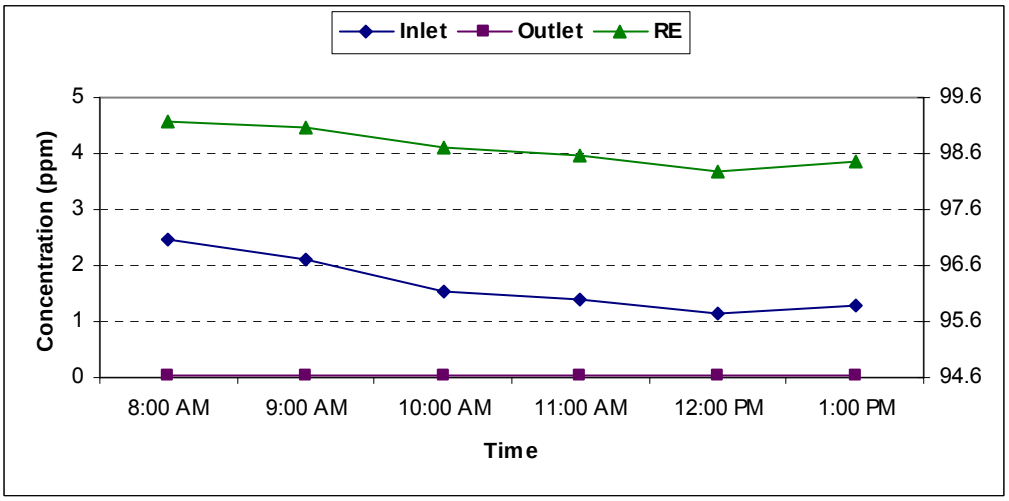
9/18/2003



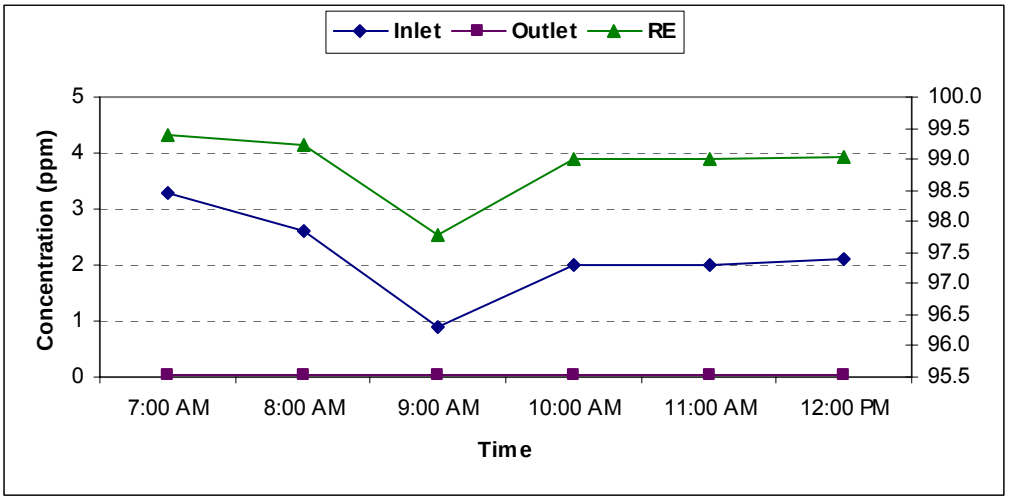
9/23/2003



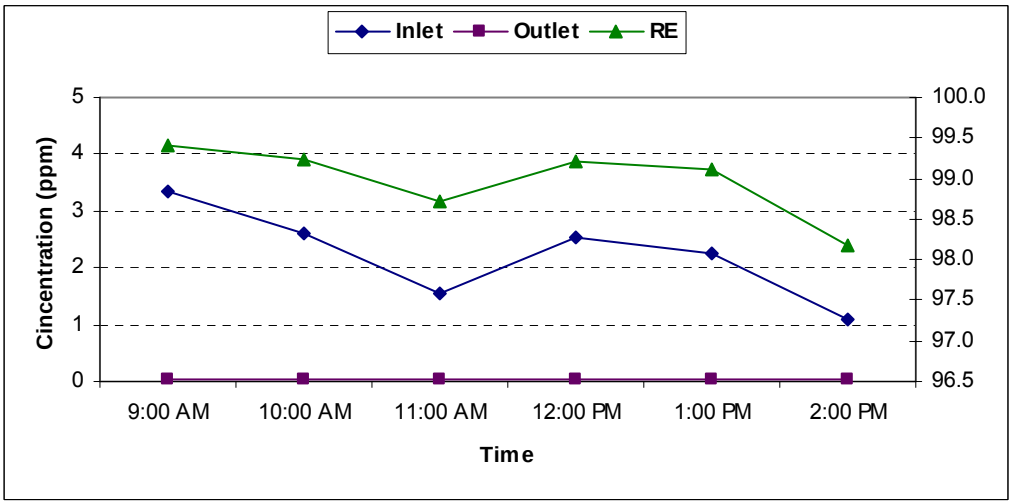
9/25/2003



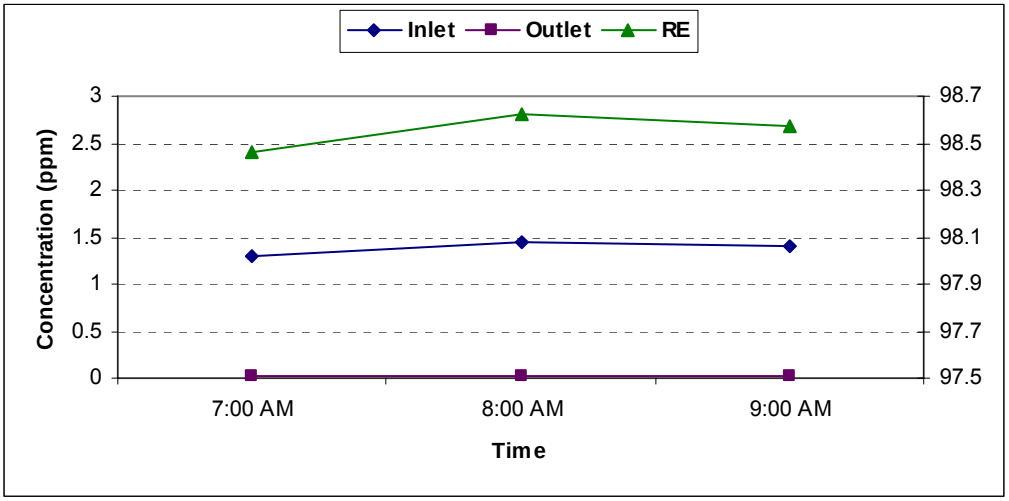
10/2/2003



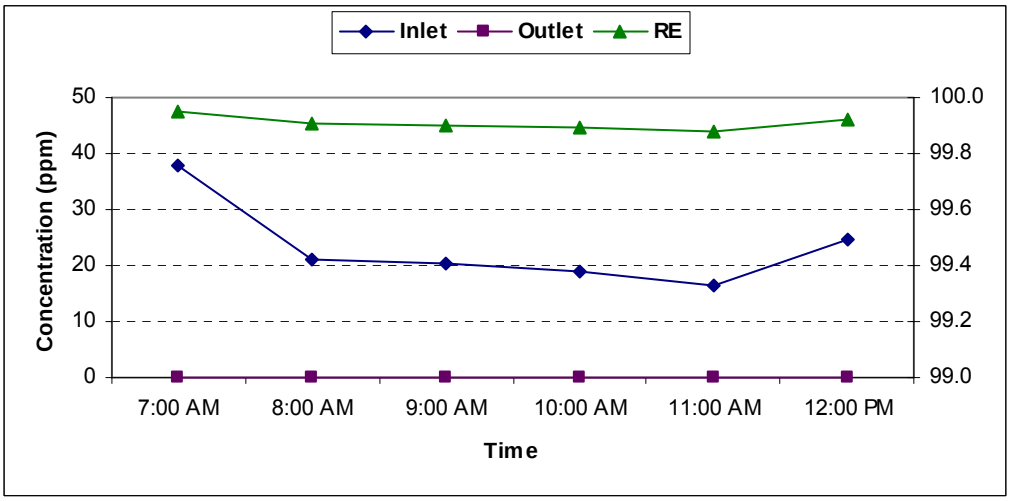
10/6/2003



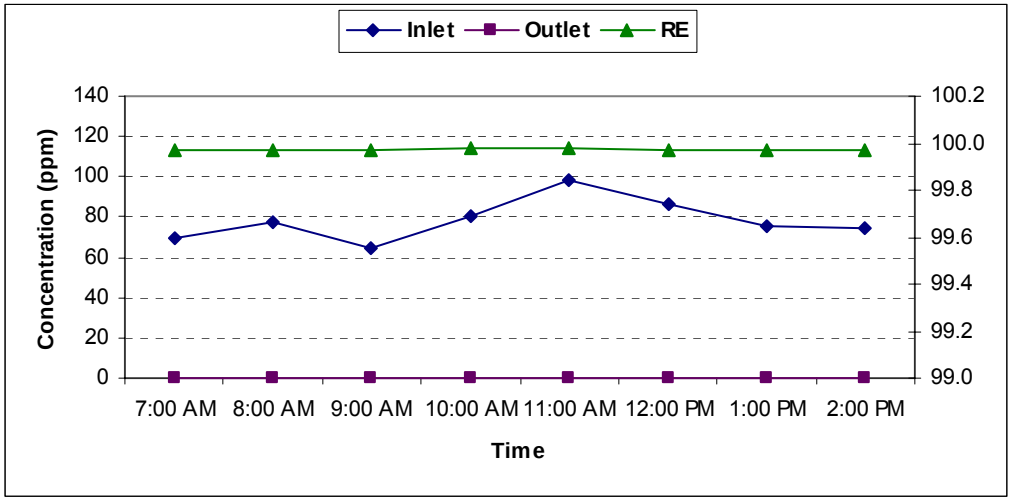
10/8/2003



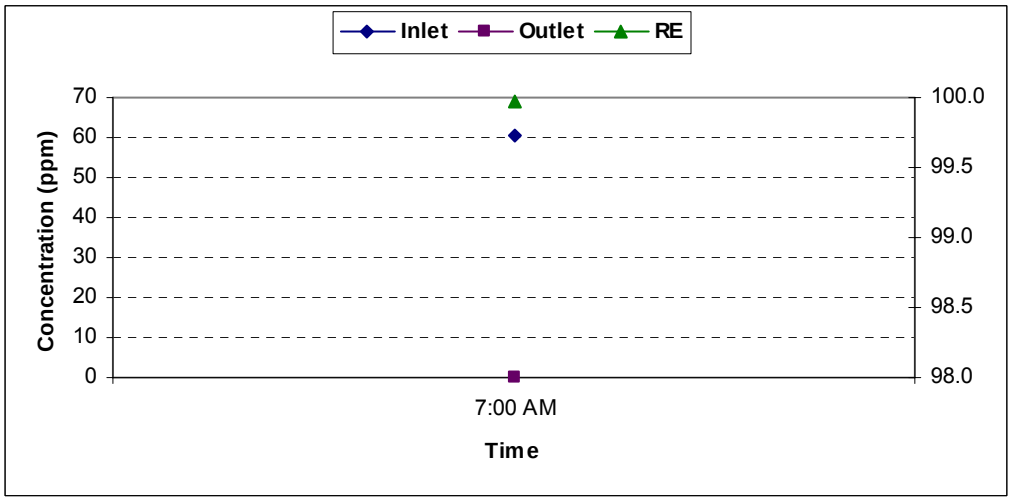
10/9/2003



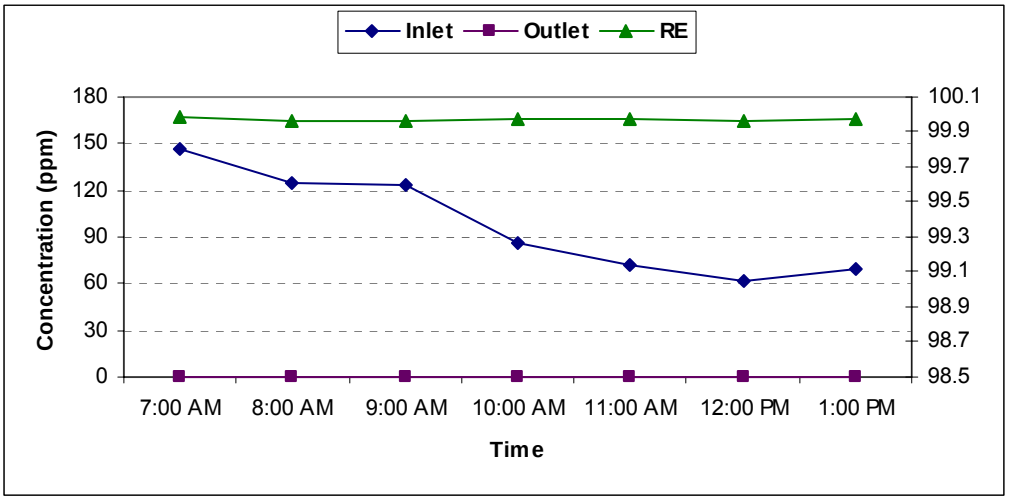
10/15/2003



10/16/2003



10/21/2003


Inlet
Outlet
RE
Concentration (ppm)
180
150
120
90
60
30
0
100.1
99.9
99.7
99.5
99.3
99.1
98.9
98.7
98.5
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
Time

APPENDIX C

Removal Efficiencies, Air Flow Rates, Mass Loads, and Empty Bed Residence Times during the evaluation period

Date	Time	RE (%)	Q (m^3/h)	Mass Load (g/m^3h)	EBRT (s)
9/3/2003	7:00 AM	99.86	4,086.84	77.79	1,513
	8:00 AM	99.76	3,961.73	43.55	1,561
9/4/2003	9:00 AM	99.88	4,587.27	99.80	1,348
	10:00 AM	99.76	3,628.11	39.53	1,705
	11:00 AM	99.81	4,378.76	60.87	1,412
	12:00 PM	99.73	4,378.76	43.40	1,412
	1:00 PM	99.78	3,628.11	43.16	1,705
9/5/2003	7:00 AM	99.85	3,586.41	64.17	1,725
9/8/2003	7:00 AM	99.87	4,462.16	93.09	1,386
9/9/2003	7:00 AM	99.90	4,211.95	117.18	1,468
	8:00 AM	99.86	4,253.65	82.90	1,454
	9:00 AM	99.82	4,587.27	68.06	1,348
	10:00 AM	99.66	4,628.97	36.05	1,336
	11:00 AM	99.43	4,295.35	20.22	1,440
	12:00 PM	99.26	4,337.05	15.79	1,426
	1:00 PM	99.71	4,211.95	39.70	1,468
9/11/2003	7:00 AM	99.50	3,586.41	19.43	1,725
	8:00 AM	99.33	4,545.57	18.44	1,361
	9:00 AM	97.50	4,503.86	4.84	1,373
	10:00 AM	99.13	4,170.25	12.82	1,483
	11:00 AM	98.82	4,170.25	9.39	1,483
	12:00 PM	98.95	4,462.16	11.24	1,386
9/16/2003	7:00 AM	99.34	3,628.11	14.69	1,705
	8:00 AM	99.15	3,544.71	11.29	1,745
	9:00 AM	98.52	4,128.54	7.51	1,498
	10:00 AM	99.18	3,628.11	11.92	1,705
	11:00 AM	99.17	4,170.25	13.35	1,483
	12:00 PM	99.13	4,170.25	12.82	1,483
	1:00 PM	97.78	4,295.35	5.12	1,440
9/18/2003	7:00 AM	98.57	3,544.71	6.57	1,745
	8:00 AM	99.38	3,586.41	15.72	1,725
	9:00 AM	98.46	4,795.78	8.38	1,290
	10:00 AM	98.57	4,253.65	7.89	1,454
	11:00 AM	99.23	3,711.52	12.75	1,666
9/23/2003	7:00 AM	99.76	4,003.44	46.11	1,545
	8:00 AM	99.68	3,961.73	33.06	1,561
	9:00 AM	99.67	4,170.25	34.16	1,483
	10:00 AM	99.57	3,669.82	23.11	1,685
	11:00 AM	99.65	4,086.84	31.75	1,513
	12:00 PM	99.57	4,503.86	28.50	1,373
	1:00 PM	99.41	4,003.44	18.47	1,545
	2:00 PM	99.36	3,503.01	14.61	1,766
9/25/2003	8:00 AM	99.18	3,586.41	11.81	1,725
	9:00 AM	99.05	3,753.22	10.60	1,648
	10:00 AM	98.71	3,878.33	8.08	1,595
	11:00 AM	98.57	3,920.03	7.34	1,578

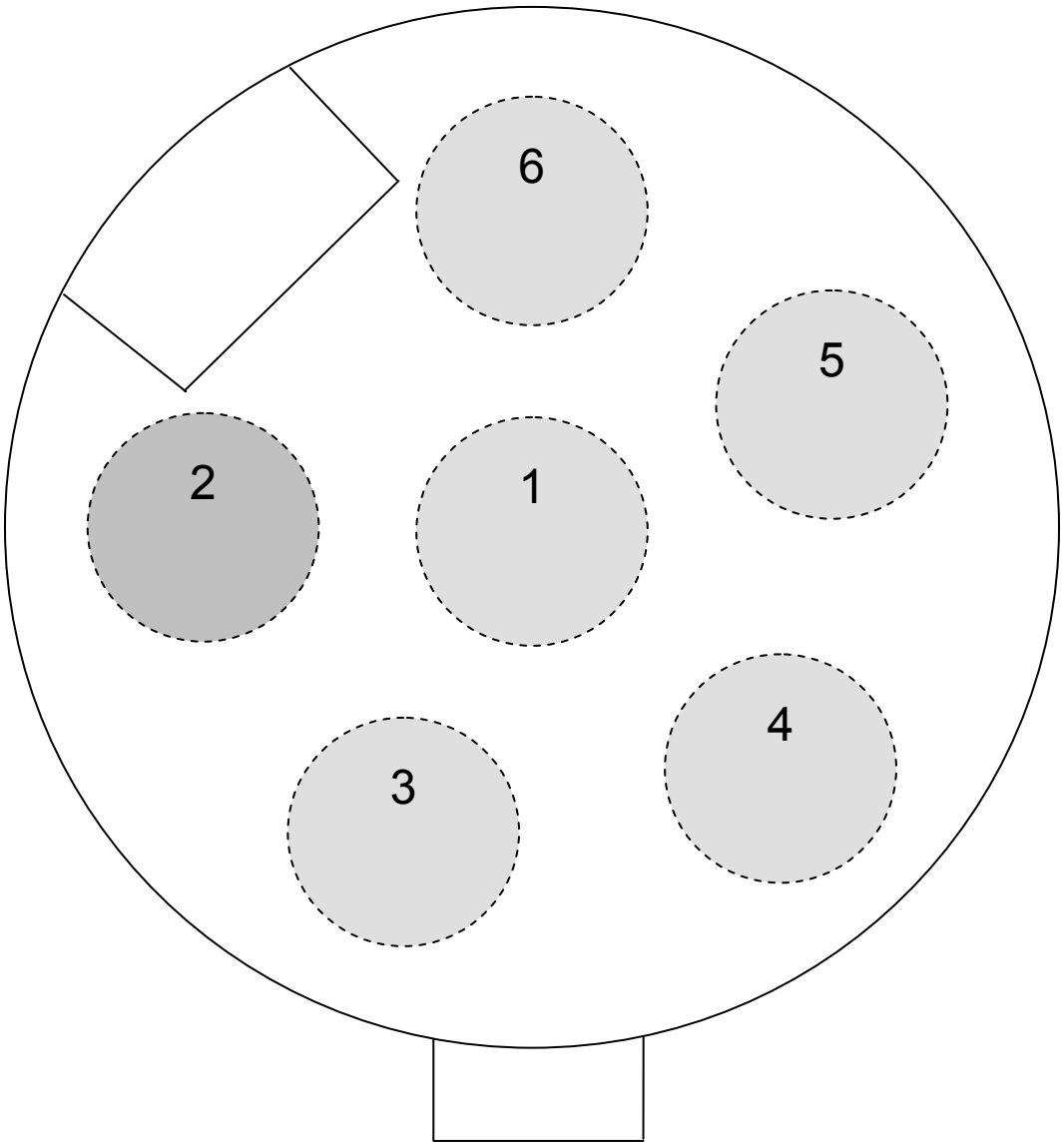
(table continued)

Date	Time	RE (%)	Q (m^3/h)	Mass Load (g/m^3h)	EBRT (s)
	12:00 PM	98.26	3,503.01	5.36	1,766
	1:00 PM	98.46	3,836.63	6.62	1,612
10/2/2003	7:00 AM	99.39	3,586.41	15.71	1,725
	8:00 AM	99.23	4,420.46	15.54	1,399
	9:00 AM	97.78	4,503.87	5.45	1,373
	10:00 AM	99.00	4,170.25	11.15	1,483
	11:00 AM	99.00	4,170.25	11.05	1,483
	12:00 PM	99.05	4,378.76	12.19	1,412
10/6/2003	9:00 AM	99.40	3,586.41	15.95	1,725
	10:00 AM	99.23	4,045.14	14.26	1,529
	11:00 AM	98.71	4,128.54	8.63	1,498
	12:00 PM	99.22	3,628.11	12.41	1,705
	1:00 PM	99.11	4,170.25	12.52	1,483
	2:00 PM	98.18	4,295.35	6.26	1,440
10/8/2003	7:00 AM	98.46	3,544.71	6.10	1,745
	8:00 AM	98.62	4,378.76	8.52	1,412
	9:00 AM	98.57	4,253.65	7.89	1,454
10/9/2003	7:00 AM	99.95	3,586.41	187.68	1,725
	8:00 AM	99.91	3,753.22	108.54	1,648
	9:00 AM	99.90	3,753.22	105.96	1,648
	10:00 AM	99.90	3,920.03	101.95	1,578
	11:00 AM	99.88	3,503.01	78.91	1,766
	12:00 PM	99.92	3,836.63	128.01	1,612
10/15/2003	7:00 AM	99.97	4,003.44	381.54	1,545
	8:00 AM	99.97	3,794.92	399.13	1,630
	9:00 AM	99.97	4,170.25	370.10	1,483
	10:00 AM	99.98	3,669.82	397.74	1,685
	11:00 AM	99.98	4,086.84	541.18	1,513
	12:00 PM	99.97	4,503.86	521.54	1,373
	1:00 PM	99.97	4,003.44	407.48	1,545
	2:00 PM	99.97	3,836.66	384.53	1,612
10/16/2003	7:00 AM	99.97	4,003.44	339.27	1,545
10/21/2003	7:00 AM	99.99	3,586.41	722.33	1,725
	8:00 AM	99.96	3,711.52	638.37	1,666
	9:00 AM	99.97	3,586.41	605.94	1,725
	10:00 AM	99.97	3,920.03	466.17	1,578
	11:00 AM	99.97	3,836.63	374.23	1,612
	12:00 PM	99.97	4,003.44	333.34	1,545
	1:00 PM	99.97	4,253.65	399.87	1,454

APPENDIX D

Media Characterization: Moisture Content, pH, and Bed Porosity

Media Sampling Areas



Sample Area #	W1 (wet)	W2 (dry)	Moisture (%)	pH[1]	pH[2]
1	4.802	0.956	80.09	4.0	-
1	11.276	2.425	78.49	4.0	-
2	5.281	2.898	45.12	4.0	-
2	4.569	2.273	50.25	4.0	-
3	6.368	2.258	64.54	4.0	-
3	8.123	2.291	71.79	4.0	-
4	11.356	5.111	54.99	4.0	-
4	6.469	2.405	62.82	4.0	-
5	12.585	3.191	74.64	4.0	-
5	13.522	3.921	71.00	4.0	-
6	7.383	2.342	68.27	4.0	-
6	6.008	1.979	67.06	4.0	-
1	6.542	1.323	79.78	4.0	-
1	4.956	1.017	79.48	4.0	-
2	9.013	4.491	50.17	4.0	-
2	6.321	2.950	53.33	4.0	-
3	5.369	2.011	62.54	4.0	-
3	5.127	1.756	65.75	5.0	-
4	8.231	3.523	57.20	4.0	-
4	9.174	3.485	62.01	5.0	-
5	6.812	2.260	66.82	4.0	-
5	7.461	2.640	64.62	4.0	-
6	8.624	2.897	66.41	5.0	-
6	6.782	2.029	70.08	4.0	-
1	14.008	2.828	79.81	4.0	-
1	13.027	2.572	80.26	4.0	-
2	7.278	3.550	51.22	4.0	-
2	7.745	4.177	46.07	4.0	-
3	7.636	2.958	61.26	4.0	-
3	13.287	3.721	71.99	5.0	-
4	8.473	3.780	55.39	4.0	-
4	7.843	2.708	65.47	4.0	-
5	7.852	2.469	68.56	4.0	-
5	23.885	5.801	75.71	4.0	-
6	15.681	4.045	74.20	4.0	-
6	9.068	2.779	69.35	5.0	-
1	7.202	2.474	65.65	4.0	-
1	4.409	1.828	58.54	5.0	-

[1] pH measured with pH paper.
[2] pH measured with Method SSSA 12-2.6.5.

(table continued)

Sample Area #	W1 (wet)	W2 (dry)	Moisture (%)	pH[1]	pH[2]
2	8.068	2.485	69.20	4.0	-
2	9.513	3.139	67.00	5.0	-
3	3.520	1.659	52.87	4.0	-
3	6.078	2.499	58.89	5.0	-
4	3.378	1.623	51.95	4.0	-
4	12.146	4.319	64.44	4.0	-
5	12.714	3.957	68.88	4.0	-
5	3.515	1.692	51.86	4.0	-
6	4.755	1.678	64.71	4.0	-
6	7.073	2.445	65.43	5.0	-
1	7.609	1.512	80.13	4.0	3.91
1	8.613	1.736	79.84	4.0	3.97
2	1.099	0.415	62.24	4.0	4.01
2	3.442	0.990	71.24	4.0	4.06
3	9.227	1.858	79.86	4.0	3.98
3	4.887	0.923	81.11	4.0	4.09
4	6.637	1.061	84.01	4.0	4.03
4	2.542	1.003	60.54	4.0	3.92
5	10.549	2.519	76.12	4.0	4.07
5	3.364	0.715	78.75	4.0	4.02
6	5.766	0.961	83.33	4.0	4.04
6	5.073	0.826	83.72	4.0	4.15

[1] pH measured with pH paper.
[2] pH measured with Method SSSA 12-2.6.5.

APPENDIX E

Leachate pH

Date	Time	pH[1]	pH[2]
9/3/2003	7:00 AM	-	7.68
	8:00 AM	-	7.12
9/4/2003	9:00 AM	-	7.31
	10:00 AM	-	7.13
	11:00 AM	3.82	7.26
	12:00 PM	3.30	7.41
	1:00 PM	3.33	7.38
9/5/2003	7:00 AM	3.26	7.15
10/15/2003	7:00 AM	-	-
	8:00 AM	3.69	6.81
	9:00 AM	3.71	7.12
	10:00 AM	3.95	7.24
	11:00 AM	3.83	7.17
	12:00 PM	3.77	7.15
	1:00 PM	3.85	7.22
	2:00 PM	-	-
10/16/2003	7:00 AM	3.13	6.98
10/21/2003	7:00 AM	2.60	6.31
	8:00 AM	2.67	6.59
	9:00 AM	2.62	6.17
	10:00 AM	2.59	6.13
	11:00 AM	2.71	6.17
	12:00 PM	2.34	6.08

[1] pH measured at the leachate draining pipe.
[2] pH measured at the underdrain sump.

APPENDIX F

Manual of System Operation and Maintenance Procedures for the Biofilter of Marrero Wastewater Treatment Plant

UNIVERSITY OF NEW ORLEANS

ODOR CONTROL BIOFILTER SYSTEM

for

MARRERO WASTEWATER TREATMENT PLANT

SYSTEM OPERATION AND MAINTENANCE PROCEDURES

December, 2003

SYSTEM OPERATION AND MAINTENANCE PROCEDURES

1. OVERVIEW

The biofilter (BF) in Marrero Wastewater Treatment Plant was specifically designed and implemented in 1998 for the removal of the hydrogen sulfide and other odorous traces. The design was made upon an existing concrete vessel which was used years before as the vessel of a trickling filter for treatment of the wastewater.

The odorous gases produced in the headworks and in the effluent radial overflow weir space of the two primary settling tanks are removed in the BF. The air stream containing the odorous compounds is forced into the filter material. The odorous gases are absorbed into a moist surface biofilm layer and adsorbed onto the surfaces of the BF stationary filter material. Microorganisms attached to the material, break down the odorous compounds into harmless products such as carbon dioxide, mineral salts, acids, water and more microorganisms cells.

It is important for this BF to keep moist so that the microbial community remains healthy and effective. The goal is to operate the BF as close to 100% humidity as possible for the inlet gas stream. It is also important to keep sufficient void space and avoid air channeling, which results in short circuiting the media. Large amounts of dust and particulate matter in the incoming foul air will build up in the BF media and shorten the replacement time. In addition, back pressure on the blowers will increase maintenance requirements. An appropriate temperature range (75-150°F) must be maintained to keep the microbial organisms healthy and functioning. Operators should carry out a BF performance monitoring routine for improvement of the odor control efficiency.

2. SYSTEM DESCRIPTION AND OPERATION

The biofilter is a biological treatment unit design to control atmospheric hydrogen sulfide (H_2S) and other noxious odors. The unit consists of the following system for its operation:

2.1. Biofilter Vessel System

The bioreactor is a 98’ diameter cylindrical vessel constructed of heavy concrete. The triangular shaped bottom is sloped gradually from the vessel perimeter to where the central leachate collection pipe is located, forming a trench which crosses the BF. The system has a maximum depth of 7’ 30” in the trench and a minimum of 7’ depth in the vessel perimeter.

The entire bottom slab and sump of the vessel are coated with a high density polyethylene liner. The sump is a concrete box added to one side of the vessel structure for collection of the leachate.

A brick wall divides the vessel into two identical left and right sides. This wall is made of 8” concrete blocks and provides the anchors to prevent floating of the air piping.

A part of the BF cylindrical vessel is occupied by a 31’ long, 6’ wide and 9’ deep damper vault. This box contains connections of the main pipes of the air distribution system, two pitot tubes for air flow measurement, and the main valves and piping of the moisture control system.

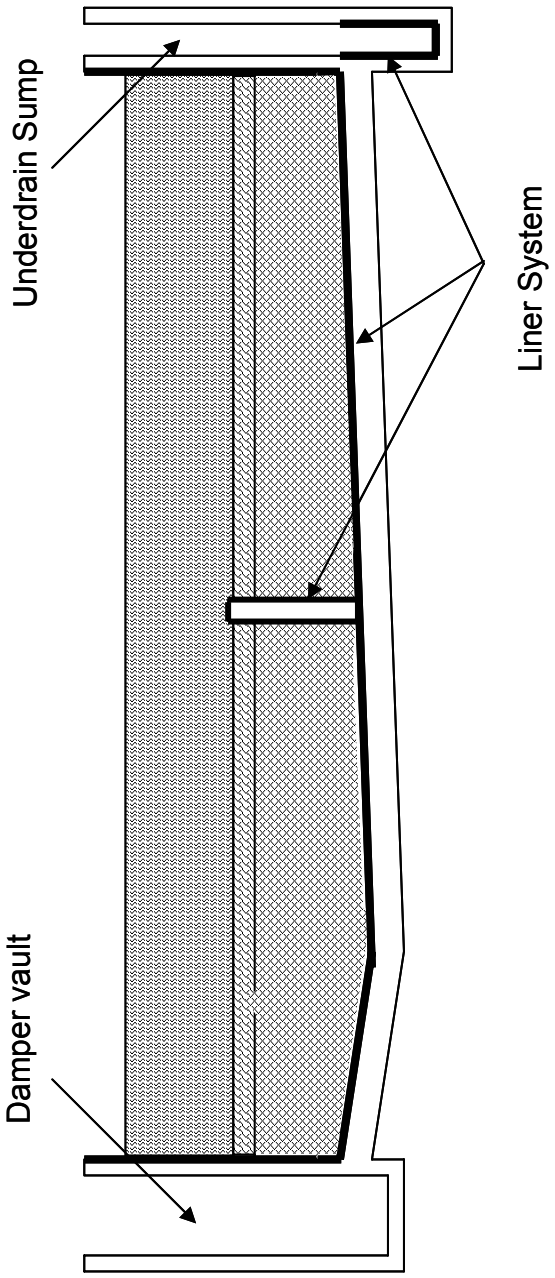


Figure 1. Biofilter Vessel and Liner Systems

2.2. Air Distribution System

Air is drawn from headworks and primary clarifiers by two blowers. The contaminated air is distributed upward through the filter material. Hoods and the unburied fragment of the 30” ducting from headworks and primary clarifiers to the BF are constructed of fiberglass reinforced with corrosion resistant, epoxy vinyl ester resin.

The buried polypropylene ducting is sloped until it reaches the air distribution zone level at the bottom of the BF. The air distribution zone consists of a 30” layer of 4” diameter rocks topped by a 6” layer of ¾” diameter rocks, and a coarse geotextile fabric spread on its top.

The main 30” ducting is divided into two perpendicular 24” polypropylene pipes. A set of 8” polypropylene pipes spaced 4’ are connected perpendicularly to the two 24” polypropylene pipes. These perforated 8” polypropylene pipes distribute the air through the circular area of the BF.

2.3. Media System

Wood bark is used as the media for the BF. The common particle sizes are 1 to 3”. It occupies 36” depth and an approximated volume of 1,718 m^3. The organic material has enough nutrient supply for the indigenous microbial population.

Because hydrogen sulfide is an acidic forming contaminant, initial preparation of the wood bark required the addition of sea shells to neutralize the acid. The media preparation will be required every time media is replaced.

A list of Louisiana wood chips suppliers is given in order to help you finding the BF media.

Table 1. Louisiana Wood Chips Suppliers

Supplier	Phone #	City	State	Zip Code	Address
L.L. Brewton Lumber Co.	318-628-4694	WINNFIELD	LA	71483	207 Thomas Mill Road
Dobson Pulpwood Co. Inc.	318-476-3338	CAMPTI	LA	71411	Hwy 480, 3 mi W
Georgia-Pacific Corp.	225-492-3435	LETTSWORTH	LA	70753	17969 La Highway 418
Kentwood Chips Inc.	504-536-8899	KENTWOOD	LA	70444	76220 Highway 51
Kisatchie Chips Inc.	318-354-1800	NATCHITOCHES	LA	71411	5690 Highway 486
Majestic Woodchip	504-536-8899	RESERVE	LA	70084	PO BOX 511
Malone Lumber Inc.	337-825-8624	MERRYVILLE	LA	70653	7019 Division St
Martin Forest Products Inc.	318-628-4191	WINNFIELD	LA	71483	7369 Highway 167 S
Anthony Forest Products Co.	318-326-5812	PLAIN DEALING	LA	71064	1003 Highway 3 N

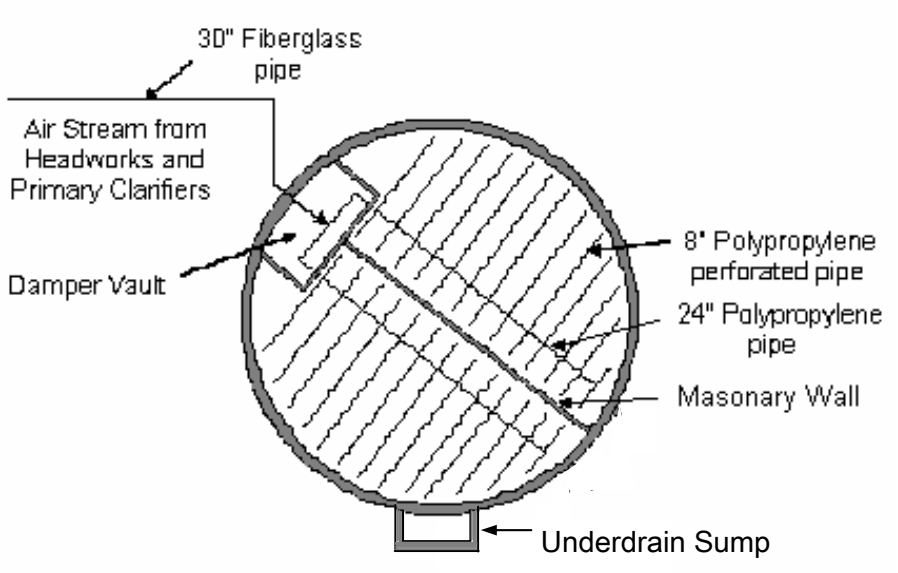


Figure 2. Biofilter Vessel and Air Distribution Systems Plan View

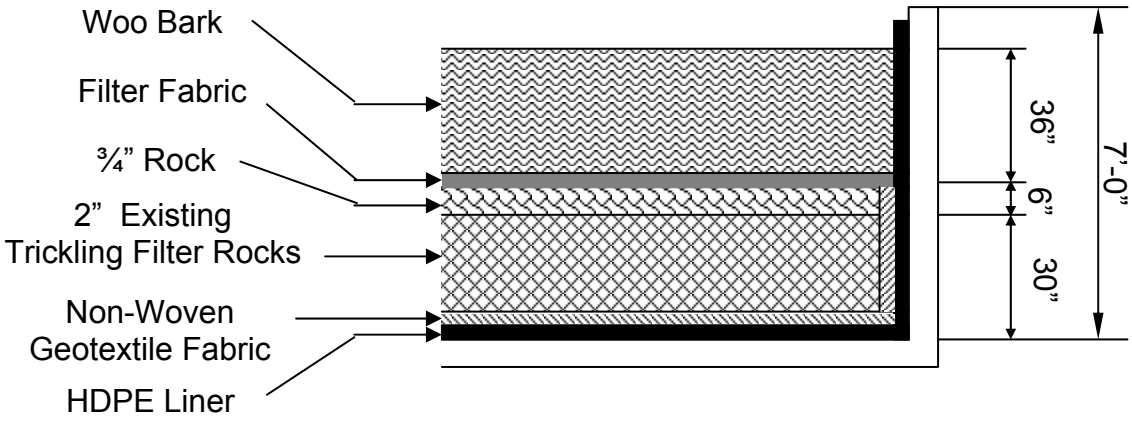


Figure 3. Media System in the Biofilter

2.4. Moisture Control System

The moisture Control system uses a humidification system and an automatic irrigation system to provide moisture to the media.

2.4.1. The Irrigation Control System

The irrigation system is controlled by a timer. It uses four sprinklers to spray potable water over the entire surface of the media. Water is pumped through two ½" diameter steel pipes. Inside the BF the water flows through the PVC piping along the masonry wall 12" bellow the top of the ¾" stone cap. Finally, water is delivered to each pressure compensated sprinkler head.

Irrigation Schedule:

For 10 minutes the surface is irrigated by two of the sprinklers, alternating with the other two every half an hour continuously. The sprinklers are located in the central area of the BF.

2.4.2. The Humidification Control System

In the damper vault, a spray humidification device is placed inside the 30" diameter main pipe for humidification of the incoming air. It consists of three ½" diameter pipes with ball valves (control valves) which end in 1/8" diameter helix nozzles. The three pipes are introduced perpendicularly into the main pipe and are spaced 4" from each other. Water is sprayed in the form of fine water drops and a relative humidity near 100% of the air stream is achieved.

2.5. Leachate Collection System

Excess water in the media is presented usually when irrigation is overdone, when condensation from the input air is heavy, or when there is rain on the open BF. The leachate collection system was design to collect the excess water and discharge it to the influent wastewater of the plant for treatment.

Liquid is moved downward through the media, geotextile fabric, and the two layers of rocks under the force of gravity. Six aligned 8” diameter orifices at the bottom liner are crossed by the liquid. These orifices are met by six 8” diameter hub strainers of 1” diameter openings. The strainers cover 8” vertical pipes connected in a “T” to an 8” diameter pipe.

The 8-in collection pipe is open to the atmosphere at both ends and is located inside a concrete encasement. The concrete encasement is a rectangular box aligned along the vertex of the bottom of the BF. The dimensions are 2’ wide, 96’ long, and from 2’ high in one end and 2’ and 6” high at the opposite end. The maximum height is reached at the underdrain sump end. The other end of the pipe empties into a small concrete box located next to the concrete vessel. The box has a drilled opening to prevent an increase in the pressure. In this way, the leachate flows by gravity inside the pipe.

Empty spaces in the encasement were filled with concrete. The leachate drained falls into the underdrain sump where it is collected. Finally, by level control, the liquid is automatically pumped to headworks.

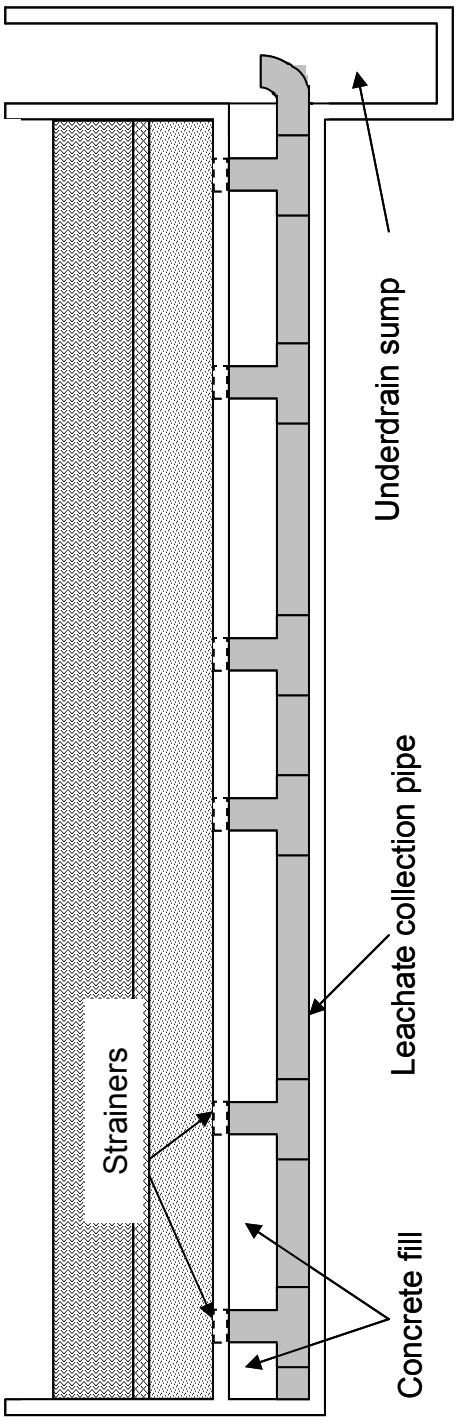


Figure 4. Leachate Collection System Cross View

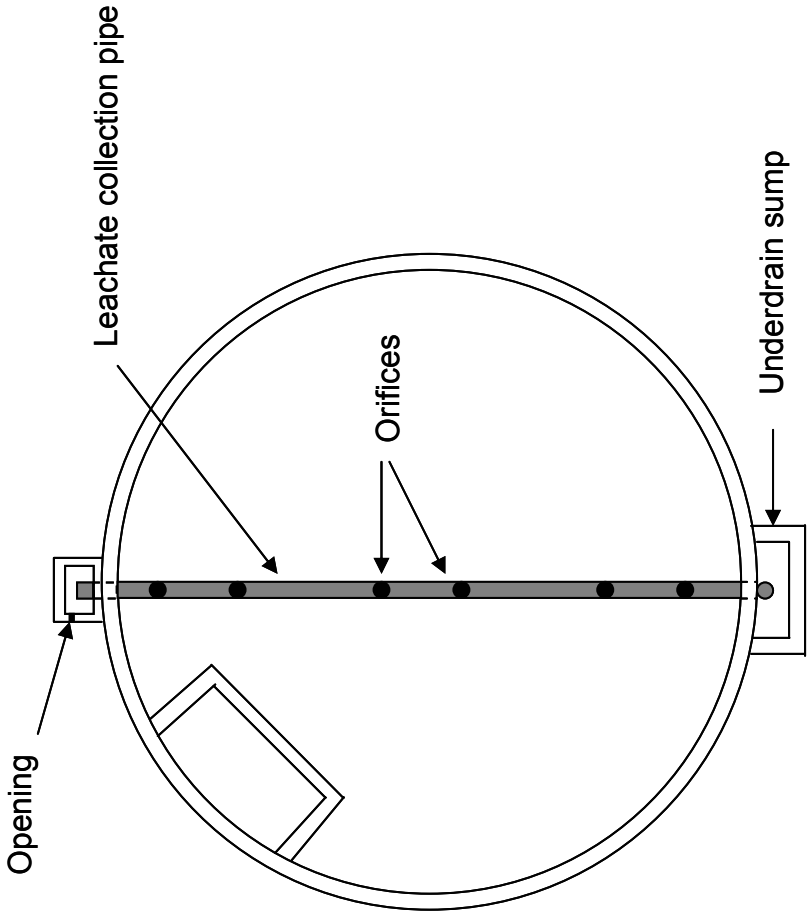


Figure 5. Leachate Collection System Plan View

2.6. Electrical System

2.6.1. Blowers

Two blowers are used to extract the waste gases from the headworks and the two primary clarifiers.

2.6.2. Pumps

Two identical centrifugal pumps are used to send the leachate to headworks and discharge it into the raw water stream.

Energy consumption of the BF is not constant in time. Due to exposition of the BF to non controlled ambient conditions, the consumption of electricity is increased on rainy days and during the fall when ambient temperatures are low and activity of microorganisms is reduced.

Table 2. Electrical Equipment Specifications

Equipment	Quantity	Voltage (VAC)	Current (Amp)	RPM	Motor size (Hp)	Frequency (Hz)
Blower	2	230/460	47.0/23.5	1760	20	60
Centrifugal Pump	2	230/460	13.0/6.5	1730	5	-

2.7. Control System

The BF consists of two control systems:

2.7.1. The Moisture Control System

The moisture control system controls the irrigation of media and humidification of the inlet air. This system is equipped with a control panel where the length of time that the irrigation discharges water onto the media can be set up and controlled. The in-line flow devices that are used for this purpose are: two rotameters, two gate valves, four globe valves (control valves), and a by pass arrangement for alternation of the sprinklers.

The flow of water used to humidify the incoming waste gas is also regulated by this control system. A rotameter, a globe valve, and three ball valves (control valves) provide a constant flow of water to be sprayed at any time.

2.7.2. The Level Control System

The level control system is used for control of the leachate volume in the underdrain sump. In the control panel the system has two indications: high level and low level. An alarm warning high level is turned on if it is reached by the leachate inside the underdrain sump.

The level control system consists of two devices called float switches inside the underdrain sump, one for each indication, which have ON and OFF positions. Once the level of leachate reaches the floats, they obtain the ON position and pumps start suctioning the leachate and pumping it to headworks.

3. SYSTEM OPERATION AND MAINTENANCE

Operations and maintenance procedures for the high-performance biofiltration system include routine inspection, gas treatment system maintenance, filter bed maintenance, and repairing or replacing failed components. These procedures are briefly reviewed here.

3.1. System Maintenance Activities

3.1.1. Visual Inspection

Generally, any significant operating problem that may affect the treatment performance will be visually evident.

All system functions should be checked periodically to verify that everything is working as required and to determine the need for executing the various maintenance procedures. This includes the following sections:

- Checking the irrigation cycle of the filter media
- Verifying that alarms work as required
- Observing condition of the filter media
- Examine condition of the structure.

A. CHECKING THE IRRIGATION CYCLE

- Observe whether the pump turns on and off when the timer “makes” and “breaks”. If not turning on and off, check the pump. If pump seems to be in good conditions, check the timer in the moisture control panel. If timer is not working properly, its replacement will be required.
- Pay attention to the pump noise since it starts. If noise is different from typical, check the pump.

- Observe the spray pattern. If it is abnormal, the nozzles head is clogged and should be cleaned. The required procedure would vary with the type of head used.

Suggested frequency: once a week.

B. CHECKING THE LEACHATE LEVEL ALARMS

Observe the operation of pumps, floats, electrical controls, and alarm.

- Check the high level alarm: with switch in high position lift the float to observe if the alarm activates. If alarm does not activate, technical assistant for its reparation will be required.
- Check the low level alarm: with switch in low position lift the float to observe if the alarm activates. If alarm does not activate, technical assistant for its reparation will be required.
- Watch and listen for activation of the pump by the control float switch. If noise is different from typical, check the pump.

Suggested frequency: twice a month.

C. CHECKING THE FILTER MEDIA CONDITION

- If accumulation of water is observed on the filter bed, or if water remains accumulated on its surface for more than a half minute or so during the normal operation of the BF, this indicates that the bed is clogged. Replacement of the media is needed. If the clogging condition is the result of a rainy day (altered operation), go to the control panel and turn off the irrigation system for one day or two as required.
- Observe any vegetative growth on the media surface, they must be removed periodically.

- Check moisture characteristics of the media. If it looks dry, verify that irrigation system is working properly by performing steps in Section A.

Suggested frequency: twice a week.

D. CHECKING THE STRUTURE CONDITION

- Look at the BF vessel routinely to detect damage such as cracks, breaks, or deterioration, leakage, indicating loss of impermeability.

In the damper vault:

- Keep the location accessible.
- Remove any accumulated solids and vegetative growth on the floor, pipes, valves, etc. as needed. Open and close the valves of the irrigation system to clear any accumulated debris and check the function.
- Check the physical integrity of the pipe network. Detect any leakages at the unions or deteriorations such as corrosion and breaks. If pipes, fittings, or any valve are in precarious damage replace them.

In the underdrain sump:

- Check the floats condition as recommended in section B. If the floats system is very rusted or present any damage, technical assistant for its reparation will be required.
- Remove the accumulated mud and rust from the liner system and walls of the underdrain sump. Every time replacement of the filter media is carried out, the underdrain sump will be empty and cleaning can be performed.
- Check the liner condition. You want to prevent the leachate percolating within the concrete walls. If finding any holes or unstuck zones, fix or replace liner as needed.

Suggested frequency: once a month.

Check other mechanical and electrical components

In addition to what you have already noted and recorded, you will also want to do the following:

1) Control panels must comply with the National Electrical Code (NEC) NFPA 70-90.7 and OSHA requirements in Title 29 Code of Federal Regulations Part 1910. The requirements help to protect workers by ensuring products that are designed for safe use in the workplace. Verify that your manufacturer is providing you a Nationally Recognized Testing Laboratory (NRTL) certified control panel. Also, remember that you can be visited by an OSHA compliance officer for a workplace inspection and your control panel must comply with the OSHA Safety Standards. Therefore:

2) Make sure all indicator lights and toggle switches function on the control panel and that conduits are sealed (preventing gases from entering the box). If using piggyback plugs, look for corrosion, overheating, bent or broken plugs and any other damages. Remove dirty and rust. If reparation of lights, switches, or plugs is required, call an appropriate technician required for the job and NEC regulations.

3) Electrical circuitry and components must be labeled, with all cables and switches in their right place and order. Check regularly for good operation and maintain it as needed.

4) Keep secure, stable, and protected the control panels. Allow access to them only to authorized personnel and prevent public access.

5) Check pumps and blowers to see that they are firmly seated. Look for abnormal vibrations, excessive noise, overheating or loose parts. These equipments must be adjusted and checked for misalignment, clearances, supports, and adherence to safety standards. By identifying these problems

before failure, and most importantly, determining the causal factors, the inherent problems with these machines can be corrected to ensure their long-term trouble-free operation. A pump trouble analysis guide is provided in order to take a fast and corrective action:

Pumps Service Manual & Troubleshooting Guide

COMPLAINT	POSSIBLE CAUSE	RECOMMENDED ACTION
No circulation	1. Set screw not tight, coupler loose on shaft 2. Impeller slipping on shaft 3. Air-bound system 4. Air-bound pump 5. Broken pump coupler 6. Clogged impeller on piping 7. System valve closed 8. Pump electrical circuit broken	1. Tighten set screw in recess in the shaft 2. Check to see if impeller is placed on the key way of the shaft. Tighten impeller nut 3. Vent system 4. Vent pump casing 5. Replace; check alignment 6. Locate and remove obstruction 7. Open 8. Check all related low and line voltage circuits
Inadequate circulation	9. Air-bound system 10. Air-bound pump 11. Clogged impeller or piping 12. Clogged strainer 13. Pump impeller damaged 14. Insufficient NPSH (Net Positive Suction Head) 15. Pump too small 16. Partially air-bound pump 17. Pump running backwards (three phase) 18. Improper motor speed	9. Vent system 10. Vent pump casing 11. Locate and remove obstruction 12. Remove and clean screen 13. Replace 14. Lower pump or raise pressure or relocate 15. Replace pump or impeller 16. Vent pump casing 17. Reverse any two motor leads 18. Check wiring and voltage
Pump or system noise	19. Entrained air 20. Pump cavitation 21. Pump misalignment 22. Worn pump coupler 23. Excessive water velocity 24. Poor foundation (base-mounted) 25. Pipe vibration	19. Vent system 20. Lower pump or raise pressure or relocate (See note) 21. Re-align pump 22. Replace; check alignment 23. Install balancing cocks or parallel piping 24. Provide rigid foundation with adequate grouting 25. Provide adequate pipe support

Premature failure of pump components	26. Improper pump (size) (type) 27. Improper pump location 28. Pump misalignment 29. Excessive water treatment 30. Over-oiling of pump 31. Under-oiling 32. Pump operating close to or beyond end point of curve 33. Excessive piping load	26. Replace 27. Relocate 28. Re-align 29. Check manufacturer's instructions 30. Check manufacturer's instructions 31. Check manufacturer's instructions 32. Balance system 33. Provide proper pipe support
Seal failures within 1 year period or less in a closed system	34. Excessive dirt, sand and oxides 35. Excessive or improper water treatment 36. Pump Cavitation: **A.** Improper selection **B.** Compression tank location 37. Air-seal without lubricant (water) 38. Excessive temperatures 39. Pumps run without fluid	34. Clean system 35. Check for proper water treatment recommendations from pump manufacturer 36. **A.** Check pump operation on its curve-overloading **B.** High head pump must have compression tank on suction side of pump 37. Vent air from pump volute 38. Check type of seal and maximum operating temperature from manufacturer 39. Pumps must be primed before operation
Seal Pitting - Oxygen corrosion - Magnetic iron oxide	40. Caused by wear and excessive amounts of free oxygen	40. Check if system has a constant lead. Fresh water feeding carries oxygen into the system

NOTE: Cavitation can be recognized by low rumbling or sharp rattling noises. The situation is created by the lack of available net positive suction head (NPSH). The pressure at some point in the pump falls below the vapor pressure of the water, causing flashing and the formation of bubbles, which are carried into the volute where the higher pressure causes them to implode. This can eventually destroy the pump.

The table presented below indicates possible areas to check when air or sound values of the blowers do not match expectations. Most blower problems can be identified to one of these common causes.

Blowers Service Manual & Troubleshooting Guide

COMPLAINT	POSSIBLE CAUSE	RECOMMENDED ACTION
No Air Flow	1. Speed too low 2. Wrong rotation 3. Obstruction in piping	1. Check by tachometer and compare with the design speed 2. Change rotation direction 3. Check piping, screen, valves, and silencer. Check valve to assure an open flow path
Low capacity	4. Speed too low 5. Excessive pressure 6. Obstruction in piping 7. Excessive slip	4. See item 1. If belt drive, check for slippage and readjust tension 5. Check inlet vacuum and discharge pressure and compare these figures with the operating conditions on your order 6. See item 3 7. Check inside of casing for worn or eroded surfaces causing excessive clearances. The discharge temperature will usually be much higher than before the clearances opened up
Excessive power	8. Speed too high 9. Pressure too high 10. Impellers rubbing	8. Check speed and compare to your order 9. See item 3 10. Inspect outside of cylinder and headplates for high temperature areas, and then check for impeller contacts at these points. Correct blower mounting and drive alignment. High temperature areas can usually be identified by discolored or burned paint
Overheating of Bearings or Gears	11. Inadequate lubrication 12. Excessive lubrication 13. Excessive Pressure Rise 14. Coupling misalignment 15. Excessive belt tension 16. Speed to low	11. Restore correct oil levels in gearbox and lubricate drive end 12. Check gear oil level. If incorrect, drain and refill with clean oil of recommended grade 13. See item 3 14. Check carefully. Realign if questionable 15. Readjust to correct tension 16. Speeds lower than the minimum (in conjunction with a particular pressure or vacuum) will overheat the entire blower

Vibration	17. Misalignment 18. Impellers rubbing 19. Worn bearings or gears 20. Unbalanced or rubbing impellers 21. Driver or blower loose 22. Piping resonances 23. Base excitation 24. Excessive load by accessory items	17. See item 14 18. See item 10 19. Check gear backlash and condition of bearings 20. Scale or process material may build up on the casing and impellers, or inside the impellers. Remove build up to restore original clearances and impeller balance 21. Tighten mounting bolts securely 22. Determine whether standing wave pressure pulsations are present in the piping. Refer to a sales office for further support 23. Determine if the base is being excited while the blower operates. The base natural frequency may correspond to the frequency of the blower. Change the base characteristics by bracing a board under a supporting member to see if this dampens the vibration. Additional reinforcement or mass may be required to prevent excitation 24. Silencers, filters and piping may be improperly isolated from the blower or may be supported by the blower. Use expansion joints or flexible connectors are required

6) Stay on top of the system, note the small problems and correct them early before they become major, and keep good records of what you do.

3.1.2. System Evaluation

Regular measurements need to be made of:

A. The hydrogen sulfide concentration
B. The media characteristics
C. Leachate pH

These measurements and calculations need to be recorded on the Normal Operation Check List form so that the performance of the BF can be evaluated over time. This provides you, the operator, with specific information to help properly maintain the system. Next, the testing procedures are provided.

A. Hydrogen Sulfide Measuring Procedure

Measurement of the hydrogen sulfide concentration would help the operator to evaluate the performance and efficiency of the unit.

The concentration of hydrogen sulfide present in the inlet air streams is measured using Draeger or Gastec Tubes. These tubes are glass vials filled with a chemical reagent that reacts to a specific pollutant. A calibrated 100 ml sample of air is drawn through the tube using the corresponding pump. If the targeted chemical (in this case H_2S) is present, the reagent in the tube changes color instantaneously and the concentration of the contaminant is read directly from the calibrated scale by assessing the length of the discoloration.

Sampling points:

1. Inlet air stream: 1” diameter hole with a rubber stopper in the 30” diameter ducting.
2. Outlet air stream: five pipes of 6” diameter and 1’ length located on top of the BF.

Recommended tubes detection ranges to use:

Sampling point	Hydrogen Sulfide Concentration Range (ppm)	
	Draeger Tubes	Gastec Tubes
Inlet air stream	1-200 1-60 0.5-15	0.25-120 1-40 ------
Outlet air stream	0.2-5	0.1-4

Tubes offer a +/- 10% standard deviation on the results.

Tubes storage recommendations:

Store tubes out of direct sunlight and at a temperature of less than 25°C (77°F). Any temperature-controlled office meets these conditions.

Step-by-step procedures for measuring the hydrogen sulfide concentration in the biofilter

- Familiarize yourself with the system
- Initially, you should be provided of some educating assistance. Acquaint yourself with the system and carry any system information and past data to the field for review if needed

H_2S inlet concentration measurement

- Use a tube of high concentration range. See the previous table for assistance
- Remove ends from the tube using the pump device for such a purpose
- Insert the tube in the pump. Check that you are inserting the right end
- Remove the rubber stopper from the BF 30” ducting and introduce the tube in the opening
- Make an stroke (drawn the air into the tube) following the instructions of the tubes and pump manufacturer you are using
- Keep the tube end inside the ducting opening for approximately 20 seconds. Then, remove the tube from the opening and pump
- Read the value on the scale where the color of content changes
- If not color change is observed, select a new tube with a lower detection range and repeat procedure

H_2S outlet concentration measurement

- Use the lower concentration range tube. See the previous table for assistance
- Remove ends from the tube using the pump device for such a purpose
- Insert the tube in the pump. Check that you are inserting the right end
- Remove a pipe cap and introduce the tube in the pipe
- Make an stroke (drawn the air into the tube) following the instructions of tubes and pump manufacturer you are using
- Keep the tube end inside the pipe for approximately 20 seconds

- Without substitution of the tube, remove the next pipe cap, introduce the tube, and make an stroke
- Repeat this procedure in the rest of the pipes (sampling points) without substitution of the tube
- Remove the tube from the pump after sampling in the five pipes
- Read the value on the scale where the color of content changes and divide this value by five
- If not color change is observed, concentration of H_2S is under detection limit and it can not be measured with the tubes
- The lower the H_2S outlet concentration, the better performance of the BF. If the H_2S is not detected, your system is working better than ever

B. Media Sampling and Measuring Procedures

Sampling and analysis of the wood bark (filter media) would help the operator to evaluate the condition of this gas treatment unit.

Step-by-step procedures for a site visit at the media system

- Familiarize yourself with the system
- Initially, you should be provided of some educating assistance. Acquaint yourself with the system and carry any system information and past data to the field for review if needed

Media pH and moisture content measurement

1. MEDIA pH:

The pH is a parameter that provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, <7 is acidic, and >7 is basic).

To calculate the media pH, will be needed:

- A pH meter (and a 250 ml glass beaker, magnetic stirrer, and a magnetic bar) or pH paper
- A bottle or bag for media collection

PROCEDURE:

- Dig holes with a shovel in different areas on top of the BF and take media particles from at least 8” deep
- Place particles in a clean bag or bottle and take them to the laboratory for analysis

Two methods can be used for pH measurement:

1. pH paper

- Saturate (wet) media particle (wood chip) with distilled water

- Break the particle and put pH paper in contact with an interior zone of the particle
- Follow the instructions of the pH paper manufacturer to provide a pH value according to the paper color change
- Check pH values, they should range between 2 and 5

2. pH meter

- Weight 10 g of sample previously dried in the oven at 104°C for 24 hours
- Place sample into a 250 ml glass beaker
- Add 20 ml of distilled water
- Agitate for 30 min using a magnetic stirrer and magnetic bar
- Determined pH using a calibrated pH meter
- Check pH values, they should range between 2 and 5

2. MEDIA MOISTURE CONTENT:

Consist in measure the particle weight loss after removal of water.

To calculate the media moisture content, will be needed:

- An oven with high temperature capacity
- An analytic balance
- A desiccator
- Crucibles

PROCEDURE:

- Dig holes with a shovel in different areas on top of the BF and take media particles from at least 8” deep
- Place particles in a clean bag or bottle and take them to the laboratory for analysis
- Identify with numbers every crucible
- Weight an empty crucible and calibrate balance in zero
- Place particles in crucibles and weight every sample

- Place samples in the oven and dry at 104°C for 24 to 48 hours
- Remove samples from the oven, cool in a desiccator and weight them again
- Use next equation for the moisture content calculation:

$$\%Moisture = \frac{P_1 - P_2}{P_1} \times 100$$

where:

P_1= wet media sample weight, and

P_2= dry media sample weight.

- Check the percent moisture value. Generally, moisture content ranges from 40-70%. If moisture is higher, media has more water than needed and this contributes to a faster compaction process of the BF media. In this case, turn off the irrigation system for one day

C. Leachate Sampling and Measuring Procedure

Sampling and analysis of the liquid drained from the BF (leachate) also would help the operator evaluate the condition of the gas treatment unit.

Leachate pH measurement

Sampling points:

- leachate collection pipe
- underdrain sump

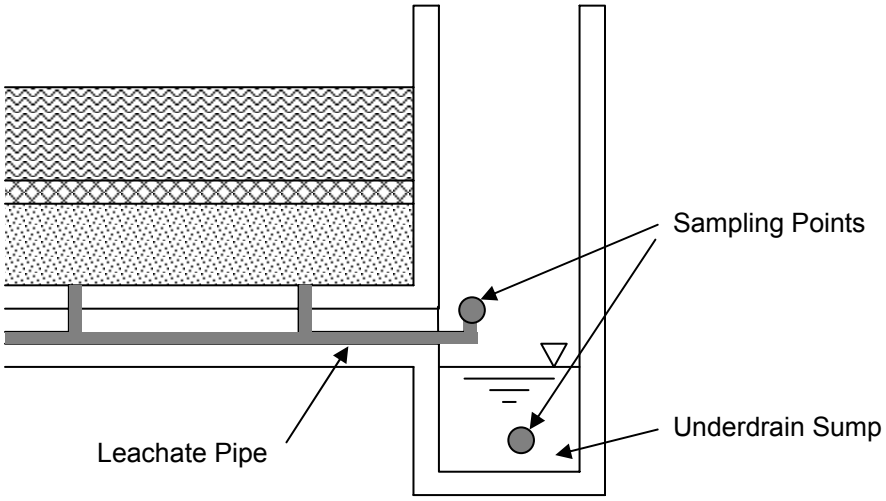


Figure 6. Leachate Collection Points of the Biofilter

PROCEDURE:

- Use clean bottles to take samples of the liquid collected in the underdrain sump and of the liquid going out of the leachate collection pipe
- Ensure the samples volume is representative
- Measure the pH with a calibrated pH meter in the laboratory
- Check pH values. Leachate from collection pipe should have pH values between 2 and 4. Leachate from underdrain sump might have pH values from 5 to neutral (7)

4. SAFETY

Operators should understand the possible safety hazards they may encounter. They also must practice good personal hygiene, avoid personal injury, know the basics of first aid, and understand proper safety approaches in open and confined spaces.

Special safety must be taken when performing the underdrain sump and damper vault inspection and clean-up. The operator must also plan for dealing with the wood bark. There is not safety hazards associated with the media handling. However, the use of gloves is recommended.

5. NORMAL OPERATION CHECK LIST

The following items should be checked and recorded

BIOFILTER OPERATING LOG DATA SHEET					
No.	Description	Date	Date	Date	Date
1	Operator				
2	Test Time, Start				
3	Test Time, Stop				
4	H_2S Concentration, Inlet				
5	H_2S Concentration, Outlet				
6	Media pH, Sample 1				
	Media pH, Sample 2				
	Media pH, Sample 3				
	Media pH, Sample 4				
7	Media % Moisture, Sample 1				
	Media % Moisture, Sample 2				
	Media % Moisture, Sample 3				
	Media % Moisture, Sample 4				
8	Leachate pH, Collection pipe				
9	Leachate pH, Underdrain sump				
10	Visual Inspection performed? (Y/N)				
11					
12					
13					
14					
Notes/Remarks					

APPENDIX G

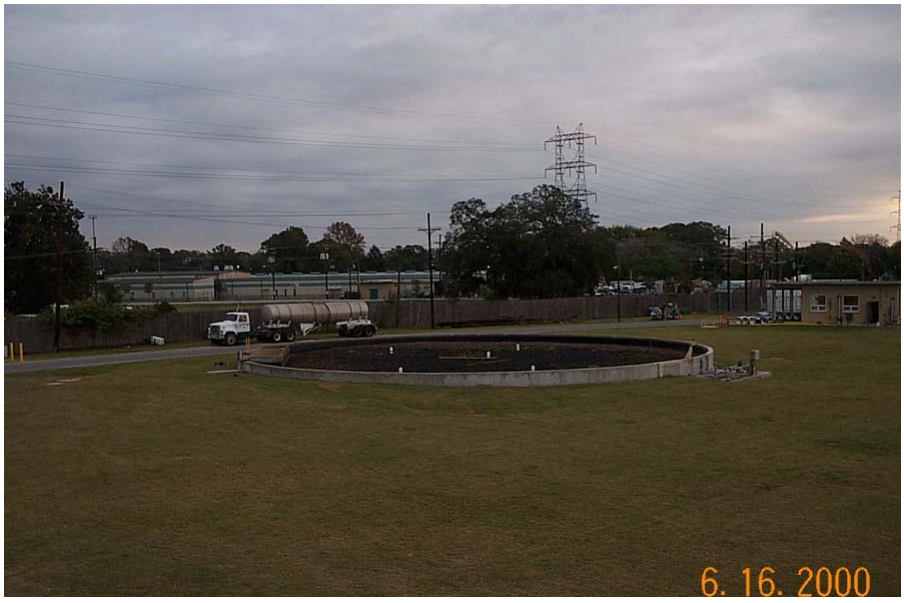
Photographic Journal

Picture 1: Headworks Foul Air Ducting

Picture 2: Primary Clarifier 1 Foul Air Ducting

Picture 3: Primary Clarifier 2 Foul Air Ducting

Picture 4: Biofilter Inlet Sample Port



Picture 5: Biofilter Outlet Sample Ports

Picture 6: H_2S Outlet Concentration Measurement

Picture 7: Inlet Air Stream Velocity and Temperature Measurements

Picture 8: Media Collection

Picture 9: Leachate Sampling

Picture 10: Leachate Collection

Picture 11: Irrigation Control System

Picture 12: Irrigation Piping and Foul Air Biofilter Inlet

Picture 13: Leachate Level Control System

Picture 14: Leachate Level Control

VITA

The author was born Vivian Bermudez to Roger and Teresa Bermudez on September 6, 1976 in Maracaibo, Venezuela. She graduated from “Colegio Nuestra Señora del Pilar” High School of Maracaibo in 1993. In July of 2000, after six years of undergraduate coursework, she received a Bachelor of Science degree in Chemical Engineering from “Universidad del Zulia”, Venezuela. The author entered the graduate program at University of New Orleans in August, 2002 and conducted a research on the biofiltration of waste gases until December, 2003. On December 19, 2003, she received a Master of Science in Environmental Engineering from the University of New Orleans, New Orleans, LA. She graduated with an overall GPA of 3.6.

UNIVERSITY OF NEW ORLEANS

MASTER'S EXAMINATION REPORT
Thesis

CANDIDATE: Vivian Bermúdez

MAJOR PROGRAM: Environmental Engineering

TITLE OF THESIS: Biofiltration for Control of H_2S from Wastewater Treatment Plant Gases

APPROVED

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DATE OF EXAMINATION:

11/17/2003