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Environmental measurements in swine confinement housing

Daniel B. McKinney

To the Graduate Council:

I am submitting herewith a thesis written by Daniel B. McKinney entitled "Environmental measurements in swine confinement housing." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Luther R. Wilhelm, Major Professor

We have read this thesis and recommend its acceptance:

Alan Mathew, John Wilkerson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Environmental Measurements in Swine Confinement Housing

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Daniel B. McKinney
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ABSTRACT

In this study, air quality measurements were made in swine production confinement facilities to monitor the internal environment. Two buildings were monitored throughout most of this study. The two buildings were identical except for the use of a pit ventilation system in one of the buildings (Barn B). The main focus of the monitoring system used in this study consisted of electrochemical gas sensors to continuously measure gas concentration levels (ppm) at human level (2 m). The gases measured were Oxygen, Carbon Monoxide, and Ammonia and Hydrogen Sulfide, which are the major gases of concern. Other measurements included that of environmental conditions, such as temperature, relative humidity, and solar radiation, and other key factors affecting gas levels, including monitoring the building's ventilation system. Data were averaged over each 30-minute period and recorded by a data logger. These data were then transmitted by the use of a cellular communication/modem system to the department at the university, which was located more than 300 miles away from the research site.

Results obtained from this study found the major manure gases, ammonia and hydrogen sulfide, to be consistently lower in the pit ventilated building (Barn B) when compared to the non-pit ventilated building (Barn A). Gas levels were monitored over two successive winters, when ventilation levels were at their lowest due to environmental conditions. Significant differences ($p < 0.05$) were found between gas levels taken in the two buildings and levels were found to change, most of the time, inversely proportional

to that of temperature. Gas levels were found to be directly affected by ventilation levels during cold weather, as found when monitoring the ventilation operating frequency. As ventilation levels were decreased in response to cold weather, gas levels increased due to accumulations of levels within the "closed" unit and vice/versa.

Measurements were also taken at the pit exhaust and inside the pit ventilated Barn B. As expected, levels of ammonia and hydrogen sulfide were found to be significantly higher ($p < 0.05$) at the pit exhaust area when compared to levels taken inside. These measurements were taken during the warm summer months, when ventilation rates were high; and gas levels were found to be directly proportional to temperature.

Measurements were also taken at animal level to see if there were differences in gas concentrations between animal and human (2 m) level. Slight differences were found between the two areas of measurement, but reliable conclusions cannot be made about why differences occurred between high and low measurements because of the inconsistent data collected.

Overall, the environments within the swine confinement units were found to be very cyclical and dependent upon environmental conditions and changes in ventilation. The use of a pit ventilation system was found to be beneficial in the control of manure gases, especially during periods of cold weather, when ventilation rates were low.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

Figure Page

CHAPTER I

INTRODUCTION

1. Background

Production of poultry and livestock in the southern region of the United States represents a major source of income and accounts for a large portion of the U.S. agriculture production. Seventy-eight percent of the 5.5 billion broilers, 37% of the 260 million turkeys, and 16% of the 54 million hogs on hand (~100,000,000 produced) in the U.S. were raised in the southern region (Gates, 1994). In 1996 there was a total of 3,400 swine farm operations in Tennessee with a crop of 764,000 pigs (Tennessee Agriculture, 1997). There has been a trend in recent years of increased numbers and stocking density of poultry and other livestock raised in agricultural production buildings. This increase improves economic efficiency, because more animals are served by the building structure and the various housing systems (Gates, 1994). The swine industry is increasingly moving towards confinement housing because of observed benefits for producers. Most beneficial is the use of electricity and mechanical equipment, eliminating such tasks as manual feeding, and the use of slotted-type floors to reduce manure clean up and labor requirements. Control of the internal environment of confinement buildings increases the profitability of swine operations and ensures the well-being of the animals and the workers in these facilities as compared to outdoor operations. There are, however, undesirable effects of intensive animal confinement production. One such effect is the

elevated levels of noxious gases and dust within the buildings and emissions of odors from them (Gates, 1994).

Problems stemming from the confinement of swine include odor control and the effects of individual gases and combinations of gases on the animals and workers. Air quality in large swine finishing barns, which can hold 1,000 or more animals, is not only important to the animals confined, but also to the individuals working several hours a day in these barns. The assessment of air quality in swine facilities is generally made by measuring toxic gases and dust within them (Jacobson et al., 1996). Several gases of concern in buildings housing swine include ammonia, hydrogen sulfide, carbon dioxide, and carbon monoxide (Donham, 1991). Ammonia and hydrogen sulfide are products of manure and urine decomposition, carbon dioxide is produced from respiration by the animals, and carbon monoxide is produced by improperly adjusted or defective space heaters burning combustible fuel (Gerber et al., 1991). Control of these gases is commonly managed by the use of ventilation (Donham, 1991).

An important aspect of environmental control is the removal of noxious gases and odors from swine confinement buildings with slotted floors over manure storage tanks. Confinement swine operations commonly use underfloor pits for manure collection and storage. Here, manure will undergo anaerobic decomposition naturally, and gases, including ammonia, hydrogen sulfide, and carbon dioxide, can be generated and emitted into the atmosphere of the confinement building. This emission contributes to the odors associated with these facilities (Zhang and Day, 1996). A specific application for

achieving the removal of gases most efficiently is the utilization of a pit ventilation system for confinement buildings with slotted floors and underfloor manure storage (Pohl and Hellickson, 1978). Pit ventilation removes gases and odors just above the liquid manure surface before they are transferred, by air movement, to the confinement area above the manure pit. This is especially important in the winter when minimum ventilation rates are employed, leading to increased accumulations of gases within and during manure agitations prior to pumping the pit, which causes higher concentrations of gases and odors (Pohl and Hellickson, 1978).

2. Research Objectives

This research project had three objectives. The first objective was to continuously monitor and collect air quality data within non-pit ventilated and pit ventilated manure storage pits in swine production confinement units. The second objective was to compare the effects of manure pit design on air quality and relate this with the effects of environmental parameters. The last objective was to monitor and analyze the differences in air quality among the two production units based on the data collected. Once these objectives and comparisons are made, suggestions and recommendations could be made concerning the effectiveness and need of ventilation in the pit-free space area.

CHAPTER II

REVIEW OF LITERATURE

In a study relating air contaminants with disease and productivity in swine, Donham (1991) concluded that the air environment within a swine building is a significant factor in productivity and animal health. An important factor in the confinement raising of livestock is the management of wastes in a liquid or slurry form, which is usually stored in pits or tanks, either under the livestock building or outside (Dohnam et al., 1982). Manure accumulations within enclosed swine buildings generate gases that can be both toxic and asphyxiating when improperly managed. The storage of liquid manure in an enclosed space can present health hazards to both animals and workers (Barker et al., 1986).

1. Characteristics of Stored Manure

When liquid manure is stored, microbiological activity takes place continuously in the manure from the time it is defecated until it is no longer recognized as manure. The three types of microbiological activity that can take place in manure are aerobic, anaerobic, and facultative, all which are determined by the amount of oxygen in the manure. When the microorganisms in manure have full access to oxygen, aerobic microorganisms grow. When oxygen is excluded, anaerobic microorganisms grow, while

facultative microorganisms can grow under either condition. The principal gas produced during the aerobic process is carbon dioxide, while during the anaerobic process, 99% of the gases produced are carbon dioxide, ammonia, hydrogen sulfide, and methane (Esmay and Dixon, 1986). This microbiological activity results in the production of about 150 different gases as metabolic by-products, many of which are potentially toxic or irritating (Dohnam et al., 1982). This study also found that ambient levels of the fixed gases within many confinement buildings commonly exceed the threshold limit value (TLV) for exposure, which is defined as the concentration of a dust or gas to which nearly all workers and animals may be repeatedly exposed, day after day, without adverse effects (Watson and Friend, 1987).

2. Manure Gases of Concern

The major manure gases in swine confinement operations are carbon dioxide, hydrogen sulfide, and ammonia, of which hydrogen sulfide apparently is the most toxic to both humans and animals (Muehling, 1970). Esmay and Dixon (1986) also stated that the most prominent gases released by excreta in anaerobic underfloor waste pits, expressed as parts per million by volume (ppm), are ammonia, carbon dioxide, methane, and hydrogen sulfide.

Oxygen

The source of oxygen, a non-toxic gas, inside a confinement building is atmospheric air at 20.9 percent oxygen. Atmospheric oxygen is essential for all animal and human life and can easily be depleted in a tight confinement building filled with hogs

when there is no ventilation (Taiganides et al., 1969). Critically dangerous conditions exist when the oxygen content in the air diminishes from the normal 21 to 10 % or less (Muehling, 1984).

Carbon Dioxide

Indoor carbon dioxide concentrations indicate the overall effectiveness of ventilation. Atmospheres from swine buildings have higher concentrations of carbon dioxide than those of poultry. This is due to the fact that pigs have greater mass loading and lower ventilation than poultry housing (Pickrell, 1991). The earth's atmosphere normally contains 300 ppm (0.03%) of carbon dioxide, while the average concentration in a normally ventilated hog confinement unit may be 0.06-0.77%. The action of manure decomposition and the normal breathing process of animals were reported to increase the level of carbon dioxide in confined spaces, with typical concentrations inside ventilated buildings ranging from 1,000 ppm (1%) during well ventilated periods to 10,000 ppm (10%) during winter (Baker et al., 1986).

Carbon dioxide is not highly toxic in itself, but is mainly responsible for oxygen deficiency or asphyxiation. Small increases above normal were found to be quite harmless, but a concentration of 10% causes violent panting. Carbon dioxide above this level was found to be narcotic even if there is an adequate oxygen supply because of the affinity of red blood cells for carbon dioxide over oxygen (Esmay and Dixon, 1986). Vansickle (1982) reported that in a totally enclosed building it takes as little as 7 hours for lethal levels of carbon dioxide to be reached due to oxygen depletion from the

respiration of animals. In animal confinement buildings, carbon dioxide constitutes 40% or more of the trapped gases in bubbles arising from liquid manures stored under slotted floors, or in lagoons or oxidation ditches (Taiganides et al, 1969). Muehling (1970) found that without any ventilation in a confinement facility, the carbon dioxide level increased to just over 4,000 ppm (4%) in 6 hours, approaching the threshold limit value of 5,000 ppm (5%).

Ammonia

Ammonia is a colorless gas with a pungent odor that can be detected at concentrations of about 5 ppm on volume basis. Because ammonia is lighter than air, it moves upward from its point of generation and can be detected readily anywhere inside a confinement building. Ammonia's solubility in water allows for the better control of odors in liquid systems through the addition of water (Taiganides and White, 1969). Because ammonia is highly water soluble, the manure pits, wooden and plywood walls, and humidity in the air cause a "bathing effect" of ammonia on swine and workers (Pickrell, 1991). Heber et al. (1987) also found ammonia to be highly water soluble, and that it can largely remain in the water in the dissociated form as ammonium, which is important because only the unionized form can become volatile and be released as a gas. The proportion of volatile ammonia to total ammonia concentration in stored manure was found to be a function of manure pH and temperature, where the higher the manure pH, the more ammonia is present in the manure in volatile form. The greatest increases in ammonia release were found to occur at high temperatures between a pH of 7 and 10.

Environmental parameters such as temperature and relative humidity were found to have strong influences on the ammonia emission rate. Ammonia emission was found to be dependent upon temperature above about 17.5°C (Ni et al., 1996). Voermans et al. (1986) also stated that the effect of temperature on ammonia emission from manure is clear, where the emission is higher in the summer than in the winter. This study also investigated the effects of temperature on cattle manure and found that an increase in the ambient temperature from 9.5 to 19.0°C caused an increase of ammonia release by 50%.

To reduce ammonia levels, manure should not be stored in the buildings' pits for long periods of time. The rate of ammonia released from manure increases for storage times longer than about one day. There are, however, no further reductions in ammonia release rates for less than one day because so much comes from dirty surfaces (slats, floor, animals, etc). Ammonia production was found to peak at three days and again at 21 days, so frequent manure removal helped to maintain low ammonia gas levels (Heber et al., 1997).

The type and status of flooring in confinement buildings also has an influence on ammonia concentration in the air inside of swine houses. A 28% higher ammonia concentration was found in the partly slatted system than the fully slatted floor system due to the feces and urine collected on the solid floor (Ni et al., 1996). Totally slotted floors with a deep pit and long term storage generated the most ammonia gas, while the partially slatted floor and manure pit produced 20% lower ammonia emissions, and the partly slatted floor combined with a sloping floor under the slats that was flushed several

times a day was 30% below that for a deep pit. The greatest ammonia reductions were achieved when the manure was collected under the slatted floor in about 4 inches of flushing water so that manure fell into the liquid and solids were submerged. The reduction in ammonia gas levels was found to be 60% if the mixture was regularly pumped out and replaced by a new flushing liquid (Heber et al., 1997). Ammonia concentrations were found to be worse from solid concrete swine floors than from slotted floor installations. Ammonia's high solubility in water explains the presence of smaller amounts of ammonia from confinement units with liquid manure than from confinement units with solid floors. Higher levels of ammonia were also reported in swine buildings with heated floors, since high temperatures promote ammonia odor (Muehling, 1970).

Ammonia is released from manure and urine during storage and decomposition (Barker et al., 1986). In swine confinement houses, gaseous ammonia is generated from animal wastes and eventually escapes to the outside atmosphere in two phases. The first is the ammonia releasing phase, which is the process of ammonia volatilizing from animal wastes in the manure pit or on the floor and entering into the air inside the confinement house. The second phase is the ammonia emission phase, which is the process of ammonia escaping out of the building to the outside atmosphere (Ni et al., 1996). Pickrell (1991) found that ammonia was often present in swine confinement buildings at concentrations exceeding the allowable level for human exposure (25 ppm). The typical ammonia levels in well-ventilated environmentally regulated buildings, as reported by Barker et al. (1986), were 10-20 ppm with liquid manure systems and 50 ppm

where manure and urine are deposited on solid floors. Levels were also reported to exceed 50 ppm with lower ventilation rates and to reach up to 100-200 ppm in poorly ventilated buildings.

High concentrations of ammonia inside animal confinement buildings represent potential health hazards to humans and animals. Respiratory diseases, such as sneezing, coughing, and pneumonia, increased for ammonia concentrations of 20-40 ppm as compared to 5-15 ppm (Ni et al., 1998). Ammonia is classified as an irritant, beginning to burn the eyes at 25-30 ppm, and concentrations above 0.02% (20 ppm) induce sneezing, salivation, and loss of appetite (Esmay and Dixon 1986). The study by Ni et al. (1998) also found that when young pigs were exposed to 50, 100, and 150 ppm of ammonia, pig growth was decreased by 12, 30, and 29% respectively as compared with controls (0 ppm).

Hydrogen Sulfide

Hydrogen sulfide is characterized as a colorless gas with a characteristic pungent odor similar to rotten eggs and is produced from the decomposition of organic wastes under anaerobic conditions (Muehling, 1970). Hydrogen sulfide is the most toxic gas associated with the decomposition of swine manure. It has been responsible for most of the deaths of livestock and humans that have occurred around liquid manure storage pits. This toxic gas has low solubility in water, so it is often trapped in bubbles in the manure pit. When the manure pits are emptied, the manure and water undergo a "slurry effect," caused by the mixing and turning of manure. This mixing and turning releases trapped

hydrogen sulfide gas and leads to greatly elevated atmospheric concentrations of hydrogen sulfide (Barker et al., 1986). The release of dissolved hydrogen sulfide is immediate and rapid when slurry mixing is started. The degree of slurry turbulence and splashing in the pit free space is the dominant contributor to hydrogen sulfide gas release and concentration inside barns (Panti and Clark, 1991).

Hydrogen sulfide is an extremely dangerous gas, and is classified, according to Esmay and Dixon (1986), as an irritant and an asphyxiant, where even low concentrations can severely irritate the eyes and respiratory tract within an hour. The effects of this gas on swine continuously exposed at 20 ppm include fear of light, loss of appetite, and nervousness. At levels of 200 ppm, pulmonary edema, breathing difficulties, loss of consciousness, and death may occur (Gerber et al., 1991). Taiganides and White (1969) warned that characteristic odor should not be relied upon to give adequate warning because our sense of smell can be fatigued rapidly. Thus, after lengthy periods of exposure, the proportionally high odor intensity due to high hydrogen sulfide concentrations may not be noticed.

Hydrogen sulfide levels are usually very low in animal confinement houses as compared with ammonia and carbon dioxide levels. The hydrogen sulfide concentration was measured at 90 parts per billion (ppb) in a normally ventilated confinement building and 280 ppb after the ventilation was shut off for six hours, as reported by Muehling (1970). Again, much higher concentrations were released in the air when the pit was agitated, when it rose to more than 100 ppm inside the building and 150 ppm in the pit

exhaust air (Patni and Clarke, 1991). Esmay and Dixon (1986) reported that hydrogen sulfide concentrations rose as high as 800 ppm (a lethal level) in confinement hog houses during agitation and for several minutes afterwards.

3. Ventilation in Confinement Housing

Taiganides and White (1969) found that under normal operations in a well-designed, adequately ventilated confinement unit, noxious gases did not reach lethal concentrations. However, this study found that when low ventilation rates are applied, gases from manure will mix rapidly enough with the air that animals with their noses to the floor could inhale oxygen-deficient gases for a few seconds to a few minutes, creating potentially hazardous situations through oxygen depletion. Animal confinement systems that allow the accumulation of solid and liquid waste materials for a number of days or weeks must have enough ventilation air exchange to remove the pollutants and excess evaporated moisture from the building. In confinement buildings that store manure in deep pits for long periods of time, anaerobic decomposition causes excessive production of ammonia and hydrogen sulfide if no moisture is removed from the manure by ventilation. It is noted that enough ventilation air exchange must be provided to lower the manure moisture content through evaporation to prevent the development of anaerobic decomposition of manure (Esmay and Dixon, 1986).

Barker et al. (1986) recommended that to ensure adequate ventilation, the maximum amount of mechanical ventilation should be used whenever stored manure is agitated. In most buildings ventilation is the only gas control system available.

However, it is noted that recommended ventilation rates for confinement houses are based on the removal of heat and moisture produced by animal respiration and not for the removal of toxic gases (Dohnam et al., 1988). Differences in toxic gas levels between buildings are due in part to variations in ventilation systems. In facilities monitored in this study, minimal recommended winter ventilation rates were sufficient to prevent ambient gas production from liquid swine manure to build to toxic levels. However, the high level off-gassing of hydrogen sulfide that occurred during pit agitation may not be offset by ventilation (Dohnam et al., 1988).

An immediate indication of the effectiveness of confinement house ventilation can be obtained by walking into the building and physically attempting to detect certain odors. Any indication of hydrogen sulfide (the rotten egg smell) and/or ammonia indicates insufficient ventilation and calls for immediate action because high levels are poisonous and may be fatal (Esmay and Dixon, 1986).

Measurements of hydrogen sulfide and ammonia in mechanically ventilated swine confinement houses during warm weather were studied in two separate reports (one for ammonia and one for hydrogen sulfide) by Ni et al. (1998). A section of these reports dealt with the influence that ventilation rate has on the concentrations of these gases in swine buildings. It was found that gas concentrations in swine houses were dependent upon the building type, ventilation rate, location of measurement, season of year, and measurement reliability. During the hottest part of the day when the ventilation rates were high, both ammonia and hydrogen sulfide were found to be at low levels. During

the latter part of the day, when the ventilation rates were lower, the gas concentrations were higher. This inverse relationship is explained by the dilution effect that ventilation has on gas concentrations inside the buildings. The ventilation rates in the test buildings used in this study were automatically controlled to adjust indoor temperature. Daily fluctuation of ammonia and hydrogen sulfide patterns were closely related to that of outdoor temperature. Thus, both gas concentrations were also found to be negatively correlated with indoor and outdoor temperatures.

In a study relating airflow obstructions on gas dispersion, Hoff et al. (1995) found that ventilation rate and relative location from the inlet were significant contributors to gas concentration variations and that as ventilation rates decreased at floor levels near the inlet, gas concentration levels increased.

In another study relating building design to ventilation, Carpenter (1987) found air leakage caused local regions of low temperature and drafts if the leaks are at low positions in the building. In exhausted systems, inward leaks from or along a slurry channel produced high concentrations of ammonia and odors.

4. Pit Ventilation in Confinement Housing

If the efficient removal of gases is to be achieved, ventilation system designs must be specifically developed for confinement buildings with slotted floors and underfloor manure storage. A potential method for achieving an atmospheric environment that is conducive both to livestock and workers is the utilization of a pit ventilation system. A properly designed and managed pit ventilation system should remove gases and odors

from the space above the liquid manure surface before natural convection currents or mechanically initiated air movement above the slotted floor transfers the gases into the livestock's environment (Pohl and Hellickson, 1978). The continuous removal of gases from the pit area below the slotted floors prevents the accumulations of hydrogen sulfide, ammonia, and methane in the room air. This is particularly important during the winter when minimum ventilation rates are employed, and during manure agitations in the pit, which can create an environment with a high concentration of gases and odors that cannot be controlled by normal ventilation (Grub et al., 1974). Patini and Clark (1991) conducted a study measuring gas concentrations in the pit exhaust air and found that hydrogen sulfide concentration was less than 3 ppm at all locations inside the barn and varied from 40 ppm to 110 ppm in the pit exhaust air. This indicated the effectiveness of the pit fans in removing hydrogen sulfide from the pit free space. Heber et al. (1997) also found that ventilation fans that exhaust air directly from the pit reduce manure gas concentrations in the swine environment. In this study, measurements of hydrogen sulfide were taken with pit ventilation during manure agitation. The gas concentrations were found to be 150 ppm under the floor and only about 5 ppm above the floor. The gas concentrations in the animal environment would have been dangerously high without pit ventilation, again indicating its effectiveness.

Pit ventilation was found to be beneficial in all mechanically ventilated slotted floor buildings, even if manure is removed frequently. A properly designed system will improve the environment inside the building by removing odors, drying the slotted floor

area, and providing a gentle flow of warm, fresh air over the animals (Jones and Friday, 1980).

Heber et al. (1997) studied the effects that manure flushing systems have on gas concentrations and found the pull-plug pit recharge system caused the greatest reduction in manure gases as compared to all other systems. In this manure handling system, drain pipes are placed under the floor of the manure pit leading to an outside manure storage. Inlets to these drain pipes are placed at regular intervals in the floor. When these drain pipes are opened, by plugs, shut-off balls, or gate valves, the liquid flows out to the outside manure storage. The openings are then closed and new flushing liquid is added to the pit. Heber et al. (1997) stated that their study agreed with other researchers that there is no advantage to other flushing systems over pull-plug pit recharge in terms of gas production.

5. Environmental Monitoring

Carbon monoxide and carbon dioxide are odorless and undetectable, and the human olfactory senses are not sensitive enough to accurately detect ammonia and hydrogen sulfide above the safe human concern levels. Therefore, gas measurement techniques should be used to accurately detect exposure levels (Gerber et al., 1991).

During the past few decades the need for measurement sensors of all types has increased dramatically with their critical involvement in today's increasingly automated society. Areas in which sensors are increasingly applied include process control, medicine and public health, and environmental quality monitoring. Process control and

environmental quality monitoring sensors are required to operate in a continuous monitoring mode, and electrochemical sensors have played an important role in the measurement of both chemical and biological substances (Fleet and Gunasingham, 1992). Electrochemical sensors offer the means to achieve the continuous on-line measurements of process parameters, as well as environmental monitoring of toxic gases and chemical vapors. Continuous measurement offers a more accurate means of process control (Venkatasetty, 1992). Electrochemical sensors are extremely successful in monitoring air components and pollutants such as oxygen, carbon monoxide, hydrogen sulfide, and ammonia, and show great promise for meeting future rigorous legislation dealing with air pollutants (Fleet and Gunasingham, 1992).

There are two types of electrochemical sensors used today, the potentiometric and amperometric. The potentiometric sensors are based on voltage measurements between the electrodes in the cell and are mainly used in industrial process control. The amperometric or voltammetric sensors are widely used in medical diagnostics and environmental monitoring and use a high conductivity acid or alkaline liquid electrolyte with a gas permeable membrane (Venkatasetty, 1992).

Ross and Daley (1986) tested electrochemical sensors for measuring ammonia in broiler houses. Electrochemical sensors are composed of an electrochemical cell and a current divider system. Electrochemical sensors work by diffusing a gas-specific molecule through a hydrophobic membrane, resulting in a reaction with the gas-specific internal electrolyte. This reaction affects the potential between the reference electrode

and an unknown electrode. This change in potential is then converted to a 4-20 mA signal.

Tests were conducted in a laboratory to determine the response time of electrochemical sensors under varying physical conditions (Ross and Daley, 1986). When compared to gas diffusion tubes, the electrochemical sensors were consistently high when exposed to 10 and 45 ppm ammonia. The difference was attributed to not allowing the sensor time to equilibrate during startup before calibration. The gas diffusion tubes gave results closer to the correct values. Sensor response and decay tests were also performed. The sensor reached only 80 percent of the 10 ppm exposure concentrations, and the sensor decayed to zero after eight minutes when it was removed from the exposure concentration. The sensor was not affected by humidity and temperature. Overall, electrochemical sensors exhibited slow response times at low concentrations, but showed promise for use in this application. Tests conducted by Venkatasetty (1992) also found electrochemical sensors to have a limited operating life, because of the high vapor pressure and high corrosion of the electrolyte solution, and poor stability and reproducibility because of the reactivity of the electrolyte solution with interferences in the environment and buildup of reaction products. Still, electrochemical sensors have shown great potential for monitoring a wide range of pollutants in the environment.

6. Role of Environment in Confinement Housing

The thermal environment plays an important role in livestock production systems.

Confinement buildings used by producers must provide a thermal environment that is the most economically feasible for specific operations. The performance of growing-finishing swine is affected by both warm and cold environments. A cold weather environment causes the animal to increase feed intake in order to maintain body temperature. A warm weather environment causes the opposite effect. During warm conditions, the animal tends to reduce feed intake, may increase maintenance demands, for panting, etc. during heat stress, and may experience environmental stress (Turner et al., 1997).

The effects of the thermal environment on swine are exerted through changes in the animal's heat exchange so that under cold conditions, when heat loss from the body is high, more dietary energy is used for thermoregulation. As the environmental temperature is increased, the animal's heat loss decreases until a temperature range is reached where it is at a minimum. This is referred to as the thermoneutral range, where the upper and lower limits are called the upper and lower critical temperatures, respectively. The energy available for growth is optimal within this zone. Above this zone, as the environmental temperature is further increased, the animal's body temperature begins to rise with a constant increase in heat production. If this situation persists and the animal is not cooled, it will eventually die (Close, 1987).

Turner et al. (1997) noted several studies relating how high environmental temperatures adversely affect swine growth and feed intake. A 21-day study on the effects of warm diurnal temperatures found that when pigs were raised in a hot

environment [22.5 to 35°C (72.5 to 95°F)], weight gains were 16.3% lower and feed intake was 10.9% greater when compared to pigs that were raised under a constant temperature of 20°C (68°F). Reduced growth rates were also observed for finishing pigs that were raised under a high temperature of 27.5°C (81.5°F) when compared to those raised at a thermoneutral temperature. Daily feed consumption, average daily gain, and reproductive performance were also found to be significantly reduced as the dry bulb and dew point temperature increased.

Growing-finishing pigs are affected more dramatically by hot weather than cold. It is generally easier and less costly to protect animals from a cold than a hot weather environment. Cold weather protection can be provided by enclosing confinement buildings to conserve the animal's sensible body heat and by supplying supplemental heat (Esmay and Dixon, 1986).

In cold weather, the sensible heat produced by swine can be utilized to heat the building and to warm incoming ventilation air, while water vapor or latent heat must be removed from the building to keep humidity levels from increasing to undesirable levels. Animals and birds will increase evaporative heat loss as the ambient temperature increases to levels at which they cannot readily dissipate the metabolic body heat by the sensible heat transfer means of convection, conduction, and radiation (Esmay and Dixon, 1986). Sensible heat loss predominates at low temperatures and depends upon the existence of temperature gradients between the animal and its environment (Close, 1987).

Sensible heat dissipation is reduced as evaporation rates are increased by the

animals during high environmental temperature conditions. Total metabolic heat production is also generally reduced by the animal to ease heat dissipation (Esmay and Dixon, 1986).

Swine do not have the capability of dissipating large amounts of heat through the evaporative process. Swine, being basically nonsweating, will have to breath faster and faster during hot weather conditions in an attempt to remove their surplus body heat by evaporation from the wetted surfaces of the lungs and air passageways (Esmay and Dixon, 1986). A study conducted by Brown-Brandl et al. (1998) relating the effects of heat stress on heat production and respiration in swine found respiration rates to increase exponentially with temperature. When respiration rate at night was compared to respiration rate during the day, the predicted night respiration rate at any temperature was found to be 33% less than the day time predicted respiration rate. This is due mainly to the reduction in activity during the night time hours.

Close (1987) calculated that the sensible component of heat loss, as a proportion of the total, decreased from 85% at 5°C to 20% at 35°C. At temperatures below the lower critical temperature, swine will attempt to conserve sensible heat loss by such physical adjustments as change in posture and huddling, whereas at temperatures above the upper critical temperature, evaporation is increased by panting and wallowing. Esmay and Dixon (1986) found that at temperatures above 27°C, sensible heat transfer decreases linearly to zero at 38°C. The body temperature at 38°C eliminates the temperature difference with the ambient environment, making sensible heat transfer

impossible. Air movement is a means of maximizing sensible heat loss as long as the ambient air temperature is less than animal body temperature.

Sensible heat transfer is shown to be dependent upon temperature difference and is fairly linear with increasing body weight for the temperature range of 5-30°C. Whereas, latent heat transfer is dependent on vapor pressure difference and air movement. Latent heat production also tends to vary more with body weight. Heavier hogs have a lower capability of dissipating latent heat at higher temperatures between 20°C and 30°C and so produce less proportionately. Latent heat dissipation is, however, a process that swine, among other animals, reverts to at higher environmental temperatures when they cannot dissipate as much in the sensible form because of the narrowing temperature difference between the environment and the body. Larger hogs have more difficulty dissipating sensible heat at higher temperatures so heat stress is more severe (Esmay and Dixon, 1986). As the environmental temperature increases, heat loss by evaporation becomes more important and depends upon a vapor pressure gradient so that water can be removed from the animal through its respiratory tract (Close, 1987).

CHAPTER III

EQUIPMENT AND PROCEDURES

1. Periods of Study

Data were collected for this study during three different time periods. The first period occurred between July, 1997 and April, 1998. This period was used for testing of the equipment and to compare gas concentrations and environmental data within the production units during cold weather. The second measurement period was during August - September, 1998. Gas emissions from the pit ventilation fans were measured during this time. The last part of this study again involved measuring gas concentrations and environmental data within the production units during the winter (November 1998 – March 1999) . Gas levels were also measured at animal level during the last part of this period.

2. Facilities

The facilities used in this study were located at a swine production operation in northwestern Tennessee. Two separate, but similar, hog-finishing houses, located side-by-side, were monitored during the periods of study. Both of the houses were curtain-sided, mechanically-ventilated, environmentally controlled units.

Both houses contained 22 separate pens measuring 5.6 m (18.5 ft) x 2.4 m (8 ft).

The pens on each side of the barn were separated by a center walk-aisle measuring 0.84 m (2.75 ft) wide. The overall dimensions of the barns were approximately 12.2 m (40 ft) x 53.6 m (176 ft). The drop curtains along the sides of the barns and on the inlet were 1.2 m (3.83 ft) high.

The barns were ventilated with four, 120 cm (48 inch) fans and two, 90 cm (36 inch) constant-speed fans. One of the smaller fans operated continuously, while the others were controlled by thermostats. The fan installation (figure 1) was symmetrical around the center door of the exhaust end, with the smaller fans closest to the door. Both barns used a pit-recharge manure handling system. Manure from the pits was drained into a primary lagoon once each week. Water from a secondary lagoon was then pumped back into the ~1 m deep pit to dilute the fresh manure and urine. This pit flushing procedure was scheduled to occur every Wednesday morning for Barn A and every Thursday morning for Barn B. The two barns were very similar in every regard except that Barn B had a pit ventilation system. This system pulled air from the approximately 25-cm (10 inch) space between the floor and pit. Air was drawn into ducts through openings spaced a few feet apart, and expelled through two 46 cm (18 inch) fans, one at each end of the barn. The configuration of this system is shown in figures 1 and 2.

3. Instrumentation System

The instrumentation system described in the following pages was used throughout the study. The specific arrangement of instrumentation described in these sections was used during most of this research (the first and last study periods). Changes from this

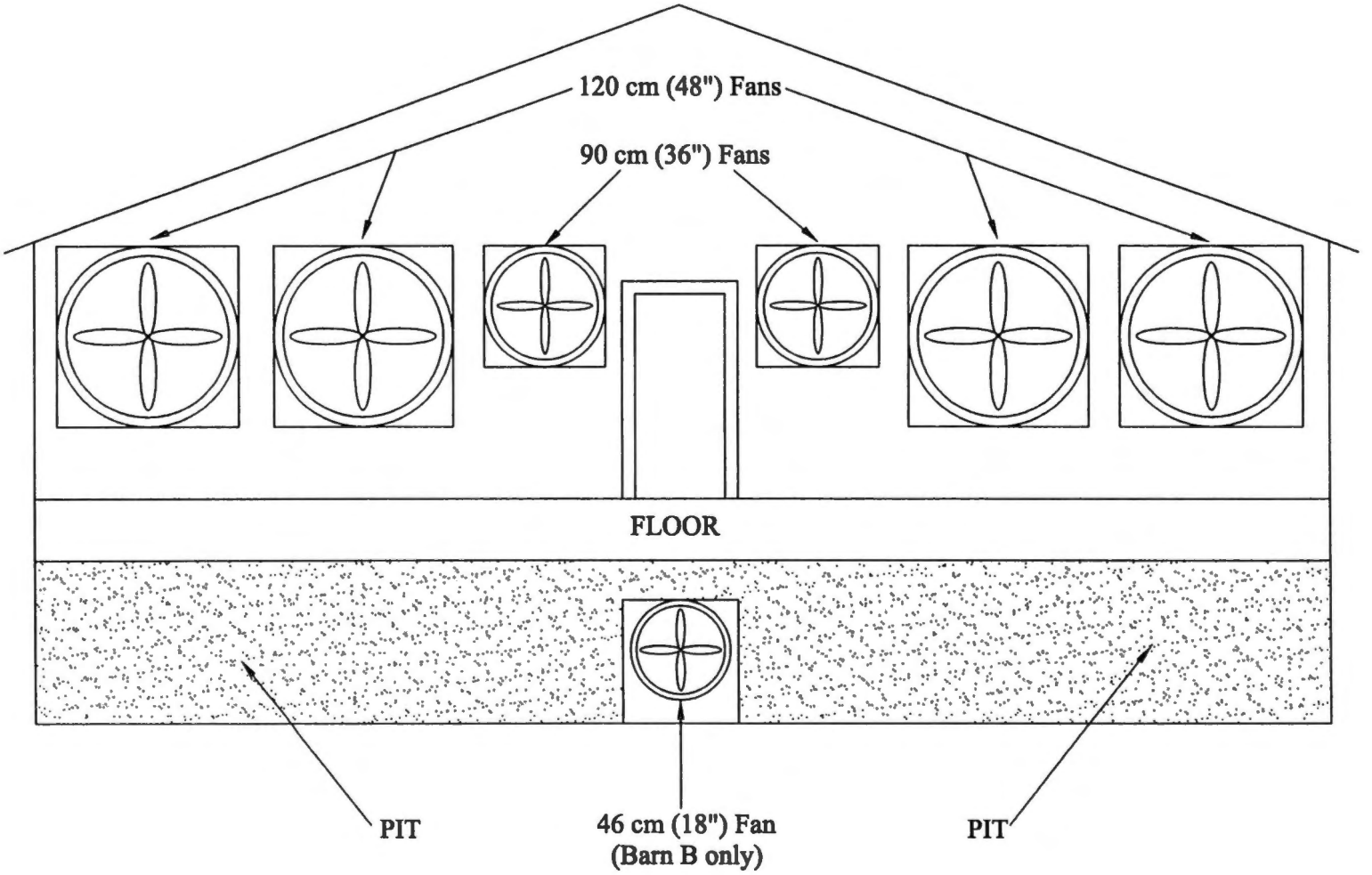


Figure 1. Diagram showing fan installation and pit ventilation system in Barn B.

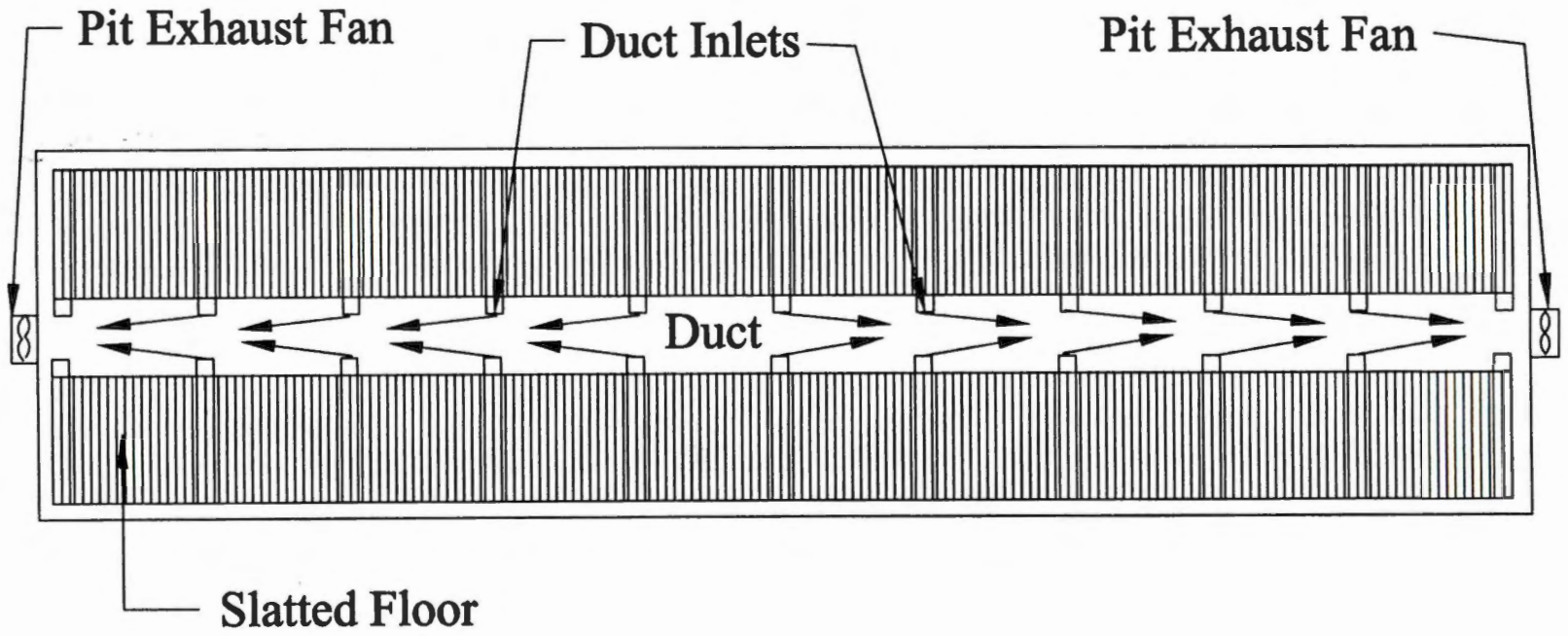


Figure 2. Diagram showing operation of pit ventilation system in Barn B.

arrangement occurred during the second study period (pit exhaust measurements) and during the latter portion of the final study period (measurements at animal level). These changes are discussed later.

The instrumentation system used in this study consisted of a data logger, three (3) multiplexers, nine (9) gas sensors, sixteen (16) thermocouples, three (3) temperature/relative humidity sensors, a small weather station and a modem/cellular phone system. The typical installed configuration was as shown in figure 3, and a listing of all major instrumentation components used in the entire study is given in table A-1.

One Campbell Scientific Inc. (CSI) 21X data logger was used to collect and store the information gathered in this study. For the amount of data collected in this study, storage capacity allowed approximately seven days of data storage in the data logger. When all storage was filled, the oldest data were overwritten. All storage was volatile such that loss of power to the data logger resulted in loss of all data.

The data logger was powered by a 12-volt deep-cycle battery connected to a "smart" battery charger. The battery charger system insured that the battery would not be discharged during extended operation, therefore preventing loss of data during power outages. The data logger, along with a multiplexer unit and phone system, were mounted inside a NEMA enclosure box that was suspended from the ceiling of Barn A. A CSI AM416 multiplexer (MPX of figure 3) permitted sequential measurement of all gas sensors and thermocouples in the barn. The relative humidity sensor and pyranometer inputs were connected directly to the data logger.

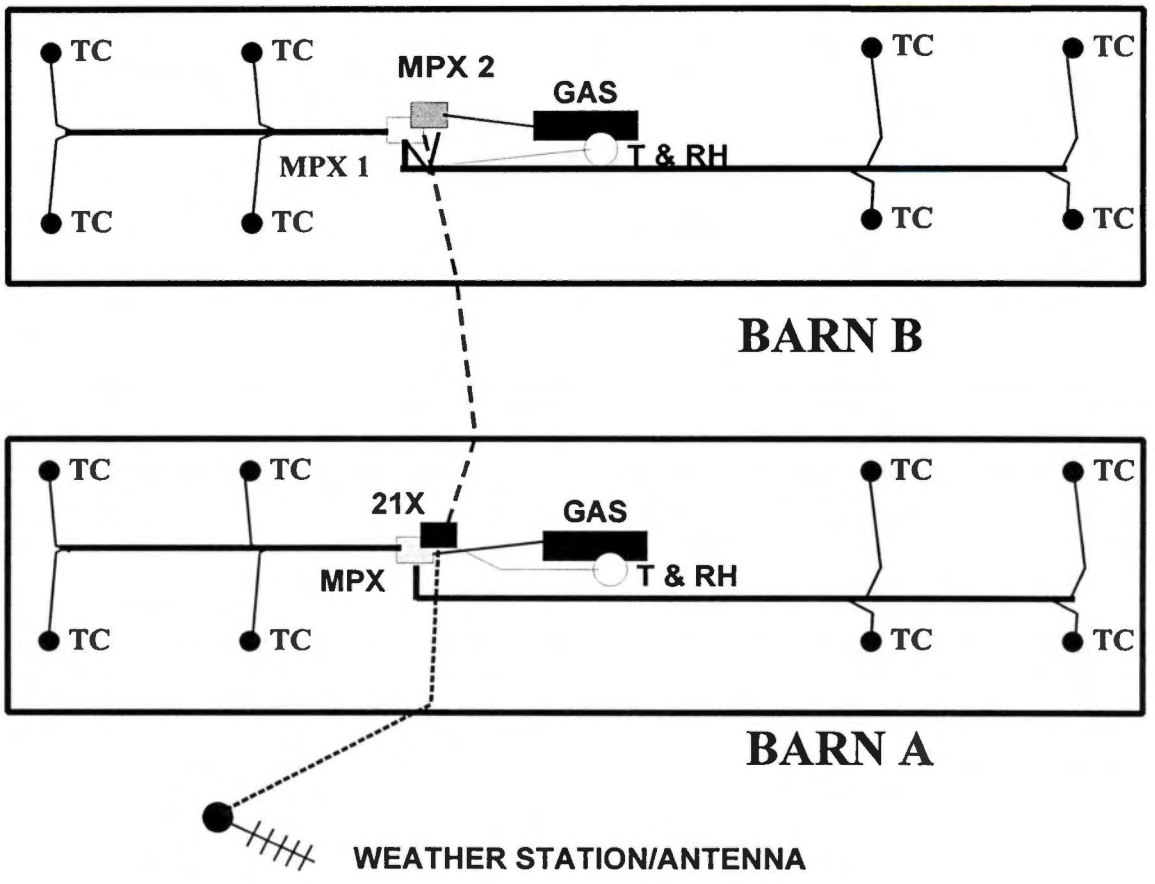


Figure 3. Diagram showing instrumentation layout and thermocouple locations.

The CSI AM32 multiplexers (MPX 1 and MPX 2 of figure 3) in Barn B (one for gas sensors and one for thermocouples) were connected to the data logger in Barn A. As with Barn A, the relative humidity sensor connected directly to the data logger. All inputs were read at 20 second intervals, averaged over each 30 minute period, and stored.

Data transfer was accomplished via cellular communication. A modem and cellular phone connected to the data logger were activated for a 30-min period each day. A computer/modem system located in the Agricultural and Biosystems Engineering Department in Knoxville was programmed to contact the data logger, via the modem and

cellular phone, on alternate days during the "on" time and upload uncollected data. The process was controlled using the CSI PC208W software. While the data logger was capable of storing data for approximately seven days, more frequent uploads allowed for monitoring the system and avoiding any significant loss of data.

4. Gas Measurement

Electrochemical sensors (Dräeger Polytron SE) were used to measure gas concentrations. Sensors for ammonia, hydrogen sulfide, carbon monoxide, and oxygen were located in each barn. The sensors were powered by the 12-volt battery. The 4-20 mA current output for each sensor (figure 4) was converted to a voltage through a 240 Ω precision resistor. This allowed the CSI 21X data logger to use most of the 5,000 mV full-scale measurement range to improve the resolution of recorded data.

Each electrochemical sensor was calibrated prior to installation and after the equipment was removed after each study period. The sensors were allowed at least 12 hours for warmup before the initial calibration. After the warmup period, the sensors were zeroed using 100% Ultra High Purity (UHP) nitrogen, following procedures

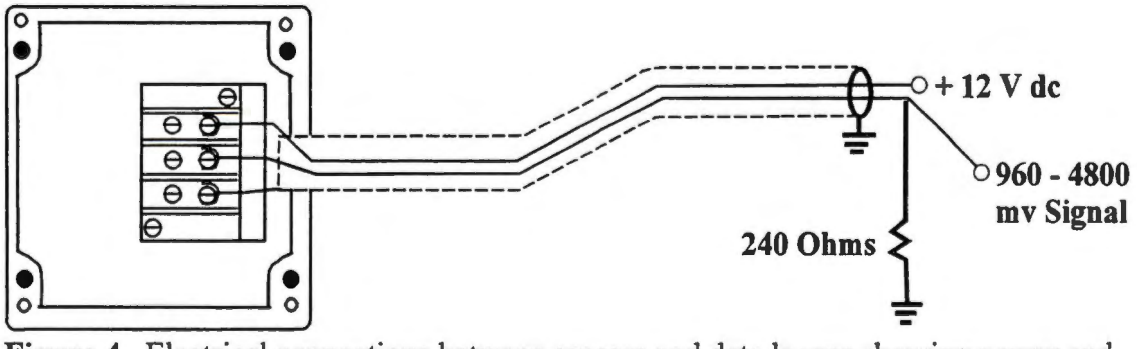


Figure 4. Electrical connections between sensors and data logger showing power and signal connections.

specified by the manufacturer. The sensor displays were adjusted to 0.0 ± 0.1 using the offset potentiometer. The voltage drop created by the current flow through the resistor was then recorded to complete the zero calibration. A similar procedure was used for span calibration. Each sensor was subjected to the appropriate calibration gas (**CO**: 209 ppm in air; $\mathbf{O_2}$: 20.9% atmospheric oxygen; $\mathbf{NH_3}$: 69 ppm in N_2; and $\mathbf{H_2S}$: 23.7 ppm in N_2). The sensor was then adjusted using the slope potentiometer to give the appropriate span readings on the sensor display. Once stabilized, the voltage drop at the precision resistor was recorded to complete the calibration. Loss of power to the sensor for more than 10 minutes resulted in loss of calibration. Thus, following initial calibration, power to all electrochemical sensors was maintained continuously throughout the test. Table B-1 provides an example of the calibration data taken for each of the houses during this study.

A carbon dioxide sensor (Dräeger infrared) was mounted with the electrochemical sensors in Barn A. The required power to this sensor was provided by a 24-V DC power supply. This sensor was self calibrating and did not lose calibration with loss of power.

The gas sensors (5 in Barn A and 4 in Barn B) were mounted inside PVC housings approximately 1 m long, open at the bottom and at each end. This housing provided significant dust protection while allowing air movement over the sensors. The housing also permitted all sensors to be handled as a single unit during installation and removal. The gas and relative humidity sensors were mounted near the center of each building at a height of approximately 2 m.

5. Environmental Parameters.

During the first period of study one CSI model 207 temperature and relative humidity probe was used to measure the temperature and relative humidity at each of the gas sensor locations. Another probe was located outside on the weather station to monitor outdoor conditions. Due to the age and inconsistency of these probes, they were replaced with CSI model HMP45C-L temperature and relative humidity probes after this period. These newer probes were used throughout the remainder of the study. The probes were connected directly to the data logger.

A CSI LI200S pyranometer was also located on the weather station to monitor solar radiation. The pyranometer was connected directly to one of the analog channels the data logger.

The multiplexers in both barns were used to allow sequential measurements of temperature at multiple locations using type T thermocouples. The thermocouples (eight in each barn) were mounted approximately 2 m above the floor and positioned as shown in figure 3.

As noted earlier, all sensors were read at 20 second intervals by the data logger and averaged over each 30 minute period. These averages were recorded in permanent storage for later retrieval by cellular communication.

6. Chronology of Events

Study Period 1

The first period of research in this study began on July 9, 1997 and ended on April

28, 1998. The instrumentation was first installed in the two barns on July 9. Two 12 volt batteries located in two metal baskets, the gas sensors assembly, and a NEMA enclosure containing the data logger, multiplexer, and modem and communications system were suspended from the ceiling (approximately 2 m above floor) along the right edge of the central corridor in the center of Barn A. Two batteries were initially used to meet the 24-V requirement of the CO_2 sensor. Thermocouples were suspended from the ceiling, approximately 2 m above the floor, above the center of the third and fourth pens on each side and end of the barn (a total of 8 TC's). A cable between the two houses connected the data logger in Barn A to the multiplexer units in Barn B. This cable ran along the ceiling in each barn, out through the side screens, down the outside wall, and underground between the buildings. The cable and thermocouple wire connecting equipment in the two barns were covered with lengths of split PVC pipe and buried in a shallow trench. The gas sensor housing and thermocouples in Barn B were installed in approximately the same relative positions as in Barn A.

The system could not be contacted remotely from Knoxville through the rest of July and early August. The next site visit, on August 12, 1997, revealed that both batteries supplying power to the system had failed. No data were found in the data logger memory. All of the equipment was removed, except for the thermocouples, and returned to Knoxville for testing and modification.

Diagnosis, repairs, and extensive modifications were made to the system. The problem with the battery failure was identified as stemming from improper installation of

the charging systems. Batteries were installed in series with the attached chargers, resulting in "fried" chargers. This, likewise, caused the batteries to fail, therefore providing no power supply to the data logger and gas sensors. The problem was solved by providing a 24 volt power supply for the CO_2 sensor, thus removing the need for a second battery. The CO_2 sensor was not affected by power failures, thus, continuous battery power was not required.

The ammonia and hydrogen sulfide sensors for both units were replaced and re-calibrated during this time. All of the connections outside of the enclosure boxes were replaced with better quality dustproof connectors. An absolute pressure sensor was also installed inside the data logger box to compare the changes in oxygen with atmospheric pressure changes. Some changes in data logger connections were also made and the data logger program was modified (appendix C-1).

New groups of pigs were added to both barns during the month of November, with a total of 830 pigs in Barn A and 931 pigs in Barn B. The equipment was reinstalled on November 10, 1997. Cable and thermocouple wires connecting the two barns was found to be severed outside of Barn A. The cut cable was pulled out and replaced with new cable. Thermocouple wires connecting the two barns were also replaced. The sensor housings and enclosure boxes were again mounted in both barns.

Remote data collection from Knoxville could not be achieved after the reinstallation. A site visit in mid-December solved the problem by replacing a blown fuse in the battery cable connection to the data logger and phone system. Defective

thermocouples were also replaced as needed.

On January 8-9, 1998 the gas sensors were re-calibrated and other minor problems with the system were resolved. More failed thermocouples were replaced and the temperature and relative humidity probes in Barn B and on the outside weather station were found to be periodically malfunctioning. Due to the instrumentation and equipment problems previously described, valid data were collected only after January 9, 1998.

On February 26, 1998 the defective temperature and relative humidity sensors were replaced and the entire system was tested to verify proper performance. While on-site, it was discovered that the two pit ventilation fans in Barn B were inoperable up to this point in the study. The farm manager repaired them the next day, and they remained operable throughout the remainder of the study.

All equipment was removed from both barns on April 28, 1998 and returned to Knoxville. The equipment removal coincided with the end of the grow out process for the hogs, marking the end of the first study period.

Study Period 2

The next portion of this study was conducted from August 13, 1998 through September 10, 1998. Instrumentation and equipment were installed on August 13, 1998. This portion of the research evaluated only the pit ventilated Barn B. The purpose of this study was to measure the emission of manure gases from the pit fans. A frame constructed from metal angle iron strips was used to support one set of gas sensors immediately downstream of one pit fan (figure 5). This framing was placed under a hog

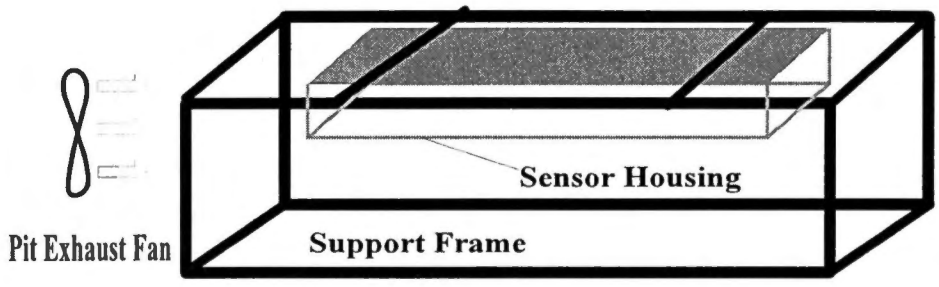


Figure 5. Support frame for gas sensors when measuring pit fan exhaust.

loading chute outside, directly in front of the pit fan at the front of the barn. Heavy plastic material was used to cover and protect the framing and sensors from the weather and dust. The plastic covered the entire frame except for the ends, allowing maximum exhaust air movement through the frame and avoiding dilution of the exhaust stream by cross flow of outside air.

A CSI HMP45C-L temperature and relative humidity probe was also placed with the gas sensor housing to measure environmental conditions at the exhaust area. This probe, along with the gas sensors, was connected to the AM32 multiplexer units which were mounted just inside of Barn B. The multiplexer units were then connected to the data logger. The second set of gas sensors, along with the data logger, AM416 multiplexer unit, and communications system were mounted near the center of Barn B approximately 2 m above the floor. With this configuration, gas concentrations were measured within the pit ventilated barn and at the pit exhaust area. The hydrogen sulfide sensor used for measuring pit fan emissions and oxygen sensor inside Barn B were replaced prior to installation due to failure. Carbon dioxide concentrations were not

measured in this part of the study due to equipment malfunction.

The instrumentation system for this part of the study differed only from the previous in the replacement of the temperature and relative humidity probes. Also, thermocouples were not used in this part of the study to record temperatures in either location. The weather station/antenna was also moved to a location just outside Barn B. Changes to the data logger program to accommodate the new temperature/relative humidity sensors were made for this period of study. In addition, all of the inputs for the thermocouple locations were removed since no temperature measurements were taken. This modification to the program (appendix C-2) also increased the number of days of data the data logger could store.

Power to the system was lost during the trip to the farm, and previous calibration data for all gas sensors were lost. Installation of equipment proceeded as described above, and on August 20, 1998 the gas sensors were re-calibrated at the barn site. The battery supplying power to the system was also replaced with a new one.

All of the instrumentation equipment was removed from the facility on September 10, 1998, concluding this study period. The entire system was returned to Knoxville for changes and repairs as needed for the next period of study. Data for this study were successfully collected over a three week period.

Study Period 3

The final period of research conducted in this study began on November 19, 1998 and ended on March 9, 1999. New groups of pigs were added to each barn prior to

equipment installation. On October 9, 1998, a total of 1,043 pigs were placed in Barn A and a total of 954 pigs were added to Barn B on November 5, 1998.

The last part of this research focused mainly, as with the first study period, on cold weather gas measurements of the pit ventilated and non-pit ventilated swine confinement buildings.

Data from the early 1998 tests clearly revealed the need for additional information regarding operation of the building ventilation system. As mentioned earlier, the ventilation fans were thermostatically controlled to turn on and off within certain temperature ranges. Mercury tilt switches were used to sense when fans were operating. The mercury tilt switches were designed so that "contact" with mercury in the switch was made when the switch is horizontal and a "breaking" point was made with the mercury in the switch when a specified angle is reached (figure 6).

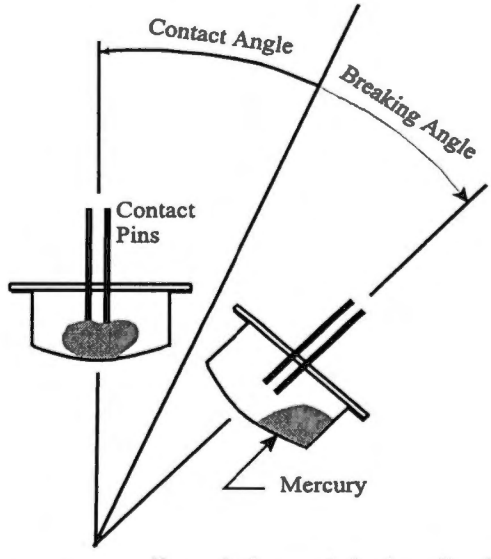


Figure 6. Diagram showing mercury tilt switch used during final study period.

One tilt switch was mounted to one of the fan shutters on each individual fan (6 in each building) in both of the confinement buildings. These switches were connected to the data logger. This was programmed to read the signal coming from the switches as 0.0 mV when the switches were horizontal, indicating the fan being off, and 1111 mV when the switch passed its "breaking" angle, indicating the fan was operating. Figure 7 illustrates the schematics of the tilt sensor operation.

In Barn A, one tilt switch was mounted to a fan shutter on each individual fan. Two lead wires (one for signal and one for ground) coming from each tilt switch were connected to terminal strips, located inside an enclosure box, which was mounted in the center of the building end wall. Signal wires for each tilt switch ran along the ceiling, where it was fastened to PVC pipe running the length of the building, and the signal from

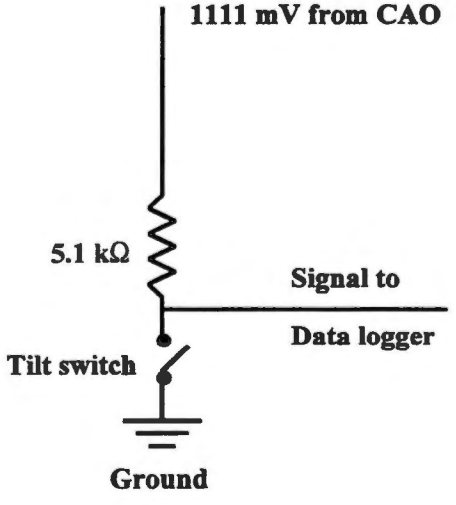


Figure 7. Diagram showing schematics of tilt sensors used to monitor ventilation system.

each switch was connected to an input channel on the multiplexer. Ground wires for each tilt switch were commonly grounded on the terminal strip, which was connected to a grounding location on the data logger. The signal responsible for converting the "breaking" readings of the switches to 1111 mV came from a continuous analog output (CAO) channel on the data logger. A wire connecting the CAO channel to the terminal strip ran along the ceiling of the building in the same way as described above. This common CAO wire was connected at the terminal strip as shown in figure 7.

The setup of the tilt switches in Barn B was the same as described for Barn A except a between-house wire connected the CAO channel on the data logger in Barn A to the terminal strip in Barn B.

The tilt switch data readings, as with all other sensors, were taken every 20 seconds and averaged over each 30 minute period. Since any fan could be on or off a number of times within this thirty minute period, the average from each of the fan readings (in mV) was divided by 1111 mV to get the percentage or frequency that each individual fan was on during a given thirty minute period. This setup allowed for the continuous monitoring of the ventilation system, in terms of fan operation percentage, in each building.

Instrumentation equipment used during this final period of study was installed at the farm site on November 19, 1998. The setup and configuration of the entire instrumentation system, other than the fan tilt switches, was nearly identical to the setup in the first study period (figure 3). The data logger program was modified (appendix C-3)

to read the inputs from the tilt switches and to simplify the program.

Power was lost to the system the day after installation at the farm site, and previous calibration data for the gas sensors were lost. Power was restored to the system the next day by replacing a blown fuse in the battery cable, and on November 24, 1998 the gas sensors were re-calibrated at the farm site. Thermocouple inputs in Barn B were also not responding, so the thermocouple wire connecting the data logger in Barn A to the multiplexer in Barn B was replaced so that temperatures in Barn B could be measured.

Data were successfully collected until mid-January, 1999. On January 18, 1999, collection of data from the farm site by cellular communication revealed that no measurements taken from Barn B were being recorded by the data logger. On January 23, 1999 the problem was solved by replacing a corroded connection in the power cable connecting the battery in Barn A to the multiplexer unit in Barn B. On January 24, 1999, gas sensors in Barn A were re-calibrated, but the set of sensors in Barn B could not be re-calibrated due to obstructions in the aisle ~~way~~ blocking access to the set of gas sensors. OK

Up to this point in the study, all gas level measurements inside the barns were taken at approximately 2 m. Near the end of the grow-out period, arrangements were made with the owner/operator of the production facility to provide an empty pen so that a set of gas sensors could be placed near the floor. On January 29, 1999, animals were removed from the pen below the set of gas sensors suspended from the ceiling in Barn A. The multiplexer unit and gas sensor unit located in Barn B was then removed from that building and placed inside the empty pen in Barn A. The gas sensors were raised to a

height of approximately 10-cm above the floor level. With this setup, gas levels were measured at human level (2 m) and at animal level (10 cm) within the same pen in Barn A. On February 4, 1999, re-calibration of the gas sensors that were moved to animal level in Barn A revealed that the ammonia sensor had malfunctioned and was giving inaccurate readings. The sensor was replaced and calibrated on February 11, 1999.

The entire instrumentation system was removed from Barn A and installed in Barn B on February 24, 1999. Measurements were again taken at human level and animal level in Barn B during this period. The setup and configuration of the instrumentation system remained the same as described for Barn A above.

All of the instrumentation equipment was removed from the site on March 9, 1999, marking the end of data collection for this research project.

CHAPTER IV

RESULTS AND DISCUSSION

Data for this research project were taken over three different periods. Each period emphasized the effect that pit ventilation has on the removal of manure gases from the swine environment inside confinement houses. Most of this study was conducted inside two separate, but similar swine housing structures. One house utilized a pit ventilation system, while the other had no form of ventilation to remove gases and odors from the manure pit. Comparisons are made between the two houses over the difference in manure gas concentrations, with the major manure gases, ammonia and hydrogen sulfide, being emphasized. The internal environment and its role in gas production and accumulation are also studied to see if there is a correlation between these factors.

A brief portion of this study (3 weeks of data) focused on measuring the gases exhausted from the manure pit by the pit ventilation system. Here again, comparisons are made between the gas levels at the pit fan exhaust and inside the barn to determine the effectiveness of pit ventilation in removing manure gases from inside the confinement building.

Data relating to the difference between gas levels at human (2 m) and animal level were also taken during the final weeks of this study. Comparisons of gas level

concentrations were made between the two measurement locations in both the pit ventilated (Barn B) and non-pit ventilated (Barn A) confinement houses.

A point of interest when analyzing the data in this chapter is that, during the initial study period, the pit ventilation system in Barn B was discovered to be inoperable during the months of December, 1997 through February, 1998. The pit ventilation system was repaired and operational throughout the remainder of the studies.

1. Temperature Effect

Figures E-1 and E-2 show the averaged temperatures for the eight thermocouples in each barn and the temperature sensor outside during the first study period. Temperatures within the barns tended to cycle around an average of approximately 20 °C. During much of the January-February period, temperatures within the two barns varied little from each other. Where differences occurred, Barn B was usually at a slightly higher temperature than Barn A. The only exception was for early January. Problems with the thermocouple input for Barn A during this period required use of a thermistor sensor inside the data logger. Although an offset adjustment was attempted, the higher values here and during the 25 to 32 day period of figure E-2 are probably due to use of the thermistor to replace the multiple thermocouple inputs.

Thermocouple inputs were not used to record temperatures during the period when the pit fan exhaust was being measured. Temperature data for this period were taken by the temperature and relative humidity probes located with the gas sensors. Figure E-3 shows the temperature readings inside of Barn B and at the pit fan. This

figure also shows a close cycling pattern between the two locations. The temperature readings at the pit fan tended to be slightly higher than those of Barn B. The temperatures in Barn B were also more variable than those at the pit fan, with lower temperatures dropping well below that of the pit fan readings. The differences in temperatures can be explained by the amount of ventilation used in Barn B. High ventilation rates kept the temperature inside the barn, for most of the time, below that of the pit fan during the hottest parts of the day and allowed enough of an air flow through the barn to keep it sufficiently cool through the evening and early morning hours.

Temperature data collection during the third study period was again accomplished by the use of thermocouple inputs and temperature and relative humidity probes. Figure E-4 shows temperature conditions inside Barns A and B, and outside during this period. Averaged thermocouple inputs in Barn A and Barn B are shown along with the outside temperature data taken from the temperature and relative humidity probe located on the outdoor weather station. Inside temperatures during this period tended to cycle in patterns close to that of outdoor conditions, with Barn B's readings being more variable than Barn A. Examination of temperature data taken from the temperature and relative humidity probes at both sets of gas sensors also revealed the same trend in Barn B, indicating more variable temperature ranges, possibly due to differences in ventilation between the two buildings. Due to instrumentation and equipment problems experienced during this period, portions of January, 1999's data are incomplete for outside conditions.

Data relating to the operating frequency of the ventilation system can be used here

to explain the differences in temperature between the two barns. Figures E-5 and E-6 show the relationship between ventilation performance and inside temperature changes in Barns A and B during December, 1998. The ventilation system, as previously described, was thermostatically controlled to regulate fan operation. As environmental conditions moved from one extreme to the other, individual fans were either turned on (cool to warm) or turned off (warm to cool). The dependent variable in figures E-5 and E-6 describing ventilation performance was derived by averaging the operating percentage of the five variably running fans over each 30-minute period. This gave the operating frequency for the "total" ventilation, minus the continuously running fan, which was operating at 100%.

The data describing the operating frequency of the ventilation system in Barn A (figure E-5) show that temperature and ventilation are positively correlated with each other. Operating frequency of the ventilation system directly followed changes in temperature. Thermostatically staged settings on the ventilation system allowed individual fans to turn on or off, as determined by temperature fluctuations, to provide a environment conducive to the animals inside. The temperature data, as seen in Barn A, consistently cycled with changes in ventilation, with little variation. The data describing conditions in Barn B (figure E-6), however, show temperature changes to be highly variable. The ventilation system did not consistently operate at levels experienced in Barn A, possibly due to differences in ventilation control settings between the two barns. Comparison of the two figures does show the same increases and decreases in ventilation

over this period. The most noticeable difference was that the operating frequency was consistently running at levels 20% less in Barn B, meaning one less fan was operating. Other reasons for the extreme fluctuations in temperature in Barn B may be due to differences in the building's structure, such as less insulation, and/or drafts or air leaks.

During the last few weeks of this study, when measurements were made at human and animal level, temperatures were recorded only by the temperature and relative humidity probes. Examination of figure E-7 shows the temperature readings at human and animal level in Barn A and Barn B. Again, the readings tended to cycle with one another, with little differences in temperature being detectable in Barn A between the two measurement locations. Levels in Barn B did show some differences between the two areas, where floor level temperatures tended to be slightly lower than that of 2 m temperatures. The lower temperatures experienced at floor level in Barn B could be attributed to, as previously suggested, a combination of differences in building structure, air leaks along the building's lower structure, and air movement due to pit ventilation fans causing cooler air at floor level. A complete listing of the average temperatures for each study period and separate months within each period is given in table D-1.

Comparison of ammonia and hydrogen sulfide levels with temperature for each barn during the first study period indicated variations in gas levels as a function of temperature. During this period of cold weather gas measurement when low ventilation rates were applied, gas levels were found to be negatively correlated with outside temperature. Comparison of figures E-8, E-9, and E-1 shows the relationship between

temperature and gas levels for January and February during the first study period. Levels of ammonia and hydrogen sulfide during this period were significantly higher due to colder temperatures, with levels in Barn B being mostly higher than those of Barn A, when compared to March and April of the same study period (figures E-10, E-11, and E-2). This would be expected due to the minimal ventilation applied. During the first part of March when temperatures were still low, gas levels also showed the same effect. A closer look at figures E-10, E-11, and E-2 for March and April shows that as the outside temperature increased, the gas levels decreased in both barns. Here, gas levels were again dictated by the temperature. Ventilation rates were increased due to the rise in temperature, therefore allowing accumulated gases inside the barn to escape. Of interest here is that both ammonia and hydrogen sulfide gas levels in Barn B were now lower than Barn A's levels due to the pit ventilation system being operational at this time. This appears to indicate that pit ventilation is effective in removing undesirable gases during these cold periods with low ventilation. This effect was not observed during January and February when the outside temperature was colder and the pit ventilation system was not operational.

Cold weather measurements taken in Barn A and Barn B during the final study period revealed similar trends and results as experienced during the previous winter. Ammonia and hydrogen sulfide levels in Barn A were found to be inversely proportional to indoor temperature, which was dictated by outdoor conditions. Regression of temperature on ammonia and hydrogen sulfide in Barn A revealed a negative correlation

pattern ($p < 0.05$), where, as temperature increased, gas levels decreased and vice/versa. 44% of changes in ammonia could be explained by changes in temperature (R^2 value), while changes in hydrogen sulfide due to temperature was at 42%. The changes in gas levels were found to lag changes in temperature by ½ hour, meaning a delayed effect in response to temperature. This action again supports results found during the first study period, where as ventilation rates were decreased by lower temperatures to maintain an optimal inside environment for the animals, gas level concentrations rose due to increased accumulations within the closed unit. Increases in temperature increased the total ventilation and provided enough air exchange to decrease gas level concentrations within the building. Examination of figures E-12 and E-13 shows the negative relationship of ammonia and hydrogen sulfide to temperature in Barn A.

During this period hydrogen sulfide levels in Barn B were also negatively correlated with temperature ($p < 0.05$), while ammonia levels were found to be directly related to temperature ($p < 0.05$). Although significant levels of ammonia and hydrogen sulfide were found, only 7.5% and 2% of changes in gas levels could only be related to changes in temperature for ammonia and for hydrogen sulfide, respectfully, indicating no useful relationship between gas levels and temperature in Barn B during this time. The highly variable temperature and ventilation patterns in Barn B, as seen in figure E-6, could explain the weaker correlation between gas levels and temperature within Barn B.

The relation of ammonia and hydrogen sulfide to temperature in Barn B can be seen in figures E-14 and E-15. Temperatures in Barn B during this period, especially

during days 11-51, were again significantly lower and more variable than Barn A's temperatures. The extreme fluctuations in temperature may not have allowed for consistent enough for gas levels to change proportionally with temperature, especially due to delayed responses from the temperature effect.

Data collected in the summer, during the second study period, also showed the role temperature has on gas levels. Comparison of figures E-16-19 shows the ammonia and hydrogen sulfide gas levels and temperature recordings taken at the pit fan and inside Barn B. Examination of these figures found a positive correlation occurring between temperature and gas levels during periods of warm weather. Gas levels for ammonia and hydrogen sulfide taken at both locations closely followed the temperature changes during most of this period.

Based upon the data collected and presented here, the effect of temperature played an important role in gas production. Gas levels were found to change consistently and in certain patterns with temperature, depending upon outdoor environmental conditions. Still, the key factor in controlling gas levels inside confinement buildings is the amount of ventilation applied. The greater amounts of air forced through the building can not only prevent higher gas levels caused from temperature increases, but also quickly remove any accumulated gases from the building before undesirable effects occur.

2. Diurnal and Other Effects

Diurnal Changes

The diurnal changes in gas levels occurring during this study were found to be

dependant on environmental conditions and the season of year, much as described in the previous section. Gas levels fluctuated in daily cycles as dictated by temperature and ventilation rates. During periods of cold weather gas measurement, such as the first and last study periods, changes in gas levels inside the barns were largely dependent upon changes in ventilation rates due to temperature fluctuations. During the second study period, when warm weather gas measurement occurred, daily changes were almost solely dependent upon temperature changes, with changes in ventilation playing little or no role.

The changes in ammonia and hydrogen sulfide levels during the first study period are closely related as shown in figures E-20-23 (the small negative values shown for hydrogen sulfide, and occasionally for ammonia, are the result of a slight bias in the zero calibration). Some diurnal change was present throughout this period, with the differences increasing as environmental conditions fluctuated. Supplemental heat was not provided in these buildings', thus, as the temperature declined due to cold weather, the ventilation in the confinement houses was lowered by the control system to conserve heat inside the barns. This period of low outside temperatures and subsequent low inside ventilation rates caused increased gas accumulations. This can be seen in figures E-22 and E-23, where gas levels tended to peak between midnight and mid-morning due to minimal ventilation. Minimum levels occurred about mid-afternoon when the highest rates of ventilation were applied.

Diurnal changes in gas levels during the second study period were found to be almost exactly opposite of the conditions experienced during the first study period.

Figures E-24 and E-25 show ammonia and hydrogen sulfide levels taken inside Barn B and at the pit exhaust area. Close examination of these figures shows gas levels peaking during the warmest part of the day, with minimal levels occurring during the coolest part of the day. The assumption here is that ventilation rates were at their highest during the warmest part of the day, indicating a positive correlation with gas production. Even though high ventilation rates helped to keep the gas levels inside the barn at relatively low, safe levels, ventilation could not keep increases in gas levels from occurring during the warmest part of the day, indicating a temperature effect. Gases are released from the manure by decomposition. The rate of release is dependent upon the amount of microbial activity taking place in the manure. Microbial activity is greater during periods of high temperatures and lower during periods of low temperatures. This biological characteristic of manure decomposition explains why gas levels were found to be highest during the day and lowest during the night.

Diurnal changes occurring during the final study period were also very similar to conditions experienced during the first study period. Gas levels tended to cycle from high to low as determined by changes in ventilation due to environmental changes. Data relating to the operating frequency of the ventilation system, as previously described, can be used here to describe the relationship affecting diurnal changes in gas concentrations.

Figure E-26 shows the relationship between ventilation performance and ammonia gas levels. The data in this figure represent a two week period in December, 1998. Levels of ammonia are plotted with ventilation performance to illustrate the

diurnal effects occurring in Barn A during this time period. Ammonia levels peaked mostly during the night time period, when ventilation rates were at their lowest, whereas levels dropped significantly during the day as ventilation rates were increased to accommodate rises in temperature. The diurnal changes occurring here illustrate the correlation between ventilation performance, which is a factor of temperature, and changes in gas levels. Changes in gas levels from day-to-day in a cyclic pattern occurred during most of this study, signifying the close relationship between gas levels and factors affecting their concentrations, such as ventilation and temperature.

Ventilation Failure

Ventilation breakdown is a concern among swine producers using mechanically ventilated confinement buildings. When this occurs, airflow through the buildings is restricted, causing accumulations of dust and manure gases, elevated temperature levels, and decreased oxygen levels within the building. This can be extremely dangerous to the animals inside, depending upon the season of year, time of day, and length of failure. Figures E-24, E-27, and E-28 shows the effects that ventilation breakdown has on gas concentrations with a confinement unit. A power outage occurred early in the morning on August 29, 1998 in Barn B, rendering the entire ventilation system inoperable for a short period of time. This failure in ventilation caused ammonia levels to dramatically increase to around 12.6 ppm within the barn from accumulations due to the lack of air movement and replenished air. On the other hand, ammonia levels taken at the pit exhaust area dropped sharply because of decreased air movement from within the pit due

to the lack of power to the pit ventilation fan. With the pit fan off and fan shutters closed, very little gas was allowed to escape from the pit area, causing a large drop off of detectable ammonia. Temperature levels (figure E-27) and oxygen levels (figure E-28) were also affected by the power outage to the ventilation system. Temperatures taken within the barn rose during this period from the buildup of heat inside the "closed" unit, while oxygen levels decreased due to the lack of replenished air and excessive hog respiration. Swine have very few sweat glands, so higher temperatures cause heavier respiration rates as they attempt to remove excess body heat, therefore causing more oxygen to be used up.

The time recorded on the data logger corresponding to the sharp rise in gas levels was around 4:00 am. This system failure lasted until around 6:30 am when a sharp rise in the pit exhaust gas levels was detected, indicating return of power. It is interesting to note here that when power was again supplied to the pit fan, ammonia levels rose sharply to levels well above those normally observed during this period. This clearly reflects the buildup of gases trapped in the pit during the ventilation failure.

Another point of interest when analyzing figure E-27 is that changes in inside temperature and ammonia levels were closely correlated during this time. They increased, reached peak values at approximately 5:00 am., and began to decrease. This decrease occurred well before the increase in ammonia levels at the pit exhaust indicated that power was restored. The confinement buildings monitored in this study utilized side-wall curtains. These curtains are thermostatically controlled to drop during periods of warmer

weather, allowing more air to circulate within the building. A safety feature designed with these curtains is that, when the ventilation system is not working and power has not been restored after a certain time, the curtains drop to allow natural ventilation within the building. This appeared to occur at approximately 5:00 am, causing inside ammonia and temperatures to drop well before pit exhaust ammonia rose. The accumulated ammonia inside the barn escaped and temperatures decreased due to air exchange following dropping of the curtains.

Ventilation failure is most critical during the warmer, summer months. However, the time of day and short period of time for this occurrence, along with implemented safety features, decreased the possibility of adverse, and perhaps fatal, effects to the animals inside. Because this occurred in the early morning hours, when daily temperatures are typically at their lowest, temperature and gas levels did not rise to dangerous levels and oxygen levels were not severely depleted inside the confinement unit. If this were to occur during the hottest part of the day and last for a significant period of time, far more adverse conditions would be experienced.

3. Pit-Recharge Effect

The manure management system used in both barns during the entire study was a pit recharge flushing procedure. This type of system allowed the manure from the storage pits to be pumped weekly and drained into an outside lagoon storage system. This provided a cycling of the manure and prevented the buildup of wastes and subsequent odor and toxic gas production inside the confinement buildings. This pit flushing

procedure did, however, cause the manure to undergo a "slurry effect", caused by manure agitation during mixing and turning. This caused the release of gases trapped in the manure, which led to elevated levels of gas concentrations, most notably, ammonia and hydrogen sulfide.

The pit flushing procedure was, as noted earlier, scheduled to occur every Wednesday morning for Barn A and every Thursday morning for Barn B. As expected, this procedure caused manure agitation, resulting in significantly higher ammonia and hydrogen sulfide gas levels for a brief period of time. The effect is shown as a sharp spike in gas levels on the dates of flushing. Such spikes did not, however, occur on all scheduled flush dates. Figures E-20-23 clearly demonstrate the effects pit flushing and manure agitation have on gas concentration. As seen here, it doesn't take long for gas concentrations to reach potentially hazardous levels. The rise in gas levels seems to be immediate, then peaking and falling to safe, low levels, indicating the overall effectiveness that the building's ventilation system has on removing the gases from inside. Recall that these measurements were taken at a height of approximately 2 m near the center of the building. It is likely that gas concentrations were higher at animal level. The highest concentrations measured at this location were approximately 21 ppm of ammonia and 3 ppm of hydrogen sulfide. Both occurred in Barn B during the flushing procedure.

Data taken during the second study period, when pit exhaust and gas concentrations from within Barn B were taken, revealed very little about the effects of

recharging the pit contents. The pit flushing schedule remained the same as previously described, with Barn B's contents being flushed and recharged every Thursday. Examination of the data taken for ammonia and hydrogen sulfide (figures E-24 and E-25, respectively) does show a sharp rise in hydrogen sulfide levels inside of Barn B and at the pit exhaust area on the scheduled flush date of August 27, 1998. A sharp rise in ammonia levels within Barn B also occurred on this date, however, no temporary increases in ammonia levels at the pit exhaust area could be detected. This was the only scheduled pit recharging during this study period where the effects on gas concentrations were noticeable.

Other "spikes" in gas levels occurred on days 32 and 36 (September 1 and 5, 1998). These dates did not fall on scheduled pit recharging dates, but these sharp, temporary increases in gas concentrations indicate a rise possibly due to some form of manure agitation.

The flushing and pit recharge procedure did not produce any profound effects on gas concentration levels during the final study period. As with the second study period, sharp increases in both ammonia (figure E-29) and hydrogen sulfide (figure E-30) did occur in regular intervals, but did not coincide with scheduled flush dates. Again, it is likely that some sort of manure agitation caused these sharp, temporary increases in observed gas levels, but we cannot be sure of a definite pit recharge effect, unless changes were unknowingly made in the pit flush schedule.

The management procedure used to handle and remove manure from the

confinement buildings did, as visually described, from time to time cause manure agitation, resulting in some substantial, but brief releases of toxic manure gases. The high releases did not, however, produce any undesirable effects due to the immediate drop in levels soon after. Because manure is removed frequently (on a weekly basis) and is heavily diluted, the manure from within the pit does not have sufficient time or capability to emit high levels of toxic gas from decomposition and anaerobic processes. The findings of this part of the study agree with the results found by Heber et al. (1997), that a pit recharge system can achieve the most reduction in toxic gas levels when compared to other forms of manure management.

4. Effect of Pit Ventilation

Data taken during the first study period was broken down further into time periods when the pit ventilation system was inoperable (January - February, 1998) and operable (March - April, 1998). When the instrumentation system was first installed, the pit ventilation system was assumed operational, but upon checking on the system in late February it was discovered to be inoperable. Defective motors on the pit fans were the reason for its inactivity and were repaired on the last day of February, 1998.

Cold Weather Measurements

Figures E-8-11 show ammonia and hydrogen sulfide gas concentrations over the time period with (figures E-10 and E-11) and without (figures E-8 and E-9) pit ventilation during the first study period. The data as presented in these figures show the effect that an operating pit ventilation system has on removing manure gases from inside

confinement buildings.

During the time period when the pit ventilation system in Barn B was inoperable (January - February, 1998), gas levels for both ammonia and hydrogen sulfide in Barn B tended to be higher than, or the same as, gas levels in Barn A. Examination of the graphical data shows no clear effect of the pit ventilation system on gas levels in Barn B during this time. The gases in Barn B were not removed from the building any differently than those in Barn A due to the inactivity of the pit ventilation system. For this reason, the manure pit gases in Barn B were not held in check and at certain times rose significantly higher than those in Barn A, especially when high releases of gases occurred during the pit flushing procedure (shown as brief spikes in gas concentrations).

Data taken during the time period when the pit ventilation system in Barn B was operational (March - April, 1998) clearly show the positive effect that pit ventilation has on removing manure gases from the building before they can be transferred to the animals' environment. During this time period, both ammonia and hydrogen sulfide gas levels taken in the pit ventilated Barn B were, for the most part, lower than the levels taken in Barn A. The graphical data presented here show how a continuously running pit ventilation system aids the internal environment of confinement buildings by removing the manure pit gases, especially during agitation, or flushing, procedures.

Statistical analysis performed on these data showed significant differences ($p < 0.05$) among gas levels during the periods of inoperable pit ventilation versus operable pit ventilation. The mean values for ammonia and hydrogen sulfide taken over

the two time periods in both barns is shown in figure 8. As seen here, both ammonia and hydrogen sulfide were significantly lower ($p < 0.05$) in both barns during March and April when compared to January and February. Of interest are the levels of ammonia and hydrogen sulfide in Barn B during both time periods. Both gases were found to be significantly higher ($p < 0.05$) in Barn B when compared to Barn A during January and February. During March and April, when the pit ventilation system was running, the levels decreased significantly ($p < 0.05$) in Barn B, falling below the levels of Barn A. We also noted the significant decline of gas levels in Barn B over the two time periods.

Data relating to the cold weather measurements taken during the final study period can be seen in figures E-29 and E-30. Levels of ammonia and hydrogen sulfide, the major toxic manure gases, in Barn A and B are plotted over this approximate two month time period to distinguish the differences between the pit ventilated (Barn B) and non-pit ventilated (Barn A) confinement buildings.

As seen in figures E-29 and E-30, levels for both ammonia and hydrogen sulfide remained lower in the pit ventilated Barn B when compared to Barn A over this time period. Changes in gas levels tended to follow each other often, but the extreme increases noticeable in Barn A were not present in Barn B, due to the effect of the pit ventilation system. The pit ventilation system present in Barn B was successful in removing high levels of ammonia and hydrogen sulfide gas from the pit area within the building before high concentrations could move upward into the animals' environment.

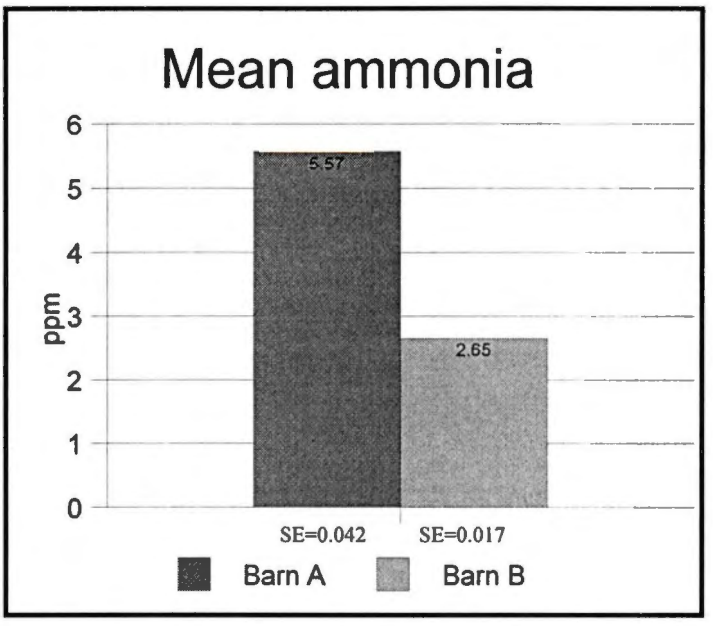
Statistical analysis performed on these data supported the visual evidence, as seen

in figures E-29 and E-30, over the differences in gas concentrations between the two barns during the final study period. Levels for ammonia and hydrogen sulfide were found to be significantly lower ($p < 0.05$) in the pit ventilated Barn B when compared to Barn A. Figure 9 shows the mean values for ammonia and hydrogen sulfide concentrations during the period in Barn A and Barn B. These data clearly show the effectiveness that pit ventilation has on the gas levels in.

An important, and possibly significant, note about this period is that there were a higher number and greater mass of animals in Barn A when compared to Barn B. This likely had an effect upon manure production, which could have led to disproportionate and higher gas level readings in Barn A.

It can be concluded here that the pit ventilation system helps in the control of noxious gases. This type of additional ventilation is especially important during colder weather when minimal ventilation rates are applied, leading to increased gas accumulations inside the barn.

The use of a pit ventilation system will help to control of gas levels within confinement buildings, however manure management style and type of confinement building seem to have the greatest impact on toxic gas production and control thereof within these buildings. It is likely that because the manure in these buildings was constantly removed and diluted, releases of high levels of toxic gases from the manure was minimized. The pit recharge system used in the test buildings played an important role in preventing the high release of toxic manure gases before they moved upward into



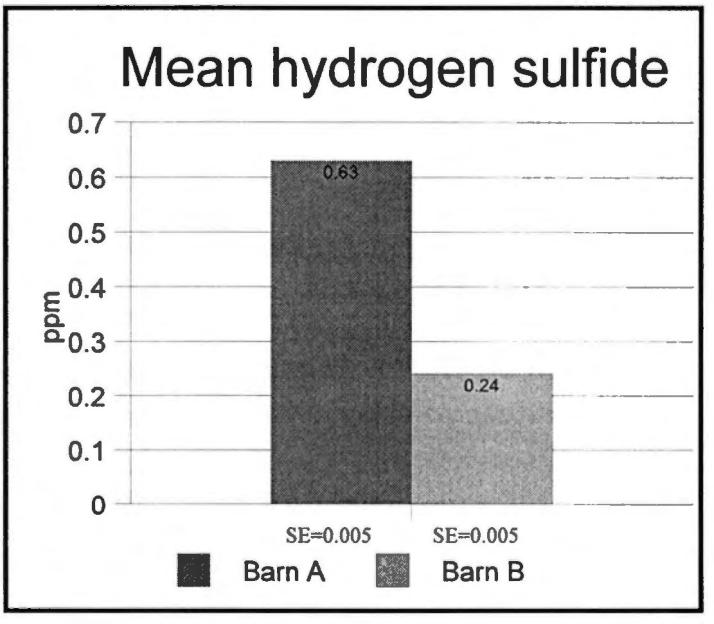


Figure 9. Mean NH_3 and H_2S levels during 3rd study period.

**Note: SE = Standard Error (ppm)

the animals environment. Swine confinement buildings that have the capacity of storing wastes in a deep concrete pit for long periods of time (up to a year) possess the capability of producing high and dangerous levels of toxic manure gases due to the amount and long storage time of manure in the pit. In fact, Heber et al. (1997) found swine confinement buildings that utilize a deep pit storage produce the highest levels of ammonia gas when compared to other building styles. The use of a pit ventilation system probably is most beneficial in this type of building where wastes are stored for long periods of time, rather than for buildings with shallow storage pits and very short storage periods.

Warm Weather/Pit Exhaust Measurements

The use of a pit ventilation system in swine confinement housing is, again, most beneficial during cold weather, when minimal ventilation rates are applied to conserve heat. Toxic manure gases in animal confinement housing during the warmer summer months are generally not considered to be a threat or problem to the animals or workers inside since high ventilation rates help to remove these gases from the building quickly and efficiently, keeping them at low, safe levels. The setup used during this period of measurement, however, allowed the measurement of the toxic manure gases being expelled from the pit area during the time of year when high microbial activity promotes more gas production and generation. The results given here indicate the levels of gas exhausted from the pit area, and compare them to levels measured within the same building.

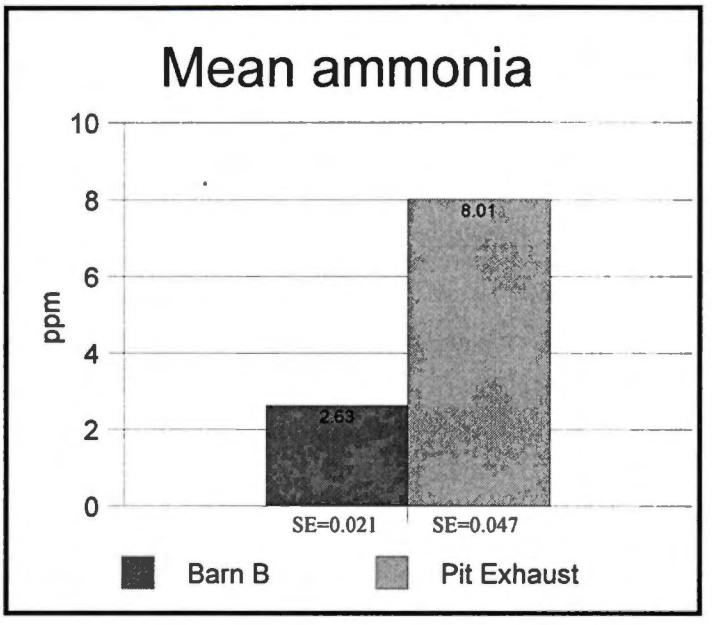
Figures E-24 and E-25 show ammonia and hydrogen sulfide gas measurements

taken inside Barn B and at one of the pit exhaust fans of Barn B. The data presented in these figures show the differences in gas concentrations between the two areas of measurement due to the effect of the pit ventilation system.

Examination of the ammonia and hydrogen sulfide data shows significant differences between the pit exhaust area and inside the barn. Hydrogen sulfide levels measured inside the building were almost always lower than the levels measured at the pit fan; and at no point in this study period did the ammonia levels inside the building reach the high levels measured at the pit fan. Both ammonia and hydrogen sulfide concentrations measurements were found to be significantly different ($p < 0.05$) between the two locations. The mean concentrations for ammonia and hydrogen sulfide inside Barn B and at the pit exhaust area are shown in figure 10. The high levels of these gases being expelled by the pit fan and the relatively low levels detected in the building indicate the effectiveness of the pit ventilation system in removing gases before they reach the animal's environment. These data clearly show that considerable manure gas generation occurs at the pit area, they also verify the need to direct gases out of the pit area before they move upward into the confinement area.

Animal Level Measurements

The results obtained during the last part of the third study period when measurements were made at both human (2 m) and animal level can be seen in figures E-31 (ammonia) and E-32 (hydrogen sulfide). A closer look at the data for ammonia shows some slight differences in concentrations between the two areas of measurement in both



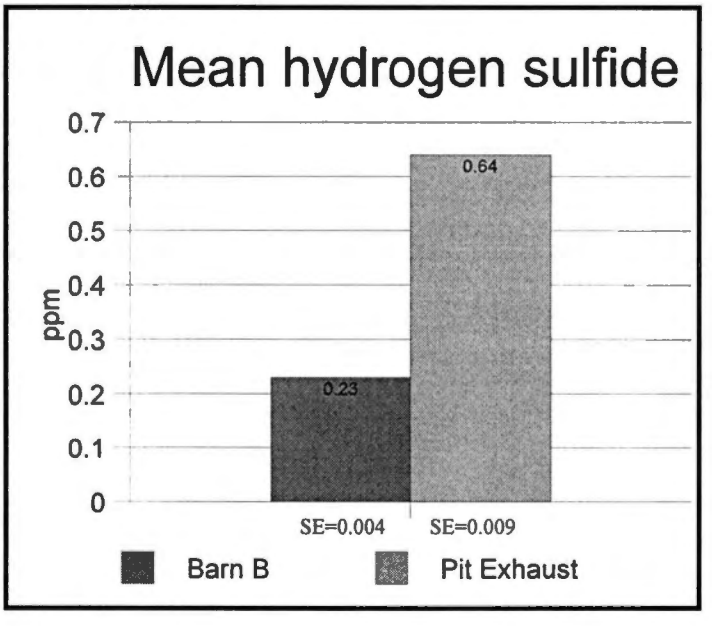


Figure 10. Mean NH_3 and H_2S levels during 2nd study period.

**Note: SE = Standard Error (ppm)

Barn A and Barn B. When measurements were made in Barn A (days 29-55), ammonia levels tended to be slightly higher at animal level than at human level during the same time period. This is to be expected since ammonia, being lighter than air, rises from the pit area and is more detectable and concentrated at its point of generation in the non-pit ventilated barn.

The same measurements taken in the pit ventilated Barn B produced results that were different from Barn A. During the time period (days 55-68) when ammonia was measured at human and animal level in Barn B, ammonia levels were found to be lower at animal level than at human level for most of this period. The differences here can be attributed to the pit ventilation system in Barn B. The emission of ammonia from the slurry in the pit is being pulled from this area by the pit ventilation fans, located on each end of the building, and expelled to the outside environment before higher levels, as detected in Barn A, rise to the animal's environment. As ammonia readily moves upward, accumulations inside Barn B account for the more elevated readings at 2 m. The results in Barn B were to be expected since ventilation rates were low due to cold weather, therefore producing higher concentrations at human level due to accumulations occurring at 2 m. The results obtained here for ammonia reaffirm the advantages of a pit ventilation system during periods of cold weather.

The results observed for hydrogen sulfide contrasted those found for ammonia. Figure E-32 shows hydrogen sulfide concentrations taken over the same time period. Hydrogen sulfide levels, except through days 29-34, were found to be mostly higher at

human level than animal level in Barn A. Measurements taken in Barn B, however, were found to be higher at animal level than at human level.

Hydrogen sulfide is heavier than air and is not very soluble in water, so the gas would normally stay trapped in bubbles in the slurry pit and, when released, remain close to its origination point, rather than move upward rapidly. However, this is not evident when analyzing the data taken in Barn A. Again, levels can be seen to be higher at human level, which suggests that this gas became more concentrated at higher levels in Barn A. Data obtained in Barn B does show gas levels to be higher at animal level, which would be expected normally, but not in a pit ventilated barn.

The inconsistent and unexpected data describing hydrogen sulfide levels in both barns and at both locations is probably due to differences in calibration between the two electrochemical sensors. The steps involved for calibrating the hydrogen sulfide sensors, as noted in an earlier section, included a scan and zero calibration. The difficulty experienced in calibrating the sensor to zero could be the reason for inaccurate and sometimes below scale readings (figure E-11). The span calibration also proved to be somewhat suspect because its high end calibration was set at 23.7 ppm, which was much higher than any recorded measurements for this study. The combination of a high end calibration and a difficult zero setting probably accounts for some of the variable readings experienced here and throughout other portions of this study. Before measurements were taken at animal and human level, both sets of gas sensors were set at floor level in the same barn to detect any differences between sensor measurements. The gas sensors were

allowed to monitor data for two recording cycles (1 hour).

Data collection from this short period revealed virtually no differences in ammonia gas concentrations between the two electrochemical sensors. Data for hydrogen sulfide, however, revealed some differences worth noting. The hydrogen sulfide sensor, placed at human level in Barn A (figure E-32), did read slightly higher than the other sensor when placed side-by-side at the same level. When the gas sensor units were moved to Barn B, the same level test measurements were not performed but results in Barn B support the same-level tests conducted in Barn A. Because of ceiling mounting hardware incompatibility, it was necessary to reverse the high-low installation combination used in Barn A. Thus the sensor with a slightly higher output signal (high location in Barn A) was moved to the floor level in Barn B. As a result, hydrogen sulfide levels taken at floor level in Barn B were noticeably higher than levels measured by the other hydrogen sulfide sensor.

The differences in floor level hydrogen sulfide readings appear to be due to calibration differences between the two sets of hydrogen sulfide sensors. The offset readings can be attributed to the difficulty in zero calibration and/or human error in calibration procedures combined with a lack of an ideal calibration location (performed at the farm site, not in a controlled lab).

Statistical analysis on these data support figure E-31. Differences were found in gas levels taken at human and animal level ammonia ($p < 0.05$) (hydrogen sulfide levels were not analyzed due to instability in readings described above). There were also

differences in gas concentrations found at human level between Barn A and Barn B and animal level between Barn A and Barn B. Table 1 shows the mean concentrations for ammonia at human and animal level in Barn A and Barn B and shows the values that are significantly different from each other.

Table 1. Mean ammonia concentrations at animal and human level (2 m) in Barn A and Barn B.

Barn	Measurement Location	Mean (ppm)	Grouping
A	Human (2 m) Level	5.79	A
A	Animal (10 cm) Level	6.96	B
B	Human (2 m) Level	5.08	C
B	Animal (10 cm) Level	4.54	D

Means with different grouping letters are significantly different from one another($p < 0.05$)

CHAPTER V

SUMMARY AND RECOMMENDATIONS

1. Summary

The primary objective of this study was to continuously monitor the inside environment of two swine confinement houses that were very similar except for the use of a pit ventilation system by one of the buildings. Results of this study revealed that there were statistically significant differences ($p < 0.05$) between the major manure gases, ammonia and hydrogen sulfide, in the pit ventilated and non-pit ventilated confinement buildings. The use of pit ventilation reduced ammonia and hydrogen sulfide gas levels within the pit ventilated building during periods of cold weather.

Temperature and the amount of ventilation applied were also found to affect manure gas levels within confinement buildings. During cold weather, gas levels were found to change inversely proportional to that of ventilation due to changes in temperature. As inside temperature decreased due to colder weather, ventilation rates decreased to conserve heat, causing an increase in levels of ammonia and hydrogen sulfide inside the closed unit. During warm weather, gas levels were found to change directly proportional to changes in temperature. The differences in rate of change over weather seasons is mainly due to the effects of higher temperatures, causing microbial

activity to enhance the emission rates of gases from stored manure.

This study found the manure management system used in the facilities (a pit flushing procedure) could produce some sharp, temporary increases in ammonia and hydrogen sulfide levels inside the buildings on some of the scheduled flush dates.

Measurements taken at animal and human level (2 m) revealed some differences in gas concentrations between the two areas of measurement in both of the confinement buildings. However, limited amounts of data were obtained during this period, so more extensive studies are recommended to fully analyze any differences that occur between gas concentrations at the two levels.

Overall, the implications of this study show the effect that the environment has on manure gas concentrations. The environment, in turn, directly affects the performance of the ventilation system, which was shown to have the most influence on gas level fluctuations. This study also shows pit ventilation to be beneficial in swine confinement buildings with slotted floors and under-floor manure storage pits. The continuous removal of ammonia and hydrogen sulfide prevented the accumulation of these gases in the room air. Therefore, pit ventilation can help to improve the air quality within these buildings to provide a safer environment to both the animals and workers inside.

One note about the pit ventilation system is that, even though it helped to improve the air quality within the pit ventilated building when compared to the non-pit ventilated building, levels for ammonia and hydrogen sulfide did not, at any time, approach dangerous levels in either building. Pit ventilation was beneficial for the removal of the

toxic manure gases from the building, but the management style, more specifically, the manure management style seems to have more effect on gas control than any form of gas removal from the pit area.

The procedure of flushing and recharging the manure pits on a regular basis, as occurred here, allowed for the continuous removal and dilution of manure, therefore keeping accumulations and excessive gas production from occurring. Swine confinement buildings that use deep storage pits underneath the slotted floor to store manure for long periods of time could benefit the most from a pit ventilation system. When swine wastes are stored for long periods of time, anaerobic decomposition causes excessive production of ammonia and hydrogen sulfide. The higher levels produced in these management systems, which can store wastes for up to a year, causes the documented dangerous, and sometimes fatal, levels within swine confinement buildings that pit ventilation was probably designed for.

2. Conclusions

1. Environmental factors, especially temperature, can affect the production and rate of release of toxic manure gases within swine confinement buildings.
2. Overall ventilation and manure management style are the biggest factors when trying to control manure gas levels within swine confinement buildings.
3. The use of pit ventilation removes manure gases from the pit area before

they move upward to the internal environment; however there is less need for this system in management styles that continuously remove manure from storage pits, such as the facilities used in this study

3. Recommendations

Based upon the data collected in this study, it is recommended that producers provide an internal environment that is conducive to both the animals and workers health and well-being. Ways to insure this include providing the proper amount of ventilation inside confinement buildings and handling the manure management system in a way that does not allow for long storage times, which can lead to elevated toxic gas levels within. The use of a pit ventilation system can help to improve the air quality within swine confinement buildings, but is only recommended if manure is stored for long periods of time and if gas concentrations consistently remain at elevated and dangerous levels.

BIBLIOGRAPHY

BIBLIOGRAPHY

Barker, J., S. Curtis, O. Hogsett and F. Humenik. 1986. Safety in Swine Production Systems. Pork Industry Handbook. PIH-104, pp 1-8.

Brown-Brandl, T.M., J.A. Nienaber and L.W. Turner. 1998. Acute Heat Stress Effects on Heat Production and Respiration Rate in Swine. Transactions of the ASAE 41 (3): 789-793.

Carpenter, G.A. 1987. Climate Control Systems and Equipment – Building Design, Ventilation and Air Cleaning. British Society of Animal Production, No. 11.

Close, W.H. 1987. The Influence of the Thermal Environment on the Productivity of Pigs – Pig Housing and the Environment. British Society of Animal Production, No. 11.

Donham, K.J. 1991. Association of Environmental Air Contaminants with Disease and Productivity in Swine. American Journal of Veterinary Research 52 (10): 1723-1730.

Donham, K.J., L.W. Knapp, R. Monson and K. Gustafson. 1982. Acute Toxic Exposure to Gases from Liquid Manure. Journal of Occupational Medicine 24 (2): 142-145.

Donham, K.J., J. Yeggy and R.R. Dague. 1988. Production Rates of Toxic Gases from Liquid Swine Manure: Health Implications for Workers and Animals in Swine Confinement Buildings. Biological Wastes 24 (1988): 161-173.

Esmay, M.L. and J.E. Dixon. 1986. Environmental Control for Agricultural Buildings. AVI Publishing Company, Inc. Westport, Connecticut.

Fleet, B and Gunasingham, H. 1992. Electrochemical Sensors for Monitoring Environmental Pollutants. Talanta 39 (11): 1449-1457.

Gates, R.S. 1994. Interior Environment and Energy Use in Poultry and Livestock Facilities. Project Proposal. University of Kentucky.

Gerber, D.B., K.M. Mancl, M.A. Veenhuizen and G.C. Shurson. 1991. Ammonia, Carbon Monoxide, Carbon Dioxide, Hydrogen Sulfide, and Methane in Swine Confinement Facilities. Compendium on Continuing Education for the Practicing Veterinarian 13 (9): 1483-1488.

Grub, W., E.P. Foerster and I.F. Tribble. 1974. Swine Building Air Contaminate Control with Pit Ventilation. ASAE Paper No. 74-4532, ASAE, St. Joseph, MI 49085.

Heber, A., D. Jones and A. Sutton. 1997. Indoor Air Quality-Controlling Ammonia Gas in Swine Buildings. Purdue Educational Materials No. IAQ-1. http://hermes.ecn.purdue.edu.

Hoff, S.J., J. Li and L. Tsao. 1995. Simulated and Measured Effect of Rectangular Obstructions on Carbon Dioxide Gas Dispersion in a Scaled Swine Building. Transactions of the ASAE 38 (5): 1519-1532.

Jacobson, L.D., K.A. Janni and V.J. Johnson. 1996. Toxic Gas and Dust Concentrations Inside Minnesota Pig Facilities. International Conference on Air Pollution from Agricultural Operations. February 7-9, 1996. Kansas City, Missouri.

Jones, D.D. and W.H. Friday. 1980. Manure Pit Ventilation in Confinement Livestock Buildings. Co-operative Extension Service, Purdue University, West Lafayette AE-98, 16 pp.

Muehling, A.J. 1970. Gases and Odors from Stored Swine Wastes. Journal of Animal Science 30 (4): 526-531.

Ni, J., D. Berckmans, J. Coenegrachts, C. Vinckien and V. Goedseels. 1996. Ammonia Emission Floor Factors for Swine Houses with Slatted Floors. International Conference on Air Pollution from Agricultural Operations. February 7-9, 1996. Kansas City, Missouri.

Ni, J., A.J. Heber, T.T. Lim, R. Duggirala, B.L. Haymore, C.A. Diehl and A.L. Sutton. 1998. Ammonia Emissions from a Mechanically-Ventilated Swine Building During Warm Weather. ASAE Paper No. 98-4051, ASAE, St. Joseph, MI 49085.

Ni, J., A.J. Heber, T.T. Lim, R. Duggirala, B.L. Haymore, C.A. Diehl and A.L. Sutton. 1998. Hydrogen Sulfide Emissions from a Mechanically-Ventilated Swine Building During Warm Weather. ASAE Paper No. 98-4050, ASAE, St. Joseph, MI 49085.

Patni, N.K. and S.P. Clarke. 1991. Transient Hazardous Conditions in Animal Buildings Due to Manure Gas Released During Slurry Mixing. Applied Engineering in Agriculture 7 (4): 478-484.

Pickrell, J. 1991. Hazards in Confinement Housing – Gases and Dusts in Confined Animal Houses for Swine, Poultry, Horses and Humans. Veterinary Human Toxicology 33 (1): 32-39.

Pohl, S.H. and M.A. Hellickson. 1978. Model Study of Five Types of Manure Pit Ventilation Systems. Transactions of the ASAE 21 (3): 542-549.

Ross, C.C. and W.D. Daley. 1986. Ammonia Sensing in Broiler House Environments. ASAE Paper No. 86-4044, ASAE, St. Joseph, MI 49085.

Taiganides, E.P. and R.K. White. 1968. The Menace of Noxious Gases in Animal Units. ASAE Paper No. 68-557, ASAE, St. Joseph, MI 49085.

Tennessee Agriculture. 1997. Tennessee Agriculture Statistics Service.

Turner, L.W., H.J. Monegue, R.S. Gates and M.D. Lindemann. 1997. Fan, Sprinkler, and Sprinkler Fan Systems for Cooling Growing-Finishing Swine. ASAE Paper No. 97-4076, ASAE, St. Joseph, MI 49085.

Vansickle, J. 1982. Pit-Related Deaths Traced to Unsafe Agitation. National Hog Farmer January 15, 1982, pp 29-31.

Venkatasetty, H.V. 1992. Measurement and Control - Understand the Potential Uses of Electrochemical Sensors. Chemical Engineering Progress 88 (7): 63-66.

Voermans, J.A.M., N. Verdoes and J.J.J Smeets. 1996. Possibilities of Ammonia Reduction on Sow Farms. International Conference on Air Pollution from Agricultural Operations. February 7-9, 1996. Kansas City, Missouri.

Watson, R.D. and J.A.R. Friend. 1987. Pig Housing and Human Health. British Society of Animal Production, No. 11.

Zhang, R.H. and D.L. Day. 1996. Anaerobic Decomposition of Swine Manure and Ammonia Generation in a Deep Pit. Transactions of the ASAE 39 (5): 1811-1815.

APPENDICES

APPENDIX A

Table A-1. Instrumentation System Components.

Device	Quantity	House Location	Description
Data logger	1	A	CSI, 21X
Multiplexer	1	A	CSI, AM416
Multiplexer	2	B	CSI, AM432
NH_3 Sensor	2	A & B	Dräeger, electrochemical
H_2S Sensor	2	A & B	Dräeger, electrochemical
CO Sensor	2	A & B	Dräeger, electrochemical
O_2 Sensor	2	A & B	Dräeger, electrochemical
CO_2 Sensor	1	A	Dräeger, infrared
T & RH Sensor	2	A, B, & Outside	CSI
Thermocouples	16	A & B	Type T
Weather Station	1	Outside	CSI
Modem	1	A	CSI
Cellular Phone	1	A	CSI

APPENDIX B

Table B-1. Gas sensor calibration example.

Gas Sensor Calibrations — 9/29/97

BARN A				
GAS	ZERO CALIBRATION		SPAN CALIBRATION	
	Sensor	Panel mV	Sensor (ppm)	Panel mV
CO	0	953	209	3610
O_2	0	960	20.9	4184
NH_3	0	953	69	3601
H_2S	0	959	23.7	2780
BARN B				
GAS	ZERO CALIBRATION		SPAN CALIBRATION	
	Sensor	Panel mV	Sensor (ppm)	Panel mV
CO	0	1001	209	3699
O_2	0	961	20.9	4160
NH_3	0	963	69	3621
H_2S	0	955	23.7	2782

APPENDIX C

Appendix C-1. Data Logger Program Used During First Study Period.

```
;{21X}
*Table 1 Program
  01: 20.0000   Execution Interval
(seconds)

1: If time is (P92)
 1: 0       Minutes into a
 2: 540     Minute Interval
 3: 44      Set Port 4 High

2: If time is (P92)
 1: 0       Minutes into a
 2: 570     Minute Interval
 3: 54      Set Port 4 Low

3: If time is (P92)
 1: 0       Minutes into a
 2: 900     Minute Interval
 3: 44      Set Port 4 High

4: If time is (P92)
 1: 0       Minutes into a
 2: 960     Minute Interval
 3: 54      Set Port 4 Low

5: If time is (P92)
 1: 0       Minutes into a
 2: 30      Minute Interval
 3: 10      Set Output Flag High

6: Real Time (P77)
 1: 120     (Same as 220) D,Hr/Mn

7: Sample (P70)
 1: 1       Reps
 2: 1       Loc [ _____ ]

8: Average (P71)
 1: 1       Reps
 2: 2       Loc [ _____ ]

9: Average (P71)
 1: 6       Reps
 2: 30      Loc [ _____ ]

10: Sample (P70)
 1: 1       Reps
 2: 29      Loc [ _____ ]

11: Average (P71)
 1: 6       Reps
 2: 3       Loc [ _____ ]

12: Average (P71)
 1: 4       Reps
 2: 17      Loc [ _____ ]

13: Average (P71)
 1: 8       Reps
 2: 9       Loc [ _____ ]

14: Average (P71)
 1: 8       Reps
 2: 21      Loc [ _____ ]

15: Batt Voltage (P10)
 1: 1       Loc [ _____ ]

16: Internal Temperature (P17)
 1: 2       Loc [ _____ ]

17: Do (P86)
 1: 41      Set Port 1 High

18: Beginning of Loop (P87)
 1: 0       Delay
 2: 8       Loop Count

19: Excitation with Delay (P22)
 1: 1       Ex Channel
 2: 30      Delay w/Ex (units = 0.01 sec)
```

3: 30 Delay After Ex (units = 0.01 sec)
4: 5000 mV Excitation

20: Thermocouple Temp (DIFF) (P14)
1: 1 Reps
2: 2 15 mV Slow Range
3: 2 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 2 Ref Temp (Deg. C) Loc [_____]
6: 9 -- Loc [_____]
7: 1 Mult
8: 0 Offset

21: End (P95)

22: Set Port (P20)
1: 0 Set Low
2: 1 Port Number

23: Do (P86)
1: 41 Set Port 1 High

24: Beginning of Loop (P87)
1: 0 Delay
2: 6 Loop Count

25: Excitation with Delay (P22)
1: 1 Ex Channel
2: 30 Delay w/Ex (units = 0.01 sec)
3: 30 Delay After Ex (units = 0.01 sec)
4: 5000 mV Excitation

26: Volt (Diff) (P2)
1: 1 Reps
2: 5 5000 mV Slow Range
3: 8 DIFF Channel
4: 3 -- Loc [_____]
5: 1 Mult
6: 0 Offset

27: End (P95)

28: Set Port (P20)
1: 0 Set Low
2: 1 Port Number

29: Do (P86)
1: 42 Set Port 2 High

30: Beginning of Loop (P87)
1: 0 Delay
2: 4 Loop Count

31: Excitation with Delay (P22)
1: 2 Ex Channel
2: 30 Delay w/Ex (units = 0.01 sec)
3: 30 Delay After Ex (units = 0.01 sec)
4: 5000 mV Excitation

32: Volt (Diff) (P2)
1: 1 Reps
2: 5 5000 mV Slow Range
3: 1 DIFF Channel
4: 17 -- Loc [_____]
5: 1 Mult
6: 0 Offset

33: End (P95)

34: Set Port (P20)
1: 0 Set Low
2: 2 Port Number

35: Do (P86)
1: 43 Set Port 3 High

36: Beginning of Loop (P87)
1: 0 Delay
2: 8 Loop Count

37: Excitation with Delay (P22)
1: 3 Ex Channel
2: 30 Delay w/Ex (units = 0.01 sec)
3: 30 Delay After Ex (units = 0.01 sec)
4: 5000 mV Excitation

38: Thermocouple Temp (DIFF) (P14)
1: 1 Reps
2: 1 5 mV Slow Range
3: 6 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 2 Ref Temp (Deg. C) Loc [_____]
6: 21 -- Loc [_____]
7: 1 Mult
8: 0 Offset
39: End (P95)

40: Set Port (P20)
1: 0 Set Low
2: 3 Port Number

41: Volt (Diff) (P2)
1: 1 Reps
2: 2 15 mV Slow Range
3: 7 DIFF Channel
4: 29 Loc [_____]
5: .09434 Mult
6: 0 Offset

42: Temp 107 Probe (P11)
1: 3 Reps
2: 5 SE Channel
3: 4 Excite all reps w/Exchan 4
4: 30 -- Loc [_____]
5: 1 Mult
6: 0 Offset

43: R.H. 207 Probe (P12)
1: 1 Reps
2: 8 SE Channel
3: 4 Excite all reps w/Exchan 4
4: 30 Temperature Loc [_____]
5: 33 Loc [_____]
6: 1 Mult
7: 0 Offset

44: R.H. 207 Probe (P12)
1: 1 Reps
2: 9 SE Channel
3: 4 Excite all reps w/Exchan 4
4: 31 Temperature Loc [_____]
5: 34 Loc [_____]
6: 1 Mult
7: 0 Offset

45: R.H. 207 Probe (P12)
1: 1 Reps
2: 10 SE Channel
3: 4 Excite all reps w/Exchan 4
4: 32 Temperature Loc [_____]
5: 35 Loc [_____]
6: 1 Mult
7: 0 Offset

*Table 2 Program
01: 0.0000 Execution Interval (seconds)

*Table 3 Subroutines

End Program

Appendix C-2. Data Logger Program Used During Second Study Period.

```
;{21X}
*Table 1 Program
  01: 20.0000   Execution Interval
(seconds)

1: If time is (P92)
 1: 0       Minutes into a
 2: 540     Minute Interval
 3: 45      Set Port 5 High

2: If time is (P92)
 1: 0       Minutes into a
 2: 570     Minute Interval
 3: 55      Set Port 5 Low

3: If time is (P92)
 1: 0       Minutes into a
 2: 900     Minute Interval
 3: 45      Set Port 5 High

4: If time is (P92)
 1: 0       Minutes into a
 2: 960     Minute Interval
 3: 55      Set Port 5 Low

5: If time is (P92)
 1: 0       Minutes into a
 2: 30      Minute Interval
 3: 10      Set Output Flag High

6: Real Time (P77)
 1: 120     (Same as 220) D,Hr/Mn

7: Sample (P70)
 1: 1       Reps
 2: 1       Loc [ _________ ]

8: Average (P71)
 1: 1       Reps
 2: 2       Loc [ _________ ]

9: Average (P71)
 1: 6       Reps
 2: 14      Loc [ _________ ]

10: Sample (P70)
 1: 1       Reps
 2: 13      Loc [ _________ ]

11: Average (P71)
 1: 6       Reps
 2: 3       Loc [ _________ ]

12: Average (P71)
 1: 4       Reps
 2: 9       Loc [ _________ ]

13: Batt Voltage (P10)
 1: 1       Loc [ _________ ]

14: Internal Temperature (P17)
 1: 2       Loc [ _________ ]

15: Do (P86)
 1: 41      Set Port 1 High

16: Beginning of Loop (P87)
 1: 0       Delay
 2: 6       Loop Count

17: Excitation with Delay (P22)
 1: 1       Ex Channel
 2: 30      Delay w/Ex (units = 0.01 sec)
 3: 30      Delay After Ex (units = 0.01
sec)
 4: 5000    mV Excitation

18: Volt (Diff) (P2)
 1: 1       Reps
 2: 5       5000 mV Slow Range
```

```
 3: 8      DIFF Channel
 4: 3    -- Loc [ _________ ]
 5: 1      Mult
 6: 0      Offset

19:  End (P95)

20:  Set Port (P20)
 1: 0      Set Low
 2: 1      Port Number

21:  Do (P86)
 1: 42     Set Port 2 High

22:  Beginning of Loop (P87)
 1: 0      Delay
 2: 4      Loop Count

23:  Excitation with Delay (P22)
 1: 2      Ex Channel
 2: 30     Delay w/Ex (units = 0.01 sec)
 3: 30     Delay After Ex (units = 0.01
sec)
 4: 5000   mV Excitation

24:  Volt (Diff) (P2)
 1: 1      Reps
 2: 5      5000 mV Slow Range
 3: 1      DIFF Channel
 4: 9    -- Loc [ _________ ]
 5: 1      Mult
 6: 0      Offset

25:  End (P95)

26:  Set Port (P20)
 1: 0      Set Low
 2: 2      Port Number

27:  Volt (Diff) (P2)
 1: 1      Reps
 2: 2      15 mV Slow Range
 3: 7      DIFF Channel
 4: 13     Loc [ _________ ]
 5: .09434 Mult
 6: 0      Offset

28:  Do (P86)
 1: 44     Set Port 4 High

29:  Excitation with Delay (P22)
 1: 4      Ex Channel
 2: 0      Delay w/Ex (units = 0.01 sec)
 3: 15     Delay After Ex (units = 0.01
sec)
 4: 0000   mV Excitation

30:  Volt (SE) (P1)
 1: 3      Reps
 2: 5      5000 mV Slow Range
 3: 5      SE Channel
 4: 14     Loc [ _________ ]
 5: .1     Mult
 6: -40    Offset

31:  Volt (SE) (P1)
 1: 3      Reps
 2: 5      5000 mV Slow Range
 3: 8      SE Channel
 4: 17     Loc [ _________ ]
 5: .1     Mult
 6: 0.0    Offset

32:  Do (P86)
 1: 54     Set Port 4 Low

*Table 2 Program
 01: 0.0000   Execution Interval
(seconds)

*Table 3 Subroutines

End Program
```

Appendix C-3. Data Logger Program Used During Final Study Period.

```
;{21X}
*   1     Table 1 Programs
 01: 20.000  Sec. Execution Interval

01:  P92     If time is
 01: 0       minutes into a
 02: 540     minute interval
 03: 45      Set high Port 5

02:  P92     If time is
 01: 0       minutes into a
 02: 570     minute interval
 03: 55      Set low Port 5

03:  P92     If time is
 01: 0       minutes into a
 02: 900     minute interval
 03: 45      Set high Port 5

04:  P92     If time is
 01: 0       minutes into a
 02: 960     minute interval
 03: 55      Set low Port 5

05:  P92     If time is
 01: 0       minutes into a
 02: 30      minute interval
 03: 10      Set high Flag 0 (output)

06:  P77     Real Time
 01: 120     Day,Hour-Minute

07:  P70     Sample
 01: 1       Rep
 02: 1       Loc Batt

08:  P71     Average
 01: 1       Rep
 02: 2       Loc Panel_t

09:  P70     Sample
 01: 1       Rep
 02: 3       Loc Pyro

10:  P71     Average
 01: 6       Reps
 02: 4       Loc temp

11:  P71     Average
 01: 12      Reps
 02: 10      Loc gasfanA

12:  P71     Average
 01: 8       Reps
 02: 22      Loc tcA

13:  P71     Average
 01: 10      Reps
 02: 30      Loc gasfanB

14:  P71     Average
 01: 8       Reps
 02: 40      Loc tcB

15:  P30     Z=F
 01: 1111    F
 02: 50      Z Loc [:CAO     ]

16:  P10     Battery Voltage
 01: 1       Loc [:Batt    ]

17:  P17     Panel Temperature
 01: 2       Loc [:Panel_t  ]

18:  P2      Volt (DIFF)
 01: 1       Rep
 02: 2       15 mV slow Range
 03: 7       IN Chan
 04: 3--     Loc [:Pyro    ]
 05: .09434  Mult
```

```
 06: 0      Offset

19: P86     Do
 01: 44     Set high Port 4

20: P22     Excitation with Delay
 01: 4      EX Chan
 02: 0      Delay w/EX (units=.01sec)
 03: 15     Delay after EX (units=.01sec)
 04: 0      mV Excitation

21: P1      Volt (SE)
 01: 3      Reps
 02: 5      5000 mV slow Range
 03: 5      IN Chan
 04: 4--    Loc [:temp     ]
 05: .1     Mult
 06: -40    Offset

22: P1      Volt (SE)
 01: 3      Reps
 02: 5      5000 mV slow Range
 03: 8      IN Chan
 04: 7--    Loc [:rh       ]
 05: .1     Mult
 06: 0.0    Offset

23: P86     Do
 01: 54     Set low Port 4

24: P86     Do
 01: 41     Set high Port 1

25: P21     Analog Out
 01: 1      CAO Chan
 02: 50     mV Loc CAO

26: P87     Beginning of Loop
 01: 0      Delay
 02: 12     Loop Count

27: P22     Excitation with Delay
 01: 1      EX Chan
 02: 30     Delay w/EX (units=.01sec)
 03: 30     Delay after EX (units=.01sec)
 04: 5000   mV Excitation

28: P2      Volt (DIFF)
 01: 1      Rep
 02: 5      5000 mV slow Range
 03: 8      IN Chan
 04: 10--   Loc [:gasfanA  ]
 05: 1.0    Mult
 06: 0.0    Offset

29: P95     End

30: P86     Do
 01: 51     Set low Port 1

31: P86     Do
 01: 41     Set high Port 1

32: P87     Beginning of Loop
 01: 0      Delay
 02: 8      Loop Count

33: P22     Excitation with Delay
 01: 1      EX Chan
 02: 30     Delay w/EX (units=.01sec)
 03: 30     Delay after EX (units=.01sec)
 04: 5000   mV Excitation

34: P14     Thermocouple Temp (DIFF)
 01: 1      Rep
 02: 2      15 mV slow Range
 03: 2      IN Chan
 04: 1      Type T (Copper-Constantan)
 05: 2      Ref Temp Loc Panel_t
 06: 22--   Loc [:tcA      ]
 07: 1      Mult
 08: 0      Offset

35: P95     End
```

```
36: P86    Do
 01: 51    Set low Port 1

37: P86    Do
 01: 42    Set high Port 2

38: P87    Beginning of Loop
 01: 0     Delay
 02: 10    Loop Count

39: P22    Excitation with Delay
 01: 2     EX Chan
 02: 30    Delay w/EX (units=.01sec)
 03: 30    Delay after EX (units=.01sec)
 04: 5000  mV Excitation

40: P2     Volt (DIFF)
 01: 1     Rep
 02: 5     5000 mV slow Range
 03: 1     IN Chan
 04: 30--  Loc [:gasfanB  ]
 05: 1     Mult
 06: 0     Offset

41: P95    End

42: P20    Set Port
 01: 0     Set low
 02: 2     Port Number

43: P86    Do
 01: 43    Set high Port 3

44: P87    Beginning of Loop
 01: 0     Delay
 02: 8     Loop Count

45: P22    Excitation with Delay
 01: 3     EX Chan
 02: 30    Delay w/EX (units=.01sec)
 03: 30    Delay after EX (units=.01sec)
 04: 5000  mV Excitation

46: P14    Thermocouple Temp (DIFF)
 01: 1     Rep
 02: 1     5 mV slow Range
 03: 6     IN Chan
 04: 1     Type T (Copper-Constantan)
 05: 2     Ref Temp Loc Panel_t
 06: 40--  Loc [:tcB     ]
 07: 1     Mult
 08: 0     Offset

47: P95    End

48: P20    Set Port
 01: 0     Set low
 02: 3     Port Number

49: P      End Table 1


*  2       Table 2 Programs
 01: 0.0000  Sec. Execution Interval

*  3       Table 3 Subroutines

End Program
```

APPENDIX D

Table D-1. Average Temperatures Recorded During Research

Average Temperature Measurements

Study Period	Month	Instrument	Barn A	Barn B	Outside/Pit Fan (SP 2)
1*	January, 1998	RH/Temp Probe	19.63°C	22.79°C	6.06°C
		Thermocouples	18.14°C	19.67°C	*******
1	February, 1998	RH/Temp Probe	20.86°C	22.57°C	9.29°C
		Thermocouples	19.08°C	19.61°C	*******
1	March, 1998	RH/Temp Probe	20.35°C	21.29°C	8.59°C
		Thermocouples	18.98°C	18.42°C	*******
1	April, 1998	RH/Temp Probe	20.28°C	21.74°C	15.00°C
		Thermocouples	18.95°C	19.39°C	*******
2	August-September, 1998	RH/Temp Probe	******	26.53°C	28.69°C
		Thermocouple	*******	*******	*******
3*	November, 1998	RH/Temp Probe	21.34°C	21.50°C	14.88°C
		Thermocouple	19.78°C	20.51°C	*******
3	December, 1998	RH/Temp Probe	20.08°C	18.28°C	7.11°C
		Thermocouple	17.79°C	16.44°C	*******
3*	January, 1999	RH/Temp Probe	19.24°C	16.73°C	6.34°C
		Thermocouple	16.96°C	14.67°C	*******
3*	Jan 29-Feb24, 1999 (Barn A only)	T Probe (2-m)	17.67°C	*******	*******
		T Probe (Floor)	17.10°C	*******	*******
3	Feb24-Mar 9, 1999 (Barn B only)	T Probe (2-m)	*******	16.61°C	*******
		T Probe (Floor)	*******	15.24°C	*******

***Denotes incomplete data**

APPENDIX E

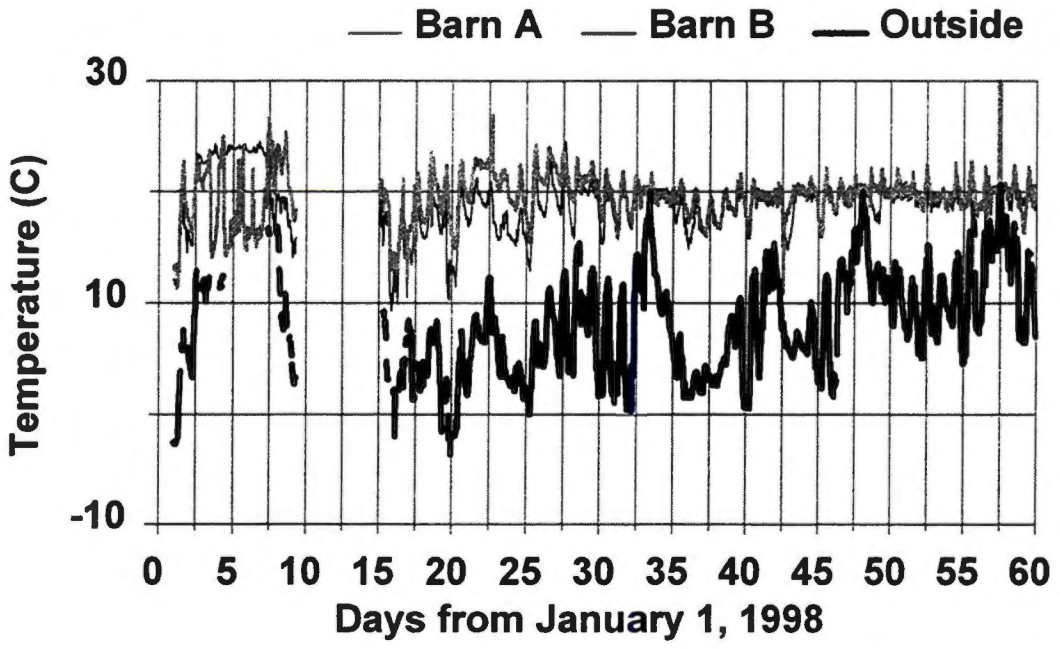


Figure E-1. Temperature data for January and February, 1998.

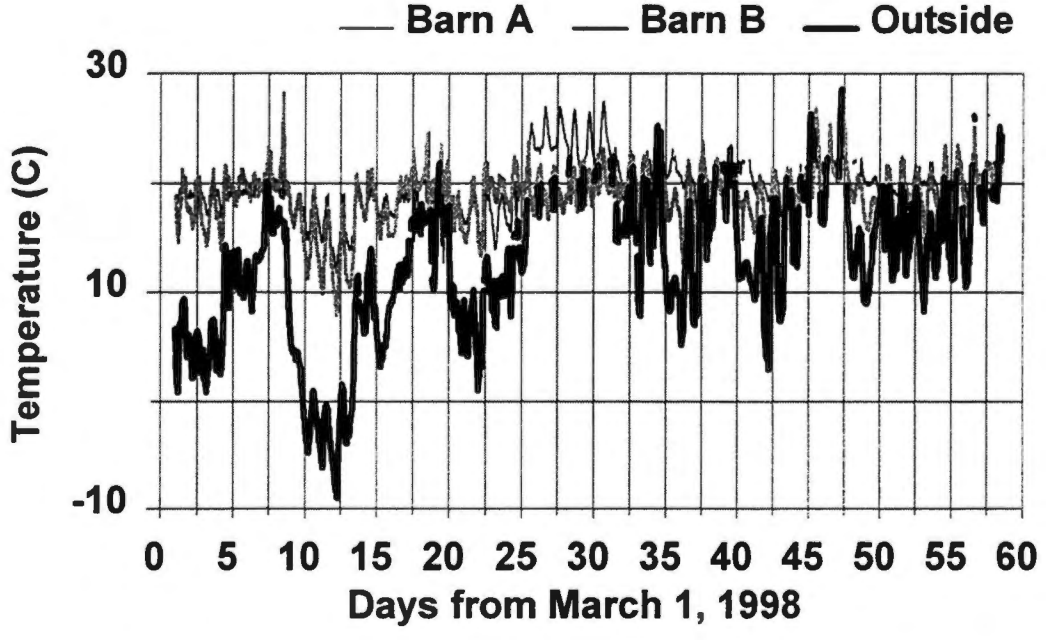


Figure E-2. Temperature data for March and April, 1998.

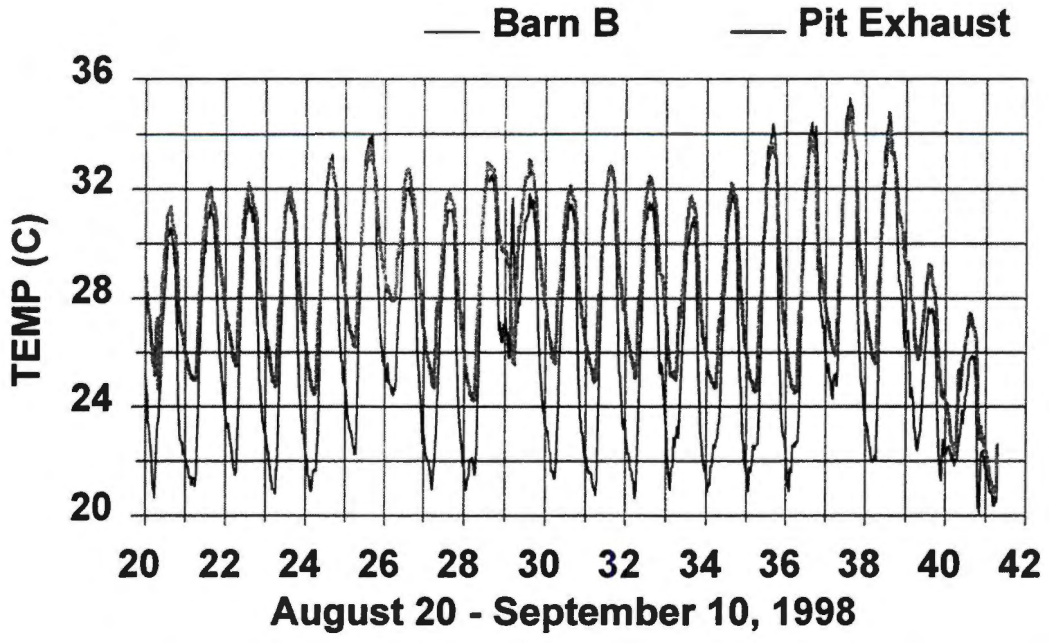


Figure E-3. Temperature data for Barn B and pit exhaust during 2nd study period.

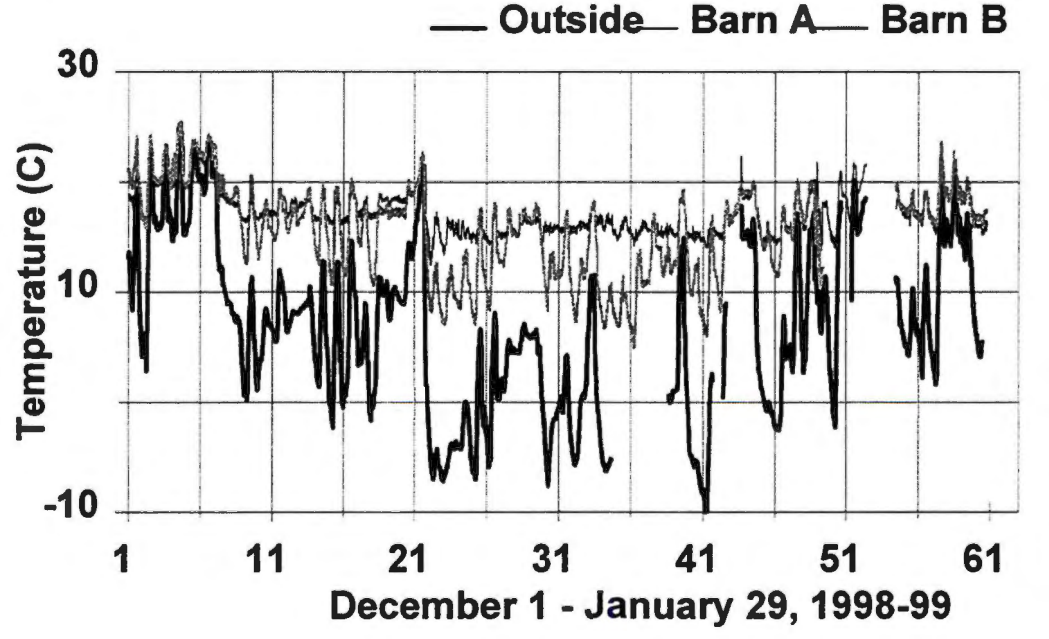


Figure E-4. Temperature data for December 1998 and January 1999.

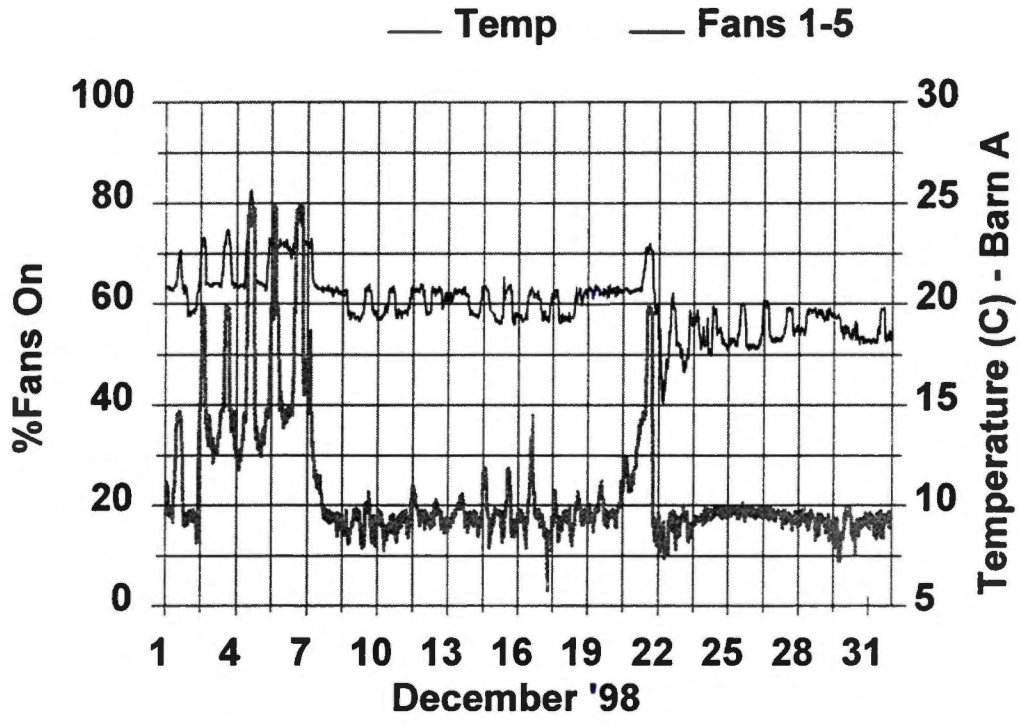


Figure E-5. Ventilation performance and temperature data for Barn A.

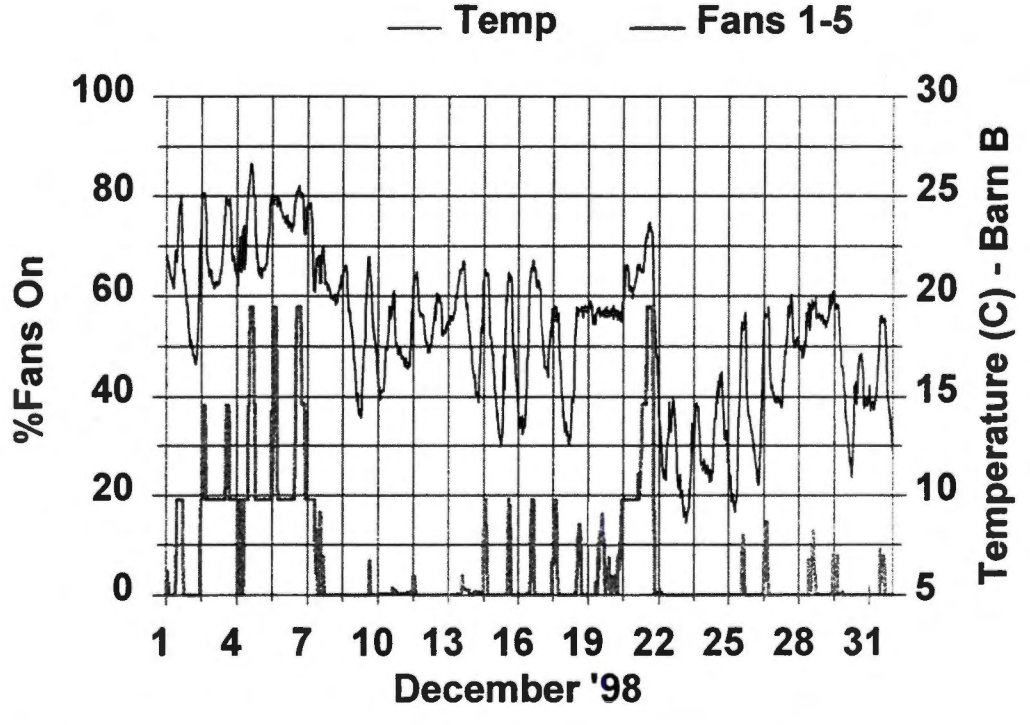


Figure E-6. Ventilation performance and temperature data for Barn B.

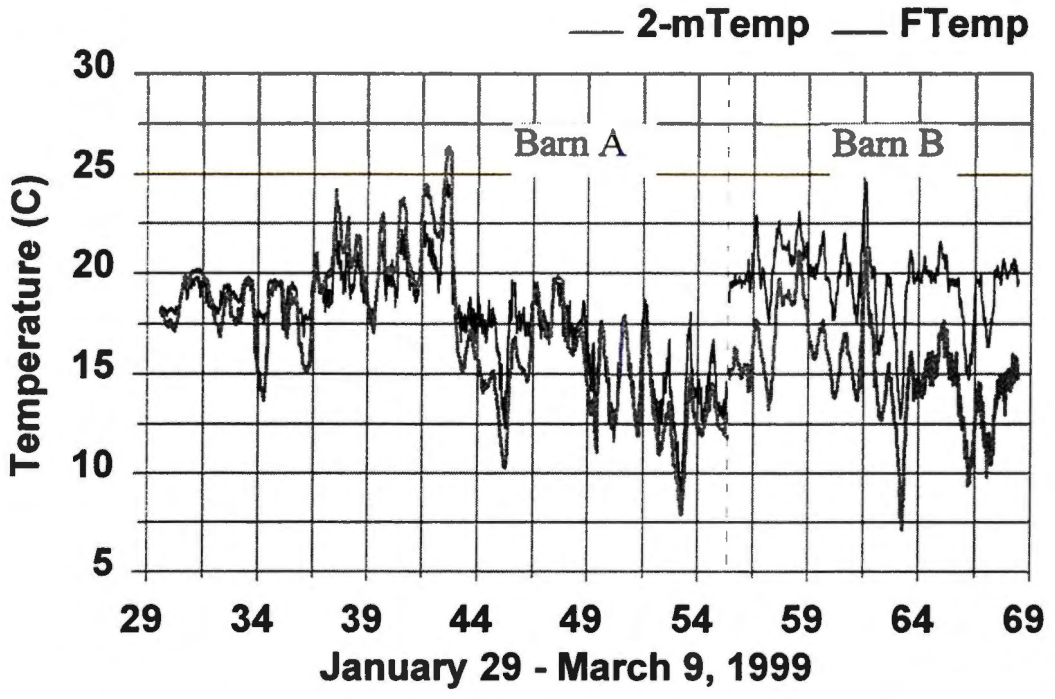


Figure E-7. Temperature data taken at 2-m and floor level in Barn A and Barn B.

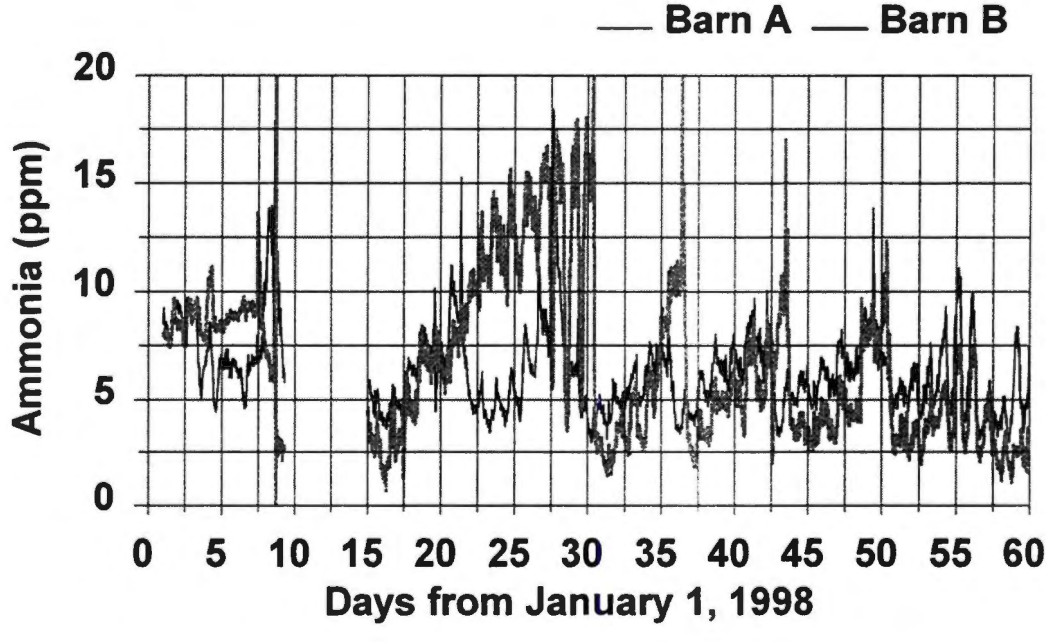


Figure E-8. Ammonia data for January and February, 1998.

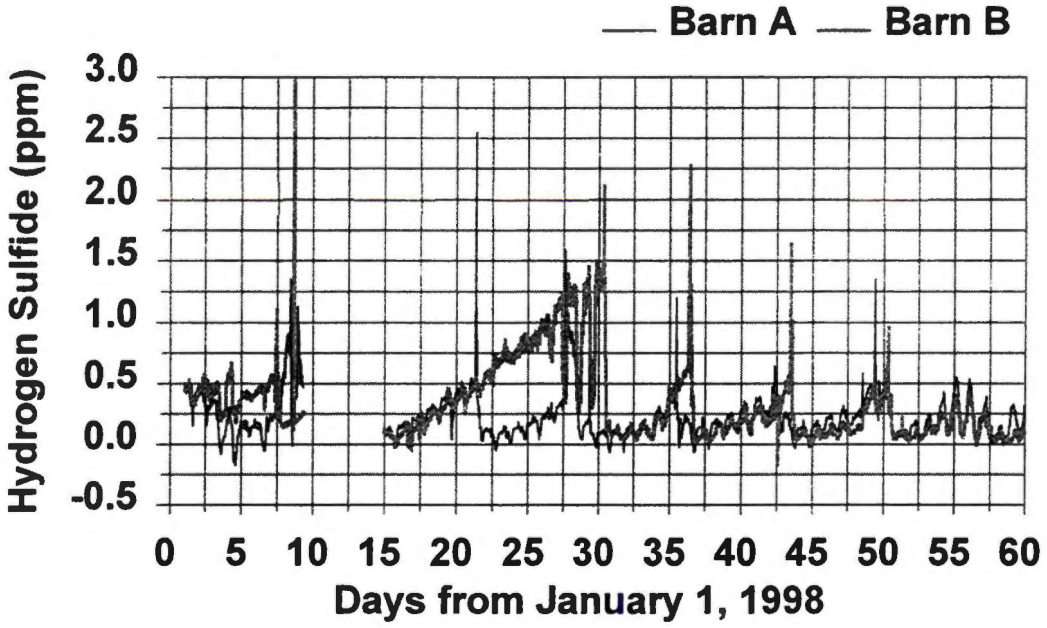


Figure E-9. Hydrogen sulfide data for January and February, 1998.

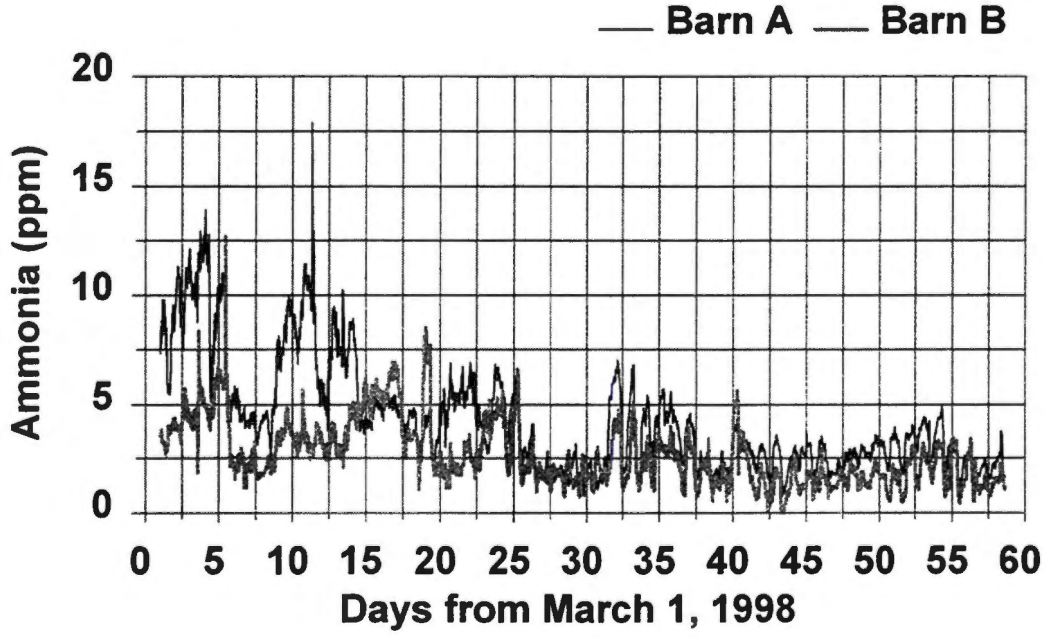


Figure E-10. Ammonia data for March and April, 1998.

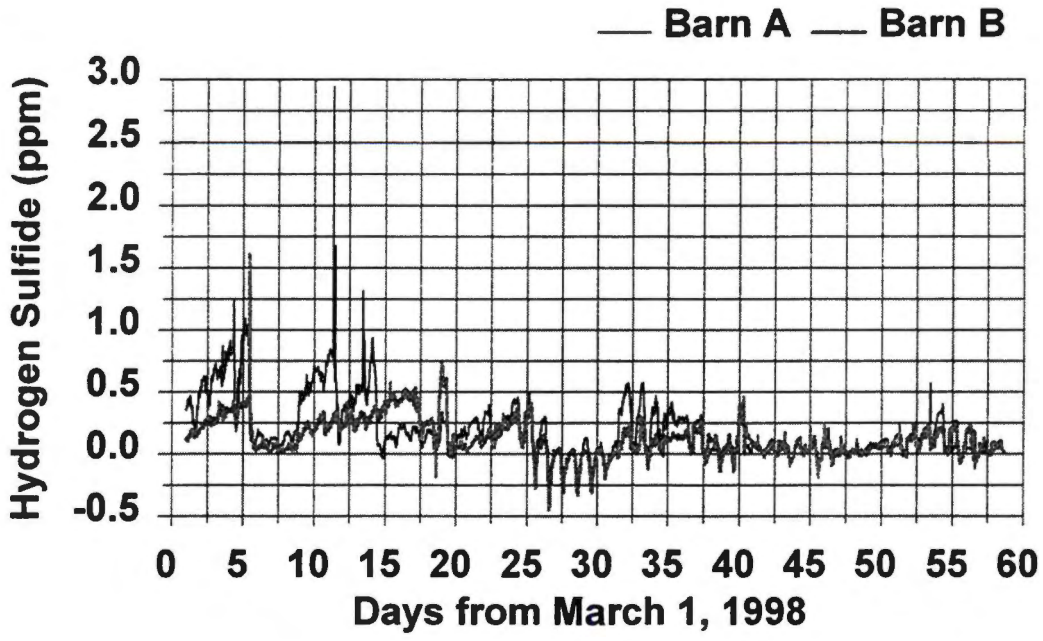


Figure E-11. Hydrogen sulfide data for March and April, 1998.

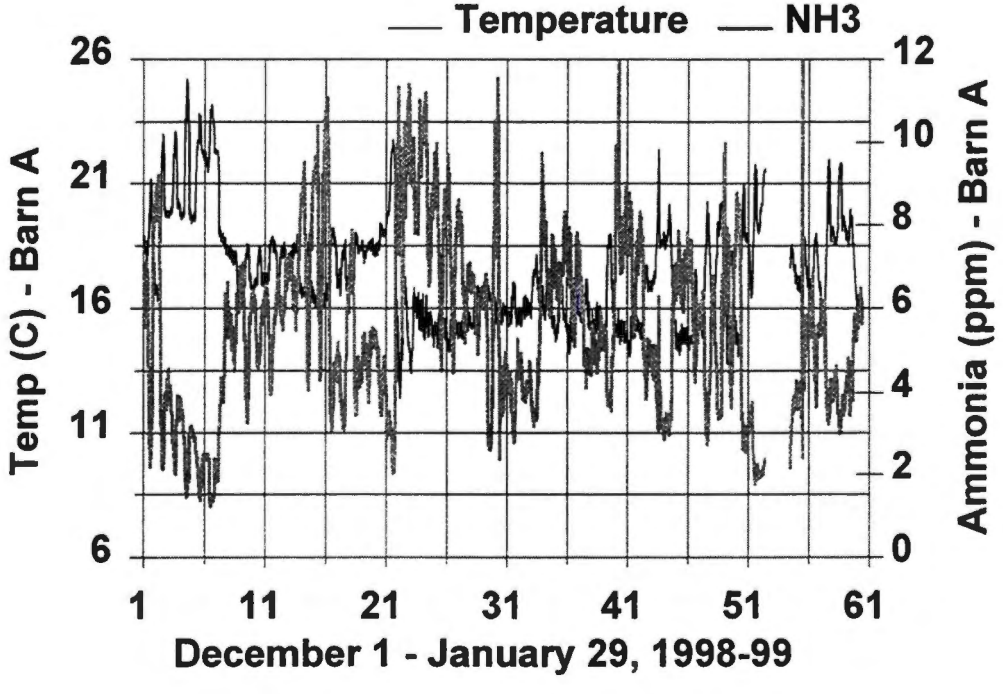


Figure E-12. Ammonia and temperature data for Barn A during 3rd study period.

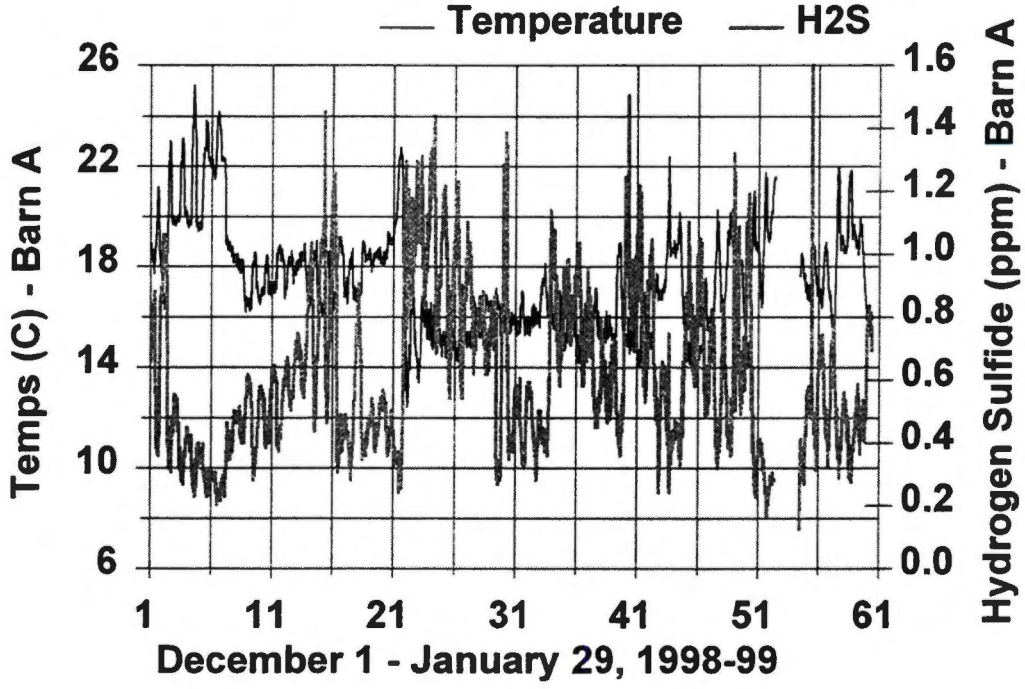


Figure E-13. Hydrogen sulfide and temperature data for Barn A during 3rd study period

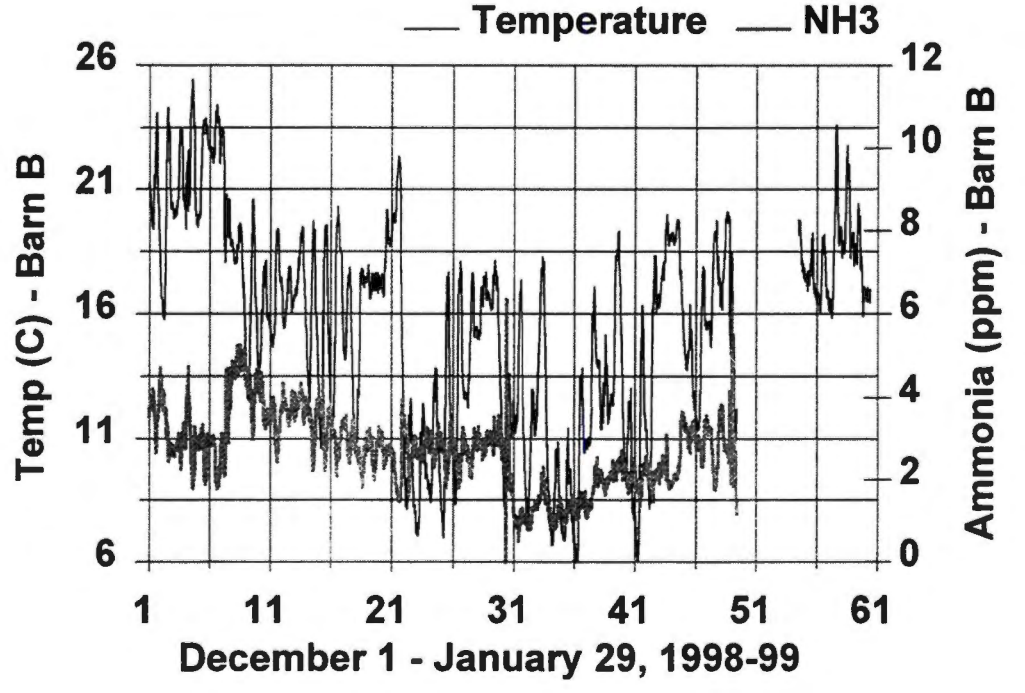


Figure E-14. Ammonia and temperature data for Barn B during 3rd study period.

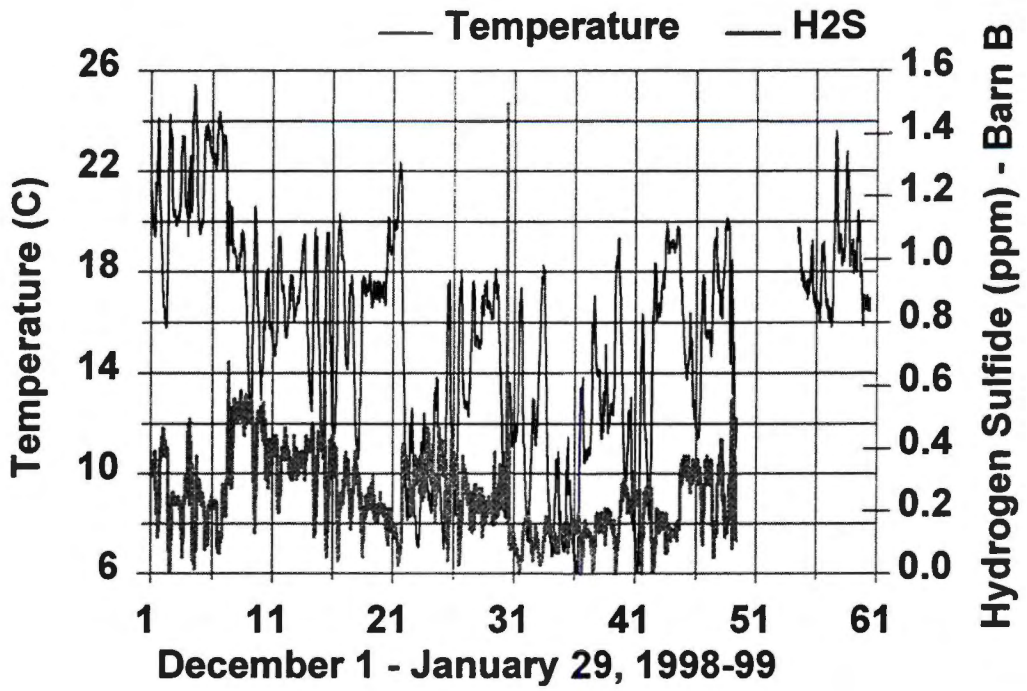


Figure E-15. Hydrogen sulfide and temperature data for Barn B during 3rd study period.

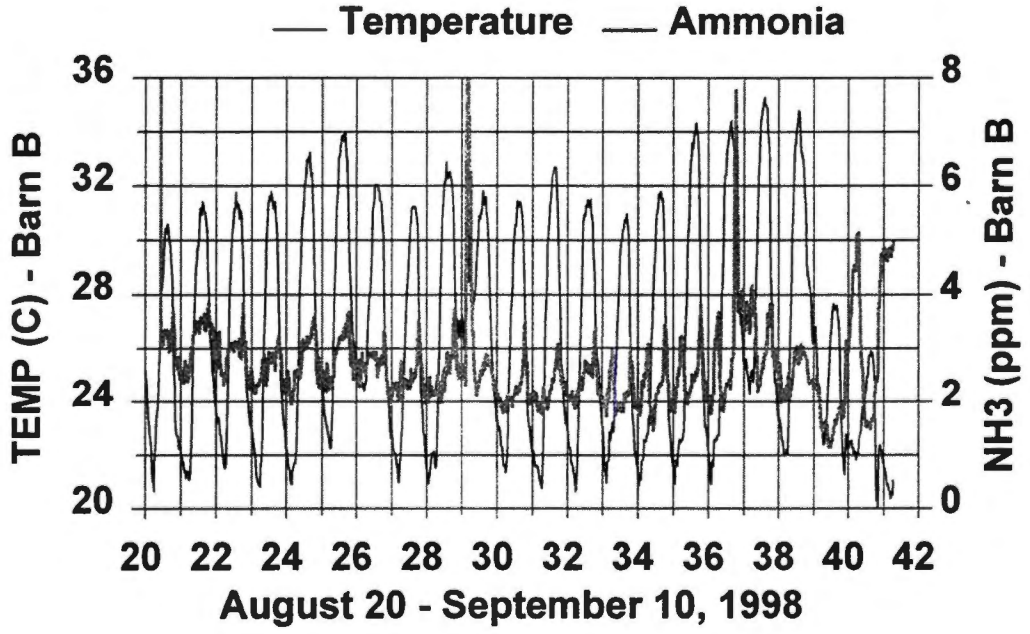


Figure E-16. Ammonia and temperature data for Barn B during 2nd study period.

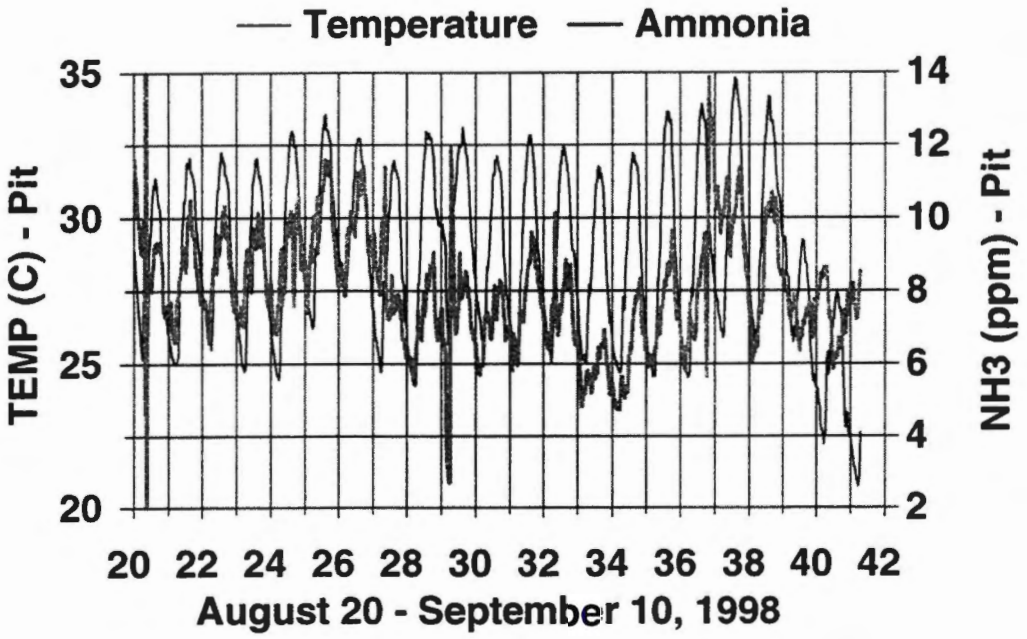


Figure E-17. Ammonia and temperature data for pit exhaust during 2nd study period.

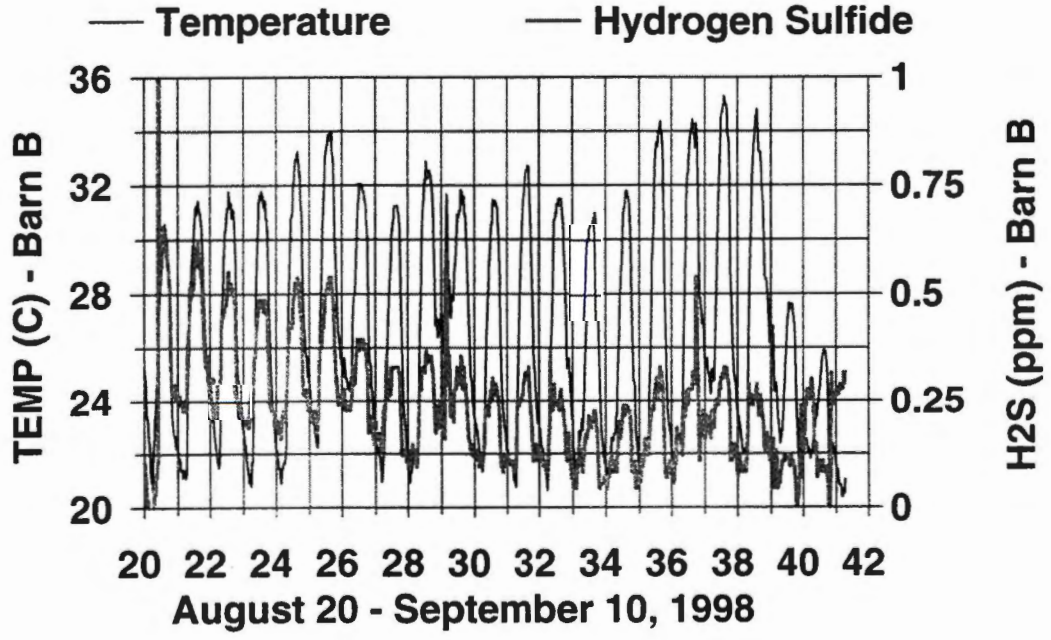


Figure E-18. Hydrogen sulfide and temperature data for Barn B during 2nd study period.

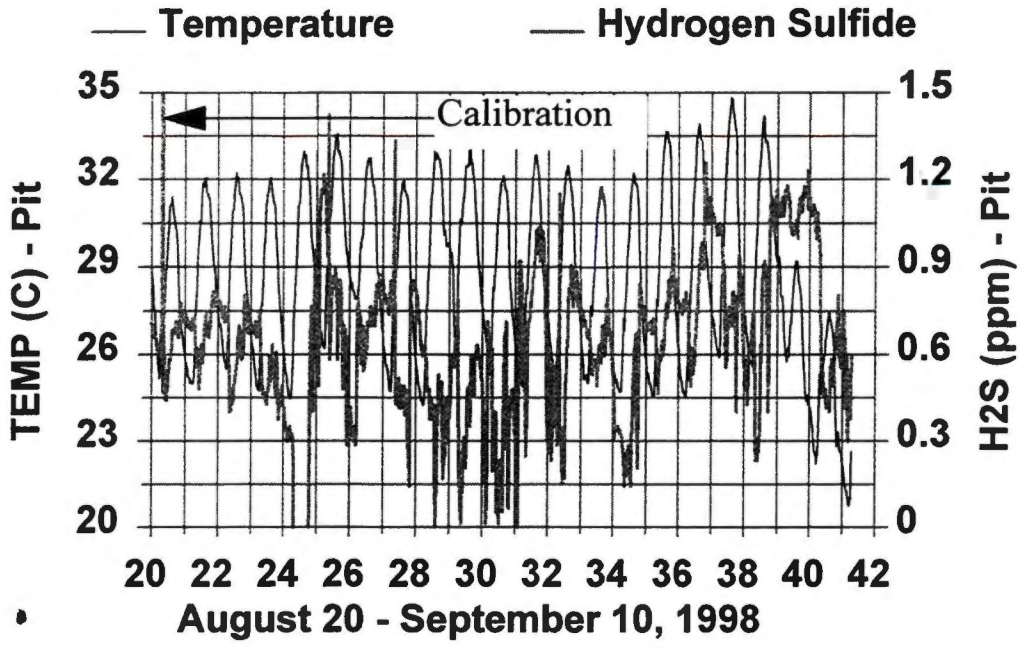


Figure E-19. Hydrogen sulfide and temperature data for pit exhaust during 2nd study period.

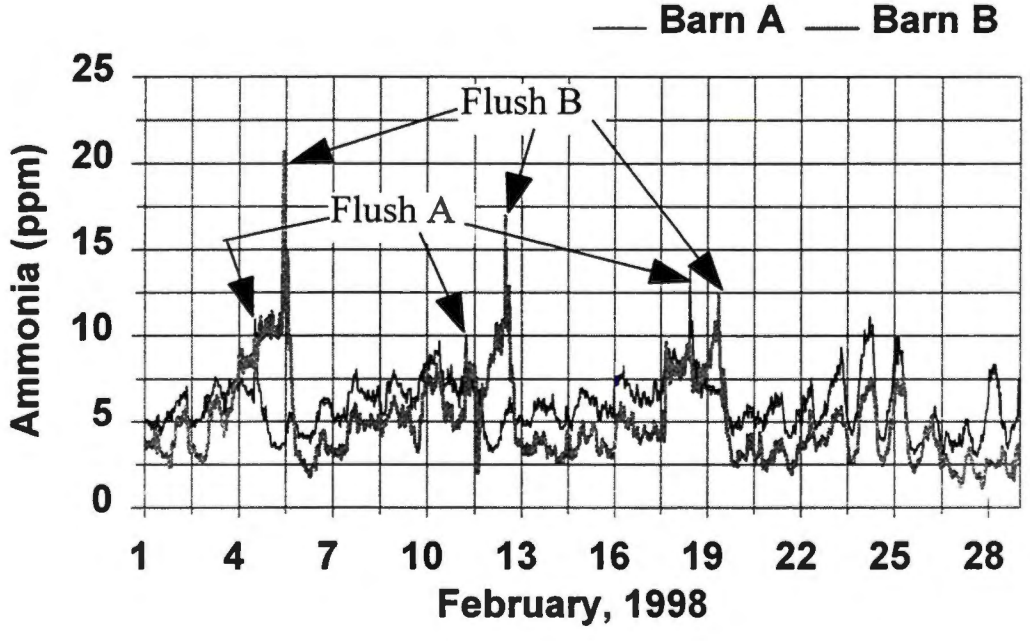


Figure E-20. Ammonia data for February, 1998 showing spikes due to flushing.

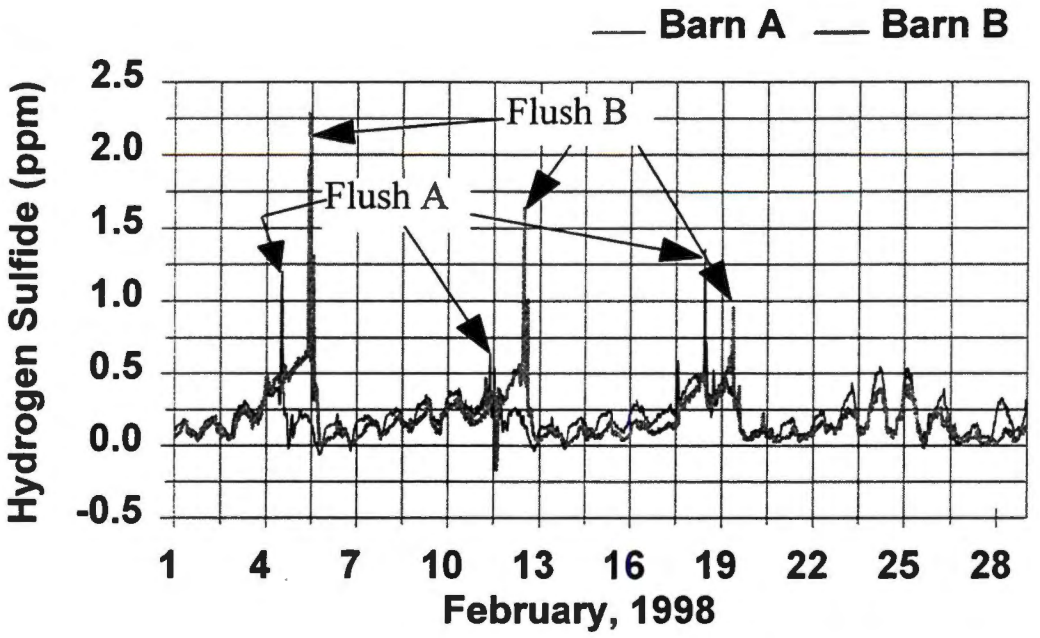


Figure E-21. Hydrogen sulfide data for February, 1998 showing flushing spikes.

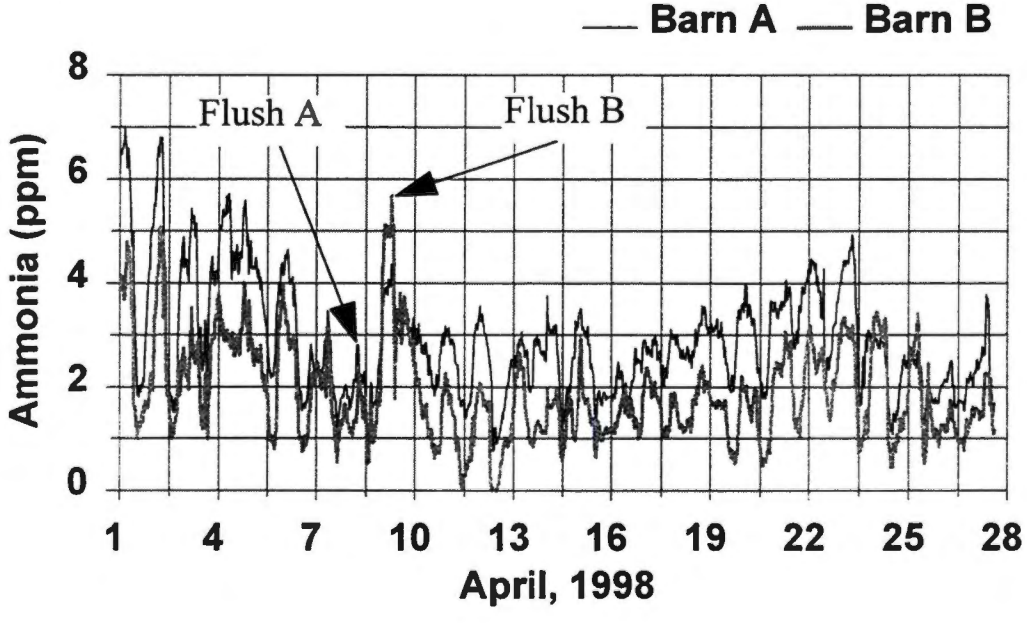


Figure E-22. Ammonia data for April, 1998 showing spikes due to flushing.

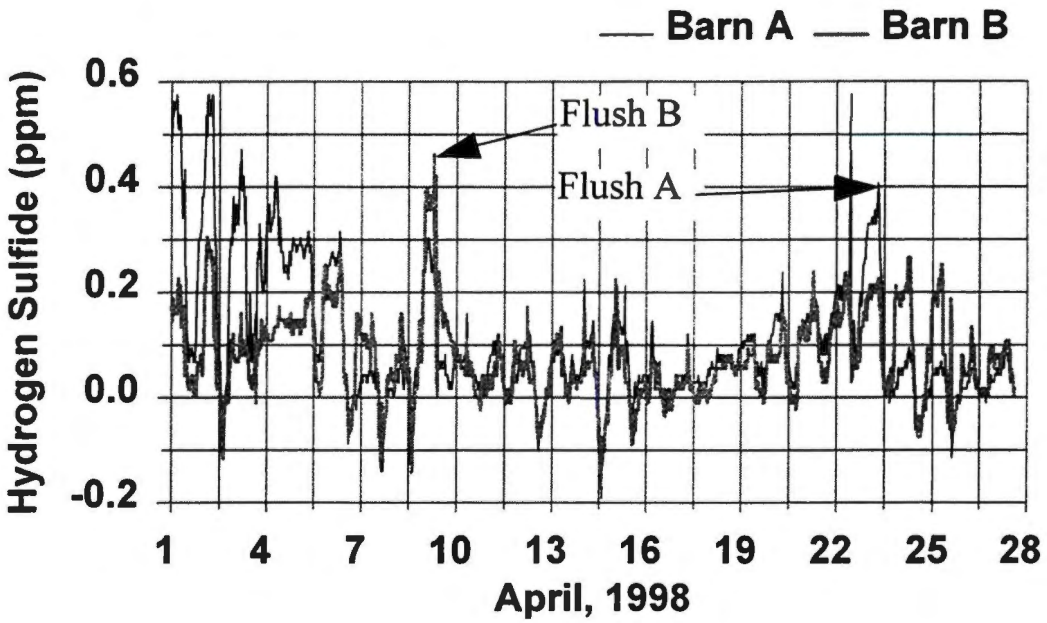


Figure E-23. Hydrogen sulfide data for April, 1998 showing spikes due to flushing.

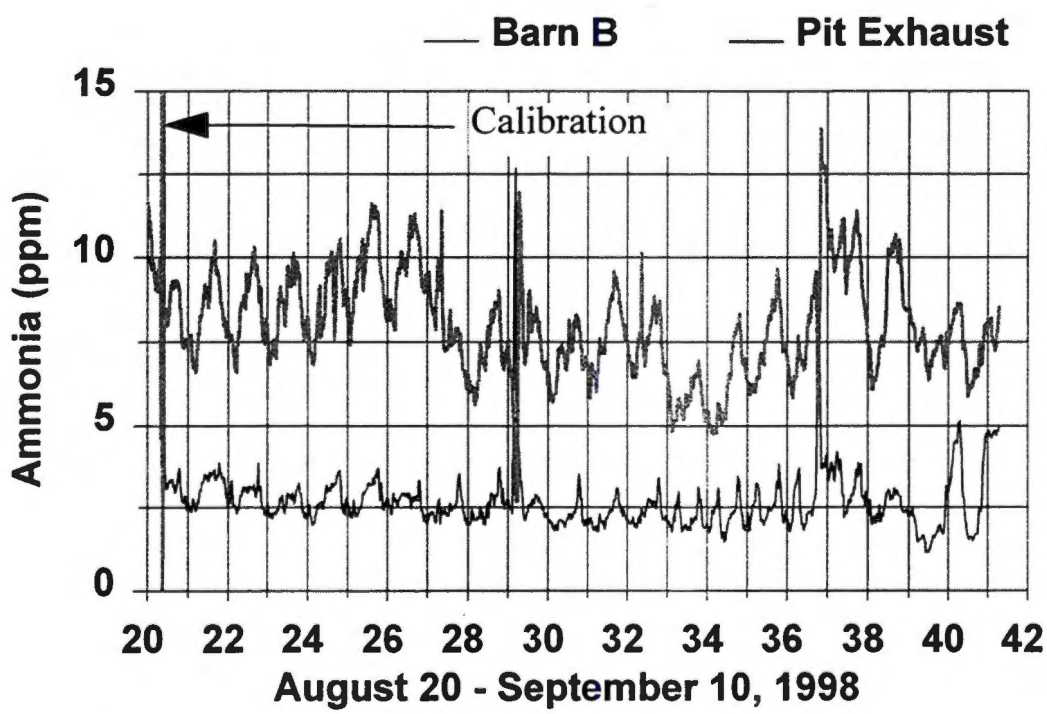


Figure E-24. Ammonia data during 2nd study period.

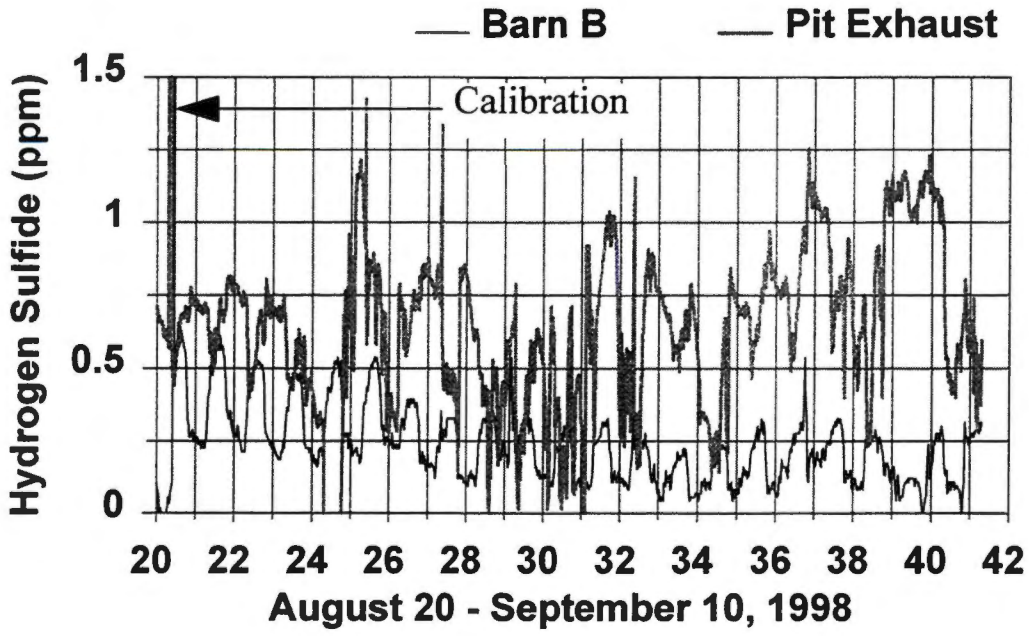


Figure E-25. Hydrogen sulfide data during 2nd study period.

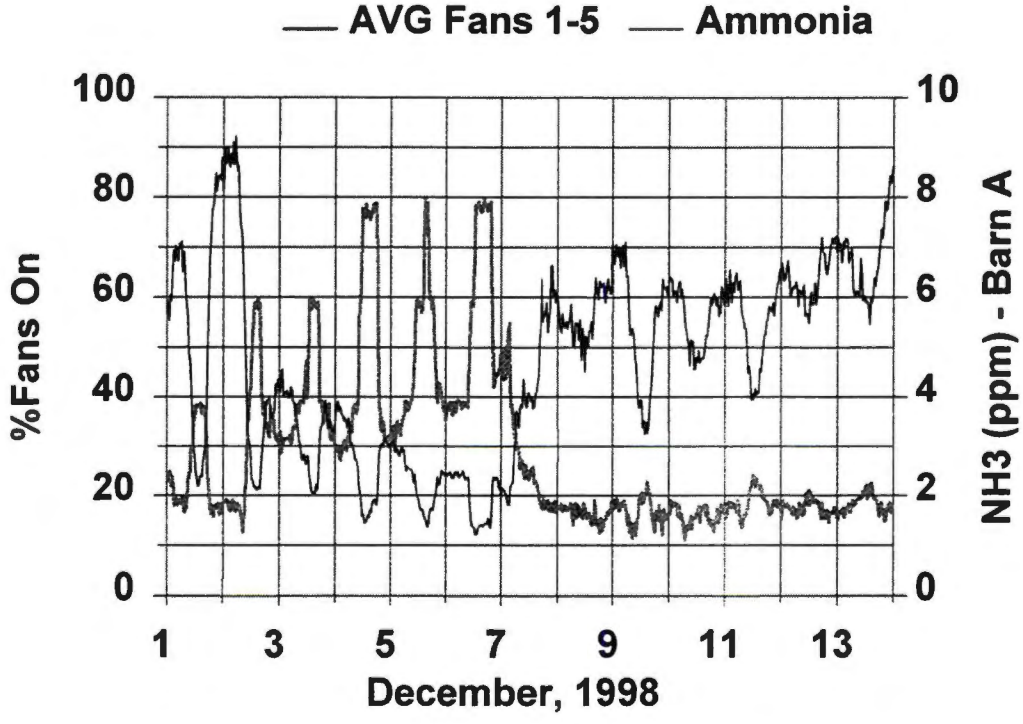


Figure E-26. Ventilation performance and ammonia in Barn A during 3rd study period.

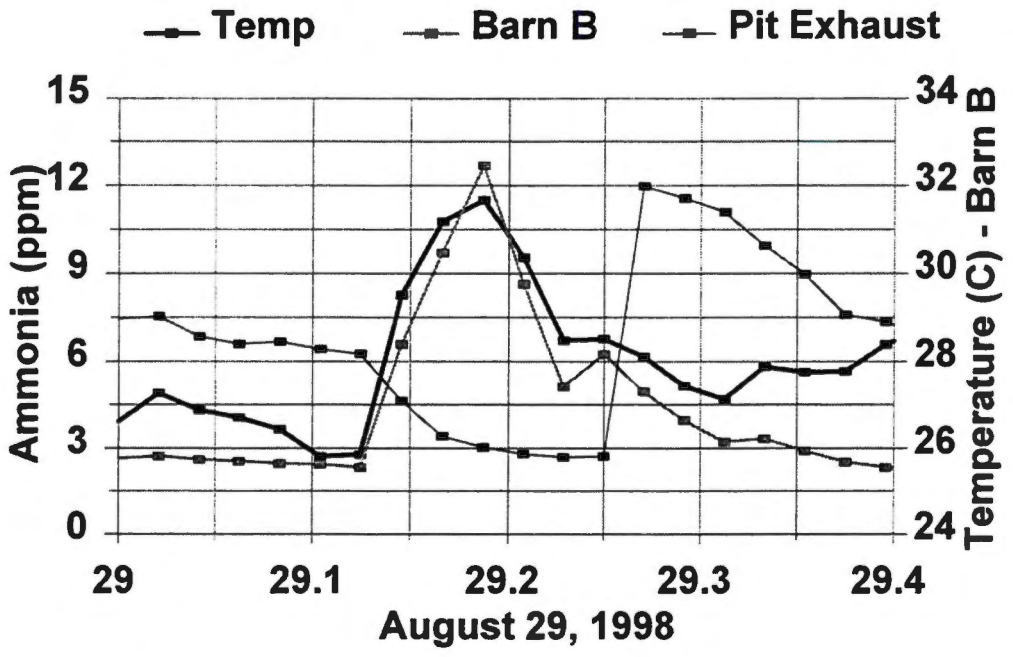


Figure E-27. Ammonia and temperature data during power outage.

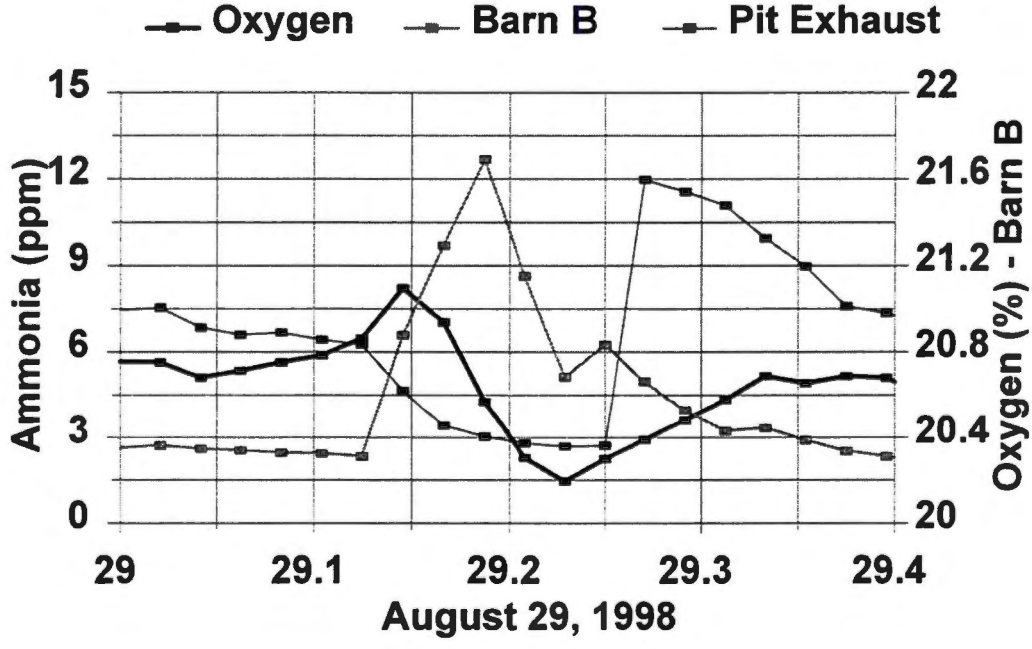


Figure E-28. Ammonia and oxygen data during power outage.

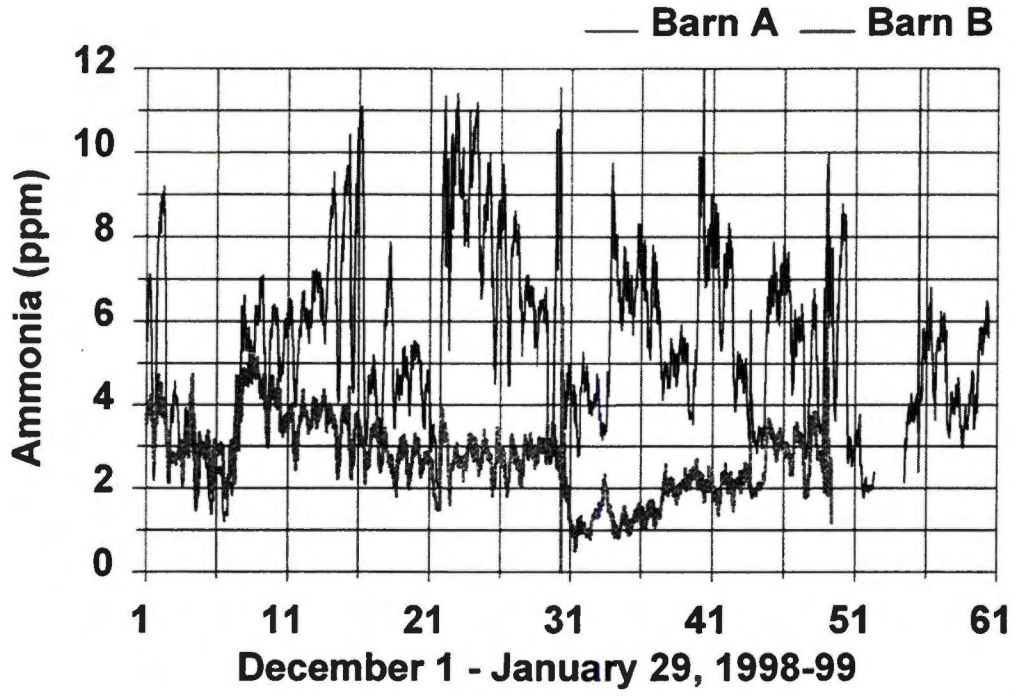


Figure E-29. Ammonia data during 3rd study period.

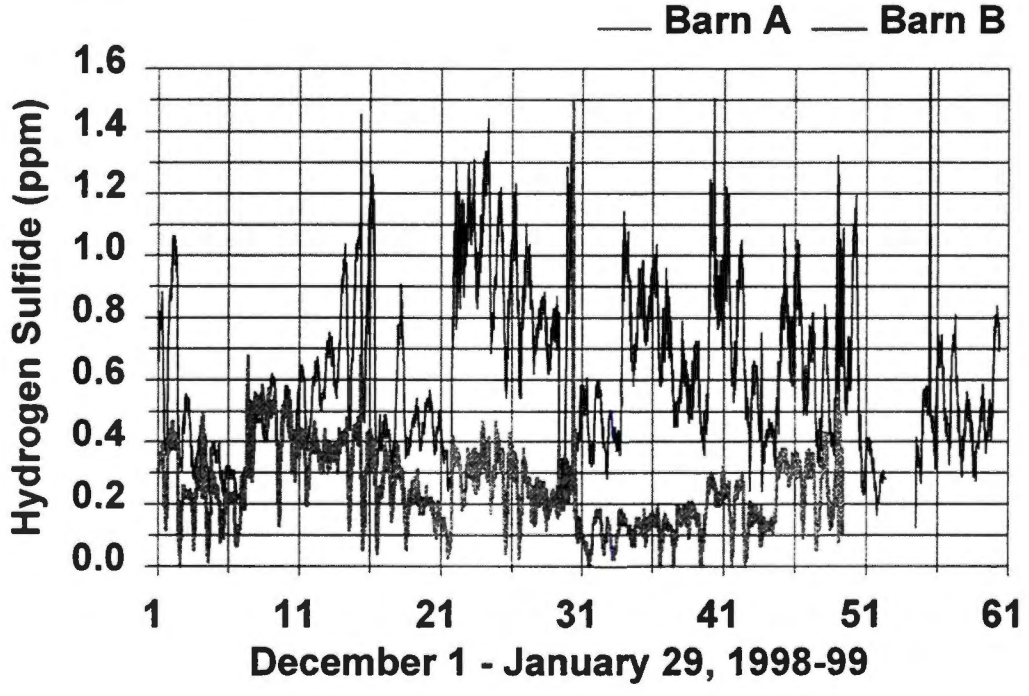


Figure E-30. Hydrogen sulfide data for 3rd study period.

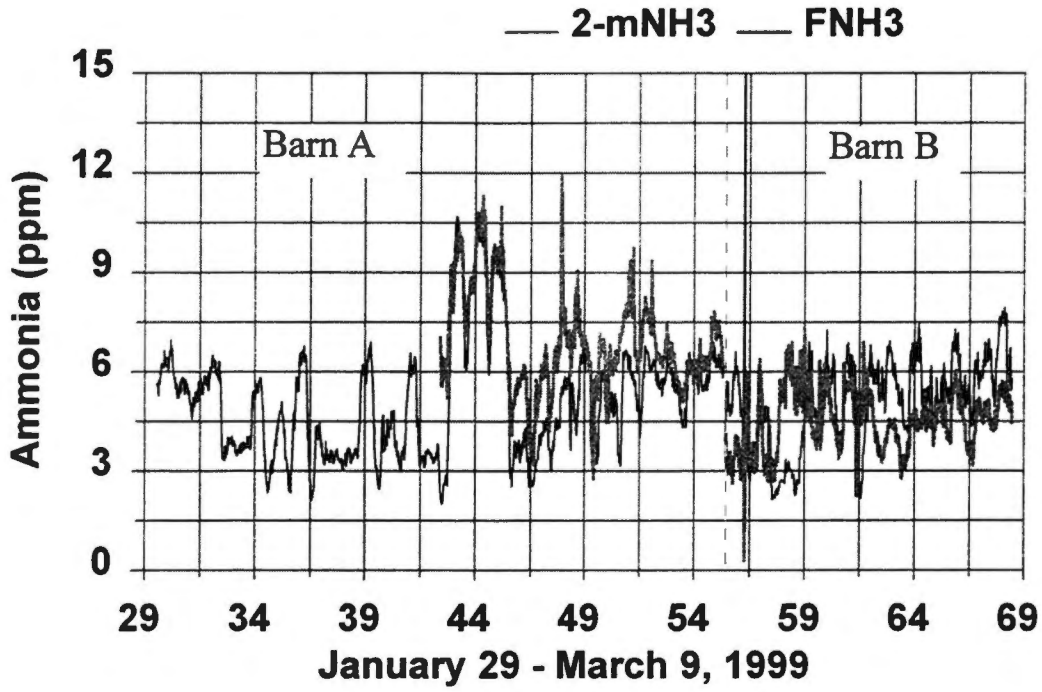


Figure E-31. Ammonia data taken at 2-m and floor level in Barn A and Barn B.

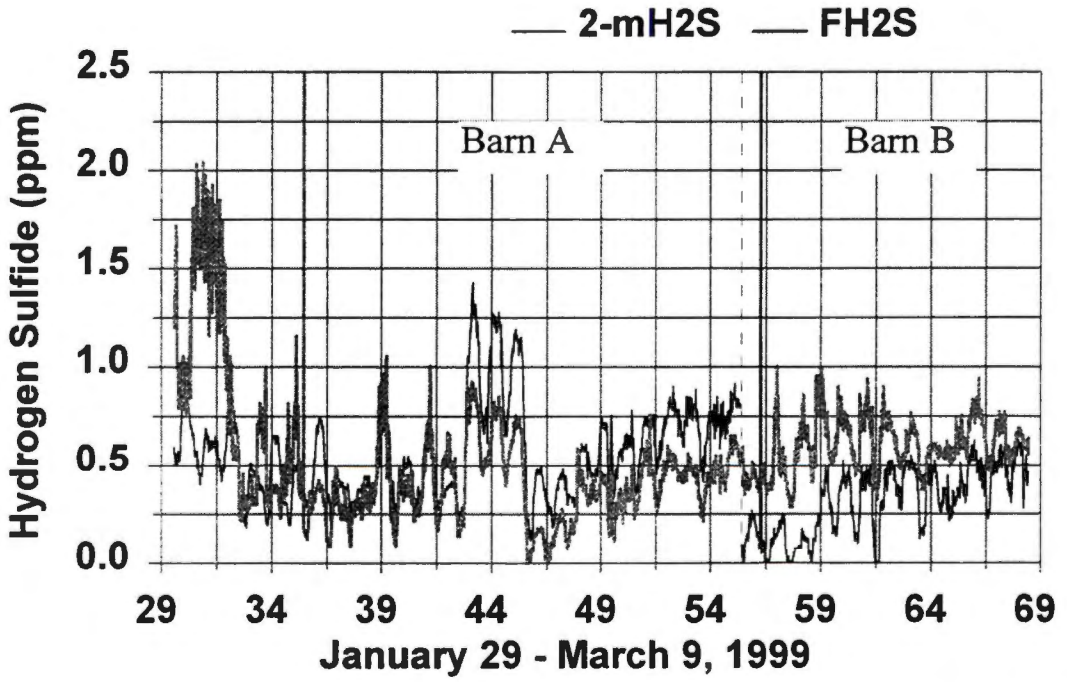


Figure E-32. Hydrogen sulfide data taken at 2-m and floor level in Barn A and Barn B.

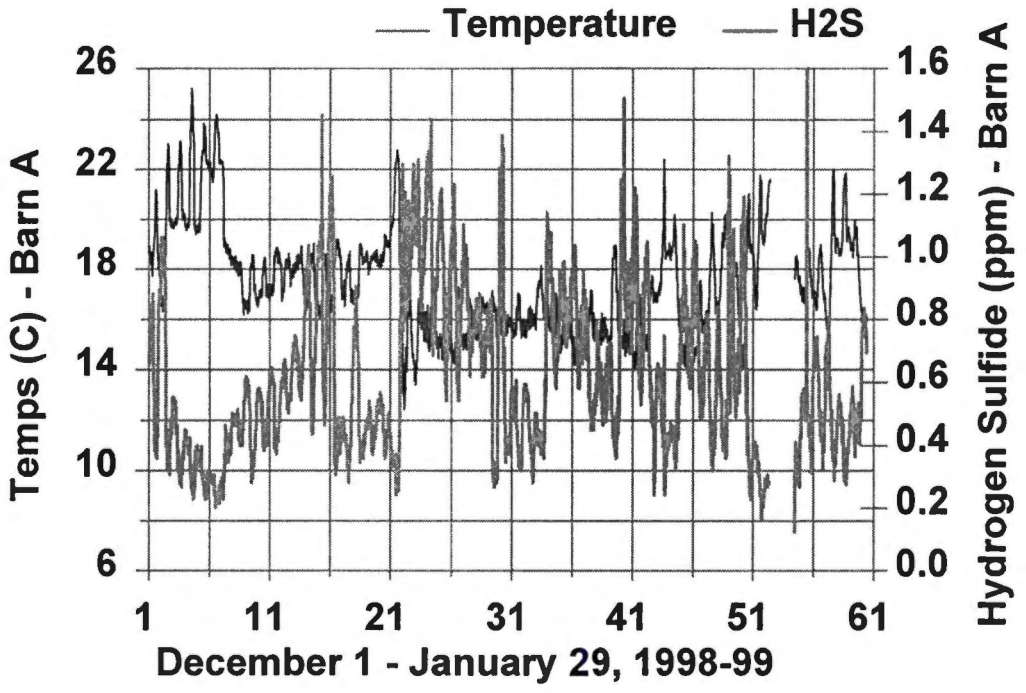


Figure E-13. Hydrogen sulfide and temperature data for Barn A during 3rd study period

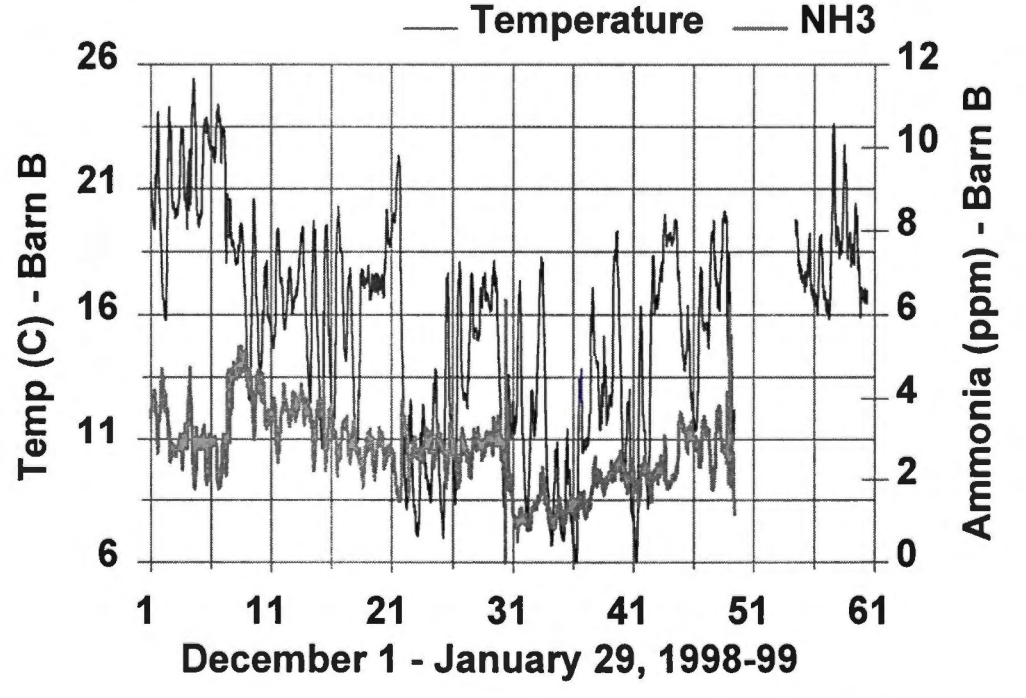


Figure E-14. Ammonia and temperature data for Barn B during 3rd study period.

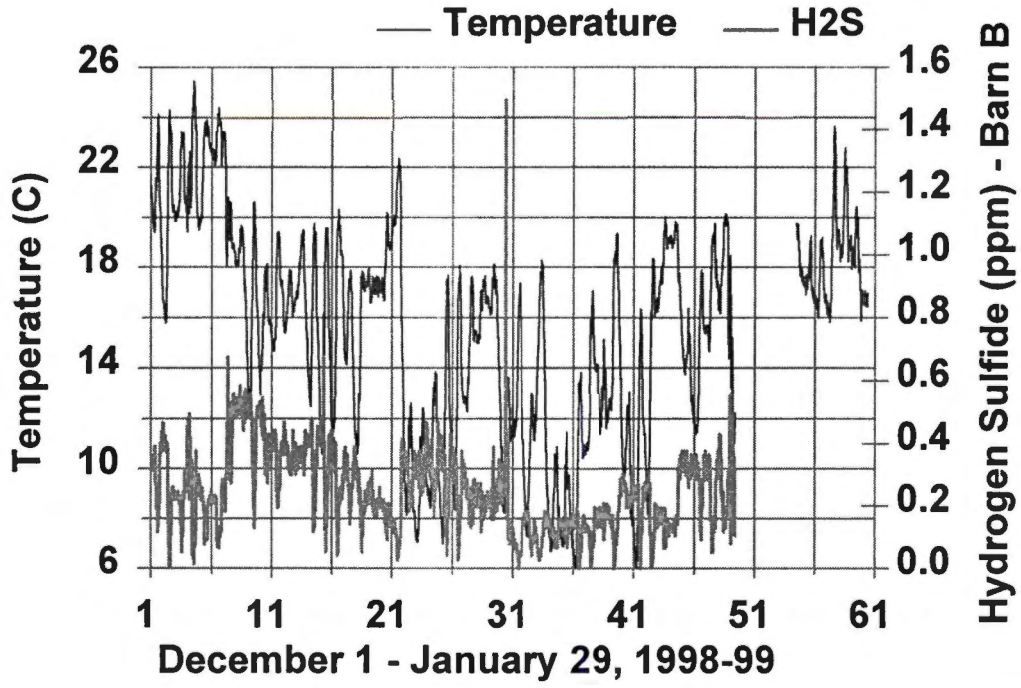


Figure E-15. Hydrogen sulfide and temperature data for Barn B during 3rd study period.

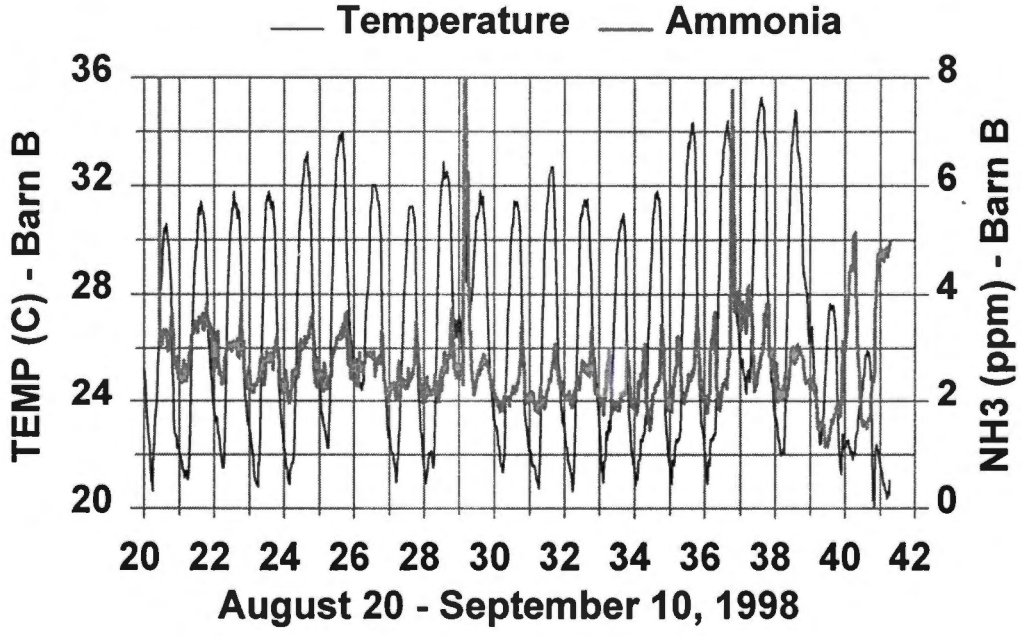


Figure E-16. Ammonia and temperature data for Barn B during 2nd study period.

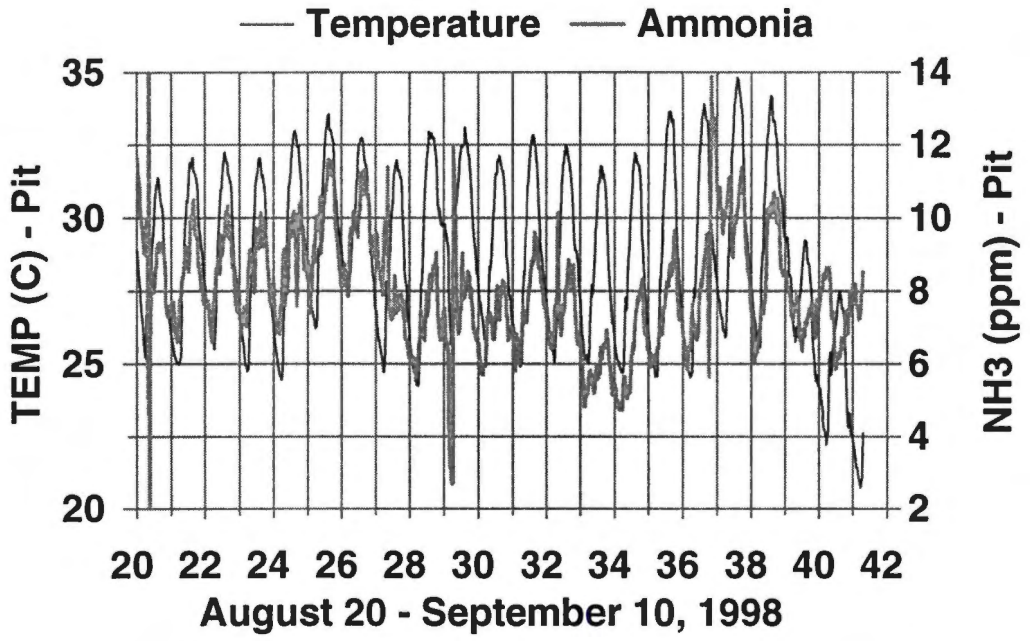


Figure E-17. Ammonia and temperature data for pit exhaust during 2nd study period.

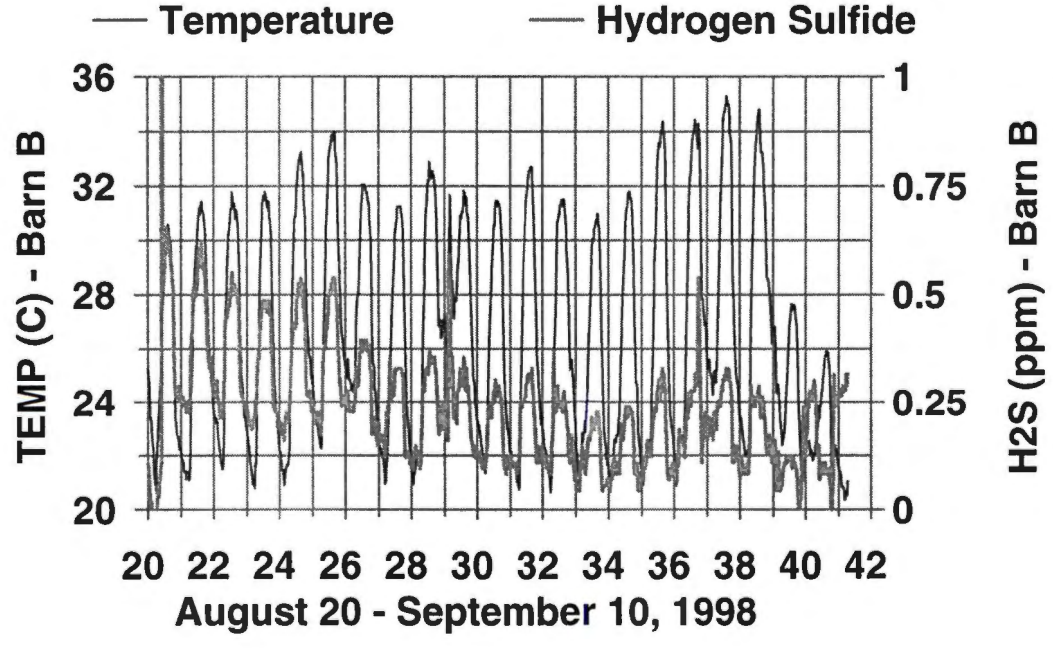


Figure E-18. Hydrogen sulfide and temperature data for Barn B during 2nd study period.

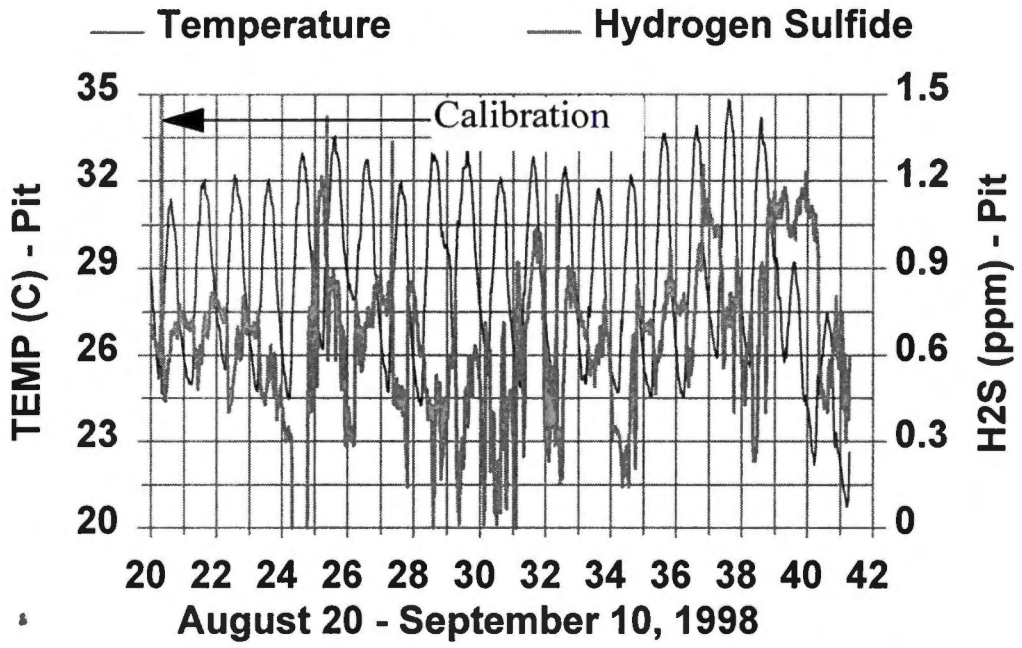


Figure E-19. Hydrogen sulfide and temperature data for pit exhaust during 2nd study period.

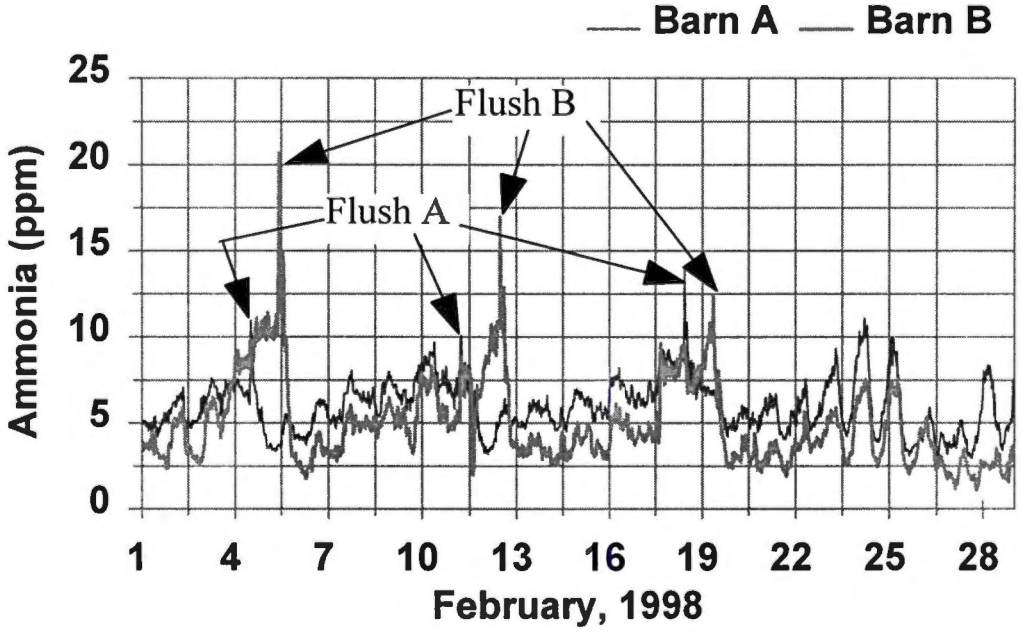


Figure E-20. Ammonia data for February, 1998 showing spikes due to flushing.

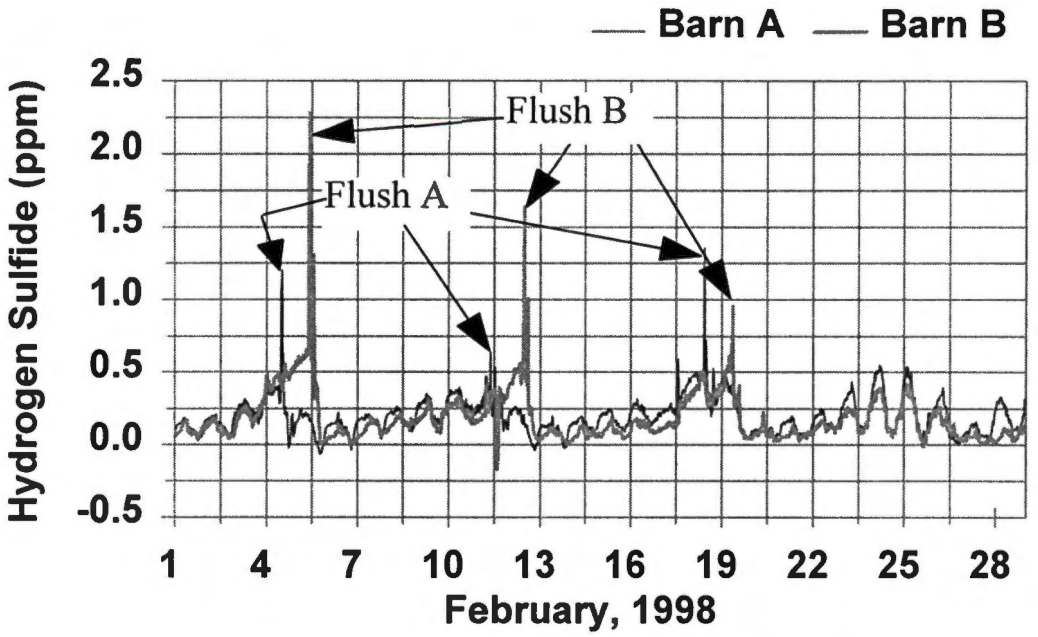


Figure E-21. Hydrogen sulfide data for February, 1998 showing flushing spikes.

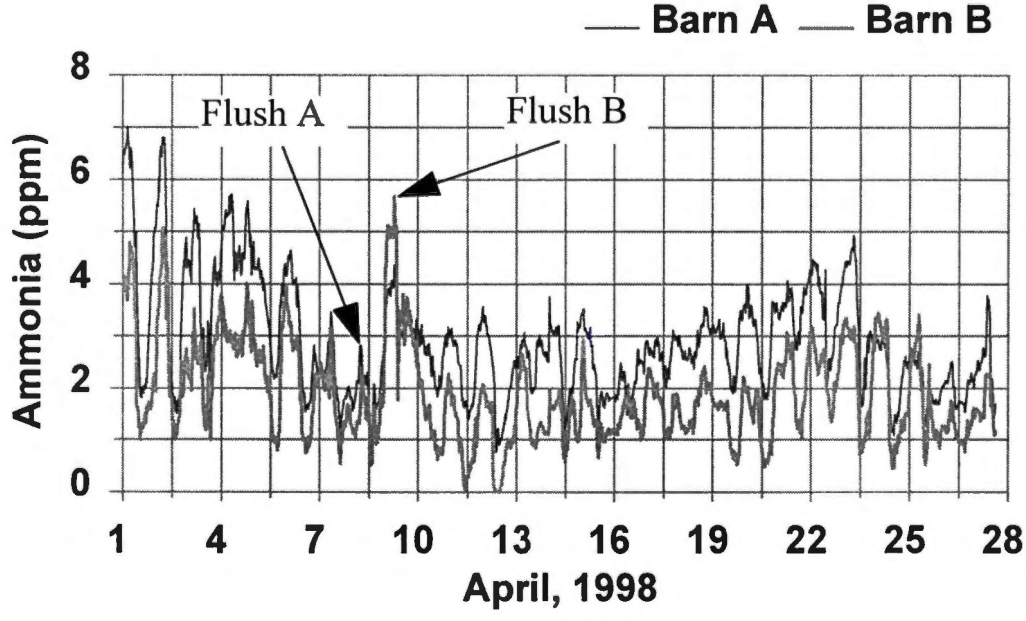


Figure E-22. Ammonia data for April, 1998 showing spikes due to flushing.

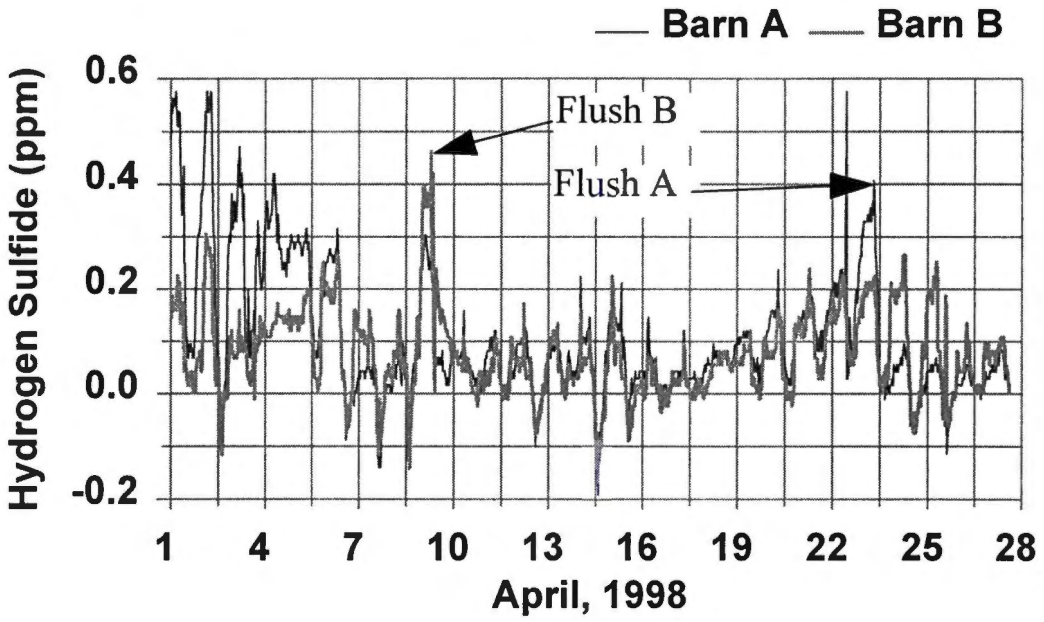


Figure E-23. Hydrogen sulfide data for April, 1998 showing spikes due to flushing.

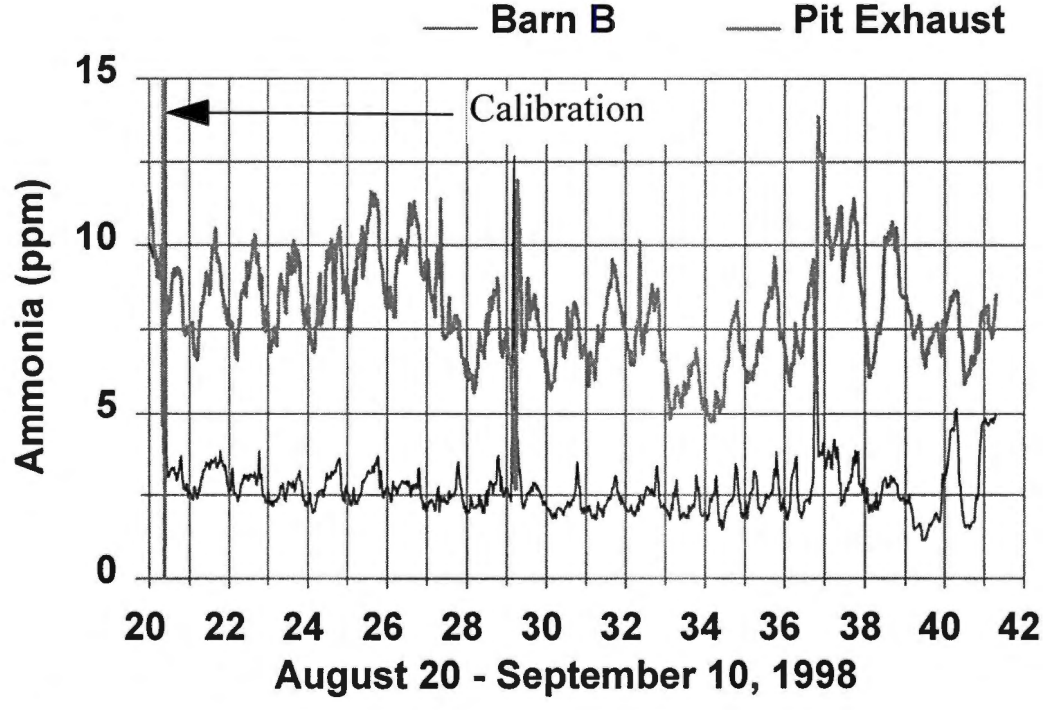


Figure E-24. Ammonia data during 2nd study period.

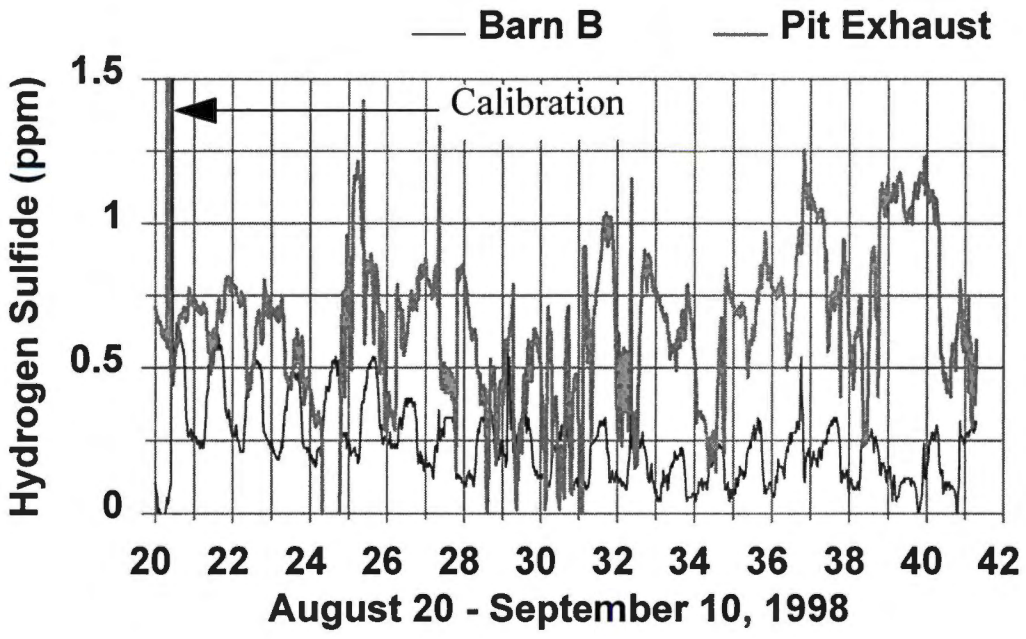


Figure E-25. Hydrogen sulfide data during 2nd study period.

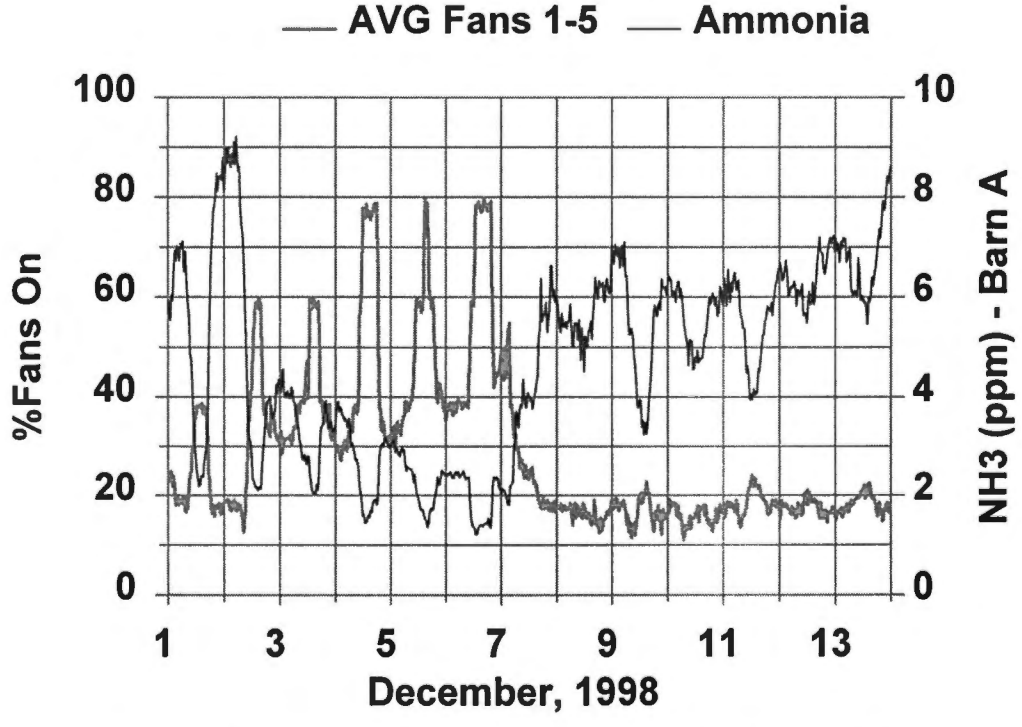


Figure E-26. Ventilation performance and ammonia in Barn A during 3rd study period.

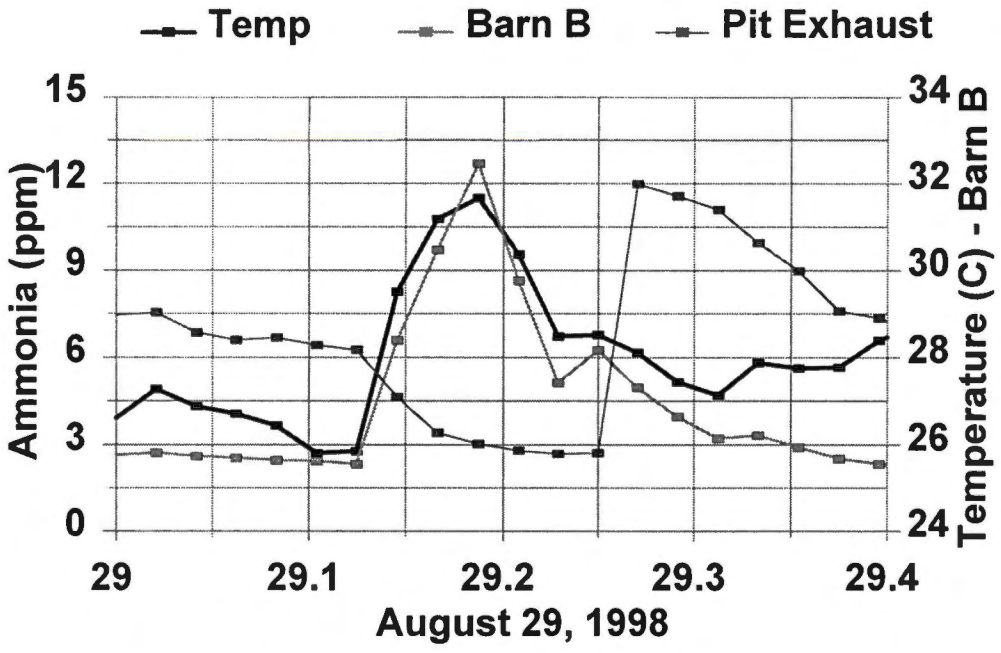


Figure E-27. Ammonia and temperature data during power outage.

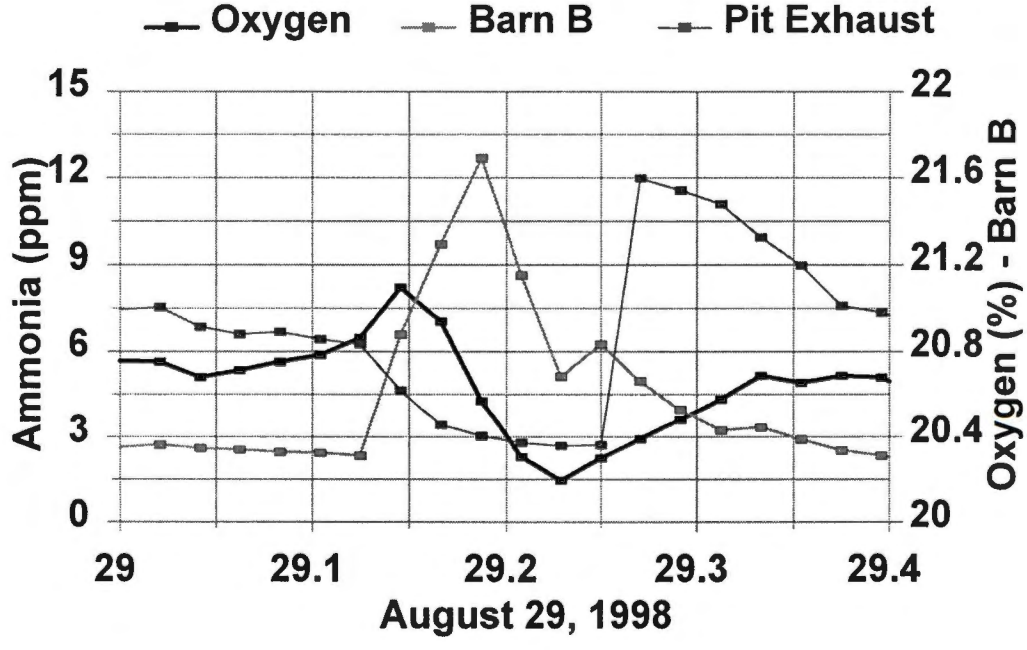


Figure E-28. Ammonia and oxygen data during power outage.

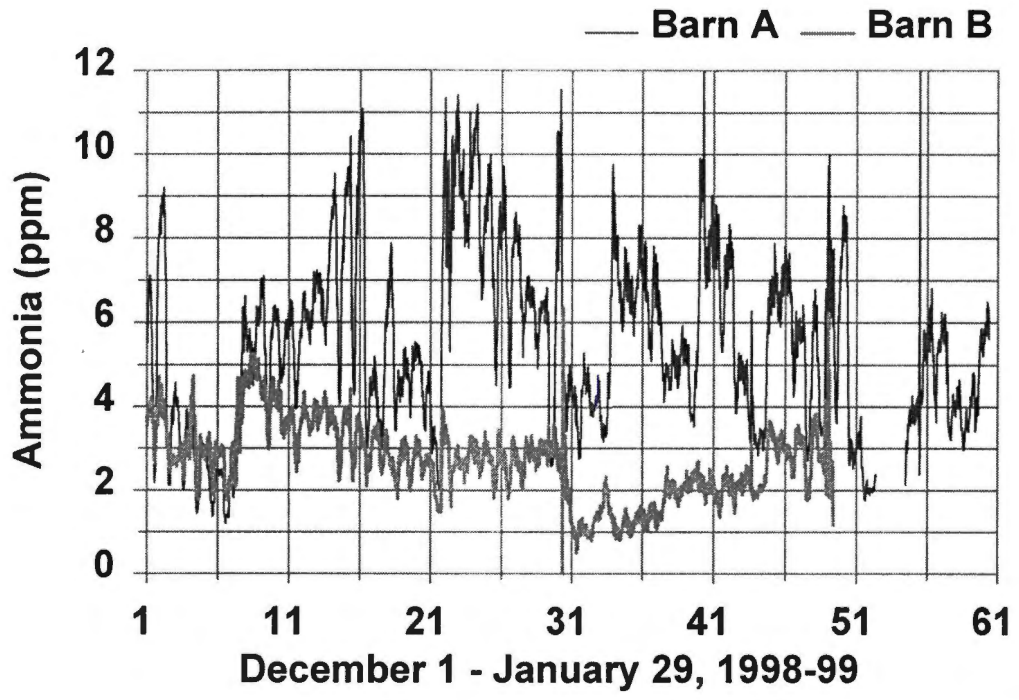


Figure E-29. Ammonia data during 3rd study period.

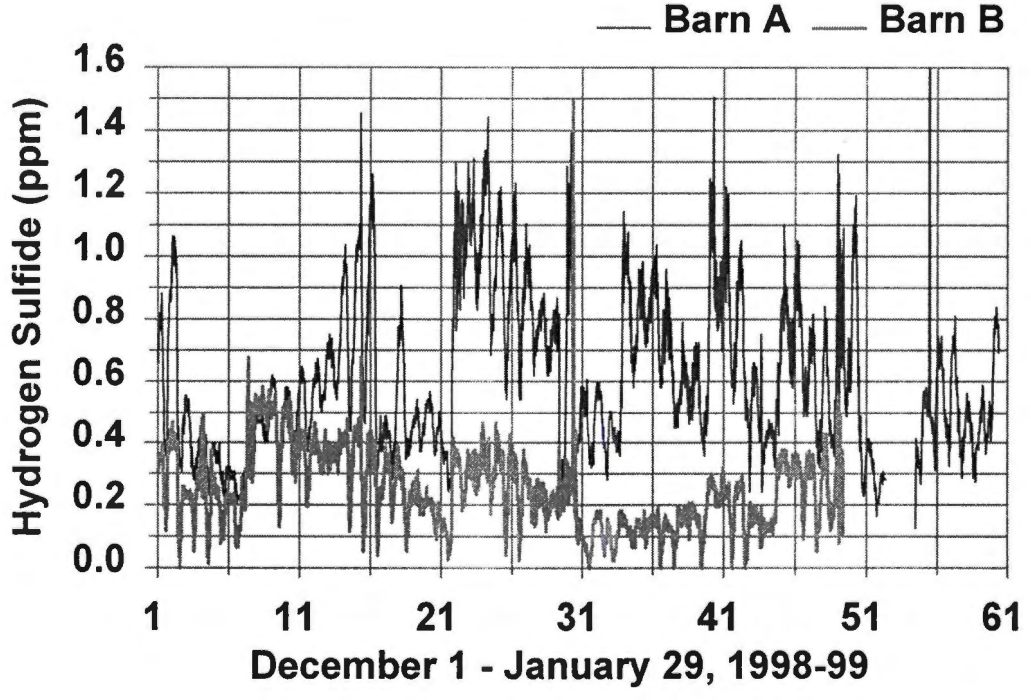


Figure E-30. Hydrogen sulfide data for 3rd study period.

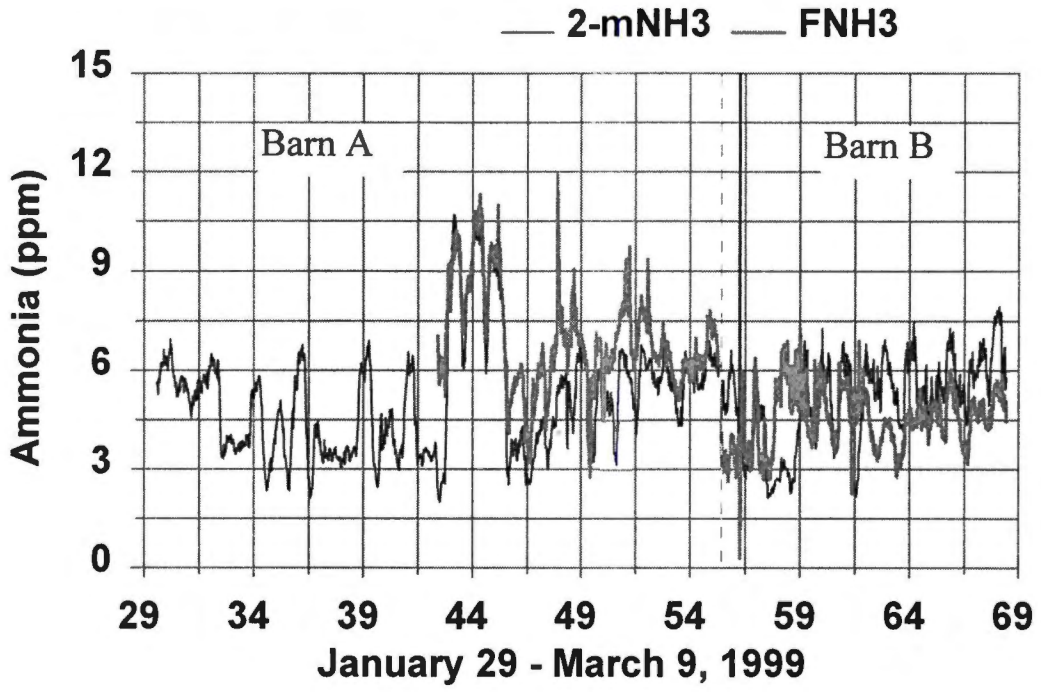


Figure E-31. Ammonia data taken at 2-m and floor level in Barn A and Barn B.

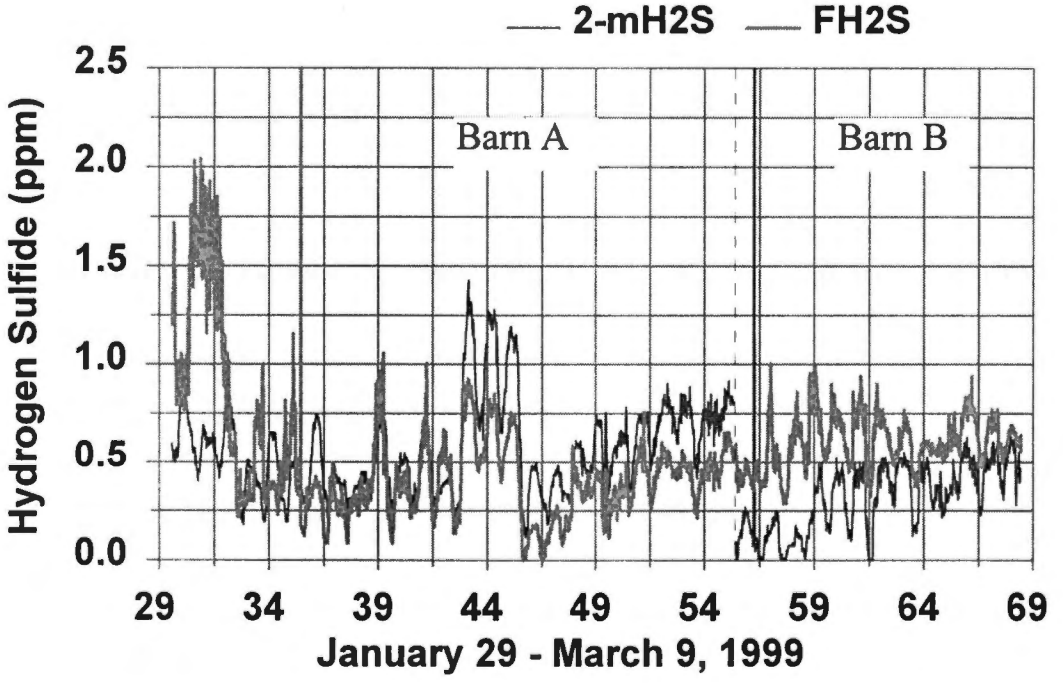


Figure E-32. Hydrogen sulfide data taken at 2-m and floor level in Barn A and Barn B.

Vita

Daniel B. McKinney was born in Nashville, Tennessee on June 5, 1974. Daniel attended elementary, middle, and high school in Centerville, Tennessee where he graduated from Hickman County High School in 1992.

Upon entering the University of Tennessee at Martin in the fall of 1992, he pursued a degree in Agriculture with a major in Animal Science. Activities involved with while at UTM include Phi Sigma Kappa Fraternity. Daniel graduated with a Bachelor of Science degree in Agriculture in May 1997.

Daniel began graduate school the following semester at the University of Tennessee at Knoxville, in the Department of Agricultural and Biosystems Engineering. Daniel completed his Master of Science degree in Agriculture, with a major in Agricultural and Biosystems Engineering Technology, in May of 1999.