THE IMPACT OF LIME DOSAGE ON ODOR REDUCTION OF BIOSOLIDS

by

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Abstract

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The amount of boisolids production is increasing due to developing cities and the mitigation of biosolids odorants is a key role to have a successful biosolids land application program. The objective of this study is to investigate the effect of lime stabilization on odor reduction of bio-solids and determine the optimum percentage of lime for each major odor compound and the overall target lime dose in terms of priority and importance of odorants. the Village Creek Water Reclamation Facility (VCWRF) was chosen to supply limed dewatered solids because of having complaints about the odor of biosolids in neighborhood. 5%, 10%, 10%, and 14% lime dosage were respectively identified are the most appropriate lime dose for Carbon disulfide, Dimethyl sulfide, Dimethyl disulfide, and ammonia. Biosolids with 10% lime addition is also identified as the most appropriate lime dose for maximum odor reduction of biosolids in summertime.

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CHAPTER 1

INTRODUCTION

1.1 Background

The reduction or elimination of odor compounds is an important factor to have a successful biosolids land application program. For this study, the Village Creek Water Reclamation Facility (VCWRF), located in Fort Worth northwest of Arlington, TX, was chosen to supply limed dewatered solids. VCWRF is noted for having complaints about the odor of biosolids in neighborhood, mostly during summertime and warm weather. Bio-solids processing has multiple parts. By operating gravity belt thickeners, primary sludge is thickened, and the waste activated sludge from the final clarifiers is concentrated by using dissolved air floatation. In the next step, the sludge is digested anaerobically in digesters with retention time of 20 days approximately, and the methane gas, which is a good renewable source for generating electricity, is produced during anaerobic digestion. Digested solids are transferred through the pumps to the bio-solids facility, which is located about a mile northeast of VCWRF. Adding polymer at the bio-solids facility dewaters the sludge. After using belt filter presses for dewatering the sludge, lime is used to adjust the pH to satisfy regulatory requirements for pathogen control. At the end, bio-solids are transported to land application sites after a day accumulation onsite.

According to City of Fort Worth data, the highest number of odor complaints start from May, with a significant reduction in August due to amount of water treatment plant (WTP) residual discharges to VCWRF. Based on the City databases since 2003, the frequency of odor complaints is also increasing during the last few years because of development in the residential, commercial, and industrial areas that feed to the plant, with a consequential increase in WTP residual discharges. Previous sampling occurred during winter by VCWRF from September 2013 to January 2014; however, odors often are greatest in summer, due to compound volatility increasing with temperature. Hence, the summertime sampling proposed in this research is particularly important.

Lime stabilization is used to treat dewatered solids from municipal wastewater treatment plants, and bio-solids can be beneficially recycled as a soil amendment at local farms. Biosolids stabilized with lime may generate offensive odors, which mainly contain ammonia, amines, and reduced sulfides. On the other hand, although lime addition produces odors, it can also reduce odors, if applied at an optimal dose. According to previous researches, lime addition is more effective than other methods in controlling biosolids odor production, and the concentration of odor compounds in bio-solids such as ammonia, amines, and reduced sulfides is correlated with lime dose. On the other hand, previous tests have shown that higher lime doses may not necessarily reduce odor compounds in biosolids and would not be a good alternative in terms of human health and economics. In other words, there exists optimal lime dose(s) that minimize odor production (Erdal et al., 2004; Murth et al., 2001).

1.2 Typical Odorants in Wastewater and Biosolids

According to the Environmental Protection Agency's (EPA's) *Guide to Field Storage of Biosolids* and Water Environment Federation's (WEF's) *Odor Control in Wastewater Treatment Plants* Manual, some typical wastewater and biosolids odorants are listed in Table 1.1, including the compound name, formula, detection threshold, recognition threshold, and odor description.

Offensive odors from land-applied biosolids should be managed and controlled to avoid public opposition to biosolid land application programs. .

Table 1.1 Typical Odors in Wastewater and Biosolids (AIHA, 1989; Moore et al., 1983; and Sullivan, 1969; Ruth, 1986)

Odor Compound Name	**Formula**	**Detection Threshold Limit (ppm)**	**Recognition Threshold Limit (ppm)**	**Odor Description**
Hydrogen Sulfide	H_2S	0.0005	0.0047	Rotten Eggs
Dimethyl Sulfide	$(CH_3)_2S$	0.001	0.001	Decayed Cabbage
Dimethyl disulfide	$(CH_3)_2S_2$	0.001	----	Decayed Vegetable
Ethyl mercaptan	C_2H_5SH	0.0003	0.001	Decayed Cabbage
Methyl mercaptan	CH_3SH	0.0005	0.001	Rotten Cabbage
Propyl mercaptan	C_3H_7SH	0.0005	0.02	Unpleasant
Carbon disulfide	CS_2	0.1 - 0.21	0.21	Disagreeable Sweet
Ammonia	NH_3	17.0	37.0	Sharp, Ammoniacal

Moreover, some biosolids odorants may cause negatively impacts on human health. Although there are insufficient reports about negative impacts of biosolids odorants on environment and human health (Toffey, 1999), inhalation of high concentration of biosolids odors may cause some issues in human health. Some negative impacts of biosolids odorants on human health in this study are listed in Table 1.2.

Table 1.2 Negative Human Health Effects Cause by Biosolids Odorants (Department of Health, 2004; EPA, 1992; Weiss et al, 1979; EPA, 2012)

Carbon Disulfide	**Dimethyl Sulfide**	**Dimethyl Disulfide**	**Ammonia**
Acute inhalation causes in breathing, chest pain, and Eye and Skin irritation Dizziness. Nausea. Fatigue. Headache. Lethargy. Blurred vision. Delirium. Convulsions. Neurologic effects. Decrease sperm. Menstrual issues	Respiratory tract. Irritation of eye. Damage lungs and liver. Kidney and heart disturbance. Skin annoyance. Tumar observed in nasal passage, lungs, and thorax.	Skin irritation. Eye irritation. Respiratory tract. Damage central nervous system.	Not poisonous. High conc. causes burning nose throat. Respiratory tract. Eye and skin irritation in high conc. Contact with ammonia causes frostbit injury.

1.3 Research Goal and Objectives

The overall goal of this study is to investigate the effect of lime stabilization on odor reduction of bio-solids. This will provide useful information for any wastewater treatment plant facing biosolids odor issues due to lime addition, and in particular will allow the bio-solids handling contractor for Village Creek to reduce odor emissions at the beneficial use sites. Specific study objectives include:

1. Determine the optimum percentage of lime for each odor compound detected (carbon disulfide, dimethyl sulfide, and dimethyl disulfide, and ammonia), via sampling during summer months when compounds tend to be most volatile;
2. Determine the overall target lime dose in terms of priority and importance of odorants. This is particularly important because there tends to be an inverse relationship between reduction of ammonia and reduced sulfides.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

2.1.1 Biosolids

The organic materials removed during treatment in WWTP are called produced sludge, or more recently biosolids. After stabilization, biosolids can be used as fertilizer for agriculture purposes. Biosolids are a source of food for microorganisms, which release odor compounds as they metabolize the biosolids. The type of biosolids organic compounds, bacteria and pathogenic organisms, odors, and metals may vary at each wastewater treatment plant facility, so the quality of biosolids strongly depends on wastewater source, and sludge treatment methods (Christie et al., 2001).

Biosolids are divided into Class A and Class B; each type has different properties and different odors. Class A can be utilized on land with less limitation compared to Class B because of meeting more severe requirements of pathogen and heavy metal reduction (Metcalf & Eddy, 2003). Adding sufficient lime to biosolds to raise the pH to 12 after 2 hours and temperature to more than 70 ℃ is the requirement of Class B, and vector attraction reduction is considered for both Class A and Class B using alkaline stabilization processes (Girovich, 1996). Figure 2.1 shows lime ratios and quicklime dosage requirements for Class A and Class B for alkaline treatment; addition of bulking material or higher lime dosages strongly depends on factors such as granularity, nutrient matter, and dryness.

Septic, or anaerobic, conditions occur in wastewater treatment plants in wastewater collection systems with long detention times, as well as in wastewater treatment plant basins without sufficient aeration, and can result in offensive odor compounds (Milner et al., 2000). In the absence of gas phase oxygen, microbes is broken down organic matters due to chemically bound oxygen and converted to biogas such as sulfate (SO_4^{2-}). This results in the sulfur being reduced to S^{2-}, forming a sulfide. Sulfate reduction in sewage sludge is not usually adequate to eliminate organic carbon completely, and forming of sulfide is not valuable as fuel source. Therefore, sulfide creation during anaerobic treatment of sulfate is the crucial concern in WWTPs (Pol et al., 1998).

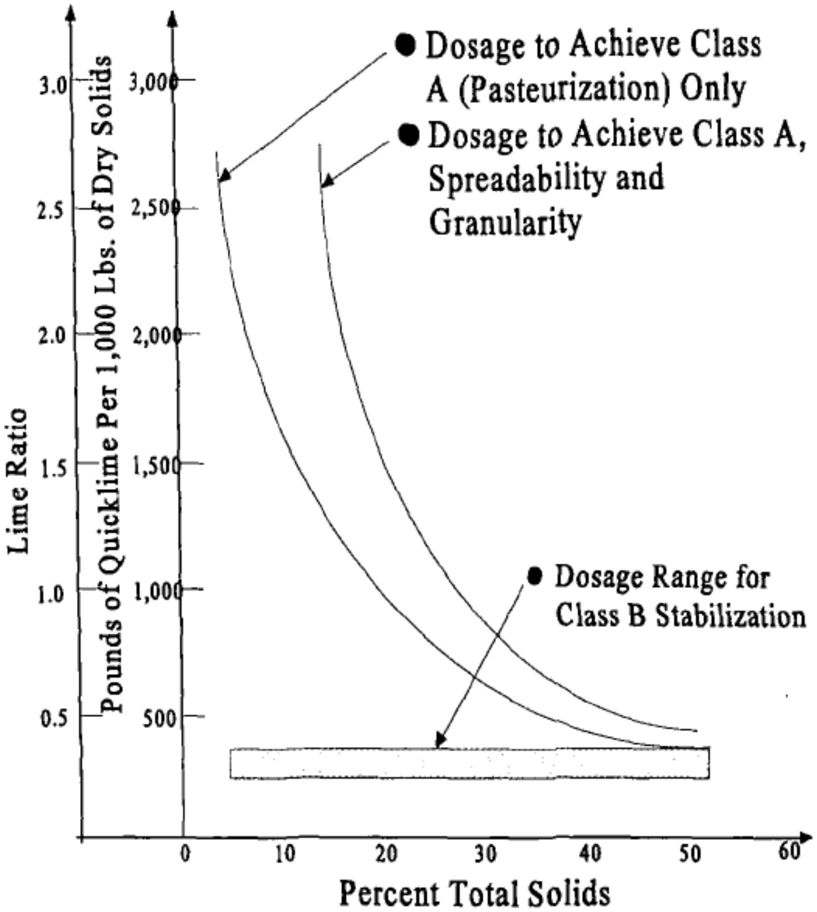


Figure 2.1 Quicklime Dosage and Lime Ratio for Class A and Class B (Girovich, 1996)

2.1.2 History of Disinfection and Odor Control of Biosolids

Today, land application and biosolids recycling is the most common alternative to biosolids disposal, due to costs of incineration and restrictions on ocean disposal (Ocean Dumping Ban, 1998). Early wastewater treatment plants mostly targeted reducing the mass, volume and odors of sludge, with no consideration or reports of negative impacts to the environment and human health. The first anaerobic digester was built in Bombay, India in 1859 to reduce sludge mass volume, mitigate sludge odorants, and produce a usable gas. In the early 1900s, one public health official recommended building anaerobic digestion units for treating residuals (Babbit, 1992).

The United States started land application of sludge and biosolids recycling programs in 20th century (Albert et al., 1996). For example, the City of Alliance, Ohio, started using municipal sludge as fertilizer in 1907. The City of Baltimore, Maryland started utilizing biosolids in agriculture at the same time as the City of Alliance, Ohio. In 1920s, the City of Milwaukee started its plan to dewater activated sludge and retail the product as a fertilizer with high nutrients for agriculture.

In United States digestion plants were not used until the 1930s; and there were some studies of the anaerobic digestion process for decreasing or eliminating of pathogens up to the 1970s (Schlenz, 1937; Fair et al., 1954). Jewell and Seabrook (1979) stated that U.S. wastewater treatment plants started treating and discharging of wastewater into lakes, rivers, and bays fifty years ago. The discharged water bodies still became considerably polluted. Since the 1950s, federal legislation has restricted the discharge of sewage into waterways and disposal of residual solids in oceans.

After investigation of all literatures between 1930-1975, the US EPA advised aerobic and anaerobic digestion to reduce sludge volume and remove indicator organisms and pathogenic organisms (USEPA, 1979).

The City of Milwaukee used two tasks to control and manage disease from WWTP sludge in 1920s (Archer, 2006): by adding ferric chloride, the city controlled sludge pH around 3.0, and dried the sludge at 82℃ to achieve close to 10% moisture. They were one of the first to use this method in the United States. Some wastewater treatment plants have used optimum air and temperature to remove pathogenic microorganisms, as researched by the U.S. Department of Agriculture (USDA) (Horvath, 1978; Burge et al., 1978). The Sanitary County of Chicago also utilized gamma rays and high-energy electrons from radioactive elements to treat pathogens. This technology could reduce effectively a large number of bacteria; however, it was not an economical method (Etzel et al., 1969).

Heating the fluid sludge to 70℃ for detention time of 30 minutes to moderate pathogens was another method, which was practiced in Europe in the 1960s and in the USA in the 1970s (Roediger, 1967; Cornell University, 2007).

According to Beech et al. (2007), the United States produced 7 million tons of biosolids in 2004, of which 15% was incinerated, 28% was disposed of in solid waste landfills, and 55% was land applied. The majority of biosolids was thus land applied, and the majority of public support is behind biosolids recycling programs (Smith, 2013). The advantages of land application over incineration and landfilling include reuse as a fertilizer, less energy-intensive compared to incineration, inexpensive, less space required compared to landfilling.

Alkaline treatment of waste in order to remove infection and control odors has been used for centuries. Smith (2013) mentioned lime was employed for physical-chemical processes of water to controls odor and eliminates bacteria in the late 1800s. Ancient Egyptians used lime in their latrines to remove unpleasant odors. In 1913, Dr. A. C. Houston of London advised lime as a sterilizer and verified the impact of lime on E.

coli reduction in 5-24 hours with CaO (Riehl et al., 1952). The USPEA research laboratory in Cincinnati started the practice of addition of quicklime to liquid sludge for the first time (Farrell et al., 1972; Noland et al., 1978). Nowadays, using lime stabilization is a common method to eliminate pathogens and reduce odors in wastewater treatment plants around the world.

2.2 The Importance of Land Application of Biosolids

The amount of biosolids production is increasing due to developing cities and growing population, and land application is considered as the most efficient and economical alternative for biosolids disposal (Haynes et al., 2009). According to Beech et al. (2007), the United States produced approximately 6.5 million tons of biosolids in 2004, of which 55% was land applied. The USEPA reported 0.1% of agricultural land in the United States was used for biosolids land application annually (CTPBA, 2002).

One of the concerns at landfill of wastes is the impacts of pathogens and odors of bioslids on human health and environmental risks. Over the last ten years, a new pathogen was discovered as a public health threat every year (WHO, 2003). Smith (2013) states that nowadays, approximately 17,000 wastewater treatment plants are treating a total of 340 billion gallons per day wastewater in the United States, which may contain large amount of pathogens and disease-causing organisms. These pathogens and disease-causing organisms come from the waste of humans and animals, patients of hospitals, rats, etc.; however the most of pathogens are destroyed during the wastewater treatment process. Typical major pathogens present in raw domestic sludge, along with their symptoms, are shown Table 2.1 (USEPA, 2003).

Therefore, biosolids land application plays a vital role in isolation and disinfecting pathogenic organisms and reducing biosolids odors in a certain location to prevent spreading in the neighborhood.

Table 2.1 Major Pathogens Present in Raw Domestic Sludge (USEPA, 2003)

CLASS	EXAMPLES	DISEASE
Bacteria	*Shigella sp.*	Bacillary dysentery
	Salmonella sp.	Salmonellosis (gastroenteritis)
	Salmonella typhi	Typhoid fever
	Vibrio cholerae	Cholera
	Enteropathogenic-Escherichia coli	A variety of gastroenteric diseases
	Yersinia sp.	Yersiniosos (gastroenteritis)
	Campylobacter jejuni	Campylobacteriosis (gastroenteritis)
Viruses	Hepatitis A	Infectious hepatitis
	Norwalk virus	Acute gastroenteritis
	Rotaviruses	Acute gastroenteritis
	Polioviruses	Poliomyelitis
	Coxsackie viruses	"flu-like" symptoms
	Echoviruses	"flu-like" symptoms
Protozoa	*Entamoeba histolytica*	Amebiasis (amoebic dysentery)
	Giardia lamblia	Giardiasis (gastroenteritis)
	Cryptosporidium sp.	Crytosporidiosis (gastroenteritis)
	Balantidium coli	Balantidiasis (gastroenteritis)
Helminths	*Ascaris sp.*	Ascariasis (roundworm infection)
	Taenia sp.	Taeniasis (tapeworm infection)
	Necator americanus	Ancylostomiasis (hookworm infection)
	Trichuris trichuria	Trichuriasis (whipworm infection)

2.2.1 Advantages of Land Application of Biosolids

Toffey (1999) cited that odors from land application may not effect human health and federal biosolids regulations have not regulated biosolids odorants; however, odors from biosolids facilities still produce severe public opposition. Therefore, some actions are essential for removing or reducing of biosolids emissions to gain public support.

Some of these actions could be cleaning of equipment periodically, minimizing the storage time of biosolids, establishing biosolids land application far from communities, and considering an appropriate location for biosolids application in terms of wind direction to prevent transport of emissions to neighborhoods (Rynk and Goldstein, 2003). Dowd et al. (2000) indicate that emissions and odors from biosolids land application may pose a problem up to a radius of 100 m.

Biosolids land applications have beneficial impacts on soil structure, and they can improve degraded soil to reestablish the vegetation and ecosystem (Baumgartl and Horn, 1991). In addition, the positive impacts of biosolids on degraded soil include increases in plant biomass yield (Syndor and Redente, 2002). Biosolids land application has been determined as a safe and economical method for improving soil for agriculture and forests (Stukenberg et al., 1993). Despite, Biosolids land application is not, however, necessarily suitable for all farm and agriculture locations. Agriculturalists need consider soil type, farming practices, field slope and other conditions before applying the boisolids on the field (Stukenberg et al, 1993). Although biosolids land application has some challenges, such as presence of heavy metals and organic pollutants, it is a suitable method to improve characteristics of soil, recycle nutrients and organic matter, and reestablish vegetation (Zhenli and Stoffella, 2012).

Biosolids are a nutrient-rich source for soil, also called a “soil conditioner”, and they can improve biological, chemical, and physical properties of soils (Tisdall and Oades, 1982). Krause (2003) states that after combining biosolids with soil organic matter, the stability and aggregate size of soil is increased. Moreover, untreated soil is highly sensitive compare to biosolids-treated soil in terms of densification due to the enhanced pore volume (Krause, 2003). Therefore, biosolids incorporation with soil can improve the physical characteristics of soil (Lindsay and Logan, 1998; Kirchmann and

Gerzabeck, 2002).

Acting as supplement or replace for fertilizer is another advantages of using biosolids application. This application provides an opportunity to slow-release nutrients; nutrients are gradually converted when needed. In other words, biosolids release nitrogen and other nutrients over a long period of time and consequently help soil bacteria to decompose at a slow pace. One report has shown that after a single biosolids application, biosolids-N were regenerated by harvest during four years; however the total biosolids-N and yield were gradually decreased during years (Binder et al., 2002).

2.2.2 Disadvantages of Land Application of Biosolids

The worries of using biosolids application include potential eutrophication of water due to inordinate nutrients, as well as the presence of organic compounds and heavy metals in sludge. Furthermore, public disagreements about pathogens and odors are another concern. Biosolids application causes eutrophication through increasing N:P ratio, which is harmful for crop growth (Sharpley et al., 1998). Using high biosolids application rate may also result in high nitrate concentration for drinking water, which is higher than EPA restrictions (Brenton et al., 2007; Stehouwer and Macneal, 2006).

After biosolids land application, heavy metals may collect at hazardous levels on the site and transfer to surface waters, which is one of the huge concerns in biosolids land application (Zhenli and Stoffella, 2012). Many organic compounds are also deposited in biosolids land application and transferred to the natural environment. These compounds such as personal care products, plastics, and steroid hormones are toxic and may cause carcinogen diseases (Giger, 1997).

During the last few years, several biosolids land applications have been restricted due to lack of public acceptance and local complaints. The wastewater and biosolids odorants can directly impact property value, aesthetics, and quality of life of its neighborhood. There are a lot of nuisance complaints in neighborhoods due to odors from wastewater treatment plants. According to McGinley et al. (2000), 10% and 20% inhaled air is carried to the top of body and area near the olfactory receptors, respectively, and based on the mass concentration olfactory nerves response the odors. The olfactory signals transfer the information to two parts of brain: the emotion part and memory part.

Moreover, the biosolids odorant products or biosolids treatment processes release odor emissions, which may have a negative influence on human health (Schiffman et. al., 2000); however, odor-causing bacteria in biosolids can be eliminated through several methods. Feng et al. (2007) also mentioned, although biosolids land application can be beneficial to improve the physical properties of soil and is a cost-effective alternative to inorganic fertilizer, the main disagreement of biosolids land application is the offensive odors of biosolids, which are dispersed in residential areas.

2.3 Alternatives for Odor Control of Biosolids

Based on EPA recommendations, biosolids facilities can use several operations to mitigate the concentration of biosolids odor emissions such as avoiding anaerobic conditions through operation and maintenance (O&M), preventing hydrogen sulfide production by adding oxidizing agents, resisting the decomposition of polymers by selection, using chemical scrubbers for removing odors (Millner et al., 2000). These alternatives will be evaluated based on the concentration of emissions and capital and maintenance costs for a particular location.

According to Millner et al., (2000), recent alternatives that are used in biosolids facilities to manage and reduce biosolids emissions include biofilters, wet chemical scrubbers, regenerative thermal oxidizers, activated sludge basins, and odor counteractant of neutralizing agents. This chapter briefly describes each method.

2.3.1 Biofilters

Biofilters eliminate emissions and foul air stream through adsorption and absorption, and subsequent oxidation. Indigenous bacteria and microorganisms oxidize the odor compounds during metabolism. The media of biofilters are made by bark, wood chips, peat moss, rock, oyster shell, and yard waste or agriculture waste compost. Oyster shell can control the pH of media, and rock, sand and bark are used for maintaining the porosity of bed (Haines et al., 1999).

Biofilters are one of the effective methods that can decrease 95% of odor compounds in biosolids facilities and they are cost-effective as well; however, they are not enough efficient to remove high concentrations of emissions (Schiffman et al., 2000). Alix (1998) mentioned that using biofilter systems have reduced or even in some cases eliminated the number of odor complaints in biosolids facilities. It is essential to keep biofilters well maintained for more efficient operation and neighborhood health. Operators should try to keep the humidity of biofilter close to 100 percent and avoid the space and air channeling that cause short-circuiting of the media. A typical biofilter structure is shown in Figure 2.2.

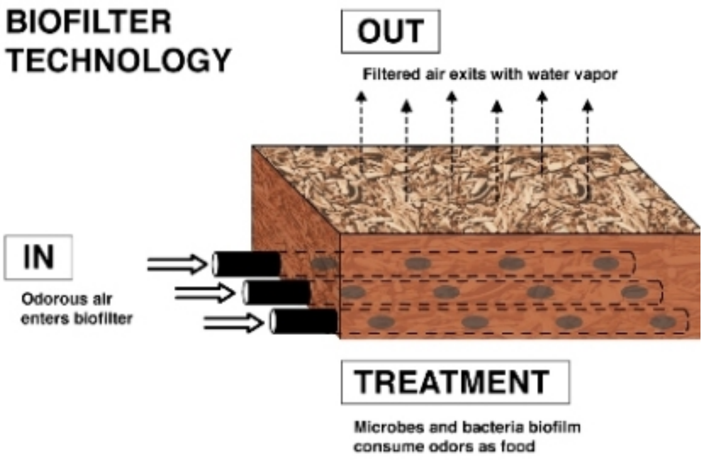


Figure 2.2 Biofilter Structure (Sorensen, 2012)

2.3.1.1 Advantages and Disadvantages of Biofilters

Biofilters operate with low energy requirements to alleviate odor emissions. They are generally low maintenance, with media needing replacement only every 5 years, and have low operating costs. .

On the other hand, the size of biofilters is one of their limitations. Biofilters usually need a considerable land surface area for installation and operation. Moreover, the lack of moisture in filter media may result in reduced efficiency. Cold temperature may impact biofilter efficiency and operation. Biofilters are not an appropriate alternative for the odors with high emission concentration. For instance, the media of biofilters is polluted due to collection of ammonium if the concentration of ammonia would be greater than 35 ppm in the foul air stream (Millner et al., 2000).

2.3.2 Activated Sludge Basins

The operation of activated sludge basins is similar to biofilters. Activated sludge basins reduce odor compounds through microbial oxidation, condensation, adsorption, and absorption. The foul air is removed by blower and diffuser system, which is submerged 8 feet, and over. The material of the blower and diffuser system is moisture traps, stainless steel, and PVC to prevent corrosion. Flat gasket covers on tanks and blending equipment can play a significant role to diminish air stream volume in activated sludge basins. To achieve high odor reduction efficiency, bed nitrification biotowers are utilized (Lutz et al., 1994). The blowers and air filter are also regularly cleaned to increase the efficiency in activated sludge basins.

2.3.2.1 Advantages and Disadvantages of Activated Sludge Basins

Activated sludge basins technology is cost effective in biosolids facilities in terms of operation cost and capital expenses (Bowker, 2001). A typical activated sludge basin life expectancy is over 40 years. Moreover, this alternative is not complex, and has low O&M expenses to treat moderate to high strength emissions (Bowker, 1997).

However, stainless steel inlet filter and PVC piping must be used to prevent blower corrosion; collection of tar-like material and greasy film on the internal parts of blowers, which causes corrosion, is a considerable weakness in the activated sludge basins method. Hence, this alternative may not be able to remove or mitigate very high the concentration of biosolids odorants.

2.3.3 Wet Chemical Scrubbers

Wet scrubber systems are appropriate method to treat emissions with high intensity and large air volume. The chemical oxidizes absorbed biosolids odorants. The quantity and quality of solubility of odors in scrubbing solution plays a major role in performance of web scrubbers' technology (Heller and Heller, 1999). The system commonly utilizes water or acid in the first step and chlorine or caustic/chlorine in the second step to eliminate, respectively, ammonia and sulfur based compounds. Three types of wet scrubbers are usually used in biosolids facilities: mist scrubbers, venturi scrubbers, and packed bed scrubbers. They have to be designed to provide maximum interaction between scrubbing chemical solution and odorants. Figure 2.3 illustrates the schematic sketch of spray nozzle scrubber configuration.

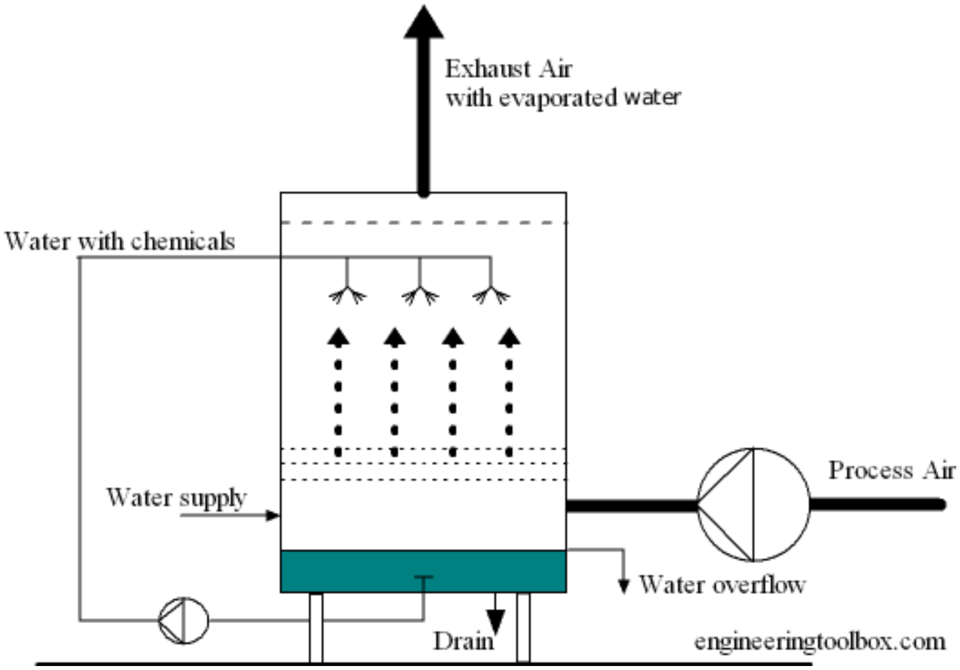


Figure 2.3 Wet Scrubbers Schematic (Semian Technology)

2.3.3.1 Advantages and Disadvantages of Wet Chemical Scrubbers

Web chemical scrubbers systems are more effective and reliable than other methods through using chemicals and are able to eliminate large amounts of emissions in two or three steps. On the contrary, if the chemical feed is not appropriately managed and controlled, the large amount of chlorinated emissions and bleach odors are released from the scrubber exhaust stack, which is harmful for neighborhoods. The method requires large amount of chemicals, power, and water, which is expensive, and it is not economical. In addition, chemical scrubbers tend to be high maintenance

2.3.4 Regenerative Thermal Oxidizers (RTO's)

This alternative is utilized for incineration of emissions through high temperature. The combustion chamber temperature in RTO's technology is 1350-1600℉, with residence time of 0.3-3 seconds. The method also needs sufficient oxygen and turbulence to have efficient combustion (Heller and Heller, 1999). Figure 2.4 shows the schematic and operation of RTO's. According to Martinson and Van Asten (2005), this technology can considerably eliminate odor compounds.

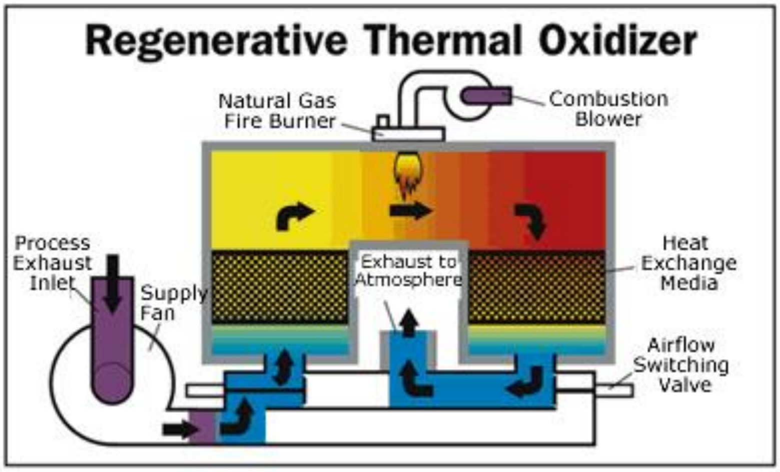


Figure 2.4 Schematic and Operation of Regenerative Thermal Oxidizers (RTO's)

(Techiedan, 2013)

2.3.4.1 Advantages and Disadvantages of RTO's

This method can properly remove or reduce emissions. Moreover, the size of equipment is considerably smaller than biofilters and web chemical scrubbers. They can treat high volume of air streams with a bigger chamber. Digester gas can provide energy for RTOs, which can be very helpful to decrease fuel costs; however, a few units of RTO's need a significant fuel, and this technology is not economical except for treating high strength of emissions. Moreover, RTO's are an expensive alternative in terms of O&M expenses.

2.3.5 Counteractants, Neutralizing Agents and Oxidizing Agents

This alternative is commonly utilized to mitigate biosolids odorants from area sources. The area source includes biosolids curing or storage piles and point sources such as ventilation exhaust stacks. Non-toxic materials are used for this method, and they have no negative impact on environment and human health. The materials are added to liquid waste stream or dispersed in the air as a mist. In other words, essential oils and compounds are periodically sprayed on biosolds in odorous tanks or storage areas. These methods likely mask the odor rather than eliminating it, and are not scientifically proven.

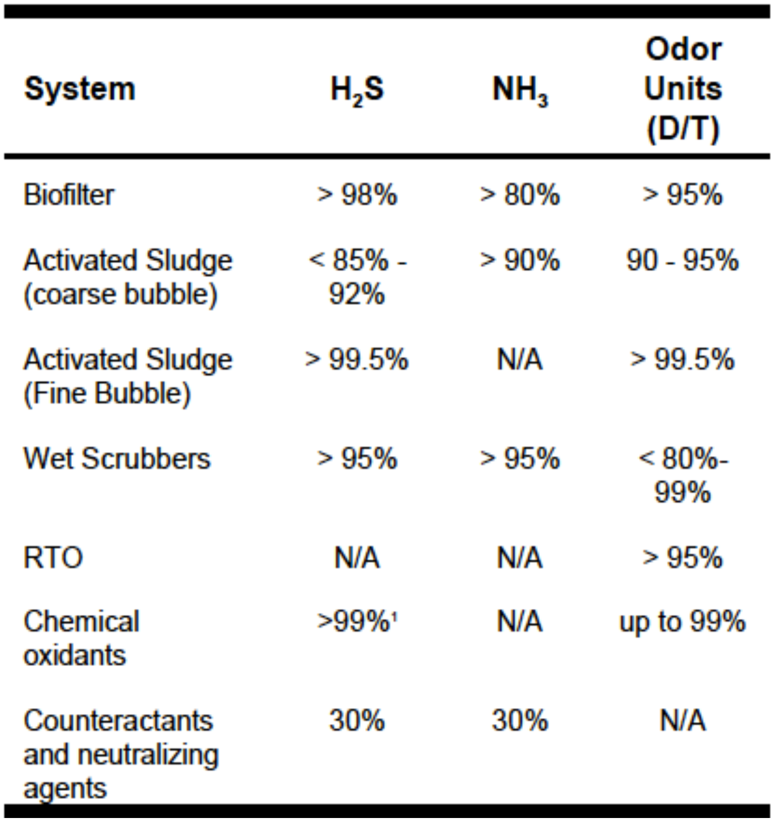
On the other hand, adding oxidizing agents into the wastewater is a proven effective technique for reducing odors. Biosolids facilities may use chlorine dioxide, potassium permanganate, or hypochlorite to avoid releasing hydrogen sulfide due to septic conditions. The amount of oxidant for adding directly depends on the amount of pH in wastewater. For example, a lesser amount of potassium permanganate is used to achieve pH 5-7. (Pisarczyk and Rossi, 1982) The O&M is not complex if appropriate dosage is determined. Ferric chloride may also be added to precipitate the sulfide as iron sulfide.

2.3.5.1 Advantages and Disadvantages of Counteractants, Neutralizing Agents and Oxidizing Agents

Counteractants and neutralizing agents are cheaper than other products in terms of capital cost; however this technology is not a preferred method for odor reduction because neutralizing agents can impact on a certain area in which they can be sprayed, and they just mask the odors. Using oxidizing agents results in proper odors mitigation for dewatering and thickening equipment. Adding potassium permanganate to biosolids is also an effective temporary solution to reduce odors (Pisarczyk and Rossi, 1982). Using oxidizing agents is, however, sometimes more expensive than their effectiveness due to presence of non-odorous substance that react with oxidizing agents (WEF, 2000).

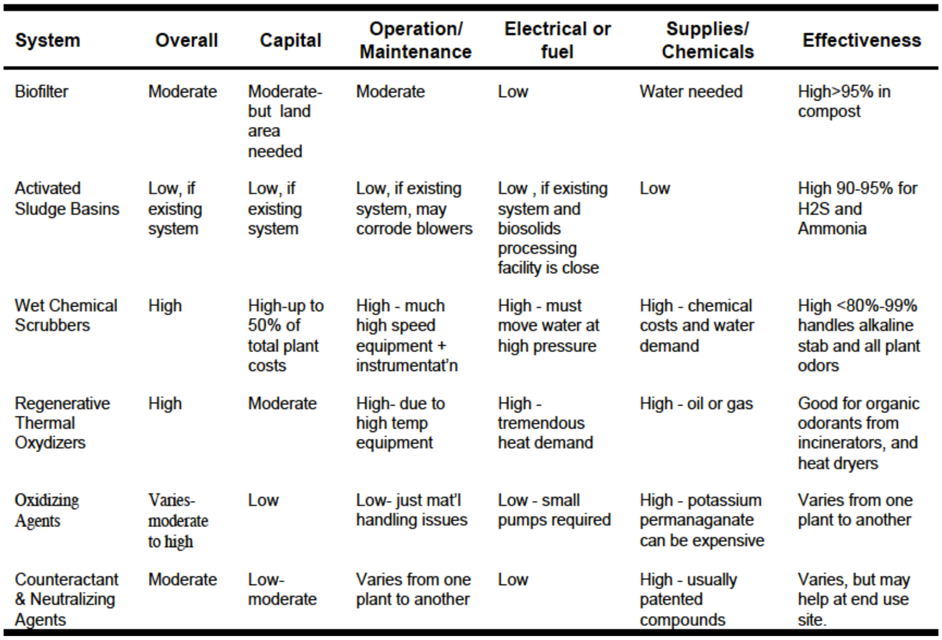
Although odor control technologies are considered as odor reduction in biosolids facilities, they need to be investigated in terms of their performance, efficiency, and capital costs. The performance of each technology in Table 2.2 is shown the removal efficiency of hydrogen sulfide and ammonia for some odor control alternatives. The relative costs of odor control technologies and their specifications are also listed in Table 2.3.

Table 2.2 Comparison of Odor Technology Removal Efficiencies (Williams, 1994; Schiffman et al., 1999; Ostijic & O’Brien, 1994; Giggey et al., 1994; Solomon, 1994; LeBeau & Milligan, 1994; Pisotti, 1994; Singleton et al., 1994; Vaith et al. 1995)



System	**H_2S**	**NH_3**	**Odor Units (D/T)**
Biofilter	> 98%	> 80%	> 95%
Activated Sludge (coarse bubble)	< 85% - 92%	> 90%	90 - 95%
Activated Sludge (Fine Bubble)	> 99.5%	N/A	> 99.5%
Wet Scrubbers	> 95%	> 95%	< 80%-99%
RTO	N/A	N/A	> 95%
Chemical oxidants	>99%[1]	N/A	up to 99%
Counteractants and neutralizing agents	30%	30%	N/A

Table 2.3 Relative Costs of Odor Control Technologies and their Specifications (Pisarczyk and Rossi, 1982; Williams, 1994; Vaith et al. 1995; Hents et al., 1992; Haines et al., 1999; Ostojic et al., 1994 Bowker, 2001)



System	Overall	Capital	Operation/ Maintenance	Electrical or fuel	Supplies/ Chemicals	Effectiveness
Biofilter	Moderate	Moderate- but land area needed	Moderate	Low	Water needed	High>95% in compost
Activated Sludge Basins	Low, if existing system	Low, if existing system	Low, if existing system, may corrode blowers	Low , if existing system and biosolids processing facility is close	Low	High 90-95% for H2S and Ammonia
Wet Chemical Scrubbers	High	High-up to 50% of total plant costs	High - much high speed equipment + instrumentat'n	High - must move water at high pressure	High - chemical costs and water demand	High <80%-99% handles alkaline stab and all plant odors
Regenerative Thermal Oxydizers	High	Moderate	High- due to high temp equipment	High - tremendous heat demand	High - oil or gas	Good for organic odorants from incinerators, and heat dryers
Oxidizing Agents	Varies- moderate to high	Low	Low- just mat'l handling issues	Low - small pumps required	High - potassium permanaganate can be expensive	Varies from one plant to another
Counteractant & Neutralizing Agents	Moderate	Low- moderate	Varies from one plant to another	Low	High - usually patented compounds	Varies, but may help at end use site.

2.4 Alkaline Stabilization

For many years, wastewater treatment plants have used various chemicals in chemical treatment to improve sludge dewaterability, modify pH, disinfect pathogens, control odors, etc. These chemicals include quicklime, potassium permanganate, ferric chloride, ozone, chloride, sodium hypochlorite, and hydrated lime. Chlorine and lime are common chemicals, which have been examined and utilized more than other chemicals. Chlorine is used to eliminate bacteria and pathogens in wastewater, and lime is considered as a pH modification and disinfective chemical.

Although lime is less efficient than chlorine in removing pathogens and odor control, it is more secure, less expensive and easier to apply. So lime and lime containing materials are selected as the primary treating chemicals for disinfection and odor control in wastewater treatment plants (Girovich, 1996). Lower lime dosages mean less cost, but pathogens may not be killed. Higher lime dosages mean greater killing of pathogens, but higher cost. Previous research indicates that if the amount of lime added is large enough to inhibit methanogens but insufficient to inhibit protein degraders that convert protein to methane thiol and dimethyl sulfide, odor production may increase (PEC, 2014). At high lime dosages, sulfide odors may decrease but ammonia increase. So in terms of odors, cost, and pathogen removal, there likely exists an optimum lime dosage.

Farrel et al. (1974) cite that in 1740s, chemical treatment of wastewater was tried in Paris for the first time, and using lime as chemical treatment was applied in England from the 1890s. Lime usage at wastewater treatment plants started in Sweden and Germany in 1967 and 1978, respectively, and other European countries have since begun widely using lime stabilization (Stone et al., 1992). The first use of quicklime to enhance soil for agronomic benefits was also examined in Pennsylvania in 1974.

The level of pH in biosolids should be regularly measured and controlled to prevent increasing biosolids acidity during wastewater treatment. Lime stabilization reduces biological activities of microorganisms, removes pathogens, and mitigates biosolids odorants due to increasing pH (Evanylo, 1999).

In 1993, U.S. EPA established biosolids stabilization standards in 40CFR Part 503, including pathogen and vector attraction reduction. This reduction was followed by considering dryness standards, temperature, pH, time, or using pasteurization (USEPA, 1993). Based on EPA (1993; 2003) regulations, the pH for Alkaline treatment (Lime Stabilization) should be 12 and above for greater than 72 hours at above of 52℃ and raise the pH to 12 for more than 2 hours of contact lime with biosolids respectively for Class A and Class B. Moreover, vector attraction reduction requirement is considered for both Class A and Class B as alkaline stabilization processes. Vector attraction requirement cites to increase the pH 12 or higher for 2 hours and 11.5 or higher for more 22 hours.

2.4.1 Lime Characteristics

Calcium oxide (Cao), commercially known as quicklime, is prepared by the thermal decomposition of limestone or seashells (Greene et al., 1985). Burning crushed limestone at high temperatures produces quicklime. Lime is mixed in biosolids for adding bulk, mitigating odors, disinfecting pathogens, and raising pH (Girovich, 1996). Hydrated lime (calcium hydroxide) is reconverted to quicklime by heating and evaporating water. Hydrated lime is used for small applications, and quicklime is commonly used for biosolids of amount greater than 2 tons per day because it is more economical. Limestone and hydrated lime are neutralized soils and utilized in biosolids treatment processes. Lime is added into the biosolids to improve dewaterability of biosolids by forming calcium carbonate and calcium hydroxide (Girovich, 1996).

Quicklime is able to raise the temperature over time and releases large amounts of heat during reaction by the formation of calcium hydroxide (Miller, 2007). For example, reaction between 6.8 lbs and one liter of water may result in 3.54 Mega Joules of energy, as shown below.

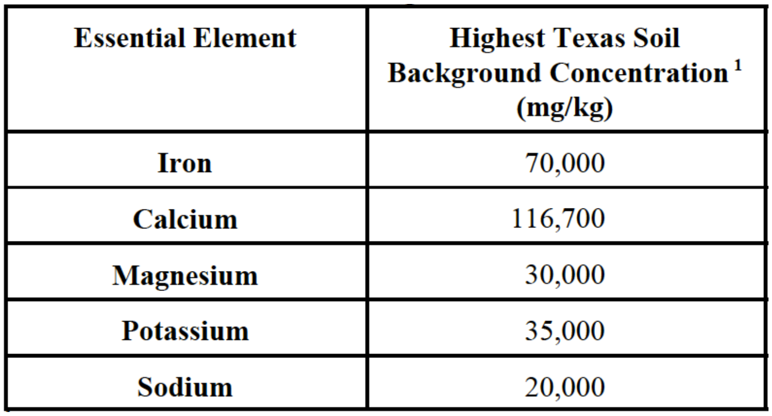
$$\mathrm{CaO\ (s) + H_2O\ (l) \rightleftharpoons Ca(OH)_2\ (aq)\ (\Delta H_r = -63.7\ kJ/mol\ of\ CaO)}$$

According to Girovich (1996), quicklime can be classified into 3 types: magnesium quicklime (5-35% magnesium oxide, MgO), dolomitic quicklime (35-40% MgO), and high calcium quicklime (majority of calcium oxide and less than 5% MgO).

Quicklime is also manufactured in various sizes: crushed lime (0×1/8"), pebble lime (3/4"×1/4"), rice lime (1/8"×1/4"), and pulverized lime (100% passes 200 mesh). Crushed lime is usually transported in bulk, and finer sized lime (pulverized) is shipped in bags. An important point is to prevent any contact with water during shipping and storing quicklime (Hassibi, 2009).

Calcium plays a crucial role in plant growth through cell wall deposition. Calcium improves chemical balance in the soil structure and helps water penetration. Calcium can be applied in soluble and insoluble forms for agricultural purposes. Soluble calcium can be supplied by irrigation in soil and it does not affect the level of pH in soil, and is thus the recommended treatment for growing crops. Inadequate presence of calcium in soil may cause various problems such as deformation of leaves, necrosis at young leaves and tips, and general chlorosis. On the other hand, the presence of a high amount of calcium in soil may harmful for farming. A high amount of calcium may increase the soil pH and decrease uptake of other cation nutrients. Table 2.4 (Boerngen, 1981), shows the maximum Texas background soil concentrations.

Table 2.4 Highest Texas Soil Background Concentration (Boerngen, 1981)



Essential Element	**Highest Texas Soil Background Concentration ^{1} (mg/kg)**
Iron	70,000
Calcium	116,700
Magnesium	30,000
Potassium	35,000
Sodium	20,000

2.4.2 Advantages and Disadvantages of Lime Stabilization

According to Lewis et al. (2002), sludge odorants such as reduced sulfide, ammonia, methanethiol, and amines and pathogens may impact human health. Symptoms include burning eyes, headache, nosebleeds, and skin rashes. Lime stabilization disinfects the bacteria and pathogens and prevents regrowth. Moreover, elimination of odorant biosolids and mitigating vector attraction is another advantage of adding lime to biosolids. Lime may raise the pH, and high pH levels can reduce or eliminate considerable odor pollutants such as mercaptans and organic sulfides. Hydrogen sulfide is almost eliminated at pH 9 (Lagnese, 1992).

In addition, lime usage is inexpensive compared to other methods for treating biosolids. According to Otoski (1981), lime stabilization has lower capital costs than other methods (digestion and thermal drying), and this benefit is very critical for municipalities, which are dealing with limited budgets. Hydrated lime and quicklime are the most popular and most cost-effective in alkalis. Over eighty plants in 29 states produced lime products, and over 18.7 million tons of lime was used for all purposes in United States in 1993 (Girovich, 1996).

Furthermore, lime usage is not complicated: lime can be simply added and mixed into biosolids. During maintenance, lime stabilization facilities may be easily stopped and started again. Thus, other methods such as incineration and thermal drying can be used when stabilization facilities are out of service. Lime stabilization application also necessitates less space than other technologies. Besides, lime application has faster and greater impact on acidic soils because lime can enhance biosolids density and the structure of soil; physically, chemically, and biologically (Rice, 1999). Lime is utilized to reduce soil acidity and disinfection toxicity on alkali-stabilized biosolids due to increased pH (Luo and Christie, 2002).

On the other hand, the reaction of lime and water is not recognized as a fire hazard, but it may cause combustion due to production of considerable heat. Beside, this combination of reaction may cause severe respiratory issues and irritation of eyes and skin (Hanson, 2009). Hydrated lime is unstable for crowded areas due to fine size and may cause some issues. Moreover, quicklime needs sufficient water to properly react with biosolids because considerable evaporation losses occur due to the heat of reaction. Therefore, lime stabilization application would not be an economical alternative in dry areas or areas with scarce water. Slurry lime also is not an efficient method for very wet soils or drying applications due to slow application rate and needs for additional equipment, which is costly (National Lime Association, 2004). Quicklime manufacturing is also harmful for the environment due to carbon dioxide and other emissions released during burning of limestone.

2.5 Summary of Perkins Engineering Consultants, Inc. Odor Study

Perkins Engineering Consultants, Inc. (PECI) assisted the City of Fort Worth in evaluating the impact of lime dosages on odor reduction of biosolids that are generated by the Village Creek Water Reclamation Facility (VCWRF). The project goal was to evaluate management options to decrease the odor emissions through improving stabilization, dewatering, storage, and transportation processes. This project was done from September 2013 to January 2014, which means in cold weather. PECI investigated the impact of co-digestion, holding time and transport policies, polymer dosing practices, and lime blending. The study found the impact of co-digestion on biosolids odor to be minimal. Storing and holding limed biosolids for a longer time at the dewatering and land application sites caused more odor complaints rather than solving the problem, because the rates of sulfur compound emissions were not changed significantly during 5 to 14 days.

Three types of polymers (Zetag polymer, GBT polymer, Mannich polymer) were applied to biosolids before lime for this study. Although Zetag contributed more to odors than GBT and Mannich polymer based on first results, the second sampling data illustrated different results, in which GBT and Mannich polymer contributed more to biosolids odors than Zetag polymer. Therefore, the report concludes that the impact of polymer on odor reduction is unclear, and additional testing needed to determine the best type of polymer for biosolids odor mitigation.

Lime dosages of 7, 14, 21, and 28% were applied to biosolids, and corresponding headspace odorants (hydrogen sulfide, ammonia, dimethyl sulfide, mercaptans, triethylamine, and amines) were measured at 2, 4, 7, 10, 14 days. According to the data of PECI study, 7% lime dose was the optimum for maximum odor reduction of biosolids at VCWRF.

Some samples in the PECI project were not collected or measured due to severe weather conditions. Moreover, Draeger gas detection instrument (accuracy ± 20%) was used for measuring the odors and reading of gas detection tubes were performed by humans, which may cause error in reading. Hence, collected data could not be enough and precise to interpret the results.

This thesis investigates the impact of lime dosage on biosolids odorants during summertime and warm weather at VCWRF. Besides, different lime dosage are used and measured into biosolids samples to obtain the most appropriate lime dose in order to maximum odor reduction at biosolids facility. This study is also attempting to utilize accurate methods and instruments during sample collecting, sample measuring, and analyzing to achieve the most precise results.

CHAPTER 3

METHODOLOGY

3.1 Biosolids Mixing with Lime Dosages

Odor sample collection was conducted as part of this study in September 2014 for 2 weeks. Fresh dewatered sludge collected at the Village Creek WWTP was used to fill in 5-gallon buckets 1/3 full (approximately 5.0 lbs of dry solids per sample). Lime from VCWRF in dosages of 0, 5, 7, 10, and 14% of biosolids weight (not total weight) were applied to the sludge in order to study the impact of increasing lime dose on odor reduction of biosolids. Different lime dosages were chosen to compare the amount of concentrations of biosolids odorants. Village Creek currently adds 7% lime. Previous testing by Perkins Consultants evaluated dosages during winter months of 7%, 14%, 21%, and 28%, finding 7% to be optimum. We thus wanted to test a variety of dosages around 7%, to better refine the optimum number.

The utilized plastic buckets were suitable for collecting and sampling odor concentrations to obtain the most accurate results because the material of buckets had the least reaction with the mixed sample. A 5/16 inch diameter hole was drilled in the center of each lid for taking samples through a tube, and the holes were covered after each sampling to avoid air leakage.

The lime dosages were added to biosolids in the buckets and mixed together by hand using disposable gloves for 5 minutes. During mixing the lime and biosolids, chemical reactions occurred with release of high heat and harsh gases. Figure 3.1 shows the procedure of maxing samples with different dosages of lime.

Figure 3.1 Mixing Samples with Lime

After lime was applied, the samples were stored outside at the Civil Engineering Lab Building for 14 days in order to capture summertime ambient temperatures, ranging from 70°F - 99°F. Table 3.1 shows minimum, average, and maximum temperatures for each of the 14 days. The percentage of lime was labeled on each bucket, as shown in Figure 3.2.

Table 3.1 Minimum, Average, and Maximum, Temperature for Each of the 14 Sampling Days

Temp. (^{o}F) ***Date (2014)***	***Max.***	***Ave.***	***Min.***
20-Aug	97	88	79
21-Aug	98	88	78
22-Aug	99	89	79
23-Aug	98	87.5	77
24-Aug	98	87.5	77
25-Aug	99	86.5	74
26-Aug	97	86	75
27-Aug	94	83	72
28-Aug	96	83	70
29-Aug	94	82.5	71
30-Aug	94	84	74
31-Aug	95	85	75
1-Sep	97	87	77
2-Sep	96	87	78
3-Sep	97	87	77

Figure 3.2 Buckets for Sample Collection and Storage

3.2 Air Sample Collection by Summa Canister and Analysis through GC/MS

Gas samples were collected for each sludge/lime mixture on days 1, 7, and 14. The lids of the buckets were left open between sampling events to simulate real-world conditions, and they were replaced on the buckets 3 hours before each sampling event to accumulate emissions in the bucket. Before collecting each headspace sample, the buckets were gently shaken back and forth three times to mix the air in the bucket headspace. Headspace gas samples were collected with tubes, which are made by plastic and transferred to 6-liter Summa canisters for odorant analysis.

According to EPA, “A Summa canister is a stainless steel vessel which has had the internal surface specially passivated using a “Summa” process. In 1965, the Summa canisters were used in U.S. Army for the purpose of air sampling. Summa canisters collect the samples, and they are filled by opening a valve, which is called “grab sampling”. This process takes 1-2 minutes (Hoyt, 2002).

Collecting air samples by summa canisters is one of the fastest and most convenient methods. They are also easy reliable for shipping due to preventing exposure to sunlight during shipment to the labs. On the other hand, some compounds with low concentrations may have attraction with canister walls and cause trouble for detecting them in the samples. A photo of Summa canisters used for collecting air sample is provided as Figure 3.3.

Figure 3.3 Summa Canisters

In this study, the canister flow controller was not used and Summa canisters were filled as grab samples. The Summa canister cap was removed without opening the canister valve. After connecting the Summa canister and sample buckets (into the hole of lid) through tubes, the valve of the canister was opened (start hearing an audible “hiss”) for approximately one minute to collect a headspace sample from the bucket. Twenty seconds after stopping the “hiss”, the canister valve was closed, the tube link was disconnected, and the cap was replaced on the Summa canister. Then, the date, time and description of the sample were recorded on the sample label. This procedure was used for all buckets (each canister for each bucket) for each of the 3 sampling events. Figure 3.4 shows the connection between bucket and canister during collecting air samples.

Figure 3.4 Air Sampling by Summa Canister

Headspace collected in summa canisters from samples with different lime dosages (0, 5, 7, 10, 14%) in 1st, 7th, and 10th days, and they transported to GD Air Testing Inc. (Plano, Texas) to measure and detect by Gas Chromatography/ Mass Spectrometry GS/MS based on EPA TO-15 method for reduced sulfides and SM-4500-NH3 B,D method for ammonia. More than 20 reduced sulfides and amines were tested, but most were not detected by GC/MS. Ammonia testing is not done directly through air, but by passing the air sample through an impinger and collecting the ammonia in water. The results were contacted the sample based on mg/L and converted to the values back to air.

General procedures for sample receipt, processing, and analysis are now described; it is assumed that GD Air used a similar procedure. Once the laboratory receives the canisters for each sampling event, the canisters labels are recorded and canisters are stored in an appropriate place until he sample is run, before 4 weeks (Kelly et al., 1993). Solid multisorbent concentrators are used to concentrate and break down water vapor in the samples prior to analysis Compounds are then thermally desorbed from the concentrators and converted to the gas phase, and the volume of air samples is reduced through trapping the volume and decreasing the temperature. The reduced sample volume is released by thermal desorption and transferred onto the GC for identification and quantification. The GC/MS needs to be calibrated at five concentrations to check the linearity and sensitivity of the instrument. Besides, the material of tubes for connection between samples and GC are copper and stainless steel. The report of the concentration of odor compounds for each sample in 3 sampling events is attached in Appendix B.

3.3 Sampling and Analyzing Calcium

40 g samples from each of the biosolids/lime mixtures were collected on the first day and store in plastic containers. The samples were transported to GD Air Testing laboratory for calcium analysis based on the EPA 6020 method, which uses Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

ICP-MS determines ions, which are produced through radio-frequency inductively coupled plasma. Ions are converted to plasma gas through high temperature, and they are extracted by a pumped vacuum interface. Gas species are separated on the basis of mass-to-charge ratio. A faraday detector or channel electron multiplier is used to measure ions. The produced exhaust gases of instrument are toxic, so providing proper ventilation and observation safety precautions need to be required. The report of calcium measurement on 14th day is attached in Appendix B.

3.4 Sampling and Measuring pH

Biosolids with different lime dosages were collected in covered plastic containers on day 14 and transported to Nedderman Hall laboratory at University of Texas at Arlington for measuring pH. Approximately 40 grams of each sample was placed in an Erlenmeyer flask and 100 ml distilled water was added to the sample. Then, a mechanical shaker was utilized for thoroughly mixing biosolids with different lime dosages and distilled water for 30 seconds. After calibration of the pH meter, samples were measured to compare the results with regulation requirements. A photo of pH measuring for this study is provided in Figure 3.5.

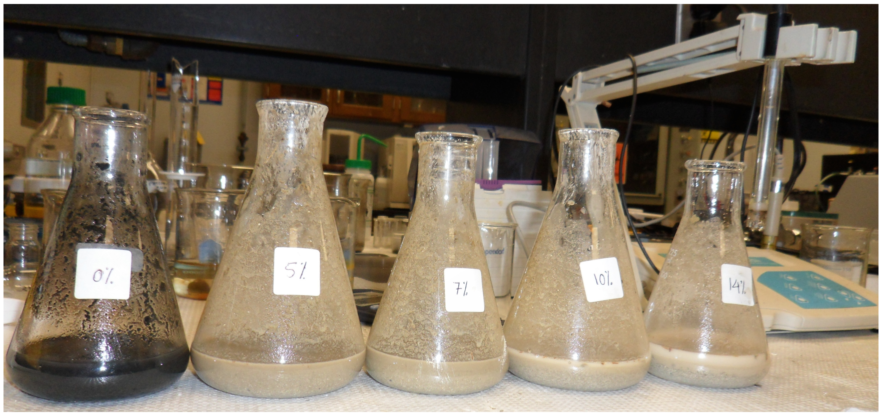


Figure 3.5 Measuring pH of Biosolids with Different Lime Dosages

3.5 Air Sample Collection by Vacuum Chamber and Odor Evaluation

Five additional headspace samples were collected in 10-liter Tedlar bags on day 14 (one from each sludge/lime mixture). This study used the VAC'SCENT vacuum chamber for transferring headspace to 10-liter Tedlar bags. The VAC'SCENT vacuum chamber is easy to use and carry, and it can be used indoor or outdoor. Vacuum chamber creates negative pressure in the camber to collect air samples in Tedlar bags without an additional sample pump, which could cause contamination. This collection method is able to fill the sample bags at a rate of 2 liters per minute, which is very fast. The 10 liter Tedlar bag is placed into the vacuum chamber and the Tedlar bag is connected to the sample valve through appropriate fittings and tubes. The other side of tube or sample line is linked to the bucket for collecting headspace. The pump inlet valve also is connected to the pump outlet valve through a tube to vacuum the air out of the chamber for providing a negative pressure condition inside the chamber. Then, the pump is turned on and the vacuum chamber and its all latches are closed. During sampling, it is difficult to open the camber due to negative pressure conditions. Air is collected until the Tedlar bag is 3/4 full (7 liters). In order to prevent pop the Tedlar bags during shipping to St. Croix sensory, they were not completely filled. After the bag is filled by air sample, the sample line is disconnected and the chamber is also de-pressurized through disconnecting the inlet/outlet valves. Then, the chamber is easily opened, and the pump should be turned off. A photo of air sample collection by vacuum chamber is provided in 3.6.

The collected air samples were placed in a special carrying box to prevent sunlight and potential punctures for shipping to St. Croix Sensory, Inc. for evaluation of:

- odor detection and recognition thresholds following EN13725 and ASTM E679-04,
- odor intensity using ASTM E544-99,
- odor description, relative strength of characters and sensations, and Hedonic tone, and
- odor persistency (Dose-response known as Steven’s Law or Power Law).

Figure 3.6 Air Sampling by VAC'SCENT Vacuum Chamber

For odor evaluation based on standards and protocols, the samples should be analyzed under 30 hours after taking samples. Because of some problems during shipping by FedEx, the samples were run after 30 hours; however, the final report showed reasonable results.

St. Croix Sensory recruited “panelists” for odor testing. Persons with chronic allergies, asthma, pregnant women, and smokers are not selected as panelists. Each panelist is trained in sniffing techniques and tested for their olfactory sensitivity based on standard odorants.

The odor evaluation of headspace is based on five parameters: Odor Threshold, Odor Intensity, Characterization, Hedonic Tone, and Odor Persistency, St. Croix sensory (2007) states that “The odor concentration or odor threshold is a number derived from the dilution of a sample of odorous air. The sample is dynamically diluted using an instrument called an olfactometer.”

In odor concentration measurements, diluted odors are emitted from one of three ports of olfactometer and assessors should detect and recognize/identify the emitted odor through sniffing. The concentration is increased to stronger levels in the next presentation. The concentration next is two times higher; in other words; it has half the dilution radio (lower dilution and higher concentration). According to St. Croix Sensory (2005), odor concentrations are assessed based on ASTM International E679-04 and EN 13725:2003. ATSM E679-04 is a method for assessment of odor and taste thresholds by assessors through increasing concentration in the next sets (starting from sub-threshold and increasing the concentration level in the next sets until the panelist detects or recognizes the odorant), which is called "ascending concentration series". The average of results for each panelist is determined as the sample's detection or recognition threshold.

The Detection Threshold (DT) is the minimum concentration of odor detected in actual air, and the Recognition Threshold (RT) is the dilution ratio of first odor recognition by assessor. It is obvious that the value of DT is always less than RT. Odor threshold can be presented as Odor Units (O.U.). Moreover, "EN13725: 2003" method is reported recognition of odorant concentration and air quality through olfactometer instrument by five assessors for a minimum of two times (St. Croix Sensory, 2007).

The odor intensity indicates the strength of the odor, and is related to the odorant concentration, as shown by Steven's Law:

$$I = k\,(C)^n$$

Where,

I = the odor intensity (ppm n-butanol)

C = odor concentration (dilution ratio)

K and n = constant values for a certain odorant

The odor intensity supra-threshold is determined following ASTM International E544-99. This test compares the odor sample intensity level to a series of n-butanol references. The butanol olfactometer carries butanol in air to eight sniffing ports, with increasing the concentration of butanol in binary scale starting at 12 ppm. The average of results by assessors is reported as odor intensity (St. Croix Sensory, 2007).

Another parameter for detecting and analyzing is odor persistency, which is describes changes in odor intensity with concentration. The persistency is determined from intensity measurements, with the odor at full-strength and several dilution levels.

Odor characterization (odor quality) includes odor assessors' descriptions of what the odor "smell like" and "feels like". Odor descriptors include eight categories: medicinal, floral, vegetable, fishy, fruity, chemical, earthy, and offensive. Panelists rate the odor descriptor from 0 to 5, that is absence to strong odor, and average results are plotted on a spider graph. Sensation descriptors also include eight categories: tingling, sharp, cool, warm, itching, metallic, burning, and pungent (St. Croix Sensory, 2007).

Hedonic tone describes the pleasantness or unpleasantness of odor. In this parameter, assessors report the hedonic tone of odors based on their personal experience and memories of various odors and rank the odors in 21 points from -10 to +10. The average result from the panelists gives the HT of the sample (St. Croix Sensory, 2007).

3.6 Using Analytic Hierarchy Process (AHP) for Weighting Odors

Analytic Hierarchy Process (AHP) usually is used to weight a multi-criteria scoring model subjectively. AHP is a common method for weighting alternatives. The most important part of this method is that the decisions of the evaluator should be fair and logical. This study used AHP to weigh biosolids odors (alternative$_{(s)}$) with respect to three key criteria: human health, Detection Threshold (DT), and skin/eye irritation.

The first step of AHP, called "Pairwise Comparison," involves creating a pairwise comparison matrix for each alternative on each criterion (Ragsdale, 2012). Example values of preferences between two alternatives are shown in Table 3.2. **In this study, higher values were given to more negative human health impacts, odors, and skin/eye irritation.**

Table 3.2 The values in Analytic Hierarchy Process (AHP) to illustrate preferences between two alternatives (Ragsdale, 2006)

Value	**Preference**
1	Equally Preferred
2	Equally to Moderately Preferred
3	Moderately Preferred
4	Moderately to Strongly Preferred
5	Strongly Preferred
6	Strongly to Very Strongly Preferred
7	Very Strongly Preferred
8	Very Strongly to Extremely Strongly Preferred
9	Extremely Strongly Preferred

A pairwise comparison matrix is generated for each criterion based on "P_{ij}," or preference of alternative i to j. For instance, the preference of carbon disulfide alternative to ammonia alternative based on DT criterion is Strongly to Very Strongly Preferred ($P_{ij}=6$). The other alternatives are compared and a pairwise comparison matrix is generated based on DT. It is obvious that “P_{ii}” is always 1 and “P_{ji}” is the reciprocal of “P_{ij}”. Then, the pairwise comparison is normalized, which means the column of each alternative is summed and each value between two alternatives is divided by its column sum and placed into the new matrix. At the end of normalizing, the score of each criterion is determined by averaging the normalized scores in each row in the matrix (Ragsdale, 2006).

In the next step, which is called “consistency”, the accuracy of pairwise comparisons is examined. This step includes consistency measure, consistency index, and consistency ratio. Each consistency measure is computed by adding the product of each score from the normalized matrix by the preferences given in one of the rows of the original pairwise comparison matrix (Ragsdale, 2012). Then, consistency index and ratio are determined using the following equations;

Consistency Index (CI) = $\frac{\lambda - n}{n - 1}$

Consistency Ratio (CR) = $\frac{\mathrm{CI}}{\mathrm{RI}}$

Where:

λ = The average consistency measure for all alternatives

n = the number of alternatives

RI = the appropriate random index from Table 3.3.

Table 3.3 Appropriate Random Index (Ragsdale, 2006)

n	2	3	4	5	6	7	8
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41

In the AHP method, the consistency ratio should be less than 0.1 to meet accuracy of pairwise comparison step. A consistency ratio greater than 0.1 indicates the comparison between alternatives has not been considered carefully and logically. All steps are performed for human health and skin/eye irritation criteria as well to obtain accurate scores (Ragsdale, 2006).

In the criterion weight step, the preferences of all criterions are compared, and all steps of the AHP method are considered to achieve the criterion weights. In the last step, called "final AHP scoring model", the scores from each criterion in columns are replaced to row in new matrix, which is created with criterions row and alternative columns. The sum of each score multiplied by its criterion weight in the row is placed in the same column as a weighted average score. The weighted average score in the end of each column is the factor of that alternative (Ragsdale, 2006).

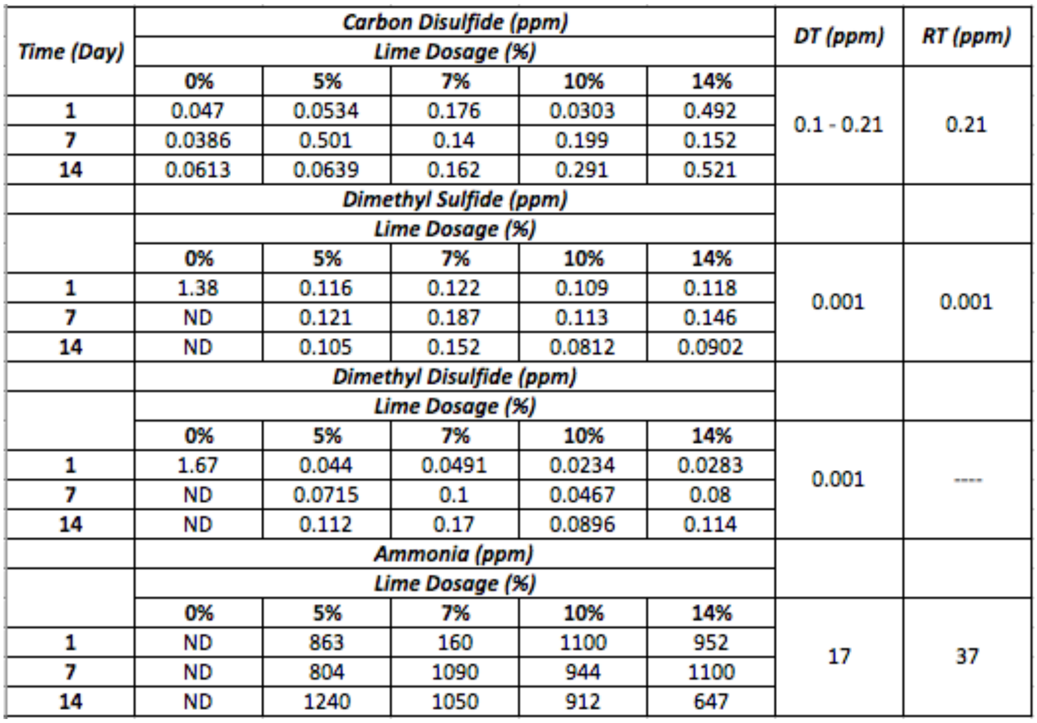
CHAPTER 4

RESULTS AND DISCUSSION

4.1 Measurement and Analysis of Odor Compounds

The headspace of samples was analyzed and the concentration of odors was measured. The concentrations of detected odor compounds are provided in Table 4.1. Looking at Day 14, increasing lime dose increases carbon disulfide concentrations, but decreases ammonia concentrations. There are no clear trends on Day 14 for dimethyl sulfide or dimethyl disulfide vs. lime dose. More than 20 reduced sulfides and amines were tested, but most were not detected by GC/MS. It is interesting that hydrogen sulfide was not detected, since it is a dominant odor from wastewater treatment plants.

Table 4.1 The Results of Odor Concentration of Biosolids with Different Lime Dosage in Three Sampling Events with their DT and RT.



Time (Day)	***Carbon Disulfide (ppm)***					***DT (ppm)***	***RT (ppm)***
	Lime Dosage (%)						
	0%	**5%**	**7%**	**10%**	**14%**		
1	0.047	0.0534	0.176	0.0303	0.492	0.1 - 0.21	0.21
7	0.0386	0.501	0.14	0.199	0.152		
14	0.0613	0.0639	0.162	0.291	0.521		
	Dimethyl Sulfide (ppm)						
	Lime Dosage (%)						
	0%	**5%**	**7%**	**10%**	**14%**		
1	1.38	0.116	0.122	0.109	0.118	0.001	0.001
7	ND	0.121	0.187	0.113	0.146		
14	ND	0.105	0.152	0.0812	0.0902		
	Dimethyl Disulfide (ppm)						
	Lime Dosage (%)						
	0%	**5%**	**7%**	**10%**	**14%**		
1	1.67	0.044	0.0491	0.0234	0.0283	0.001	----
7	ND	0.0715	0.1	0.0467	0.08		
14	ND	0.112	0.17	0.0896	0.114		
	Ammonia (ppm)						
	Lime Dosage (%)						
	0%	**5%**	**7%**	**10%**	**14%**		
1	ND	863	160	1100	952	17	37
7	ND	804	1090	944	1100		
14	ND	1240	1050	912	647		

The concentration of biosolids odors with 0% lime is provides in a separate figure due to most of concentrations are not detected or detected as an unreasonable concentration in the report, which influenced other results in terms of realizing and comparing. According to Table 4.1, the concentration of odor compounds for biosolids without lime based on sampling events is illustrated in Figure 4.1.

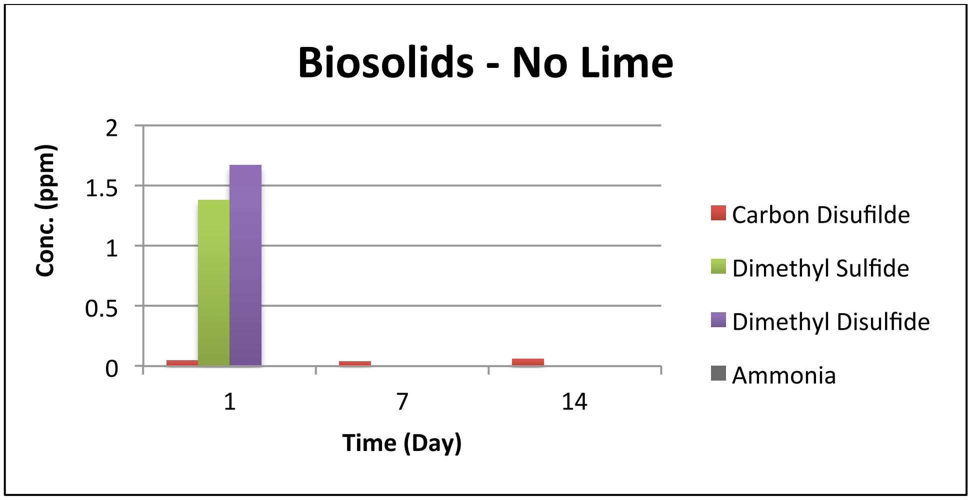


Figure 4.1 The Concentration Biosolids of Odor Compounds with No Lime Added

Figures 4.2 to 4.5 respectively illustrate the impact of various lime doses on carbon disulfide, dimethyl sulfide, dimethyl disulfide, and ammonia in 3 sampling events based on Table 4.1.

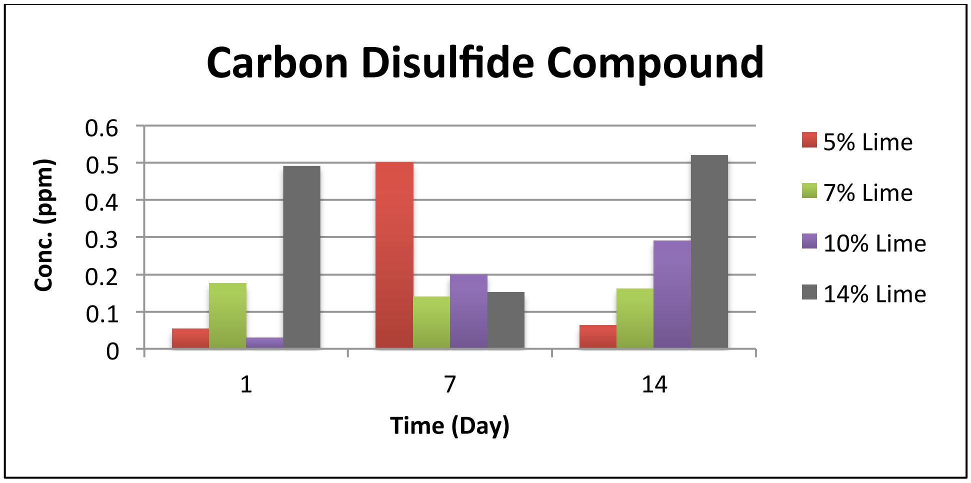


Figure 4.2 The Impact of Lime Dose on Biosolid Carbon Disulfide Concentrations

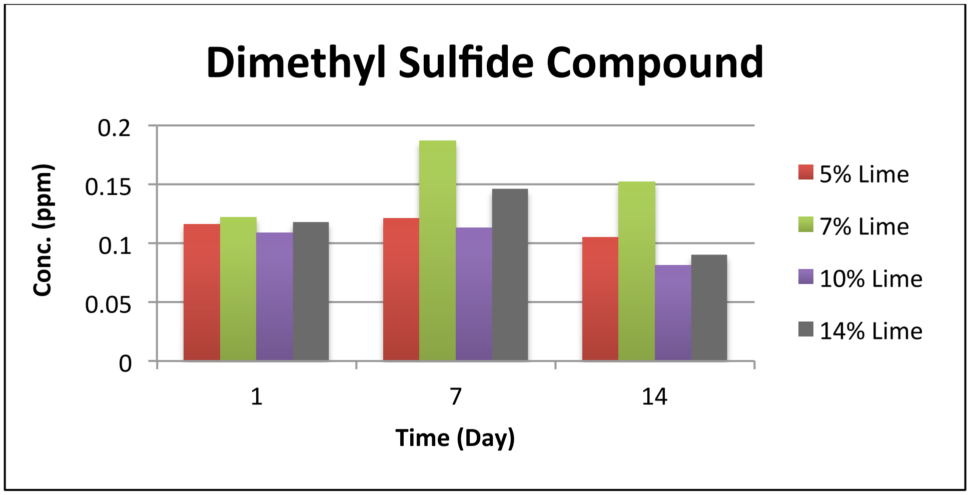


Figure 4.3 The Impact of Lime Dose on Biosolid Dimethyl Sulfide Concentrations

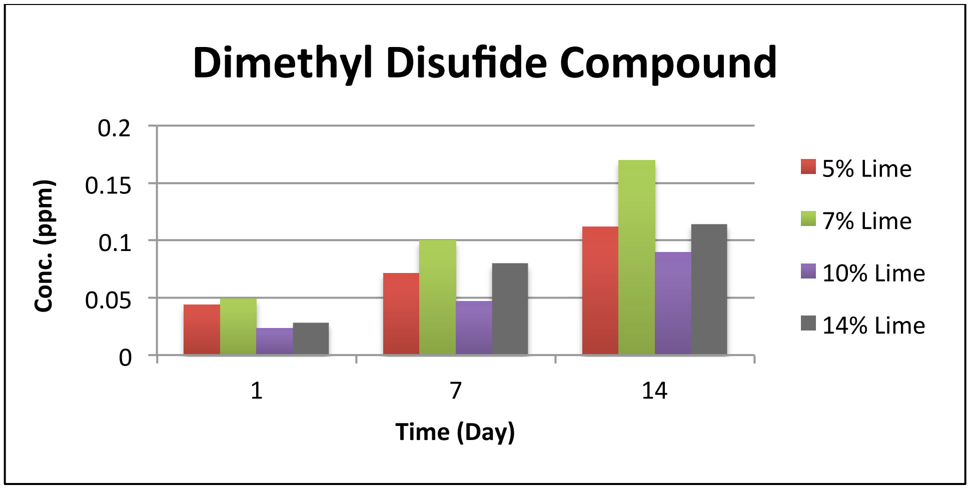


Figure 4.4 The Impact of Lime Dose on Biosolid Dimethyl Disulfide Concentrations

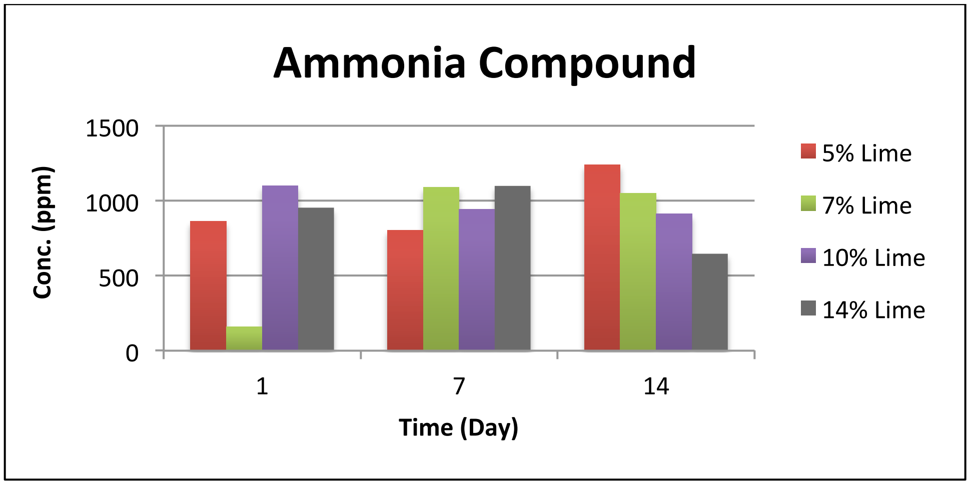
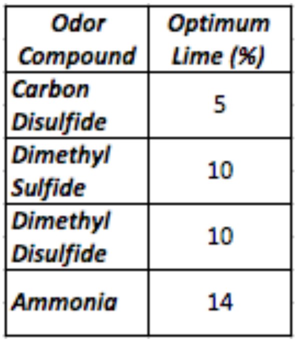


Figure 4.5 The Impact of Lime Dose on Biosolid Ammonia Concentrations

According to Figures 4.2 to 4.5, once lime is added to biosolids in 1st day the overall odor compounds is reduced which is reasonable because lime stabilization raises considerably pH in first 2 hours and reduces temporarily biosolids odorants. Moreover, enough concentration of odors is not produced in first hour of sampling to obtain correct results. Hence, the overall odor compounds concentrations in the first day are slightly lower than other days. The sulfur compound testing results of different lime dosages were also very low in comparison to ammonia in all sampling events. . 5%, 10%, 10%, and 14% lime dosage were respectively identified are the most appropriate lime dose for carbon disulfide, dimethyl sulfide, dimethyl disulfide, and ammonia. The optimum of lime dose for each odor compound is listed in Table 4.2.

Table 4.2 The Optimum Lime Dose for Each Odor Compound



Odor Compound	***Optimum Lime (%)***
Carbon Disulfide	5
Dimethyl Sulfide	10
Dimethyl Disulfide	10
Ammonia	14

Analytical Hierarchy Process (AHP) is applied in this study to weight the odor compounds for evaluation and comparison between each other based on some criteria. After weighting the odors, choosing the most appropriate lime dosage in biosolids is easier. Three criteria have been considered (ratio of considered odor compounds to Detection Threshold (DT), skin and eye irritation, and overall negative human health impacts) for the purpose of this study in order to weight the detected odor compounds. The amount of Detection Threshold (DT) is always equal or lower than Recognition Threshold (RT). In other words, odors are detected in the first step and in higher level of concentrations are recognized. Hence, DT is chosen as one of criteria instead on RT. Weighting of DT is based on Table 1.1 in Chapter 1. For example, dimethyl sulfide and dimethyl disulfide have DTs of 0.001 ppm; carbon disulfide has a DT of 0.1 to 0.21 ppm; ammonia has a DT of 17 ppm. A compound with a lower DT produces annoyance at a lower concentration; hence, it is given a higher weighting (with higher values representing greater nuisance). Thus, dimethyl sulfide and dimethyl disulfide are given weightings of 8 and 9, carbon disulfide 4, and ammonia 1 (relative to ammonia). Table 1.1 shows that dimethyl sulfide and dimethyl disulfide are the same DT; however, the DT of dimethyl sulfide is slightly higher than dimethyl disulfide in some researches (Sekyiamah et. al, 2008; Ruth, 1986). Hence, the preference of dimethyl disulfide to diethyl sulfide is considered 2 based on DT. The procedures and results of DT are shown in Table 4.1.2. Sample calculations are also provided in Appendix A.

Table 4.3. Weighting Based on Odor DT

Detection Threshold						
	CS_2	**DMS**	**DMDS**	**NH_3**		
CS_2	1.000	0.250	0.200	4.000		
DMS	4.000	1.000	0.500	8.000		
DMDS	5.000	2.000	1.000	9.000		
NH_3	0.250	0.125	0.111	1.000		
SUM	10.250	3.375	1.811	22.000		
	Normalized Comparisons				***DT Scores***	***Consistency Measure***
	CS_2	**DMS**	**DMDS**	**NH_3**		
CS_2	0.098	0.074	0.110	0.182	0.116	4.046
DMS	0.390	0.296	0.276	0.364	0.332	4.184
DMDS	0.488	0.593	0.552	0.409	0.510	4.177
NH_3	0.024	0.037	0.061	0.045	0.042	4.023
Ave.						4.107

Consistency Index = 0.0357

Consistency Ratio = 0.0397

If the value of consistency ratio is less than 0.1, which is the best fit for consistency ratio, the considered values in pairwise comparison are more acceptable and logical.

Skin and eye irritation criterion is weighted based on the negative impact of odors on skin and eye in Table 1.2. Table 4.4 provides the results of skin and eye irritation.

Table 4.4 Weighting Based on Skin and Eye Irritation

Skin and Eye Irritation						
	CS_2	**DMS**	**DMDS**	**NH_3**		
CS_2	1.000	0.333	0.250	4.000		
DMS	3.000	1.000	0.500	8.000		
DMDS	4.000	2.000	1.000	9.000		
NH_3	0.250	0.125	0.111	1.000		
SUM	8.250	3.458	1.861	22.000		
	Normalized Comparisons				***S&E Irr. Scores***	***Consist. Measure***
	CS2	**DMS**	**DMDS**	**NH_3**		
CS_2	0.121	0.096	0.134	0.182	0.133	4.030
DMS	0.364	0.289	0.269	0.364	0.321	4.096
DMDS	0.485	0.578	0.537	0.409	0.502	4.110
NH_3	0.030	0.036	0.060	0.045	0.043	4.015
Ave.						4.063

Consistency Index = 0.0208

Consistency Ratio = 0.0232

Overall human health criterion is weighted based on negative impacts of considered odor compounds on human health in Table 1.2. Table 4.5 illustrates the results of overall human health impacts.

Table 4.5 Weighting Based on Human Health

Overall Human Health						
	CS_2	**DMS**	**DMDS**	**NH_3**		
CS_2	1.000	3.000	5.000	8.000		
DMS	0.333	1.000	2.000	5.000		
DMDS	0.200	0.500	1.000	3.000		
NH_3	0.125	0.200	0.333	1.000		
SUM	1.658	4.700	8.333	17.000		
	Normalized Comparisons				***Human Health Scores***	***Consist. Measure***
	CS_2	**DMS**	**DMDS**	**NH_3**		
CS_2	0.603	0.638	0.600	0.471	0.578	4.112
DMS	0.201	0.213	0.240	0.294	0.237	4.061
DMDS	0.121	0.106	0.120	0.176	0.131	4.031
NH_3	0.075	0.043	0.040	0.059	0.054	4.013
Ave.						4.054

Consistency Index = 0.0108

Consistency Ratio = 0.0200

Now, weighting criterions based on each other are conducted using the same procedure. Table 4.6 shows the criterion weights. Human health is weighted more heavily (weight of 6) and skin and eye irritation is weighted more heavily (weight of 3) compared to DT (weight of 1). DT reflects odor, which is a nuisance, but doesn’t constitute real or long-term health impacts. Skin and eye irritation is less serious than the human health impacts.

Table 4.6 Weighting Based on Criteria

Criterion Weights					
	DT	**S&E Irr.**	**Human Health**		
DT	1.000	0.333	0.167		
S&E Irr.	3.000	1.000	0.333		
Human Health	6.000	3.000	1.000		
SUM	10.000	4.333	1.500		
	Normalized Comparisons			***Criterion Weight***	***Consist. Measure***
	DT	**S&E Irr.**	**Human Health**		
DT	0.100	0.077	0.111	0.096	3.005
S&E Irr.	0.300	0.231	0.222	0.251	3.015
Human Health	0.600	0.692	0.667	0.653	3.035
Ave.					3.018

Consistency Index = 0.091

Consistency Ratio = 0.0015

Consistency test is done with the result of consistency ratio in all Tables, and they meet consistency test requirement. Thus, pairwise comparisons between odor compounds and criterions are logical and acceptable.

The last matrix is created, which is called “Final AHP Scoring Model”, to analyze and weight odors compounds using scoring model. The results of final AHP scoring model are provided in Table 4.7.

Table 4.7. Final AHP Scoring Model

Final AHP Scoring Model						
	Alternatives					***Criterion Weights***
Criterion	**CS_2**	**DMS**	**DMDS**	**NH_3**		
DT	0.116	0.332	0.510	0.042		0.096
S&E Irr.	0.133	0.321	0.502	0.043		0.251
Human Health	0.578	0.237	0.131	0.054		0.653
Sum of Weighted Score	0.422	0.267	0.261	0.050		1.000

According to AHP model, based on three considered criterions, weighted average scores for carbon disulfide, dimethyl sulfide, dimethyl disulfide, and ammonia are respectively 0.422, 0.267, 0.261, and 0.050.

AHP factors for each odor compounds are multiplied by the concentration of each odor compound to obtain weighted consistent values for comparing overall maximum odor concentration based of sampling events and lime dosage. Tables 4.8 to 4.14 and Figures 4.6 to 4.12 illustrate the impact of lime doses on weighted odor compound based on three sampling events and five lime dosages.

Table 4.8 The Results of Weighted Odor Compounds in 1st Day

Lime (%)	***Odor Compounds***				***Sum of Reduced sulfides***
	CS_2	**DMS**	**DMDS**	**NH_3**	
5%	0.02	0.0310	0.0115	43.15	0.0650
7%	0.0743	0.0326	0.0128	8.00	0.1197
10%	0.0128	0.0291	0.0061	55.00	0.0480
14%	0.0208	0.0315	0.0074	47.60	0.0597

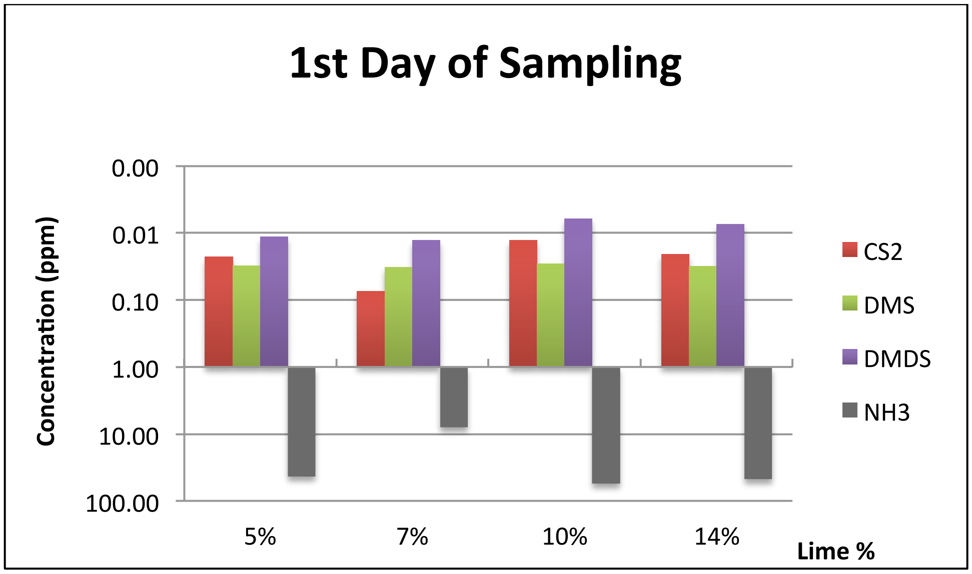


Figure 4.6 Impacts of Lime Dosages on Weighted Odor Compounds– First Day of Sampling

Table 4.9 The Results of Weighted Odor Compounds in 7th Day

Lime (%)	***Odor Compounds***				***Sum of Reduced sulfides***
	CS_2	**DMS**	**DMDS**	**NH_3**	
5%	0.21	0.0323	0.0187	40.20	0.2624
7%	0.0591	0.0499	0.0261	54.50	0.1351
10%	0.0840	0.0302	0.0122	47.20	0.1263
14%	0.0641	0.0390	0.0209	55.00	0.1240

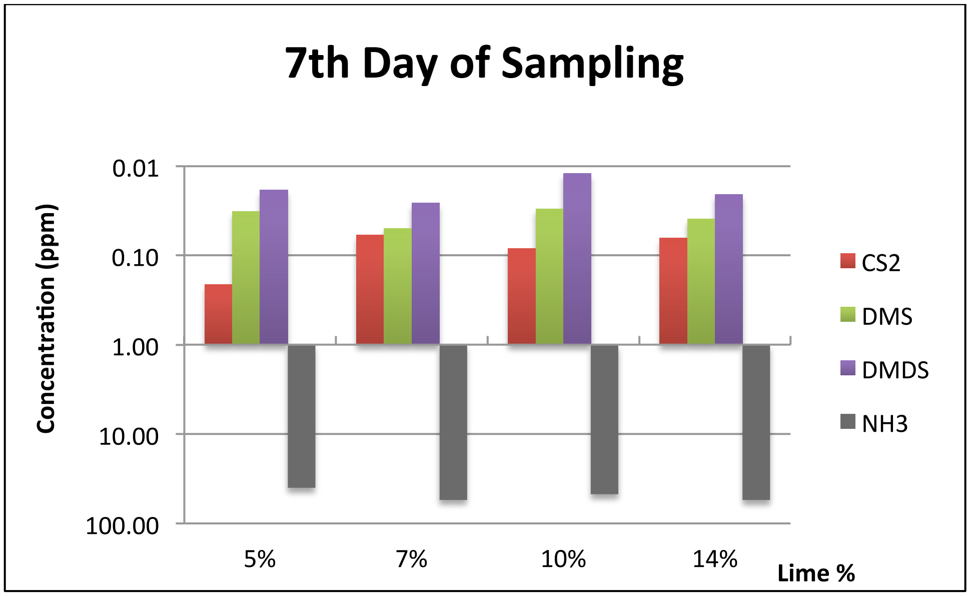


Figure 4.7 Impacts of Lime Dosages on Weighted Odor Compounds – 7th Day of Sampling

Table 4.10 The Results of Weighted Odor Compounds in 14th Day

Lime (%)	***Odor Compounds***				***Sum of Reduced sulfides***
	CS_2	**DMS**	**DMDS**	**NH_3**	
5%	0.03	0.0280	0.0292	62.00	0.0842
7%	0.0684	0.0406	0.0444	52.50	0.1533
10%	0.1228	0.0217	0.0234	45.60	0.1679
14%	0.2199	0.0241	0.0298	32.35	0.2737

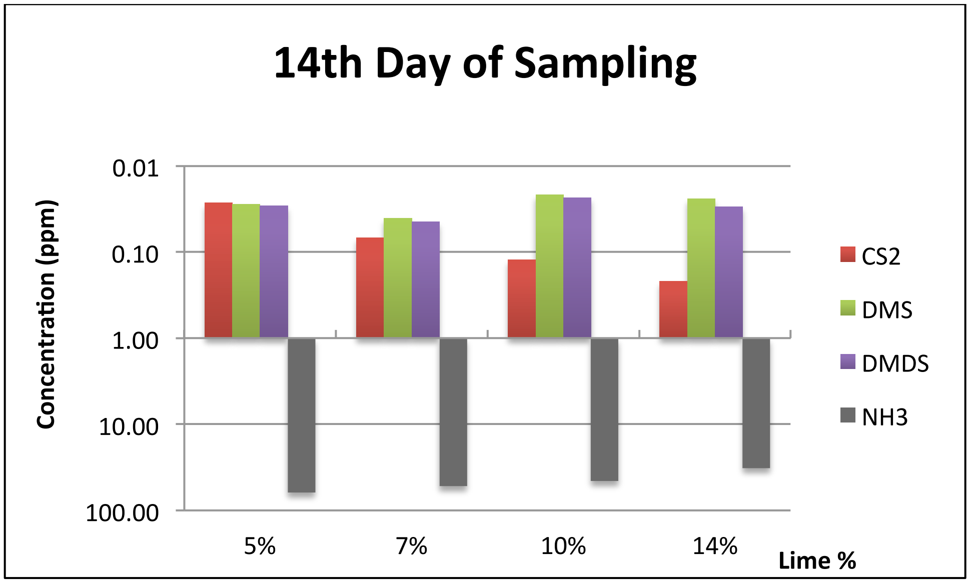


Figure 4.8 Impact of Lime Dosages on Weighted Odor Compounds – 14th Day of Sampling

Table 4.11 The Results of Weighted Odor Compounds of Biosolids with 5% Lime Addition

DAY	***Odor Compounds***				***Sum of Reduced sulfides***
	CS_2	**DMS**	**DMDS**	**NH_3**	
1	0.0225	0.0310	0.0115	43.15	0.0650
7	0.2114	0.0323	0.0187	40.20	0.2624
14	0.0270	0.0280	0.0292	62.00	0.0842

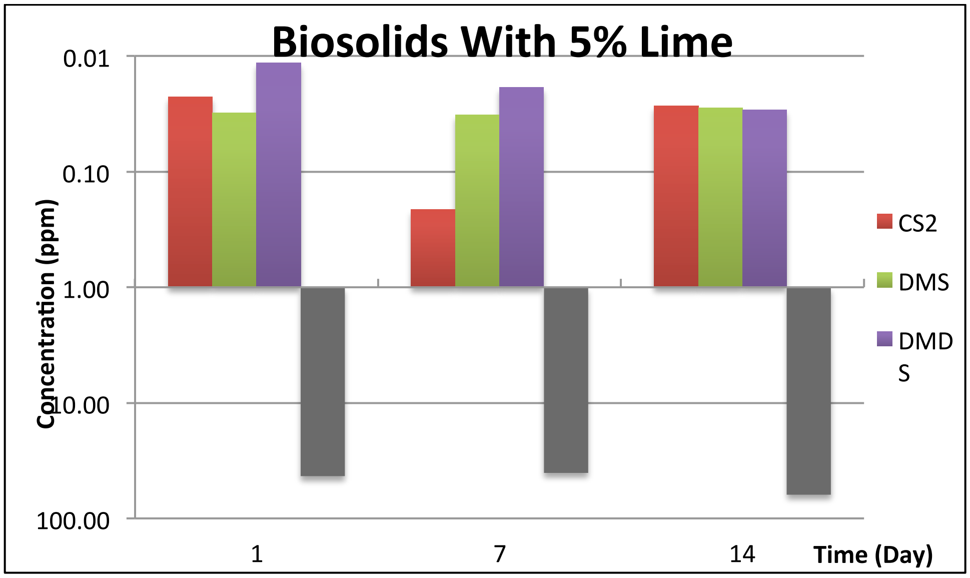


Figure 4.9 Impact of 5% Lime Dosage on Concentration of Weighted Odor Compounds in Three Sampling Events

Table 4.12 The Results of Weighted Odor Compounds of Biosolids with 7% Lime Addition

Day	***Odor Compounds***				***Sum of Reduced sulfides***
	CS_2	**DMS**	**DMDS**	**NH_3**	
1	0.07	0.0326	0.0128	8.00	0.1197
7	0.0591	0.0499	0.0261	54.50	0.1351
14	0.0684	0.0406	0.0444	52.50	0.1533

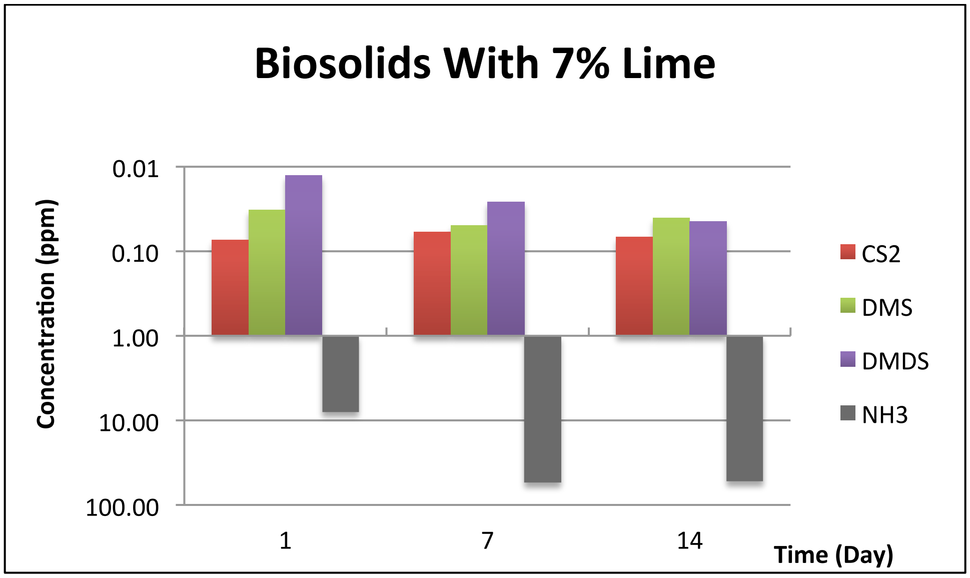


Figure 4.10 Impact of 7% Lime Dosage on Concentration of Weighted Odor Compounds in Three Sampling Events

Table 4.13 The Results of Weighted Odor Compounds of Biosolids with 10% Lime Addition

Day	***Odor Compounds***				***Sum of Reduced sulfides***
	CS_2	**DMS**	**DMDS**	**NH_3**	
1	0.01	0.0291	0.0061	55.00	0.0480
7	0.0840	0.0302	0.0122	47.20	0.1263
14	0.1228	0.0217	0.0234	45.60	0.1679

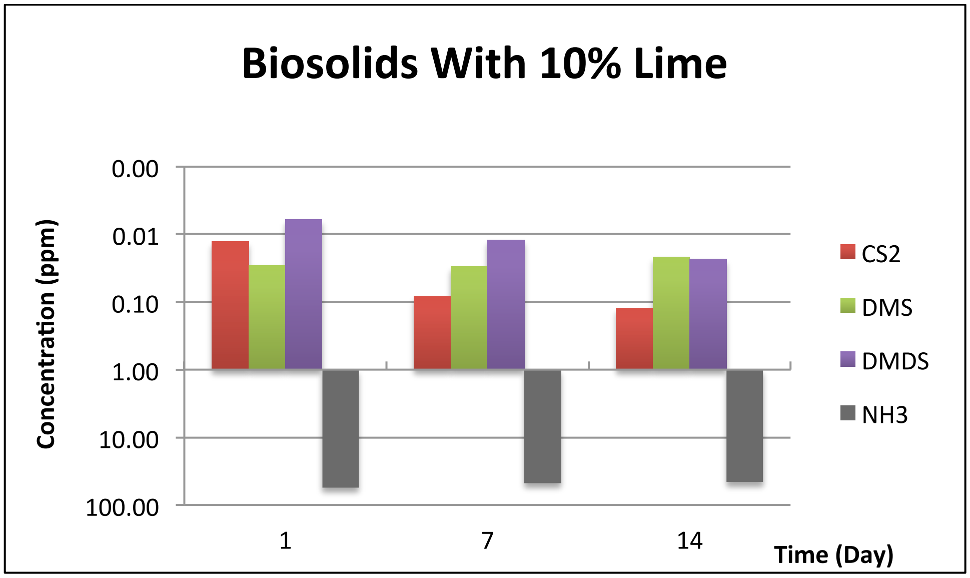


Figure 4.11 Impact of 10% Lime Dosage on Concentration of Weighted Odor Compounds in Three Sampling Events

Table 4.14 The Results of Weighted Odor Compounds of Biosolids with 14% Lime Addition

Day	***Odor Compounds***				***Sum of Reduced sulfides***
	CS_2	**DMS**	**DMDS**	**NH_3**	
1	0.02	0.0315	0.0074	47.60	0.0597
7	0.0641	0.0390	0.0209	55.00	0.1240
14	0.2199	0.0241	0.0298	32.35	0.2737

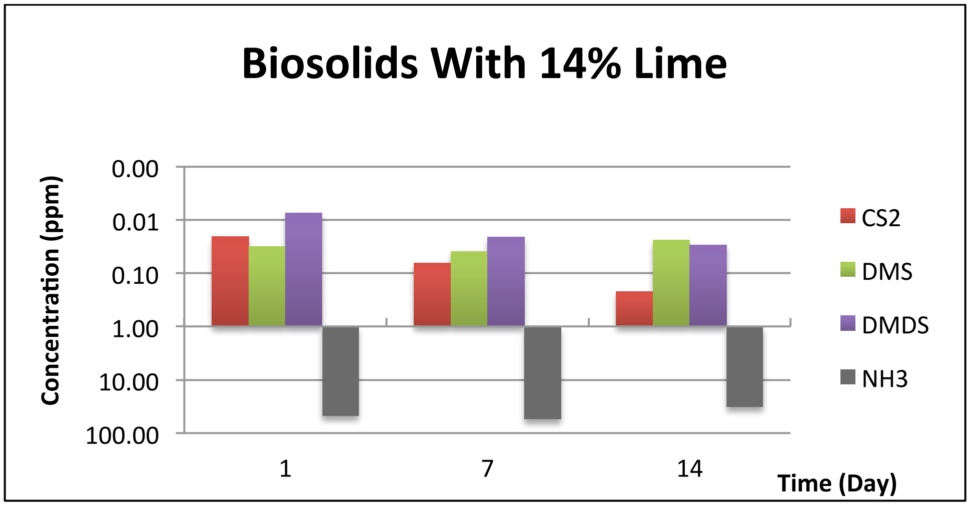


Figure 4.12 Impact of 14% Lime Dosage on Concentration of Weighted Odor Compounds in Three Sampling Events

Since ammonia concentrations in all samples are approximately the same amount and DT of ammonia is significantly higher than other odors, the sum of weighted reduced sulfides are considered higher priority to choose the appropriate limes, and then based on selected limes with low reduced sulfides, the weighted ammonia concentrations are considered as the second priority to determine the most appropriate lime dose into biosolids. According to Figures 4.6 to 4.8 and Tables 4.8 to 4.10, the sum of weighted reduced sulfides compounds in 1st day are lower than other sampling events, and 10% lime addition into biosolids seemed the more appropriate lime dose for odor reduction in the first day. However, the results of first day sampling is not valid to determine as the optimum lime dose due to high pH in first hours results in temporarily considerable odor reduction and pathogen activities need more time to return in stable conditions. Although the sum of weighted reduced sulfides compounds for 14% lime is slightly lower than 10% lime in 7th day, the difference is not substantial.

In another aspect, based on Figure 4.9 to 4.12 and Tables 4.11 to 4.14, the sum of weighted reduced sulfides for 5% lime dose addition into biosolids in 14th day is the lowest value; however, it is not considered as the optimum lime dose due to high level of ammonia concentration compare to other appropriate lime dosage.

Moreover, the sum of weighted reduced sulfides compounds for 10% and 14% lime doses are the lowest value in 7th day. Although the value of weighted odor compounds in 14% lime dose is lower than 10% in 7th day, 10% lime dose is chosen as more appropriate lime percentage because of considerable higher level of ammonia concentration in 14% lime dose in 7th day. Besides, it is not economical to use 4% more lime dose because of insignificant difference in overall weighted concentration (0.002 difference). Therefore, 10% lime is recommended as the most appropriate lime dosage for odor reduction of biosolids in summertime. The concentration of odors of biosolids with 10% lime addition in 1st, 7th, 14th day is also compared to their DT and RT limit. Although all odor concentrations (except carbon disulfide in 7th day) are above DT and RT limits, 10% lime addition into biosolids is still the most appropriate lime dose for maximum odor reduction of biosolids. The comparison between biosolids odor compound in three sampling events and their DT and RT limits is listed in Table 4.15.

Table 4.15 Comparing Odor Concentrations in Three Sampling events with their DT and RT

Odor Compounds Name	**Conc. in 1st of sampling (ppm)**	**Conc. in 7th of sampling (ppm)**	**Conc. in 14th of sampling (ppm)**	**Detection Threshold Limit (ppm)**	**Recognition Threshold Limit (ppm)**
Carbon disulfide	0.0303	0.199	0.291	0.1 - 0.21	0.21
Dimethyl Sulfide	0.109	0.113	0.0812	0.001	0.001
Dimethyl disulfide	0.0234	0.0467	0.0896	0.001	-----
Ammonia	1100	944	912	17	37

4.2 pH and Calcium Content

The amount of calcium and pH of biosolids with different lime dosages in 14th day was measured to check if they meet regulatory requirements. The pH of samples was measured two times that the results are shown in Table 4.16. The results of calcium measurement are also provided in Table 4.17.

Table 4.16 pH Measurement for Biosolids with Different Lime Dosage in 14th Day

pH Measurement	***Biosolids - No Lime (0%)***	***Biosolids with 5% Lime***	***Biosolids with 7% Lime***	***Biosolids with 10% Lime***	***Biosolids with 14% Lime***
First Measurement	8.29	12.42	12.56	12.65	12.7
Second Measurement	8.47	12.37	12.89	12.87	12.97
Average	8.38	12.40	12.73	12.76	12.84

Table 4.17 Calcium Measurement for Biosolids with Different Lime Dosage in 14th Day

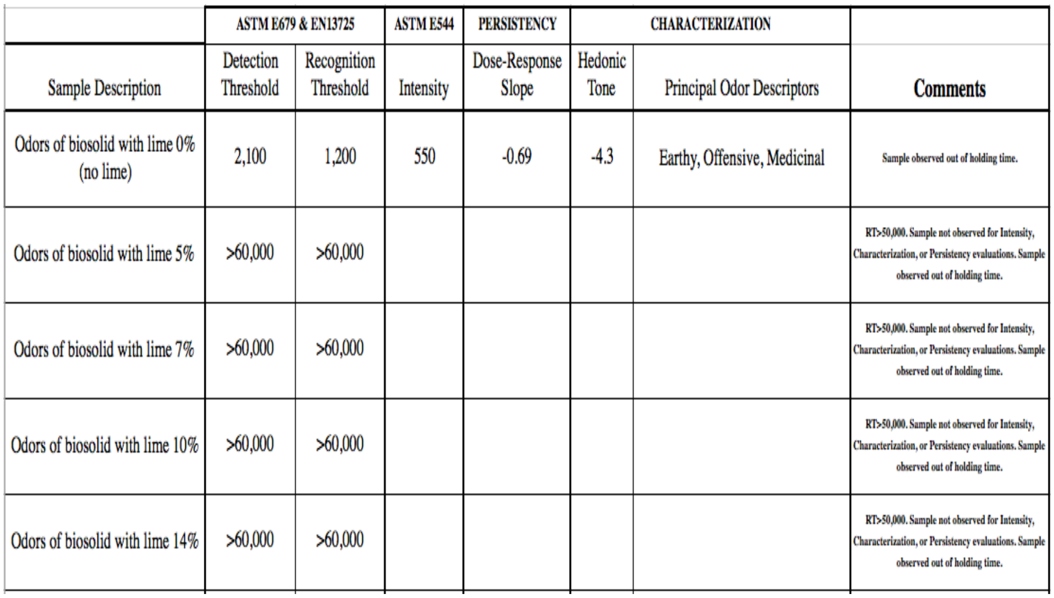
Calcium Measurement	***Biosolids - No Lime (0%) (mg/Kg)***	***Biosolids with 5% Lime (mg/Kg)***	***Biosolids with 7% Lime (mg/Kg)***	***Biosolids with 10% Lime (mg/Kg)***	***Biosolids with 14% Lime (mg/Kg)***
Measurement	7,310	42,900	61,600	80,000	92,700

According to the average of the pH measurements in Figure 4.16, the pH of all biosolids samples after lime addition is greater than 12, which meets pathogen control and vector attraction reduction requirements in EPA Part 503 rule. The recommended lime (10%) also meets pH requirements. The measurements of calcium in Table 4.17 are lower than calcium concentration limits. In other words, calcium concentration limits in soil following by US Department of Interior (1981) is 116,700 mg/Kg, and all samples meet this requirement.

4.3 Odor Evaluation

St. Croix Sensory, Inc. analyzed samples based on five odor parameters: odor threshold (DT and RT), intensity, persistency, hedonic tone and odor characterization (odor descriptor and sensation descriptor). The odor evaluation for five samples of biosolids with different lime dosages is shown in Table 4.18.

Table 4.18 Odor Evaluation Based on Odor Parameters



	ASTM E679 & EN13725		ASTM E544	PERSISTENCY	CHARACTERIZATION		
Sample Description	Detection Threshold	Recognition Threshold	Intensity	Dose-Response Slope	Hedonic Tone	Principal Odor Descriptors	Comments
Odors of biosolid with lime 0% (no lime)	2,100	1,200	550	-0.69	-4.3	Earthy, Offensive, Medicinal	Sample observed out of holding time.
Odors of biosolid with lime 5%	>60,000	>60,000					RT>50,000. Sample not observed for Intensity, Characterization, or Persistency evaluations. Sample observed out of holding time.
Odors of biosolid with lime 7%	>60,000	>60,000					RT>50,000. Sample not observed for Intensity, Characterization, or Persistency evaluations. Sample observed out of holding time.
Odors of biosolid with lime 10%	>60,000	>60,000					RT>50,000. Sample not observed for Intensity, Characterization, or Persistency evaluations. Sample observed out of holding time.
Odors of biosolid with lime 14%	>60,000	>60,000					RT>50,000. Sample not observed for Intensity, Characterization, or Persistency evaluations. Sample observed out of holding time.

According to Table 4.18, odor thresholds for bisolids with lime 5, 7, 10, and 14% are more than 60,000 (O.U). Based on ASTM E679 and E13725, Recognition Threshold values are more than 50,000, and they are not observed for intensity, persistency, and characterization evaluation. Odor threshold for "No lime" sample is illustrated in Table 4.18, and Detection Threshold (DT) and Recognition Threshold (RT) are respectively 2,100 and 1,200, which is reasonable because the odor can be detected at greater dilutions. Based on ASTM E544, the intensity parameter (odor strength super higher than RT) is 550 (O.U.), which the concentration of butanol (standard odorant which is tested and certified on panelists by St. Croix Sensory) started at 12 ppm and increased based on binary scale till the assessors recognize the odor.

The odor persistency was analyzed through a "Dose-Response" graph to find how the odor intensity changes based on its dilution ratio. According to Figure 4.13, the results show a line on a logarithmic plot. On 'Dose-Response" graph, the slope of the line

(-0.69) is the exposed persistency parameter and the y-axis intercept (2.79) illustrated the full strength intensity. The first point at 2.74-ppm butanol with zero dilution ratio is n-butanol odor intensity of full strength odor sample on “Dose Response” graph, which is converted from the intensity parameter (Log550 = 2.74). Three more dilution ratios are utilized to determine odor intensity rate. Odor intensity of full strength at various dilution rates is illustrated in Table 4.19, which can interpret on “Dose-Response” graph. As shown in Figure 4.13, increasing dilution ratio results in odor intensity reduction.

Table 4.19 Odor Intensity for Different Dilution Ratios - Biosolids without Lime Addition

Dilution Ratio	***Odor Intensity***	***Log Dilution Ratio***	***Log Odor Intensity***
1	550	0	2.74
5	245	0.7	2.39
13	105	1.1	2.02
50	38	1.7	1.58

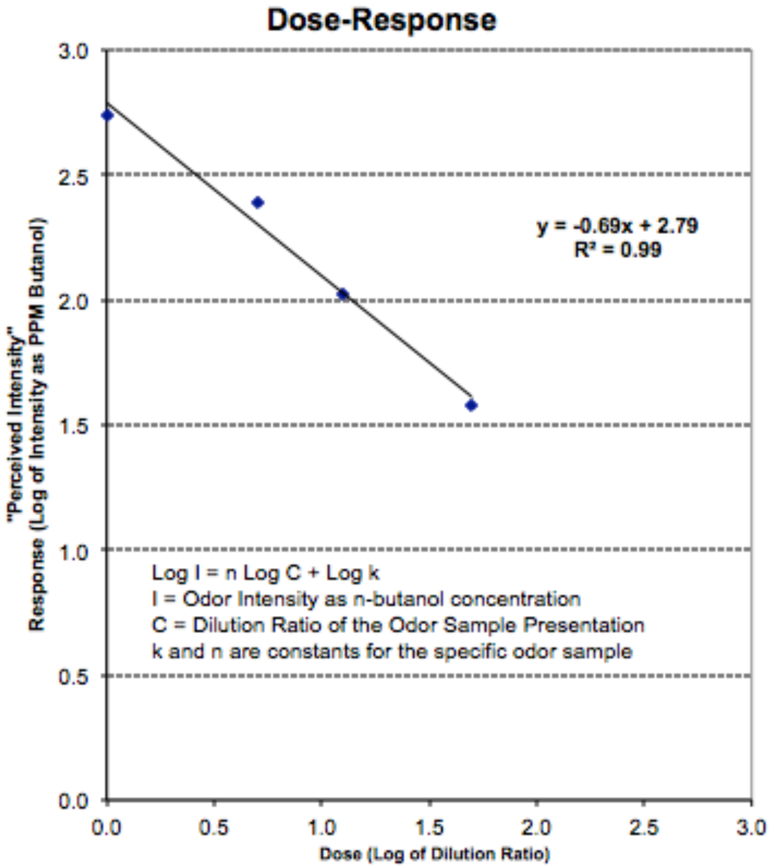


Figure 4.13 "Dose-Response" - Biosolids without Lime Addition

St. Croix Sensory (2007) states that "This "Dose-Response". Persistence, graph can be converted to a Power Law graph showing how the intensity changes with the odor concentration, represented in 'Odor Units.' This conversion is completed by taking the recognition threshold of the odorous air sample, the full strength odor concentration, into consideration". Dividing RT by the dilution ratio calculates the odor concentration. The results of intensity versus odor concentration are shown in Table 4.20.

Table 4.20 Odor intensity in Different Odor Concentrations - Biosolids without Lime

Odor Conc.	*Odor Intensity*	*Log Odor Conc.*	*Log Odor Intensity*
240	245	2.38	2.39
92	105	1.97	2.02
24	38	1.38	1.58

Based on the value of RT (1200) and three dilution ratios (5, 13, and 50), the RT/dilution ratio (odor concentration) is determined, and "Dose-Response as Power Law" is created, as shown in Figure 4.14.

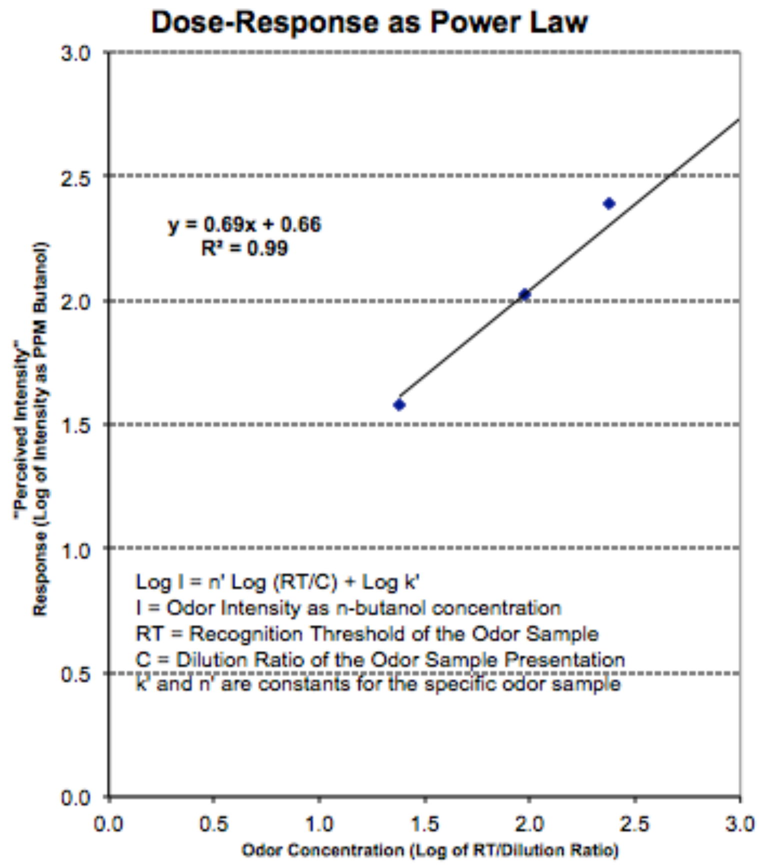


Figure 4.14 "Dose-Response as Power Law" - Biosolids Before Lime

The “odor quality” was also determined for biosolids without lime addition, which included odor descriptors and sensation descriptors. Each descriptor is presented in eight standard categories that panelists rate from 1 to 5 for each category, and the average ratings for each category is illustrated in a spider graph. The percentage of categories for odor descriptors is also shown as a histogram. The histogram percentage of odor descriptors is provided in Figure 4.15, and the spider graph for sensation and odor descriptors is also illustrated in Figure 4.16.

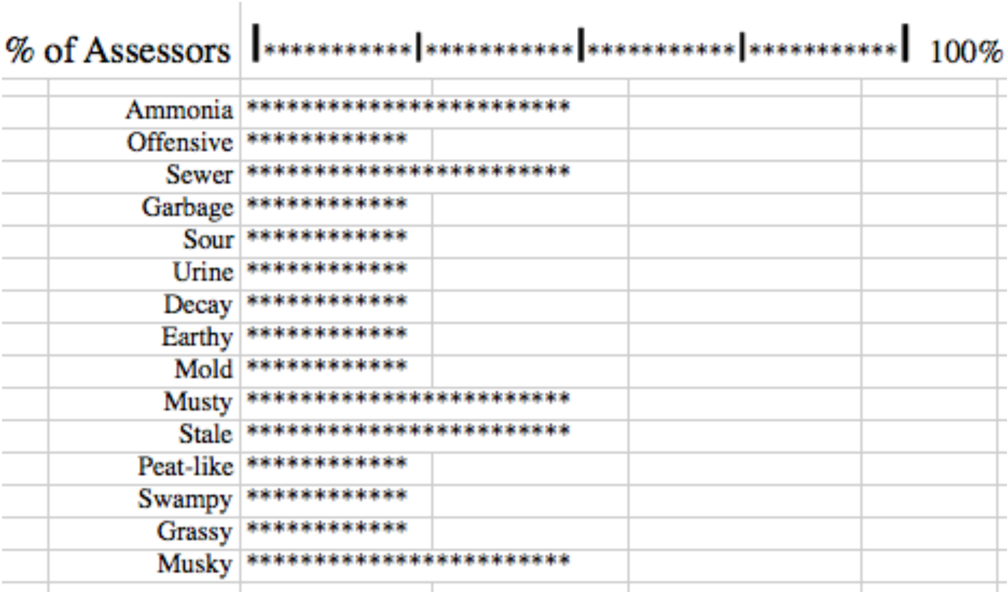
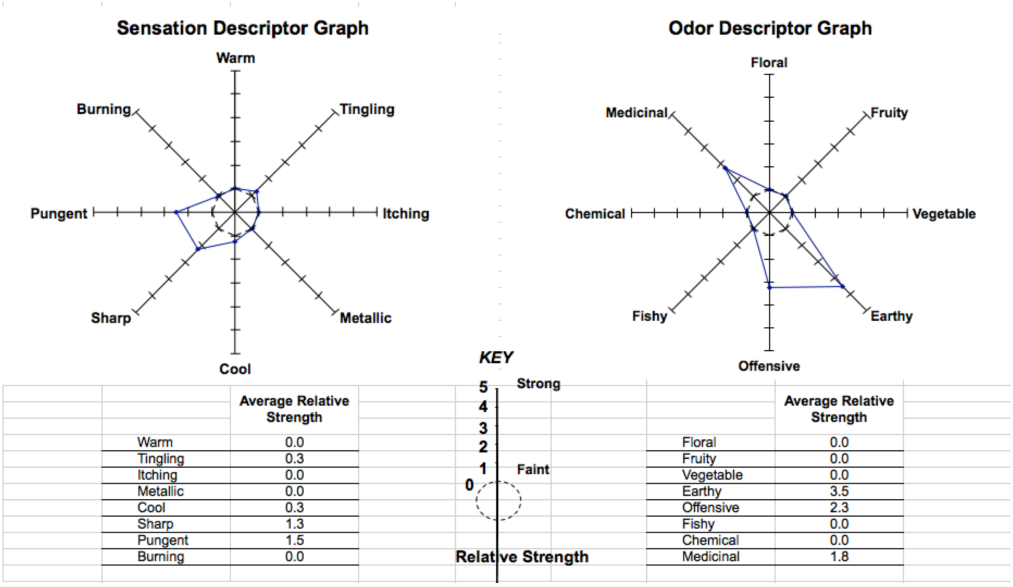


Figure 4.15 The Histogram Percentage - Biosolids without Lime



	Average Relative Strength
Warm	0.0
Tingling	0.3
Itching	0.0
Metallic	0.0
Cool	0.3
Sharp	1.3
Pungent	1.5
Burning	0.0

	Average Relative Strength
Floral	0.0
Fruity	0.0
Vegetable	0.0
Earthy	3.5
Offensive	2.3
Fishy	0.0
Chemical	0.0
Medicinal	1.8

Figure 4.16 Sensation and Odor Descriptor Graph – Biosolids without Lime

According to Figure 4.15, most assessors identified that the odor sample (biosolids – no lime) has highs ammonia concentration, and it smells like sewer, musty, stale, and musky. Moreover, the descriptors of pungent, sharp, medicinal, offensive, and earthy were frequently chosen.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results indicated the impact of lime dosage on odor reduction of biosolids over 14 days. 4 different lime dosages were mixed with biosolids and odorous compounds were measured to obtain the optimum lime dose for maximum odor reduction in summertime. 5%, 10%, 10%, and 14% lime dosage were respectively identified are the most appropriate lime dose for Carbon disulfide, Dimethyl sulfide, Dimethyl disulfide, and ammonia.

All odor compounds are weighted by AHP method and sum of weighted odorants are compared together to find the lowest overall odor concentration. Since the overall sum of weighted reduce sulfides and ammonia for biosolids with 10% lime dose is the lowest value compare to other lime dosages, 10% lime into biosolids was identified as the most appropriate lime dose for this study. The recommended lime addition (10%) into biosolids also meets pH and calcium requirements. Moreover, odor evaluation is analyzed for all samples. Since RTs of biosolids odorants with lime dosages are above than 50,000 ppm, the odor evaluation could only be conducted for biosolids without lime sample.

5.2 Recommendations for Future Research

According to Forbes et al. (2003), increasing solids retention time (SRT) in digester may eliminate more volatile solids during anaerobic treatment and result in reducing reduced sulfur compounds and consequently lower odor emissions in dewatered biosolids. Investigating the impacts of digester retention time during anaerobic treatment of odor reduction of biosolids can be considered as future research. In other words, cleaning the digester regularly, using technologies to improve digester mixing, and adding lime or other chemicals in the digester to decrease biosolids odorants can be researched in the future.

Moreover, the impact of wind on odor concentration can be researched in the future studies. Using various wind speeds and stabilities along with terrain data, concentrations, as functions of time and distance can be determined through dispersion modeling. Besides, installing monitors at several receptor sites in nearby residential areas would provide useful information.

Uncertainty analysis can be done in the future studies in terms of the quality of sample collection and the quality of instruments for collecting and analyzing odors. In addition, impact of lime dosage on wastewater facilities before transport to biosolids facilities in order to reduce odor concentration of biosolids is recommended as future research. A comparative cost analysis of increasing lime dosages can be done in the future. The future researches also can be conducted at a pilot level in the field to analyze cost and feasibility of the quicklime treatment.

Appendix A

Sample calculation of AHP

Pairwise comparison:

P $_{\text{(DMS to CS2)}}$ = 4 → P $_{\text{(CS2 to DMS)}}$ = 1/4 = 0.25

Or,

P $_{\text{(DMDS to CS2)}}$ = 5 → P $_{\text{(CS2 to DMDS)}}$ = 1/5 = 0.2

, and so on.

Then, the values of each column are summed at the end of column.

For example, Sum of CS_2 column = 10.25

Normalizing for column CS_2:

CS_2 row: 1/10.25 = 0.098

DMS row: 4/10.25 = 0.390

DMDS row: 5/10.25 = 0.488

NH_3 row: 0.25/10.25 = 0.024

DT Scores (average of each row):

CS_2 = (0.098 + 0.074 + 0.110 + 0.182) / 4 = 0.116

To normalization and DT scoring, all odor columns are followed the same procedure.

Consistency Test:

Consistency measure for CS_2 in row = $\frac{(0.116 \times 1)+(0.332 \times 0.25)+(0.510 \times 0.2)+(0.0420 \times 4)}{0.116}$ = 4.045

Consistency measure for DMS in row = $\frac{(0.116 \times 4)+(0.332 \times 1)+(0.510 \times 0.5)+(0.0420 \times 8)}{0.332}$ = 4.183

Consistency measure for DMDS in row = $\frac{(0.116 \times 5)+(0.332 \times 2)+(0.510 \times 1)+(0.0420 \times 9)}{0.510}$ = 4.176

Consistency measure for NH_3 in row = $\frac{(0.116\times 0.25)+(0.332 \times 0.125)+(0.510 \times 0.11)+(0.0420 \times 1)}{0.0420}$ = 4.023

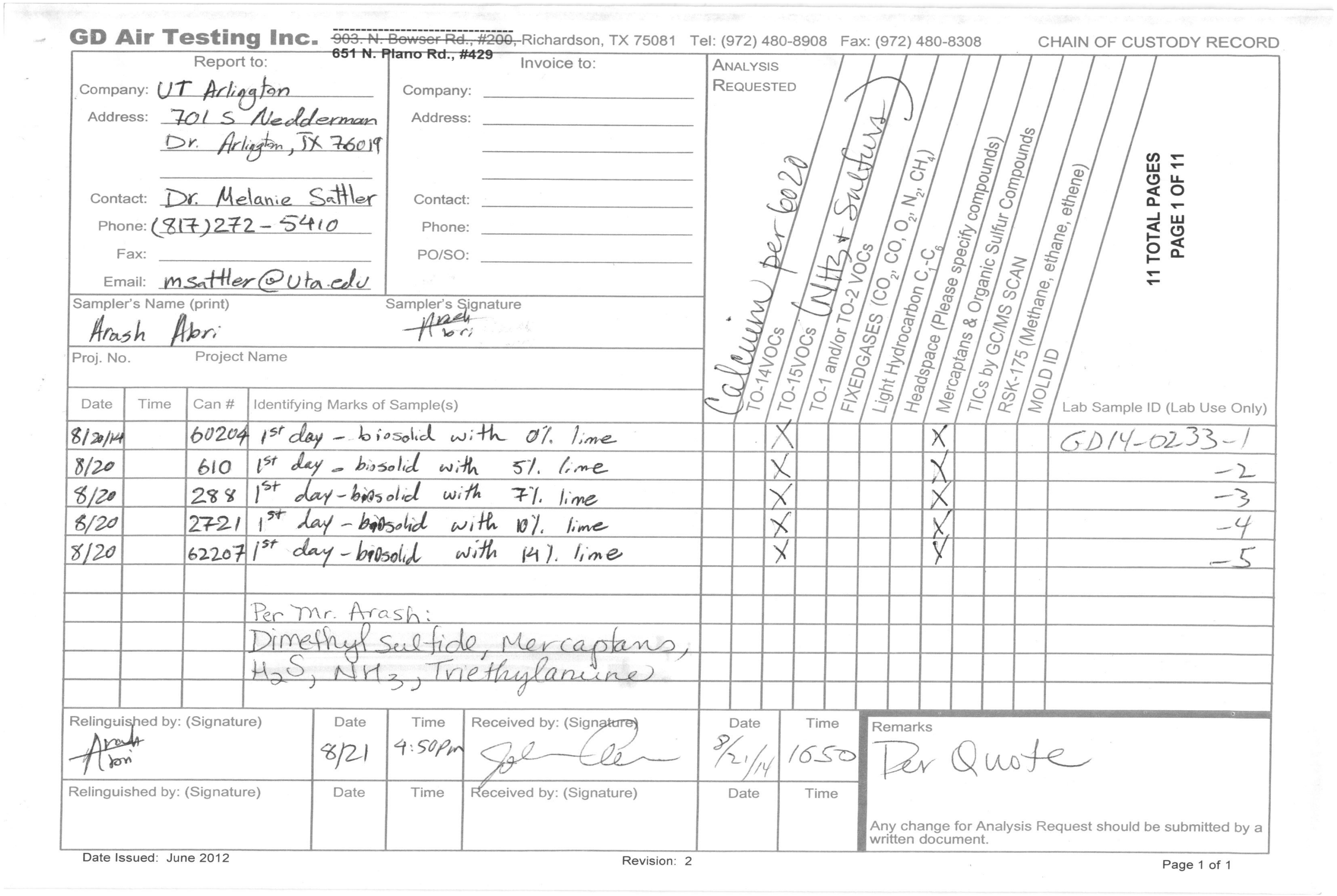
$$\lambda = \frac{4.045+4.183+4.176+4.023}{4} = 4.107$$

Consistency Index (CI) = $\frac{\lambda - n}{n - 1} = \frac{4.107 - 4}{3}$ = 0.0357

Consistency Ratio (CR) $= \frac{\mathrm{CI}}{\mathrm{RI}} = \frac{0.0357}{\mathrm{RI\ for\ (n{=}4)\ 0.9}}$ = 0.0397 $\leq 0.1 \rightarrow OK$

Appendix B

Report of Analytical Results



GD Air Testing Inc. ~~903. N. Bowser Rd., #200,~~ Richardson, TX 75081 Tel: (972) 480-8908 Fax: (972) 480-8308 CHAIN OF CUSTODY RECORD
651 N. Plano Rd., #429

Report to:		Invoice to:	
Company:	UT Arlington	Company:	
Address:	701 S Nedderman Dr. Arlington, TX 76019	Address:	
Contact:	Dr. Melanie Sattler	Contact:	
Phone:	(817)272-5410	Phone:	
Fax:		PO/SO:	
Email:	msattler@uta.edu		

Sampler's Name (print): Arash Abri
Sampler's Signature: Arash Abri
Proj. No.:
Project Name:

ANALYSIS REQUESTED

Date	Time	Can #	Identifying Marks of Sample(s)	Calcium per 6020	TO-14VOCs	TO-15VOCs (NH3 + Sulfurs)	TO-1 and/or TO-2 VOCs	FIXEDGASES (CO_2, CO, O_2, N_2, CH_4)	Light Hydrocarbon C_1-C_6	Headspace (Please specify compounds)	Mercaptans & Organic Sulfur Compounds	TICs by GC/MS SCAN	RSK-175 (Methane, ethane, ethene)	MOLD ID	Lab Sample ID (Lab Use Only)
8/20/14		60204	1st day - biosolid with 0% lime			X					X				GD14-0233-1
8/20		610	1st day - biosolid with 5% lime			X					X				-2
8/20		288	1st day - biosolid with 7% lime			X					X				-3
8/20		2721	1st day - biosolid with 10% lime			X					X				-4
8/20		62207	1st day - biosolid with 14% lime			X					X				-5
			Per Mr. Arash:												
			Dimethyl sulfide, Mercaptans,												
			H_2S, NH_3, Triethylamine)												

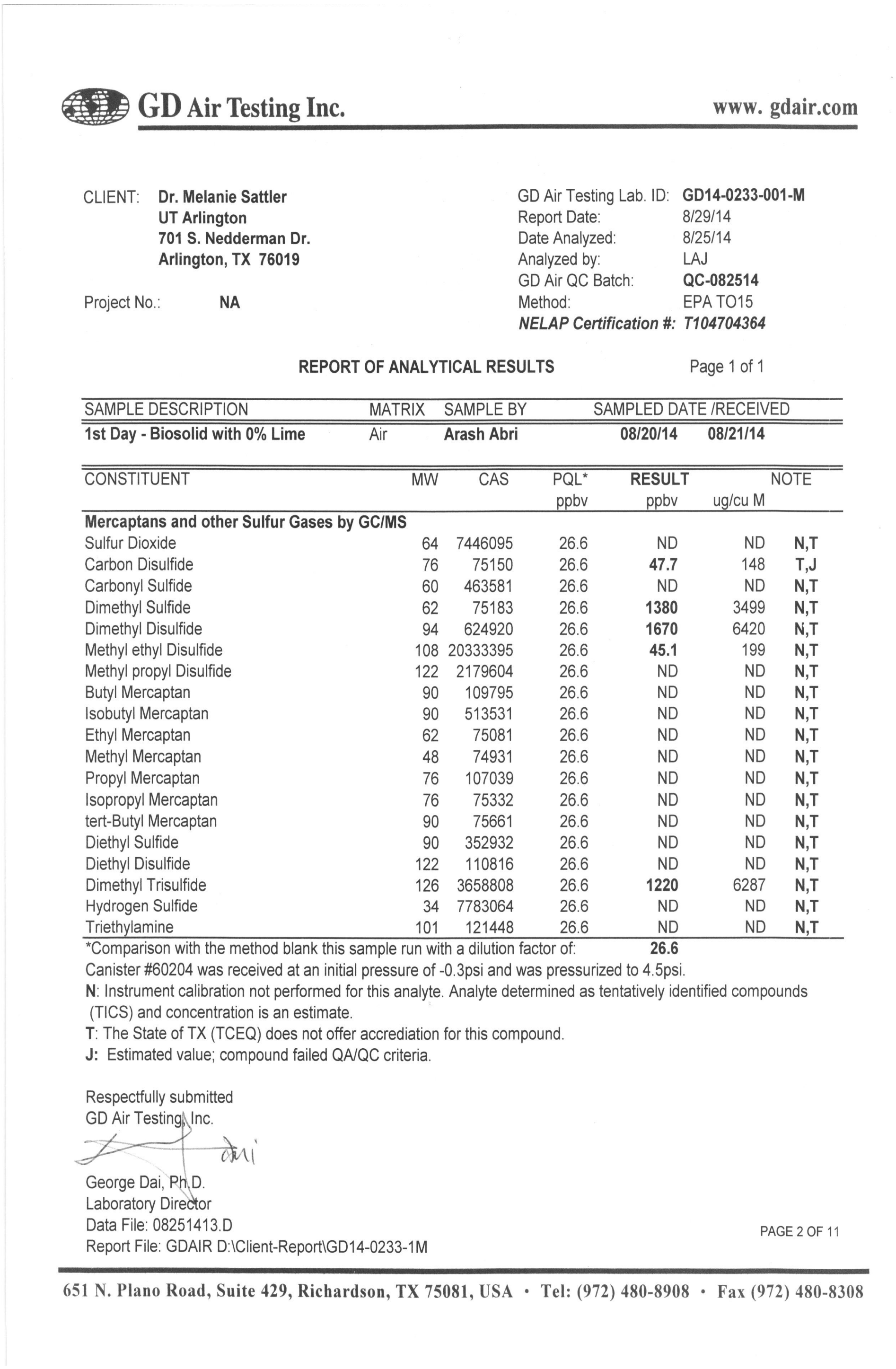
11 TOTAL PAGES
PAGE 1 OF 11

Relinquished by: (Signature)	Date	Time	Received by: (Signature)	Date	Time
Arash Abri	8/21	4:50pm		8/21/14	1650
Relinquished by: (Signature)	Date	Time	Received by: (Signature)	Date	Time

Remarks: Per Quote

Any change for Analysis Request should be submitted by a written document.

Date Issued: June 2012 Revision: 2 Page 1 of 1



GD Air Testing Inc. www. gdair.com

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0233-001-M**
Report Date:	8/29/14
Date Analyzed:	8/25/14
Analyzed by:	LAJ
GD Air QC Batch:	**QC-082514**
Method:	EPA TO15
NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
1st Day - Biosolid with 0% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	MW	CAS	PQL* ppbv	RESULT ppbv	 ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	26.6	ND	ND	**N,T**
Carbon Disulfide	76	75150	26.6	**47.7**	148	**T,J**
Carbonyl Sulfide	60	463581	26.6	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	26.6	**1380**	3499	**N,T**
Dimethyl Disulfide	94	624920	26.6	**1670**	6420	**N,T**
Methyl ethyl Disulfide	108	20333395	26.6	**45.1**	199	**N,T**
Methyl propyl Disulfide	122	2179604	26.6	ND	ND	**N,T**
Butyl Mercaptan	90	109795	26.6	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	26.6	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	26.6	ND	ND	**N,T**
Methyl Mercaptan	48	74931	26.6	ND	ND	**N,T**
Propyl Mercaptan	76	107039	26.6	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	26.6	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	26.6	ND	ND	**N,T**
Diethyl Sulfide	90	352932	26.6	ND	ND	**N,T**
Diethyl Disulfide	122	110816	26.6	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	26.6	**1220**	6287	**N,T**
Hydrogen Sulfide	34	7783064	26.6	ND	ND	**N,T**
Triethylamine	101	121448	26.6	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **26.6**

Canister #60204 was received at an initial pressure of -0.3psi and was pressurized to 4.5psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

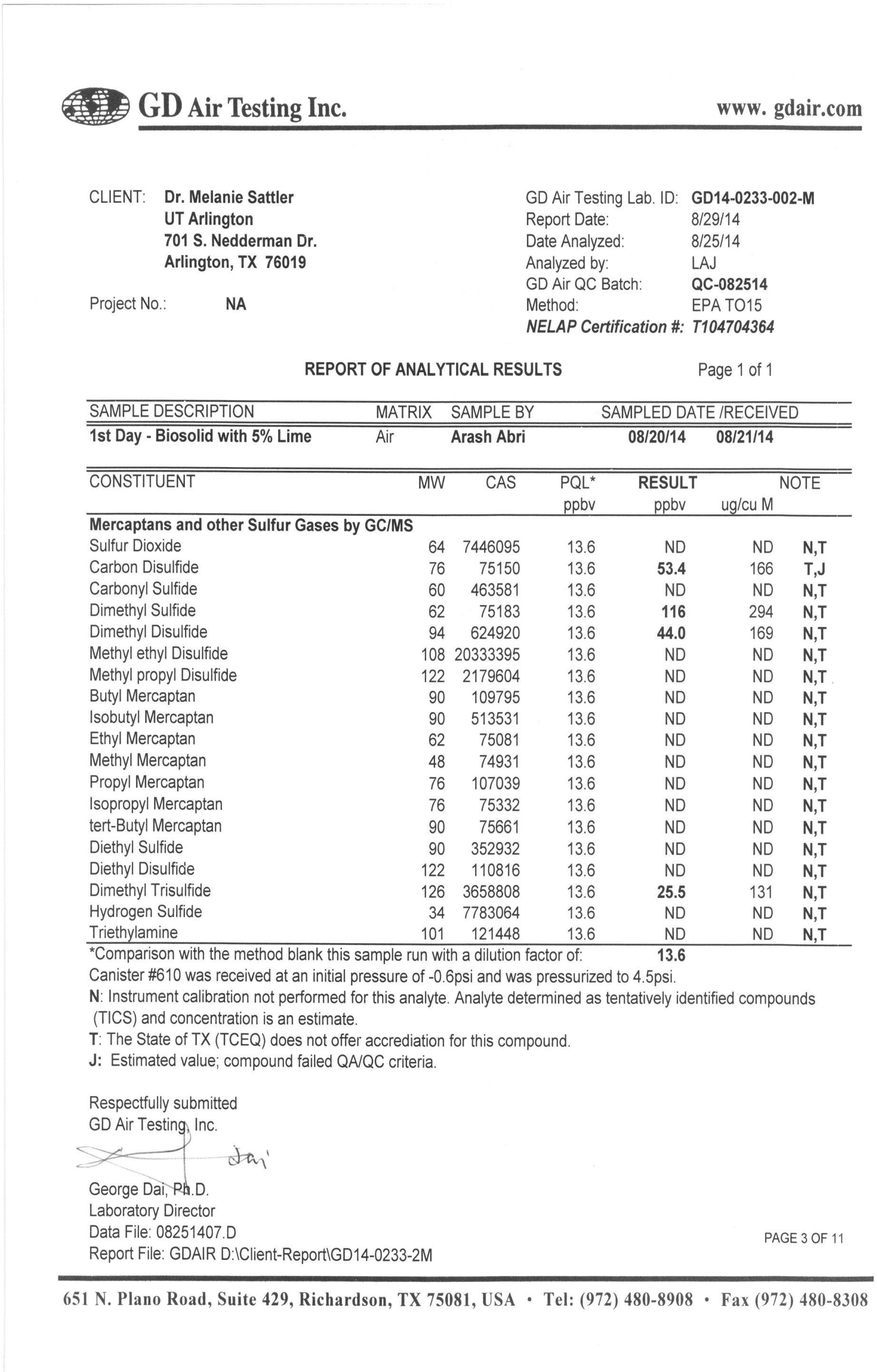
T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

Dai

George Dai, Ph.D.
Laboratory Director
Data File: 08251413.D
Report File: GDAIR D:\Client-Report\GD14-0233-1M



GD Air Testing Inc. **www. gdair.com**

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0233-002-M**
Report Date:	8/29/14
Date Analyzed:	8/25/14
Analyzed by:	LAJ
GD Air QC Batch:	**QC-082514**
Method:	EPA TO15
NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED	
1st Day - Biosolid with 5% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.6	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.6	**53.4**	166	**T,J**
Carbonyl Sulfide	60	463581	13.6	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.6	**116**	294	**N,T**
Dimethyl Disulfide	94	624920	13.6	**44.0**	169	**N,T**
Methyl ethyl Disulfide	108	20333395	13.6	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.6	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.6	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.6	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.6	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.6	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.6	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.6	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.6	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.6	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.6	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.6	**25.5**	131	**N,T**
Hydrogen Sulfide	34	7783064	13.6	ND	ND	**N,T**
Triethylamine	101	121448	13.6	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.6**

Canister #610 was received at an initial pressure of -0.6psi and was pressurized to 4.5psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 08251407.D
Report File: GDAIR D:\Client-Report\GD14-0233-2M

GD Air Testing Inc. www. gdair.com

CLIENT:	**Dr. Melanie Sattler**	GD Air Testing Lab. ID:	**GD14-0233-003-M**
	UT Arlington	Report Date:	8/29/14
	701 S. Nedderman Dr.	Date Analyzed:	8/25/14
	Arlington, TX 76019	Analyzed by:	LAJ
		GD Air QC Batch:	**QC-082514**
Project No.:	**NA**	Method:	EPA TO15
		NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
1st Day - Biosolid with 7% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.4	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.4	**176**	547	**T,J**
Carbonyl Sulfide	60	463581	13.4	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.4	**122**	309	**N,T**
Dimethyl Disulfide	94	624920	13.4	**49.1**	189	**N,T**
Methyl ethyl Disulfide	108	20333395	13.4	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.4	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.4	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.4	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.4	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.4	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.4	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.4	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.4	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.4	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.4	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.4	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.4	ND	ND	**N,T**
Triethylamine	101	121448	13.4	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.4**

Canister #288 was received at an initial pressure of -1.0psi and was pressurized to 4.5psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 08251408.D
Report File: GDAIR D:\Client-Report\GD14-0233-3M

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0233-004-M**
Report Date: 8/29/14
Date Analyzed: 8/25/14
Analyzed by: LAJ
GD Air QC Batch: **QC-082514**
Method: EPA TO15
NELAP Certification #: T104704364

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
1st Day - Biosolid with 10% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	MW	CAS	PQL*	**RESULT**		NOTE
			ppbv	ppbv	ug/cu M	
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.4	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.4	**30.3**	94	**T,J**
Carbonyl Sulfide	60	463581	13.4	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.4	**109**	276	**N,T**
Dimethyl Disulfide	94	624920	13.4	**23.4**	90	**N,T**
Methyl ethyl Disulfide	108	20333395	13.4	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.4	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.4	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.4	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.4	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.4	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.4	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.4	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.4	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.4	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.4	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.4	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.4	ND	ND	**N,T**
Triethylamine	101	121448	13.4	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.4**

Canister #2721 was received at an initial pressure of -0.5psi and was pressurized to 4.4psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 08251409.D
Report File: GDAIR D:\Client-Report\GD14-0233-4M

GD Air Testing Inc. www. gdair.com

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID:	**GD14-0233-005-M**
		Report Date:	8/29/14
		Date Analyzed:	8/25/14
		Analyzed by:	LAJ
		GD Air QC Batch:	**QC-082514**
Project No.:	**NA**	Method:	EPA TO15
		NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
1st Day - Biosolid with 14% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.5	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.5	**49.2**	153	**T,J**
Carbonyl Sulfide	60	463581	13.5	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.5	**118**	299	**N,T**
Dimethyl Disulfide	94	624920	13.5	**28.3**	109	**N,T**
Methyl ethyl Disulfide	108	20333395	13.5	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.5	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.5	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.5	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.5	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.5	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.5	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.5	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.5	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.5	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.5	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.5	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.5	ND	ND	**N,T**
Triethylamine	101	121448	13.5	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.5**

Canister #62207 was received at an initial pressure of -0.5psi and was pressurized to 4.5psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 08251410.D
Report File: GDAIR D:\Client-Report\GD14-0233-5M

GD Air Testing Inc. www. gdair.com

CLIENT: **GD Air Testing, Inc.**

Project No.:

GD Air Testing Lab. ID:	**Method Blank**
Report Date:	08/29/14
Date Analyzed:	08/25/14
Analyzed by:	LAJ
GD Air QC Batch:	QC-082514
Method:	EPA TO15
NELAP Certification #:	***T104704364***

REPORT OF METHOD BLANK RESULTS

Page 1 of 3

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
BLK	Air		

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Acetone	58	67641	1.00	**ND**	ND	T
Benzene	78	71432	1.00	**ND**	ND	
Benzylchloride	127	100447	1.00	**ND**	ND	
Bromodichloromethane	164	75274	1.00	**ND**	ND	
Bromoform	253	75252	1.00	**ND**	ND	
Bromomethane (Methyl Bromide)	95	74839	1.00	**ND**	ND	
1,3-Butadiene	54	106990	1.00	**ND**	ND	
Carbon disulfide	76	75150	1.00	**ND**	ND	T
Carbon tetrachloride	154	56235	1.00	**ND**	ND	
Chlorobenzene	113	108907	1.00	**ND**	ND	
Chloroethane (Ethyl Chloride)	65	75003	1.00	**ND**	ND	
Chloroform	119	67663	1.00	**ND**	ND	
Chloromethane (Methyl Chloride)	50	74873	1.00	**ND**	ND	
3-Chloro-1-Propene (Allyl Chloride)	77	107051	1.00	**ND**	ND	T
Cyclohexane	84	110827	1.00	**ND**	ND	
Dibromochloromethane	208	124481	1.00	**ND**	ND	
1,2-Dibromoethane (EDB)	188	106934	1.00	**ND**	ND	
1,2-Dichlorobenzene	147	95501	1.00	**ND**	ND	
1,3-Dichlorobenzene	147	541731	1.00	**ND**	ND	
1,4-Dichlorobenzene	147	106467	1.00	**ND**	ND	
1,1-Dichloroethane	99	75343	1.00	**ND**	ND	
1,1-Dichlorethene	97	75354	1.00	**ND**	ND	
Dichlorodifluoromethane (F12)	121	75718	1.00	**ND**	ND	
Dichlorotetrafluoroethane (F114)	171	76142	1.00	**ND**	ND	
1,2-Dichloroethane (EDC)	99	107062	1.00	**ND**	ND	
cis-1,2-Dichloroethene	97	156592	1.00	**ND**	ND	
trans-1,2-Dichloroethene	97	156605	1.00	**ND**	ND	
Dichloromethane (Methylene chloride)	85	75092	1.00	**ND**	ND	
1,2-Dichloropropane	113	78875	1.00	**ND**	ND	
cis-1,3-Dichloropropene	111	10061015	1.00	**ND**	ND	
trans-1,3-Dichloropropene	111	10061026	1.00	**ND**	ND	
1,4-Dioxane	88	123911	1.00	**ND**	ND	
Ethyl acetate	88	141786	1.00	**ND**	ND	T
Ethylbenzene	106	100414	1.00	**ND**	ND	

CLIENT: GD Air Testing, Inc.

Project No.: **QC**

GD Air Testing Lab. ID:	**Method Blank**
Report Date:	08/29/14
Date Analyzed:	08/25/14
Analyzed by:	LAJ
GD Air QC Batch:	QC-082514
Method:	EPA TO15
NELAP Certification #:	***T104704364***

REPORT OF METHOD BLANK RESULTS Page 2 of 3

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
BLK	Air		

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
4-Ethyltoluene	120	622968	1.00	**ND**	ND	
Heptane	100	142825	1.00	**ND**	ND	
Hexachlorobutadiene	261	87683	1.00	**ND**	ND	
Hexane	86	110543	1.00	**ND**	ND	
Isopropanol	60	67630	1.00	**ND**	ND	**T**
Methyl t-butyl ether (MTBE)	88	1634044	1.00	**ND**	ND	
Methyl butyl ketone (2-Hexanone)	100	591786	1.00	**ND**	ND	**T**
Methyl ethyl ketone (MEK)	72	78933	1.00	**ND**	ND	
Methyl isobutyl ketone (MIBK)	100	108101	1.00	**ND**	ND	
Propene	44	115071	1.00	**ND**	ND	
Styrene	104	100425	1.00	**ND**	ND	
1,1,2,2-Tetrachloroethane	168	79345	1.00	**ND**	ND	
Tetrachloroethene (PCE)	166	127184	1.00	**ND**	ND	
Tetrahydrofuran (THF)	72	109999	1.00	**ND**	ND	**T**
Toluene	92	108883	1.00	**ND**	ND	
1,1,1-Trichloroethane (TCA)	133	71556	1.00	**ND**	ND	
1,1,2-Trichloroethane	133	79005	1.00	**ND**	ND	
1,3,5-Trimethylbenzene	120	108678	1.00	**ND**	ND	
1,2,4-Trimethylbenzene	120	95636	1.00	**ND**	ND	
2,2,4-Trimethylpentane	114	540841	1.00	**ND**	ND	
1,2,4-Trichlorobenzene	182	120821	1.00	**ND**	ND	
Trichloroethene (TCE)	131	79016	1.00	**ND**	ND	
Trichlorofluoromethane (F-11)	137	75694	1.00	**ND**	ND	
Trichloritrifluoroethane (F-113)	187	76131	1.00	**ND**	ND	
Vinyl acetate	86	108054	1.00	**ND**	ND	
Vinyl bromide (Bromoethene)	107	593602	1.00	**ND**	ND	
Vinyl chloride	63	75014	1.00	**ND**	ND	
m&p-Xylenes	106	1330207	2.00	**ND**	ND	
o-Xylene	106	95476	1.00	**ND**	ND	

Surrogate Recovery Report			Spiked ppbv	Found ppbv	R%
1,4-Difluorobenzene (SS1)	118.1	540363	5.00	4.30	86
Bromofluorobenzene (SS2)	175	460004	5.00	4.62	92

*Comparison with the method blank this sample run with a dilution factor of: **1.0**

CLIENT: GD Air Testing, Inc.

Project No.: **QC**

GD Air Testing Lab. ID:	**Method Blank**
Report Date:	08/29/14
Date Analyzed:	08/25/14
Analyzed by:	LAJ
GD Air QC Batch:	QC-082514
Method:	EPA TO15
NELAP Certification #:	***T104704364***

REPORT OF METHOD BLANK RESULTS

Page 3 of 3

J: Estimated value, compound failed the initial calibration criteria.
T: The State of Texas (TCEQ) does not offer accreditation for this compound.
C: Instrument calibrated for this compound. Currently pending NELAC accreditation.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).
* The control limit for Surrogate Recovery % of all spiked compound is 70% - 130%. Only one is required to pass.
*Concentrations in ug/cu M reported at 760 mm Hg pressure and 298 deg.K.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director

Data File: 08251405.D
Report File: QC-14-TO15\Blank

Blank Spike/Blank Spike Duplicate Results

(BS/BSD)

Lab:
GD Air Testing, Inc.
651 N. Plano Rd., #429
Richardson, TX 75081

Date Analyzed: 08/25/14
Analyzed by: LAJ
GD Air QC Batch: **QC-082514**
Method: EPA TO15
NELAP Certification #: ***T104704364***
Page 1 of 2

Spike Control Compounds	Spiked	Found and Recovery					Recovery
	ppbv	BS/ppbv	BS R%	BSD/ppbv	BSD R%	% RPD	Limits (%)
Propene	5.0	5.28	106	5.13	103	2.9	50-150
Difluorodichloromethane	5.0	5.19	104	4.94	99	4.9	70-130
Chloromethane	5.0	5.05	101	4.90	98	3.0	70-130
Dichlorotetrafluoroethane	5.0	5.17	103	4.95	99	4.3	70-130
Vinyl Chloride	5.0	5.00	100	4.89	98	2.2	70-130
1,3-Butadiene	5.0	4.91	98	4.80	96	2.3	70-130
Bromomethane	5.0	5.11	102	4.93	99	3.6	70-130
Chloroethane	5.0	5.05	101	4.89	98	3.2	70-130
Bromoethene	5.0	5.02	100	4.83	97	3.9	70-130
Acetone	5.0	5.72	114	4.39	88	26.3	50-150
Isopropanol	5.0	5.69	114	6.11	122	7.1	50-150
Trichlorofluoromethane	5.0	5.17	103	4.94	99	4.5	70-130
1,1-Dichloroethene	5.0	5.08	102	5.00	100	1.6	70-130
Methylene chloride	5.0	5.10	102	4.93	99	3.4	70-130
3-Chloro-1-Propene	5.0	3.70	74	3.64	73	1.6	70-130
Trichlorotrifluoroethane	5.0	5.22	104	5.02	100	3.9	70-130
Carbon Disulfide *	5.0	7.24	145	6.91	138	4.7	70-130
trans-1,2-Dichloroethene	5.0	5.05	101	4.90	98	3.0	70-130
1,1-Dichloroethane	5.0	5.31	106	5.12	102	3.6	70-130
MTBE	5.0	5.59	112	5.33	107	4.8	70-130
Vinyl Acetate	5.0	5.89	118	5.61	112	4.9	50-150
2-Butanone (MEK)	5.0	6.27	125	5.92	118	5.7	50-150
cis-1,2-Dichloroethene	5.0	5.15	103	4.98	100	3.4	70-130
Ethyl Acetate	5.0	5.35	107	5.11	102	4.6	50-150
Hexane	5.0	5.56	111	5.18	104	7.1	70-130
Chloroform	5.0	5.16	103	4.95	99	4.2	70-130
Tetrahydrofuran	5.0	5.58	112	5.44	109	2.5	50-150
1,2-Dichloroethane (EDC)	5.0	5.19	104	4.99	100	3.9	70-130
1,1,1-Trichloroethane	5.0	5.25	105	5.07	101	3.5	70-130
Benzene	5.0	5.55	111	5.32	106	4.2	70-130
Carbon tetrachloride	5.0	5.20	104	5.02	100	3.5	70-130
Cyclohexane	5.0	5.10	102	4.89	98	4.2	70-130
1,2-Dichloropropane	5.0	5.26	105	5.04	101	4.3	70-130
Bromodichloromethane	5.0	5.33	107	5.11	102	4.2	70-130
1,4-Dioxane	5.0	5.22	104	5.53	111	5.8	50-150
2,2,4-Trimethylpentane	5.0	5.51	110	5.19	104	6.0	70-130

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0233-1-NH3** 9/10/2014 9/3/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
1st Day - Biosolid with 0% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	19.0	**ND**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0233-1-NH3

5 TOTAL PAGES
PAGE 1 OF 5

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0233-2-NH3** 9/10/2014 9/3/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
1st Day - Biosolid with 5% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	472	**863**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0233-2-NH3

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CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0233-3-NH3** 9/10/2014 9/3/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
1st Day - Biosolid with 7% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

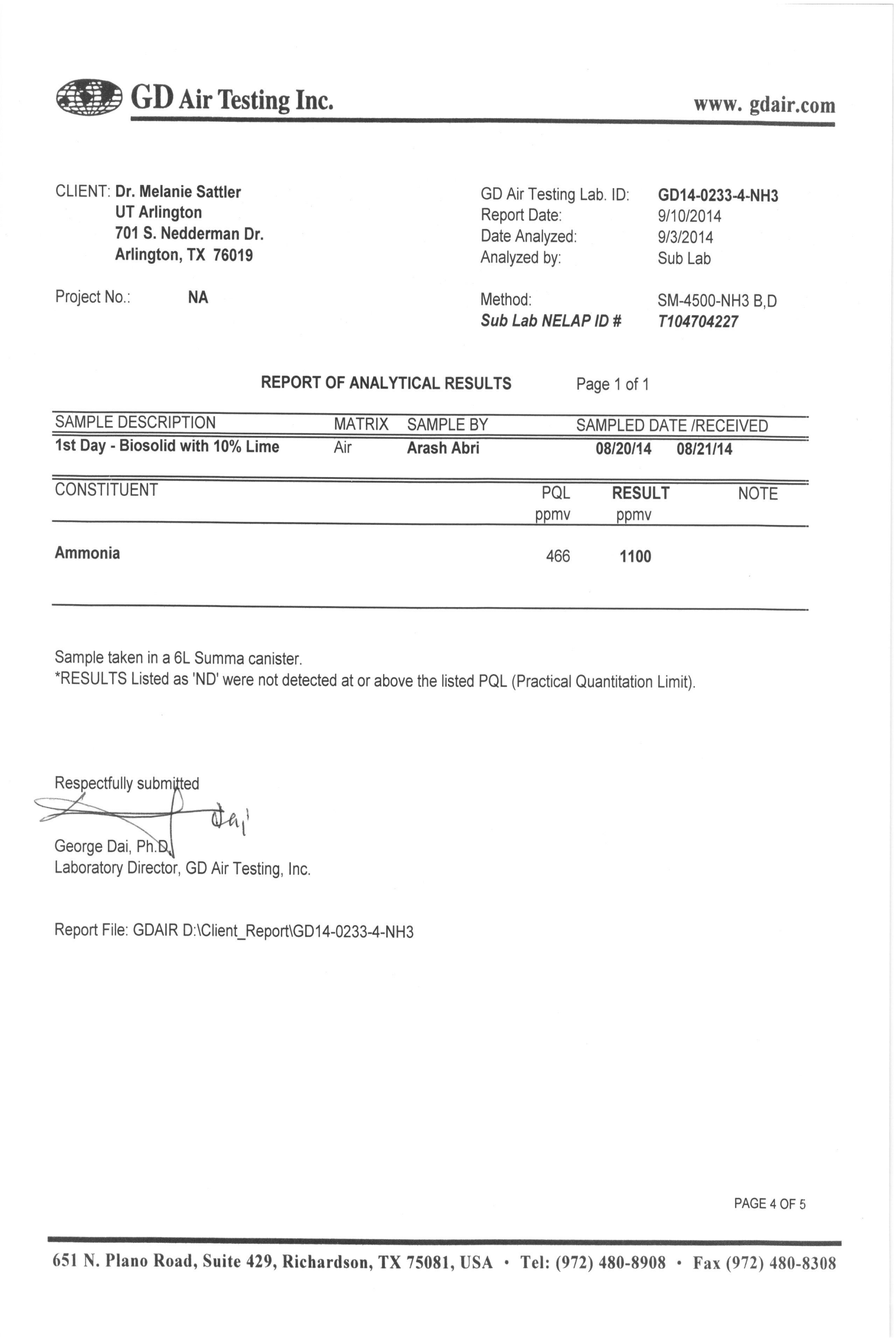
CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	19.3	**160**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0233-3-NH3



GD Air Testing Inc. www. gdair.com

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0233-4-NH3** 9/10/2014 9/3/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
1st Day - Biosolid with 10% Lime	Air	**Arash Abri**	**08/20/14 08/21/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	466	**1100**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0233-4-NH3

PAGE 4 OF 5

651 N. Plano Road, Suite 429, Richardson, TX 75081, USA • Tel: (972) 480-8908 • Fax (972) 480-8308

GD Air Testing Inc. www. gdair.com

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0233-5-NH3**
Report Date:	9/10/2014
Date Analyzed:	9/3/2014
Analyzed by:	Sub Lab
Method:	SM-4500-NH3 B,D
Sub Lab NELAP ID #	***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
1st Day - Biosolid with 14% Lime	Air	**Arash Abri**	**08/20/14 08/21/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	93.3	**952**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0233-5-NH3

GD Air Testing Inc. www. gdair.com

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0255-001-M**
Report Date: 09/12/14
Date Analyzed: 09/09/14
Analyzed by: LAJ
GD Air QC Batch: **QC-090914**
Method: EPA TO15
NELAP Certification #: ***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 0% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL*	**RESULT**		NOTE
			ppbv	ppbv	ug/cu M	
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.3	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.3	**38.6**	120	**T,J**
Carbonyl Sulfide	60	463581	13.3	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.3	ND	ND	**N,T**
Dimethyl Disulfide	94	624920	13.3	ND	ND	**N,T**
Methyl ethyl Disulfide	108	20333395	13.3	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.3	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.3	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.3	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.3	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.3	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.3	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.3	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.3	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.3	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.3	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.3	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.3	ND	ND	**N,T**
Triethylamine	101	121448	13.3	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.3**

Canister #2517 was received at an initial pressure of -0.1psi and was pressurized to 4.8psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091415.D
Report File: GDAIR D:\Client-Report\GD14-0255-1M

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0255-1-NH3**
Report Date:	9/19/2014
Date Analyzed:	9/12/2014
Analyzed by:	Sub Lab
Method:	SM-4500-NH3 B,D
Sub Lab NELAP ID #	***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED	
7 Days - Biosolid with 0% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	17.8	**ND**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted,

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-1-NH3

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0255-002-M**
Report Date: 09/12/14
Date Analyzed: 09/09/14
Analyzed by: LAJ
GD Air QC Batch: **QC-090914**
Method: EPA TO15
NELAP Certification #: ***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 5% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	RESULT ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.6	ND	ND	N,T
Carbon Disulfide	76	75150	27.2	**501**	1557	T,J
Carbonyl Sulfide	60	463581	13.6	ND	ND	N,T
Dimethyl Sulfide	62	75183	13.6	**121**	307	N,T
Dimethyl Disulfide	94	624920	13.6	**71.5**	275	N,T
Methyl ethyl Disulfide	108	20333395	13.6	ND	ND	N,T
Methyl propyl Disulfide	122	2179604	13.6	ND	ND	N,T
Butyl Mercaptan	90	109795	13.6	ND	ND	N,T
Isobutyl Mercaptan	90	513531	13.6	ND	ND	N,T
Ethyl Mercaptan	62	75081	13.6	ND	ND	N,T
Methyl Mercaptan	48	74931	13.6	ND	ND	N,T
Propyl Mercaptan	76	107039	13.6	ND	ND	N,T
Isopropyl Mercaptan	76	75332	13.6	ND	ND	N,T
tert-Butyl Mercaptan	90	75661	13.6	ND	ND	N,T
Diethyl Sulfide	90	352932	13.6	ND	ND	N,T
Diethyl Disulfide	122	110816	13.6	ND	ND	N,T
Dimethyl Trisulfide	126	3658808	13.6	ND	ND	N,T
Hydrogen Sulfide	34	7783064	13.6	ND	ND	N,T
Triethylamine	101	121448	13.6	ND	ND	N,T

*Comparison with the method blank this sample run with a dilution factor of: **13.6**

Canister #267 was received at an initial pressure of -0.1psi and was pressurized to 5.1psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091416.D
Report File: GDAIR D:\Client-Report\GD14-0255-2M

GD Air Testing Inc. **www. gdair.com**

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0255-2-NH3**
Report Date: 9/19/2014
Date Analyzed: 9/15/2014
Analyzed by: Sub Lab

Method: SM-4500-NH3 B,D
Sub Lab NELAP ID # ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 5% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	90.8	**804**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-2-NH3

GD Air Testing Inc. **www. gdair.com**

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0255-003-M**
Report Date:	09/12/14
Date Analyzed:	09/09/14
Analyzed by:	LAJ
GD Air QC Batch:	**QC-090914**
Method:	EPA TO15
NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 7% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	RESULT ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.7	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.7	**140**	435	**T,J**
Carbonyl Sulfide	60	463581	13.7	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.7	**187**	474	**N,T**
Dimethyl Disulfide	94	624920	13.7	**100**	384	**N,T**
Methyl ethyl Disulfide	108	20333395	13.7	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.7	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.7	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.7	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.7	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.7	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.7	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.7	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.7	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.7	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.7	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.7	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.7	ND	ND	**N,T**
Triethylamine	101	121448	13.7	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.7**

Canister #2879 was received at an initial pressure of -0.35psi and was pressurized to 5.0psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091417.D
Report File: GDAIR D:\Client-Report\GD14-0255-3M

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0255-3-NH3** 9/19/2014 9/15/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
7 Days - Biosolid with 7% Lime	Air	**Arash Abri**	**08/27/14 09/05/14**

CONSTITUENT	PQL ppmv	RESULT ppmv	NOTE
Ammonia	90.8	**1090**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-3-NH3

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by: GD Air QC Batch:	**GD14-0255-004-M** 09/12/14 09/09/14 LAJ **QC-090914**
Project No.:	**NA**	Method:	EPA TO15
		NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 10% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.5	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.5	**199**	619	**T,J**
Carbonyl Sulfide	60	463581	13.5	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.5	**113**	287	**N,T**
Dimethyl Disulfide	94	624920	13.5	**46.7**	180	**N,T**
Methyl ethyl Disulfide	108	20333395	13.5	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.5	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.5	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.5	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.5	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.5	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.5	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.5	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.5	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.5	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.5	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.5	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.5	ND	ND	**N,T**
Triethylamine	101	121448	13.5	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.5**

Canister #62208 was received at an initial pressure of -0.1psi and was pressurized to 5.0psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D
Laboratory Director
Data File: 09091418.D
Report File: GDAIR D:\Client-Report\GD14-0255-4M

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0255-4-NH3** 9/19/2014 9/15/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 10% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	89.0	**944**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-4-NH3

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID:	**GD14-0255-005-M**
		Report Date:	09/12/14
		Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	**QC-090914**
Project No.:	**NA**	Method:	EPA TO15
		NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 14% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	RESULT ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.7	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.7	**152**	472	**T,J**
Carbonyl Sulfide	60	463581	13.7	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.7	**146**	370	**N,T**
Dimethyl Disulfide	94	624920	13.7	**80.0**	308	**N,T**
Methyl ethyl Disulfide	108	20333395	13.7	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.7	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.7	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.7	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.7	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.7	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.7	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.7	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.7	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.7	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.7	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.7	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.7	ND	ND	**N,T**
Triethylamine	101	121448	13.7	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.7**

Canister #62039 was received at an initial pressure of -0.0psi and was pressurized to 5.4psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091431.D
Report File: GDAIR D:\Client-Report\GD14-0255-5M

CLIENT:	**Dr. Melanie Sattler**	GD Air Testing Lab. ID:	**GD14-0255-5-NH3**
	UT Arlington	Report Date:	9/19/2014
	701 S. Nedderman Dr.	Date Analyzed:	9/15/2014
	Arlington, TX 76019	Analyzed by:	Sub Lab
Project No.:	**NA**	Method:	SM-4500-NH3 B,D
		Sub Lab NELAP ID #	***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
7 Days - Biosolid with 14% Lime	Air	**Arash Abri**	**08/27/14**	**09/05/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	90.2	**1100**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-5-NH3

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0255-006-M**
Report Date:	09/12/14
Date Analyzed:	09/09/14
Analyzed by:	LAJ
GD Air QC Batch:	**QC-090914**
Method:	EPA TO15
NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
14 Days - Biosolid with 0% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	14.0	ND	ND	**N,T**
Carbon Disulfide	76	75150	14.0	**61.3**	191	**T,J**
Carbonyl Sulfide	60	463581	14.0	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	14.0	ND	ND	**N,T**
Dimethyl Disulfide	94	624920	14.0	ND	ND	**N,T**
Methyl ethyl Disulfide	108	20333395	14.0	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	14.0	ND	ND	**N,T**
Butyl Mercaptan	90	109795	14.0	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	14.0	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	14.0	ND	ND	**N,T**
Methyl Mercaptan	48	74931	14.0	ND	ND	**N,T**
Propyl Mercaptan	76	107039	14.0	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	14.0	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	14.0	ND	ND	**N,T**
Diethyl Sulfide	90	352932	14.0	ND	ND	**N,T**
Diethyl Disulfide	122	110816	14.0	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	14.0	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	14.0	ND	ND	**N,T**
Triethylamine	101	121448	14.0	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **14.0**

Canister #2516 was received at an initial pressure of -0.65psi and was pressurized to 5.0psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091432.D
Report File: GDAIR D:\Client-Report\GD14-0255-6M

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0255-6-NH3**
Report Date:	9/19/2014
Date Analyzed:	9/15/2014
Analyzed by:	Sub Lab
Method:	SM-4500-NH3 B,D
Sub Lab NELAP ID #	***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
14 Days - Biosolid with 0% Lime	Air	**Arash Abri**	**09/03/14 09/05/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	18.8	**ND**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-6-NH3

GD Air Testing Inc. **www. gdair.com**

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0255-007-M**
Report Date: 09/12/14
Date Analyzed: 09/09/14
Analyzed by: LAJ
GD Air QC Batch: **QC-090914**
Method: EPA TO15
NELAP Certification #: ***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED	
14 Days - Biosolid with 5% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	RESULT ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.5	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.5	**63.9**	199	**T,J**
Carbonyl Sulfide	60	463581	13.5	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.5	**105**	266	**N,T**
Dimethyl Disulfide	94	624920	13.5	**112**	431	**N,T**
Methyl ethyl Disulfide	108	20333395	13.5	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.5	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.5	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.5	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.5	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.5	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.5	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.5	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.5	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.5	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.5	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.5	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.5	ND	ND	**N,T**
Triethylamine	101	121448	13.5	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.5**

Canister #2875 was received at an initial pressure of -0.25psi and was pressurized to 4.9psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091421.D
Report File: GDAIR D:\Client-Report\GD14-0255-7M

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0255-7-NH3**
Report Date: 9/19/2014
Date Analyzed: 9/15/2014
Analyzed by: Sub Lab

Method: SM-4500-NH3 B,D
Sub Lab NELAP ID # ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
14 Days - Biosolid with 5% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	90.5	**1240**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-7-NH3

GD Air Testing Inc. www. gdair.com

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID:	**GD14-0255-008-M**
		Report Date:	09/12/14
		Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	**QC-090914**
Project No.:	**NA**	Method:	EPA TO15
		NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
14 Days - Biosolid with 7% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	14.1	ND	ND	**N,T**
Carbon Disulfide	76	75150	14.1	**162**	504	**T,J**
Carbonyl Sulfide	60	463581	14.1	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	14.1	**152**	385	**N,T**
Dimethyl Disulfide	94	624920	14.1	**170**	654	**N,T**
Methyl ethyl Disulfide	108	20333395	14.1	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	14.1	ND	ND	**N,T**
Butyl Mercaptan	90	109795	14.1	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	14.1	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	14.1	ND	ND	**N,T**
Methyl Mercaptan	48	74931	14.1	ND	ND	**N,T**
Propyl Mercaptan	76	107039	14.1	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	14.1	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	14.1	ND	ND	**N,T**
Diethyl Sulfide	90	352932	14.1	ND	ND	**N,T**
Diethyl Disulfide	122	110816	14.1	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	14.1	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	14.1	ND	ND	**N,T**
Triethylamine	101	121448	14.1	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **14.1**

Canister #60197 was received at an initial pressure of -0.75psi and was pressurized to 5.1psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

Dai

George Dai, Ph.D.
Laboratory Director
Data File: 09091422.D
Report File: GDAIR D:\Client-Report\GD14-0255-8M

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0255-8-NH3** 9/19/2014 9/15/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED	
14 Days - Biosolid with 7% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	PQL ppmv	RESULT ppmv	NOTE
Ammonia	93.8	**1050**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-8-NH3

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID:	**GD14-0255-009-M**
		Report Date:	09/12/14
		Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	**QC-090914**
Project No.:	**NA**	Method:	EPA TO15
		NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
14 Days - Biosolid with 10% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.6	ND	ND	**N,T**
Carbon Disulfide	76	75150	13.6	**291**	905	**T,J**
Carbonyl Sulfide	60	463581	13.6	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.6	**81.2**	206	**N,T**
Dimethyl Disulfide	94	624920	13.6	**89.6**	344	**N,T**
Methyl ethyl Disulfide	108	20333395	13.6	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.6	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.6	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.6	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.6	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.6	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.6	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.6	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.6	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.6	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.6	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.6	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.6	ND	ND	**N,T**
Triethylamine	101	121448	13.6	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.6**

Canister #60185 was received at an initial pressure of -0.1psi and was pressurized to 5.2psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091423.D
Report File: GDAIR D:\Client-Report\GD14-0255-9M

PAGE 18 OF 26

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID: Report Date: Date Analyzed: Analyzed by:	**GD14-0255-9-NH3** 9/19/2014 9/15/2014 Sub Lab
Project No.:	**NA**	Method: ***Sub Lab NELAP ID #***	SM-4500-NH3 B,D ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED	
14 Days - Biosolid with 10% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	PQL ppmv	**RESULT** ppmv	NOTE
Ammonia	89.4	**912**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-9-NH3

CLIENT:	**Dr. Melanie Sattler** **UT Arlington** **701 S. Nedderman Dr.** **Arlington, TX 76019**	GD Air Testing Lab. ID:	**GD14-0255-010-M**
		Report Date:	09/12/14
		Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	**QC-090914**
Project No.:	**NA**	Method:	EPA TO15
		NELAP Certification #:	***T104704364***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
14 Days - Biosolid with 14% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	MW	CAS	PQL* ppbv	RESULT ppbv	ug/cu M	NOTE
Mercaptans and other Sulfur Gases by GC/MS						
Sulfur Dioxide	64	7446095	13.4	ND	ND	**N,T**
Carbon Disulfide	76	75150	26.8	**521**	1619	**T,J**
Carbonyl Sulfide	60	463581	13.4	ND	ND	**N,T**
Dimethyl Sulfide	62	75183	13.4	**90.2**	229	**N,T**
Dimethyl Disulfide	94	624920	13.4	**114**	438	**N,T**
Methyl ethyl Disulfide	108	20333395	13.4	ND	ND	**N,T**
Methyl propyl Disulfide	122	2179604	13.4	ND	ND	**N,T**
Butyl Mercaptan	90	109795	13.4	ND	ND	**N,T**
Isobutyl Mercaptan	90	513531	13.4	ND	ND	**N,T**
Ethyl Mercaptan	62	75081	13.4	ND	ND	**N,T**
Methyl Mercaptan	48	74931	13.4	ND	ND	**N,T**
Propyl Mercaptan	76	107039	13.4	ND	ND	**N,T**
Isopropyl Mercaptan	76	75332	13.4	ND	ND	**N,T**
tert-Butyl Mercaptan	90	75661	13.4	ND	ND	**N,T**
Diethyl Sulfide	90	352932	13.4	ND	ND	**N,T**
Diethyl Disulfide	122	110816	13.4	ND	ND	**N,T**
Dimethyl Trisulfide	126	3658808	13.4	ND	ND	**N,T**
Hydrogen Sulfide	34	7783064	13.4	ND	ND	**N,T**
Triethylamine	101	121448	13.4	ND	ND	**N,T**

*Comparison with the method blank this sample run with a dilution factor of: **13.4**

Canister #2471 was received at an initial pressure of -0.0psi and was pressurized to 5.0psi.

N: Instrument calibration not performed for this analyte. Analyte determined as tentatively identified compounds (TICS) and concentration is an estimate.

T: The State of TX (TCEQ) does not offer accrediation for this compound.

J: Estimated value; compound failed QA/QC criteria.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director
Data File: 09091430.D
Report File: GDAIR D:\Client-Report\GD14-0255-10M

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0255-10-NH3**
Report Date: 9/19/2014
Date Analyzed: 9/16/2014
Analyzed by: Sub Lab

Method: SM-4500-NH3 B,D
Sub Lab NELAP ID # ***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
14 Days - Biosolid with 14% Lime	Air	**Arash Abri**	**09/03/14**	**09/05/14**

CONSTITUENT	PQL ppmv	RESULT ppmv	NOTE
Ammonia	91.8	**647**	

Sample taken in a 6L Summa canister.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0255-10-NH3

CLIENT: **GD Air Testing, Inc.**		GD Air Testing Lab. ID:	**Method Blank**
		Report Date:	09/12/14
		Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	QC-090914
Project No.:		Method:	EPA TO15
		NELAP Certification #	***T104704364***

REPORT OF METHOD BLANK RESULTS

Page 1 of 3

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
BLK	Air		

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
Acetone	58	67641	1.50	**ND**	ND	T
Benzene	78	71432	1.00	**ND**	ND	
Benzylchloride	127	100447	1.00	**ND**	ND	
Bromodichloromethane	164	75274	1.00	**ND**	ND	
Bromoform	253	75252	1.00	**ND**	ND	
Bromomethane (Methyl Bromide)	95	74839	1.00	**ND**	ND	
1,3-Butadiene	54	106990	1.00	**ND**	ND	
Carbon disulfide	76	75150	1.00	**ND**	ND	T
Carbon tetrachloride	154	56235	1.00	**ND**	ND	
Chlorobenzene	113	108907	1.00	**ND**	ND	
Chloroethane (Ethyl Chloride)	65	75003	1.00	**ND**	ND	
Chloroform	119	67663	1.00	**ND**	ND	
Chloromethane (Methyl Chloride)	50	74873	1.00	**ND**	ND	
3-Chloro-1-Propene (Allyl Chloride)	77	107051	1.00	**ND**	ND	T
Cyclohexane	84	110827	1.00	**ND**	ND	
Dibromochloromethane	208	124481	1.00	**ND**	ND	
1,2-Dibromoethane (EDB)	188	106934	1.00	**ND**	ND	
1,2-Dichlorobenzene	147	95501	1.00	**ND**	ND	
1,3-Dichlorobenzene	147	541731	1.00	**ND**	ND	
1,4-Dichlorobenzene	147	106467	1.00	**ND**	ND	
1,1-Dichloroethane	99	75343	1.00	**ND**	ND	
1,1-Dichlorethene	97	75354	1.00	**ND**	ND	
Dichlorodifluoromethane (F12)	121	75718	1.00	**ND**	ND	
Dichlorotetrafluoroethane (F114)	171	76142	1.00	**ND**	ND	
1,2-Dichloroethane (EDC)	99	107062	1.00	**ND**	ND	
cis-1,2-Dichloroethene	97	156592	1.00	**ND**	ND	
trans-1,2-Dichloroethene	97	156605	1.00	**ND**	ND	
Dichloromethane (Methylene chloride)	85	75092	1.00	**ND**	ND	
1,2-Dichloropropane	113	78875	1.00	**ND**	ND	
cis-1,3-Dichloropropene	111	10061015	1.00	**ND**	ND	
trans-1,3-Dichloropropene	111	10061026	1.00	**ND**	ND	
1,4-Dioxane	88	123911	1.00	**ND**	ND	
Ethyl acetate	88	141786	1.00	**ND**	ND	T
Ethylbenzene	106	100414	1.00	**ND**	ND	

CLIENT:	GD Air Testing, Inc.	GD Air Testing Lab. ID:	Method Blank
		Report Date:	09/12/14
		Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	QC-090914
Project No.:	**QC**	Method:	EPA TO15
		NELAP Certification #	***T104704364***

REPORT OF METHOD BLANK RESULTS

Page 2 of 3

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED
BLK	Air		

CONSTITUENT	MW	CAS	PQL* ppbv	**RESULT** ppbv	ug/cu M	NOTE
4-Ethyltoluene	120	622968	1.00	**ND**	ND	
Heptane	100	142825	1.00	**ND**	ND	
Hexachlorobutadiene	261	87683	1.00	**ND**	ND	
Hexane	86	110543	1.00	**ND**	ND	
Isopropanol	60	67630	1.00	**ND**	ND	T
Methyl t-butyl ether (MTBE)	88	1634044	1.00	**ND**	ND	
Methyl butyl ketone (2-Hexanone)	100	591786	1.00	**ND**	ND	T
Methyl ethyl ketone (MEK)	72	78933	1.00	**ND**	ND	
Methyl isobutyl ketone (MIBK)	100	108101	1.00	**ND**	ND	
Propene	44	115071	1.00	**ND**	ND	
Styrene	104	100425	1.00	**ND**	ND	
1,1,2,2-Tetrachloroethane	168	79345	1.00	**ND**	ND	
Tetrachloroethene (PCE)	166	127184	1.00	**ND**	ND	
Tetrahydrofuran (THF)	72	109999	1.00	**ND**	ND	T
Toluene	92	108883	1.00	**ND**	ND	
1,1,1-Trichloroethane (TCA)	133	71556	1.00	**ND**	ND	
1,1,2-Trichloroethane	133	79005	1.00	**ND**	ND	
1,3,5-Trimethylbenzene	120	108678	1.00	**ND**	ND	
1,2,4-Trimethylbenzene	120	95636	1.00	**ND**	ND	
2,2,4-Trimethylpentane	114	540841	1.00	**ND**	ND	
1,2,4-Trichlorobenzene	182	120821	1.00	**ND**	ND	
Trichloroethene (TCE)	131	79016	1.00	**ND**	ND	
Trichlorofluoromethane (F-11)	137	75694	1.00	**ND**	ND	
Trichloritrifluoroethane (F-113)	187	76131	1.00	**ND**	ND	
Vinyl acetate	86	108054	1.00	**ND**	ND	
Vinyl bromide (Bromoethene)	107	593602	1.00	**ND**	ND	
Vinyl chloride	63	75014	1.00	**ND**	ND	
m&p-Xylenes	106	1330207	2.00	**ND**	ND	
o-Xylene	106	95476	1.00	**ND**	ND	

Surrogate Recovery Report			Spiked ppbv	Found ppbv	R%
1,4-Difluorobenzene (SS1)	118.1	540363	5.00	4.65	93
Bromofluorobenzene (SS2)	175	460004	5.00	4.37	87

*Comparison with the method blank this sample run with a dilution factor of: **1.0**

CLIENT: GD Air Testing, Inc.		GD Air Testing Lab. ID:	Method Blank
		Report Date:	09/12/14
		Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	QC-090914
Project No.:	**QC**	Method:	EPA TO15
		NELAP Certification #	***T104704364***

REPORT OF METHOD BLANK RESULTS

Page 3 of 3

J: Estimated value, compound failed the initial calibration criteria.
T: The State of Texas (TCEQ) does not offer accreditation for this compound.
C: Instrument calibrated for this compound. Currently pending NELAC accreditation.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).
* The control limit for Surrogate Recovery % of all spiked compound is 70% - 130%. Only one is required to pass.
*Concentrations in ug/cu M reported at 760 mm Hg pressure and 298 deg.K.

Respectfully submitted
GD Air Testing, Inc.

George Dai, Ph.D.
Laboratory Director

Data File: 090914.D
Report File: QC-14-TO15\Blank

Blank Spike/Blank Spike Duplicate Results

(BS/BSD)

Lab:
GD Air Testing, Inc.
651 N. Plano Rd., #429
Richardson, TX 75081

Date Analyzed: 09/09/14
Analyzed by: LAJ
GD Air QC Batch: **QC-090914**
Method: EPA TO15
NELAP Certification #: ***T104704364***
Page 1 of 2

Spike Control Compounds	Spiked ppbv	Found and Recovery				% RPD	Recovery Limits (%)
		BS/ppbv	BS R%	BSD/ppbv	BSD R%		
Propene	5.0	5.76	115	5.83	117	1.2	50-150
Difluorodichloromethane	5.0	5.61	112	5.57	111	0.7	70-130
Chloromethane	5.0	5.89	118	5.89	118	0.0	70-130
Dichlorotetrafluoroethane	5.0	5.72	114	5.68	114	0.7	70-130
Vinyl Chloride	5.0	5.79	116	5.76	115	0.5	70-130
1,3-Butadiene	5.0	5.90	118	5.86	117	0.7	70-130
Bromomethane	5.0	6.17	123	6.26	125	1.4	70-130
Chloroethane	5.0	5.42	108	5.54	111	2.2	70-130
Bromoethene	5.0	5.27	105	5.37	107	1.9	70-130
Acetone	5.0	6.37	127	6.39	128	0.3	50-150
Isopropanol	5.0	5.46	109	5.71	114	4.5	50-150
Trichlorofluoromethane	5.0	5.14	103	5.20	104	1.2	70-130
1,1-Dichloroethene	5.0	5.58	112	6.04	121	7.9	70-130
Methylene chloride	5.0	5.35	107	5.37	107	0.4	70-130
3-Chloro-1-Propene *	5.0	2.27	45	2.30	46	1.3	70-130
Trichlorotrifluoroethane	5.0	5.20	104	5.31	106	2.1	70-130
Carbon Disulfide *	5.0	7.89	158	8.03	161	1.8	70-130
trans-1,2-Dichloroethene	5.0	5.25	105	5.55	111	5.6	70-130
1,1-Dichloroethane	5.0	5.36	107	5.52	110	2.9	70-130
MTBE	5.0	5.83	117	5.92	118	1.5	70-130
Vinyl Acetate	5.0	6.14	123	6.25	125	1.8	50-150
2-Butanone (MEK)	5.0	6.45	129	6.32	126	2.0	50-150
cis-1,2-Dichloroethene	5.0	5.38	108	5.47	109	1.7	70-130
Ethyl Acetate	5.0	5.59	112	5.67	113	1.4	50-150
Hexane	5.0	5.36	107	5.23	105	2.5	70-130
Chloroform	5.0	5.30	106	5.35	107	0.9	70-130
Tetrahydrofuran	5.0	5.80	116	5.84	117	0.7	50-150
1,2-Dichloroethane (EDC)	5.0	5.49	110	5.51	110	0.4	70-130
1,1,1-Trichloroethane	5.0	5.69	114	5.78	116	1.6	70-130
Benzene	5.0	5.51	110	5.60	112	1.6	70-130
Carbon tetrachloride	5.0	5.45	109	5.53	111	1.5	70-130
Cyclohexane	5.0	4.96	99	5.01	100	1.0	70-130
1,2-Dichloropropane	5.0	5.32	106	5.40	108	1.5	70-130
Bromodichloromethane	5.0	5.44	109	5.44	109	0.0	70-130
1,4-Dioxane	5.0	4.79	96	4.47	89	6.9	50-150
2,2,4-Trimethylpentane	5.0	5.41	108	5.47	109	1.1	70-130

Blank Spike/Blank Spike Duplicate Results
(BS/BSD)

Lab:	**GD Air Testing, Inc.** **651 N. Plano Rd., #429** **Richardson, TX 75081**	Date Analyzed:	09/09/14
		Analyzed by:	LAJ
		GD Air QC Batch:	**QC-090914**
		Method:	EPA TO15
		NELAP Certification #:	***T104704364***
			Page 2 of 2

Spike Control Compounds		Spiked	Found and Recovery					Recovery
		ppbv	BS/ppbv	BS R%	BSD/ppbv	BSD R%	% RPD	Limits (%)
Trichloroethene (TCE)		5.0	5.34	107	5.32	106	0.4	70-130
Heptane		5.0	5.58	112	5.60	112	0.4	50-150
4-Methyl-2-Pentanone (MiBK)		5.0	5.66	113	5.59	112	1.2	70-130
trans-1,3-Dichloropropene		5.0	5.31	106	5.28	106	0.6	70-130
cis-1,3-Dichloropropene		5.0	5.50	110	5.60	112	1.8	70-130
1,1,2-Trichloroethane		5.0	5.37	107	5.51	110	2.6	70-130
Toluene		5.0	6.12	122	6.05	121	1.2	70-130
2-Hexanone (MBK)		5.0	5.88	118	5.73	115	2.6	50-150
Dibromochloromethane		5.0	5.49	110	5.45	109	0.7	70-130
1,2-Dibromoethane		5.0	5.50	110	5.44	109	1.1	70-130
Tetrachloroethene		5.0	5.95	119	5.90	118	0.8	70-130
Chlorobenzene		5.0	5.50	110	5.47	109	0.5	70-130
Ethylbenzene		5.0	6.08	122	6.01	120	1.2	70-130
m&p-Xylenes		10.0	12.2	122	12.1	121	0.8	70-130
Bromoform		5.0	5.44	109	5.34	107	1.9	70-130
Styrene		5.0	6.19	124	6.16	123	0.5	70-130
1,1,2,2-Tetrachloroethane		5.0	5.69	114	5.54	111	2.7	70-130
o-Xylene		5.0	6.24	125	6.17	123	1.1	70-130
4-Ethyltoluene		5.0	6.46	129	6.49	130	0.5	70-130
1,3,5-Trimethylbenzene		5.0	6.44	129	6.24	125	3.2	70-130
1,2,4-Trimethylbenzene	*	5.0	6.58	132	6.30	126	4.3	70-130
Benzyl Chloride	*	5.0	1.48	30	1.40	28	5.6	50-150
1,3-Dichlorobenzene		5.0	6.04	121	5.83	117	3.5	70-130
1,4-Dichlorobenzene		5.0	6.36	127	6.14	123	3.5	70-130
1,2-Dichlorobenzene		5.0	6.22	124	5.97	119	4.1	70-130
1,2,4-Trichlorobenzene	*	5.0	4.97	99	3.64	73	30.9	50-150
Hexachlorobutadiene		5.0	5.69	114	5.57	111	2.1	50-150
Surrogate Recovery Report								
1,4-Difluorobenzene (SS1)		5.0	4.70	94	4.78	96	1.7	70-130
Bromofluorobenzene (SS2)		5.0	5.09	102	4.99	100	2.0	70-130

**** Compound failed BS/BSD criteria. If detected in the sample, results should be considered as an estimated value.***
The control limit for the %RPD of BS/BSD is 30%.

Respectfully Submitted

George Dai, Ph.D.
Laboratory Director
Data File: 09091408,10.D
Report File: D:\QC-TO15\BS-BSD

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0234-1-Ca**
Report Date:	9/8/2014
Date Analyzed:	9/3/2014
Analyzed by:	Sub Lab
Method:	6020
Sub Lab NELAP ID #	***T104704227***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
Biosolid with 0% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	PQL mg/Kg	**RESULT** mg/Kg	NOTE
Calcium	500	**7310**	**W**

W: Result reported on a wet weight basis.
Sample digested by method 3050B on 8/29/14.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0234-1-Ca

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID: **GD14-0234-2-Ca**
Report Date: 9/8/2014
Date Analyzed: 9/3/2014
Analyzed by: Sub Lab

Method: 6020
Sub Lab NELAP ID # ***T104704227***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED	
Biosolid with 5% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	PQL mg/Kg	**RESULT** mg/Kg	NOTE
Calcium	500	**42900**	**W**

W: Result reported on a wet weight basis.
Sample digested by method 3050B on 8/29/14.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D.
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0234-2-Ca

CLIENT: **Dr. Melanie Sattler**
UT Arlington
701 S. Nedderman Dr.
Arlington, TX 76019

Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0234-3-Ca**
Report Date:	9/8/2014
Date Analyzed:	9/3/2014
Analyzed by:	Sub Lab
Method:	6020
Sub Lab NELAP ID #	***T104704227***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
Biosolid with 7% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	PQL mg/Kg	**RESULT** mg/Kg	NOTE
Calcium	1000	**61600**	**W**

W: Result reported on a wet weight basis.
Sample digested by method 3050B on 8/29/14.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

George Dai, Ph.D
Laboratory Director, GD Air Testing, Inc.

Report File: GDAIR D:\Client_Report\GD14-0234-3-Ca

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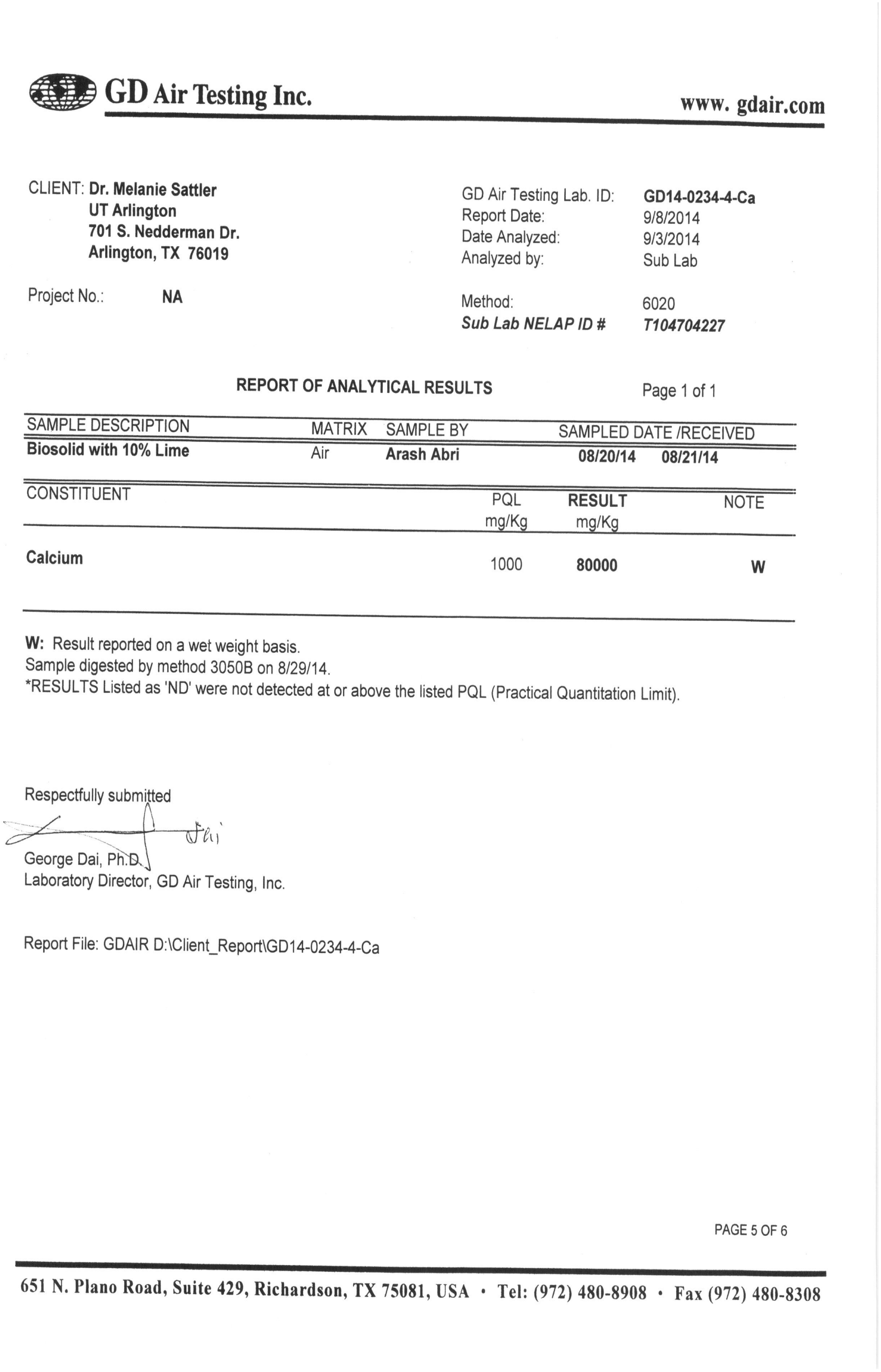

GD Air Testing Inc. www. gdair.com

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Project No.: **NA**

GD Air Testing Lab. ID:	**GD14-0234-4-Ca**
Report Date:	9/8/2014
Date Analyzed:	9/3/2014
Analyzed by:	Sub Lab
Method:	6020
Sub Lab NELAP ID #	***T104704227***

REPORT OF ANALYTICAL RESULTS Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE /RECEIVED	
Biosolid with 10% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	PQL mg/Kg	**RESULT** mg/Kg	NOTE
Calcium	1000	**80000**	**W**

W: Result reported on a wet weight basis.
Sample digested by method 3050B on 8/29/14.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

Dai

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GD Air Testing Lab. ID: **GD14-0234-5-Ca**
Report Date: 9/8/2014
Date Analyzed: 9/3/2014
Analyzed by: Sub Lab

Method: 6020
Sub Lab NELAP ID # ***T104704227***

REPORT OF ANALYTICAL RESULTS

Page 1 of 1

SAMPLE DESCRIPTION	MATRIX	SAMPLE BY	SAMPLED DATE	/RECEIVED
Biosolid with 14% Lime	Air	**Arash Abri**	**08/20/14**	**08/21/14**

CONSTITUENT	PQL mg/Kg	**RESULT** mg/Kg	NOTE
Calcium	1000	**92700**	**W**

W: Result reported on a wet weight basis.
Sample digested by method 3050B on 8/29/14.
*RESULTS Listed as 'ND' were not detected at or above the listed PQL (Practical Quantitation Limit).

Respectfully submitted

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Report File: GDAIR D:\Client_Report\GD14-0234-5-Ca

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