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The Effects of Atmospheric Pressure Changes on Landfill Gas Collection Efficiency and Quality

Jason Leone

Rochester Institute of Technology

THE EFFECTS OF ATMOSPHERIC PRESSURE CHANGES ON LANDFILL GAS COLLECTION EFFICIENCY AND QUALITY

By Jason Leone

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Department of Civil Engineering Technology,
Environmental Management & Safety
Rochester Institute of Technology
Rochester, NY

Approved by:

Maureen Valentine, PE, Department Chair — Date

John Morelli, PE, Ph.D., Graduate Committee Chair — Date

Jeff Kocian, Committee Member — Date

Keith Ott, Committee Member — Date

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ABSTRACT

The effects of atmospheric pressure changes on landfill gas collection efficiency and quality are relatively complex and also very important to the effective management of these systems not only for practical operation and maintenance of these systems, but to also minimize the impacts of these fluctuations on the system in general. This thesis examined three areas of collection and control systems that effectively manage landfill gas (LFG), which is generated by the anaerobic decomposition of organic matter in municipal solid waste and analyzed the effects of barometric pressure on those systems. The three areas of analysis included the effects of barometric pressure on (1) individual LFG well quality, (2) flare flow, and (3) power plant flow and LFG quality. The results were as follows: (1) no statistically significant correlation was found on the effects of barometric pressure on LFG quality in wells; (2) statistically significant correlations were found for flare flow in comparison to barometric pressure, however, in opposing directions therefore being inconclusive; (3) statistically significant correlations were found for power plant LFG quality (measured as nitrogen) in comparison to barometric pressure as expected: (4) statistically significant correlations were found for power plant flow in comparison to barometric pressure, however, in opposing directions therefore being inconclusive. The implications of this thesis are that additional research needs to be completed in this area to fully understand the affects of barometric pressure on individual gas collection wells, but also on LFG flare control systems as well. Power plants are more defined as they control the quantity and quality of the LFG that they consume based on energy needs and have better controls in place than flare systems or individual LFG monitoring wells.

1 Introduction and Background

1.1 Introduction and Background

The amount of Municipal Solid Waste (MSW) that is accepted over the course of a year at Waste Management of New York, LLC at High Acres Landfill & Recycling Center (HALRC) is truly astounding. Beyond providing a secure way to dispose of society's waste, burying tremendous amounts of MSW can benefit society by providing an opportunity to generate an economically attractive energy product in the form of landfill gas (LFG). LFG is produced by the anaerobic decomposition of organic matter in the solid waste and is then actively collected from the landfill through a network of vertical and horizontal LFG collection wells and associated underground piping.

HALRC has been operational since 1971 and currently has one LFG collection system located in the closed section of the landfill and one in the western expansion.[1] At HALRC, there are approximately 111 vertical and horizontal LFG wells currently being utilized to collect LFG. Once LFG is extracted from the landfill, it is either burned in a flare or turned into power at the High Acres Power Production Plant (plant). In 1992 HALRC began generating electricity, using LFG collected from the existing closed section of the landfill. The plant consists of four reciprocating engines that use the LFG as fuel to generate electricity[2] All four engines together

[1] Earth Tech, NSPS Collection and Control System Design Plan and Monitoring Plan for Waste Management of New York High Acres Landfill & Recycling Center, I-1, June 1997, Amended March 2004.
[2] Waste Management High Acres Landfill, "Landfill Gas" http://highacreslandfill.com/Power%20Production%20Plant.htm (accessed November 4, 2006).

produce 3.2 Megawatts of power or enough electricity to supply 3000 homes each day.[3] An enclosed flare is available to combust the LFG not utilized by the plant.

LFG consists mainly of methane, carbon dioxide, oxygen, nitrogen, and other trace compounds. In general the LFG is composed of 55% methane and 45% percent carbon dioxide; however there may be present a small amount of other gases such as oxygen and nitrogen.

The LFG collection system is a dynamic system and keeping the quality of LFG in a landfill consistent is important especially for HALRC, as power production depends on it. For example, if too much LFG is extracted from a particular well, there may be a risk of air intrusion, which may lead to lower LFG quality and the possibility of negatively impacting the anaerobic microbes that generate the methane.[4] On the other hand if too little LFG is collected, there is a risk of causing odors, potential for LFG migration and the loss of a revenue source if not able to produce the power in the plant.[5]

In preparation for this work, a review of the literature that was conducted focused on atmospheric pressure effects as it relates to LFG collection efficiency and quality. Much of the literature reviewed related to LFG generation models that take into account how atmospheric pressure affect surface emissions and LFG migration in landfills and quantifying those emissions with field test procedures such as the use of flux chambers and surface monitoring with flame

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[3] Waste Management High Acres Landfill, "Landfill Gas" http://highacreslandfill.com/Power%20Production%20Plant.htm (accessed November 4, 2006).
[4] Lenny Blackman, Larry Myers, Linman Bjerkin, Pat Freemon, "Spadra Landfill Gas System Design and Operation with Respect To Barometric Pressure, Temperature, and Gas Density", pg.229, *Proceedings from SWANA's 20th Annual Landfill Gas Symposium, March 25-27* (pp.229-269), Publication #GR-LG0020.
[5] Blackman, Myers, Bjerkin, Freemon, p.229.

ionization detection equipment. These models did not focus specifically on how atmospheric pressure affected LFG quality or collection efficiency or how to combat these fluctuations. However there was some literature that was reviewed that touched upon the effects of atmospheric pressure as it relates to changing the dynamics of LFG quality, migration and collection efficiency. In Chapter 2, Literature Review, Section 2.1, Impacts of Weather, high and low pressure system changes are shown to have an impact on LFG operation. In this section it is also noted that the rate of change of atmospheric pressure is an important factor in LFG emissions.

Two specific works that looked at atmospheric pressure and its effects on LFG collection systems were at the Spadra Landfill in Pomona, California where their LFG system design and operation took into account barometric pressure, temperature and LFG density.[6] The second work was conducted by Richard Prosser who evaluated the effects of atmospheric pressure on the availability of LFG from a landfill.[7] In doing so Prosser determined that "a landfill's internal pressure increases and decreases in response to variations in atmospheric pressure. During decreasing atmospheric pressure periods, the internal landfill pressure may be greater than the external pressure, thus causing a temporary increase in the flow rate of LFG from the landfill. Conversely, during periods of increasing atmospheric pressure, less LFG will be vented."[8]

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[6] Blackman, Myers, Bjerkin, Freemon, p.229.
[7] Richard W. Prosser, "The Effects of Atmospheric Pressure on the Availability of Gas From a Landfill", p.12, Copyright 1985, GC Environmental, Inc.
[8] Prosser, p.12.

1.2 Topic Statement

The objective of this thesis was to determine the impact of atmospheric pressure on the LFG collection systems efficiency and LFG quality by evaluating well field data, power plant data, and flare data. These data were correlated with variations in atmospheric pressure to better understand the effects of atmospheric pressure on LFG collection and to provide insights into strategies to maximize collection efficiency and improve LFG quality for the plant.

1.3 Significance of Topic

"Landfills are the largest human-related source of methane in the U.S., accounting for 34% of all methane emissions."[9] Methane is a greenhouse gas and greenhouse gases trap outgoing terrestrial radiation and warm the earth's atmosphere.[10] Increasing greenhouse gas concentrations tend to warm the planet. "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. In short, a number of scientific analyses indicate, that rising levels of greenhouse gases in the atmosphere are contributing to climate change (as theory predicts). In the coming decades, scientists anticipate that as atmospheric concentrations of greenhouse gases continue to rise, average global temperatures and sea levels will continue to rise as a result and precipitation patterns will change."[11] "Methane's overall contribution to global warming is signficant because it is estimated to be more than 20 times as effective at trapping heat in the atomsphere that carbon dioxide."[12]

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[9] http://www.epa.gov/methane/sources.html
[10] http://www.epa.gov/methane/sources.html
[11] http://www.epa.gov/climatechange/science/stateofknowledge.html
[12] http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR5CZKVE/$File/ghgbrochure.pdf

In addition landfill operators can maximize the profitability of energy production by gaining a better understanding of the effects of atmospheric pressure on LFG quality and as a result could improve the economic feasibility of LFG energy production. These reports present a strong case that it is important to collect and destroy methane generated in landfills, as methane is such a significant contributor to global warming.

1.4 Reason for Interest in Topic

It is important to better understand the effects of atmospheric pressure on LFG collection efficiency and quality in order to maximize the efficiency of the LFG collection system. This will help mitigate fugitive emissions from escaping the LFG collection system and therefore reduce associated odors with such as well as mitigate the impact of the landfill as a contributor to greenhouse gases in the atmosphere. Over the three plus years that this researcher has been employed at the landfill conversations with the plant manager revealed that weather, specifically high and low pressure weather systems has an affect on LFG quality at the plant and also individual LFG wells as he has experienced it first hand as can be seen in the plant flows, plant LFG quality readings and flare flows. For example during low pressure weather systems, it is more likely to have LFG escaping the surface of the landfill causing odors because LFG flows more easily with less atmospheric pressure on the surface of the landfill. Waste Management, Inc. (WMI) is an industry leader in providing comprehensive waste management services including collection, disposal, recycling, and environmental services. It is this researcher's belief that WMI can leverage that expertise at its 283 active landfill disposal sites and reduce methane emissions from these landfills.

1.5 Definition of Terms

B.P. – Barometric Pressure

LFG - Landfill Gas

HALRC - High Acres Landfill & Recycling Center

MSW Municipal Solid Waste

Greenhouse Gases – Carbon Dioxide, methane, nitrous oxide, ozone, hydrofluorocarbons (HFCs), perfluorcarbons (PFCs), and sulfur hexafluoride (SF_6).

Western Expansion – WEX

Waste Management Inc. – WMI

Atmospheric Pressure – The pressure above any area in the Earth's atmosphere caused by the weight of air.

2 Literature Review

2.1 Impacts of Weather

The collection efficiency and quality of LFG is impacted by atmospheric pressure fluctuations as evidenced in the literature. "Meteorological parameters (precipitation, atmospheric pressure and temperature, and air humidity), have an important effect on the production, composition and transport of LFG in the waste mass."[13] During high-pressure weather systems landfills have a tendency to store additional LFG as evidenced by greater vacuum in the landfill being needed to collect the LFG and it is not available.[14] When low-pressure weather systems come through an area, LFG tends to flow more easily with less resistance from the lower atmospheric pressure on the surface of the landfill and if the collection system cannot increase vacuum and adjust to these influences, LFG is released.[15] Gas collection systems that extract LFG for electricity generation are typically statistically balanced to mitigate the intrusion of air into the system and therefore not able to compensate for rises and falls in atmospheric pressures necessary in order to capture that additional LFG.[16] Dependent on the configuration of the collection system it may take some time to compensate to these fluctuations in atmospheric pressure.

At the Spadra Landfill in Monterey, California it was noted that when there were high and low pressure system changes and the temperature throughout the day was consistent, the conditions dictated that atmospheric pressure had a greater impact on the LFG operation as compared to the

[13] Matgorzata Meres, Elzbeita Szczepaniec-Cieciak, Anna Sadowska, Krzysztof Piejko, Konrad Szafnicki, "Operational and Meteorological Influence on the Utilized Biogas Composition at the Barycz Landfill Site in Cracow, Poland", Waste Management & Research, 195, Waste Manage Res 2004: 22: 195–201, Printed in UK – all right reserved Copyright © ISWA 2004, Waste Management & Research ISSN 0734–242X.
[14]Alan Janeckek, Richard Prosser, GC Environmental Inc., "Landfill Gas Collection and Groundwater Protection", pg 6, Copyright 1995, Presented at the Eighteenth International Madison Waste Conference, September 20-21, 1995, Dept. of Engineering Professional Development, University of Wisconsin-Madison.
[15] Janeckek and Prosser, p.6
[16] Janeckek and Prosser, p.6

temperature.[17] "From strip chart recordings, it was determined that atmospheric pressure fluctuations occur in a fairly cyclic pattern throughout a 24-hour day except when storms are present."[18] Atmospheric pressure tends to increase from early morning to around noon then it begins to fall until late afternoon, where it will stay reasonably constant, until the next day when the cycle will repeat itself.[19] A study at a Swedish landfill demonstrated that there were clear daily variations in the emissions of methane from landfills and that "a clear difference was found between daytime and night-time emissions."[20] However, in this particular study temperature and atmospheric pressure were correlated, it was difficult to determine which of these two factors contributed more significantly to the daily variation.

Seasonal fluctuations in LFG quality and quantity have been observed and are dependent upon the amount of rainfall, snowfall, and frost or ice formation on the surface of the landfill.[21] When the surface of the landfill is frozen, or has snow on it or has a layer of moist soil on it, the methane percentage in the LFG increased because ambient air didn't penetrate through the surface of the "Barycz" landfill site in Cracow, Poland.[22] During the summer months when temperatures typically rise and rainfall is minimal, the surface of the "Barycz" landfill became more susceptible to air intrusion through potential cracks in the cover soil and the migration of LFG as well, therefore reducing the methane concentration utilized in the collection system.[23] At the "Barycz" landfill site it was observed that, "in winter, due to the formation of an impervious

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[17] Lenny Blackman, Larry Myers, Linman Bjerkin, Pat Freemon, "Spadra Landfill Gas System Design and Operation with Respect To Barometric Pressure, Temperature, and Gas Density", pg.241, *Proceedings from SWANA's 20th Annual Landfill Gas Symposium, March 25-27* (pp.229-269), Publication #GR-LG0020.
[18] Prosser, p.4
[19] Prosser, p.4
[20] Gunnar Borjesson, Bo H. Svensson, "Seasonal and Diurnal Methane Emissions from a landfill and their regulation by methane oxidation", pg.51, Waste Management & Research (1997): 15, pg 33-54.
[21] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.196
[22] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.199
[23] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.200

landfill surface preventing contact between biogas and the atmospheric air, no influence of the atmospheric pressure upon the composition of the landfill gas was observed".[24] However, this depends on the geographic location of the landfill and the severity of the winter weather.

Prior work by Young developed a model that demonstrated that variations in atmospheric pressure led to greater changes in LFG emissions and it was the rate of change of atmospheric pressure that was more critical than its absolute value.[25] State-space analysis of data obtained from a Danish municipal landfill also determined the same thing in that it is the rate of change in atmospheric pressure rather than the absolute level of pressure itself that controls gas flux and/or emissions.[26]

2.2 Efficiency of LFG Collection System

"Gas collection efficiency is important for a variety of environmental, regulatory and engineering purposes and accordingly may be defined differently."[27] The efficiency of a collection system is determined by the amount of gas collected by that system in comparison to what is theoretically generated based on gas generation models. In order to fully understand what effects the efficiency of a LFG collection system you must first understand that methane generated in landfills can be separated into the following pathways: methane recovered (and subsequently destroyed), methane emitted, methane oxidized, methane migrated and methane

[24] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.200
[25] Alan Young, "The Effects of Fluctuations in Atmospheric Pressure on Landfill Gas Migration and Composition", pg. 601, Water, Air, and Soil Pollution, 64:601-616, 1992 Kluwer Academic Publishers. Printed in the Netherlands.
[26] Tjalfe Poulsen, Mette Christophersen, Per Moldrup, Peter Kjeldsen, "Relating landfill gas emissions to atmospheric pressure using numerical modeling and state-space analysis", pg. 364, Waste Management & Research, Waste Manage Res 2003: 21: 356–366, Printed in UK – all right reserved Copyright © ISWA 2003, Waste Management & Research ISSN 0734–242X.
[27] Raymond Huitric, Dung Kong, "Measuring Landfill Gas Collection Efficiency Using Surface Methane Concentrations", no page number, Solid Waste Management Department Los Angeles County Sanitation Districts, Whittier, California.

storage within the landfill.[28] "Because methane production is typically modeled from waste inputs and thus difficult to validate at field scale, the sum of methane pathways (especially recovery, emissions, and oxidation) provides an improved methodology to evaluate the actual methane generation and percent recovery at field scale."[29] The focus of this research is on how atmospheric pressure specifically affects collection efficiency of LFG. Consideration must be given to the methane pathways however.

Reducing the spacing of individual LFG wells in order to facilitate greater coverage and control for each LFG well should be considered on a case-by-case basis as each landfill exhibits unique qualities based on waste stream variability.[30] The radius of influence of individual wells varies with time and "its magnitude is primarily a function of the imposed pumping rate (suction) in the well, but it depends also on other properties, such as the gas generation rate in the waste, the age of wastes, the waste physical properties, the thickness of the waste, and variations in atmospheric pressure."[31] Historical well data should be collected and reviewed to evaluate effectiveness of individual gas wells so that a plan can be developed for installation of additional gas wells as necessary.[32] The gas collection system should be examined periodically to see if there are any configurations or operational improvements that can be made to improve collection efficiency such as placing gas wells at the limits of waste to minimize off-site migration, adjust individual

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[28] K.Spokas, J.Bogner, J.P. Chanton, M. Morcet, C. Aran, C. Grafff, Y. Moreau-Le Golvan, I. Hebe, "Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems?" pg.517, Waste Management 26, (2006) 516-525, Copyright 2005 Elseveir Ltd.
[29] Spokas, Bogner, Chanton, Morcet, Aran, Grafff, Moreau Le Golvan, Hebe, pg.523.
[30] Janeckek and Prosser, p.7
[31] Harold Vigneault, Rene Lefebvre, Miroslav Nastev, "Numerical Simulation of the Radius of Influence for Landfill Gas Wells", Published in Vadose Zone Journal, pg.909, 3:909-916 (2004), Copyright Soil Science Society of America.
[32] Janeckek and Prosser, p.7

wells based on LFG flow, and improve upon the instruction that the landfill gas technician receives to manage the entire well field and its effectiveness.[33]

2.3 Waste Consistency

The movement of LFG in a landfill through the MSW and soils is very difficult to predict based on the variability of MSW.[34] LFG will travel through the MSW and cover soils based on "the path of least resistance," which may cause migration of LFG through these areas in the landfill.[35] When conditions in the MSW are constant, weekly methane and carbon dioxide readings from individual gas wells remained fairly constant with methane concentration varying "$\pm$ 0.2% volume" and carbon dioxide concentration varying "$\pm$ 0.5% volume" at the Barycz landfill.[36] The same is true for monthly methane and carbon dioxide readings as little difference was seen and was in the range from "0.3 –2.5% volume" for methane and "0.3-3.3% volume" for carbon dioxide at the Barycz landfill.[37] However, by looking at multiple months in succession, it became apparent that there was a greater range of methane and carbon dioxide concentrations than previously seen in the weekly and monthly readings in the range of "1.2-6.7% volume", and "0.5-6.2% volume" respectively.[38]

2.4 LFG Well Characteristics

Each LFG well has unique characteristics that affect performance based on a number of variables such as well depth, length of slotted and solid piping and applied vacuum to name a few. It is

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[33] Janeckek and Prosser, p.7
[34] Philip O'Leary, Patrick Walsh, "Landfill Gas Movement, Control and Energy Recovery", Waste Age; 49, March 2002: 33: 3: ABI/INFORM Global, http://proquest.umi.com.ezproxy.rit.edu/ (accessed September 16, 2006).
[35] O'Leary, Walsh, p.49
[36] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.198
[37] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.198
[38] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.198

critical that each LFG well has a control mechanism, that allows for adjustments of vacuum at each well.[39] The quality of LFG that each well produces is dependent on the location of the wells and is impacted even more so if it is located in an area with low permeability or excessive moisture from leachate in the landfill.[40] "The fluctuating availability of LFG can be accounted for by adjusting the collection rate as LFG becomes available. This can be done by automatically adjusting the LFG extraction rate at either individual wells or the total field as a function of rising or falling atmospheric pressure. Another alternative is to control extraction well flow rates to maintain a constant absolute pressure."[41]

2.5 Summary

Much of what was reviewed deals with methane flux from the surface of landfills and the methods for measuring these emissions in the surface soil and surrounding areas in order to determine how much methane was escaping through the surface soils, the effects of various types of soils on methane oxidation, methane migration and methane storage within a landfill. Many of the studies were attempting to establish a better model to determine methane generation and emissions from landfills through field data collection and measurements.

This review suggests atmospheric pressure impacts LFG availability; quality and collection efficiency of LFG collection systems and that each landfill needs to evaluate their LFG control system in order to effectively manage for these changes. The rate of change in atmospheric pressure has more of an impact on LFG emissions than the absolute value. Some challenges that come to mind would be the time commitment of personnel to adjust wells on an individual basis

[39] O'Leary, Walsh, p.52
[40] Meres, Cieciak, Sadowska, Piejko, Szafnicki, p.198
[41] Janeckek and Prosser, p.6

during fluctuations of atmospheric pressure in order to capture the additional LFG generated. In addition each LFG well reacts differently to changes in the atmospheric pressure and a thorough evaluation would need to completed prior to automating the gas collection system.

3 Methodology

3.1 Case Study Methodology

"Case study research excels at bringing us to an understanding of a complex issue or object and can extend experience or add strength to what is already known through previous research. Case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships. Researchers have used the case study research method for many years across a variety of disciplines."[42] "Some of the early criticisms of the case study as a research methodology was that it was unscientific in nature, and because replication was not possible. The literature contains major refutations by Yin, Stake, Feagin, and others whose work resulted in a suggested outline for what a case study protocol could include."[43] Case Study Methodology was the principal method of data collection used in this research. Elements of Case Study Methodology are discussed below in the following sections: 3.2 Overview of the Case Study Project, 3.3 Field Procedures, and 3.4 Case Study Questions.[44]

3.2 Overview of the case study project

The objective of this case study was to understand to what extent atmospheric pressure fluctuations effect LFG collection efficiency (i.e., flow) and quality (i.e., methane %) and therefore better manage the system to exploit these influences. In order to determine if a relationship existed, three specific areas of the LFG collection and control system were evaluated. The first area evaluated was the monthly well field data for both the Closed Landfill

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[42] Susan K. Soy, *The Case Study as a Research Method*, Unpublished paper, University of Texas at Austin, 1997.
[43] Winston Tellis, "Application of a Case Study Methodology", *The Qualitative Report*, Volume 3, Number 3, September, 1997, pg.5, (**http://www.nova.edu/ssss/QR/QR3-3/tellis2.html**) Yin, R. (1994). *Case study research: Design and methods* (2nd ed.). Thousand Oaks, CA: Sage Publishing
[44] Tellis, Yin, pg 5.

and the Western Expansion (WEX). The WEX well field LFG is predominately being consumed by the flare whereas the Closed Landfill LFG is going to the power plant. The second area evaluated was the flare, which controls LFG by burning and destroying what the power plant cannot utilize and the WEX LFG. The third area evaluated was the power plant, which collects LFG from the Closed Landfill and generates electricity. A combination of 37 vertical and horizontal collection wells extract the LFG from the Closed Landfill and send it through a main LFG header system to the power plant to be consumed as fuel in internal reciprocating combustion engines. The portion of LFG being consumed by the power plant and the flare equals the amount of LFG that the collection system is effectively collecting through a network of 111 gas collection wells. In theory the amount of gas collected via the power plant and flare should represent the amount of LFG generated from the entire landfill, however there are numerous factors that influence the effectiveness of the collection and control system, one of which is the focus of this project as stated above.

Some Case Study issues that may have effected data collection and analysis include LFG wells that were abandoned or failed due to malfunctions in the collection system, LFG wells that were added to the collection system as needed to improve LFG collection capability, start-up/shut downs of the power plant and/or flare due to routine or non-routine maintenance, and data collection recording interruptions due to software/hardware malfunctions.

3.3 Field Procedures

All data for this project was readily accessible either in hard copy format or electronically on site. However, due to time constraints with data input, and for consistency of all data from the same source (i.e. hourly LFG quality data vs. average daily LFG quality), all hard copy data was omitted and only electronic data was used. Access to the data sources was not restricted. Historical weather data including atmospheric pressure data was obtained from the Website http://www.wunderground.com.

3.4 Case Study questions

Many of the following questions were unanswered as there weren't any strong correlations or statistically significant results to warrant further inquiry as the data and results limited the assessment of these influences in this particular case. Future studies may consider them worthwhile as data can be collected with these parameters in mind.

1. How do routine changes in atmospheric pressure and the subsequent changes to the temperature and density of the ambient air affect LFG Quality and/or LFG Flows?
    a. Are atmospheric pressure changes in morning vs. afternoon the same for all four seasons? What is the variability? Impacts?
    b. Is there a greater degree of variation of atmospheric pressures during any one season or particular month of a season?
2. How do major changes in atmospheric pressure (high and low pressure systems) that are short in duration and the subsequent changes to the temperature and density of the ambient air affect LFG quality and/or LFG flows?
    a. How do these short shifts in atmospheric pressure affect the quality and flow of LFG in the collection system?
    b. Is there a time lag during these short shifts in atmospheric pressure before the effects are seen in the LFG collection system?

3. Do any automated systems exist that would more effectively manage for atmospheric pressure influences on the landfill and its gas collection system from an individual well basis as well as a system wide basis? What systems or controls exist that may adjust individual wellheads, the flare and/or power plant to adjust to these fluctuations in barometric pressure and improve collection efficiency?

3.5 Data Collection Activities

"Good case studies benefit from having multiple sources of evidence."[45] There are a variety of data sources that were used in this case study including documents such as reports and physical artifacts such as computer printouts. "In collecting case study data, the main idea is to "triangulate" or establish converging lines of evidence to make your findings as robust as possible."[46] By looking at the power plant data, the individual LFG well data for both the closed and active landfills, and the flare data, the data becomes more robust in nature.

The power plant analyzes LFG quality including methane, carbon dioxide, oxygen, and nitrogen percentage. A gas chromatograph analyzes the power plant LFG quality and the data is stored electronically. In addition, monthly well field data is available electronically and includes monitoring data such as: methane %, carbon dioxide %, oxygen %, balance gas (or nitrogen), LFG temperature, flow and applied vacuum to the well. Flow to the flare is also recorded and stored electronically.

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[45] Robert K. Yin, "Case Study Methods", COSMOS Corporation, pg. 9 Revised Draft, January 20, 2004, to appear in the 3rd edition of *Complementary Methods for Research in Education*. American Educational Research Association, Washington, DC, forthcoming.
[46] Yin, pg 9.

3.5.1 Weather Data

Site-specific weather data was not available for the entire time period needed. Software and program issues prevented retrieving complete historic site-specific barometric pressure weather from the on-site weather station and due to time considerations another alternative was utilized. The Website, http://www.wunderground.com had historical weather data available for the years of interest (2003 through 2006) and the data was typically logged hour by hour and included hourly and daily temperatures (high, low and average), dew point (high, low and average), humidity (high, low and average), atmospheric pressure (high, low and average) and precipitation. There were some instances where the weather data would skip an hour and in those cases the barometric pressure closest to the data set being analyzed (i.e. power plant, individual LFG wells, flare) was used. However, there weren't many instances like this as the weather data was significantly complete. In order to correlate the weather data, barometric pressure was retrieved from the on-site weather station computer for November 21, 2006 and that was compared to historic weather data from the above-mentioned Website. The comparison can be found in Chapter 4, Results & Analysis.

3.5.2 Individual LFG Well Data for 2003, 2004, 2005, and 2006

Originally individual LFG well data was going to be reviewed from January 2003 through July 2006, however it was determined for consistency of data that it would be better to limit the data to what was collected in the same format and by the same instrument in order minimize any variability that may be inherent within different gas analysis equipment. Therefore data from January 2003 through June 2003 was eliminated based on this parameter.

Monthly well field readings, which include LFG quality (methane, carbon dioxide, oxygen, and balance gas (nitrogen), LFG temperature, and LFG pressure, were collected using a LANDTEC® GEM 2000 and downloaded to a computer system during each monthly monitoring event. This data was reviewed from July 2003 through July 2006 for both the Closed Landfill and the active WEX Landfill.

LFG wells were monitored monthly with the date and time recorded for each event, which in turn were then matched up with the corresponding barometric pressure for that specific date and time corresponding to the data set. These data were input into a Microsoft Excel® Spreadsheet for ease of use and data manipulation. The data set included wells that were in sections of the landfill that were capped and well as uncapped. Barometric Pressure was compared to LFG quality (specifically Balance Gas (nitrogen) for each monitoring event using Lowry's Linear Correlation method, in order to determine any correlations that may exist between these variables. The method of analysis is discussed in Section 3.6, Data Analysis, and the results are discussed in detail in Chapter 4, Results & Analysis.

<u>Variables for Individual LFG Well Analysis</u>

While reviewing the data there were instances where data was eliminated in order to remove bad or inaccurate readings from the analysis of individual wells. Any well reading with a total LFG quality greater than 100%, had positive static pressure, or had any manual adjustments for a particular month or monitoring event were eliminated. In addition any wells that may have malfunctioned (lost vacuum, cracked casing due to landfill settlement, etc.), were also eliminated from the analysis. This was done in an effort to minimize known factors that could possibly skew the results. This data can be found in Attachment A, Closed Landfill Monthly LFG Well Field Data and Attachment B, WEX Landfill Monthly LFG Well Data.

3.5.3 Flare Flow Data for 2005 and 2006

Originally flare flow was going to be looked at beginning in 2003, however to coincide with the power plant data, flare flow data from 2003 and 2004 was eliminated. LFG flow readings for the flare, which were recorded hourly, were reviewed for 2005 and 2006. Typically in a 24-hour period there were approximately 23 sampling events that recorded date, time and LFG flow identical to the power plant data. For each of these events barometric pressure was matched up with the date and time that corresponded to its data set. These data were input into a Microsoft Excel® Spreadsheet for ease of use and data manipulation. Barometric Pressure was then compared to LFG flow for the flare using Lowry's Linear Correlation method, in order to determine any correlations that may exist between these variables. The method of analysis is discussed in Section 3.6, Data Analysis, and the results are discussed in detail in Chapter 4, Results & Analysis.

Variables for Flare Data

While reviewing the flare flow data there were many instances where flow was interrupted during the normal operating conditions of the flare. A review of the Flare Shut Down Logs (included as Attachment C) eliminated those bad data points, which were removed from the analysis. The flare typically would be shut down anywhere from a few minutes to multiple hours depending on the activity and/or problem encountered during routine and non-routine maintenance. During these times, reduced flows were observed when reviewing the data for those specific dates.

3.5.4 Power Plant Data for 2005 and 2006

Originally power plant LFG flow and quality was going to be reviewed from July 2003 through July 2006, however it was determined for data consistency, that data recorded in the same format (i.e. hourly) instead of daily averages, would be more meaningful and lead to more accurate findings. Therefore data from July 2003 through 2004 were eliminated.

Hourly readings, which recorded LFG quality (methane, carbon dioxide, oxygen and nitrogen) and flow, were reviewed for 2005 and 2006. Typically in a 24-hour period there were approximately twenty-three sampling events that recorded date, time, LFG quality and flow. For each of these events barometric pressure was matched up with the date and time that corresponded to its data set. These data were input into a Microsoft Excel® Spreadsheet for ease of use and data manipulation. Barometric Pressure was compared to both LFG quality and flow for the power plant using Lowry's Linear Correlation method in order to determine any correlations that may exist between these variables. The method of analysis is discussed in Section 3.6, Data Analysis, and the results are discussed in detail in Chapter 4, Results & Analysis.

Variables for Power Plant LFG Quality and Flow

While reviewing the power plant LFG quality and flow data there were many instances where flow was directly affected by the normal operating conditions of the power plant and LFG quality data was missing (due to a malfunction of the gas chromatograph). A review of the Power Plant Shut Down Logs (included as Attachment D) eliminated those bad data points, which were removed from the analysis. During routine and non-routine maintenance on engines at the power plant typically the engines would be down anywhere from 30 minutes to a few hours depending on the activity and/or problem encountered. During these times, reduced flow and/or no flow or gas quality parameters were observed when reviewing the data for those specific dates. However, the flare is able to compensate and burn the additional LFG, which would otherwise be consumed by the power plant, although the flare systems aren't as efficient as the power plant and most likely results in 1/3 lost due to these inefficiencies.

3.6 Data Analysis

State-space analysis was utilized by Poulsen et.al (2003) in order to distinguish associations of gas migration from the surface of a landfill to hourly fluctuations in the atmospheric pressure.[47] State-space modeling can be utilized to help identify correlations between dissimilar variables in order to further understand what controls these variables.[48] A second method that would potentially be useful for statistical evaluation of data is time series analysis which requires data that is complete and of sufficient length (several years).[49]

Further research was conducted to help find statistical tools that would assist in the statistical analysis of the collected data. A Website that I was referred to, http://faculty.vassar.edu/lowry/VassarStats.html, led me to Richard Lowry's Introduction to

[47] Poulsen, Christophersen, Moldrup, Kjeldsen, pg. 356
[48] Poulsen, Christophersen, Moldrup, Kjeldsen, pg. 359
[49] Darcy Campbell, David Epperson, Rebecca Peer, Walter Gray, "Analysis of Factors Affecting Methane Gas Recovery from Six Landfills", pg.2, United State Environmental Protection Agency, Center for Environmental Research Information. EPA/600/S2-91/055, December 1991

Linear Correlation and Regression. This was the statistical tool of choice for analysis of data as discussed below.

3.6.1 Lowry's Linear Correlation and Regression

"Correlation and regression refer to the relationship that exists between two variables, X and Y, in the case where each particular value of X_i is paired with one particular value of Y_i."[50] Correlation measures the associated strength of the relationship as well. There are two types of correlations that were looked at, positive and negative. Positive correlation is when you have more of one variable (X), you also have more of the other variable (Y) and vice versa. Negative correlation is just the opposite, the more of one variable (X) the less of the other variable (Y) and vice versa.[51]

The Measurement of Linear Correlation

"The primary measure of linear correlation is the *Pearson product-moment correlation coefficient*, symbolized by the lower-case Roman letter **r**, which ranges in value from -1 to +1, with 0 indicating a complete absence of correlation. Values falling between **r** = 0.0 and **r** = +1.0 represent varying degrees of *positive correlation*, while those falling between **r** = 0.0 and **r** = -1.0 represent varying degrees of *negative correlation*."[52]

"A closely related companion measure of linear correlation is the *coefficient of determination*, symbolized as $\mathbf{r}^2$, which is simply the square of the *correlation coefficient*. The coefficient of

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[50] Richard Lowry, "Concepts and Applications of Inferential Statistics," Chapter 3, Introduction to Linear Correlation and Regression, http://faculty.vassar.edu/lowry/VassarStats.html (accessed February 1, 2007).
[51] Lowry, Chapter 3.
[52] Lowry, Chapter 3.

determination can have only positive values ranging from $r^2 = +1.0$ for a perfect correlation (positive or negative) down to $r^2 = 0.0$ for a complete absence of correlation. The advantage of the correlation coefficient, **r**, is that it can have either a positive or a negative sign and thus provide an indication of the positive or negative *direction* of the correlation. The advantage of the coefficient of determination, r^2, is that it provides an equal interval and ratio scale measure of the *strength* of the correlation. In effect, the *correlation coefficient*, **r**, gives you the true direction of the correlation (+ or -) but only the square root of the strength of the correlation; while the *coefficient of determination*, r^2, gives you the true strength of the correlation but without an indication its direction."[53] Both of these together give you the strength and direction of the correlation.

3.6.2 Statistical Significance

Random variability may be present in the data being analyzed and there is a possibility that the observed results may in fact result from nothing other than pure luck or chance and until that possibility is tested, no final analysis can be drawn with reason from a sample, either way.[54] "Statistical significance is the logical and mathematical apparatus by which that assessment is accomplished."[55] "Within the context of correlation, the question of statistical significance concerns the relationship between **r**, which is the correlation that is observed within a limited sample of X_I Y_I pairs, and **rho,** which is the correlation that exists, in the larger reality beyond the sample, between X and Y in general."[56]

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[53] Lowry, Chapter 3.
[54] Richard Lowry, "Concepts and Applications of Inferential Statistics," Chapter 4, A First Glance at the Question of Statistical Significance, http://faculty.vassar.edu/lowry/VassarStats.html (accessed February 1, 2007).
[55] Lowry, Chapter 4.
[56] Lowry, Chapter 4.

It is evident that the size of the sample is important in reproducing statistically significant results. "In most areas of scientific research, the criterion for statistical significance in conventionally set at the **5% level**. That is, an observed result is regarded as statistically significant – as something more than a mere fluke – only if it had a 5% or smaller likelihood of occurring by mere chance coincidence. Otherwise it is regarded as statistically non-significant."[57] When reviewing the data and looking at the r values (correlation coefficients), guidelines needed to be set in order to determine the significance of the correlation coefficient. The minimum significant correlation coefficient r for each sample size was calculated by utilizing the Website http://department.obg.cuhk.edu.hk/researchsupport/Minimum_correlation.asp. The site calculated the minimum significant correlation coefficient r for the sample set entered into a web-based program. "This is a quick calculation to obtain the smallest correlation coefficient r that is significant at a sample size (n). t value for the sample size is calculated, then r is found by the formula r = square root (t * t / (t * t + n 2)."[58] A review was conducted at the p<0.5, or 5% level of significance for all data sets meaning that with 95% confidence you have statistically significant results. In Chapter 4, Results & Analysis, tables for each area of data analysis will list the sample size, correlation coefficients, and the minimum significant correlation coefficient for each data set that was reviewed in order to fully understand the statistical significance of the relationships as outlined in this chapter.

[57] Lowry, Chapter 4
[58] http://department.obg.cuhk.edu.hk/researchsupport/Minimum_correlation.asp

4 Results & Analysis

4.1 Weather Data

As mentioned in section 3.5.1, on-site weather station data was unavailable in its entirety for the time period needed (2003-2006) and it was agreed (see Attachment F) that a comparison be made between the two sources in order to validate barometric pressure as valid and comparable as seen below in Table 1. For a sample set of n = 23, the minimum **r** significant at p = 0.001 (99.9 % confidence) is 0.6402, therefore with r-values at 0.988, barometric pressure data used from http://www.wunderground.com is valid and comparable to site barometric pressure data.

Table 1 – Comparison of Barometric Pressure from HALRC Weather Station to http://www.wunderground.com

Date & Time	High Acres Weather Station B.P.	Historic B.P. from www.wunderground.com	r value	r^2
11/21/06				
12:55 A.M.	30.39	30.42	0.988	0.9761
1:55 A.M.	30.42	30.44	0.988	0.9761
2:55 A.M.	30.43	30.45	0.988	0.9761
3:55 A.M.	30.43	30.46	0.988	0.9761
4:55 A.M.	30.45	30.48	0.988	0.9761
5:55 A.M.	30.45	30.48	0.988	0.9761
6:55 A.M.	30.48	30.50	0.988	0.9761
7:55 A.M.	30.51	30.53	0.988	0.9761
8:55 A.M.	30.51	30.55	0.988	0.9761
9:55 A.M.	30.53	30.57	0.988	0.9761
10:55 A.M.	30.54	30.58	0.988	0.9761
11:55 A.M.	30.53	30.56	0.988	0.9761
12:55 P.M.	30.51	30.55	0.988	0.9761
1:55 P.M.	30.49	30.52	0.988	0.9761
3:55 P.M.	30.47	30.51	0.988	0.9761
4:55 P.M.	30.49	30.52	0.988	0.9761
5:55 P.M.	30.49	30.52	0.988	0.9761
6:55 P.M.	30.50	30.53	0.988	0.9761
7:55 P.M.	30.49	30.52	0.988	0.9761
8:55 P.M.	30.49	30.51	0.988	0.9761
9:55 P.M.	30.47	30.50	0.988	0.9761
10:55 P.M.	30.46	30.49	0.988	0.9761
11:55 P.M.	30.46	30.48	0.988	0.9761

4.2 Individual LFG Well Data

4.2.1 Closed Landfill LFG Wells

The Closed Landfill is a non-active landfill that has been encapsulated with an approximately 4.5 foot soil cap since the early 1990's. There are 37 active LFG wells that are monitored on a monthly basis. As mentioned in Section 3.5.2, monthly well monitoring data was analyzed and compared to barometric pressure for those monitoring dates. This well data can be found in Attachment A, Closed Landfill Monthly LFG Well Field Data. The expected result was that there would be a ***positive correlation*** when barometric pressure increased, so too would balance gas (or nitrogen) in the LFG collection wells. In addition, when barometric pressure decreased, so too would balance gas (or nitrogen) in the LFG collection wells. In Table 2 below, the statistical results are listed for 12 vertical and 2 horizontal wells that include East GW4, East GW9, East GW10, East GW11, East GW12R, East GW14, East GW18, East GW22, East GW27, East GW34, East GW44, East GW50, East HC2 and East HC5. All well data covers July 2003 thru July 2006, except HC5, which covers January 2005 thru July 2006.

Table 2 – Balance Gas (nitrogen) in LFG Collection Well Network in Closed Landfill vs. Barometric Pressure

Well ID	Vertical/ Horizontal Well	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Minimum r significant at p=0.05
					+3	-11	
East GW4	Vertical	42	-0.1699	0.0289		X	0.3044
East GW9	Vertical	38	-0.1703	0.029		X	0.3202
East GW10	Vertical	37	-0.1746	0.0305		X	0.3246
East GW11	Vertical	32	0.2197	0.2197	X		0.3494
East GW12R	Vertical	40	-0.0596	0.0036		X	0.3120

Table 2 – Balance Gas (nitrogen) in LFG Collection Well Network in Closed Landfill vs. Barometric Pressure

Well ID	Vertical/ Horizontal Well	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Minimum r significant at p=0.05
East GW14	Vertical	38	-0.1862	0.0347		X	0.3202
East GW18	Vertical	37	-0.1633	0.0267		X	0.3246
East GW22	Vertical	37	-0.0687	0.0047		X	0.3246
East GW27	Vertical	38	-0.2049	0.042		X	0.3202
East GW34	Vertical	37	-0.2551	0.0651		X	0.3246
East GW44	Vertical	38	-0.1562	0.0244		X	0.3202
East GW 50	Vertical	36	0.0825	0.0068	X		0.3291
East HC2	Horizontal	36	0.2126	0.0452	X		0.3291
East HC5	Horizontal	19	-0.1299	0.0169		X	0.4555

There were a total of 3 positive correlations, and 11 negative correlations, however statistically speaking there wasn't any significance to these correlations as the correlation coefficients were below the minimum for significance. In summary there was not any evidence of statistical significance of a positive correlation that an increase in barometric pressure, leads to an increase in balance gas (or nitrogen), or that a decrease in barometric pressure, leads to a decrease in balance gas (or nitrogen) during routine monthly well field monitoring on the Closed Landfill. Lastly, additional LFG wells were not analyzed, as the results for this set of wells did not warrant further analysis.

4.2.2 Western Expansion LFG Wells

The Western Expansion (WEX) is the active portion of HALRC where there are 74 active wells that are monitored on a monthly basis. The majority of the WEX has no installed engineered final cap for cover, however on-site soils are placed in 2-3 foot layers over areas that are left uncapped as an interim measure until capping can be completed. As mentioned in Section 3.5.2, monthly well monitoring data was analyzed and compared to barometric pressure for those monitoring dates. This well data can be found in Attachment B, WEX Landfill Monthly LFG Well Field Data. The expected result was that there would be a ***positive correlation*** when barometric pressure increased, so too would balance gas (or nitrogen) in the collection wells. In addition, when barometric pressure decreased, so too would balance gas (or nitrogen) in the collection wells. In Table 3 below, the statistical results are listed for 15 vertical and 4 horizontal wells that include West GW1, GW3, GW5, GW8, GW11R, GW15R, GW23, GW29, GW31, GW33, GW37, GW41, GW46, GW53, GW57, CELL 5_6CN, CELL 5_6CS, 6V_7VAN and 6V_7VAS. All well data covers July 2003 thru July 2006 unless otherwise noted. West GW37, 41, 46, and 53 data covers November 2003 thru July 2006. West GW57 data covers February 2005 thru July 2006. Horizontal Well 6V_7VAS & 6V_7VAN data covers March 2004 thru July 2006.

Table 3 – Balance Gas (nitrogen) in LFG Collection Well Network (Western Expansion) vs. Barometric Pressure

Well ID	**Western Expansion**		**n= Sample Size**	**r value**	**r^2**	**Positive Correlation**	**Negative Correlation**	**Minimum r significant at p=0.05**
	Cap	**No Cap**				+14	-5	
West GW1	X		42	0.1714	0.0294	X		0.3044

Table 3 – Balance Gas (nitrogen) in LFG Collection Well Network (Western Expansion) vs. Barometric Pressure

Well ID	Western Expansion		n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Minimum r significant at p=0.05
	Cap	No Cap				+14	-5	
West GW3	X		42	0.0416	0.0017	X		0.3044
West GW5	X		37	0.1217	0.0148	X		0.3246
West GW8	X		39	-0.1231	0.0152		X	0.3161
West GW11R		X	42	0.0714	0.0051	X		0.3044
West GW15R		X	33	-0.0103	0.0001		X	
West GW23		X	49	0.148	0.0219	X		0.2816
West GW29		X	45	-0.0738	0.0054		X	
West GW31		X	37	0.215	0.0462	X		0.3246
West GW33		X	36	0.143	0.0204	X		0.3291
West GW37		X	23	0.1487	0.0221	X		0.4133
West GW41		X	30	0.1076	0.0116	X		0.3611
West GW46		X	26	0.0837	0.007	X		0.3883
West GW53		X	39	-0.0507	0.0020		X	0.3161
West GW57		X	17	-0.0053	0		X	0.4822
CELL 5_6 CN	Horizontal gas well.		50	0.037	0.0014	X		0.2787
CELL 5_6 CS	Horizontal gas well.		47	0.1757	0.0309	X		0.2876
6V_7V AN	Horizontal gas well.		33	0.0884	0.0078	X		0.3440
6V_7V AS	Horizontal gas well.		33	0.2034	0.0414	XX		0.3440

There were a total of 14 positive correlations, and 5 negative correlations, however statistically speaking there wasn't any significance to these correlations as the correlation coefficients were below the minimum for significance. In summary there isn't statistical significance of a positive correlation that an increase in barometric pressure, leads to an increase in balance gas (or nitrogen), or that a decrease in barometric pressure, leads to a decrease in balance gas (or nitrogen) during routine monthly well field monitoring on the WEX. Lastly, additional wells were not analyzed, as the results for this set of wells did not warrant further analysis.

4.3 Flare Flow vs. Barometric Pressure

As mentioned in Section 3.5.3, hourly flare flow data was analyzed and compared to barometric pressure for 2005 and 2006. This hourly flare LFG flow data can be found in Attachment E, Flare LFG Flow Data. Time intervals were chosen in an attempt to capture all four seasons of the year, however the sample size had to be restricted based on the capabilities of the statistical program as well any variables as outlined in Section 3.5.3. The expected result was that there would be a ***negative correlation*** so when barometric pressure increased, LFG flow would decrease. Also, when barometric pressure decreased, LFG flow would increase. In Table 4 below, there are 7 statistical significant ***negative correlations*** as originally expected.

Table 4 – Flare LFG Flow vs. Barometric Pressure

Time Interval	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Comment	Minimum r significant at p=0.05
2005				+5	-7		
1/10 - 2/10	714	-0.1003	0.0101		X	Significant r-value	0.0734
3/1 - 4/31	1459	0.2772	0.0768	X		Significant r-value	0.0513

Table 4 – Flare LFG Flow vs. Barometric Pressure

Time Interval	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Comment	Minimum r significant at p=0.05
4/1 - 4/31	715	0.4346	0.1889	X		Significant r-value	0.0733
7/1 8/30	1465	0.0182	0.0003	X		Not Significant	0.0512
9/1 - 9/31	719	-0.0044	0		X	Not Significant	0.0731
11/20 - 12/20	729	-0.4254	0.181		X	Significant r-value	0.0726
2006							
1/1 – 1/5	98	-0.7365	0.5424		X	Significant r-value	0.1986
1/1 - 1/31	744	-0.0985	0.0097		X	Significant r-value	0.0719
2/1 2/9	201	-0.6588	0.434		X	Significant r-value	0.1385
4/15 - 4/23	216	-0.1701	0.0289		X	Significant r-value	0.1335
5/1 - 6/31	1456	0.1747	0.0305	X		Significant r-value	0.0514
7/1 7/31	744	0.1795	0.0322	X		Significant r-value	0.0719
10/1 10/31	721	0.4018	0.1614	X		Significant r-value	0.0730
12/1 - 12/31	714	-0.351	0.1232		X	Significant r-value	0.0734

However, there are also 5 statistically significant ***positive correlations***, meaning that when barometric pressure increases, then LFG flow to the flare would also increase, the exact opposite of our ***negative correlation***. The ***negative correlation*** here is supported by what is typically seen when barometric pressure increases, and the LFG quality at the power plant decreases as a result, flow to the engines increases as more lower quality LFG is needed to maintain a certain value of energy in order for the engines to run, which diverts LFG flow from the flare.

4.4 Power Plant

4.4.1 Power Plant LFG Quality vs. Barometric Pressure

As mentioned in Section 3.5.4, hourly power plant LFG quality data was analyzed and compared to barometric pressure for 2005 and 2006. The power plant hourly LFG quality data can be found in Attachment F, Power Plant LFG Quality & Flow Data. Time intervals were chosen in an attempt to capture all four seasons of the year, however the sample size had to be restricted based on the capabilities of the statistical program as well any variables as outlined in Section 3.5.4. The expected result was that there would be a ***positive correlation*** so when barometric pressure increased LFG quality (measured as nitrogen) would increase. In addition, when barometric pressure decreased, LFG quality (measured as nitrogen) would decrease. In Table 5 below, there are 8 statistically significant ***positive correlations*** (expected) and 3 statistically significant ***negative correlations*** (unexpected).

Table 5 – Power Plant LFG Quality (nitrogen) vs. Barometric Pressure

Time Interval	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Comment	Minimum r significant at p=0.05
2005				+8	-3		
1/10 1/29	435	0.7014	0.492	X		Significant r-value	0.0940
1/10 - 1/31	505	0.2799	0.0783	X		Significant r-value	0.0873
2/1 - 3/31	1416	-0.2479	0.0615		X	Significant r-value	0.0521
4/1 5/31	1463	0.2887	0.0833	X		Significant r-value.	0.0513
7/1 - 7/31	744	-0.038	0.0014		X	Not Significant	0.0719
12/1 12/20	465	0.7271	0.5287	X		Significant r-value	0.0910
2006							
1/1 1/31	744	0.6258	0.3916	X		Significant r-value	0.0719

Table 5 – Power Plant LFG Quality (nitrogen) vs. Barometric Pressure

Time Interval	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Comment	Minimum r significant at p=0.05
2/1 3/31	1416	0.7091	0.5028	X		Significant r-value	0.0521
4/1 5/31	1463	0.4607	0.2122	X		Significant r-value	0.0513
7/1 - 7/31	744	-0.1204	0.0145		X	Significant r-value	0.0719
10/1 10/31	744	-0.3689	0.1361		X	Significant r-value	0.0719
12/1 12/22	514	0.2465	0.0608	X		Significant r-value	0.0865

When barometric pressure increases, typically LFG quality, specifically methane quality goes down and nitrogen goes up. Therefore the ***8 statistically significant positive correlations*** that were seen in the power plant LFG quality were in fact expected. However, there also were ***3 statistically significant negative correlations***, which were unexpected. The negative correlation states that when barometric pressure increases, nitrogen decreases, the opposite of what is expected. There isn't a definitive line here from the analysis due to the fact that we measured ***3 negative correlations***, however roughly just over 70% of the results were ***positive correlations***, which were expected and agreed with what was originally thought to be true.

4.4.2 Power Plant LFG Flow vs. Barometric Pressure

As mentioned in Section 3.5.4, hourly power plant flow data was analyzed and compared to barometric pressure for 2005 and 2006. The hourly flow data can be found in Attachment F, Power Plant LFG Quality & Flow Data. Time intervals were chosen in an attempt to capture all four seasons of the year, however the sample size had to be restricted based on the capabilities of the statistical program used as well as any variables as outlined in Section 3.5.4. The expected result was that there would be a ***positive correlation*** so when barometric pressure increased LFG flow would increase. In addition, when barometric pressure decreased, LFG flow would decrease. In Table 6 below, there are 3 statistically significant ***positive correlations*** (expected) and 7 statistically significant ***negative correlations*** (unexpected).

Table 6 – Power Plant LFG Flow vs. Barometric Pressure

Time Interval	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Comment	Minimum r significant at p=0.05
2005				+3	-7		
1/10 - 1/31	484	0.0159	0.0003	X		Not significant	0.0891
2/1 2/28	661	0.2621	0.0687	X		Significant r-value	0.0763
2/1 3/31	1395	0.166	0.0276	X		Significant r-value	0.0525
3/1 3/31	736	0.1596	0.0255	X		Significant r-value	0.0723
4/1 - 4/30	603	-0.0137	0.0002		X	Not significant	0.0799
6/1 6/30	698	-0.2083	0.0434		X	Significant r-value	0.0742
7/1 7/30	725	-0.005	0		X	Not significant	0.0728
12/1 - 12/20	456	-0.1196	0.0143		X	Significant r-value	0.0919
2006							
1/1 - 1/31	744	-0.0225	0.0005		X	Not significant	0.0719
2/1 3/31	1416	-0.2208	0.0488		X	Significant r-value	0.0521
5/1 - 5/31	725	-0.2848	0.0811		X	Significant r-value	0.0728
7/1 7/31	733	-0.3	0.09		X	Significant r-value	0.0724
8/1 8/31	735	-0.2256	0.0509		X	Significant r-value	0.0723
10/1 10/7	164	-0.2292	0.0525		X	Significant r-value	0.1533
12/1 - 12/31	640	-0.032	0.001		X	Significant r-value	0.1775

The 7 statistically significant ***negative correlations*** would mean that as barometric pressure increased, LFG flow decreased and vice-versa. When barometric pressure is rising, the landfill may store additional LFG unless the collection systems can increase vacuum to compensate as supported by the literature in Section 2.1. If this were true for the collection system, the ***negative correlation*** would support this premise. However, as mentioned in section 4.4.1, as barometric pressure increases, LFG quality goes down and the power plant increases flow in response to compensate for the reduced energy value of the LFG. But there may be less total LFG available in this instance as well.

4.5 Total Flow (Power Plant & Flare) vs. Barometric Pressure

In an attempt to find some correlation of the effects of barometric pressure on flow at the landfill, total flow, a combination of power plant and flare LFG flow was compared against barometric pressure. This wasn't originally planned however it was determined that after finding no distinct correlations during the analyses it was worth a try. This data already existed in the spreadsheets and was analyzed just like all the other parameters and can be found in Attachment G, Total LFG Flow Data. There wasn't an expectation however with this analysis as both the power plant and flare operate with different parameters in mind. The same time intervals as were used in Table 6 in section 4.4.2 above, were used below in Table 7.

Table 7 – LFG Total Flow (Power Plant & Flare) vs. Barometric Pressure

Time Interval	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Comment	Minimum r significant at p=0.05
2005				+7	-6		
1/10 - 1/31	477	-0.1616	0.0261		X	Significant r-value	0.0898

Table 7 – LFG Total Flow (Power Plant & Flare) vs. Barometric Pressure

Time Interval	n= Sample Size	r value	r^2	Positive Correlation	Negative Correlation	Comment	Minimum r significant at p=0.05
2/1 - 2/28	665	-0.1353	0.0183		X	Significant r-value	0.0761
2/1 3/31	1406	-0.0967	0.0094		X	Significant r-value	0.0523
3/1 3/31	741	-0.0185	0.0003		X	Not Significant	0.0723
4/1 4/30	714	0.4487	0.2013	X		Significant r-value	0.0720
6/1 6/30	690	0.3038	0.0923	X		Significant r-value	0.0734
7/1 7/30	725	0.0385	0.0015	X		Not Significant	0.0746
12/1 12/20	465	-0.4636	0.2149			Significant r-value	0.0910
2006							
1/1 - 1/31	741	-0.3671	0.1348		X	Significant r-value	0.0720
2/1 3/31	1411	-0.4833	0.2366		X	Significant r-value	0.0522
5/1 5/31	744	0.2017	0.0407	X		Significant r-value	0.0719
7/1 7/31	732	0.252	0.0635	X		Significant r-value	0.0725
8/1 8/31	739	0.0877	0.0077	X		Significant r-value	0.0721
10/1 10/7	168	0.2457	0.0604	X		Significant r-value	0.1515
12/1 12/31	743	0.2136	0.0456	X		Significant r-value	0.0719

The results didn't clarify anything unfortunately as there were 7 statistically significant ***positive correlations*** and 6 statistically significant ***negative correlations***. A ***positive correlation*** would mean that when barometric pressure increased, so to would total LFG flow and vice-versa. A ***negative correlation*** would mean that an increase in barometric pressure would lead to a decrease in total LFG flow and vice-versa. Even though there were no expectations for this particular analysis, there is still no clear correlation one-way or the other.

5 Conclusion

5.1 Individual LFG Wells

In section 4.2.1 and 4.2.2 both the Closed and WEX vertical and horizontal LFG collection wells were analyzed for a statistically significant correlation between barometric pressure increase/decrease and the subsequent effect on LFG quality as it related to each individual LFG well. However, of the 33 LFG wells that were analyzed from the network of 111 LFG wells, not one proved to have a statistically significant correlation coefficient and therefore no conclusions could be drawn from the analysis to validate the initial hypothesis. It is believed that the nature of the existing data for the individual LFG wells was somewhat incomplete as each LFG well is typically only monitored once per month and only gives a snapshot of what that particular well is doing at that moment in time. There are definite variations in barometric pressure throughout the course of a day, and a month, but taking a single reading in a month proved in this analysis that there wasn't enough data to establish a positive correlation.

Some additional variables that should be considered when looking at correlations include locations of LFG wells. For example, wells that are located on a slope are more likely to be influenced by air intrusion as there radius of influence closer to the surface of the landfill itself will negatively impact LFG quality (nitrogen) (less waste as you get closer to surface of landfill on slopes). An interior well would have less likelihood of air intrusion based on the radius of influence being in the waste mass for the entire length of the well. Waste consistency should also be considered in analysis as this may contribute to better/worse LFG quality based on the types of waste disposed in a particular area of a landfill. A comparison of a cluster of wells in one area of the landfill can be compared to another cluster of wells in a totally separate area of the landfill to see if there is any significant difference with negative or positive correlations based on waste consistency and/or the location of the wells (slope or interior). In addition, the depth of the well or how much waste the well is influencing and the amount of screened/slotted surface area of the well should be considered.

5.1.1 Recommendations for future work

A real time study would be suggested for future work where specific guidelines could be set up with the end goal in mind prior to initiating the project. This would allow many of the variables to be eliminated from the analysis and also would allow adaptation to changes as they occurred leading to better results in the end. Additionally, it is recommended that data be collected at much more frequent intervals for individual LFG wells (i.e. one sample per hour for a week) analysis. This could be done manually with existing field monitoring equipment (i.e. LANDTEC® GEM 2000), however this would be very time consuming for the individual(s). There are automated extraction monitoring systems available that would log desired gas quality, pressure and barometric pressure readings from a network of wells that would reduce manual labor, but increase cost potentially. CES-LANDTEC has a system that could monitor up to 9 LFG sources, logging all the data electronically, at specified intervals. This would help in acquiring adequate data for a thorough analysis of individual LFG wells and the effects of barometric pressure on these systems.

5.2 LFG Flare

The LFG flare system at HALRC is designed to burn off the excess LFG that the power plant cannot consume in the process of producing power. During rising barometric pressure when

LFG quality (methane is reduced), the power plant consumes more LFG, therefore reducing LFG flow to the flare, independent of any impacts barometric pressure may or may not have on flow in the landfill. This affect on the flare should not go unnoticed for those facilities that have both power plant and flare systems as this is an important relationship as each operation affects the other. This relationship is very complex as was discovered upon detailed analysis of the data and therefore should be considered at sites with both operations. If a facility only has a flare this complexity is eliminated. Also, there wouldn't be competing systems (power plant electricity generation vs. flare LFG combustion & destruction) working against each other, as is the case here. The objectives of the two systems are very different, whereas a power plant isn't concerned with destroying as much LFG as possible (flare is), but with producing electricity. At a landfill where power generation isn't a concern and only a flare exists the potential exists to be more aggressive with LFG collection as LFG quality isn't a consideration in the operation of the flare. However, applying too much vacuum on the landfill also could potentially cause fires inside the landfill itself if not monitored closely.

The HALRC flare maintains a specified level of vacuum determined by the input parameters and it maintains that level of vacuum through a variable frequency drive (VFD). However, as can be seen in the statistical analysis, there was no clear relationship between increasing/decreasing barometric pressure and flows, either way. During times of rising barometric pressure LFG will be stored in the landfill if additional vacuum isn't applied to the landfill while during times of lower barometric pressure LFG tends to flow easier and if the LFG system cannot increase vacuum to take advantage of this occurrence then LFG will escape the landfill. This analysis was very difficult and the flare is much more complex than originally thought.

Some questions to be answered include: Are there limitations to the blowers, compressors, etc. associated with the flare that don't allow greater flexibility for adjustments to barometric pressure changes? Does the VFD take into account the fluctuations of barometric pressure and take full advantage of LFG when it is generated and easily collected or not? How could this be determined? What other systems are available out there that might be more adept at taking advantage of the above-mentioned circumstances?

5.3 Power Plant

The power plant at HALRC is designed to burn LFG and produce power. LFG quality is very critical to its operation and the better the quality the smoother the plant runs. The power plant is affected by barometric pressure swings and during rising barometric pressure when LFG quality (methane is reduced, nitrogen is increased), the power plant consumes more LFG, and when barometric pressure is down, LFG quality is good, then the power plant consumes less LFG. In Section 4.4.1, the statistics support this and it is reflected in how the power plant operates. However, regarding flow, the statistics didn't support the way in which the power plant operates, which is directly related to LFG quality because the lower the LFG quality the more flow the plant needs. The one thing that may have not been considered in this assessment is the variables that affect flow such as moisture content and temperature of the LFG. Also, the flare system may also have an effect on this analysis if it consumes more LFG during these times when the plant needs additional flow and there may be some time lag associated with this change. Lastly, the power plant is very sophisticated in that there are many systems in place to allow the plant to run as smoothly as possible without interruption, and these systems are designed to produce power and not maximize LFG flow, therefore there are inherent variables as mentioned above that are built into the system that most likely skewed the results and analysis.

5.4 Final Remarks & Comments

LFG collection systems and controls are complicated systems that have physical limitations and are only as good as the personnel overseeing them. What made these analyses so difficult as mentioned earlier is the complexity of all these various systems working together, yet against one another for various reasons. A simpler study may have eliminated many of the variables that were discussed above. For example, examining only the well field, with real time data at more frequent intervals to see what the impacts of fluctuating barometric pressure are on that specific system may have led to a different conclusion. Other alternatives could be to conduct studies at facilities that only have one type of LFG collection system (flare or power plant) so that variability would be limited to the system being studied. Diligence in this work may go as far as any automated system that may be out there. There are still many unknowns. Although this work did not ultimately accomplish what it initially set out to do, perhaps some good will come of this research and analysis of data that will benefit someone in the future.

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