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Effect of heater type on CO/CO2 concentrations in a farrowing barn

Anthony Yuan-Jung Yang
University of Iowa

EFFECT OF HEATER TYPE ON CO/CO_2 CONCENTRATIONS IN A FARROWING BARN

by

Anthony Yuan-Jung Yang

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Thesis Supervisor: Associate Professor T. Renée Anthony

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Anthony Yuan-Jung Yang

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Occupational and Environmental Health at the August 2015 graduation.

Thesis Committee:

T. Renée Anthony, Thesis Supervisor

Matthew W. Nonnenmann

Diane S. Rohlman

To all of my incredible friends and family.

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ABSTRACT

Clear evidence shows a relationship between working in swine facilities and developing respiratory illnesses. Health effects have been associated with exposures to the combination of dust, ammonia, and carbon dioxide (CO_2). This study examined whether room concentrations of combustion gases could be improved by changing the in-room vented heaters common to animal production operations to heaters that vent combustion gases outside.

Concentrations of CO_2 and carbon monoxide (CO) were monitored during two winter seasons, with the 2013-14 season using the traditional gas-fired heater (Guardian 60, L.B.White Co.) and the 2014-15 winter using new vented heaters (Effinity93, Modine Manufacturing Co.) Direct-reading CO (VRAE, Rae Systems) and CO_2 (ToxieRAE Pro, Rae Systems) monitors were deployed at fixed stations throughout the farrowing barn to measure gas concentrations. Differences in mean gas concentrations between heater types, as well as the relationship between CO_2 and temperature, sow, and piglet count, were evaluated using linear regression.

Carbon dioxide concentrations exceeded industry recommended limits (1540 ppm) on all sample days (N = 18) with the standard in-room vented heaters in operation: concentrations averaged half of the TLV (2500 ppm). With the new vented heaters, 24-hour averaged CO_2 concentrations exceeded industry recommended limits on only three out of 20 sample days: concentrations averaged 1400 ppm. The new heater significantly reduced CO_2 by 44% and CO by 60% from 2.0 to 0.8 ppm ($p < 0.001$). Linear regression identified a significant relationship ($R^2 = 0.75$) between CO_2 and production factors (temperature, sow and piglet count) for the new heater: CO_2 (ppm) = 482 - 22.4 (Temp ^oC) + 43 (# sow) + 5.6 (# piglet). Similar analysis for the old heater identified similar trends but substantially different intercept (1700 ppm) and temperature factor (-36.9).

While CO_2 is still generated from swine respiration, we found significant reductions in room concentrations with the simple replacement of commonly used equipment. Future work will include an assessment of the longevity of these heaters in the swine barn environment.

PUBLIC ABSTRACT

Heaters that are traditionally used in swine barns release harmful gases directly into the swine barn. The purpose of this study was to see if replacing traditional swine barn heaters with heaters that sends harmful gases outside will improve swine barn conditions and ultimately protect worker health.

Gas levels were measured during two winter seasons. During the first winter the traditional heater was in operation. During the second winter the traditional heater was replaced with a heater that sends harmful gases outside. Gas measuring instruments were positioned at several locations throughout the barn. The levels of gas produced each season were compared, and other potential contributors to the gas levels found in the swine barn were also considered.

Researchers have developed recommended limits for the levels of harmful gases a person can be exposed to before they begin experiencing negative health effects. The data collected during the first winter season showed that levels produced by the first heater exceeded what has been recommended by researchers. After the new heater was installed, levels of harmful gases were dramatically reduced. The study also showed that the amount of pigs present in the room affected the levels of harmful gases present in the room.

Although the amount of pigs present in the swine barn affect the amount of harmful gases produced, gas levels may be dramatically lowered by using a heater that releases harmful gases outside. Future research will involve determining how long these heaters are able to last in swine barns.

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CHAPTER I

LITERATURE REVIEW

Workers Involved in Swine Production

According to recent agricultural census data, there are an estimated 250,000 workers involved in the production of over 66 million pigs at over 63,000 swine facilities across the United States. These pigs are primarily raised in large-scale operation facilities and the majority of them are found in the Midwestern states, particularly in Iowa (USDA, 2012). Thousands of workers, especially those in the Midwest, are exposed to the respiratory hazards present in large-scale swine operation facilities. These workers are at greater risk during the wintertime, when windows and doors are kept closed for warmth, trapping hazardous contaminants inside (O'Shaughnessy et al., 2010).

Swine Barn Production Steps

Pork production can be logically divided into several distinct steps with different facilities used for each step (US EPA, 2014).

Breeding and Gestation

While sows are in heat, boars are placed into their pens to impregnate them or they are artificially inseminated. If a sow fails to become pregnant after her first heat cycle, she is generally replaced by a young female. After the sow becomes pregnant, her litter is developed in the womb for 113-116 days (US EPA, 2014).

Farrowing

The sow is typically placed in a temperature-controlled farrowing room when she is close to giving birth. Temperatures are maintained between 72-75º Fahrenheit (Vansickle, 2006). Heating lamps are positioned over piglets to provide additional warmth for newborns. These rooms are usually equipped with a farrowing pen which limits sow movement and prevents the sow from crushing her piglets after they are born. These pens also make the mother's udders readily available to piglets for nourishment. After piglets are born, they are generally raised in this area for approximately 21 days (US EPA, 2014).

Nursery

From the farrowing room, the piglets are weaned in a nursery for a period of 6 to 10 weeks. The floors in these rooms are generally slotted, and each pig has about three square feet of roaming space. Food and water are made readily available to pigs in these rooms, and the rooms are kept at temperatures that are optimal for their health. When pigs are first introduced into the nursery, temperatures may be kept as high as 85º F, but will be gradually decreased to approximately 70º as the pigs grow (US EPA, 2014).

Growing and Finishing

During the growing and finishing step, pigs are able to partake of as much food as they desire until they become heavy enough to transfer to the marketplace. Pigs are generally sent to market when they are around five to six months old. Some young female pigs will be kept for the purpose of breeding (US EPA, 2014).

Worker Actions

Swine barn workers are involved in a wide range of tasks during each stage of the hog production process. General tasks in the breeding and gestation room include marking and artificially inseminating sows that are in heat (O'Shaughnessy et al., 2010). Swine workers spend the majority of their time in farrowing rooms, where they are involved in tasks such as administering vaccinations to piglets, placing identification notches or tags on piglet ears, and clipping piglet needle teeth and tails. Once the piglets are moved from the farrowing barn to the nursery, workers prepare the farrowing room for pressure washing, which involves the disassembly and removal of equipment. In the nursery area workers separate the male and female pigs into different holding pens and monitor pig health. In the growing and finishing area, as well as all other areas of the swine barn, pigs are fed by the workers (O'Shaughnessy et al., 2010). Feed is typically comprised of corn and soybean meal with added vitamins and minerals (EPA, 2014). Workers also check swine health and ensure equipment is in proper working order in all areas of the swine facility (O'Shaughnessy et al., 2010).

Modern Swine Facilities

Over the past century, the majority of hog farms have shifted from producing fewer than 200 pigs (Cromwell and Hays, 1999) to over 5000 pigs annually (O'Shaughnessy et al, 2010; US EPA, 2014). According to USDA data, the 2014 total hog inventory in the US was 65.4 million head. The average amount of pigs per litter has steadily increased from 7.7 in 1988 to 10.1 in 2012 (USDA, 2014). The increased production capacity of swine farms can be attributed to technological advances over recent decades such as improved feed formulations, pharmaceuticals, and animal breeding. Large scale swine operations are now the most cost-effective method for growing pigs (Hribar, 2010).

Modern pork production facilities are now enclosed, which allow for a controlled environment with temperatures that are optimal for swine health year round. These enclosed facilities also allow for a more efficient use of available space (Crook et. al, 1991). Most modern swine facilities have slotted floors with a deep concrete storage pit or shallow gutter underneath for falling manure. The manure in these storage areas is typically handled as a slurry or liquid. Manure is removed from the swine facility through pumping, flushing, or draining methods, and is used for fertilizing purposes (EPA, 2014).

With the cost of feed continuing to rise, pork producers are increasingly concerned about developing ways to increase growth and production efficiency. It is the aim of the National Pork Board to create building designs in the future that are more environmentally friendly, require less energy, promote better indoor air quality, and maintain the welfare of the animals inside (Miller, 2011).

Unfortunately, many of the changes that have facilitated swine barn growth and efficiency have also presented new respiratory health challenges for workers as well as swine (Donham et al., 1984; Larsson et al., 1994; McDonnell et al., 2008; Hribar, 2010).

Health Effects

Clear evidence shows a link between working in swine environments and developing adverse health outcomes, particularly respiratory conditions (Zejda et. al., 1993).

Swine confinement workers commonly complain about coughing and the presence of phlegm. Chronic bronchitis is a condition characterized by coughing and phlegm, resulting from irritation to the mucous membrane of the airways. A large portion of swine confinement workers experience these symptoms at least three months out of the year for over three years. (Donham, 1991; Donham et al., 1984; Pedersen et al., 1996). In a lung function study conducted by Donham et al., over half of the swine confinement workers experienced chronic bronchitis. The control group of non-confinement swine producers in the study had significantly lower incidences of chronic bronchitis compared to swine confinement workers (Donham et al., 1984). Swine confinement workers also commonly experienced acute bronchitis, which lasted for one to three weeks (Donham, 1991). In addition to coughing and phlegm, swine workers often experienced wheezing and chest tightness from airway irritation as a result of their exposure to contaminants in swine confinement buildings (Donham, 1991; Larsson et al., 1994; Tian et al., 2013).

A dose-response study conducted by Donham et al. (1984) identified a decline in pulmonary function in swine confinement workers over the course of a single work period. Other dose-response studies have shown a decline in forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) for swine barn workers (Radon et al., 2001; Zejda and Hurst, 1993; Donham et al., 1995; Vogelzang et al., 1996).

Swine barn workers also report frequently experiencing a condition known as organic dust toxic syndrome, characterized by fevers, headaches, tightening of the chest, and muscle pains as a result of their exposure to dusty activities in swine barns. (Donham, 1991; Cormier and Israel-Assayag 2004; Radon et al., 2001). This syndrome is believed to be primarily caused by endotoxins released from the breakdown of bacterial cells found in the confined environment (Donham, 1991; Charavaryamath et al., 2005).

Symptoms of mucous membrane irritations, particularly of the throat, sinuses, eyes, and nose have also been reported among swine workers (Donham, 1991). Chronic sinusitis and a byssinosis-like condition are also potentially resulting conditions from working in swine confinement buildings (Donham, 1991).

The information regarding the linkage between swine barn environments and other non-respiratory ailments, such as gastrointestinal distress and heart disease, is currently limited (Cormier and Israel-Assayang, 2004; Tian et al., 2013).

Working in swine confinement facilities has been associated with various respiratory symptoms that affect the entire respiratory tract. The magnitude of these symptoms and the location of impact depend on the contaminant involved.

Swine Barn Contaminants

The gases that generally contribute to respiratory problems in swine barns are carbon monoxide, carbon dioxide, hydrogen sulfide, ammonia, and methane. These gases are mainly produced by swine manure and bacterial decomposition of manure. In addition to gases, workers are also exposed to dusts and airborne microorganisms (McDonnell et al., 2008). Table 1 summarizes the sources, characteristics and health hazards of these contaminants.

Carbon Monoxide and Carbon Dioxide

Carbon monoxide and carbon dioxide may be produced at dangerous concentrations due to the combustion of fossil-fuels from the swine barn's heating system. Carbon dioxide may also be produced at hazardous levels from swine respiration (Donham, 2010; Ni et al., 2010). Both gases can cause asphyxiation if the swine facility is not properly ventilated (McDonnell et al., 2008).

Hydrogen Sulfide

Hydrogen sulfide is generated through bacterial breakdown of manure (OSHA, 2015). Workers are at risk of hydrogen sulfide poisoning when liquid fecal matter in swine manure pits is agitated and hydrogen sulfide gas is expelled. If workers are exposed to levels at or above 400 parts per million, fluid will accumulate in their lungs and they will collapse and stop breathing. Over half of the swine barn manure pits in the Midwest have the potential to emit hydrogen sulfide concentrations high enough to cause acute hydrogen sulfide poisoning (Donham, 1991; Ni et al., 2010).

Ammonia

In addition to hydrogen sulfide, bacterial manure decomposition produces ammonia as a by-product (Attwood et al., 1987) Ammonia is also released into the barn atmosphere from swine urine (Colina et al., 2000). Ammonia causes damage to the upper airways, and is easily detectable at low levels (McDonnell et al., 2008). Ammonia causes eye, nose, and throat irritation at concentrations in the range of 20 to 25 ppm (NIOSH, 2015).

Methane

Anaerobic bacterial breakdown of slurry produces methane gas. When present at high enough levels, methane can cause asphyxiation. This odorless and colorless gas can also be an explosion hazard when it is present at the right level (McDonnell et al., 2008).

Respirable and Inhalable Dusts

The dust that is generated in swine confinement buildings is composed of animal dander, fecal matter, urine, and animal feed. Microbes such as bacteria, molds, yeasts, and viruses are also commonly found in these dusts. These organic dusts are known as bioaerosols (McDonnell et al., 2008; Cormier and Israel-Assayag, 2004).

Dusts are solid particles with diameters of 0.5 to 1000 micrometers (μm). Dust particles smaller than 10.0 μm are considered respirable dusts. Respirable dusts are able to enter deep into the human or animal lung when inhaled and can deposit in the alveoli where they can cause damage. Inhalable dusts include all particles that are able to be inhaled through the nose and mouth (up to 100 μm). These particles can cause irritation when trapped in the nose, windpipe, and upper respiratory tract. In swine barns, respirable dust is mainly comprised of manure particles mixed with endotoxin. Inhalable dust is mainly comprised of feed matter mixed with endotoxin (Lemay et al., 2002).

Swine Health

Many of the contaminants that negatively affect worker health also affect the health of pigs, such as ammonia, dust, and microbes (Morris et al., 1985). Several studies have demonstrated the negative effects of ammonia on the growth rate of pigs (Drummond et al., 1980; Murphy and Cargill, 2004, Stombaugh, 1969). In a study conducted by Murphy and Cargill, a synergistic effect of exposure to bacteria and ammonia was observed. It was hypothesized that ammonia harms the pigs' mucosal membranes, allowing bacteria to exert its greatest effects (Murphy and Cargill, 2004). Donham (1991) found a correlation between CO_2 concentrations and swine health problems. Therefore, improving air quality for workers may not only protect worker health but may also increase animal productivity.

Exposure Assessment

Various methods may be used to assess worker exposure to swine barn contaminants. Direct-reading instruments provide real-time measurements of worker exposure to various airborne contaminants and allow users to make prompt safety decisions (OSHA, 2014). These instruments are commonly used to assess worker exposure to airborne hazards in swine barns. O'Shaughnessy et al. (2012) used a direct-reading instrument to assess worker exposure to carbon dioxide. An optical particle counter (Model 1.108; Grimm Technologies, Inc., Douglasville, GA,) was also used to determine the size range of particles present in the swine facility, which provided information on the health impact of the particles.

Air sampling pumps are commonly used to assess worker exposure to particulate matter in swine barns. These instruments draw air through a filter or other capturing devices. The captured contaminants are then analyzed in a lab. Lab analysis allows low levels of these captured contaminants to be detected (NIOSH, 2015).

Aerosol mapping can be used in conjunction with direct-reading instruments to determine the spatial distribution of particles in swine barns. This method involves dividing the swine barn into smaller sections and measuring the contaminant levels in each section (Peters et al., 2012).

Reeve et al. (2013) used this method in a smaller farrowing room and concluded that measuring at a single location does not give an accurate representation of average exposure.

Contaminant Concentration Variation

Concentrations of gases, dust, and microbes in swine barns vary according to several factors. The feeding system, feed type, and amount of pigs present affect contaminant concentrations (Donham et al., 1990). Other factors that influence contaminant levels in swine buildings are pig age, housekeeping practices and building design as well as humidity, temperature, and amount of ventilation (Crook et al., 1991). A study conducted by O'Shaughnessy et al. (2010) revealed that concentrations of dust varied according to worker task. The study found that workers involved in tasks near active animals are exposed to the highest concentrations of swine barn contaminants (O'Shaughnessy et al., 2010).

In a study performed by Attwood et al. (1987), average dust levels were found to be higher in nursery and farrowing barns than in growing and finishing buildings. Sun et al. (2008) and O'Shaughnessy et al. (2002) found diurnal variations in contaminant concentrations as well as seasonal variations, with greatest concentrations observed during the winter. Peters et al. (2012) reported spatial variations in contaminant levels in gestation barns. Reeve et al. (2013) reported that contaminant concentrations were significantly lower when pit fans were in operation.

Contaminant concentrations vary in swine confinement facilities due to a variety of factors. Decreased ventilation in the wintertime as well as a greater amount of activity in young pigs may contribute to the differences in contaminant levels (Attwood et al., 1987). Workers involved in tasks around active swine may be at the greatest risk of exposure to swine barn contaminants, especially during the winter months.

Occupational Standards and Recommended Limits

Worker exposure limits have been developed for the specific contaminants found in swine buildings based on time-weighted averages over the course of an eight-hour work period. Regulatory agencies and consensus groups developed these limits based on health outcomes associated with individual compounds. Industry studies, however, recommend lower limits based on the health effects of exposures to combined contaminants in swine production facilities. The Occupational Safety and Health Administration (OSHA) is a federal agency that has the charge of creating enforceable permissible exposure limits (PELs) for workplace hazards. The National Institute of Occupational Safety and Health (NIOSH) is another federal agency that conducts research and creates recommended exposure limits (RELs) for worker safety. The American Conference of Governmental Industrial Hygienists (ACGIH) is a professional organization of occupational safety and health professionals from governmental and research organizations that creates threshold limit values (TLVs) for workplace hazards. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is a group that creates exposure limits to promote better indoor air quality and maintain comfort. Table 2 summarizes the personal occupational exposure limits set by these regulatory agencies and consensus groups for individual contaminants found in swine barns.

Literature Recommended Limits

Although exposure limits exist for individual contaminants, these individual exposure limits do not account for the additive effect of multiple contaminants in a swine barn setting. For this reason, there are recommended limits found in the literature that were specifically created for swine confinement buildings when a mixture of contaminants are present. A dose-response study conducted by Donham et al. (1989) sought to determine the maximum amount of swine barn contaminants workers could safely be exposed to, while taking into account the additive effect of multiple contaminants. This study recommended that swine barn concentrations of CO_2 should not exceed 1540 ppm, NH_3 should not exceed 7 ppm, and respirable and inhalable dust should not exceed 0.23 mg/m^3 and 2.4 mg/m^3 respectively. Contaminant concentrations above these values were associated with decreased lung function.

Although there are currently no exposure limit values created by industry for bacteria (Atwood et al., 1987), Donham et al. (1989), recommended that endotoxin levels not exceed 0.08 µg/m^3 in the room (0.09 µg/m^3 personal) and the room concentration of total microbes not exceed 4.3 x 10^5 cfu/m^3.

Control Methods

Several control options are available to reduce worker exposure to hazardous contaminants found throughout swine facilities. The industrial hygiene hierarchy of controls prioritizes the preferred selection of control strategies. Elimination, which involves removing the hazard entirely from the workplace, is the ideal control for workplace hazards. When removal of the hazard is not feasible, substitution of hazardous equipment or materials with safer alternatives is the next best option. Other engineering controls, including methods to isolate hazards from the worker, such as ventilation and shielding, are given the next highest priority. Administrative controls come next in the priority list and are intended to manage exposure through methods such as worker rotation and training. Personal protective equipment (PPE) includes the use of protective devices such as gloves or respirators. This control strategy is the last line of defense against workplace hazards because of its need to involve action from workers. Several studies have examined the usefulness of these many control options to protect workers in swine confinement buildings.

Misting

A swine barn engineering control that has been found to significantly reduce worker exposure to dust concentrations by up to 75% is misting with oil or water droplets (Zhu et al., 2005). Senthilselvan et al. (1997) found that misting with canola oil reduced the incidence of respiratory illness among swine workers in comparison to the control group of swine workers that did not use misting. The study also found that canola oil misting reduced concentrations of NH_3.

Ventilation

In order to reduce heating expenses, swine barns generally have limited amounts of exhaust ventilation through manure pit fans or wall fans during the winter months. Ventilation with air cleaning equipment is an engineering control that has been shown to effectively reduce contaminant concentrations while still maintaining temperatures that are necessary for pig health (Anthony et al., in press).

Respirators

The use of respirators has been found to effectively reduce adverse respiratory health effects in swine barn workers (Dosman et al., 2000; Sunblad et al., 2006). This PPE requires workers to be trained for effective use and unfortunately respirator use rates are low (Jones, 2004).

Engineering Control: Equipment Substitution

Although misting, ventilation and respirators are effective at reducing worker exposure to particulate matter and other swine barn contaminants, none of these options effectively control against CO and CO_2. Carbon dioxide has been linked to respiratory conditions among swine workers when combined with other swine barn contaminants (Donham et al., 1989), and studies have found CO_2 concentrations in swine barns above industry recommended limits (Donham et al., 1989; Letourneau et al., 2010). Although elimination of metabolic CO_2 production in swine barns is not feasible, substituting traditional in-room vented heaters with heaters that vent harmful combustion gases outside is possible, and may help to reduce CO_2 concentrations.

Objectives

The purpose of this study is to determine whether the replacement of a traditional in-room vented heater with a heating system that vents combustion gases outside will significantly reduce CO and CO_2 concentrations. In order to characterize the effect of colder time periods and heater proximity on combustion gas concentrations, temporal and spatial variability of the contaminants will be assessed. This study will also evaluate CO_2 production factors in order to compare heater performance and account for production and temperature differences between winter seasons.

Table 1. Common contaminants found in swine barns.

Contaminant	**Source**	**Characteristics**	**Health Hazards**
Carbon Monoxide	Heater combustion†	Colorless, odorless, tasteless‡	Headache, dizziness, vomiting, nausea, unconsciousness, death‡
Carbon Dioxide	Heater combustion, swine respiration†	Colorless, odorless at low concentrations, sharp, acidic odor at high concentrations‡	Headache, breathing difficulty, malaise, dizziness, asphyxia‡
Hydrogen Sulfide	Anaerobic microbial breakdown of protein and organic matter containing sulfur*‡	Colorless, rotten egg odor, odorless at lethal levels, flammable, corrosive, explosive*‡	Eye and respiratory tract inflammation, olfactory neuron loss, death*‡
Ammonia	Microbial manure decomposition, urine*‡	Colorless, pungent, suffocating odor*‡	Respiratory and eye irritation, chronic lung disease, severe cough, headache, nausea, reduced appetite*‡
Methane	Anaerobic microbial breakdown of organic matter*‡	Colorless, odorless, flammable*‡	Headache, suffocation, loss of consciousness*‡
Particulate Matter	Feed, dried fecal matter, dander, bedding*‡	Comprised of manure, feed, fungi, skin cells, bacteria, silicates, pollen, molds, yeasts, viruses*‡	Bronchitis, respiratory symptoms, lung function declines, organic dust toxic syndrome*‡

*Hribar (2010), †Donham (2010), ‡NIOSH (2015)

Table 2. Swine barn contaminant exposure limits.

Contaminant	OSHA PEL	NIOSH REL	ACGIH TLV	ASHRAE	Literature Recommended Limits*
Carbon Monoxide	50 ppm	35 ppm	25 ppm	9 ppm (indoor)	N/A
Carbon Dioxide	5,000 ppm	5,000 ppm	5,000 ppm	700 ppm (indoor)	1,540 ppm
Hydrogen Sulfide	10 ppm	10 ppm	10 ppm	N/A	N/A
Methane	N/A	1,000 ppm	1,000 ppm	N/A	N/A
Ammonia	50 ppm	25 ppm	25 ppm	N/A	7 ppm
Respirable Dust	5 mg/m^3	N/A	3 mg/m^3	N/A	0.23 mg/m^3
Total Dust	10 mg/m^3 (Grain) 15 mg/m^3 (Nuisance)	4 mg/ m^3 (Grain)	4 mg/ m^3 (Grain) 10 mg/ m^3 (Nuisance)	N/A	2.4 mg/m^3
Endotoxin	N/A	N/A	N/A	N/A	0.08 µg/m^3
Total Microbes	N/A	N/A	N/A	N/A	4.3 x 10^5 cfu/m^3

*Donham et al., 1989

CHAPTER II

FARROWING BARN EVALUATION

Introduction

Estimates from agricultural census data indicate that around 250,000 workers are involved in swine production at over 63,000 swine confinement facilities throughout the United States (USDA, 2012). Due to new technologies in recent decades, the majority of swine barns have become large-scale operations, producing over 5,000 swine annually (Hribar, 2010). The increased production capacity of swine barns has led to workers spending full workdays in these facilities (Pedersen et al., 1996). Swine workers spend the majority of their time in farrowing units, where they are involved in a wide range of specialized tasks, such as administering vaccinations, notching piglet ears, and preparing the room for pressure washing (O'Shaughnessy et al., 2010).

Studies have observed associations between working in these confined large-scale environments and developing respiratory illnesses. Increased prevalence of chronic and acute bronchitis (Donham, 1991; Donham et al., 1984; Pedersen et al., 1996), organic dust toxic syndrome (Donham, 1991; Cormier and Israel-Assayag 2004; Radon et al., 2001), mucous membrane irritation, chronic sinusitis, and byssinosis-like condition (Donham, 1991) have been observed among swine confinement workers. Dose-response studies have shown that swine barn workers may experience a decline in pulmonary function (FEV_1 and FVC) after the course of a single work period (Donham et al., 1984). These respiratory conditions are associated with an exposure to a complex mixture of contaminants, including dust, NH_3, and CO_2. Contaminant concentrations are highest during the wintertime when there is little general exhaust ventilation in order to maintain optimal temperatures for swine health (Donham, 2010).

Donham et al. (1989) proposed recommended exposure limits which focused on preventing health outcomes due to the mixture of contaminants found in swine barns. This study recommended room values of NH_3 not exceed 7 ppm, respirable dust not exceed 0.23 mg/m^3, and CO_2 not exceed 1540 ppm. In addition to industry recommended limits for mixed contaminants, regulatory agencies and consensus groups have developed health outcome based standards for individual compounds found in swine barns.

Due to the known health effects associated with swine barn contaminants, controlling these contaminants is necessary. Studies have shown that misting with oil or water droplets in swine facilities or adding oil or water directly to swine feed can effectively reduce worker exposure to particulate contaminants found in swine barns, and lower the incidence of respiratory illness (Zhu et al., 2005; Senthilselvan et al., 1997; Croggins et al., 2007). Other studies have shown the effectiveness of N95 respirators in reducing negative respiratory health effects associated with swine barn contaminants (Dosman et al., 2000; Sundblad et al., 2006). Unfortunately there are limited options to control gases, particularly CO_2. Therefore, alternative methods to reduce CO_2 generation should be a priority.

Carbon dioxide gas is commonly found in swine confinement buildings and contributes to the development of respiratory illnesses among hog farmers (Ni et al., 2010; Croggins, 2007; Pearson and Sharples, 1995). Carbon dioxide is generated from combustion sources found in farrowing barns, such as gas-fired heaters and pig respiration. Carbon monoxide gas is also generated from heaters. This odorless and colorless gas is typically found at low levels in the swine barn environment, but may be generated at high levels if heater combustion is faulty. Chronic exposure to even low levels (above 9 ppm) of carbon monoxide can lead to flu-like symptoms such as headaches, nausea, and malaise (CDC, 2015).

Concentrations of CO and CO_2 found in swine facilities vary by the number of swine present, outside temperature (as an indication of heater operation), and the amount of ventilation (O'Shaughnessy et al., 2010). Studies in swine grower/finisher and gestation barns have observed diurnal, seasonal, and spatial variations in these gas concentrations (Sun et al., 2008; Peters et al., 2012). Reeve et al., (2013) reported significantly higher concentrations of CO_2 when pit fans were not in operation.

While CO and CO_2 are generated by sources found in farrowing barns, such as gas-fired heaters and pig exhalation, information regarding the extent to which these sources contribute to overall room concentrations is lacking. Previous studies have estimated CO and CO_2 generation rates in swine barns based on the emission rate of natural gas combustion. According to these models, typical gas-fired heaters generate CO and CO_2 at 0.6 mg/s and 1800 mg/s, respectively (EPA, 1998). The generation rate of CO_2 from swine aspiration has been estimated to be 1060 mg/s for a barn containing 20 swine (Blanes and Pederson, 2005).

Since CO and CO_2 gases can accumulate in a poorly ventilated livestock building, options to control sources are necessary. Controlling swine respiration to minimize CO_2 generation is, obviously, not feasible. Anthony et al (2014) modeled the effectiveness of using ventilation to improve the air quality of swine confinement facilities, including reducing CO_2. According to simulations in the study, installing heaters that do not contribute to room concentrations of CO_2 may effectively reduce CO_2 concentrations in swine facilities below industry recommended levels.

The purpose of this study was, therefore, to test whether a heater that vents combustion gases outside can significantly reduce CO and CO_2 concentrations in a demonstration barn. In order to evaluate the impact of colder time periods and heater proximity on contaminant concentrations, temporal and spatial variation of the contaminants among the two heater types was assessed. Carbon dioxide production factors were also assessed in order to compare heater performance and account for production and temperature differences between winter seasons.

Methods

Test Site Description

The test site was located at a swine farrowing room at the Mansfield Swine Education Center at Kirkwood Community College (Figure 1). The study took place during two winter seasons (December-February): 18 days were randomly sampled in 2013-14 and 20 days in 2014-15. The farrowing room (9.2 m by 14 m) included three rows of five farrowing crates, each 1.5 m by 2.4 m, and one row of four 2 m by 2.4 m crates (19 sow capacity). The heads of the sows faced the aisles between Row I and Row II and between Row III and Row IV. Sources of ventilation included four radial exhaust fans on the north and south walls, eight inlet vents along the ceiling (RayDot Industries, Cokato, MN), two pressure louvers along the east wall, and two under-floor manure pit fans. The radial exhaust fans were closed throughout the study but were sealed with plastic only during the 2013-2014 winter season. The ceiling pressure louvres were kept in the closed position throughout both test periods. The pressure louvers (1.17 m wide) on the east wall remained at least partially open during the entirety of the study (around 2 to 5 cm), allowing the exchange of farrowing room air with air from the hallway. Workers kept the two doors between the farrowing room (east wall) and the hallway open during most of each study period. The pit fans were in operation throughout the whole 2013-14 winter season, but were off at the beginning of 2014-15 winter season (turned on January 15th).

Operations in this room were typical of farrowing operations. Sows that were close to giving birth in the breeding-gestation room were rotated into the farrowing room. Sows and piglets were rotated out of the farrowing room when piglets were 21 to 28 days of age.

The old in-room vented heaters were in operation in the 2013-14 season: AE060, Guardian 60 (L.B. White Co, Onalaska, WI). These heaters were positioned above the second row of farrowing crates near the east wall (Figure 1), although only Heater I was operational. Owing to a particularly cold winter season, the temperature sensors in the room kept this heater on for the majority of the 2013-14 winter season, with limited on/off cycling observed on study days. During fall of 2014, the old Guardian heaters were replaced with two new ventilated heaters, with intake air and combustion gases from heater plumbed to outside the farrowing room (Effinity93, Modine Manufacturing Company, Racine, WI). During the 2014-15 winter season, the temperature sensors in the room also only activated Heater I. Within the other three rooms in this building (second farrowing room, nursery, hallway), traditional unvented heaters (Guardian) remained in operation throughout the study.

Sampling Strategy

Gas concentrations were measured using direct reading instruments attached to poles at six different stations throughout the farrowing barn, marked A through F (Figure 1). Monitors were attached to the poles at the height of a worker's breathing zone (1.5 m). The fixed area monitoring occurred for 24-hour periods during both winter seasons. Monitors for CO_2 were positioned at each of the six locations (A-F) both seasons. Monitors for CO concentrations were positioned at the same six locations in the first season but, owing to relatively low concentrations, only three CO monitors were deployed in the second season (at A, C, and E).

Equipment and Data Collection

ToxiRAE Pro monitors (Model PGM-1850, Rae Systems Inc., San Jose, CA) were used to measure CO_2 concentrations. Carbon monoxide concentrations were measured using VRAE multi-gas monitors (Model 7800, Rae Systems Inc., San Jose, CA). Each direct reading instrument was calibrated in a clean laboratory before taking the devices to the field for deployment. Following the manufacturer's instructions, a fresh air calibration gas (0 ppm CO_2) and a reference gas (25,000 ppm CO_2 for 2013-14 winter and 5000 ppm CO_2 for 2014-15 winter) were used for the ToxiRAE Pro monitor. The sensitivity of this instrument was 100 ppm CO_2. The VRAE multi-gas monitors were calibrated in the laboratory, first with fresh air, then calibrated with a mixed gas containing 50 ppm CO. The sensitivity of this instrument was 1 ppm CO. All of the direct reading instruments logged data once every minute.

Prior to each day's field deployment, all of the direct-reading instruments were first turned on, with data logging, to collocate in the hallway adjacent to the farrowing barn for ten minutes. After collocation, instruments were positioned in the farrowing barn. After 24 hours, the direct reading instruments were retrieved from their locations and, while still logging, were again collocated in the hallway for 10 minutes. Collocation allowed the determination of whether and how much sensor drift occurred over the 24-hour sampling period. After retrieval, the instruments were taken back to the lab to be calibrated and for the data to be downloaded.

On each sample day, additional qualitative data were also collected to characterize factors that may contribute to gas concentrations in the room. These factors included: the temperature of the farrowing room, the number of heat lamps turned on, the number of sows and piglets, and the ventilation conditions of the farrowing room. Outside temperature data from the nearest weather station (KCID, Cedar Rapids Airport, approximately 2 miles to the west, via http://www.wunderground.com) were obtained to quantify outdoor temperatures over each 24-hour test period. An evaluation of which production factors, by heater type, contributed to estimates of CO_2, will allow the determination of heater performance between test seasons.

Data Analysis

Collocation data from all of the instruments was analyzed to determine whether sensor drift occurred. If differences in the 10-minute averages between collocated monitors exceeded drift criteria (200 ppm CO_2, 1 ppm CO), the sensor data were adjusted to the mean of the collocated concentration using linear regression. The adjusted data set was then plotted and compared with the other data sets to assess the appropriateness of the adjustment. As expected, sensor drift occurred more frequently towards the end of the study.

For each compound and sensor location, average concentrations over 24-hour and three 8-hour shifts were computed, where Shift 1 was 8:30 am to 4:30 pm, Shift 2 was 4:30 pm to 12:30 am, and Shift 3 was 12:30 am to 8:30 am. For each of the four time periods, the Shapiro-Wilk test was used to assess the normality of both the data and the natural log transformed gas concentration data. To determine if there was a difference in gas concentrations by heater type, between winter data were analyzed using a one-way ANOVA test. To assess whether changes in heater type affected room concentrations differently over colder time periods or by proximity to the heater, Tukey-Kramer pairwise comparison tests were used for analyzing normally distributed data, and Kruskal-Wallis tests were used for data that were not normally distributed.

Finally, to better evaluate performance between heater types, significant factors associated with room CO_2 concentrations (e.g., temperatures, room animal counts) were analyzed using multiple linear regression and backward elimination. To assess heater performance between study years, model 1 (old heater) was used to estimate the room concentration of CO_2 that might have occurred in year 2 if the new heater was not installed, using the observed production conditions (pig counts and outdoor temperatures) of the second winter (new heater). Likewise, model 2 was used to estimate the CO_2 concentrations that might have occurred in year 1 if the new heater was deployed in the colder season. Therefore, the differences in concentration between modeled and measured CO_2 concentrations provided a reasonable estimate of the contribution of heater type on room concentration. Seasonal averages were computed for measured and modeled CO_2 concentrations, and differences could be attributed to production factors and heater type, independently.

Results

General Findings

Table 3 summarizes 8 and 24-hour concentrations (the raw data collected during this study is provided in Appendix B). Figure 2 illustrates the 24-hour CO_2 concentrations, by season, averaged over all positions for a given sample day. Error bars show the highest and lowest concentrations across all positions on each sample day. The dotted line represents the literature recommended limit for CO_2 (1540 ppm), which takes into account the additive effect of multiple swine barn contaminants. With the old heater, 24-hour mean CO_2 ranged from 1900 ppm to 3300 ppm, with a mean of 2500 ppm (SD = 630 ppm). All samples with the old heater had 24-hour average CO_2 concentrations that exceeded the 1540 ppm recommended limit. With the new heater, the 24-hour CO_2 concentrations ranged from 600 ppm to 2000 ppm, with a winter mean of 1400 ppm (SD = 320 ppm). The 24-hour CO concentration data are shown in Figure 3. With the old heater, 24-hour averaged CO concentrations ranged from 1.1 ppm to 2.5 ppm, with a mean of 2.0 ppm (SD = 1.6 ppm) With the new heater, CO ranged from 0.01 ppm to 1.6 ppm, with a mean of 0.8 ppm (SD = 0.5 ppm).

Table 4 provides outdoor temperature, sow and piglet count ranges when both heater types were in operation. Study factor means and standard deviations are also included. When the first heater type was in operation, there were colder temperatures and higher sow and piglet counts on average.

Normality Tests

The results of the Shapiro-Wilk normality test confirmed that most of the data obtained during the study were not normally distributed. For data sets that were normally distributed, it was confirmed that parametric tests could be used for further analysis. For data sets that were not normally distributed, log transformed data were analyzed. If the log transformed data set was also not normally distributed, it was determined that non-parametric tests would be needed to analyze that data set. Table 5 summarizes normality test results.

Differences by Shift and Position

To assess whether the time of day significantly affected combustion gas concentrations, Tukey-Kramer pairwise comparison tests and non-parametric Kruskal-Wallis tests were used. The parametric and nonparametric test results for all data sets showed no statistically significant variation in CO and CO_2 concentrations by shift for both winter seasons. As such, 24-hour concentration averages were determined to be reasonable for air quality comparisons between heater types.

In order to determine differences in CO and CO_2 concentrations between sampling locations, Kruskal-Wallis tests were performed for 24-hour and 8-hour position data that were not normally distributed. No statistically significant difference was observed in 24-hour CO_2 concentrations by position when both the old and new heaters were in operation. Twenty-four hour CO data showed that position D was significantly higher than position E and F. This may have been due to the proximity (~ 1 m) of the D instrument to the heater. Eight-hour CO_2 concentration data for the old heater showed that CO_2 concentrations were significantly higher at position F compared to positions B, C and E. Differences in CO_2 concentrations for position F may have been due to the fact that station F was positioned closest to the hallway door, which may have exposed the CO_2 monitor to additional CO_2 concentrations from the hallway heater (Anthony et al., in press). There was also a statistically significant difference in 8-hour CO concentrations by position when the old heater was in operation. For this 8-hour CO data, position D was significantly higher than F. Again, this may have been due to the nearness of position D to the old heater. There was no difference in CO and CO_2 concentrations by position using the 8-hour data when the new heater was in operation.

Between-year Heater Type

In order to assess differences in combustion gas concentrations between heater types, a one-way ANOVA test was performed using 24-hour CO and CO_2 data averaged across all positions. The results of the test showed a significant 60% reduction in CO (2.0 to 0.8 ppm) and a 44% reduction in CO_2 (2500 to 1400 ppm) when the new heater was introduced ($p < 0.001$).

Carbon Dioxide Production Factors

The following best-fitting CO_2 models were used to estimate concentrations from both heater types:

$$\text{Old Heater: } CO_2\,(\text{ppm}) = 1719 - 36.9\,T + 16.8\,S + 2.8\,P \qquad (R^2=0.85) \qquad (1)$$

$$\text{New Heater: } CO_2\,(\text{ppm}) = 483 - 22.4\,T + 42.7\,S + 5.7\,P \qquad (R^2=0.75) \qquad (2)$$

where T is outdoor temperature (°C), S is the number of sows housed in the room, and P is the number of piglets housed in the room.

Model 1 shows that when the old heater was in operation, background concentrations of CO_2 were much higher than when the new heater was in operation. Temperatures also had a greater impact on CO_2 concentrations when the old heater was in operation compared to when the new heater was in operation. Sow and piglet count had a greater impact on CO_2 concentrations with the new heater compared to the old heater. Figure 4 plots modeled CO_2 concentration versus measured CO_2 concentration using these two equations.

Using these two models to estimate room concentrations for each year when the alternate heater was in operation, seasonal averages using the new heater equation identified that approximately 200 ppm differences in CO_2 concentrations would be expected in year 1 because of increased pig housing and the colder winter season. Further, by comparing modeled CO_2 estimates of the new heater in year 1 to actual measurements in that first year (with the old heater), a decrease of 800 ppm CO_2 was observed. Figure 5 plots modeled and measured CO_2 concentrations using both the old and new heater by outdoor temperature, demonstrating differences in concentration by heater type.

Discussion

Although CO_2 is perhaps not the most hazardous contaminant found in swine facilities, studies identified that CO_2 along with ammonia and dust all contributed to the decline in respiratory health (Donham et al., 1989). Past research has indicated that CO_2 concentrations commonly found in swine facilities are above what has been recommended in literature. Donham et al. (1989) reported CO_2 concentrations as high as 4500 ppm, Letourneau et al. (2010) reported up to 4010 ppm, and Sun et al. (2008) reported up to 4030 ppm. Although heater type was not mentioned in any of these studies, the similar CO_2 concentrations noted across studies indicates that traditional heaters were likely used. Although our test site's CO_2 concentrations ranged up to only 3200 ppm with the traditional heater, concentrations exceeded the literature recommended limit of 1540 ppm, indicating that the reduction in CO_2 by changing heater design may be generalizable to other production barns.

Although the longevity of these ventilating heaters (Effinity93, Modine Manufacturing Co.) in the swine barn environment is still a matter of study, the heater itself is made of corrosion resistant materials, and will likely outperform the traditional in-room vented gas-fired heater. This heater has an anticipated lifespan of up to 30 years (Petrovic, 2015). Regardless of direct cost differences (around $500 difference per unit), these heaters have been shown to effectively reduce concentrations of contaminants linked to respiratory illnesses in workers and swine. By protecting workers and swine, other hidden costs, such as a decrease in swine productivity, can be avoided. If other heater models are chosen, it is recommended that these models be built with stainless steel to withstand corrosion, have a clean air intake and the ability to vent exhausted air outside of the building.

There were no differences in contaminant concentrations by shift noted during this study. The expected increase in CO_2 concentrations during colder nighttime temperatures may have been offset by the slowed swine breathing that occurred during the nighttime. Combustion gas concentrations differed by position when the old heater was in operation. As would be expected from a heater that directly emits combustion gases into the swine barn air, higher contaminant concentrations were noted closest to the heater.

During the second winter season with the new heater in operation, contaminant concentrations increased as the winter progressed, and the test site still had CO_2 concentrations above the industry recommended limit (1540 ppm) on six of the 20 study days. Even so, this was a substantial improvement over the first season with all 17 test days exceeding the recommended limit. When year 2 was modeled using the year 1 equation, it was demonstrated that even with the warmer temperatures of year 2, the old heater would still have resulted in all study days being over the industry recommended limit (Figure 5).

According to the industrial hygiene hierarchy of controls, engineering controls should be prioritized when selecting methods to protect workers. These new heating systems are a feasible engineering control for reducing room concentrations of CO_2, one of the main swine barn contaminants. Ventilation is a feasible engineering control option for reducing dust concentrations in the swine barn environment, and has been shown to be effective in previous studies (Anthony et al., in press). Although no engineering control currently exists for the third main swine barn contaminant, NH_3, adopting new heater technology along with ventilation systems may significantly reduce the overall health burden associated with the mixture of key contaminants and increase the amount of NH_3 a worker can be exposed to before they begin experiencing negative health effects. Administrative controls, such as reducing the amount of time a worker spends in swine confinement facilities, are the next best option after engineering controls have been considered. Respirators have been shown to be effective at controlling dust concentrations, but due to the requirement for worker action, this PPE should be selected as a last line of defense after all other control options have been considered. Respirators exist for NH_3, but the effectiveness of respirators to control NH_3 is not well documented. Although respirators may appear to be a quick and inexpensive solution to control for contaminants in the workplace, there are many associated costs. Employers must provide respirators to workers as well as a respiratory protection program that includes medical evaluations, training, and other associated costs (OSHA, 2006). Swine producers are encouraged to adopt engineering technologies and administrative control options before considering PPE.

Carbon monoxide concentrations were well below recommended limits with both heaters, and although levels were never of concern to human health throughout the study, it is important to note that there was still a significant decrease in concentrations. Testing differences in CO concentrations allowed for another indication of the effectiveness of the new heater in reducing combustion gas concentrations. Testing CO concentrations also helped determine whether or not combustion was faulty with the old heater type.

Limitations

When the new heater was in operation, the farrowing barn never reached its full 19 sow capacity, which may have resulted in an underestimation of what CO_2 concentrations would have been if the farrowing barn was in full production. The impact of swine on CO_2 concentrations was accounted for through linear models, and according to the year 2 model the difference in concentrations due to a single sow would only be 43 ppm.

During the second winter season, pit fans were only in operation for a portion of the study, which may have affected combustion gas concentrations in the farrowing room. Carbon dioxide concentrations may have been slightly higher than they would have been if the pit fans were in operation throughout the entire study. During the first portion of the second winter season with the pits fans turned off, CO_2 concentrations averaged 1200 ppm. According to a study conducted by Reeve et al. (2013), mean area CO_2 concentrations were 25% higher when the pit fans were turned off. If the effect of pit fans was similar in this study, it would be expected that there would be around a 240 ppm difference due to pit fans. This would be a statistically significant but insubstantial difference.

Finally, it is important to note that traditional gas-fired heaters were still in operation in other rooms of this building, including the hallway adjacent to the test room, during the study.

Collocation data from the second winter season, with the new heaters in the farrowing room, showed higher CO_2 concentrations in the hallway than the farrowing room. The traditional heaters that were still present at the building may have contributed to additional CO_2 concentrations in the farrowing room that were not accounted for by the model. Concentrations in the farrowing room may have been reduced even further if the traditional heaters from other areas of the building were also replaced.

Conclusion

A traditional gas-fired heater was identified as a significant contributor to in-room concentrations of CO_2 in a swine farrowing barn. A heater that vented combustion gases outside of the occupied room resulted in significant and substantial reductions of this contaminant from 2500 to 1400 ppm seasonal averages, resulting in a 44% reduction ($p < 0.001$). These findings suggest that the replacement of old heaters with simple, new heater technology can contribute to substantial reductions in one of the main hazardous components of wintertime swine confinement facilities. Although CO concentrations never reached hazardous levels during the course of the study, concentrations were still significantly reduced from 2.0 to 0.8 ppm, resulting in a 60% reduction ($p < 0.001$). While additional work is needed to characterize the long-term usefulness of this unit, livestock producers should be encouraged to adopt a different heater technology to control CO_2 concentrations that may improve the health of workers and possibly animals produced.

Table 3. Gas concentration data using 8-hour and 24-hour averaging periods.

		Old Heater			New Heater		
Contaminant	Averaging Period	Mean, ppm	SD, ppm	N	Mean, ppm	SD, ppm	N
CO_2	8-hour	2480	363	319	1413	347	353
	24-hour	2478	346	107	1414	326	119
CO	8-hour	2.0	1.3	268	0.74	0.52	167
	24-hour	2.0	1.3	90	0.74	0.50	56

Table 4. Qualitative factors observed over each study season.

		Old Heater	New Heater
Outdoor Temperature (^{o}C)			
	Range	-23.9 to 0.2	-19.0 to 2.9
	Mean	-9.1	-6.0
	SD	6.7	7.0
Sow Count			
	Range	0 to 19	3 to 18
	Mean	13.7	12.2
	SD	4.4	4.6
Piglet Count			
	Range	0 to 119	0 to 93
	Mean	68.1	49.2
	SD	35.6	24.8

Table 5. Results of Shapiro-Wilk normality tests.

Contaminant	Data Set	Old Heater p	New Heater p
CO_2 (ppm)	8-hour by position	<0.01*	<0.01*
	8-hour all positions averaged	0.10	0.24
	24-hour by position	**0.13**	0.02*
	24-hour all positions averaged	0.38	0.82
CO (ppm)	8-hour by position	<0.01*	<0.01*
	8-hour all positions averaged	0.70	<0.01*
	24-hour by position	<0.01*	<0.01*
	24-hour all positions averaged	0.98	0.16

*These data sets were not normally distributed. **Bold** indicates the logged concentration data were normally distributed.

Table 6. Summary of position averaged 8-hour CO and CO_2 concentrations.

	Old Heater					New Heater				
Contaminant	Shift	Mean, ppm	SD, ppm	N	p	Shift	Mean, ppm	SD, ppm	N	p
	1	2467	352	18		1	1382	283	20	
CO_2	2	2448	350	18	0.79	2	1398	347	20	0.73
	3	2522	387	18		3	1464	399	20	
	1	1.9	1.4	18		1	0.73	0.50	20	
CO	2	2.0	1.3	18	0.61	2	0.77	0.52	20	0.87*
	3	2.1	1.3	18		3	0.85	0.55	20	

*Indicates a non-parametric test was performed because data were not normally distributed.

Table 7. Summary of 8-hour CO and CO_2 concentrations including all positions.

	Old Heater					New Heater				
Contaminant	Shift	Mean, ppm	SD, ppm	N	p	Shift	Mean, ppm	SD, ppm	N	p
	1	2468	352	107		1	1380	289	119	
CO_2	2	2451	350	107	0.41*	2	1398	346	118	0.13*
	3	2522	387	105		3	1462	398	116	
	1	2.0	1.4	90		1	0.68	0.50	57	
CO	2	2.0	1.3	90	0.14*	2	0.72	0.52	57	0.35*
	3	2.1	1.3	88		3	0.83	0.55	53	

*Indicates non-parametric tests were used because data were not normally distributed.

Table 8. Summary of 24-hour CO and CO_2 concentration data by position.

		Old Heater					New Heater			
		Mean, ppm	SD, ppm	N	p		Mean, ppm	SD, ppm	N	p
CO_2	A	2518	354	18	**0.06**	A	1425	332	20	0.54*
	B	2362	344	18		B	1359	344	20	
	C	2388	354	18		C	1368	317	20	
	D	2494	311	17		D	1394	324	18	
	E	2427	317	18		E	1467	355	20	
	F	2679	340	18		F	1479	340	20	
CO	A	1.7	0.42	17	< 0.01*	A	0.68	0.47	19	0.49*
	B	1.6	0.38	17						
	C	2.4	0.99	16		C	0.69	0.52	19	
	D	3.0	2.5	16						
	E	1.4	0.49	18		E	0.85	0.51	18	
	F	1.4	0.37	6						

*Indicates non-parametric tests were used for the data that was not normally distributed.
Bold indicates the log transformed data were normally distributed.

Table 9. Summary of 8-hour CO and CO_2 concentration data by position.

		Old Heater				New Heater				
		Mean, ppm	SD, ppm	N	p		Mean, ppm	SD, ppm	N	p
CO_2	A	2518	354	54	< 0.001*	A	1424	332	60	0.13*
	B	2362	344	54		B	1358	344	60	
	C	2397	354	53		C	1369	317	59	
	D	2494	311	51		D	1392	324	56	
	E	2432	317	54		E	1454	355	58	
	F	2677	340	53		F	1479	340	60	
CO	A	1.7	0.42	51	< 0.001*	A	0.68	0.47	55	0.17*
	B	1.6	0.38	52						
	C	2.5	0.99	47		C	0.70	0.52	56	
	D	2.7	2.5	48						
	E	1.5	0.49	53		E	0.84	0.51	56	
	F	1.1	0.37	18						

*Indicates non-parametric tests were used for data that was not normally distributed.

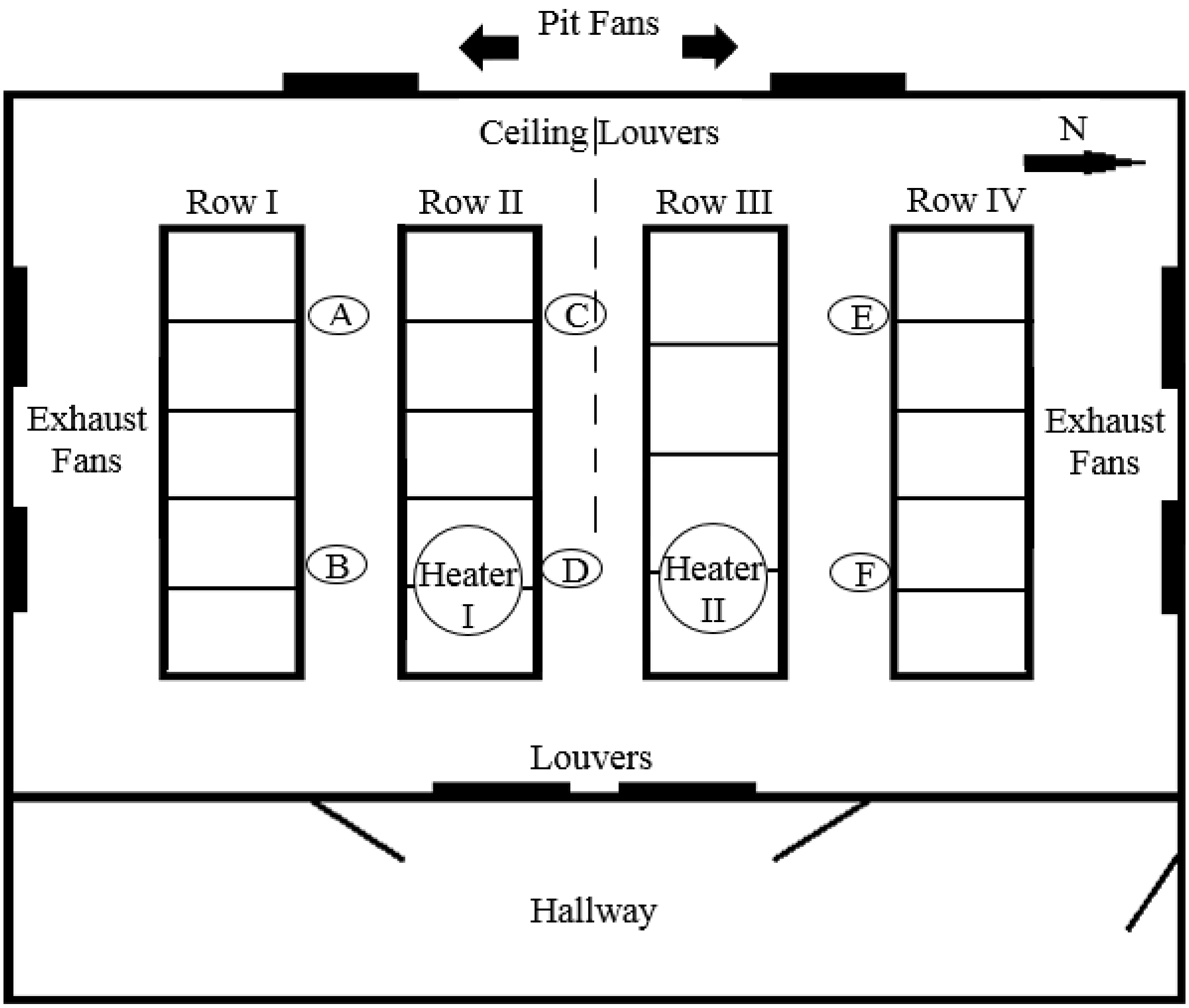


Figure 1. Swine farrowing barn layout.

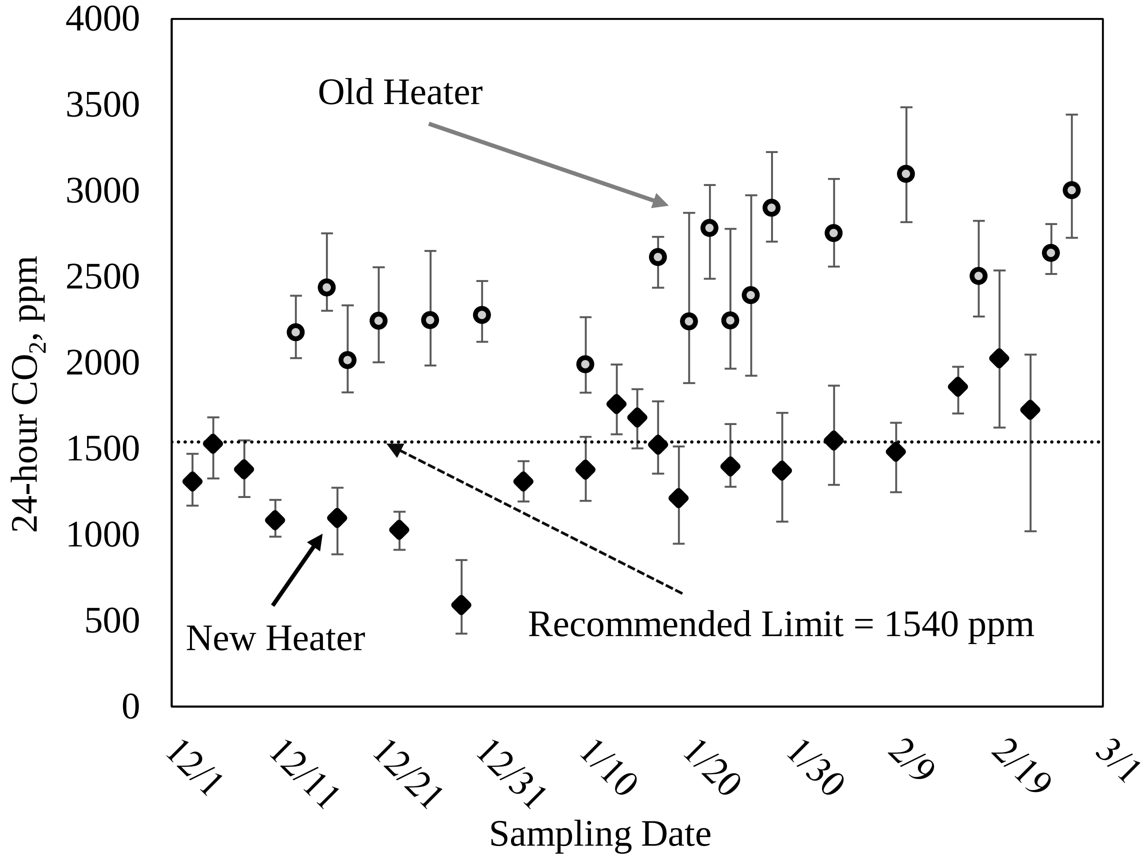


Figure 2. Average CO_2 concentrations (24-hour, over all positions). Error bars represent highest and lowest concentrations on each sample day across all positions.

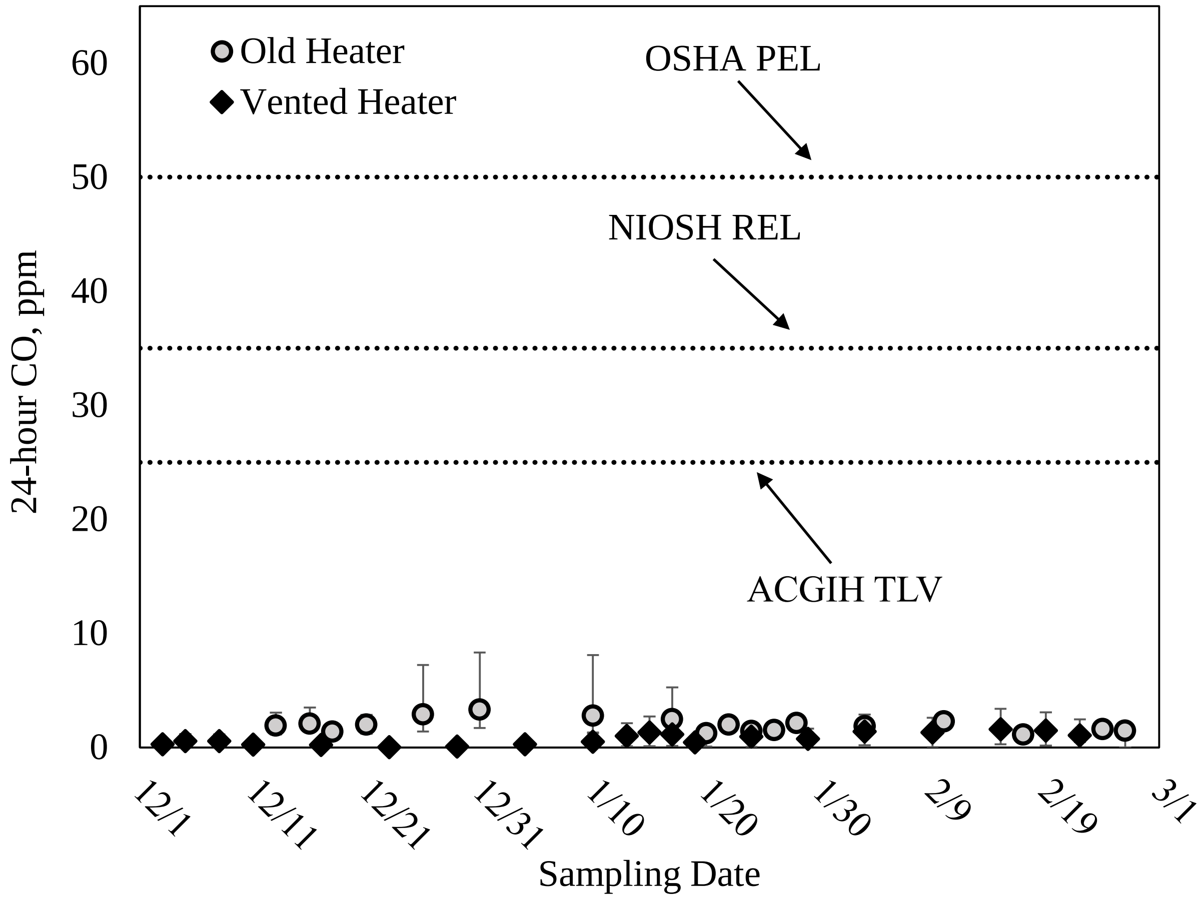


Figure 3. Average CO concentrations (24-hour, over all positions). Error bars represent highest and lowest concentrations on each sample day across all positions.

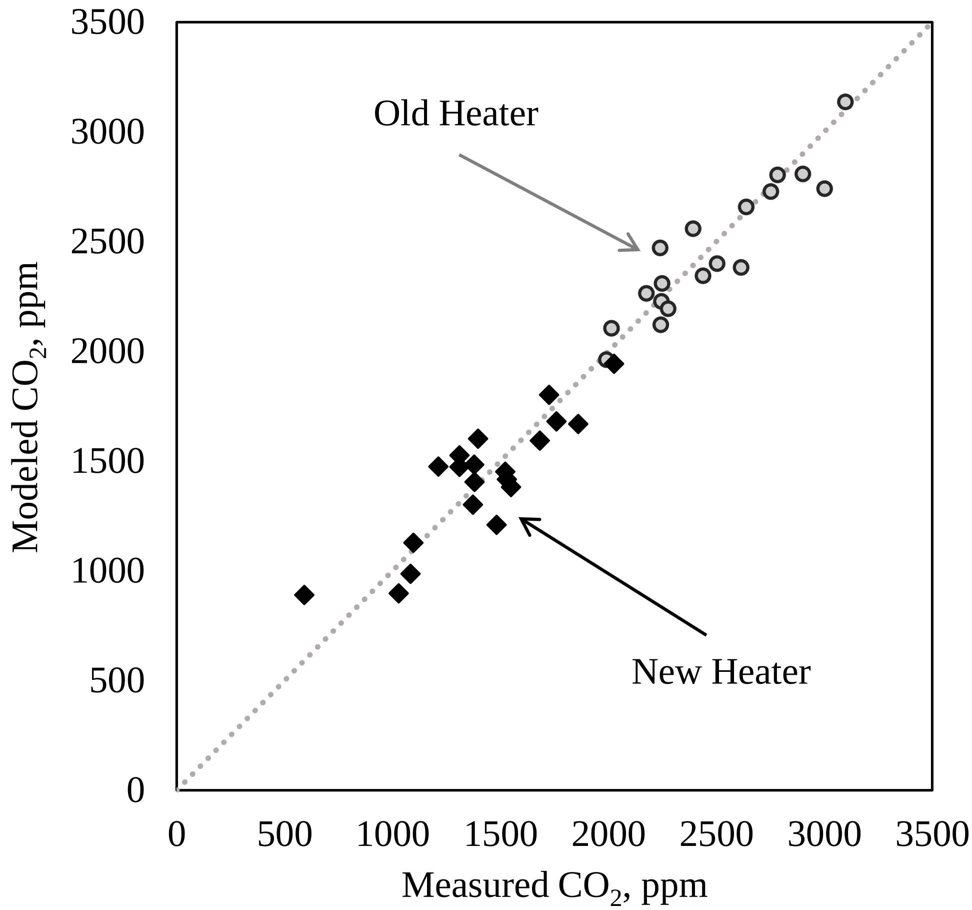


Figure 4. Modeled versus measured CO_2 concentrations using equations (1) and (2).

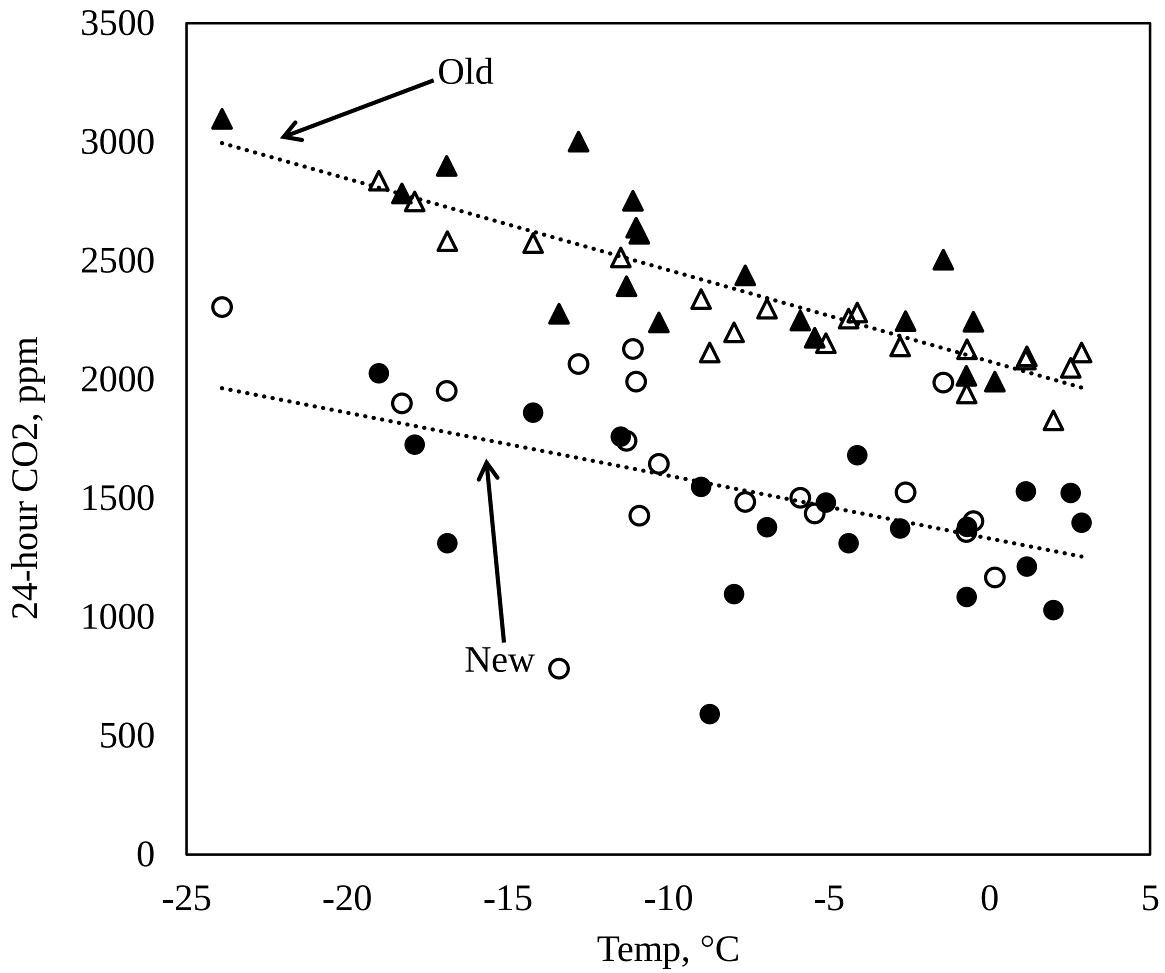


Figure 5. Measured and modeled CO_2 by outdoor temperature (°C). Solid triangles represent actual year 1 measurements with the old heater. Open triangles represent modeled year 2 measurements using equation (1). Solid circles represent actual year 2 measurements with the new heater. Open circles represent modeled year 1 measurements using equation (2).

CHAPTER III

CONCLUSIONS

This study examined the effectiveness of outdoor venting heaters in reducing farrowing barn combustion gas concentrations below industry recommended limits. The study took place over the course of two winter seasons, during the months of December through February. Carbon monoxide and CO_2 concentrations were monitored at fixed-area stations throughout the 19-crate farrowing barn for 24-hours. Instruments were collocated in the hallway of the farrowing barn for 10 minutes on each deployment and retrieval day to assess whether sensor drift occurred. Carbon dioxide production factor data (temperature and pig count) were recorded on each sample day. Gas concentrations were analyzed to see if data were normally distributed, if concentrations could be lowered regardless of the time of day and position, and to see if there was a significant reduction in CO and CO_2 concentrations after the new heater was introduced. Carbon dioxide production factors were also estimated using multiple linear regression and backward elimination.

Temperatures were colder during the first winter season (-9^{o}C average) compared to the second winter season (-6^{o}C average). Sow and piglet counts were also slightly higher during the first winter compared to the second winter.

Collected data were averaged and divided into three 8-hour shifts. Normality tests confirmed that most of the data sets were not normally distributed. For those data sets that were not normally distributed, non-parametric tests were used to analyze the data. Statistical test results showed no difference in combustion gas concentrations by time of day. Differences in gas concentrations by position were present during the first year of the study. These concentration differences by location can were explained by the fact that the instruments showing higher values were positioned closest to the heater.

Previous swine barn simulation research supports the idea that outdoor venting heaters should be able to effectively reduce combustion gas concentrations below industry recommended levels (Anthony et al., 2014). During the second year when the new heater was installed, CO concentrations were significantly reduced from 2.0 ppm to 0.7 ppm (60% reduction, $p < 0.001$) and CO_2 concentrations were significantly reduced from 2500 ppm to 1400 ppm (44% reduction, $p < 0.001$).

Carbon monoxide concentrations never exceeded industry recommended limits throughout the course of the study, although CO concentrations were still significantly reduced. Carbon dioxide concentrations exceeded the 1,540 ppm industry recommended limit on every sampling day during the first winter, and the average CO_2 concentration was half of the TLV (2,500 ppm). After the new heater was installed CO_2 concentrations averaged below the 1,540 ppm recommended limit at 1400 ppm.

Multiple linear regression and backward elimination found a significant relationship between CO_2 and other production factors for both the old and new heaters. The old heater identified the following relationship between CO_2 and production factors: CO_2 (ppm) = 1719 – 36.9 (Temp °C) + 16.8 (#sow) + 2.8 (# piglet), with an $R^2 = 0.85$. The following relationship between CO_2 and production factors were found for the new heater: CO_2 (ppm) = 483 – 22.4 (Temp °C) + 42.7 (# sow) + 5.7 (# piglet), with an $R^2 = 0.75$.

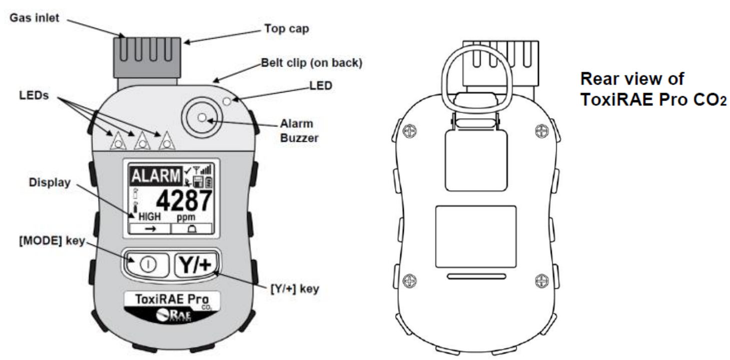
Although initial installation and unit costs may be greater with new vented heaters compared to traditional models, the new heaters have a longer anticipated lifespan, and therefore may be ultimately more economical. The widespread adoption of these upgraded heating units may not only provide long term economic benefits, but may also substantially reduce the prevalence of respiratory diseases frequently noted among production workers as well as swine. The increase in worker and animal productivity associated with these health improvements provides additional economic incentive for swine producers. In addition to replacing commonly used swine barn heaters with corrosion resistant heaters that have a clean air intake and vent combustion gases outside, farmers are also encouraged to also install ventilation systems in swine facilities to control dust concentrations. Using ventilation systems and outdoor venting heaters simultaneously may provide the most feasible and effective solution to reduce the overall respiratory health impact associated with mixed swine barn contaminants.

An immediate upgrade of all heating units within an existing swine facility is not practical, so swine producers are encouraged to gradually upgrade to newer units when old units are in need of replacement. When new swine facilities are constructed, it is recommended that buildings are designed with outdoor venting technology.

Future research looking at the longevity of outdoor venting heaters in farrowing barns is needed in order to further strengthen the argument towards using these heaters in the swine barn environment. Although limitations were present in this study, the findings of this study are still important and generalizable towards other swine operations.

APPENDIX A: STANDARD OPERATING PROCEDURES

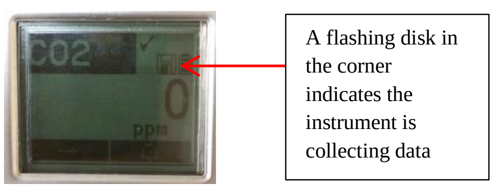
ToxiRAE Pro CO_2 User Manual



Turn On: Press and hold **[MODE]** for 3 seconds.

After the **ToxiRAE** is turned on, the buzzer, vibration alarm, and LEDs will be tested. Afterwards a battery test and a self-test will be performed. This process will take about one minute.

After the tests are complete, the main screen will look like this:

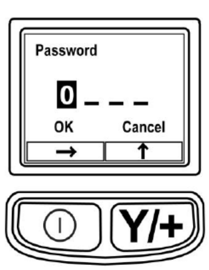


Before the **ToxiRAE** can be taken to the swine barn to collect data, it must first be calibrated.

Calibration:

In order to calibrate the **ToxieRAE**, the instrument must first be in **Programming Mode**. The password is **0000**.

To enter **Programming Mode**: Press and hold **[MODE]** and **[Y/+]** at the same time until the password screen appears:



Steps to input password:

- Press **[Y/+]** then press **[MODE]**
- Repeat this step until there are four zeroes
- Press **[MODE]** and make sure the **OK** option is highlighted then press **[Y/+]**

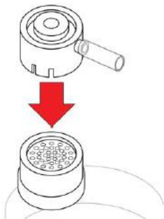
When you have entered **Programming Mode**, this screen will appear:

Select '**Calibration**' by pressing the **[Y/+]** button. The **Calibration** icon is highlighted first by default.

After you select the **Calibration** icon, the following screen will appear:

Select the **Zero Calib** icon by pressing the **[Y/+]** key. In the **Calibration** menu, select **Zero Calib** by pressing the [**Y/+]** key. Once selected, "**Apply zero gas…"** will appear on the screen.

Attach the plastic portion of the calibration adapter to the **ToxiRAE** by pressing firmly onto the gas inlet of the instrument:



Attach the metal portion of the adapter to the **Zero Air** gas cylinder by twisting it onto the top of the cylinder. The setup should look like so:

Note: DO NOT turn the dial counterclockwise until the instrument is ready to receive gas. In between calibrating instruments, make sure the gas is not being released. This is done by turning the dial completely in the clockwise direction.

Turn the dial *counterclockwise* on the flow regulator to release gas. Once gas is released, select the **Start** icon by pressing the **[Y/+]** key. After the key is pressed, there will be a 60-second countdown. The screen will show the word "**Zeroing…**" and the countdown.

When the **Zero Calibration** is complete, the screen will say "**Zeroing is done! Reading = 0.0 ppm**" (the reading should be 0.0 ppm or very close). Turn the dial counterclockwise on the flow regulator to shut off the gas and repeat the same procedure on the five other **ToxiRAE** instruments.

The **Span Calibration** is done by first highlighting and selecting the **Span Calibration** icon. Once selected, a screen will appear to ask if you want to change the amount of calibration gas. It should already be set at **5000 ppm** (2013-14 it should have read 25,000 ppm) by default. The screen will ask if the gas amount needs to be changed. Select the **No** icon by pressing the **[MODE]** button.

Connect the unit to the **CO_2** gas cylinder in the same fashion as the **Zero Calibration**. Turn the dial *counterclockwise* to release gas then select the **Start** icon by pressing **[Y/+]** to begin gas flow. There will be a 60 second countdown. After the **Span Calibration** is complete, the screen will say "**Span is done**!" The reading should be within 10% of the span gas concentration (in this case it should be within 10% of **5000 ppm**). Complete the same **Span Calibration** procedure for the other five instruments.

After the instrument is connected to the **CO_2** gas cylinder, select the **Bump Test** icon and twist the dial on the flow regulator in the *counterclockwise* direction.

Once the gas is released, select the **Start** icon on the **ToxiRAE** by pressing the **[Y/+]** key. After the **Start** icon is selected, a countdown will happen. Once the **ToxiRAE** detects gas, the **Bump Test** will occur.

After the **Bump Test** is complete, twist the dial on the flow regulator in the *clockwise* direction.

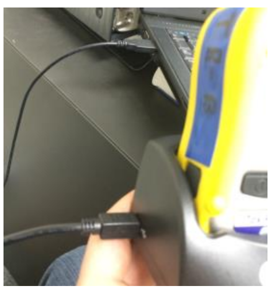
Repeat the bump test on the other five **ToxiRAE** instruments.

Once you are done with the **Zero Calibration**, and **Span Calibration**, and **Bump Test**, exit the **Calibration** menu by highlighting the **Exit** icon and pressing **[Y/+].**

<u>Uploading Data to the Laptop</u>

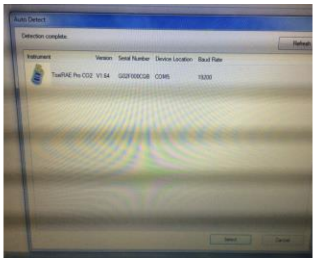
Once you are ready to upload data onto the laptop, first turn the instrument on and wait until you arrive at the main screen (see above for startup details) then press the **[MODE]** button three times until you arrive at this screen:

Attach the **ToxiRAE** to the charging cradle and connect the communications cable to the computer and charging cradle like so:

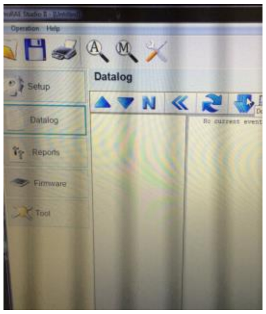


Once the cables are connected, double click the **ProRAE Studio II** icon on the laptop. Select **Yes** on the **ToxiRAE** to **Enter Communications Mode**. Once you open **ProRAE Studio II**, the following screen will appear:

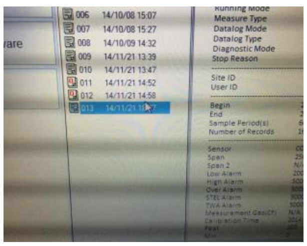
Select the **Administrator** option then type “**rae**” as the password. Click **OK**. After this, click **Operation→Auto Detect**. The following screen should appear:



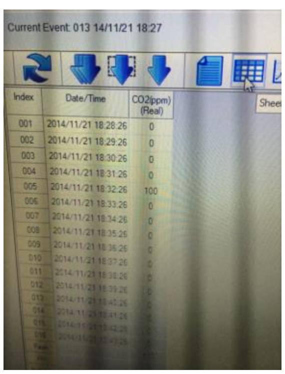
Click the **Select** button. After you click the Select button, click **Datalog** then double-click the triple arrow icon to download the data:



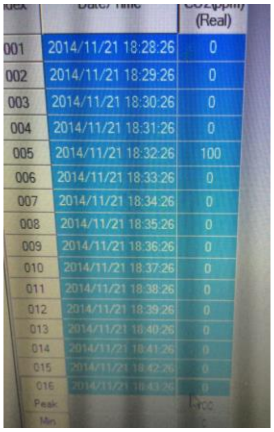
After the data from the instrument downloads onto the computer, double click the data that matches the date and time you wish to look at:



Once you click on the correct date, click the **Sheet** button at the top the page to view the individual $\mathbf{CO_2}$ data readings:

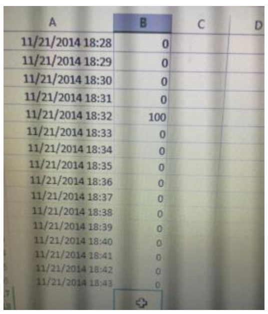


Highlight all the data like so:



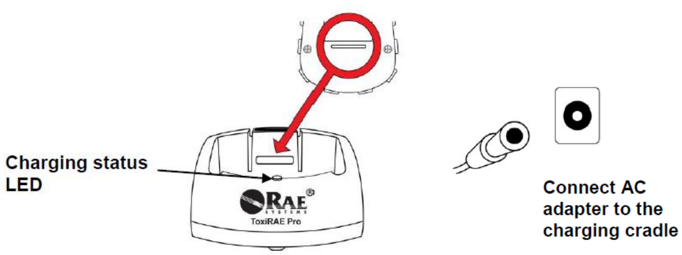
Index	Date/Time	CO2(ppm) (Real)
001	2014/11/21 18:28:26	0
002	2014/11/21 18:29:26	0
003	2014/11/21 18:30:26	0
004	2014/11/21 18:31:26	0
005	2014/11/21 18:32:26	100
006	2014/11/21 18:33:26	0
007	2014/11/21 18:34:26	0
008	2014/11/21 18:35:26	0
009	2014/11/21 18:36:26	0
010	2014/11/21 18:37:26	0
011	2014/11/21 18:38:26	0
012	2014/11/21 18:39:26	0
013	2014/11/21 18:40:26	0
014	2014/11/21 18:41:26	0
015	2014/11/21 18:42:26	0
016	2014/11/21 18:43:26	0
Peak		
Min		

Copy the data directly into an Excel file and save the Excel file on the laptop and shared drive.

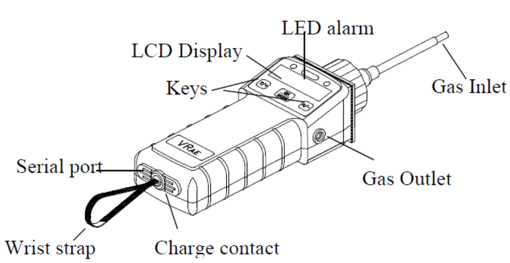


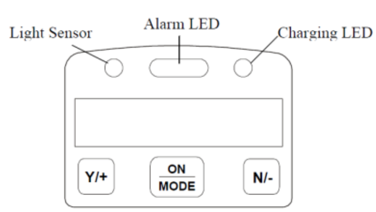
A	B	C	D
11/21/2014 18:28	0		
11/21/2014 18:29	0		
11/21/2014 18:30	0		
11/21/2014 18:31	0		
11/21/2014 18:32	100		
11/21/2014 18:33	0		
11/21/2014 18:34	0		
11/21/2014 18:35	0		
11/21/2014 18:36	0		
11/21/2014 18:37	0		
11/21/2014 18:38	0		
11/21/2014 18:39	0		
11/21/2014 18:40	0		
11/21/2014 18:41	0		
11/21/2014 18:42	0		
11/21/2014 18:43	0		

On deployment days, ensure that the instrument is attached to the charging cradle and is plugged in at the swine barn. An LED will indicate that the instrument is attached and charging:



VRAE Multi Gas Monitor User Manual



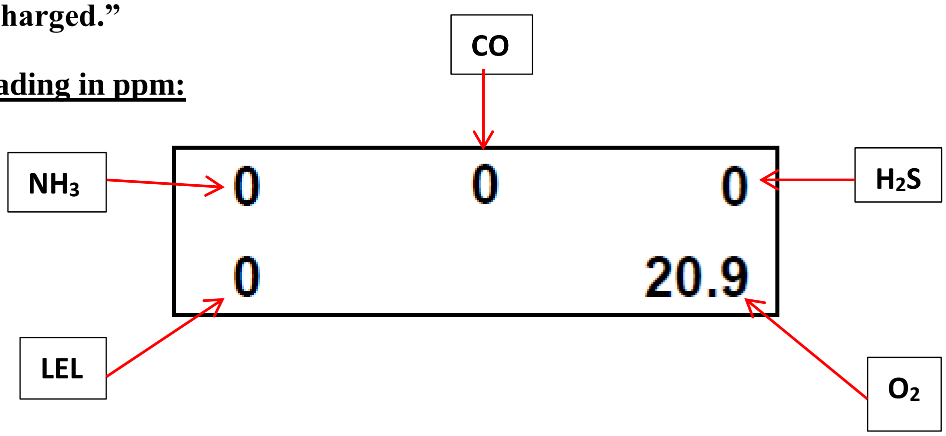


Turn on: Press and hold the **[MODE]** key until the monitor beeps once and the display shows **"ON!..."** The monitor will then display all of its settings (~1 minute). The monitor will then do a **10 second** countdown and then immediately begin monitoring gases. The display will show direct concentration readings in **ppm**. The monitor is defaulted to automatically datalog after it is turned on.

Turn off: Press and hold the **[MODE]** key for **5 seconds**. The message **"Off!.."** will appear then the screen will go black, indicating that the monitor is off.

*Note: If the monitor is turned off while plugged in, the display will say **"Charging…"** or **"Battery Charged."**

Instant Reading in ppm:



Calibration:

In order to calibrate the **VRAE**, the monitor must first be in **programming mode**. After the monitor is already turned on, press and hold the **[MODE]** and **[N/-]** keys simultaneously for **three seconds. "Calibrate Monitor?"** will then be displayed. Press the **[Y/+]** key. The first display will say **"Fresh Air Calibration?"** Take the monitors outside (if at IREH, just stand by the door, and expose the monitors to the outside air). Press the **[Y/+]** key to start the "fresh air calibration."

The display with then show **"Zero…In Progress"** followed by each sensor name along with the message **"Zeroed."** All sensors should show a reading of "0.0" (or a very small number). A **30 second** pause will occur, followed by the message **"Zero Cal Done! Reading ="** along with the instant air readings. Record the **Fresh Air** readings for each of the different gases along with the time that the fresh air calibration occurred.

After the "fresh air calibration" is complete, the display will show **"Multiple Sensor Calibration?"** Press **[Y/+].** The display will then show all of the pre-selected gases for the mixed gas bottles (should be **CO** and **H_2S** by default). Press the **[Y/+]** key to accept the section and start the calibration. Attach the monitor to the **Mixed Gas** like so:

The display will show **“Apply Mixed Gas”** and will begin calibrating once the gas reaches the sensor. The display will show **“Calibration In Progress…60.”** A countdown will then occur. If there is no gas flow that reaches the sensor in **60 seconds**, the display will show **“No Gas Flow…”** and the calibration will be aborted. Record the **Mixed Gas** values along with the times that each **Mixed Gas** test occurs. *Note: The readings should be very close to the **Mixed Gas** values. After a **30 second** pause, the display will show **“Span Cal Done! Turn Off Gas”**

Disconnect the calibration adapter from the cylinder to avoid wasting gas.

After the **Mixed Gas** calibration is complete, the monitor will automatically display **“Single Sensor Calibration? “** Press the **[Y/+]** key. The monitor will then display different gases to choose from. The **NH_3** should be highlighted first by default. Press the **[Y/+]** key to select **NH_3**, and attach the monitor to an **NH_3** cylinder.

Once the **NH_3** is selected, the display will say **“Apply NH_3**…” The monitor will automatically detect the gas flow. The reading on the monitor should be very close to the span gas value. After a **30 second** pause, the display will show the message **“Span Cal is Done! Turn off Gas.”** Record the **NH_3** values for all three monitors and write down the times that each test occurred. Note: If the monitor does not initially receive gas after **60 seconds**, the display will show **“No Gas Flow…”** and the calibration will be aborted. If the calibration needs to be manually aborted at any time, press the **[MODE]** button.

Modifying Span Gas Values:

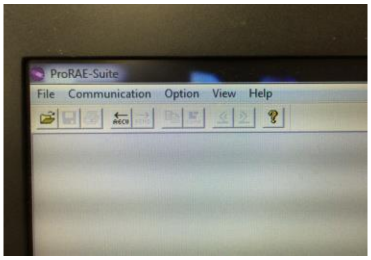
If any of the span gas values need to be changed, when the sensor displays **“Modify Span Gas Value,”** press the **[Y/+]** key. Use the **[Y/+]** and **[N/-]** keys to change numbers and the **[MODE]** key to scroll to the next number. To exit this display, press and hold the **[MODE]** key. The monitor will display **“Save?”** Press **[Y/+]** to accept changes and **[N/-]** to keep previous settings.

To exit programming mode, press the **[MODE]** key once.

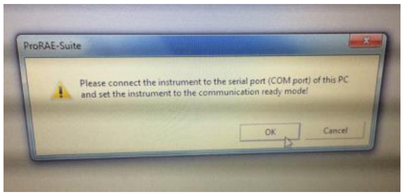
Downloading Data:

After the monitor is turned on, press the **[MODE]** key several times until **“Communicate with PC?”** is displayed. Press the **[Y/+]** key and the display will show **“Monitor will pause, OK?”** Press **[Y/+]** to confirm. The display will then show **“Ready…”** Plug the communications cable into the left port on the bottom of the VRAE and plug the other end of the cable into the PC like so:

Double click on the **ProRAE– Suite** Icon on the desktop of the laptop. The main screen should look like this:

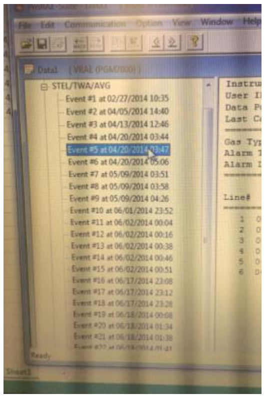


To receive the data from the **VRAE**, click the **Communications** button then click **Receive Data.** The following notification will appear on your screen:

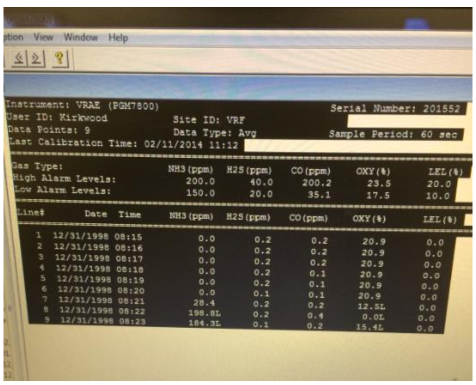


Click **OK**. The data will proceed to download on the laptop.

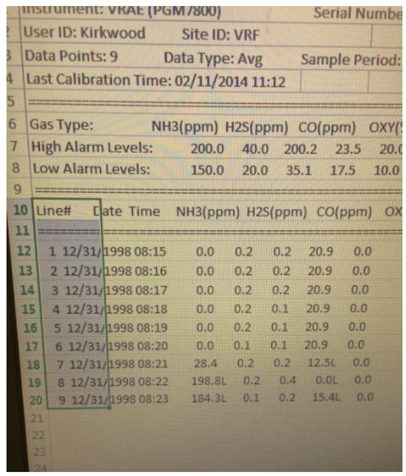
Find the date that includes the data you wish to look at on the left:



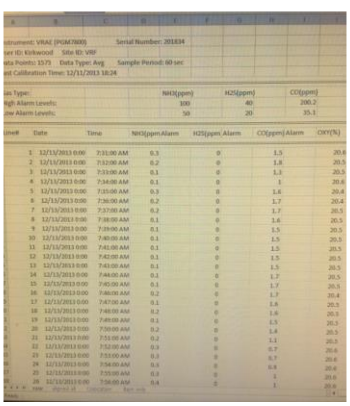
Highlight all of the data then copy and paste it into an **Excel** file:



→



Highlight the first column then go **Data→Text to Columns→Fixed With→Next Finish**. The end result should have all of the columns split. Save data on the organized **Excel** file data on the laptop and on the share drive.



APPENDIX B: RAW DATA

Eight-hour all position data set – 2013-14, Part 1:

CODE	Heater	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	TEMP C	SOW	SWINE	lnCO2	LnROUNDCO2	lnCO	LnROUNDCO
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	1	A	1.2	2326	34.2	1.2	11	78	7.75	7.80	0.1570	0.20
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	1	B	1.1	2112	34.2	1.2	11	78	7.66	7.70	0.0862	0.10
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	1	C	2.1	2210	34.2	1.2	11	78	7.7	7.70	0.7178	0.70
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	1	D	2.5		34.2	1.2	11	78			0.9243	0.90
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	1	E	1.2	2304	34.2	1.2	11	78	7.74	7.70	0.1740	0.20
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	1	F		2555	34.2	1.2	11	78	7.85	7.80		
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	1	A	1.2	2127	27.7	-2.4	11	74	7.66	7.70	0.1484	0.10
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	1	B	1.1	1985	27.7	-2.4	11	74	7.59	7.60	0.0953	0.10
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	1	C	2.5	2123	27.7	-2.4	11	74	7.66	7.70	0.9042	0.90
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	1	D	6.3	2220	27.7	-2.4	11	74	7.71	7.70	1.8421	1.80
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	1	E	1.4	2234	27.7	-2.4	11	74	7.71	7.70	0.3148	0.30
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	1	F		2585	27.7	-2.4	11	74	7.86	7.90		
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	1	A	2.1	2475	6.5	-14.2	0	0	7.81	7.80	0.7419	0.70
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	1	B	2.2	2204	6.5	-14.2	0	0	7.7	7.70	0.7975	0.80
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	1	C	3.8	2293	6.5	-14.2	0	0	7.74	7.70	1.3297	1.30
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	1	D	8.8	2393	6.5	-14.2	0	0	7.78	7.80	2.1725	2.20
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	1	E	1.8	2268	6.5	-14.2	0	0	7.73	7.70	0.5822	0.60
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	1	F	2.3	2375	6.5	-14.2	0	0	7.77	7.80	0.8286	0.80
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	1	A	1.4	2094	32.2	0.1	16	0	7.65	7.60	0.3436	0.30
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	1	B	1.5	1930	32.2	0.1	16	0	7.57	7.60	0.4121	0.40
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	1	C	4.1	1970	32.2	0.1	16	0	7.59	7.60	1.4110	1.40
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	1	D	9.0	2090	32.2	0.1	16	0	7.64	7.60	2.1928	2.20
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	1	E	1.4	2004	32.2	0.1	16	0	7.6	7.60	0.3001	0.30
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	1	F	1.7	2266	32.2	0.1	16	0	7.73	7.70	0.5068	0.50
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	1	A	1.9	2724	11.8	-11.2	15	10	7.91	7.90	0.6152	0.60
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	1	B	1.9	2605	11.8	-11.2	15	10	7.87	7.90	0.6152	0.60
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	1	C	5.4	2605	11.8	-11.2	15	10	7.87	7.90	1.6882	1.70
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	1	D		2733	11.8	-11.2	15	10	7.91	7.90		
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	1	E	1.4	2601	11.8	-11.2	15	10	7.86	7.90	0.3646	0.40
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	1	F	1.8	2716	11.8	-11.2	15	10	7.91	7.90	0.5988	0.60
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	1	A	1.0	1914	33.3	0.7	16	43.5	7.56	7.60	-0.0284	0.00
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	1	B	0.9	1892	33.3	0.7	16	43.5	7.55	7.50	-0.0823	-0.10
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	1	C	1.7	1881	33.3	0.7	16	43.5	7.54	7.50	0.5306	0.50
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	1	D	0.9	2073	33.3	0.7	16	43.5	7.64	7.60	-0.1462	-0.10
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	1	E	0.7	2013	33.3	0.7	16	43.5	7.61	7.60	-0.2930	-0.30
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	1	F		2114	33.3	0.7	16	43.5	7.66	7.70		
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	1	A	2.2	2860	4.9	-15.1	13	95	7.96	8.00	0.8065	0.80
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	1	B	2.1	2711	4.9	-15.1	13	95	7.91	7.90	0.7324	0.70
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	1	C	2.2	2752	4.9	-15.1	13	95	7.92	7.90	0.7930	0.80
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	1	D	1.6	2877	4.9	-15.1	13	95	7.96	8.00	0.4947	0.50
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	1	E	1.7	2704	4.9	-15.1	13	95	7.9	7.90	0.5128	0.50
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	1	F		3056	4.9	-15.1	13	95	8.02	8.00		
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	1	A	1.9	2798	12.7	-10.7	17	119	7.94	7.90	0.6627	0.70
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	1	B	1.6	2568	12.7	-10.7	17	119	7.85	7.90	0.4947	0.50
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	1	C	1.8	2685	12.7	-10.7	17	119	7.9	7.90	0.5988	0.60
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	1	D	1.6	2701	12.7	-10.7	17	119	7.9	7.90	0.4700	0.50
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	1	E	2.3	2747	12.7	-10.7	17	119	7.92	7.90	0.8459	0.80
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	1	F		3069	12.7	-10.7	17	119	8.03	8.00		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	1	A	2.3	3077	-4.7	-20.4	19	84	8.03	8.00	0.8154	0.80
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	1	B	2.2	2818	-4.7	-20.4	19	84	7.94	7.90	0.7839	0.80
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	1	C		3023	-4.7	-20.4	19	84	8.01	8.00		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	1	D		2964	-4.7	-20.4	19	84	7.99	8.00		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	1	E	1.8	2886	-4.7	-20.4	19	84	7.97	8.00	0.5988	0.60
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	1	F		3182	-4.7	-20.4	19	84	8.07	8.10		
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	1	A	1.1	2497	25.0	-3.9	19	117	7.82	7.80	0.1310	0.10
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	1	B	1.2	2376	25.0	-3.9	19	117	7.77	7.80	0.1989	0.20
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	1	C	1.2	2407	25.0	-3.9	19	117	7.79	7.80	0.1570	0.20
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	1	D	1.2	2489	25.0	-3.9	19	117	7.82	7.80	0.1398	0.10
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	1	E	1.1	2573	25.0	-3.9	19	117	7.85	7.90	0.0770	0.10
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	1	F	0.0	2738	25.0	-3.9	19	117	7.91	7.90		
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	1	A	1.6	2722	14.3	-9.8	17	95	7.91	7.90	0.4447	0.40
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	1	B	1.5	2516	14.3	-9.8	17	95	7.83	7.80	0.4187	0.40
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	1	C	1.8	2567	14.3	-9.8	17	95	7.85	7.90	0.5878	0.60
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	1	D	1.4	2576	14.3	-9.8	17	95	7.85	7.90	0.3221	0.30
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	1	E	1.3	2603	14.3	-9.8	17	95	7.86	7.90	0.2469	0.20
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	1	F	0.0	2752	14.3	-9.8	17	95	7.92	7.90		
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	2	A	1.4	2277	31.7	-0.2	11	78	7.73	7.70	0.3221	0.30
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	2	B	1.2	2052	31.7	-0.2	11	78	7.63	7.60	0.1823	0.20
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	2	C	2.5	2223	31.7	-0.2	11	78	7.71	7.70	0.9243	0.90
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	2	D	2.9		31.7	-0.2	11	78			1.0682	1.10
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	2	E	1.5	2216	31.7	-0.2	11	78	7.7	7.70	0.3784	0.40
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	2	F		2444	31.7	-0.2	11	78	7.8	7.80		

Eight-hour all position data set – 2013-14, Part 2:

CODE	Heater	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	TEMP C	SOW	SWINE	lnCO2	LnROUNDCO2	lnCO	LnROUNDCO
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	2	A	1.5	2166	24.5	-4.2	11	74	7.68	7.70	0.4055	0.40
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	2	B	1.4	2014	24.5	-4.2	11	74	7.61	7.60	0.3075	0.30
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	2	C	3.1	2121	24.5	-4.2	11	74	7.66	7.70	1.1410	1.10
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	2	D	7.4	2206	24.5	-4.2	11	74	7.7	7.70	1.9988	2.00
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	2	E	1.7	2190	24.5	-4.2	11	74	7.69	7.70	0.5008	0.50
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	2	F		2535	24.5	-4.2	11	74	7.84	7.80		
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	2	A	2.0	2402	9.8	-12.3	0	0	7.78	7.80	0.7129	0.70
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	2	B	2.0	2123	9.8	-12.3	0	0	7.66	7.70	0.7129	0.70
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	2	C	3.4	2219	9.8	-12.3	0	0	7.7	7.70	1.2326	1.20
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	2	D	8.2	2310	9.8	-12.3	0	0	7.75	7.70	2.1005	2.10
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	2	E	1.6	2181	9.8	-12.3	0	0	7.69	7.70	0.4947	0.50
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	2	F	2.0	2253	9.8	-12.3	0	0	7.72	7.70	0.6981	0.70
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	2	A	1.2	2004	33.2	0.7	16	0	7.6	7.60	0.1740	0.20
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	2	B	1.3	1841	33.2	0.7	16	0	7.52	7.50	0.2390	0.20
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	2	C	3.4	1855	33.2	0.7	16	0	7.53	7.50	1.2267	1.20
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	2	D	7.9	1998	33.2	0.7	16	0	7.6	7.60	2.0605	2.10
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	2	E	1.2	1958	33.2	0.7	16	0	7.58	7.60	0.1740	0.20
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	2	F	1.3	2165	33.2	0.7	16	0	7.68	7.70	0.2624	0.30
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	2	A	2.0	2653	9.4	-12.6	15	10	7.88	7.90	0.6981	0.70
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	2	B	1.9	2534	9.4	-12.6	15	10	7.84	7.80	0.6419	0.60
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	2	C	5.4	2524	9.4	-12.6	15	10	7.83	7.80	1.6919	1.70
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	2	D		2710	9.4	-12.6	15	10	7.9	7.90		
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	2	E	1.6	2608	9.4	-12.6	15	10	7.87	7.90	0.4762	0.50
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	2	F	1.8	2723	9.4	-12.6	15	10	7.91	7.90	0.5933	0.60
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	2	A	1.5	2195	21.3	-5.9	16	43.5	7.69	7.70	0.3784	0.40
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	2	B	1.3	2104	21.3	-5.9	16	43.5	7.65	7.70	0.2390	0.20
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	2	C	2.3	2101	21.3	-5.9	16	43.5	7.65	7.70	0.8416	0.80
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	2	D	1.1	2288	21.3	-5.9	16	43.5	7.74	7.70	0.0583	0.10
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	2	E	1.0	2193	21.3	-5.9	16	43.5	7.69	7.70	-0.0460	0.00
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	2	F		2331	21.3	-5.9	16	43.5	7.75	7.80		
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	2	A	2.4	2941	1.3	-17.1	13	95	7.99	8.00	0.8879	0.90
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	2	B	2.3	2786	1.3	-17.1	13	95	7.93	7.90	0.8109	0.80
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	2	C	2.5	2806	1.3	-17.1	13	95	7.94	7.90	0.9083	0.90
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	2	D	1.7	2945	1.3	-17.1	13	95	7.99	8.00	0.5068	0.50
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	2	E	1.9	2828	1.3	-17.1	13	95	7.95	7.90	0.6575	0.70
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	2	F		3174	1.3	-17.1	13	95	8.06	8.10		
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	2	A	1.9	2840	13.3	-10.4	17	119	7.95	8.00	0.6313	0.60
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	2	B	1.6	2644	13.3	-10.4	17	119	7.88	7.90	0.4762	0.50
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	2	C	1.7	2664	13.3	-10.4	17	119	7.89	7.90	0.5423	0.50
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	2	D	1.5	2722	13.3	-10.4	17	119	7.91	7.90	0.3784	0.40
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	2	E	2.3	2753	13.3	-10.4	17	119	7.92	7.90	0.8109	0.80
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	2	F		3062	13.3	-10.4	17	119	8.03	8.00		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	2	A	2.3	3142	-8.0	-22.2	19	84	8.05	8.10	0.8329	0.80
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	2	B	2.2	2890	-8.0	-22.2	19	84	7.97	8.00	0.7975	0.80
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	2	C		3055	-8.0	-22.2	19	84	8.02	8.00		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	2	D		2970	-8.0	-22.2	19	84	8	8.00		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	2	E	1.8	2958	-8.0	-22.2	19	84	7.99	8.00	0.6098	0.60
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	2	F		3211	-8.0	-22.2	19	84	8.07	8.10		
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	2	A	1.1	2431	30.5	-0.8	19	117	7.8	7.80	0.0677	0.10
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	2	B	1.1	2269	30.5	-0.8	19	117	7.73	7.70	0.1310	0.10
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	2	C	1.0	2285	30.5	-0.8	19	117	7.73	7.70	0.0198	0.00
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	2	D	0.9	2426	30.5	-0.8	19	117	7.79	7.80	-0.1087	-0.10
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	2	E	0.8	2527	30.5	-0.8	19	117	7.83	7.80	-0.1661	-0.20
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	2	F	0.0	2740	30.5	-0.8	19	117	7.92	7.90		
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	2	A	1.6	2751	13.9	-10.1	17	95	7.92	7.90	0.4824	0.50
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	2	B	1.6	2525	13.9	-10.1	17	95	7.83	7.80	0.4383	0.40
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	2	C	1.8	2559	13.9	-10.1	17	95	7.85	7.80	0.5933	0.60
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	2	D	1.4	2560	13.9	-10.1	17	95	7.85	7.80	0.3221	0.30
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	2	E	1.3	2606	13.9	-10.1	17	95	7.87	7.90	0.2624	0.30
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	2	F		2709	13.9	-10.1	17	95	7.9	7.90		
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	3	A	1.7	2222	28.6	-1.9	11	78	7.71	7.70	0.5481	0.50
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	3	B	1.5	2002	28.6	-1.9	11	78	7.6	7.60	0.3853	0.40
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	3	C	3.2		28.6	-1.9	11	78			1.1569	1.20
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	3	D	3.4		28.6	-1.9	11	78			1.2238	1.20
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	3	E	1.8	2122	28.6	-1.9	11	78	7.66	7.70	0.5596	0.60
APC 1 Dec 21-22 2013	1	APC1	1	12/21/13	3	F		2377	28.6	-1.9	11	78	7.77	7.80		
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	3	A	1.5	2314	16.9	-8.4	11	74	7.75	7.70	0.4253	0.40
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	3	B	1.5	2154	16.9	-8.4	11	74	7.68	7.70	0.3716	0.40
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	3	C	3.1	2254	16.9	-8.4	11	74	7.72	7.70	1.1151	1.10
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	3	D	7.9	2336	16.9	-8.4	11	74	7.76	7.80	2.0643	2.10
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	3	E	1.7	2297	16.9	-8.4	11	74	7.74	7.70	0.5306	0.50
APC 2 Dec 26-27 2013	1	APC2	1	12/26/13	3	F		2651	16.9	-8.4	11	74	7.88	7.90		

Eight-hour all position data set – 2013-14, Part 3:

CODE	Heater	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	TEMP C	SOW	SWINE	lnCO2	LnROUNDCO2	lnCO	LnROUNDCO
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	3	A	2.1	2414	8.2	-13.2	0	0	7.79	7.80	0.7178	0.70
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	3	B	2.1	2121	8.2	-13.2	0	0	7.66	7.70	0.7227	0.70
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	3	C	3.4	2200	8.2	-13.2	0	0	7.7	7.70	1.2090	1.20
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	3	D	8.0	2332	8.2	-13.2	0	0	7.75	7.80	2.0807	2.10
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	3	E	1.7	2183	8.2	-13.2	0	0	7.69	7.70	0.5008	0.50
APC 3 Dec 31-Jan 1 2014	1	APC3	1	12/31/13	3	F	1.9	2231	8.2	-13.2	0	0	7.71	7.70	0.6366	0.60
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	3	A	1.1	1986	31.3	-0.4	16	0	7.59	7.60	0.0953	0.10
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	3	B	1.2	1826	31.3	-0.4	16	0	7.51	7.50	0.1989	0.20
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	3	C	3.0	1847	31.3	-0.4	16	0	7.52	7.50	1.1119	1.10
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	3	D	7.4	1988	31.3	-0.4	16	0	7.59	7.60	1.9961	2.00
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	3	E	1.1	1902	31.3	-0.4	16	0	7.55	7.60	0.0862	0.10
APC 4 Jan 10-11 2014	1	APC4	1	1/10/14	3	F	1.2	2126	31.3	-0.4	16	0	7.66	7.70	0.2151	0.20
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	3	A	1.9	2575	15.4	-9.2	15	10	7.85	7.90	0.6206	0.60
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	3	B	1.8	2436	15.4	-9.2	15	10	7.8	7.80	0.5653	0.60
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	3	C	4.9	2446	15.4	-9.2	15	10	7.8	7.80	1.5974	1.60
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	3	D		2641	15.4	-9.2	15	10	7.88	7.90		
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	3	E	1.5	2554	15.4	-9.2	15	10	7.85	7.80	0.4253	0.40
APC 5 Jan 17-18 2014	1	APC5	1	1/17/14	3	F	1.7	2655	15.4	-9.2	15	10	7.88	7.90	0.5481	0.50
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	3	A	2.2	2780	1.8	-16.8	16	43.5	7.93	7.90	0.7839	0.80
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	3	B	1.9	2637	1.8	-16.8	16	43.5	7.88	7.90	0.6419	0.60
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	3	C		2300	1.8	-16.8	16	43.5	7.74	7.70		
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	3	D	1.6	2811	1.8	-16.8	16	43.5	7.94	7.90	0.4447	0.40
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	3	E		2385	1.8	-16.8	16	43.5	7.78	7.80		
APC 6 Jan 20-21 2014	1	APC6	1	1/20/14	3	F		2871	1.8	-16.8	16	43.5	7.96	8.00		
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	3	A	2.5	2981	-1.5	-18.6	13	95	8	8.00	0.9243	0.90
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	3	B	2.3	2834	-1.5	-18.6	13	95	7.95	7.90	0.8329	0.80
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	3	C	2.5	2840	-1.5	-18.6	13	95	7.95	8.00	0.9123	0.90
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	3	D	1.7	2997	-1.5	-18.6	13	95	8.01	8.00	0.5481	0.50
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	3	E	2.1	2893	-1.5	-18.6	13	95	7.97	8.00	0.7227	0.70
APC 7 Jan 28-29 2014	1	APC7	1	1/28/14	3	F		3226	-1.5	-18.6	13	95	8.08	8.10		
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	3	A	2.1	2772	12.1	-11.1	17	119	7.93	7.90	0.7275	0.70
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	3	B	1.8	2559	12.1	-11.1	17	119	7.85	7.80	0.5766	0.60
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	3	C	1.9	2622	12.1	-11.1	17	119	7.87	7.90	0.6419	0.60
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	3	D	1.6	2662	12.1	-11.1	17	119	7.89	7.90	0.4447	0.40
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	3	E	2.4	2689	12.1	-11.1	17	119	7.9	7.90	0.8629	0.90
APC 8 Feb 03-04 2014	1	APC8	1	2/3/14	3	F		2989	12.1	-11.1	17	119	8	8.00		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	3	A	2.8	3360	-16.5	-26.9	19	84	8.12	8.10	1.0438	1.00
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	3	B	2.7	3121	-16.5	-26.9	19	84	8.05	8.00	0.9858	1.00
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	3	C		3253	-16.5	-26.9	19	84	8.09	8.10		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	3	D		3224	-16.5	-26.9	19	84	8.08	8.10		
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	3	E	2.3	3151	-16.5	-26.9	19	84	8.06	8.10	0.8198	0.80
APC 9 Feb 10-11 2014	1	APC9	1	2/10/14	3	F		3485	-16.5	-26.9	19	84	8.16	8.20		
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	3	A	1.3	2561	23.3	-4.8	19	117	7.85	7.80	0.2311	0.20
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	3	B	1.3	2335	23.3	-4.8	19	117	7.76	7.80	0.2624	0.30
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	3	C	1.3	2454	23.3	-4.8	19	117	7.81	7.80	0.2546	0.30
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	3	D	1.2	2519	23.3	-4.8	19	117	7.83	7.80	0.1740	0.20
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	3	E	1.1	2629	23.3	-4.8	19	117	7.87	7.90	0.0953	0.10
APC 10 Feb 17-18 2014	1	APC10	1	2/17/14	3	F		2825	23.3	-4.8	19	117	7.95	7.90		
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	3	A	1.8	2807	8.3	-13.2	17	95	7.94	7.90	0.5710	0.60
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	3	B	1.8	2599	8.3	-13.2	17	95	7.86	7.90	0.5653	0.60
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	3	C	2.2	2666	8.3	-13.2	17	95	7.89	7.90	0.7701	0.80
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	3	D	1.7	2591	8.3	-13.2	17	95	7.86	7.90	0.5068	0.50
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	3	E	1.5	2625	8.3	-13.2	17	95	7.87	7.90	0.3784	0.40
APC 11 Feb 24-25 2014	1	APC11	1	2/24/14	3	F			8.3	-13.2	17	95				

Eight-hour all position data set – 2014-15, Part 1:

CODE	Heater	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	TEMP C	SOW	SWINE	lnCO2	LnROUNDCO2	lnCO	LnROUNDCO
B1 Dec 3-4 2014	0	B1	0	12/3/2014	1	A	0.3	1253	29.5	-1.4	11	75	7.1331	7.1	-1.2887	-1.3
B1 Dec 3-4 2014	0	B1	0	12/3/2014	2	A	0.5	1417	20.5	-6.4	11	75	7.2561	7.3	-0.7275	-0.7
B1 Dec 3-4 2014	0	B1	0	12/3/2014	3	A	0.4	1341	22.3	-5.4	11	75	7.2013	7.2	-0.8430	-0.8
B1 Dec 3-4 2014	0	B1	0	12/3/2014	1	B		1244	29.5	-1.4	11	75	7.1259	7.1		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	2	B		1393	20.5	-6.4	11	75	7.2390	7.2		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	3	B		1299	22.3	-5.4	11	75	7.1693	7.2		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	1	C	0.0	1174	29.5	-1.4	11	75	7.0680	7.1	-3.2669	-3.3
B1 Dec 3-4 2014	0	B1	0	12/3/2014	2	C	0.3	1312	20.5	-6.4	11	75	7.1795	7.2	-1.3471	-1.3
B1 Dec 3-4 2014	0	B1	0	12/3/2014	3	C	0.2	1240	22.3	-5.4	11	75	7.1228	7.1	-1.7311	-1.7
B1 Dec 3-4 2014	0	B1	0	12/3/2014	1	D		1170	29.5	-1.4	11	75	7.0646	7.1		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	2	D		1294	20.5	-6.4	11	75	7.1655	7.2		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	3	D		1229	22.3	-5.4	11	75	7.1139	7.1		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	1	E	0.1	1249	29.5	-1.4	11	75	7.1301	7.1	-2.8706	-2.9
B1 Dec 3-4 2014	0	B1	0	12/3/2014	2	E	0.4	1456	20.5	-6.4	11	75	7.2838	7.3	-0.9513	-1
B1 Dec 3-4 2014	0	B1	0	12/3/2014	3	E	0.3	1353	22.3	-5.4	11	75	7.2099	7.2	-1.1692	-1.2
B1 Dec 3-4 2014	0	B1	0	12/3/2014	1	F		1323	29.5	-1.4	11	75	7.1878	7.2		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	2	F		1470	20.5	-6.4	11	75	7.2927	7.3		
B1 Dec 3-4 2014	0	B1	0	12/3/2014	3	F		1370	22.3	-5.4	11	75	7.2229	7.2		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	1	A	0.7	1446	36.0	2.2	11.5	83	7.2768	7.3	-0.3308	-0.3
B2 Dec 5-6 2014	0	B2	0	12/5/2014	2	A	0.6	1542	34.5	1.4	11.5	83	7.3410	7.3	-0.5907	-0.6
B2 Dec 5-6 2014	0	B2	0	12/5/2014	3	A	0.6	1566	31.9	-0.1	11.5	83	7.3564	7.4	-0.5234	-0.5
B2 Dec 5-6 2014	0	B2	0	12/5/2014	1	B		1450	36.0	2.2	11.5	83	7.2795	7.3		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	2	B		1528	34.5	1.4	11.5	83	7.3318	7.3		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	3	B		1574	31.9	-0.1	11.5	83	7.3616	7.4		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	1	C	0.4	1355	36.0	2.2	11.5	83	7.2114	7.2	-0.8660	-0.9
B2 Dec 5-6 2014	0	B2	0	12/5/2014	2	C	0.4	1458	34.5	1.4	11.5	83	7.2847	7.3	-0.8064	-0.8
B2 Dec 5-6 2014	0	B2	0	12/5/2014	3	C	0.5	1507	31.9	-0.1	11.5	83	7.3181	7.3	-0.7528	-0.8
B2 Dec 5-6 2014	0	B2	0	12/5/2014	1	D		1327	36.0	2.2	11.5	83	7.1906	7.2		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	2	D		1424	34.5	1.4	11.5	83	7.2613	7.3		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	3	D		1496	31.9	-0.1	11.5	83	7.3104	7.3		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	1	E	0.6	1524	36.0	2.2	11.5	83	7.3292	7.3	-0.5408	-0.5
B2 Dec 5-6 2014	0	B2	0	12/5/2014	2	E	0.6	1660	34.5	1.4	11.5	83	7.4146	7.4	-0.4489	-0.4
B2 Dec 5-6 2014	0	B2	0	12/5/2014	3	E	0.6	1668	31.9	-0.1	11.5	83	7.4192	7.4	-0.4998	-0.5
B2 Dec 5-6 2014	0	B2	0	12/5/2014	1	F		1559	36.0	2.2	11.5	83	7.3517	7.4		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	2	F		1668	34.5	1.4	11.5	83	7.4195	7.4		
B2 Dec 5-6 2014	0	B2	0	12/5/2014	3	F		1682	31.9	-0.1	11.5	83	7.4279	7.4		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	1	A	0.6	1442	36.9	2.7	11	77.5	7.2740	7.3	-0.5411	-0.5
B3 Dec 8-9 2014	0	B3	0	12/8/2014	2	A	0.6	1410	34.5	-1.3	11	77.5	7.2516	7.3	-0.5419	-0.5
B3 Dec 8-9 2014	0	B3	0	12/8/2014	3	A	0.6	1423	25.3	-3.7	11	77.5	7.2605	7.3	-0.5922	-0.6
B3 Dec 8-9 2014	0	B3	0	12/8/2014	1	B		1379	36.9	2.7	11	77.5	7.2288	7.2		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	2	B		1294	34.5	-1.3	11	77.5	7.1651	7.2		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	3	B		1330	25.3	-3.7	11	77.5	7.1926	7.2		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	1	C	0.4	1310	36.9	2.7	11	77.5	7.1779	7.2	-0.9049	-0.9
B3 Dec 8-9 2014	0	B3	0	12/8/2014	2	C	0.3	1220	34.5	-1.3	11	77.5	7.1066	7.1	-1.3649	-1.4
B3 Dec 8-9 2014	0	B3	0	12/8/2014	3	C	0.2		25.3	-3.7	11	77.5			-1.7756	-1.8
B3 Dec 8-9 2014	0	B3	0	12/8/2014	1	D		1315	36.9	2.7	11	77.5	7.1819	7.2		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	2	D		1271	34.5	-1.3	11	77.5	7.1474	7.1		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	3	D		1312	25.3	-3.7	11	77.5	7.1795	7.2		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	1	E	0.7	1548	36.9	2.7	11	77.5	7.3447	7.3	-0.4269	-0.4
B3 Dec 8-9 2014	0	B3	0	12/8/2014	2	E	0.5	1387	34.5	-1.3	11	77.5	7.2350	7.2	-0.6199	-0.6
B3 Dec 8-9 2014	0	B3	0	12/8/2014	3	E		1450	25.3	-3.7	11	77.5	7.2793	7.3		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	1	F		1504	36.9	2.7	11	77.5	7.3159	7.3		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	2	F		1381	34.5	-1.3	11	77.5	7.2304	7.2		
B3 Dec 8-9 2014	0	B3	0	12/8/2014	3	F		1462	25.3	-3.7	11	77.5	7.2873	7.3		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	1	A	1.0	1705	14.0	-10.0	17	37.5	7.4414	7.4	-0.0232	0
B4 Jan 13-14 2015	0	B4	0	1/13/2015	2	A	1.2	1834	9.0	-12.8	17	37.5	7.5143	7.5	0.1441	0.1
B4 Jan 13-14 2015	0	B4	0	1/13/2015	3	A	1.0	1760	11.9	-11.2	17	37.5	7.4731	7.5	0.0033	0
B4 Jan 13-14 2015	0	B4	0	1/13/2015	1	B		1584	14.0	-10.0	17	37.5	7.3678	7.4		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	2	B		1740	9.0	-12.8	17	37.5	7.4618	7.5		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	3	B		1634	11.9	-11.2	17	37.5	7.3990	7.4		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	1	C	0.7	1641	14.0	-10.0	17	37.5	7.4029	7.4	-0.3173	-0.3
B4 Jan 13-14 2015	0	B4	0	1/13/2015	2	C	1.0	1757	9.0	-12.8	17	37.5	7.4716	7.5	-0.0343	0
B4 Jan 13-14 2015	0	B4	0	1/13/2015	3	C	0.9	1696	11.9	-11.2	17	37.5	7.4359	7.4	-0.1453	-0.1
B4 Jan 13-14 2015	0	B4	0	1/13/2015	1	D		1616	14.0	-10.0	17	37.5	7.3878	7.4		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	2	D		1718	9.0	-12.8	17	37.5	7.4491	7.4		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	3	D		1677	11.9	-11.2	17	37.5	7.4246	7.4		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	1	E	0.8	1811	14.0	-10.0	17	37.5	7.5019	7.5	-0.2213	-0.2
B4 Jan 13-14 2015	0	B4	0	1/13/2015	2	E	1.3	1990	9.0	-12.8	17	37.5	7.5960	7.6	0.2392	0.2
B4 Jan 13-14 2015	0	B4	0	1/13/2015	3	E	1.2	1924	11.9	-11.2	17	37.5	7.5624	7.6	0.2106	0.2
B4 Jan 13-14 2015	0	B4	0	1/13/2015	1	F		1821	14.0	-10.0	17	37.5	7.5071	7.5		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	2	F		1918	9.0	-12.8	17	37.5	7.5588	7.6		
B4 Jan 13-14 2015	0	B4	0	1/13/2015	3	F		1841	11.9	-11.2	17	37.5	7.5180	7.5		

Eight-hour all position data set – 2014-15, Part 2:

CODE	Heater	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	TEMP C	SOW	SWINE	lnCO2	LnROUNDCO2	lnCO	LnROUNDCO
B5 Jan 15-16 2015	0	B5	0	1/15/2015	1	A	1.3	1647	30.9	-0.6	17	51.5	7.4064	7.4	0.2920	0.3
B5 Jan 15-16 2015	0	B5	0	1/15/2015	2	A	1.3	1709	27.9	-2.3	17	51.5	7.4435	7.4	0.2469	0.2
B5 Jan 15-16 2015	0	B5	0	1/15/2015	3	A	1.4	1695	19.1	-7.2	17	51.5	7.4357	7.4	0.3086	0.3
B5 Jan 15-16 2015	0	B5	0	1/15/2015	1	B		1502	30.9	-0.6	17	51.5	7.3146	7.3		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	2	B		1592	27.9	-2.3	17	51.5	7.3725	7.4		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	3	B		1558	19.1	-7.2	17	51.5	7.3508	7.4		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	1	C	1.2	1589	30.9	-0.6	17	51.5	7.3710	7.4	0.1748	0.2
B5 Jan 15-16 2015	0	B5	0	1/15/2015	2	C	1.1	1612	27.9	-2.3	17	51.5	7.3853	7.4	0.1183	0.1
B5 Jan 15-16 2015	0	B5	0	1/15/2015	3	C	1.2	1644	19.1	-7.2	17	51.5	7.4051	7.4	0.1987	0.2
B5 Jan 15-16 2015	0	B5	0	1/15/2015	1	D		1618	30.9	-0.6	17	51.5	7.3890	7.4		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	2	D		1666	27.9	-2.3	17	51.5	7.4182	7.4		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	3	D		1723	19.1	-7.2	17	51.5	7.4520	7.5		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	1	E	1.4	1846	30.9	-0.6	17	51.5	7.5207	7.5	0.3324	0.3
B5 Jan 15-16 2015	0	B5	0	1/15/2015	2	E	1.4		27.9	-2.3	17	51.5			0.3240	0.3
B5 Jan 15-16 2015	0	B5	0	1/15/2015	3	E	1.5		19.1	-7.2	17	51.5			0.4046	0.4
B5 Jan 15-16 2015	0	B5	0	1/15/2015	1	F		1790	30.9	-0.6	17	51.5	7.4899	7.5		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	2	F		1816	27.9	-2.3	17	51.5	7.5047	7.5		
B5 Jan 15-16 2015	0	B5	0	1/15/2015	3	F		1846	19.1	-7.2	17	51.5	7.5207	7.5		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	1	A	1.1	1596	40.2	4.5	15	68	7.3750	7.4	0.1027	0.1
B6 Jan 17-18 2015	0	B6	0	1/17/2015	2	A	1.0	1488	37.1	2.8	15	68	7.3054	7.3	0.0390	0
B6 Jan 17-18 2015	0	B6	0	1/17/2015	3	A	0.9	1423	31.3	-0.4	15	68	7.2605	7.3	-0.0546	-0.1
B6 Jan 17-18 2015	0	B6	0	1/17/2015	1	B		1474	40.2	4.5	15	68	7.2960	7.3		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	2	B		1407	37.1	2.8	15	68	7.2491	7.2		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	3	B		1354	31.3	-0.4	15	68	7.2109	7.2		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	1	C	1.3	1509	40.2	4.5	15	68	7.3192	7.3	0.2477	0.2
B6 Jan 17-18 2015	0	B6	0	1/17/2015	2	C	1.2	1451	37.1	2.8	15	68	7.2797	7.3	0.1923	0.2
B6 Jan 17-18 2015	0	B6	0	1/17/2015	3	C	1.2	1402	31.3	-0.4	15	68	7.2459	7.2	0.1486	0.1
B6 Jan 17-18 2015	0	B6	0	1/17/2015	1	D		1449	40.2	4.5	15	68	7.2785	7.3		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	2	D		1392	37.1	2.8	15	68	7.2382	7.2		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	3	D		1378	31.3	-0.4	15	68	7.2285	7.2		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	1	E	1.2	1777	40.2	4.5	15	68	7.4824	7.5	0.1630	0.2
B6 Jan 17-18 2015	0	B6	0	1/17/2015	2	E	1.1	1714	37.1	2.8	15	68	7.4468	7.4	0.1358	0.1
B6 Jan 17-18 2015	0	B6	0	1/17/2015	3	E	1.1	1633	31.3	-0.4	15	68	7.3983	7.4	0.1183	0.1
B6 Jan 17-18 2015	0	B6	0	1/17/2015	1	F		1692	40.2	4.5	15	68	7.4335	7.4		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	2	F		1681	37.1	2.8	15	68	7.4269	7.4		
B6 Jan 17-18 2015	0	B6	0	1/17/2015	3	F		1591	31.3	-0.4	15	68	7.3719	7.4		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	1	A	1.2	1837	1.7	-16.8	17.5	50.5	7.5161	7.5	0.1399	0.1
B7 Feb 15-16 2015	0	B7	0	2/18/2015	2	A	1.4	2003	-0.7	-18.1	17.5	50.5	7.6023	7.6	0.3136	0.3
B7 Feb 15-16 2015	0	B7	0	2/18/2015	3	A	2.2	2536	-8.2	-22.3	17.5	50.5	7.8384	7.8	0.7989	0.8
B7 Feb 15-16 2015	0	B7	0	2/18/2015	1	B		1738	1.7	-16.8	17.5	50.5	7.4602	7.5		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	2	B		1914	-0.7	-18.1	17.5	50.5	7.5569	7.6		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	3	B		2457	-8.2	-22.3	17.5	50.5	7.8069	7.8		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	1	C		1639	1.7	-16.8	17.5	50.5	7.4019	7.4		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	2	C		1864	-0.7	-18.1	17.5	50.5	7.5306	7.5		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	3	C		2408	-8.2	-22.3	17.5	50.5	7.7867	7.8		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	1	D		1792	1.7	-16.8	17.5	50.5	7.4911	7.5		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	2	D		2004	-0.7	-18.1	17.5	50.5	7.6031	7.6		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	3	D		2409	-8.2	-22.3	17.5	50.5	7.7871	7.8		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	1	E	0.9	1624	1.7	-16.8	17.5	50.5	7.3924	7.4	-0.1547	-0.2
B7 Feb 15-16 2015	0	B7	0	2/18/2015	2	E	1.2	1860	-0.7	-18.1	17.5	50.5	7.5284	7.5	0.2096	0.2
B7 Feb 15-16 2015	0	B7	0	2/18/2015	3	E	2.0	2428	-8.2	-22.3	17.5	50.5	7.7950	7.8	0.6696	0.7
B7 Feb 15-16 2015	0	B7	0	2/18/2015	1	F		1690	1.7	-16.8	17.5	50.5	7.4326	7.4		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	2	F		1834	-0.7	-18.1	17.5	50.5	7.5142	7.5		
B7 Feb 15-16 2015	0	B7	0	2/18/2015	3	F		2430	-8.2	-22.3	17.5	50.5	7.7954	7.8		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	1	A	0.8	1446	7.2	-13.8	15	49	7.2768	7.3	-0.2221	-0.2
B8 Feb 22-23 2015	0	B8	0	2/22/2015	2	A	1.4	1888	0.3	-17.6	15	49	7.5434	7.5	0.3415	0.3
B8 Feb 22-23 2015	0	B8	0	2/22/2015	3	A		2047	-8.2	-22.3	15	49	7.6242	7.6		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	1	B		1361	7.2	-13.8	15	49	7.2162	7.2		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	2	B		1747	0.3	-17.6	15	49	7.4659	7.5		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	3	B		1908	-8.2	-22.3	15	49	7.5539	7.6		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	1	C	0.1	1294	7.2	-13.8	15	49	7.1656	7.2	-2.2679	-2.3
B8 Feb 22-23 2015	0	B8	0	2/22/2015	2	C	0.7	1709	0.3	-17.6	15	49	7.4439	7.4	-0.2934	-0.3
B8 Feb 22-23 2015	0	B8	0	2/22/2015	3	C	0.9	1879	-8.2	-22.3	15	49	7.5385	7.5	-0.0985	-0.1
B8 Feb 22-23 2015	0	B8	0	2/22/2015	1	D		1020	7.2	-13.8	15	49	6.9271	6.9		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	2	D		1682	0.3	-17.6	15	49	7.4278	7.4		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	3	D			-8.2	-22.3	15	49				
B8 Feb 22-23 2015	0	B8	0	2/22/2015	1	E	1.0	1410	7.2	-13.8	15	49	7.2510	7.3	-0.0265	0
B8 Feb 22-23 2015	0	B8	0	2/22/2015	2	E	1.6	1813	0.3	-17.6	15	49	7.5029	7.5	0.4593	0.5
B8 Feb 22-23 2015	0	B8	0	2/22/2015	3	E	1.7	1995	-8.2	-22.3	15	49	7.5986	7.6	0.5480	0.5
B8 Feb 22-23 2015	0	B8	0	2/22/2015	1	F		1436	7.2	-13.8	15	49	7.2693	7.3		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	2	F		1911	0.3	-17.6	15	49	7.5554	7.6		
B8 Feb 22-23 2015	0	B8	0	2/22/2015	3	F		2034	-8.2	-22.3	15	49	7.6177	7.6		

Eight-hour all position data set – 2014-15, Part 3:

CODE	Heater	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	TEMP C	SOW	SWINE	lnCO2	LnROUNDCO2	lnCO	LnROUNDCO
B1 Dec 13-14 2013	1	B1	0	12/13/13	1	A	1.2	2306	21.3	-5.9	11	64	7.74	7.7	0.2070	0.2
B1 Dec 13-14 2013	1	B1	0	12/13/13	1	B	0.0	2134	21.3	-5.9	11	64	7.67	7.70	-6.9078	-6.90
B1 Dec 13-14 2013	1	B1	0	12/13/13	1	C	2.7	2206	21.3	-5.9	11	64	7.7	7.70	0.9933	1.00
B1 Dec 13-14 2013	1	B1	0	12/13/13	1	D	3.3	2227	21.3	-5.9	11	64	7.71	7.70	1.2030	1.20
B1 Dec 13-14 2013	1	B1	0	12/13/13	1	E	1.2	2166	21.3	-5.9	11	64	7.68	7.70	0.2070	0.20
B1 Dec 13-14 2013	1	B1	0	12/13/13	1	F	2.0	2390	21.3	-5.9	11	64	7.78	7.80	0.6831	0.70
B2 Dec 16-17 2013	1	B2	0	12/16/13	1	A		2535	16.4	-8.7	11	64	7.84	7.80		
B2 Dec 16-17 2013	1	B2	0	12/16/13	1	B	1.6	2435	16.4	-8.7	11	64	7.8	7.80	0.4511	0.50
B2 Dec 16-17 2013	1	B2	0	12/16/13	1	C	2.5	2489	16.4	-8.7	11	64	7.82	7.80	0.9282	0.90
B2 Dec 16-17 2013	1	B2	0	12/16/13	1	D	3.7	2482	16.4	-8.7	11	64	7.82	7.80	1.3164	1.30
B2 Dec 16-17 2013	1	B2	0	12/16/13	1	E	1.6	2455	16.4	-8.7	11	64	7.81	7.80	0.4447	0.40
B2 Dec 16-17 2013	1	B2	0	12/16/13	1	F	1.8	2752	16.4	-8.7	11	64	7.92	7.90	0.6098	0.60
B3 Dec 18-19 2013	1	B3	0	12/18/13	1	A	1.0	2018	34.7	1.5	11	69	7.61	7.60	0.0392	0.00
B3 Dec 18-19 2013	1	B3	0	12/18/13	1	B	1.1	1885	34.7	1.5	11	69	7.54	7.50	0.0488	0.00
B3 Dec 18-19 2013	1	B3	0	12/18/13	1	C	1.6	1964	34.7	1.5	11	69	7.58	7.60	0.4511	0.50
B3 Dec 18-19 2013	1	B3	0	12/18/13	1	D	1.9	2061	34.7	1.5	11	69	7.63	7.60	0.6206	0.60
B3 Dec 18-19 2013	1	B3	0	12/18/13	1	E	0.9	2078	34.7	1.5	11	69	7.64	7.60	-0.1625	-0.20
B3 Dec 18-19 2013	1	B3	0	12/18/13	1	F	0.9	2333	34.7	1.5	11	69	7.75	7.80	-0.1312	-0.10
P1 Jan 22-23 2014	1	P1	0	1/22/14	1	A	1.8	2652	12.1	-11.1	16	57	7.88	7.90	0.6098	0.60
P1 Jan 22-23 2014	1	P1	0	1/22/14	1	B	1.9	2607	12.1	-11.1	16	57	7.87	7.90	0.6366	0.60
P1 Jan 22-23 2014	1	P1	0	1/22/14	1	C	1.9	2489	12.1	-11.1	16	57	7.82	7.80	0.6471	0.60
P1 Jan 22-23 2014	1	P1	0	1/22/14	1	D	1.6	2611	12.1	-11.1	16	57	7.87	7.90	0.4947	0.50
P1 Jan 22-23 2014	1	P1	0	1/22/14	1	E	1.8	2562	12.1	-11.1	16	57	7.85	7.80	0.5822	0.60
P1 Jan 22-23 2014	1	P1	0	1/22/14	1	F		2830	12.1	-11.1	16	57	7.95	7.90		
P2 Jan 24-25 2014	1	P2	0	1/24/14	1	A	1.7	2474	22.5	-5.3	13	76	7.81	7.80	0.5423	0.50
P2 Jan 24-25 2014	1	P2	0	1/24/14	1	B	1.7	2326	22.5	-5.3	13	76	7.75	7.80	0.5008	0.50
P2 Jan 24-25 2014	1	P2	0	1/24/14	1	C	1.9	2370	22.5	-5.3	13	76	7.77	7.80	0.6523	0.70
P2 Jan 24-25 2014	1	P2	0	1/24/14	1	D	1.8	2474	22.5	-5.3	13	76	7.81	7.80	0.5766	0.60
P2 Jan 24-25 2014	1	P2	0	1/24/14	1	E	1.5	2407	22.5	-5.3	13	76	7.79	7.80	0.3988	0.40
P2 Jan 24-25 2014	1	P2	0	1/24/14	1	F		2779	22.5	-5.3	13	76	7.93	7.90		
P3 Jan 26-27 2014	1	P3	0	1/26/14	1	A	1.0	2036	30.8	-0.7	13	80	7.62	7.60	-0.0050	0.00
P3 Jan 26-27 2014	1	P3	0	1/26/14	1	B	1.3	1943	30.8	-0.7	13	80	7.57	7.60	0.2231	0.20
P3 Jan 26-27 2014	1	P3	0	1/26/14	1	C	1.3	1925	30.8	-0.7	13	80	7.56	7.60	0.2624	0.30
P3 Jan 26-27 2014	1	P3	0	1/26/14	1	D	0.9	2079	30.8	-0.7	13	80	7.64	7.60	-0.1335	-0.10
P3 Jan 26-27 2014	1	P3	0	1/26/14	1	E	1.1	2075	30.8	-0.7	13	80	7.64	7.60	0.0677	0.10
P3 Jan 26-27 2014	1	P3	0	1/26/14	1	F		2400	30.8	-0.7	13	80	7.78	7.80		
P4 Feb 26-27 2014	1	P4	0	2/26/14	1	A	1.8	3185	7.9	-13.4	17	101	8.07	8.10	0.5596	0.60
P4 Feb 26-27 2014	1	P4	0	2/26/14	1	B	1.7	3026	7.9	-13.4	17	101	8.01	8.00	0.5365	0.50
P4 Feb 26-27 2014	1	P4	0	2/26/14	1	C		3095	7.9	-13.4	17	101	8.04	8.00		
P4 Feb 26-27 2014	1	P4	0	2/26/14	1	D	1.7	2992	7.9	-13.4	17	101	8	8.00	0.5247	0.50
P4 Feb 26-27 2014	1	P4	0	2/26/14	1	E	1.6	3035	7.9	-13.4	17	101	8.02	8.00	0.4762	0.50
P4 Feb 26-27 2014	1	P4	0	2/26/14	1	F	0.0	3443	7.9	-13.4	17	101	8.14	8.10		
B1 Dec 13-14 2013	1	B1	0	12/13/13	2	A	1.2	2211	24.8	-4.0	11	64	7.7	7.70	0.1398	0.10
B1 Dec 13-14 2013	1	B1	0	12/13/13	2	B	0.0	2026	24.8	-4.0	11	64	7.61	7.60		
B1 Dec 13-14 2013	1	B1	0	12/13/13	2	C	2.5	2102	24.8	-4.0	11	64	7.65	7.70	0.9163	0.90
B1 Dec 13-14 2013	1	B1	0	12/13/13	2	D	3.0	2123	24.8	-4.0	11	64	7.66	7.70	1.0919	1.10
B1 Dec 13-14 2013	1	B1	0	12/13/13	2	E	1.1	2058	24.8	-4.0	11	64	7.63	7.60	0.1310	0.10
B1 Dec 13-14 2013	1	B1	0	12/13/13	2	F	1.6	2268	24.8	-4.0	11	64	7.73	7.70	0.4637	0.50
B2 Dec 16-17 2013	1	B2	0	12/16/13	2	A		2448	18.1	-7.7	11	64	7.8	7.80		
B2 Dec 16-17 2013	1	B2	0	12/16/13	2	B	1.4	2363	18.1	-7.7	11	64	7.77	7.80	0.3646	0.40
B2 Dec 16-17 2013	1	B2	0	12/16/13	2	C	2.4	2336	18.1	-7.7	11	64	7.76	7.80	0.8671	0.90
B2 Dec 16-17 2013	1	B2	0	12/16/13	2	D	3.5	2419	18.1	-7.7	11	64	7.79	7.80	1.2442	1.20
B2 Dec 16-17 2013	1	B2	0	12/16/13	2	E	1.4	2358	18.1	-7.7	11	64	7.77	7.80	0.3577	0.40
B2 Dec 16-17 2013	1	B2	0	12/16/13	2	F	1.5	2595	18.1	-7.7	11	64	7.86	7.90	0.3853	0.40
B3 Dec 18-19 2013	1	B3	0	12/18/13	2	A	1.4	1933	32.0	0.0	11	69	7.57	7.60	0.3148	0.30
B3 Dec 18-19 2013	1	B3	0	12/18/13	2	B	1.3	1858	32.0	0.0	11	69	7.53	7.50	0.2776	0.30
B3 Dec 18-19 2013	1	B3	0	12/18/13	2	C	2.1	1827	32.0	0.0	11	69	7.51	7.50	0.7324	0.70
B3 Dec 18-19 2013	1	B3	0	12/18/13	2	D	2.3	1970	32.0	0.0	11	69	7.59	7.60	0.8286	0.80
B3 Dec 18-19 2013	1	B3	0	12/18/13	2	E	1.1	2025	32.0	0.0	11	69	7.61	7.60	0.1310	0.10
B3 Dec 18-19 2013	1	B3	0	12/18/13	2	F	1.0	2190	32.0	0.0	11	69	7.69	7.70	-0.0513	-0.10
P1 Jan 22-23 2014	1	P1	0	1/22/14	2	A	2.1	2944	1.4	-17.0	16	57	7.99	8.00	0.7372	0.70
P1 Jan 22-23 2014	1	P1	0	1/22/14	2	B	2.2	2893	1.4	-17.0	16	57	7.97	8.00	0.7885	0.80
P1 Jan 22-23 2014	1	P1	0	1/22/14	2	C	2.3	2795	1.4	-17.0	16	57	7.94	7.90	0.8372	0.80
P1 Jan 22-23 2014	1	P1	0	1/22/14	2	D	1.9	2892	1.4	-17.0	16	57	7.97	8.00	0.6575	0.70
P1 Jan 22-23 2014	1	P1	0	1/22/14	2	E	2.0	2780	1.4	-17.0	16	57	7.93	7.90	0.7031	0.70
P1 Jan 22-23 2014	1	P1	0	1/22/14	2	F		3034	1.4	-17.0	16	57	8.02	8.00		
P2 Jan 24-25 2014	1	P2	0	1/24/14	2	A	1.2	2133	32.3	0.2	13	76	7.67	7.70	0.1906	0.20
P2 Jan 24-25 2014	1	P2	0	1/24/14	2	B	1.2	2009	32.3	0.2	13	76	7.61	7.60	0.1655	0.20
P2 Jan 24-25 2014	1	P2	0	1/24/14	2	C	1.4	2024	32.3	0.2	13	76	7.61	7.60	0.3436	0.30
P2 Jan 24-25 2014	1	P2	0	1/24/14	2	D	1.3	2167	32.3	0.2	13	76	7.68	7.70	0.2390	0.20
P2 Jan 24-25 2014	1	P2	0	1/24/14	2	E	1.0	2147	32.3	0.2	13	76	7.67	7.70	0.0198	0.00
P2 Jan 24-25 2014	1	P2	0	1/24/14	2	F		2504	32.3	0.2	13	76	7.83	7.80		

Eight-hour position averaged data set – 2013-14:

HEATER	ID	APC	DATE	SHIFT	Position	CO	CO2	lnCO	lnROUNDCO	lnCO2	lnROUND CO2	TEMPF	CTEMP	SOW	SWINE
1	B2	0	12/16/13	1	MEAN	2.19	2525	0.784	0.8	7.83	7.80	16.4	-8.7	11	64
1	B3	0	12/18/13	1	MEAN	1.21	2057	0.191	0.2	7.63	7.60	34.7	-17.7	11	69
1	P1	0	1/22/14	1	MEAN	1.82	2625	0.599	0.6	7.87	7.90	12.1	-17.4	16	57
1	P2	0	1/24/14	1	MEAN	1.71	2472	0.536	0.5	7.81	7.80	22.5	-17.5	13	76
1	P3	0	1/26/14	1	MEAN	1.10	2076	0.095	0.1	7.64	7.60	30.8	-17.7	13	80
1	P4	0	2/26/14	1	MEAN	1.69	3129	0.525	0.5	8.05	8.00	7.9	-17.5	17	101
1	B1	0	12/13/13	2	MEAN	1.56	2135	0.445	0.4	7.67	7.70	24.8	-17.6	11	64
1	B2	0	12/16/13	2	MEAN	2.04	2420	0.713	0.7	7.79	7.80	18.1	-17.4	11	64
1	B3	0	12/18/13	2	MEAN	1.53	1967	0.425	0.4	7.58	7.60	32.0	-17.6	11	69
1	P1	0	1/22/14	2	MEAN	2.11	2890	0.747	0.7	7.97	8.00	1.4	-17.4	16	57
1	P2	0	1/24/14	2	MEAN	1.22	2164	0.199	0.2	7.68	7.70	32.3	-17.7	13	76
1	P3	0	1/26/14	2	MEAN	1.52	2383	0.419	0.4	7.78	7.80	12.2	-17.6	13	80
1	P4	0	2/26/14	2	MEAN	1.68	2833	0.519	0.5	7.95	7.90	16.7	-17.5	17	101
1	B1	0	12/13/13	3	MEAN	1.47	2161	0.385	0.4	7.68	7.70	21.5	-17.6	11	64
1	B2	0	12/16/13	3	MEAN	1.98	2370	0.683	0.7	7.77	7.80	18.1	-17.4	11	64
1	B3	0	12/18/13	3	MEAN	1.39	2157	0.329	0.3	7.68	7.70	26.7	-17.6	11	69
1	P1	0	1/22/14	3	MEAN	2.05	2838	0.718	0.7	7.95	8.00	-7.8	-17.4	16	57
1	P2	0	1/24/14	3	MEAN	1.36	2102	0.307	0.3	7.65	7.70	28.2	-17.6	13	76
1	P3	0	1/26/14	3	MEAN	1.90	2722	0.642	0.6	7.91	7.90	-2.9	-17.4	13	80
1	P4	0	2/26/14	3	MEAN	2.05	3043	0.718	0.7	8.02	8.00	1.9	-17.4	17	101
1	APC1	1	12/21/13	1	MEAN	1.75	2301	0.560	0.6	7.74	7.70	34.2	-17.4	11	78
1	APC2	1	12/26/13	1	MEAN	1.53	2226	0.425	0.4	7.71	7.70	27.7	-17.6	11	74
1	APC3	1	12/31/13	1	MEAN	2.44	2335	0.892	0.9	7.76	7.80	6.5	-17.3	0	0
1	APC4	1	1/10/14	1	MEAN	2.01	2059	0.698	0.7	7.63	7.60	32.2	-17.4	16	0
1	APC5	1	1/17/14	1	MEAN	2.47	2664	0.904	0.9	7.89	7.90	11.8	-17.3	15	10
1	APC6	1	1/20/14	1	MEAN	1.04	1981	0.039	0.0	7.59	7.60	33.3	-17.8	16	43.5
1	APC7	1	1/28/14	1	MEAN	1.97	2827	0.678	0.7	7.95	7.90	4.9	-17.4	13	95
1	APC8	1	2/3/14	1	MEAN	1.87	2761	0.626	0.6	7.92	7.90	12.7	-17.4	17	119
1	APC9	1	2/10/14	1	MEAN	2.09	2992	0.737	0.7	8.00	8.00	-4.7	-17.4	19	84
1	APC10	1	2/17/14	1	MEAN	1.15	2513	0.140	0.1	7.83	7.80	25.0	-17.7	19	117
1	APC11	1	2/24/14	1	MEAN	1.51	2623	0.412	0.4	7.87	7.90	14.3	-17.6	17	95
1	APC1	1	12/21/13	2	MEAN	2.19	2242	0.784	0.8	7.72	7.70	31.7	-17.3	11	78
1	APC2	1	12/26/13	2	MEAN	1.91	2192	0.647	0.6	7.69	7.70	24.5	-17.4	11	74
1	APC3	1	12/31/13	2	MEAN	2.23	2248	0.802	0.8	7.72	7.70	9.8	-17.3	0	0
1	APC4	1	1/10/14	2	MEAN	1.67	1970	0.513	0.5	7.59	7.60	33.2	-17.5	16	0
1	APC5	1	1/17/14	2	MEAN	2.55	2625	0.936	0.9	7.87	7.90	9.4	-17.3	15	10
1	APC6	1	1/20/14	2	MEAN	1.41	2202	0.344	0.3	7.70	7.70	21.3	-17.6	16	43.5
1	APC7	1	1/28/14	2	MEAN	2.15	2913	0.765	0.8	7.98	8.00	1.3	-17.3	13	95
1	APC8	1	2/3/14	2	MEAN	1.78	2781	0.577	0.6	7.93	7.90	13.3	-17.4	17	119
1	APC9	1	2/10/14	2	MEAN	2.12	3038	0.751	0.8	8.02	8.00	-8.0	-17.3	19	84
1	APC10	1	2/17/14	2	MEAN	0.997	2446	-0.003	0.0	7.80	7.80	30.5	-17.8	19	117
1	APC11	1	2/24/14	2	MEAN	1.53	2618	0.425	0.4	7.87	7.90	13.9	-17.6	17	95
1	APC1	1	12/21/13	3	MEAN	1.80	2181	0.588	0.6	7.69	7.70	28.6	-17.4	11	78
1	APC2	1	12/26/13	3	MEAN	1.93	2326	0.658	0.7	7.75	7.80	16.9	-17.4	11	74
1	APC3	1	12/31/13	3	MEAN	2.20	2247	0.788	0.8	7.72	7.70	8.2	-17.3	0	0
1	APC4	1	1/10/14	3	MEAN	1.54	1946	0.432	0.4	7.57	7.60	31.3	-17.6	16	0
1	APC5	1	1/17/14	3	MEAN	2.36	2551	0.859	0.9	7.84	7.80	15.4	-17.3	15	10
1	APC6	1	1/20/14	3	MEAN	1.88	2631	0.631	0.6	7.88	7.90	1.8	-17.4	16	43.5
1	APC7	1	1/28/14	3	MEAN	2.23	2962	0.802	0.8	7.99	8.00	-1.5	-17.3	13	95
1	APC8	1	2/3/14	3	MEAN	1.94	2715	0.663	0.7	7.91	7.90	12.1	-17.4	17	119
1	APC9	1	2/10/14	3	MEAN	2.60	3266	0.956	1.0	8.09	8.10	-16.5	-17.2	19	84
1	APC10	1	2/17/14	3	MEAN	1.23	2554	0.207	0.2	7.85	7.80	23.3	-17.7	19	117
1	APC11	1	2/24/14	3	MEAN	1.76	2657	0.565	0.6	7.88	7.90	8.3	-17.4	17	95

Eight-hour position averaged data set – 2014-2015:

HEATER	ID	APC	DATE	SHIFT	Position	CO	CO2	lnCO	lnROUNDCO	lnCO2	lnROUND CO2	TEMPF	CTEMP	SOW	SWINE
0	B1	0	12/3/2014	1	MEAN	0.1	1235	-2.09174	-2.1	7.119107	7.1	29.5	-1.4	11	75
0	B2	0	12/5/2014	1	MEAN	0.6	1491	-0.51083	-0.5	7.306927	7.3	36.0	2.2	11.5	83
0	B3	0	12/8/2014	1	MEAN	0.6	1416	-0.51083	-0.5	7.255866	7.3	36.9	2.7	11	77.5
0	B4	0	1/13/2015	1	MEAN	0.9	1696	-0.10536	-0.1	7.436302	7.4	14.0	-10.0	17	37.5
0	B5	0	1/15/2015	1	MEAN	1.3	1665	0.262364	0.3	7.417749	7.4	30.9	-0.6	17	51.5
0	B6	0	1/17/2015	1	MEAN	1.2	1583	0.182322	0.2	7.366872	7.4	40.2	4.5	15	68
0	B7	0	2/18/2015	1	MEAN	1.0	1720	0	0.0	7.450073	7.5	1.7	-16.8	17.5	50.5
0	B8	0	2/22/2015	1	MEAN	0.6	1378	-0.5	-0.5	7.228479	7.2	7.2	-13.8	15	49
0	B1	0	12/3/2014	2	MEAN	0.4	1390	-0.91629	-0.9	7.237259	7.2	20.5	-6.4	11	75
0	B2	0	12/5/2014	2	MEAN	0.5	1515	-0.69315	-0.7	7.323492	7.3	34.5	1.4	11.5	83
0	B3	0	12/8/2014	2	MEAN	0.5	1328	-0.69315	-0.7	7.191189	7.2	34.5	-1.3	11	77.5
0	B4	0	1/13/2015	2	MEAN	1.3	1826	0.262364	0.3	7.51005	7.5	9.0	-12.8	17	37.5
0	B5	0	1/15/2015	2	MEAN	1.3	1686	0.262364	0.3	7.430311	7.4	27.9	-2.3	17	51.5
0	B6	0	1/17/2015	2	MEAN	1.1	1522	0.09531	0.1	7.32782	7.3	37.1	2.8	15	68
0	B7	0	2/18/2015	2	MEAN	1.3	1913	0.262364	0.3	7.55655	7.6	-0.7	-18.1	17.5	50.5
0	B8	0	2/22/2015	2	MEAN	1.2	1826	0.182322	0.2	7.509655	7.6	0.3	-17.6	15	49
0	B1	0	12/3/2014	3	MEAN	0.3	1305	-1.20397	-1.2	7.174242	7.2	22.3	-5.4	11	75
0	B2	0	12/5/2014	3	MEAN	0.6	1582	-0.51083	-0.5	7.366629	7.4	31.9	-0.1	11.5	83
0	B3	0	12/8/2014	3	MEAN	0.3	1395	-1.20397	-1.2	7.240859	7.2	25.3	-3.7	11	77.5
0	B4	0	1/13/2015	3	MEAN	1.2	1755	0.182322	0.2	7.470422	7.5	11.9	-11.2	17	37.5
0	B5	0	1/15/2015	3	MEAN	1.4	1693	0.336472	0.3	7.43443	7.4	19.1	-7.2	17	51.5
0	B6	0	1/17/2015	3	MEAN	1.1	1464	0.09531	0.1	7.288615	7.3	31.3	-0.4	15	68
0	B7	0	2/18/2015	3	MEAN	2.1	2445	0.741937	0.7	7.801762	7.8	-8.2	-22.3	17.5	50.5
0	B8	0	2/22/2015	3	MEAN	1.3	1974	0.262364	0.3	7.587669	7.6	-8.2	-22.3	15	49
0	APC1	1	12/11/2015	1	MEAN	0.2	1124	-1.60944	-1.6	7.025011	7	30.8	-0.7	6	41
0	APC2	1	12/17/2015	1	MEAN	0.1	984	-2.30259	-2.3	6.891702	6.9	22.1	-5.5	6	37.5
0	APC3	1	12/23/2015	1	MEAN	0.0	1080	-3.96003	-4.0	6.984755	7	38.1	3.4	6	36
0	APC4	1	12/29/2015	1	MEAN	0.1	767	-2.30259	-2.3	6.642097	6.6	24.7	-4.1	3	15
0	APC5	1	1/4/2015	1	MEAN	0.4	1254	-0.91629	-0.9	7.134026	7.1	9.0	-12.8	15.5	0
0	APC6	1	1/10/2015	1	MEAN	1.2	1371	0.182322	0.2	7.22334	7.2	17.9	-7.8	17	20.5
0	APC7	1	1/19/2015	1	MEAN	0.3	1168	-1.20397	-1.2	7.062945	7.1	37.2	2.9	14.5	70.5
0	APC8	1	1/24/2015	1	MEAN	0.9	1346	-0.10536	-0.1	7.204546	7.2	41.6	5.3	15.5	92.5
0	APC9	1	1/29/2015	1	MEAN	0.8	1379	-0.22314	-0.2	7.229025	7.2	33.6	0.9	9	66
0	APC10	1	2/3/2015	1	MEAN	1.5	1698	0.405465	0.4	7.436935	7.4	14.5	-9.8	9	55.5
0	APC11	1	2/9/2015	1	MEAN	1.2	1361	0.182322	0.2	7.215938	7.2	27.6	27.6	9	40.5
0	APC12	1	2/15/2015	1	MEAN	1.6	1928	0.470004	0.5	7.564374	7.6	5.4	-14.8	18	17
0	APC1	1	12/11/2015	2	MEAN	0.3	1045	-1.20397	-1.2	6.952142	7	31.2	-0.4	6	41
0	APC2	1	12/17/2015	2	MEAN	0.3	1201	-1.20397	-1.2	7.091207	7.1	16.9	-8.4	6	37.5
0	APC3	1	12/23/2015	2	MEAN	0.0	1042	-4.24954	-4.2	6.948761	6.9	35.1	1.7	6	36
0	APC4	1	12/29/2015	2	MEAN	0.0	496	-3.9564	-4.0	6.206082	6.2	10.3	-12.1	3	15
0	APC5	1	1/4/2015	2	MEAN	0.2	1289	-1.60944	-1.6	7.161266	7.2	-0.4	-18.0	15.5	0
0	APC6	1	1/10/2015	2	MEAN	1.1	1344	0.09531	0.1	7.203158	7.2	22.8	-5.1	17	20.5
0	APC7	1	1/19/2015	2	MEAN	0.2	1043	-1.60944	-1.6	6.950096	7	33.7	0.9	14.5	70.5
0	APC8	1	1/24/2015	2	MEAN	1.0	1490	0.000278	0.0	7.306855	7.3	36.4	2.4	15.5	92.5
0	APC9	1	1/29/2015	2	MEAN	0.4	1136	-0.99575	-1.0	7.03485	7	28.2	-2.1	9	66
0	APC10	1	2/3/2015	2	MEAN	1.4	1514	0.330652	0.3	7.322594	7.3	18.5	-7.5	9	55.5
0	APC11	1	2/9/2015	2	MEAN	1.3	1510	0.245122	0.2	7.320033	7.3	23.7	23.7	9	40.5
0	APC12	1	2/15/2015	2	MEAN	1.6	1834	0.44722	0.4	7.513984	7.5	8.1	-13.3	18	17
0	APC1	1	12/11/2015	3	MEAN	0.2	1082	-1.60874	-1.6	6.986297	7	30.1	-1.0	6	41
0	APC2	1	12/17/2015	3	MEAN	0.3	1105	-1.2757	-1.3	7.007883	7	13.5	-10.2	6	37.5
0	APC3	1	12/23/2015	3	MEAN	0.0	963	-6.90776	-6.9	6.870544	6.9	34.0	1.1	6	36
0	APC4	1	12/29/2015	3	MEAN	0.0	509	-3.24526	-3.2	6.232503	6.2	3.8	-15.6	3	15
0	APC5	1	1/4/2015	3	MEAN	0.2	1388	-1.54783	-1.5	7.235734	7.2	-5.8	-21.0	15.5	0
0	APC6	1	1/10/2015	3	MEAN	1.1	1419	0.072127	0.1	7.257483	7.3	17.8	-7.9	17	20.5
0	APC7	1	1/19/2015	3	MEAN	0.8	1424	-0.24429	-0.2	7.261562	7.3	31.9	0.0	14.5	70.5
0	APC8	1	1/24/2015	3	MEAN	1.0	1354	-0.01202	0.0	7.210791	7.2	34.3	1.3	15.5	92.5
0	APC9	1	1/29/2015	3	MEAN	1.0	1604	-0.00739	0.0	7.380309	7.4	17.9	-7.8	9	66
0	APC10	1	2/3/2015	3	MEAN	1.2	1433	0.220139	0.2	7.267443	7.3	14.9	-9.5	9	55.5
0	APC11	1	2/9/2015	3	MEAN	1.4	1574	0.302417	0.3	7.361519	7.4	16.5	16.5	9	40.5
0	APC12	1	2/15/2015	3	MEAN	1.5	1820	0.435833	0.4	7.506655	7.5	5.8	-14.6	18	17

Twenty-four hour all position data set – 2013-14, Part 1:

HEATER	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	CTEMP	SOW	SWINE	lnCO2	lnROUNDCO2	lnCO	lnROUNDCO
1	B1	0	12/13/13	4	A	1.1	2260	22.2	-5.44	11	64	7.72	7.7	0.131028	0.1
1	B1	0	12/13/13	4	B	-	2072	22.2	-5.44	11	64	7.64	7.6	-	-
1	B1	0	12/13/13	4	C	2.5	2155	22.2	-5.44	11	64	7.68	7.7	0.912283	0.9
1	B1	0	12/13/13	4	D	3.1	2173	22.2	-5.44	11	64	7.68	7.7	1.115142	1.1
1	B1	0	12/13/13	4	E	1.1	2091	22.2	-5.44	11	64	7.65	7.6	0.131028	0.1
1	B1	0	12/13/13	4	F	1.7	2307	22.2	-5.44	11	64	7.74	7.7	0.524729	0.5
1	B2	0	12/16/13	4	A	-	2454	18.3	-7.61	11	64	7.81	7.8	-	-
1	B2	0	12/16/13	4	B	1.5	2368	18.3	-7.61	11	64	7.77	7.8	0.371564	0.4
1	B2	0	12/16/13	4	C	2.4	2376	18.3	-7.61	11	64	7.77	7.8	0.862890	0.9
1	B2	0	12/16/13	4	D	3.5	2421	18.3	-7.61	11	64	7.79	7.8	1.252763	1.3
1	B2	0	12/16/13	4	E	1.5	2379	18.3	-7.61	11	64	7.77	7.8	0.378436	0.4
1	B2	0	12/16/13	4	F	1.6	2631	18.3	-7.61	11	64	7.88	7.9	0.451076	0.5
1	B3	0	12/18/13	4	A	1.2	1988	30.7	-0.722	11	69	7.59	7.6	0.173953	0.2
1	B3	0	12/18/13	4	B	1.2	1888	30.7	-0.722	11	69	7.54	7.5	0.182322	0.2
1	B3	0	12/18/13	4	C	1.8	1897	30.7	-0.722	11	69	7.55	7.5	0.587787	0.6
1	B3	0	12/18/13	4	D	2.1	2016	30.7	-0.722	11	69	7.61	7.6	0.741937	0.7
1	B3	0	12/18/13	4	E	1.0	2054	30.7	-0.722	11	69	7.63	7.6	-0.009041	0
1	B3	0	12/18/13	4	F	1.0	2245	30.7	-0.722	11	69	7.72	7.7	-0.028399	0
1	P1	0	1/22/14	4	A	2.0	2817	-1.0	-18.3	16	57	7.94	7.9	0.683097	0.7
1	P1	0	1/22/14	4	B	2.1	2775	-1.0	-18.3	16	57	7.93	7.9	0.732368	0.7
1	P1	0	1/22/14	4	C	2.2	2679	-1.0	-18.3	16	57	7.89	7.9	0.765468	0.8
1	P1	0	1/22/14	4	D	1.8	2783	-1.0	-18.3	16	57	7.93	7.9	0.598837	0.6
1	P1	0	1/22/14	4	E	1.9	2698	-1.0	-18.3	16	57	7.9	7.9	0.657520	0.7
1	P1	0	1/22/14	4	F	-	2953	-1.0	-18.3	16	57	7.99	8	-	-
1	P2	0	1/24/14	4	A	1.4	2239	27.3	-2.61	13	76	7.71	7.7	0.357674	0.4
1	P2	0	1/24/14	4	B	1.4	2115	27.3	-2.61	13	76	7.66	7.7	0.329304	0.3
1	P2	0	1/24/14	4	C	1.6	2119	27.3	-2.61	13	76	7.66	7.7	0.494696	0.5
1	P2	0	1/24/14	4	D	1.5	2257	27.3	-2.61	13	76	7.72	7.7	0.398776	0.4
1	P2	0	1/24/14	4	E	1.2	2194	27.3	-2.61	13	76	7.69	7.7	0.173953	0.2
1	P2	0	1/24/14	4	F	-	2551	27.3	-2.61	13	76	7.84	7.8	-	-
1	P3	0	1/26/14	4	A	1.4	2393	11.7	-11.3	13	80	7.78	7.8	0.357674	0.4
1	P3	0	1/26/14	4	B	1.7	2312	11.7	-11.3	13	80	7.75	7.7	0.518794	0.5
1	P3	0	1/26/14	4	C	1.8	2238	11.7	-11.3	13	80	7.71	7.7	0.576613	0.6
1	P3	0	1/26/14	4	D	1.3	2419	11.7	-11.3	13	80	7.79	7.8	0.223144	0.2
1	P3	0	1/26/14	4	E	1.4	2336	11.7	-11.3	13	80	7.76	7.8	0.329304	0.3
1	P3	0	1/26/14	4	F	-	2662	11.7	-11.3	13	80	7.89	7.9	-	-
1	P4	0	2/26/14	4	A	1.9	3116	8.9	-12.8	17	101	8.04	8	0.631272	0.6
1	P4	0	2/26/14	4	B	1.9	2942	8.9	-12.8	17	101	7.99	8	0.620576	0.6
1	P4	0	2/26/14	4	C	-	2951	8.9	-12.8	17	101	7.99	8	-	-
1	P4	0	2/26/14	4	D	1.8	2887	8.9	-12.8	17	101	7.97	8	0.582216	0.6
1	P4	0	2/26/14	4	E	1.7	2897	8.9	-12.8	17	101	7.97	8	0.536493	0.5
1	P4	0	2/26/14	4	F	-	3220	8.9	-12.8	17	101	8.08	8.1	-	-

Twenty-four hour all position data set – 2013-14, Part 2:

HEATER	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	CTEMP	SOW	SWINE	lnCO2	lnROUNDCO2	lnCO	lnROUNDCO
1	APC1	1	12/21/13	4	A	1.4	2275	31.1	-0.5	11	78	7.73	7.7	0.364643	0.4
1	APC1	1	12/21/13	4	B	1.2	2055	31.1	-0.5	11	78	7.63	7.6	0.182322	0.2
1	APC1	1	12/21/13	4	C	2.5	2211	31.1	-0.5	11	78	7.7	7.7	0.896088	0.9
1	APC1	1	12/21/13	4	D	2.9	-	31.1	-0.5	11	78	-	-	1.047319	1
1	APC1	1	12/21/13	4	E	1.4	2214	31.1	-0.5	11	78	7.7	7.7	0.336472	0.3
1	APC1	1	12/21/13	4	F	-	2459	31.1	-0.5	11	78	7.81	7.8	-	-
1	APC10	1	2/17/14	4	A	1.2	2496	29.4	-1.44	19	117	7.82	7.8	0.148420	0.1
1	APC10	1	2/17/14	4	B	1.2	2326	29.4	-1.44	19	117	7.75	7.8	0.198851	0.2
1	APC10	1	2/17/14	4	C	1.2	2381	29.4	-1.44	19	117	7.78	7.8	0.148420	0.1
1	APC10	1	2/17/14	4	D	1.1	2478	29.4	-1.44	19	117	7.82	7.8	0.076961	0.1
1	APC10	1	2/17/14	4	E	1.0	2576	29.4	-1.44	19	117	7.85	7.9	0.009950	0
1	APC10	1	2/17/14	4	F	-	2767	29.4	-1.44	19	117	7.93	7.9	-	-
1	APC11	1	2/24/14	4	A	1.7	2760	12.2	-11.0	17	95	7.92	7.9	0.500775	0.5
1	APC11	1	2/24/14	4	B	1.6	2546	12.2	-11.0	17	95	7.84	7.8	0.476234	0.5
1	APC11	1	2/24/14	4	C	1.9	2597	12.2	-11.0	17	95	7.86	7.9	0.652325	0.7
1	APC11	1	2/24/14	4	D	1.5	2576	12.2	-11.0	17	95	7.85	7.9	0.385262	0.4
1	APC11	1	2/24/14	4	E	1.4	2611	12.2	-11.0	17	95	7.87	7.9	0.300105	0.3
1	APC11	1	2/24/14	4	F	-	2746	12.2	-11.0	17	95	7.92	7.9	-	-
1	APC2	1	12/26/13	4	A	1.4	2199	21.4	-5.89	11	74	7.7	7.7	0.336472	0.3
1	APC2	1	12/26/13	4	B	1.3	2048	21.4	-5.89	11	74	7.63	7.6	0.270027	0.3
1	APC2	1	12/26/13	4	C	2.9	2163	21.4	-5.89	11	74	7.68	7.7	1.064711	1.1
1	APC2	1	12/26/13	4	D	7.2	2251	21.4	-5.89	11	74	7.72	7.7	1.976855	2
1	APC2	1	12/26/13	4	E	1.6	2237	21.4	-5.89	11	74	7.71	7.7	0.457425	0.5
1	APC2	1	12/26/13	4	F	-	2588	21.4	-5.89	11	74	7.86	7.9	-	-
1	APC3	1	12/31/13	4	A	2.1	2431	7.9	-13.4	0	0	7.8	7.8	0.722706	0.7
1	APC3	1	12/31/13	4	B	2.1	2149	7.9	-13.4	0	0	7.67	7.7	0.746688	0.7
1	APC3	1	12/31/13	4	C	3.5	2237	7.9	-13.4	0	0	7.71	7.7	1.258461	1.3
1	APC3	1	12/31/13	4	D	8.3	2345	7.9	-13.4	0	0	7.76	7.8	2.118662	2.1
1	APC3	1	12/31/13	4	E	1.7	2211	7.9	-13.4	0	0	7.7	7.7	0.530628	0.5
1	APC3	1	12/31/13	4	F	2.1	2286	7.9	-13.4	0	0	7.73	7.7	0.722706	0.7
1	APC4	1	1/10/14	4	A	1.2	2028	32.3	0.167	16	0	7.61	7.6	0.215111	0.2
1	APC4	1	1/10/14	4	B	1.3	1865	32.3	0.167	16	0	7.53	7.5	0.285179	0.3
1	APC4	1	1/10/14	4	C	3.5	1891	32.3	0.167	16	0	7.54	7.5	1.258461	1.3
1	APC4	1	1/10/14	4	D	8.1	2025	32.3	0.167	16	0	7.61	7.6	2.086914	2.1
1	APC4	1	1/10/14	4	E	1.2	1954	32.3	0.167	16	0	7.58	7.6	0.190620	0.2
1	APC4	1	1/10/14	4	F	1.4	2186	32.3	0.167	16	0	7.69	7.7	0.336472	0.3
1	APC5	1	1/17/14	4	A	1.9	2652	12.3	-10.9	15	10	7.88	7.9	0.647103	0.6
1	APC5	1	1/17/14	4	B	1.8	2526	12.3	-10.9	15	10	7.83	7.8	0.609766	0.6
1	APC5	1	1/17/14	4	C	5.3	2526	12.3	-10.9	15	10	7.83	7.8	1.660131	1.7
1	APC5	1	1/17/14	4	D	-	2696	12.3	-10.9	15	10	7.9	7.9	-	-
1	APC5	1	1/17/14	4	E	1.5	2588	12.3	-10.9	15	10	7.86	7.9	0.425268	0.4
1	APC5	1	1/17/14	4	F	1.8	2699	12.3	-10.9	15	10	7.9	7.9	0.576613	0.6
1	APC6	1	1/20/14	4	A	1.5	2297	13.4	-10.3	16	43.5	7.74	7.7	0.431782	0.4
1	APC6	1	1/20/14	4	B	1.4	2211	13.4	-10.3	16	43.5	7.7	7.7	0.314811	0.3
1	APC6	1	1/20/14	4	C	2.0	1991	13.4	-10.3	16	43.5	7.6	7.6	0.688135	0.7
1	APC6	1	1/20/14	4	D	1.2	2390	13.4	-10.3	16	43.5	7.78	7.8	0.148420	0.1
1	APC6	1	1/20/14	4	E	0.1	2112	13.4	-10.3	16	43.5	7.66	7.7	-2.476938	-2.5
1	APC6	1	1/20/14	4	F	-	2439	13.4	-10.3	16	43.5	7.8	7.8	-	-
1	APC7	1	1/28/14	4	A	2.4	2927	1.6	-16.9	13	95	7.98	8	0.875469	0.9
1	APC7	1	1/28/14	4	B	2.2	2777	1.6	-16.9	13	95	7.93	7.9	0.792993	0.8
1	APC7	1	1/28/14	4	C	2.4	2799	1.6	-16.9	13	95	7.94	7.9	0.871293	0.9
1	APC7	1	1/28/14	4	D	1.7	2939	1.6	-16.9	13	95	7.99	8	0.524729	0.5
1	APC7	1	1/28/14	4	E	1.9	2808	1.6	-16.9	13	95	7.94	7.9	0.636577	0.6
1	APC7	1	1/28/14	4	F	-	3152	1.6	-16.9	13	95	8.06	8.1	-	-
1	APC8	1	2/3/14	4	A	2.0	2804	12.1	-11.1	17	119	7.94	7.9	0.678034	0.7
1	APC8	1	2/3/14	4	B	1.7	2590	12.1	-11.1	17	119	7.86	7.9	0.518794	0.5
1	APC8	1	2/3/14	4	C	1.8	2657	12.1	-11.1	17	119	7.88	7.9	0.593327	0.6
1	APC8	1	2/3/14	4	D	1.5	2695	12.1	-11.1	17	119	7.9	7.9	0.431782	0.4
1	APC8	1	2/3/14	4	E	2.3	2730	12.1	-11.1	17	119	7.91	7.9	0.841567	0.8
1	APC8	1	2/3/14	4	F	-	3040	12.1	-11.1	17	119	8.02	8	-	-
1	APC9	1	2/10/14	4	A	2.5	3193	-11.0	-23.9	19	84	8.07	8.1	0.904218	0.9
1	APC9	1	2/10/14	4	B	2.4	2943	-11.0	-23.9	19	84	7.99	8	0.858662	0.9
1	APC9	1	2/10/14	4	C	-	3110	-11.0	-23.9	19	84	8.04	8	-	-
1	APC9	1	2/10/14	4	D	-	3053	-11.0	-23.9	19	84	8.02	8	-	-
1	APC9	1	2/10/14	4	E	2.0	2998	-11.0	-23.9	19	84	8.01	8	0.683097	0.7
1	APC9	1	2/10/14	4	F	-	3293	-11.0	-23.9	19	84	8.1	8.1	-	-

Twenty-four hour all position data set – 2014-15, Part 1:

HEATER	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	CTEMP	SOW	SWINE	lnCO2	lnROUNDCO2	lnCO	lnROUNDCO
0	B1	0	12/3/2015	4	A	0.4	1337	24.1	-4.4	11	75	7.198038	7.2	-0.925360	-0.9
0	B1	0	12/4/2015	4	B		1312	24.1	-4.4	11	75	7.179107	7.2		
0	B1	0	12/5/2015	4	C	0.2	1242	24.1	-4.4	11	75	7.124378	7.1	-1.842614	-1.8
0	B1	0	12/6/2015	4	D		1231	24.1	-4.4	11	75	7.11539	7.1		
0	B1	0	12/7/2015	4	E	0.3	1353	24.1	-4.4	11	75	7.209813	7.2	-1.381583	-1.4
0	B1	0	12/8/2015	4	F		1388	24.1	-4.4	11	75	7.235259	7.2		
0	B2	0	12/5/2015	4	A	0.6	1524	34.0	1.1	11.5	83	7.328884	7.3	-0.475463	-0.5
0	B2	0	12/5/2015	4	B		1522	34.0	1.1	11.5	83	7.32779	7.3		
0	B2	0	12/5/2015	4	C	0.4	1445	34.0	1.1	11.5	83	7.275768	7.3	-0.807343	-0.8
0	B2	0	12/5/2015	4	D		1421	34.0	1.1	11.5	83	7.259341	7.3		
0	B2	0	12/5/2015	4	E	0.6	1623	34.0	1.1	11.5	83	7.392109	7.4	-0.495777	-0.5
0	B2	0	12/5/2015	4	F		1642	34.0	1.1	11.5	83	7.40351	7.4		
0	B3	0	12/8/2015	4	A	0.4	1425	30.7	-0.7	11	77.5	7.262073	7.3	-0.857494	-0.9
0	B3	0	12/8/2015	4	B		1334	30.7	-0.7	11	77.5	7.195854	7.2		
0	B3	0	12/8/2015	4	C	0.5	1266	30.7	-0.7	11	77.5	7.143421	7.1	-0.678878	-0.7
0	B3	0	12/8/2015	4	D		1300	30.7	-0.7	11	77.5	7.169746	7.2		
0	B3	0	12/8/2015	4	E	-	1462	30.7	-0.7	11	77.5	7.287333	7.3	-	-
0	B3	0	12/8/2015	4	F		1449	30.7	-0.7	11	77.5	7.278504	7.3		
0	B4	0	1/13/2015	4	A	1.0	1766	11.3	-11.5	17	37.5	7.476653	7.5	0.044150	0
0	B4	0	1/13/2015	4	B		1653	11.3	-11.5	17	37.5	7.410255	7.4		
0	B4	0	1/13/2015	4	C	0.9	1698	11.3	-11.5	17	37.5	7.437157	7.4	-0.158931	-0.2
0	B4	0	1/13/2015	4	D		1670	11.3	-11.5	17	37.5	7.420787	7.4		
0	B4	0	1/13/2015	4	E	1.1	1909	11.3	-11.5	17	37.5	7.554095	7.6	0.097139	0.1
0	B4	0	1/13/2015	4	F		1860	11.3	-11.5	17	37.5	7.528182	7.5		
0	B5	0	1/15/2015	4	A	1.3	1684	24.6	-4.1	17	51.5	7.428655	7.4	0.282827	0.3
0	B5	0	1/15/2015	4	B		1550	24.6	-4.1	17	51.5	7.346234	7.3		
0	B5	0	1/15/2015	4	C	1.2	1615	24.6	-4.1	17	51.5	7.387219	7.4	0.164513	0.2
0	B5	0	1/15/2015	4	D		1669	24.6	-4.1	17	51.5	7.420038	7.4		
0	B5	0	1/15/2015	4	E	1.4	1832	24.6	-4.1	17	51.5	7.512909	7.5	0.354367	0.4
0	B5	0	1/15/2015	4	F		1817	24.6	-4.1	17	51.5	7.505141	7.5		
0	B6	0	1/17/2015	4	A	1.0	1502	36.5	2.5	15	68	7.314793	7.3	0.031108	0
0	B6	0	1/17/2015	4	B		1412	36.5	2.5	15	68	7.252674	7.3		
0	B6	0	1/17/2015	4	C	1.2	1454	36.5	2.5	15	68	7.282045	7.3	0.197028	0.2
0	B6	0	1/17/2015	4	D		1406	36.5	2.5	15	68	7.248682	7.2		
0	B6	0	1/17/2015	4	E	1.1	1708	36.5	2.5	15	68	7.443111	7.4	0.139218	0.1
0	B6	0	1/17/2015	4	F		1654	36.5	2.5	15	68	7.411137	7.4		
0	B7	0	2/18/2015	4	A	1.6	2125	-2.2	-19.0	17.5	50.5	7.66171	7.7	0.457776	0.5
0	B7	0	2/18/2015	4	B		2036	-2.2	-19.0	17.5	50.5	7.618832	7.6		
0	B7	0	2/18/2015	4	C	-	1970	-2.2	-19.0	17.5	50.5	7.586001	7.6	-	-
0	B7	0	2/18/2015	4	D		2068	-2.2	-19.0	17.5	50.5	7.634561	7.6		
0	B7	0	2/18/2015	4	E	1.3	1971	-2.2	-19.0	17.5	50.5	7.586096	7.6	0.298457	0.3
0	B7	0	2/18/2015	4	F		1984	-2.2	-19.0	17.5	50.5	7.593069	7.6		
0	B8	0	2/22/2015	4	A	1.0	1794	-0.2	-17.9	15	49	7.492451	7.5	0.046138	0
0	B8	0	2/22/2015	4	B		1672	-0.2	-17.9	15	49	7.421909	7.4		
0	B8	0	2/22/2015	4	C	0.6	1629	-0.2	-17.9	15	49	7.395611	7.4	-0.536856	-0.5
0	B8	0	2/22/2015	4	D		-	-0.2	-17.9	15	49	-	-		
0	B8	0	2/22/2015	4	E	1.4	1741	-0.2	-17.9	15	49	7.462	7.5	0.356703	0.4
0	B8	0	2/22/2015	4	F		1793	-0.2	-17.9	15	49	7.491599	7.5		

Twenty-four hour all position data set – 2014-15, Part 2:

HEATER	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	CTEMP	SOW	SWINE	lnCO2	lnROUNDCO2	lnCO	lnROUNDCO
0	APC1	1	12/11/2014	4	A	0.2	1144	30.7	-0.7	6	41	7.042007	7	-1.646577	-1.6
0	APC1	1	12/11/2014	4	B		1160	30.7	-0.7	6	41	7.056235	7.1		
0	APC1	1	12/11/2014	4	C	0.4	1024	30.7	-0.7	6	41	6.931499	6.9	-0.965029	-1
0	APC1	1	12/11/2014	4	D		-	30.7	-0.7	6	41	-	-		
0	APC1	1	12/11/2014	4	E	0.1	1042	30.7	-0.7	6	41	6.949044	6.9	-2.155603	-2.2
0	APC1	1	12/11/2014	4	F		1050	30.7	-0.7	6	41	6.956082	7		
0	APC2	1	12/17/2014	4	A	0.2	1138	17.9	-7.9	6	37.5	7.036832	7	-1.516314	-1.5
0	APC2	1	12/17/2014	4	B		1123	17.9	-7.9	6	37.5	7.023442	7		
0	APC2	1	12/17/2014	4	C	0.4	1100	17.9	-7.9	6	37.5	7.003507	7	-0.978425	-1
0	APC2	1	12/17/2014	4	D		1112	17.9	-7.9	6	37.5	7.013616	7		
0	APC2	1	12/17/2014	4	E	0.1	1005	17.9	-7.9	6	37.5	6.912328	6.9	-2.248518	-2.2
0	APC2	1	12/17/2014	4	F		1105	17.9	-7.9	6	37.5	7.007852	7		
0	APC3	1	12/23/2014	4	A	0.0	1107	35.6	2.0	6	36	7.009672	7	-3.806662	-3.8
0	APC3	1	12/23/2014	4	B		1006	35.6	2.0	6	36	6.913434	6.9		
0	APC3	1	12/23/2014	4	C	0.0	989	35.6	2.0	6	36	6.896442	6.9	-6.907755	0
0	APC3	1	12/23/2014	4	D		1087	35.6	2.0	6	36	6.990742	7		
0	APC3	1	12/23/2014	4	E	-	977	35.6	2.0	6	36	6.884288	6.9	-	-
0	APC3	1	12/23/2014	4	F		1006	35.6	2.0	6	36	6.913572	6.9		
0	APC4	1	12/29/2014	4	A	0.1	594	16.3	-8.7	3	15	6.386341	6.4	-2.228139	-2.2
0	APC4	1	12/29/2014	4	B		525	16.3	-8.7	3	15	6.263927	6.3		
0	APC4	1	12/29/2014	4	C	0.0	583	16.3	-8.7	3	15	6.368282	6.4	-	-
0	APC4	1	12/29/2014	4	D		585	16.3	-8.7	3	15	6.372442	6.4		
0	APC4	1	12/29/2014	4	E	0.1	605	16.3	-8.7	3	15	6.40454	6.4	-2.419587	-2.4
0	APC4	1	12/29/2014	4	F		652	16.3	-8.7	3	15	6.480066	6.5		
0	APC5	1	1/4/2015	4	A	0.2	1302	1.6	-16.9	15.5	0	7.171294	7.2	-1.527419	-1.5
0	APC5	1	1/4/2015	4	B		1270	1.6	-16.9	15.5	0	7.147046	7.1		
0	APC5	1	1/4/2015	4	C	0.1	1291	1.6	-16.9	15.5	0	7.162882	7.2	-2.132364	-2.1
0	APC5	1	1/4/2015	4	D		1303	1.6	-16.9	15.5	0	7.172201	7.2		
0	APC5	1	1/4/2015	4	E	0.4	1348	1.6	-16.9	15.5	0	7.206006	7.2	-0.936472	-0.9
0	APC5	1	1/4/2015	4	F		1348	1.6	-16.9	15.5	0	7.206006	7.2		
0	APC6	1	1/10/2015	4	A	0.4	1359	19.5	-6.9	17	20.5	7.21478	7.2	-0.948219	-0.9
0	APC6	1	1/10/2015	4	B		1237	19.5	-6.9	17	20.5	7.120213	7.1		
0	APC6	1	1/10/2015	4	C	0.4	1358	19.5	-6.9	17	20.5	7.214113	7.2	-0.932745	-0.9
0	APC6	1	1/10/2015	4	D		1383	19.5	-6.9	17	20.5	7.23237	7.2		
0	APC6	1	1/10/2015	4	E	0.8	1432	19.5	-6.9	17	20.5	7.26679	7.3	-0.227580	-0.2
0	APC6	1	1/10/2015	4	F		1509	19.5	-6.9	17	20.5	7.319127	7.3		
0	APC7	1	1/19/2015	4	A	0.4	1187	34.1	1.2	14.5	70.5	7.078962	7.1	-0.835928	-0.8
0	APC7	1	1/19/2015	4	B		1125	34.1	1.2	14.5	70.5	7.025106	7		
0	APC7	1	1/19/2015	4	C	0.4	1195	34.1	1.2	14.5	70.5	7.086134	7.1	-0.989571	-1
0	APC7	1	1/19/2015	4	D		1205	34.1	1.2	14.5	70.5	7.094581	7.1		
0	APC7	1	1/19/2015	4	E	0.5	1273	34.1	1.2	14.5	70.5	7.148739	7.1	-0.689543	-0.7
0	APC7	1	1/19/2015	4	F		1287	34.1	1.2	14.5	70.5	7.160296	7.2		
0	APC8	1	1/24/2015	4	A	0.9	1374	37.2	2.9	15.5	92.5	7.225477	7.2	-0.152601	-0.2
0	APC8	1	1/24/2015	4	B		1390	37.2	2.9	15.5	92.5	7.236983	7.2		
0	APC8	1	1/24/2015	4	C	1.0	1327	37.2	2.9	15.5	92.5	7.190903	7.2	0.009675	0
0	APC8	1	1/24/2015	4	D		1352	37.2	2.9	15.5	92.5	7.209151	7.2		
0	APC8	1	1/24/2015	4	E	1.0	1524	37.2	2.9	15.5	92.5	7.329166	7.3	-0.008999	0
0	APC8	1	1/24/2015	4	F		1424	37.2	2.9	15.5	92.5	7.260923	7.3		
0	APC9	1	1/29/2015	4	A	0.5	1345	27.0	-2.8	9	66	7.204046	7.2	-0.693147	-0.7
0	APC9	1	1/29/2015	4	B		1294	27.0	-2.8	9	66	7.165569	7.2		
0	APC9	1	1/29/2015	4	C	0.8	1330	27.0	-2.8	9	66	7.192882	7.2	-0.192961	-0.2
0	APC9	1	1/29/2015	4	D		1343	27.0	-2.8	9	66	7.202651	7.2		
0	APC9	1	1/29/2015	4	E	0.9	1457	27.0	-2.8	9	66	7.284049	7.3	-0.126178	-0.1
0	APC9	1	1/29/2015	4	F		1469	27.0	-2.8	9	66	7.292545	7.3		
0	APC10	1	2/3/2015	4	A	1.2	1500	15.8	-9.0	9	55.5	7.312989	7.3	0.145662	0.1
0	APC10	1	2/3/2015	4	B		1393	15.8	-9.0	9	55.5	7.238906	7.2		
0	APC10	1	2/3/2015	4	C	1.5	1487	15.8	-9.0	9	55.5	7.304712	7.3	0.374003	0.4
0	APC10	1	2/3/2015	4	D		1583	15.8	-9.0	9	55.5	7.367331	7.4		
0	APC10	1	2/3/2015	4	E	1.5	1665	15.8	-9.0	9	55.5	7.417706	7.4	0.418573	0.4
0	APC10	1	2/3/2015	4	F		1662	15.8	-9.0	9	55.5	7.415618	7.4		
0	APC11	1	2/9/2015	4	A	1.3	1390	22.8	-5.1	9	40.5	7.236904	7.2	0.269815	0.3
0	APC11	1	2/9/2015	4	B		1403	22.8	-5.1	9	40.5	7.246345	7.2		
0	APC11	1	2/9/2015	4	C	1.3	1480	22.8	-5.1	9	40.5	7.29985	7.3	0.242619	0.2
0	APC11	1	2/9/2015	4	D		1509	22.8	-5.1	9	40.5	7.318952	7.3		
0	APC11	1	2/9/2015	4	E	1.3	1535	22.8	-5.1	9	40.5	7.336571	7.3	0.254319	0.3
0	APC11	1	2/9/2015	4	F		1573	22.8	-5.1	9	40.5	7.36096	7.4		
0	APC12	1	2/15/2015	4	A	-	1895	6.4	-14.2	18	17	7.546727	7.5	-	-
0	APC12	1	2/15/2015	4	B		1765	6.4	-14.2	18	17	7.476152	7.5		
0	APC12	1	2/15/2015	4	C	1.8	1867	6.4	-14.2	18	17	7.532224	7.5	0.612065	0.6
0	APC12	1	2/15/2015	4	D		1856	6.4	-14.2	18	17	7.526189	7.5		
0	APC12	1	2/15/2015	4	E	1.3	1874	6.4	-14.2	18	17	7.535779	7.5	0.267054	0.3
0	APC12	1	2/15/2015	4	F		1907	6.4	-14.2	18	17	7.553294	7.6		

Twenty-four hour position averaged data set –2013-14:

HEATER	CODE	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	Ctemp	SOW	SWINE	lnCO	lnROUND CO	lnROUNDCO2
1	P4 Feb 26-27 2014	P4	0	2/26/14	4	MEAN	1.81	3002	8.9	-12.8	17	101	0.593	0.6	8.007
1	P3 Jan 26-27 2014	P3	0	1/26/14	4	MEAN	1.51	2393	11.7	-11.3	13	80	0.412	0.4	7.780
1	P2 Jan 24-25 2014	P2	0	1/24/14	4	MEAN	1.43	2246	27.3	-2.6	13	76	0.358	0.4	7.717
1	P1 Jan 22-23 2014	P1	0	1/22/14	4	MEAN	1.99	2784	-1.0	-18.3	16	57	0.688	0.7	7.932
1	B3 Dec 18-19 2013	B3	0	12/18/13	4	MEAN	1.37	2015	30.7	-0.7	11	69	0.315	0.3	7.608
1	B2 Dec 16-17 2013	B2	0	12/16/13	4	MEAN	2.07	2438	18.3	-7.6	11	64	0.728	0.7	7.799
1	B1 Dec 13-14 2013	B1	0	12/13/13	4	MEAN	1.59	2176	22.2	-5.4	11	64	0.464	0.5	7.685
1	APC 9 Feb 10-11 2014	APC9	1	2/10/14	4	MEAN	2.27	3098	-11.0	-23.9	19	84	0.820	0.8	8.039
1	APC 8 Feb 03-04 2014	APC8	1	2/3/14	4	MEAN	1.86	2753	12.1	-11.1	17	119	0.621	0.6	7.920
1	APC 7 Jan 28-29 2014	APC7	1	1/28/14	4	MEAN	2.12	2900	1.6	-16.9	13	95	0.751	0.8	7.972
1	APC 6 Jan 20-21 2014	APC6	1	1/20/14	4	MEAN	1.37	2240	13.4	-10.3	16	43.5	0.315	0.3	7.714
1	APC 5 Jan 17-18 2014	APC5	1	1/17/14	4	MEAN	2.46	2614	12.3	-10.9	15	10	0.900	0.9	7.869
1	APC 4 Jan 10-11 2014	APC4	1	1/10/14	4	MEAN	1.73	1991	32.3	0.2	16	0	0.548	0.5	7.596
1	APC 3 Dec 31-Jan 1 201	APC3	1	12/31/13	4	MEAN	2.29	2277	7.9	-13.4	0	0	0.829	0.8	7.731
1	APC 2 Dec 26-27 2013	APC2	1	12/26/13	4	MEAN	1.80	2248	21.4	-5.9	11	74	0.588	0.6	7.718
1	APC 11 Feb 24-25 2014	APC11	1	2/24/14	4	MEAN	1.60	2639	12.2	-11.0	17	95	0.470	0.5	7.878
1	APC 10 Feb 17-18 2014	APC10	1	2/17/14	4	MEAN	1.13	2504	29.4	-1.4	19	117	0.122	0.1	7.826
1	APC 1 Dec 21-22 2013	APC1	1	12/21/13	4	MEAN	1.93	2243	31.1	-0.5	11	78	0.658	0.7	7.716

Twenty-four hour position averaged data set – 2014-15:

HEATER	CODE	ID	APC	DATE	SHIFT	Position	CO	CO2	TEMP F	Ctemp	SOW	SWINE	lnCO	lnROUND CO	lnROUNDCO2
0	B1 Dec 3-4 2014	B1	0	12/3/2014	4	MEAN	0.3	1310	24.1	-4.4	11.0	75	-1.314	-1.3	7.178
0	B2 Dec 5-6 2014	B2	0	12/5/2014	4	MEAN	0.6	1529	34.0	1.1	11.5	83	-0.582	-0.6	7.332
0	B3 Dec 8-9 2014	B3	0	12/8/2014	4	MEAN	0.5	1380	30.7	-0.7	11.0	77.5	-0.604	-0.6	7.230
0	B4 Jan 13-14 2015	B4	0	1/13/2015	4	MEAN	1.1	1759	11.3	-11.5	17.0	37.5	0.109	0.1	7.473
0	B5 Jan 15-16 2015	B5	0	1/15/2015	4	MEAN	1.3	1682	24.6	-4.1	17.0	51.5	0.270	0.3	7.428
0	B6 Jan 17-18 2015	B6	0	1/17/2015	4	MEAN	1.1	1523	36.5	2.5	15.0	68	0.124	0.1	7.328
0	B7 Feb 15-16 2015	B7	0	2/19/2015	4	MEAN	1.5	2026	-2.22	-19.0	17.5	50.5	0.381	0.4	7.614
0	B8 Feb 22-23 2015	B8	0	2/22/2015	4	MEAN	1.1	1726	-0.22	-17.9	15	49	0.058	0.1	7.453
0	APC1 Dec 11-12 2014	APC1	1	12/11/2014	4	MEAN	0.2	1084	30.7	-0.7	6.0	41	-1.470	-1.5	6.988
0	APC2 Dec 17-18 2014	APC2	1	12/17/2014	4	MEAN	0.2	1097	17.9	-7.9	6.0	37.5	-1.545	-1.5	7.000
0	APC3 Dec 23-24 2014	APC3	1	12/23/2014	4	MEAN	0.0	1028	35.6	2.0	6.0	36	-4.500	-4.5	6.936
0	APC4 Dec 29-30 2014	APC4	1	12/29/2014	4	MEAN	0.1	591	16.3	-8.7	3.0	15	-2.811	-2.8	6.381
0	APC5 Jan 4-5 2015	APC5	1	1/4/2015	4	MEAN	0.3	1310	1.6	-16.9	15.5	0	-1.320	-1.3	7.178
0	APC6 Jan 10-11 2015	APC6	1	1/10/2015	4	MEAN	0.6	1378	19.5	-6.9	17.0	20.5	-0.590	-0.6	7.228
0	APC7 Jan 19-20 2015	APC7	1	1/19/2015	4	MEAN	0.4	1212	34.1	1.2	14.5	70.5	-0.831	-0.8	7.100
0	APC8 Jan 24-25 2015	APC8	1	1/24/2015	4	MEAN	1.0	1397	37.2	2.9	15.5	92.5	-0.048	0	7.242
0	APC9 Jan 29-30 2015	APC9	1	1/29/2015	4	MEAN	0.7	1373	27.0	-2.8	9.0	66	-0.307	-0.3	7.225
0	APC10 Feb 3-4 2015	APC10	1	2/3/2015	4	MEAN	1.4	1548	15.8	-9.0	9.0	55.5	0.320	0.3	7.345
0	APC11 Feb 9-10 2015	APC11	1	2/9/2015	4	MEAN	1.3	1482	22.8	-5.1	9.0	40.5	0.256	0.3	7.301
0	APC12 Feb 12-13 2015	APC12	1	2/15/2015	4	MEAN	1.6	1861	6.4	-14.2	18.0	17	0.454	0.5	7.529

APPENDIX C: SHAPIRO-WILK NORMALITY TEST RESULTS

The results of the UNIVARIATE PROCEDURE to generate descriptive statistics and assess whether or not CO and CO_2 concentrations were normally distributed when the old and new heaters were in operation. Eight-hour and 24-hour data were both assessed. This test was run using SAS v.9.3. (SAS Institute Inc., Cary, NC). SAS outputs are included below.

Combustion Gas Data from 8-hour averaged data set

The UNIVARIATE Procedure
Variable: CO (CO)
HEATER=OLD

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.984326	**Pr < W**	0.6996
Kolmogorov-Smirnov	**D**	0.060504	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.02852	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.20293	**Pr > A-Sq**	>0.2500

Combustion Gas Data from 8-hour averaged data set

The UNIVARIATE Procedure
Variable: CO (CO)
HEATER=NEW

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.932208	**Pr < W**	0.0025
Kolmogorov-Smirnov	**D**	0.145085	**Pr > D**	<0.0100
Cramer-von Mises	**W-Sq**	0.27251	**Pr > W-Sq**	<0.0050
Anderson-Darling	**A-Sq**	1.573067	**Pr > A-Sq**	<0.0050

Combustion Gas Data from 24-hour averaged data set

The UNIVARIATE Procedure
Variable: CO (CO)
HEATER=OLD

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.983008	**Pr < W**	0.9756
Kolmogorov-Smirnov	**D**	0.093676	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.017705	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.134806	**Pr > A-Sq**	>0.2500

Combustion Gas Data from 24-hour averaged data set

The UNIVARIATE Procedure
Variable: CO (CO)
HEATER=NEW

Moments

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.930109	**Pr < W**	0.1552
Kolmogorov-Smirnov	**D**	0.152941	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.086081	**Pr > W-Sq**	0.1663
Anderson-Darling	**A-Sq**	0.516224	**Pr > A-Sq**	0.1747

Combustion Gas Data from 8-hour averaged data set

The UNIVARIATE Procedure Variable: CO2 (CO2)

HEATER=OLD

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	W	0.963778	Pr < W	0.1018
Kolmogorov-Smirnov	D	0.122348	Pr > D	0.0429
Cramer-von Mises	W-Sq	0.094472	Pr > W-Sq	0.1333
Anderson-Darling	A-Sq	0.581173	Pr > A-Sq	0.1295

Combustion Gas Data from 8-hour averaged data set

The UNIVARIATE Procedure Variable: CO2 (CO2)

HEATER=NEW

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	W	0.974	Pr < W	0.2424
Kolmogorov-Smirnov	D	0.084	Pr > D	>0.1500
Cramer-von Mises	W-Sq	0.062	Pr > W-Sq	>0.2500
Anderson-Darling	A-Sq	0.433	Pr > A-Sq	>0.2500

Combustion Gas Data from 24-hour averaged data set

The UNIVARIATE Procedure Variable: CO2 (CO2)

HEATER=OLD

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.946736	**Pr < W**	0.3761
Kolmogorov-Smirnov	**D**	0.170267	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.066261	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.388372	**Pr > A-Sq**	>0.2500

Combustion Gas Data from 24-hour averaged data set

The UNIVARIATE Procedure Variable: CO2 (CO2)

HEATER=NEW

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.972996	**Pr < W**	0.8165
Kolmogorov-Smirnov	**D**	0.123856	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.036923	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.241877	**Pr > A-Sq**	>0.2500

Combustion Gas Data from 8-hour positional data set

The UNIVARIATE Procedure Variable: CO (CO)

Heater=NEW

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	W	0.949366	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.0969	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.417336	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	2.621696	Pr > A-Sq	<0.0050

Combustion Gas Data from 8-hour positional data set

The UNIVARIATE Procedure Variable: CO2 (CO2)

Heater=NEW

Tests for Normality

Test	Statistic		p Value	
Shapiro-Wilk	W	0.979239	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.049668	Pr > D	0.0334
Cramer-von Mises	W-Sq	0.18707	Pr > W-Sq	0.0080
Anderson-Darling	A-Sq	1.506378	Pr > A-Sq	<0.0050

Combustion Gas Data from 8-hour positional data set

The UNIVARIATE Procedure Variable: CO (CO)

Heater=OLD

Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.61538	**Pr < W**	<0.0001
Kolmogorov-Smirnov	**D**	0.241431	**Pr > D**	<0.0100
Cramer-von Mises	**W-Sq**	4.981117	**Pr > W-Sq**	<0.0050
Anderson-Darling	**A-Sq**	28.15613	**Pr > A-Sq**	<0.0050

Combustion Gas Data from 8-hour positional data set

The UNIVARIATE Procedure Variable: CO (CO)

Heater=OLD

Tests for Normality

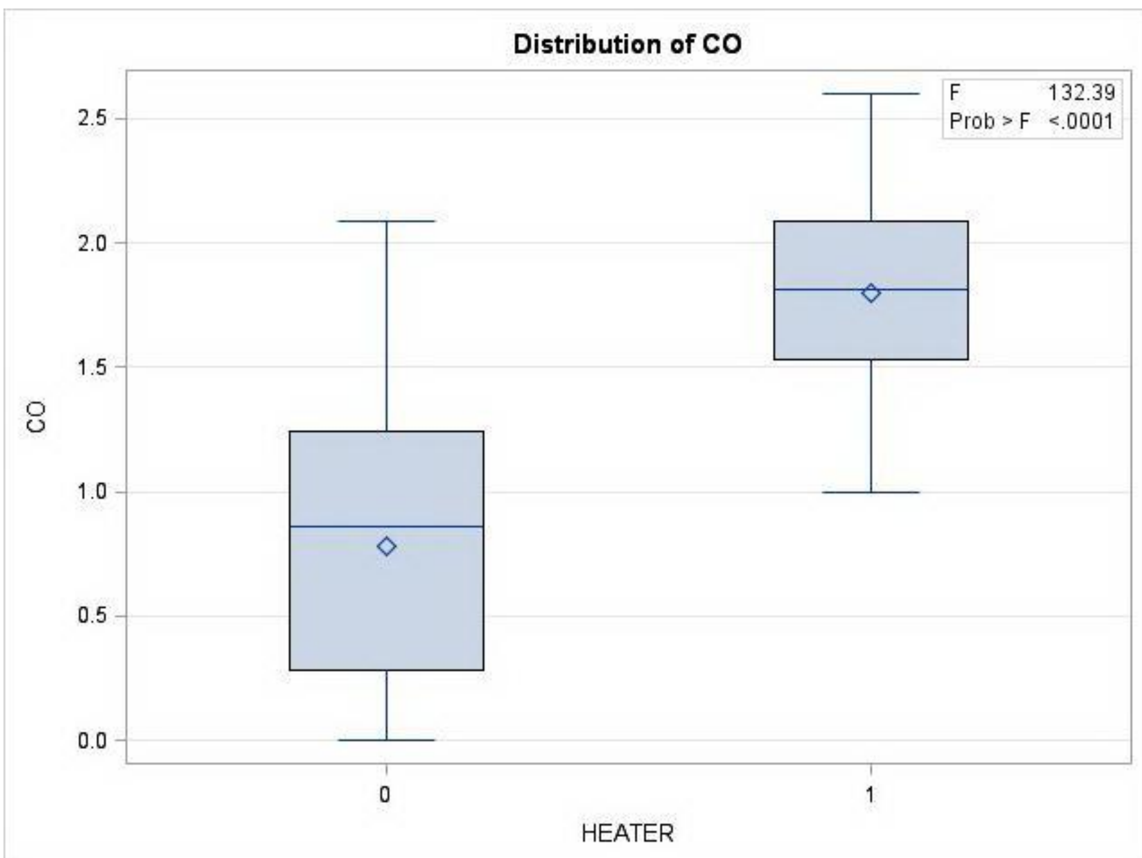
Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.977911	**Pr < W**	<0.0001
Kolmogorov-Smirnov	**D**	0.064514	**Pr > D**	<0.0100
Cramer-von Mises	**W-Sq**	0.274615	**Pr > W-Sq**	<0.0050
Anderson-Darling	**A-Sq**	1.784197	**Pr > A-Sq**	<0.0050

APPENDIX D: ANALYSIS OF CONCENTRATIONS BETWEEN YEARS

The GLM PROCEDURE was used to perform a one-way ANOVA test to compare CO and CO_2 mean concentrations when the old and new heaters were in operation. Eight-hour and 24-hour average data was assessed. This test was run using SAS v.9.3. (SAS Institute Inc., Cary, NC). SAS outputs are included below.

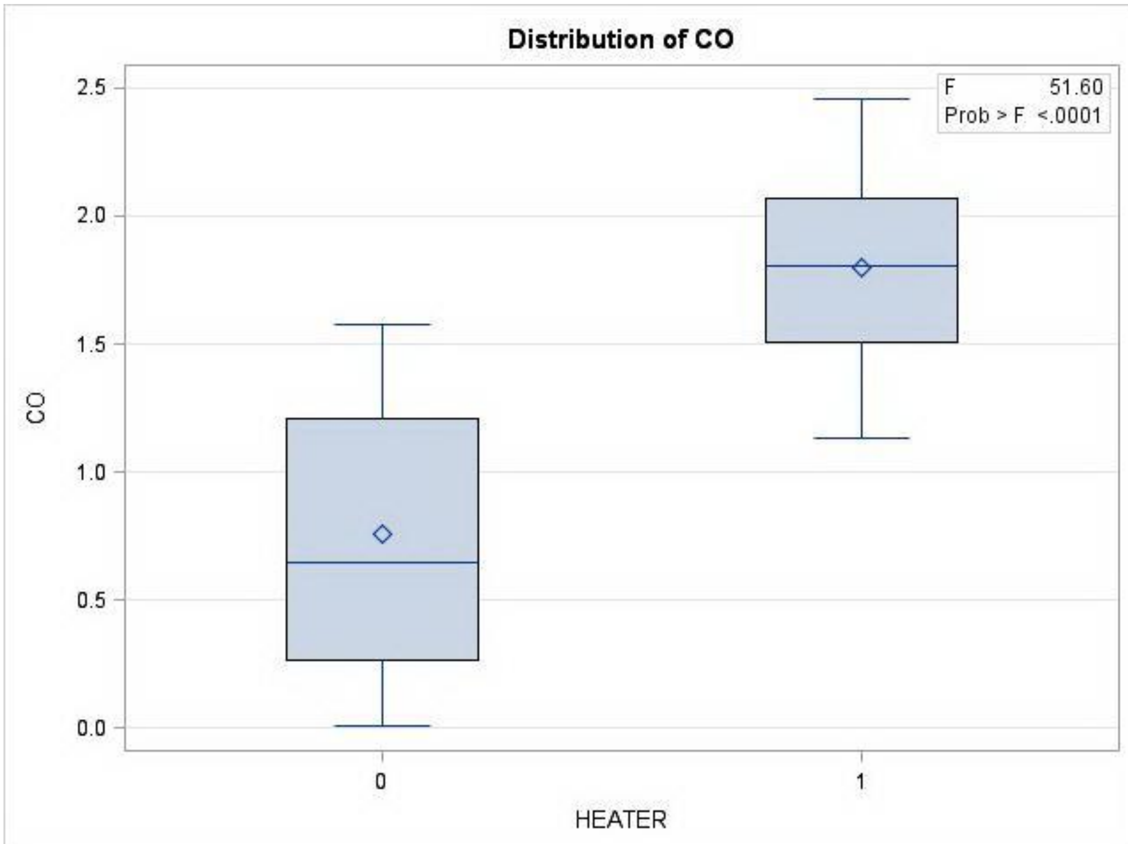
Analysis of Concentrations by Heater Type - 8 Hour
The GLM Procedure
Dependent Variable: CO

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HEATER	1	29.37531242	29.37531	132.39	<.0001



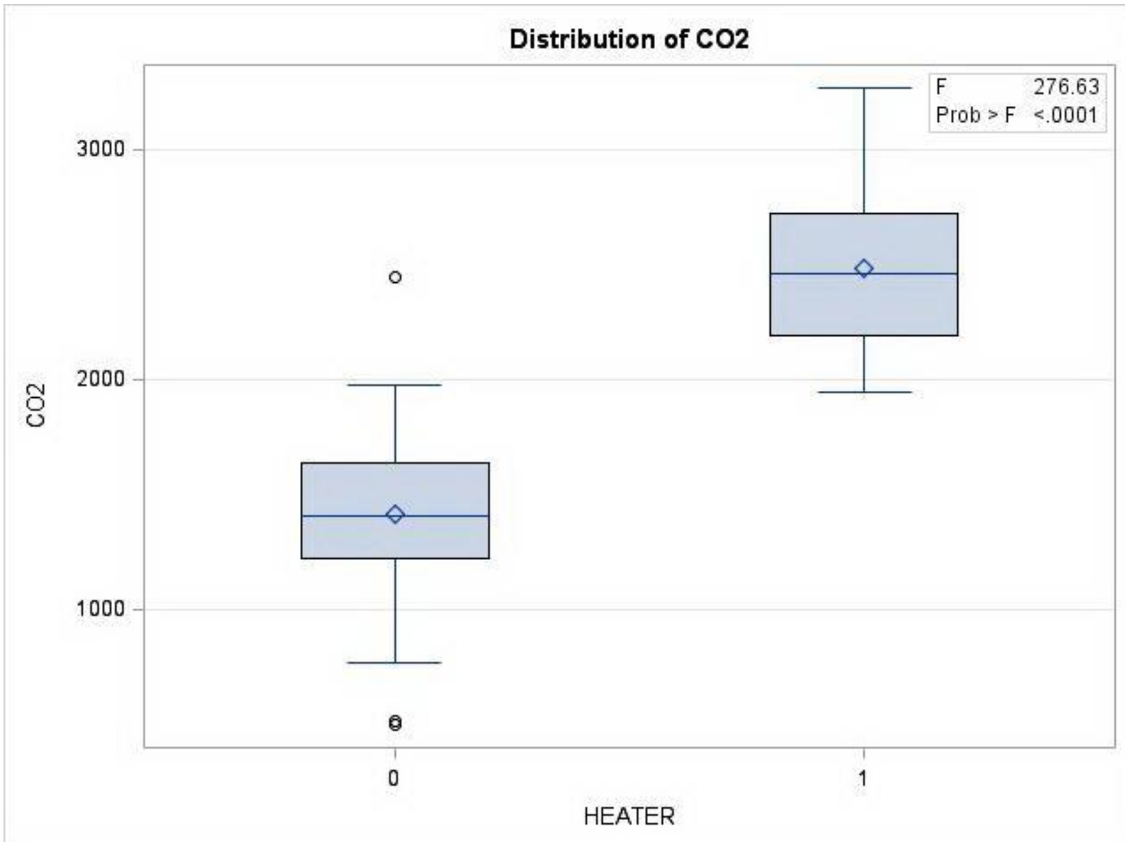
Analysis of Concentrations by Heater Type - 24 Hour
The GLM Procedure
Dependent Variable: CO

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HEATER	1	10.21056804	10.21056804	51.60	<.0001



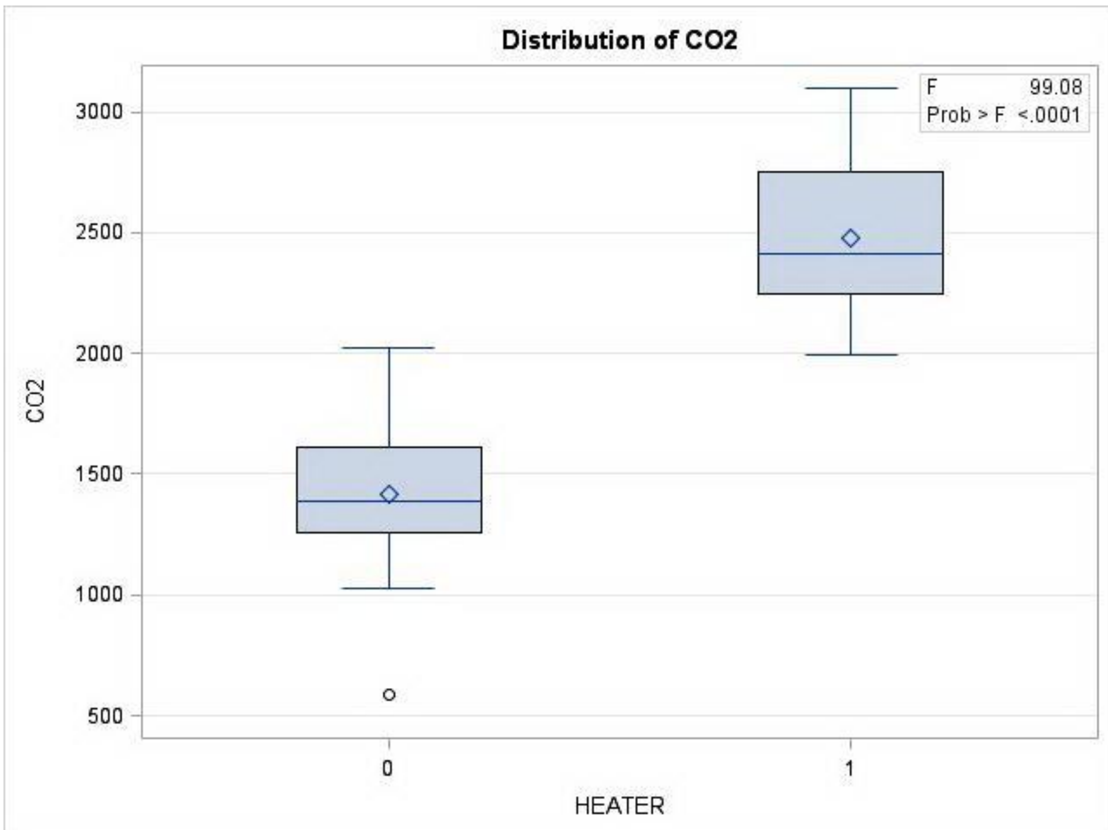
Analysis of Concentrations by Heater Type - 8 Hour
The GLM Procedure
Dependent Variable: CO2

Source	DF	Type I SS	Mean Square	F Value	Pr > F
HEATER	1	32233483.49	32233483.4	276.63	<.0001



Analysis of Concentrations by Heater Type - 24 Hour
The GLM Procedure
Dependent Variable: CO2

Source	DF	Type I SS	Mean	F Value	Pr > F
HEATER	1	10662839.03	10662839.03	99.08	<.0001



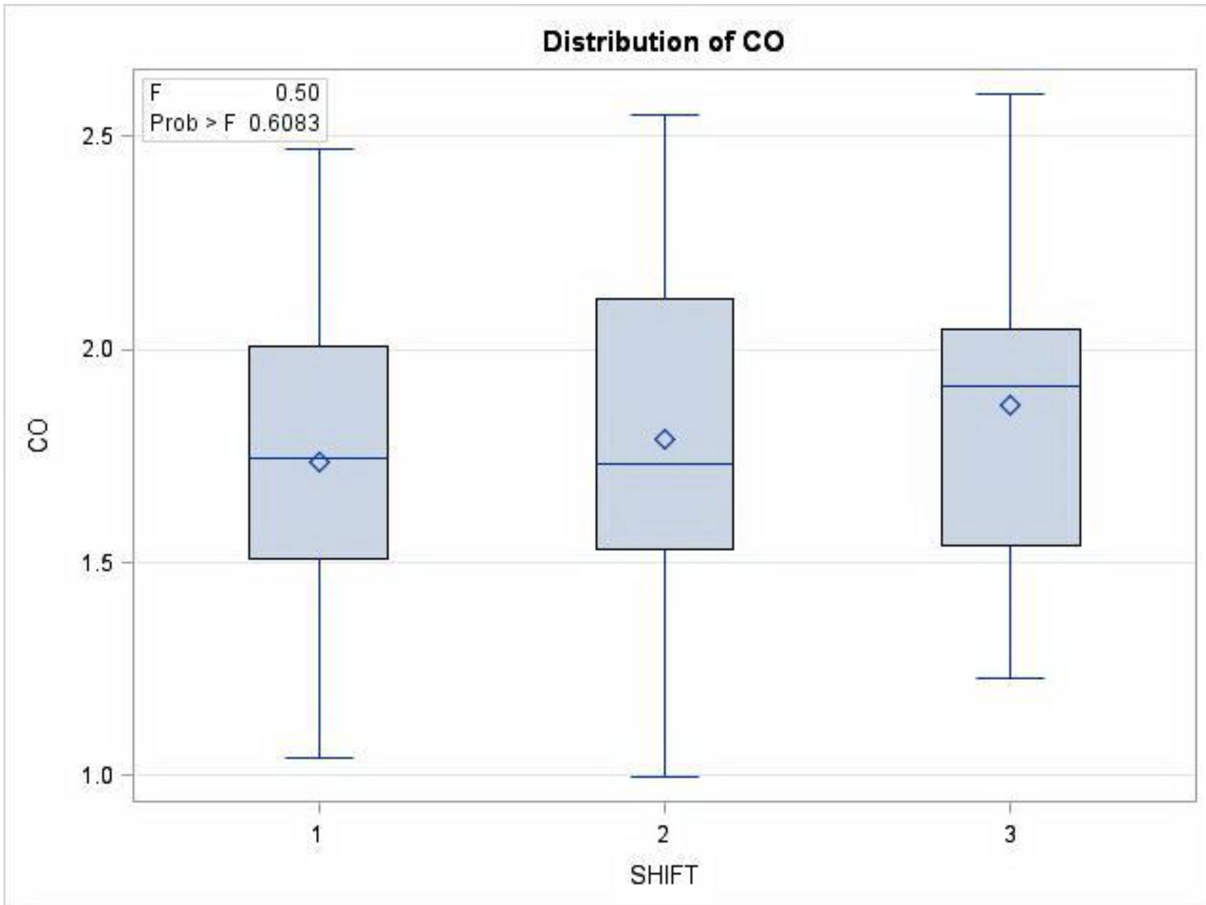
APPENDIX E: ANALYSIS OF CONCENTRATIONS BY SHIFT

The GLM PROCEDURE was used to perform a Tukey-Kramer pairwise comparison and assess differences in CO and CO_2 concentrations by shift when the old and new heaters were in operation. The NPAR1WAY was used to perform a Kruskal-Wallis test to compare differences in data that were not normally distributed. These tests were run using SAS v.9.3. (SAS Institute Inc., Cary, NC). SAS outputs are included below.

Analysis of Concentrations by Shift
The GLM Procedure
Dependent Variable: CO
Heater=OLD

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SHIFT	2	0.16031070	0.08015535	0.50	0.6083

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 vs 2	1	0.02285136	0.02285136	0.14	0.7068
2 vs 3	1	0.06027025	0.06027025	0.38	0.5417
1 vs 3	1	0.15734444	0.15734444	0.99	0.3256
1&2 vs 3	1	0.13745934	0.13745934	0.86	0.3579
1 vs 2&3	1	0.10004045	0.10004045	0.63	0.4323


Distribution of CO
F 0.50
Prob > F 0.6083
2.5
2.0
1.5
1.0
CO
1
2
3
SHIFT

Analysis of Concentrations by Shift
The NPAR1WAY Procedure
Dependent Variable: CO
Heater=NEW

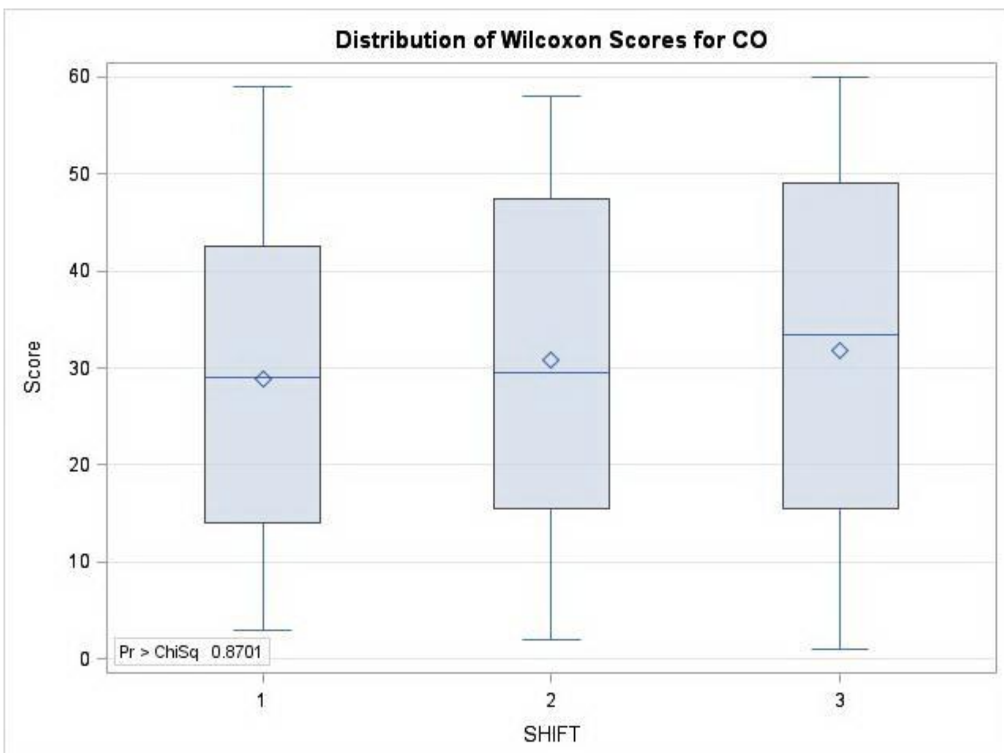
Wilcoxon Scores (Rank Sums) for Variable CO Classified by Variable SHIFT

SHIFT	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
1	20	578.0	610.0	63.767764	28.900
2	20	617.0	610.0	63.767764	30.850
3	20	635.0	610.0	63.767764	31.750

Average scores were used for ties.

Kruskal-Wallis Test

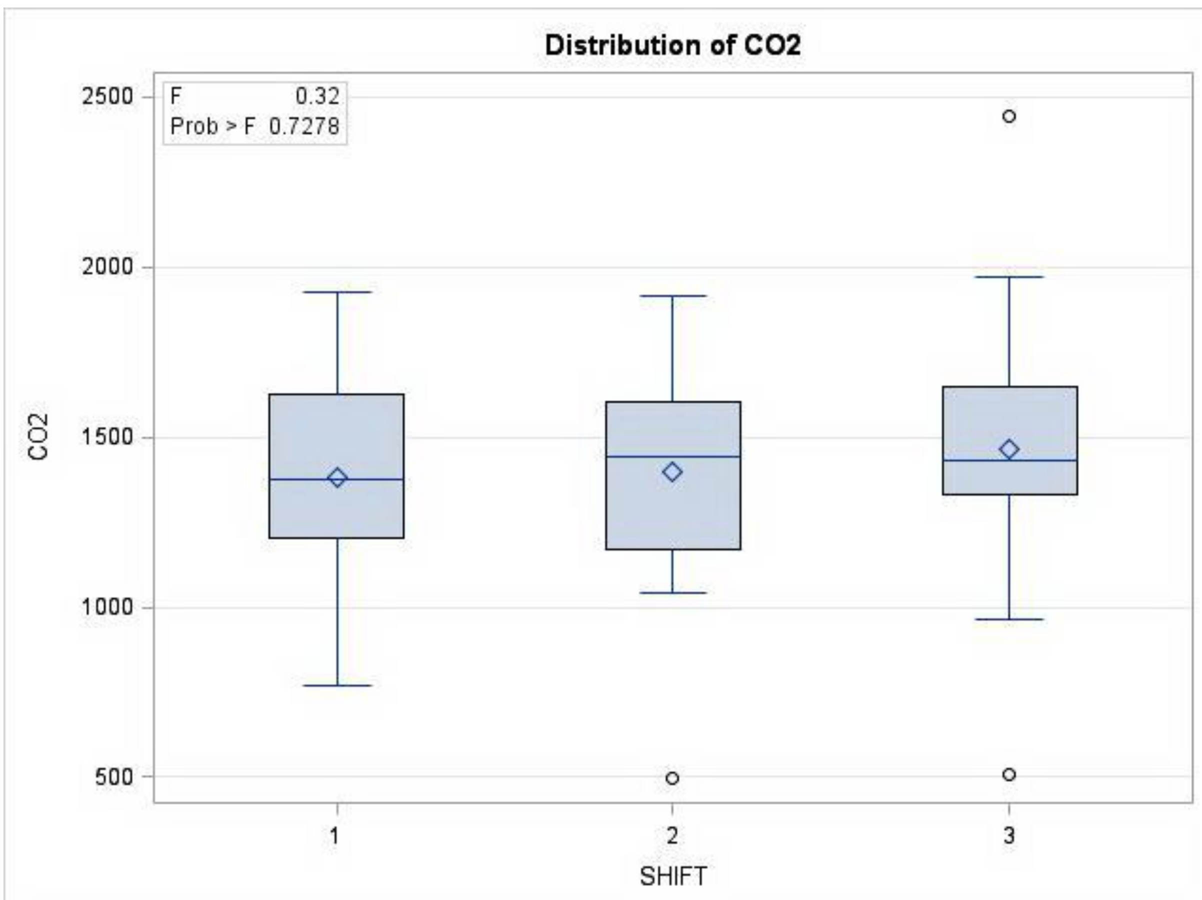
Chi-Square	0.2784
DF	2
Pr > Chi-	0.8701



Analysis of Concentrations by Shift
The GLM Procedure
Dependent Variable: CO2
Heater=OLD

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SHIFT	2	55735.53560	27867.76780	0.23	0.7925

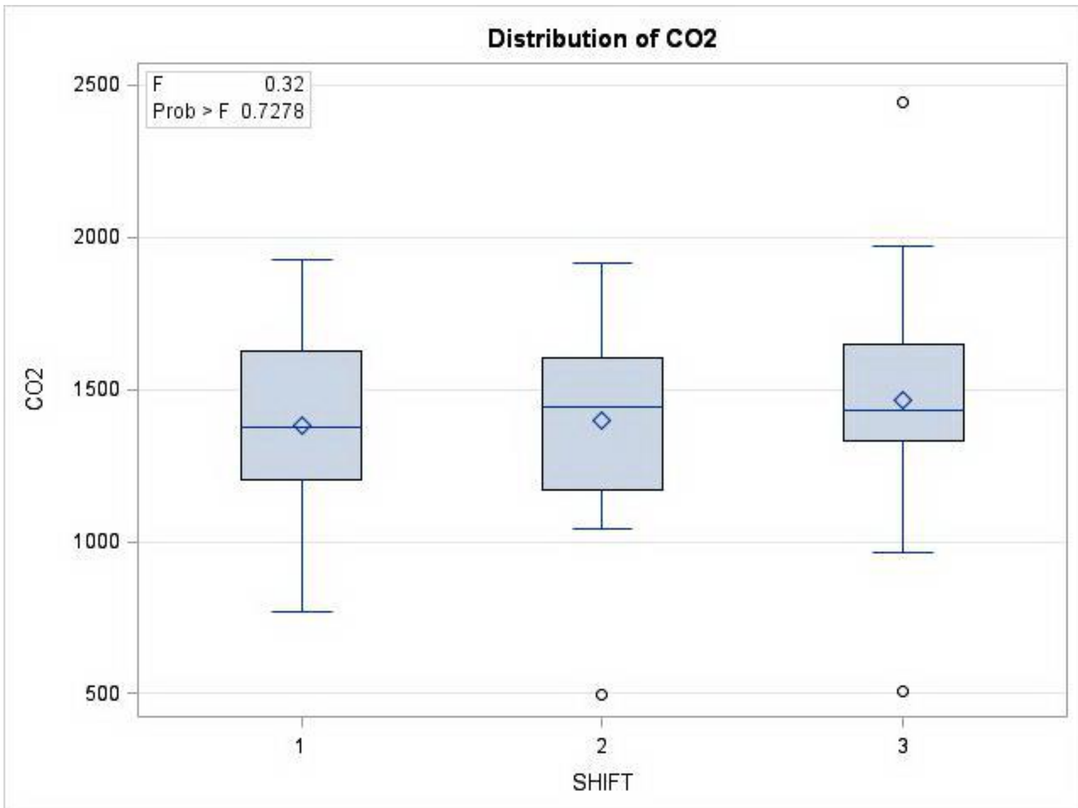
Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 vs 2	1	3246.38191	3246.38191	0.03	0.8696
2 vs 3	1	51483.32162	51483.32162	0.43	0.5142
1 vs 3	1	28873.59987	28873.59987	0.24	0.6249
1&2 vs 3	1	52489.15369	52489.15369	0.44	0.5101
1 vs 2&3	1	4252.21398	4252.21398	0.04	0.8510



Analysis of Concentrations by Shift
The GLM Procedure
Dependent Variable: CO2
Heater=NEW

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SHIFT	2	76598.86498	38299.43249	0.32	0.7278

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 vs 2	1	2349.46676	2349.46676	0.02	0.8892
2 vs 3	1	44836.10824	44836.10824	0.37	0.5433
1 vs 3	1	67712.72247	67712.72247	0.56	0.4554
1&2 vs 3	1	74249.39822	74249.39822	0.62	0.4345
1 vs 2&3	1	31762.75674	31762.75674	0.26	0.6087

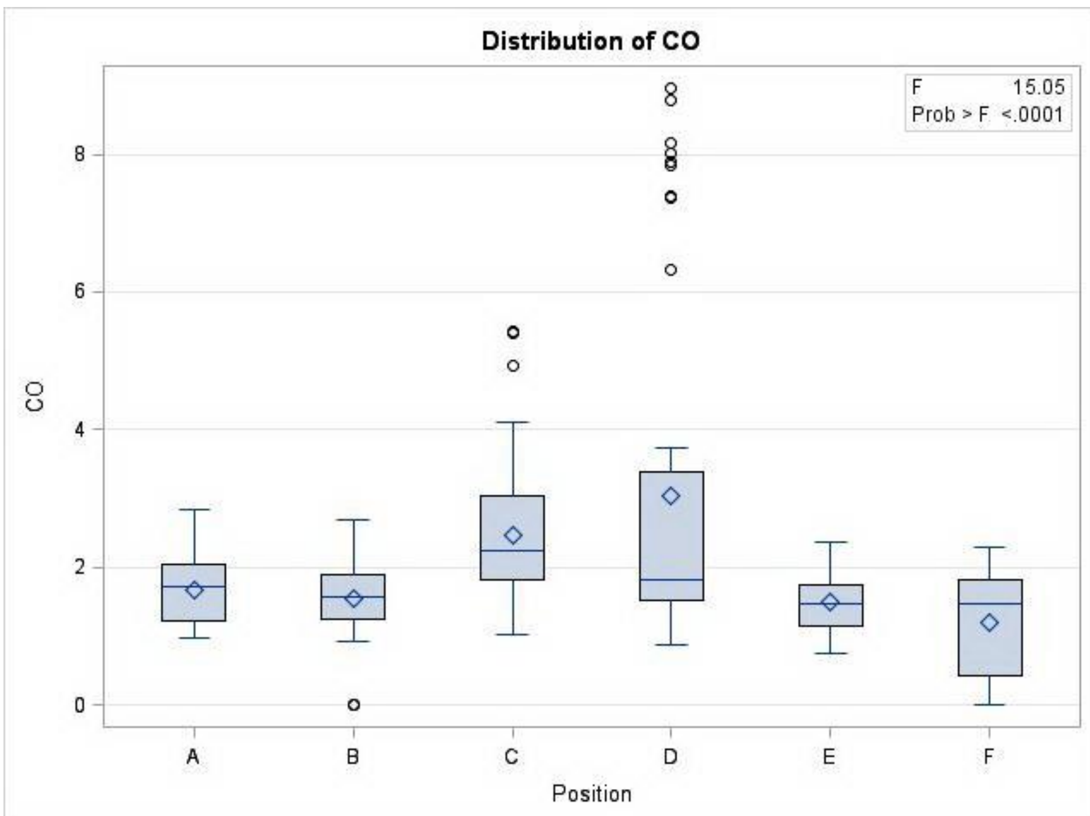


APPENDIX F: ANALYSIS OF CONCENTRATIONS BY POSITION

The GLM PROCEDURE was used to perform a Tukey-Kramer pairwise comparison and assess differences in CO and CO_2 concentrations, by position, when the old heaters and new heaters were in operation. Eight-hour and 24-hour data were assessed. The NPAR1WAY PROCEDURE was used to perform a Kruskal-Wallis test to assess differences in position for eight-hour new heater data (not normally distributed). These tests were run using SAS v.9.3. (SAS Institute Inc., Cary, NC). SAS outputs are included below.

Analysis of Concentrations by Position - 8 Hour
The GLM Procedure
Dependent Variable: CO
Heater=OLD

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	106.0345267	21.2069053	15.05	<.0001



Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Position	CO	LSMEAN
A	1.66190196	1
B	1.55298148	2
C	2.46638298	3
D	3.02929167	4
E	1.49415094	5
F	1.19029167	6

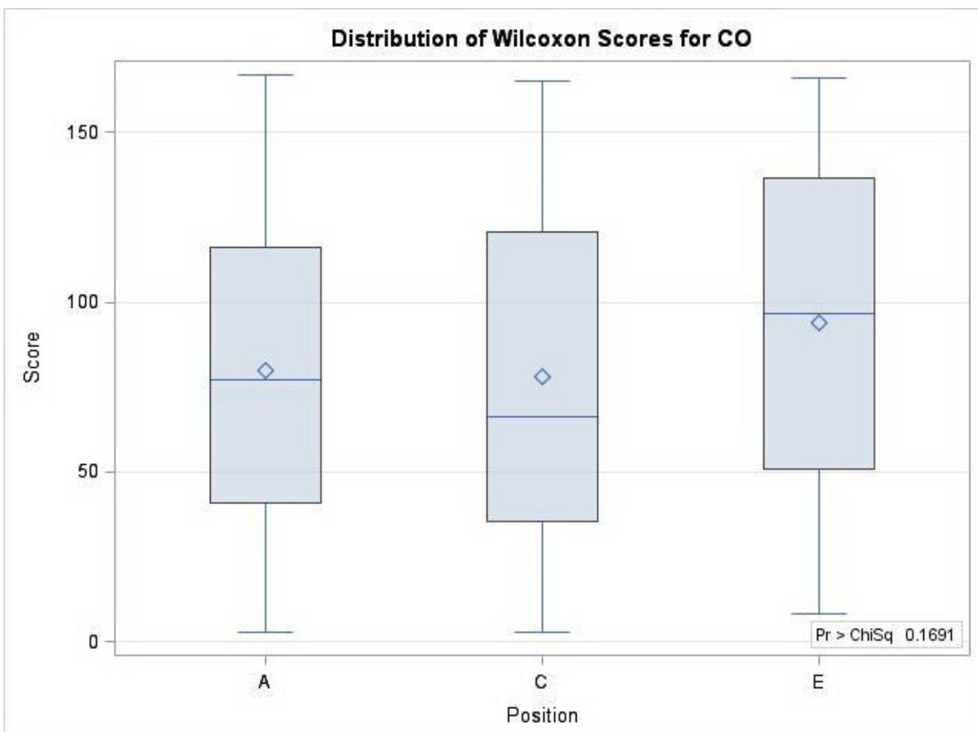
Least Squares Means for effect Position Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: CO

i/j	1	2	3	4	5	6
1		0.9971	0.0117	<.0001	0.9794	0.5961
2	0.9971		0.0020	<.0001	0.9998	0.8141
3	0.0117	0.0020		0.1934	0.0008	0.0004
4	<.0001	<.0001	0.1934		<.0001	<.0001
5	0.9794	0.9998	0.0008	<.0001		0.9039

Analysis of Concentrations by Position - 8 Hour
The NPAR1WAY Procedure
Dependent Variable: CO
Heater=NEW

Wilcoxon Scores (Rank Sums) for Variable CO Classified by Variable Position					
Position	**N**	**Sum of Scores**	**Expected Under H0**	**Std Dev Under H0**	**Mean Score**
A	55	4397.0	4620.0	293.662694	79.945455
C	56	4374.0	4704.0	294.994505	78.107143
E	56	5257.0	4704.0	294.994505	93.875000
Average scores were used for ties.					

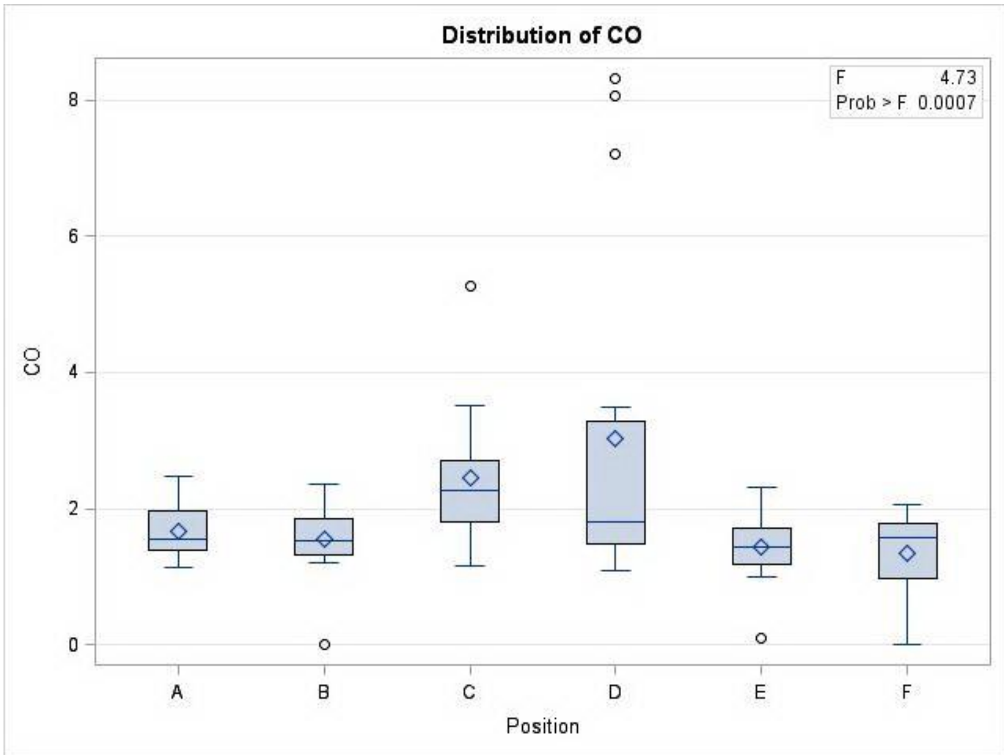
Kruskal-Wallis Test	
Chi-Square	3.5543
DF	2
Pr > Chi-	0.1691



Analysis of Concentrations by Position - 24 Hour

The GLM Procedure
Dependent Variable: CO
Heater=OLD

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	33.91858262	6.78371652	4.73	0.0007



Least Squares Means

Adjustment for Multiple Comparisons: Tukey-Kramer

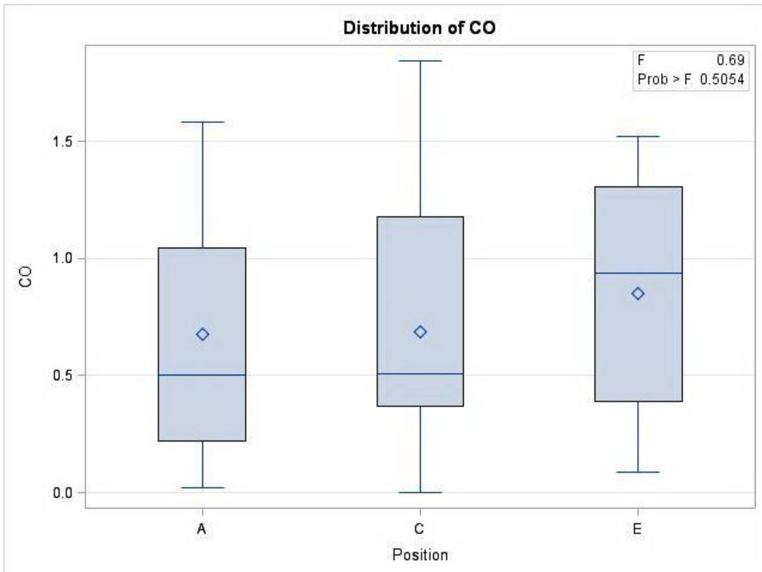
Position	CO	LSMEAN
A	1.66411765	1
B	1.55000000	2
C	2.44687500	3
D	3.02437500	4
E	1.43694444	5
F	1.35314286	6

Least Squares Means for effect Position Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: CO

i/j	1	2	3	4	5	6
1		0.9998	0.4240	0.0193	0.9933	0.9922
2	0.9998		0.2584	0.0072	0.9997	0.9991
3	0.4240	0.2584		0.7485	0.1499	0.3428
4	0.0193	0.0072	0.7485		0.0029	0.0322
5	0.9933	0.9997	0.1499	0.0029		1.0000
6	0.9922	0.9991	0.3428	0.0322	1.0000	

Analysis of Concentrations by Position - 24 Hour
The GLM Procedure
Dependent Variable: CO
Heater=NEW

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	2	0.34746447	0.17373223	0.69	0.5054



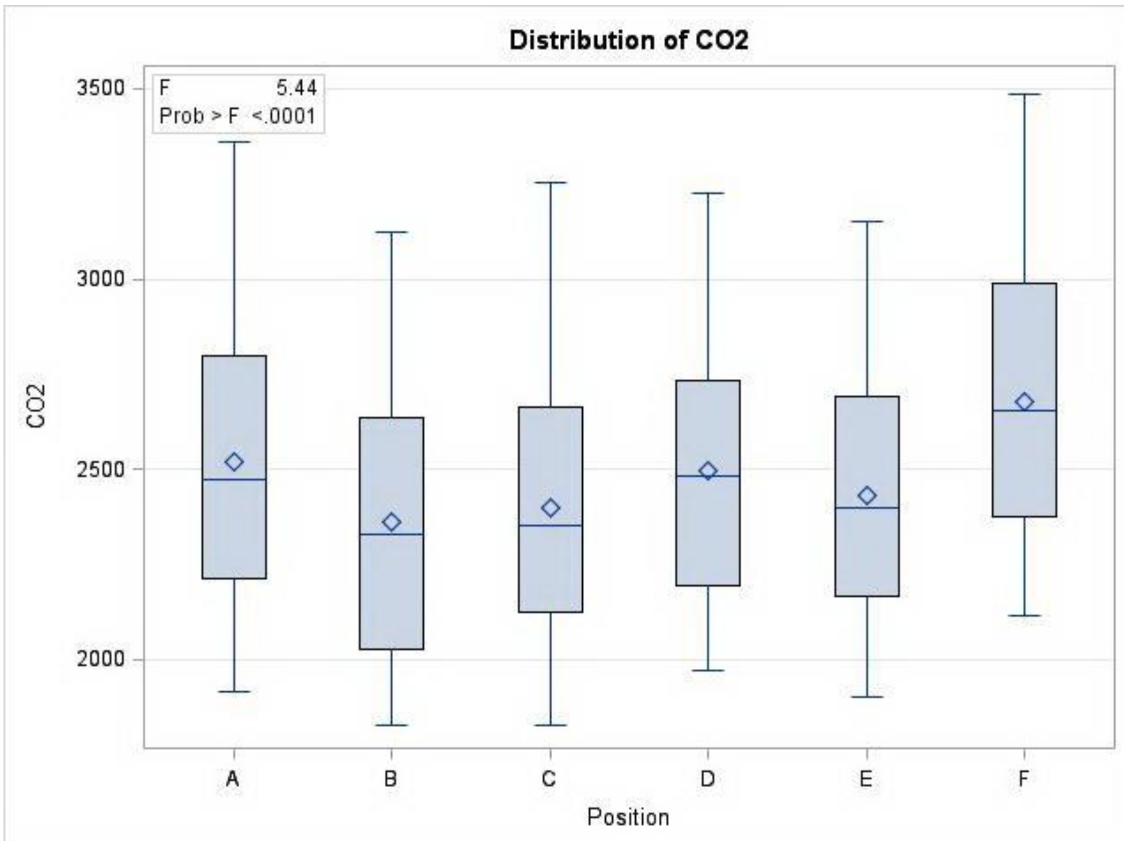
Position	CO	LSMEAN
A	0.67783012	1
C	0.68531685	2
E	0.85010772	3

Least Squares Means for effect Position Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: CO

i/j	1	2	3
1		0.9988	0.5523
2	0.9988		0.5805
3	0.5523	0.5805	

Analysis of Concentrations by Position - 8 Hour
The GLM Procedure
Dependent Variable: CO2
Heater=OLD

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	3360914.321	672182.864	5.44	<.0001



Least Squares Means

Adjustment for Multiple Comparisons: Tukey-Kramer

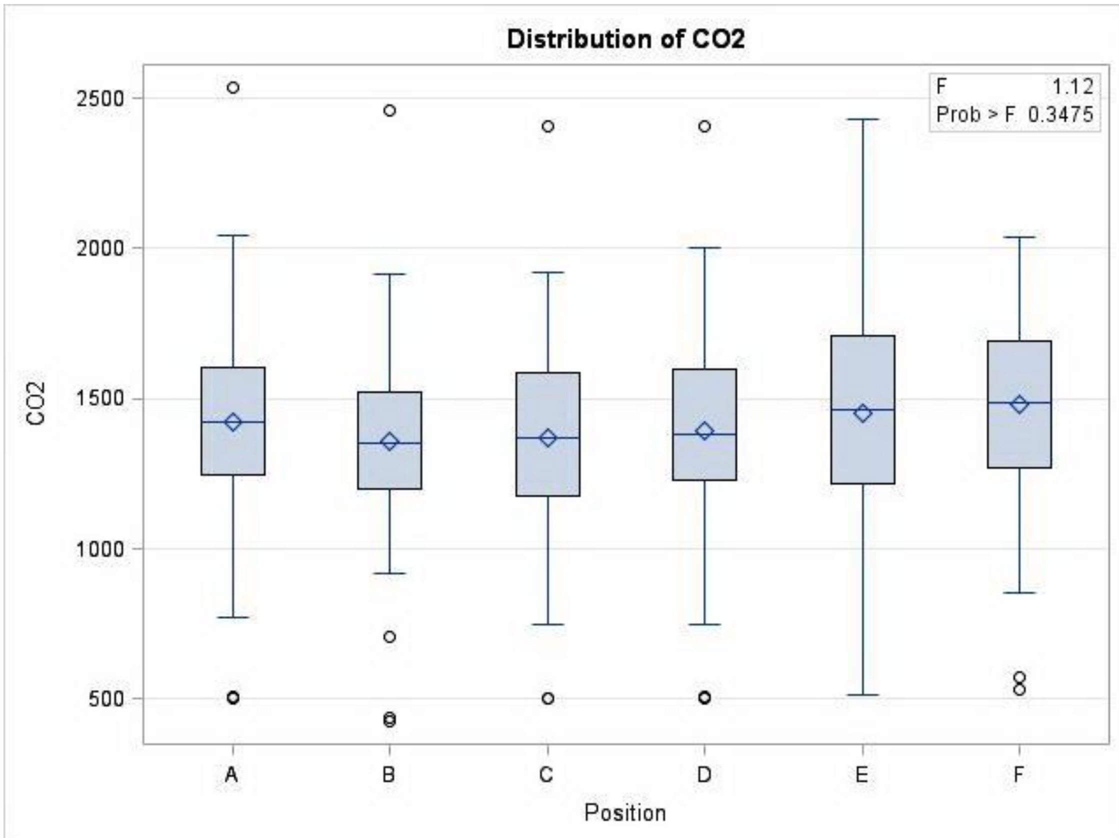
Position	CO2	LSMEAN
A	2518.06574	1
B	2361.70321	2
C	2400.52232	3
D	2494.40956	4
E	2431.95933	5
F	2677.31002	6

Least Squares Means for effect Position Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: CO2

i/j	1	2	3	4	5	6
1		0.1923	0.5186	0.9994	0.7995	0.1800
2	0.1923		0.9930	0.3834	0.9045	<.0001
3	0.5186	0.9930		0.7534	0.9974	0.0010
4	0.9994	0.3834	0.7534		0.9438	0.0879
5	0.7995	0.9045	0.9974	0.9438		0.0048
6	0.1800	<.0001	0.0010	0.0879	0.0048	

Analysis of Concentrations by Position - 8 Hour
The GLM Procedure
Dependent Variable: CO2
Heater=NEW

Source	DF	Type I SS	Mean Square	F Value	Pr >
Position	5	677976.8713	135595.3743	1.12	0.347



Least Squares Means

Adjustment for Multiple Comparisons: Tukey-Kramer

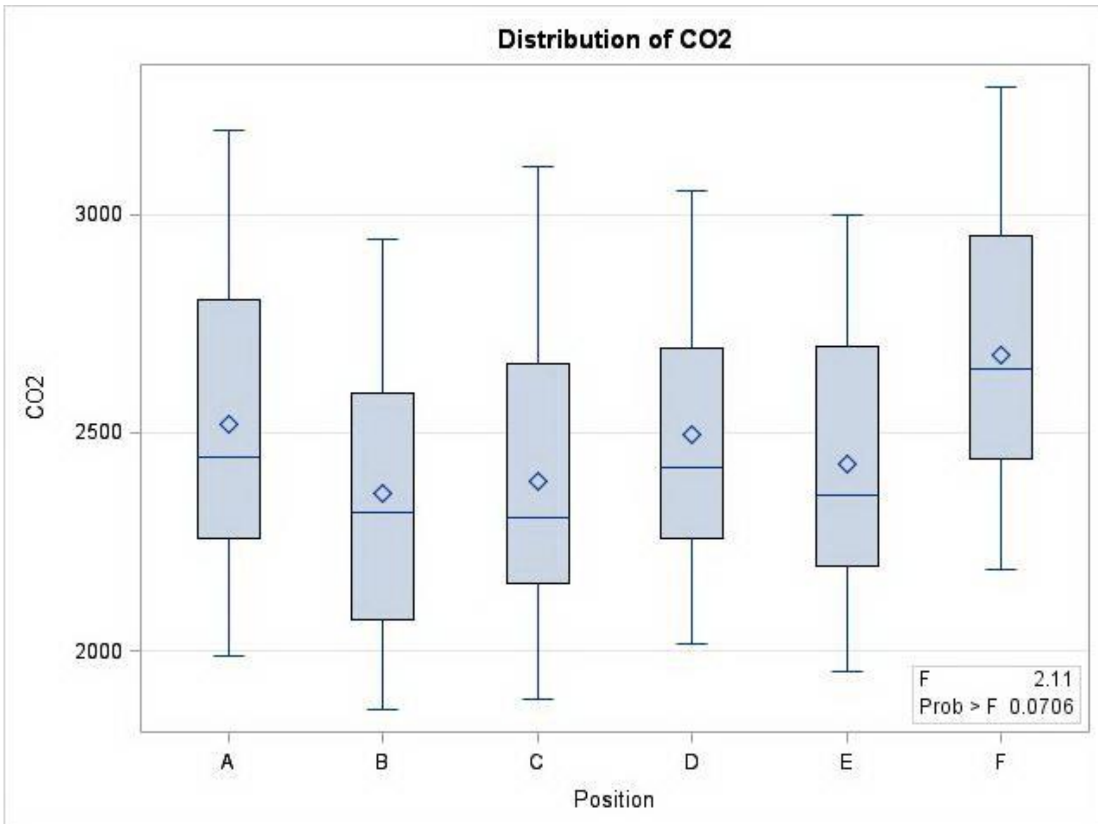
Position	CO_2	LSMEAN
A	1424.53927	1
B	1358.61571	2
C	1369.27862	3
D	1393.55544	4
E	1454.29787	5
F	1478.88784	6

Least Squares Means for effect Position Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: CO2

i/j	1	2	3	4	5	6
1		0.9043	0.9539	0.9970	0.9973	0.9563
2	0.9043		1.0000	0.9947	0.6673	0.4062
3	0.9539	1.0000		0.9991	0.7719	0.5189
4	0.9970	0.9947	0.9991		0.9400	0.7797
5	0.9973	0.6673	0.7719	0.9400		0.9989
6	0.9563	0.4062	0.5189	0.7797	0.9989	

Analysis of Concentrations by Position - 24 Hour
The GLM Procedure
Dependent Variable: CO2
Heater=OLD

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	1198934.401	239786.880	2.11	0.0706



Least Squares Means

Adjustment for Multiple Comparisons: Tukey-Kramer

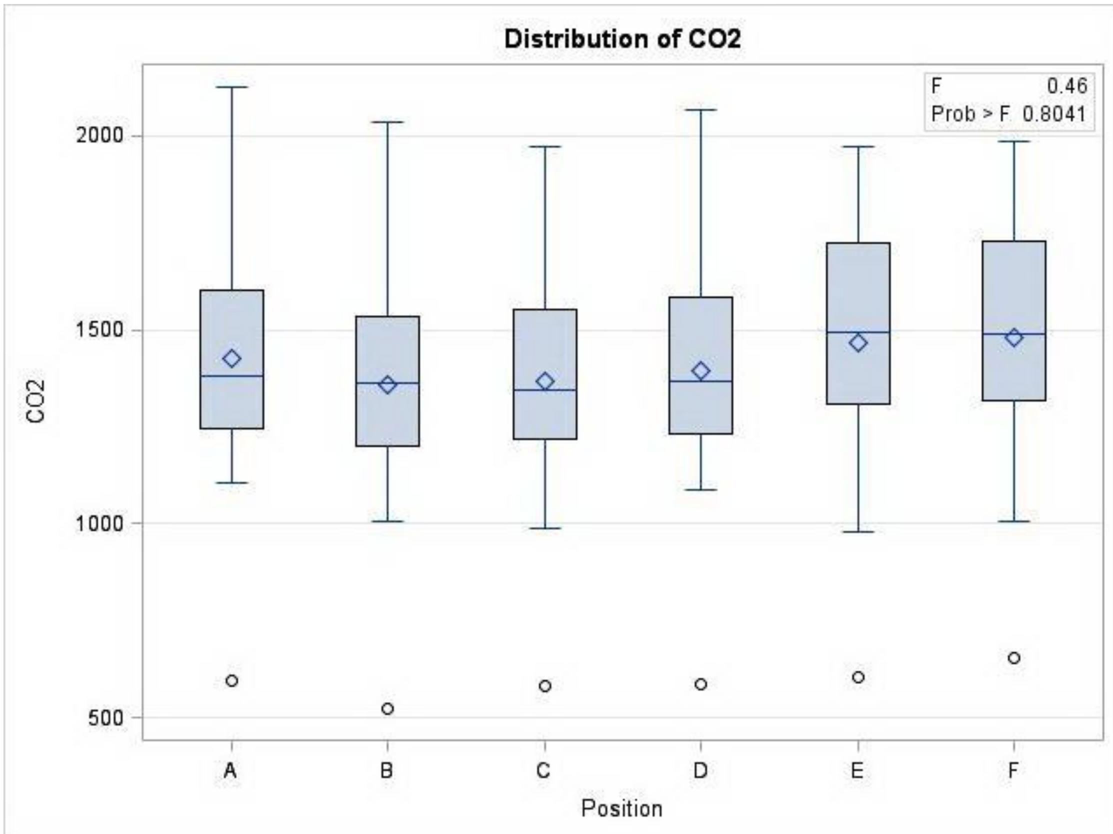
Position	CO_2	LSMEAN
A	2518.23655	1
B	2361.55653	2
C	2387.67826	3
D	2494.33706	4
E	2427.14499	5
F	2679.08012	6

Least Squares Means for effect Position Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: CO2

i/j	1	2	3	4	5	6
1		0.7309	0.8541	0.9999	0.9651	0.7085
2	0.7309		0.9999	0.8528	0.9919	0.0618
3	0.8541	0.9999		0.9365	0.9993	0.1088
4	0.9999	0.8528	0.9365		0.9916	0.5878
5	0.9651	0.9919	0.9993	0.9916		0.2288
6	0.7085	0.0618	0.1088	0.5878	0.2288	

Analysis of Concentrations by Position - 24 Hour
The GLM Procedure
Dependent Variable: CO2
Heater=NEW

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Position	5	252611.5704	50522.3141	0.46	0.8041



Least Squares Means

Adjustment for Multiple Comparisons: Tukey-Kramer

Position	CO_2 LSMEAN	LSMEAN Number
A	1424.53223	1
B	1359.06677	2
C	1367.56768	3
D	1393.54625	4
E	1466.61982	5
F	1478.90212	6

Least Squares Means for effect Position Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: CO_2

i/j	1	2	3	4	5	6
1		0.9889	0.9942	0.9997	0.9986	0.9953
2	0.9889		1.0000	0.9995	0.9076	0.8612
3	0.9942	1.0000		0.9999	0.9333	0.8944
4	0.9997	0.9995	0.9999		0.9838	0.9680
5	0.9986	0.9076	0.9333	0.9838		1.0000
6	0.9953	0.8612	0.8944	0.9680	1.0000	

Non-parametric Kruskal-Wallis for CO2 8 hour position

The NPAR1WAY Procedure

Heater=NEW

Kruskal-Wallis Test	
Chi-Square	8.6108
DF	5
Pr > Chi-Square	0.1256

Non-parametric Kruskal-Wallis for CO2 8 hour position

The NPAR1WAY Procedure

Heater=OLD

Kruskal-Wallis Test	
Chi-Square	22.8275
DF	5
Pr > Chi-Square	0.0004

Non-parametric Kruskal-Wallis for CO 8 hour position

The NPAR1WAY Procedure

Heater=NEW

Kruskal-Wallis Test	
Chi-Square	3.5543
DF	2
Pr > Chi-Square	0.1691

Non-parametric Kruskal-Wallis for CO 8 hour position

The NPAR1WAY Procedure

Heater=OLD

Kruskal-Wallis Test	
Chi-Square	48.8002
DF	5
Pr > Chi-Square	<.0001

APPENDIX G: LINEAR REGRESSION ANALYSIS

The REG PROCEDURE was used to perform a linear regression analysis to determine which factors significantly contributed to CO_2 concentrations during both years. This test was run using SAS v.9.3. (SAS Institute Inc., Cary, NC). SAS outputs are included below.

Linear Regression Analysis
The REG Procedure
Dependent Variable: CO2
Heater=OLD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1592320	530773	27.59	<.0001
Error	14	269355	19240		
Corrected	17	1861676			

Root MSE	138.70714	**R-Square**	0.8553
Dependent	2475.62935	**Adj R-Sq**	0.8243
Coeff Var	5.60290		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	1718.89192	114.43070	15.02	<.0001
Ctemp	Ctemp	1	-36.87870	5.05293	-7.30	<.0001
SOW	SOW	1	16.82170	8.72355	1.93	0.0743
SWINE	SWINE	1	2.80233	1.07528	2.61	0.0207

Linear Regression Analysis
The REG Procedure
Dependent Variable: CO2
Heater=NEW

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1510484	503495	16.04	<.0001
Error	16	502143	31384		
Corrected	19	2012626			

Root MSE	177.15509	**R-Square**	0.7505
Dependent	1414.72318	**Adj R-Sq**	0.7037
Coeff Var	12.52224		

Parameter Estimates

Variable	Label	DF	arameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	482.56054	151.99141	3.17	0.0059
Ctemp	Ctemp	1	-22.37390	8.10915	-2.76	0.0140
SOW	SOW	1	42.67757	9.80118	4.35	0.0005
SWINE	SWINE	1	5.65307	2.17900	2.59	0.0196

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