

Prediction of CO₂ and H₂S Emissions from Wastewater Wet Wells

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Abstract

The transportation of wastewater through sewer networks can cause potential problems due to the formation of lethal gases such as ammonia, carbon dioxide, hydrogen sulphide and methane. As a result, they can cause irritating, toxic, and microbial induced corrosion. The true depth of these problems can be measured by measuring the emission of such lethal gasses in the sewer atmosphere. The amount of gases released from such sewer networks has to be controlled. In this paper, we present a simple experimental methodology used to determine the emissions of Carbon Dioxide (CO₂) and Hydrogen Sulphide (H₂S) using Landtec GEM-2000 plus multi-gas analyser from wastewater wet wells.

Keywords

Wastewater Lift Station; Hydrogen Sulfide; Carbon Monoxide; Air Pollutants

1. Introduction

The sewage collection stations, commonly known as a Lift Station, are designed to pump raw sewage that comes from underground gravity pipelines. This raw sewage is accumulated in the collection pit or tank known as a wet well. Electrical level indicator is located in the wet well to determine the instantaneous accumulation of raw sewage. When these level indicators trip, they energize pumps to evacuate the raw sewage through a pressurized pipe system called a sewer force main. From this stage, it is transferred to sewage discharge and a gravity manhole. The cycle is repeated herein until the sewage reaches the treatment plant.

The process in which wastewater is collected, conveyed or treated has the potential to generate and release several gases to the surrounding area that are asphyxiating, irritating, toxic or flammable. These include ammonia (NH₃), carbon dioxide (CO₂), carbon monoxide (CO), hydrogen sulfide (H₂S) and methane (CH₄). This paper's main focus is only on CO₂ and H₂S emissions from the wastewater wet wells

1.1. Carbon Dioxide

Carbon Dioxide (CO₂) is a colorless, odorless, non-flammable gas and is the most prominent Greenhouse Gas (GHG) in Earth's atmosphere. It is recycled through the atmosphere by the process photosynthesis, which makes human life possible. It is an asphyxiant. When carbon dioxide accumulates to more than 10% of the atmosphere,

narcosis may occur in individuals breathing the carbon dioxide. Carbon dioxide is heavier than air and collects in the lower levels of confined spaces (Gerardi Michael & Zimmerman Mel, 2005). Under anaerobic conditions carbohydrates are converted into acetate, hydrogen and carbon dioxide, hence CO₂ is released from wet wells. Human activities such as the production and consumption of fossil fuels, as well as agricultural and industrial activities have caused an increase in the atmospheric concentration of harmful GHGs, particularly CO₂, CH₄, and N₂O (El-Fadel & Massoud, 2001). The increase in atmospheric GHG concentration has led to climate change and global warming effect. The contribution of a GHG to global warming is commonly expressed by its global warming potential (GWP), which enables the comparison of global warming impact of a gas and that of a reference gas, typically carbon dioxide. On a 100-year basis, the GWP of carbon dioxide, methane and nitrous oxide are 1, 23, and 296, respectively (IPCC, 2001).

1.2. Hydrogen Sulfide

In most instances, the odors associated with collection systems and primary treatment facilities are generated as a result of an anaerobic or “septic” condition. This condition occurs when oxygen transfer to the wastewater is limited such as in a force main. In the anaerobic state, the microbes present in the wastewater have no dissolved oxygen available for respiration. This allows microbes known as “sulfate-reducing bacteria” to thrive. These bacteria utilize the sulfate ion (SO₄⁻) that is naturally abundant in most waters as an oxygen source for respiration. The byproduct of this activity is hydrogen sulfide (H₂S). This byproduct has a low solubility in the wastewater and a strong, offensive, rotten-egg odor. In addition to its odor, H₂S can cause severe corrosion problems. (Palmer et al., 2000) Due to its low solubility in the wastewater, it is released into the atmosphere in areas like wet wells, head works, grit chambers and primary clarifier. There are typically other “organic” odorous compounds, such as mercaptans and amines, present in these areas, but H₂S is the most prevalent compound (Vaughan Harshman & Tony Barnette, 2000).

The distinctive odor (rotten egg smell) of H₂S gas is easily perceptible at very low levels (<1 ppm in air). Exposure to moderate H₂S levels (10 - 50 ppm) can cause headaches, dizziness, nausea and vomiting, coughing and breathing difficulty. Exposure to H₂S Levels above 100 ppm can result in severe respiratory tract and eye irritation and extreme cases even death (US Department of Health Education and Welfare, Public Health Service, National Institute for Occupational Safety and Health, Cincinnati).

2. Details of the Lift Station

2.1. Name: Wet Well #1

The station is a three pump, flooded suction type station. The station is enclosed in block wall superstructure, and it consists of a rectangular wet well, approximately 36 ft long, 20.5 ft wide and 18.67 ft deep as shown in **Figure 1**.

The pump capacities of this lift station with 100% valve opening are

Pump 1: 11042 gpm @ 47 ft of total dynamic head

Pump 2: 6771 gpm @ 50 ft of total dynamic head

Pump 3: 6601 gpm @ 48 ft of total dynamic head

Both when pump 1 and pump 2 are running with 100% valve opening, the capacity of the lift station is 14665 gpm at 50 ft of total dynamic head.

2.2. Name: Wet Well #2

The lift station is a two pump, suction lift type station. The station has no superstructure, but wooden fencing with locking gate and it consists of a circular wet well with a circular shaft. The dimension of the circular shaft is 4 ft in diameter and 9 ft deep. The actual wet well is 9 ft in diameter and 7.42 ft deep as shown in **Figure 2**. When both the pumps are running the capacity of the lift station is 1300 gpm @ 44 ft of total dynamic head.

3. Landtec GEM 2000 Plus Instrument

The GEM 2000 Plus instrument designed by Landtec is a landfill gas analyzer which samples and analyzes methane, carbon dioxide and oxygen content in percentage and carbon monoxide and hydrogen sulfide in parts per million. The gas readings are displayed and can be stored in the instrument and downloaded to a personal com-

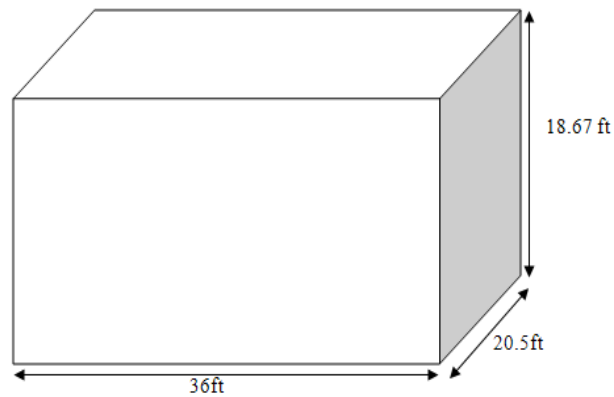


Figure 1. Schematic diagram of a wet well (Site 1).

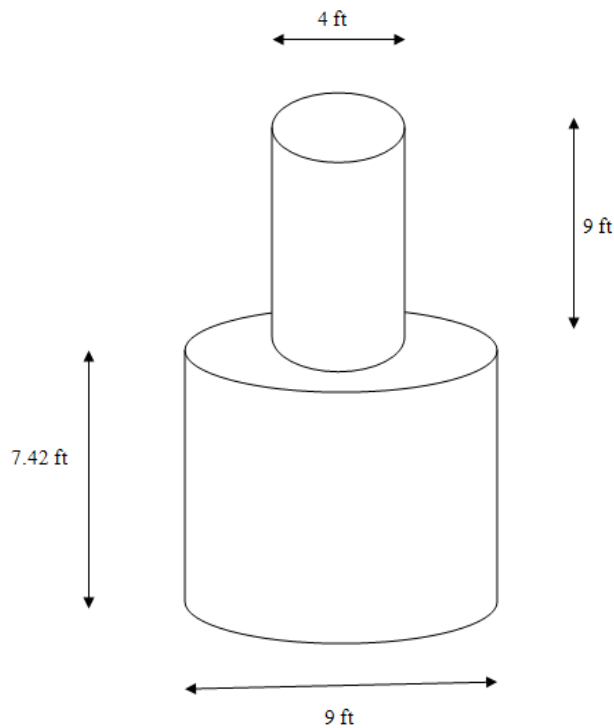


Figure 2. Schematic diagram of a wet well (Site 2).

puter for reporting, analyzing and archiving. The best thing about this instrument is the data logging function which it has. The time interval between the readings can be set in the instrument, and the instrument will take the readings by turning on and off itself to the time interval specified. This instrument measures CO₂ in percent (%) which has to be converted to parts per million by multiplying the percentage with 10⁴. The H₂S readings are measured directly in ppm by the instrument. The range of CO₂ and H₂S for this instrument are 0% - 100% and 0 - 500 ppm respectively.

4. Methods to Control H₂S Emissions Wastewater

Listed below are few methods available to control the rate of hydrogen sulfide corrosion.

- 1) Reducing the dissolved sulfide content of the wastewater
- 2) Using corrosion-resistant materials and coatings
- 3) Providing ventilation of the enclosed area of the sewer and
- 4) Conducting routine preventive maintenance.

Three basic techniques to control dissolved sulfide:

- a) Oxidation by the addition of chemical oxidants such as hydrogen peroxide, chlorine or potassium permanganate, or by the introduction of air or oxygen.
- b) Precipitation of dissolved sulfide by the addition of metallic salts such as ferrous chloride and ferrous sulfate.
- c) pH elevation through the addition of sodium hydroxide. Since low pH is favorable to produce H₂S gas, so it has to be increased (EPA, 1991).

5. Methodology

Wastewater during its stay in a wet well produces CO₂ and H₂S gas. When the volume of wastewater increases in the well these gases are expelled out. Landtec GEM-2000 Plus, a CO₂ and H₂S detecting instrument is used to measure these gases inside the wet well. This instrument gives the concentration of CO₂ in percentage and H₂S in ppm (parts per million). The percentage measure is converted into ppm by multiplying it by 10⁴ (0.1% = 1000 ppm). One ppm here means one part of CO₂ or H₂S is present in one million parts of air.

As the volume of the wastewater in the wet well increases, these gases are pushed out, when the volume of wastewater decreases the surrounding ambient air is dragged into the well to fill the water column with the air. Hence the concentrations in the air volume of the wet well changes depending upon the water level in the well.

Steps for Calculation:

CO₂ and H₂S emissions from the wet well in terms of pounds can be calculated as below:

CO₂ expelled out of the wet well (lb) = Volume of Air Expelled Due to Increase in the water level * Average Hourly Concentration of CO₂/H₂S in the Wet Well * CO₂/H₂S density

Assuming CO₂ density at standard temperature and pressure = 1.98 kg/m³ = 0.124 lb/ft³

The density of H₂S is 1.363 kg/m³ equal to 0.0851 lb/ft³.

CO₂ and H₂S emissions from the wet well in terms of pounds per cubic feet can be calculated as below:

CO₂ or H₂S emitted per unit volume of wastewater (lb/ft³)

= mass of CO₂ or H₂S emitted/average hourly volume of wastewater present in the wet well

= mass of CO₂ or H₂S/[(V₁ + V₂)/2]

where

V₁ = Initial volume of wastewater present in the wet well

V₂ = Final volume of wastewater present in the wet well.

If a person takes a gas (CO₂ or H₂S) measurement at 8 A.M. and another gas measurement at 9 A.M., the Volume of wastewater present in the wet well at 8 A.M. is considered as the initial volume of wastewater and the volume of wastewater present in the wet well at 9 A.M. is considered as the final volume of the wastewater. If that person takes another gas measurement at 10 A.M., for the next calculation the volume of wastewater present in the wet well at 9 A.M. will become initial volume of wastewater present in the wet well and the volume of wastewater present in the wet well at 10 A.M. will be the final volume of wastewater present in the well.

5.1. Tables and Calculations

Below calculations are made assuming the wet well is closed, and anaerobic conditions exist within the well. The measurements of the concentrations were taken on dry and hot day.

Sample calculation for Table 1:

Column 1: Time at which the CO₂ reading is taken

Column 2: Wastewater level in the wet well at the time of reading = 3.3 ft

Dimensions of the wet well:

Length = 36 ft

Width = 20.5 ft

Depth = 18.67 ft

Column 3:

Volume of wastewater present in the wet well

= Length * Width * Wastewater level in the wet well

= 36ft * 20.5ft * 3.3ft

= 2435.4 ft³

Total volume of the wet well
 = Length * Width * Total Depth
 = 36ft *20.5 ft *18.67ft
 = 13778.46 ft³

Column 4:

Volume of Air in the wet well
 = Total Volume of the wet well – Volume of water in the wet well
 = 13778.46 ft³ – 2435.4 ft³
 = 11343.06 ft³

Column 5:

Volume of Air expelled out due to increase in the water level
 = Difference between two consecutive air volumes
 = 11343.06 ft³ – 10752.66 ft³
 = 590.4 ft³

Column 6:

Concentration of CO₂ in the Air in the Wet Well (ppm)
 = 3000 ppm, CO₂ reading in the Landtec GEM-2000 Plus instrument inside the wet well

Column 7:

Average hourly concentration of CO₂ in the wet well
 = Sum of two consecutive readings/2
 = (3000 ppm +1000 ppm)/2
 = 2000 ppm

Column 8:

Assuming CO₂ density at standard temperature and pressure = 1.98 kg/m³ = 0.124 lb/ft³
 CO₂ expelled out of the wet well (lb)
 = Volume of Air Expelled Due to Increase in the water level
 * Average Hourly Concentration of CO₂ in the Wet Well * CO₂ density
 = 590.4 ft³ * 2000 ppm *0.124 lb/ft³
 = 590.4 ft³ * 2000 ft³/ft³ *10⁻⁶ * 0.124 lb/ft³
 = 0.146 lb

Column 9:

Average Hourly Volume of Water present in the Wet Well (ft³)
 = (2435.4 ft³ + 3025.8 ft³)/2
 = 2730.6 ft³

Column 10:

CO₂ Emitted per unit volume of waste water (lb/ft³)
 = (CO₂ expelled out of the wet well (lb)/Average Hourly Volume of Water present in the Wet Well (ft³))
 = 0.146 lb/2730.6 ft³
 = 5.3622E-05 lb/ ft³

Every hour 0.146 pounds of CO₂ is emitted out of the wet well. For one cubic feet of wastewater 5.3622E-05 lb of CO₂ is emitted.

Similarly CO₂ expelled out for the other wet well and H₂S expelled out for the same wet well are calculated. The density of H₂S is 1.363 kg/m³ equal to 0.0851 lb/ft³.

For the Wet Well #2 lift station the H₂S emissions could not be detected as the emissions were lower than the least count of the instrument.

6. Health Impacts

6.1. Health effects of CO₂

Exposure to CO₂ can produce a variety of health effects. These may include headaches, dizziness, restlessness, a tingling or pins or needles feeling, difficulty breathing, sweating, tiredness, increased heart rate, elevated blood pressure, coma, asphyxia to convulsions and even frostbite if exposed to dry ice.

The levels of CO₂ in the air and potential health problems are:

- 1) 250 - 350 ppm—background (normal) outdoor air level.
- 2) 350 - 1000 ppm—typical level found in occupied spaces with good air exchange.
- 3) 1000 - 2000 ppm—level associated with complaints of drowsiness and poor air.
- 4) 2000 - 5000 ppm—level associated with headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
- 5) >5000 ppm—Exposure may lead to severe oxygen deprivation resulting in permanent brain damage, coma and even death.

Also, CO₂ in the atmosphere increases the Earth's temperature which is known as "green house effect" (US Department of Health Education and Welfare, Public Health Service, Centre for Disease Control, National Institute for Occupational Safety and Health, 1976).

6.2. Health effects of H₂S

The levels of H₂S in the air and potential health problems are:

- 1) 0.13 ppm—This is the odor threshold. Odor is unpleasant.
- 2) 4.6 ppm—Strong, intense odor, but tolerable. Prolonged exposure may deaden the sense of smell.
- 3) 10 - 20 ppm—Causes painful eyes, nose and throat irritation, headaches, fatigue, irritability, insomnia, gastrointestinal disturbance, loss of appetite, dizziness. Prolonged exposure may cause bronchitis and pneumonia.
- 4) 50 ppm—May cause muscle fatigue, inflammation and dryness of nose, throat and tubes leading to the lungs. Exposure for one hour or more at levels above 50 ppm can cause severe eye tissue damage. Long-term exposure can cause lung disease.
- 5) 100 - 150 ppm—Loss of smell, stinging of eyes and throat. Fatal after 8 to 48 hours of continuous exposure.
- 6) 200 - 250 ppm—Nervous system depression (headache, dizziness and nausea are symptoms). Prolonged exposure may cause fluid accumulation in the lungs. Fatal in 4 to 8 hours of continuous exposure.
- 7) 250 - 600 ppm—Pulmonary edema (lungs fill with fluid, foaming in the mouth, chemical damage to lungs).
- 8) 300 ppm—May cause muscle cramps, low blood pressure and unconsciousness after 20 minutes.
- 9) 300 to 500 ppm may be fatal in 1 to 4 hours of continuous exposure.
- 10) 500 ppm—Paralyzes the respiratory system and overcomes victim almost instantaneously. Death after exposure of 30 to 60 minutes.
- 11) 700—Paralysis of the nervous system.
- 12) 1000—Immediately fatal.

If caught in time, poisoning can be treated, and its effects are reversible. Some workers may experience abnormal reflexes-dizziness, insomnia and loss of appetite that lasts for months or years. Acute poisoning does not result in death, may produce long-term symptoms such as loss of memory or depression, paralysis of facial muscles (Canadian Centre for Occupational Health and Safety, 1985).

7. Results and Discussion

At Wet Well # 1

On an average CO₂ expelled out of the wet well every one hour = 0.139 lb

On an average H₂S expelled out of the wet well every one hour = 0.002 lb

CO₂ emitted per unit volume of wastewater (lb/ft³) = 4.3715E-05 lb/ft³

H₂S emitted per unit volume of wastewater (lb/ft³) = 6.7177E-07 lb/ft³

At Wet Well #2

On an average CO₂ expelled out of the wet well every one hour = 0.002 lb

CO₂ emitted per unit volume of wastewater (lb/ft³) = 2.2545E-05 lb/ft³

It can be observed from **Tables 1-3** that the concentrations of pollutants in the well change with temperature, size of the well, and volume of water present in the wet well. The concentrations of the pollutants also depend upon whether the wet well is directly exposed to the atmosphere or a superstructure exists above it. If a superstructure exists over a wet well, the conditions in the wet well may be considered as strictly anaerobic. Temperature is a very significant component for the H₂S emissions, higher the temperature greater the gas emitted. CO₂ emissions are less dependent on temperature when compared to H₂S emissions. According to EPA, even at very low concentration (<1 ppm) of hydrogen sulfide, it can corrode the electrical and mechanical devices and also the concrete structures. The observed lift station exhibits higher hydrogen sulfide levels posing corrosion risks to

Table 1. CO₂ emissions from the wet well.

LIFT STATION: Wet Well # 1									
Time (1) (Date: 06/12/09) Dry Weather	WW Level in the Well (ft) (2)	Volume of WW in the Wet Well (ft ³) (3)	Volume of Air in the Wet Well (ft ³) (Total Volume of the wet well = 13778.46 ft ³) (4)	Volume of Air Expelled Due to Increase in water level (ft ³) (5)	Concentration of CO ₂ in the Air in the Wet Well (ppm) (6)	Average Hourly Concentration of CO ₂ in the Wet Well (ppm) (7)	CO ₂ Expelled out of the Wet Well (lb) (8)	Average Hourly Volume of WW present in the Wet Well (ft ³) (9)	CO ₂ Emitted per unit vo- lume of WW (lb/ft ³) (10)
10.00 AM	3.3	2435.4	11343.06	-	3000.0	-	-	-	-
11.00 AM	4.1	3025.8	10752.66	590.4	1000.0	2000.0	0.146	2730.6	5.3622E-05
12 NOON	5.2	3837.6	9940.86	811.8	4000.0	2500.0	0.252	3431.7	7.3333E-05
1.00 PM	3.6	2656.8	11121.66	0.0	3000.0	3500.0	0.000	3247.2	0
2.00 PM	5.5	4059.0	9719.46	1402.2	2000.0	2500.0	0.435	3357.9	0.00012945
3.00 PM	4.6	3394.8	10383.66	0.0	0.0	1000.0	0.000	3726.9	0
4.00PM	3.0	2214.0	11564.46	0.0	1000.0	500.0	0.000	2804.4	0
5.00 PM	4.5	3321.0	10457.46	1107.0	1000.0	1000.0	0.137	2767.5	0.0000496
Average CO ₂ Expelled out of the Wet Well per one hour =							0.139	CO ₂ emitted/unit volume of WW =	4.3715E-05

Table 2. H₂S emissions from the wet well.

LIFT STATION: Wet Well # 1									
Time (1) (Date: 06/12/09) Dry Weather Time	WW Level in the Well (ft)	Volume of WW in the Wet Well (ft ³)	Volume of Air in the Wet Well (ft ³) (Total Volume of the wet well = 13778.46 ft ³)	Volume of Air Expelled Due to Increase in WW level (ft ³)	Concentration of H ₂ S in the Air in the Wet Well (ppm)	Average Hourly Concentration of H ₂ S in the Wet Well (ppm)	H ₂ S Expelled out of the Wet Well (lb)	Average Hourly Volume of WW present in the Wet Well (ft ³)	H ₂ S Emitted per unit volume of WW (lb/ft ³)
10.00 AM	3.3	2435.4	11343.06	-	19.0	-	-	-	-
11.00 AM	4.1	3025.8	10752.66	590.4	6.0	12.5	0.001	2730.6	0.00000023
12 NOON	5.2	3837.6	9940.86	811.8	69.0	37.5	0.003	3431.7	7.5492E-07
1.00 PM	3.6	2656.8	11121.66	0.0	89.0	79.0	0.000	3247.2	0
2.00 PM	5.5	4059.0	9719.46	1402.2	57.0	73.0	0.009	3357.9	2.5941E-06
3.00 PM	4.6	3394.8	10383.66	0.0	2.0	29.5	0.000	3726.9	0
4.00 PM	3.0	2214.0	11564.46	0.0	26.0	14.0	0.000	2804.4	0
5.00 PM	4.5	3321.0	10457.46	1107.0	40.0	33.0	0.003	2767.5	1.1233E-06
Average H ₂ S Expelled out of the Wet Well per one hour =							0.002	H ₂ S emitted/unit volume of WW =	6.7177E-07

Table 3. CO₂ emissions from the wet well.

LIFT STATION: Wet Well # 2									
Time (1) (Date: 06/12/09) Dry Weather Time	WW Level in the Well (ft)	Volume of WW in the Wet Well (ft ³)	Volume of Air in the Wet Well (ft ³) (Total Volume of the wet well = 585.1 ft ³)	Volume of Air Expelled Due to Increase in water level (ft ³)	Concentration of CO ₂ in the Air in the Wet Well (ppm)	Average Hourly Concentration of CO ₂ in the Wet Well (ppm)	CO ₂ Expelled out of the Wet Well (lb)	Average Hourly Volume of WW present in the Wet Well (ft ³)	CO ₂ Emitted per unit volume of WW (lb/ft ³)
9.30 AM	1.2	76.3	508.8	-	3000	-	-	-	-
10.30 AM	2.1	133.6	451.5	57.3	1000	2000	0.014	104.96871	0.00013527
11.30 AM	2.3	146.3	438.8	12.7	1000	1000	0.002	139.95828	1.1273E-05
12.30 PM	2.0	127.2	457.9	0.0	0	500	0.000	136.77741	0
1.30 PM	1.5	95.4	489.7	0.0	1000	500	0.000	111.33045	0
2.30 PM	1.8	114.5	470.6	19.1	0	500	0.001	104.96871	1.1273E-05
3.30 PM	2.3	146.3	438.8	31.8	0	0	0.000	130.41567	0
4.30 PM	1.4	89.1	496.1	0.0	0	0	0.000	117.69219	0
Average CO ₂ Expelled out of the Wet Well per one hour =							0.002	CO ₂ emitted/unit volume of WW =	2.2545E-05

the Kenner City's wastewater infrastructure.

8. Limitations

Practically no wet well is completely closed. There may be some leakages from the well which are not considered in this approach of quantifying emissions. The emissions may change depending upon the composition of the wastewater, pH, temperature, and residence time inside the wet well which should be further investigated.

References

- American Public Health Association, American Water Works Association, Water Environment Federation (1995). *Standard Methods for the Examination of Water and Wastewater* (19th ed.). Washington DC: APHA.
- Canadian Centre for Occupational Health and Safety (1985). *Chemical Hazard Summary: Hydrogen Sulfide No. 12*. Hamilton: Canadian Centre for Occupational Health and Safety.
- El-Fadel, M., & Massoud, M. (2001). Methane Emissions from Wastewater Management. *Environmental Pollution*, 114.
- Gerardi Michael, H, & Zimmerman Mel, C. (2005). *Wastewater Pathogens*. Hoboken: John Wiley & Sons, Inc.
- IPCC (2001). Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (398 p). In Watson, R.T., & the Core Writing Team (Eds.), Cambridge, United Kingdom, and New York: Cambridge University Press.
- Metcalf, & Eddy Inc. (1991). *Wastewater Engineering: Treatment, Disposal, and Reuse* (3rd ed.). In G. Tchobanoglous, & F. L. Burton (Eds.), New York: McGraw-Hill.
- National Institute for Occupational Safety and Health/Occupational Safety and Health Administration (1981) *NIOSH/OSHA: Occupational Health Guidelines for Chemical Hazards*.
- Palmer, T., Lagasse, P., & Ross, M. (2000). Hydrogen Sulfide Control in Wastewater Collection systems. *Water Engineering and Management*, 27-29.
- US Department of Health Education and Welfare, Public Health Service, Centre for disease control, National Institute for Occupational Safety and Health (1976). *Occupational Exposure to Carbon Dioxide* (pp. 76-194). NIOSH.
- US Department of Health Education and Welfare, Public Health Service, National Institute for Occupational Safety and

Health, Cincinnati. *A Recommended Standard for Occupational Exposure to Hydrogen Sulfide*.

US Environmental Protection Agency (1991). *Hydrogen Sulfide Corrosion: Its Consequences, Detection and Control*.

Vaughan Harshman, P. E., & Barnette, T. (2000). *Wastewater Odor Control: An Evaluation of Technologies*.