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Evaluation of broiler house environmental management systems in East Tennessee : a case study

Scott D. Snyder

To the Graduate Council:

I am submitting herewith a thesis written by Scott D. Snyder entitled "Evaluation of broiler house environmental management systems in East Tennessee : a case study." 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:

Mike Smith, 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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Michael R. Smith

Accepted for the Council:

C W Minkel

Associate Vice Chancellor
and Dean of the Graduate School

Evaluation of Broiler House Environmental Management Systems in East Tennessee: A Case Study

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

Scott D. Snyder
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ABSTRACT

An air quality study was conducted for two different types of broiler house environmental management styles: naturally ventilated, and mechanically ventilated. A continuous sampling, stand alone, monitoring system was used to monitor four gases within the houses. These gases were Ammonia, Carbon Monoxide, Hydrogen Sulfide and Oxygen. Data points were logged every thirty minutes. Dust samples were also collected using universal flow sampling pumps and cartridge-type filters. Other data collected but not analyzed in this study were interior temperature and relative humidity and exterior temperature, relative humidity, and solar radiation.

Statistical analyses were performed to test for differences in gas levels between environmental management styles. These tests revealed that a significant difference ($p<0.5$) existed between management systems for maximum oxygen, maximum ammonia, and maximum hydrogen sulfide levels. Significant differences ($p<0.5$) between farms with the same environmental management style were found for ammonia and carbon monoxide levels. These differences were attributed to the occurrence of an in house flood at Farm B2 (mechanically ventilated) and poor conditions observed at Farm D (naturally ventilated). A significant difference ($p<0.5$) between weeks for maximum and average CO level was also found. This difference was attributed to the intense use of propane brooders during the early stages of production.

Mean total dust concentrations ranged from 0.0010 to 0.0056 mg/L. Differences in dust concentration appeared to be a factor of exterior temperature and ventilation rate.

Warmer exterior temperatures allowed for increased ventilation and dust concentrations were reduced.

Conclusive results determining the overall effectiveness of either environmental management system (natural or mechanical) could not be formulated because of the significant differences ($p<0.5$) that were found within farms with the same management system. This study concluded that the effectiveness of the management system was controlled by the producer and not the system itself.

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CHAPTER I

INTRODUCTION

1. Background and Statement of Problem

Broiler production in Tennessee has increased 42 percent between 1985 and 1993 (TAS 1993). This increase is noted in new farms, increased numbers of houses per farm, and an increase in the ratio of animals per unit area. As house numbers increase on individual farms the total number of hours workers are exposed to the environments inside these houses also increases. Other trends in poultry production such as partial house brooding and reduced ventilation rates have increased the chance of excessive ammonia concentrations during the brooding stage of production (Reece, 1979). The parameters that often govern air quality management decisions within these houses are air temperature and humidity (Van Wicklen et al., 1986). Air quality within an animal system has been defined as a function of inert particles, viable particles, and toxic gases (Van Wicklen et al., 1986). Making management decisions based only on the temperature and humidity often neglects these other air quality factors that can be harmful to both humans and animals.

Ventilation in animal confinement systems may be either natural or mechanical. Natural ventilation is a function of the wind velocity and the position of the curtains on the sides of the house. Mechanical ventilation is accomplished using a series of fans to either force air into or out of a house. Forcing air into a house creates a positive static pressure inside while forcing air out of a house creates a negative static pressure within the house. These types of systems are called respectively positive and negative pressure ventilation systems.

Gas and respirable aerosol particle levels peak during the winter months when houses are subjected to minimal ventilation rates to conserve energy. These concentrations reach high levels due to the necessity of keeping temperatures higher during brooding periods. Minimizing ventilation during these times increases the humidity in the house that in turn increases the decomposition of manure, producing ammonia and other toxic gases. Other gases present at high levels are carbon monoxide, carbon dioxide, and hydrogen sulfide. Carbon monoxide is produced from burning fossil fuels in space heaters that are improperly adjusted or defective (Gerber et al., 1991). The carbon dioxide present within the houses is a product of animal respiration. Hydrogen sulfide is a product of manure decomposition (Gerber et al., 1991).

2. Research Objectives

This research project had two objectives. The first objective was to continuously monitor the air quality within natural and forced ventilation poultry confinement units, and obtain an accurate data set for analysis. Objective two was to determine the overall effectiveness of the management system, based on the data from objective one. Once measurements of the interior environment were made, a comparison could be made between the data and the production performance (percent livability and feed efficiency) for each flock. Based upon the comparisons, suggestions could be made to the producer to remedy possible problems.

CHAPTER II

REVIEW OF LITERATURE

Inert particles are those that are sterile and viable particles are microbes ranging from virus particles to aggregates of bacteria or fungal spores (Harry, 1978). The inert and viable airborne concentrations within a broiler house may affect the ability of a disease organism to transfer among the birds resulting in decreased bird growth and increased bird condemnation rate at the processing plant (Van Wicklen et al., 1986). High concentrations of these particles reduce the function of the upper respiratory system (Harry, 1978), and in 1985 led to the condemnation of 29.7 million broilers in the United States (NASS, 1986).

Respirable aerosol concentrations (RAC) and gas levels also affect humans. An eight-hour RAC exposure limit has been determined by the Occupational Safety and Health Administration (OSHA) to be 5 mg/m^3. Meyer (1986) collected data from eight commercial hog farms and found that the average concentration of total dust in nine farrowing houses to be 1.23 mg/m^3. Respirable dust levels in two of the farrowing houses were 0.20 and 1.36 mg/m^3 (Meyer et al., 1986).

Gerber (1991) reviewed ammonia, carbon monoxide, carbon dioxide, hydrogen sulfide, and methane in swine confinement facilities and discussed toxicity levels for humans and swine. The Occupational Safety and Health Administration has declared an eight-hour ammonia exposure limit for humans to be 35 ppm. Poultry subjected to levels of ammonia at 25 ppm have poor feed conversion rates and if exposed to these levels at brooding age experience poor growth rates (Quarles et al., 1974). In addition these researchers determined that exposure to levels greater than 50 ppm decreased weights of 8-week-old broilers up to 4% and caused increased condemnation.

Bottcher et al. (1989) conducted a study of broiler house ventilation systems from the fall of 1987 to the spring of 1989. The research included data from three different ventilation systems, earth-tube cooling, tunnel ventilation, and an evaporative cooled system. Ammonia levels in the three systems ranged from 7-20 ppm over the research period. Meyer (1986) conducted a study of mechanically ventilated swine barns and found that ammonia levels in farrowing facilities reached levels of 57, 58 and 105 ppm in separate facilities, with the highest level of ammonia recorded from a facility that used a recirculation ventilation strategy.

Berry (1995) conducted research to develop a system that could accurately and continuously monitor ammonia levels inside poultry houses. The resulting system used a central instrumentation building to which air was pumped from four similar houses on the same farm. Continuous duty piston pumps were used to pull the air through automotive type filters, and then push the air to the instrument building. The air from the houses passed through a manifold system with solenoid valves. All valves were controlled by a datalogger that switched the air from each house to the infrared gas analyzer.

Preliminary results from this research showed that accurate measurements could be collected at a frequency that would allow the detection of ventilation system operation. Ammonia levels for the tests averaged 30 ppm with the ventilation system operating four minutes out of every five.

Van Wicklen et al. (1987) measured the respirable aerosol concentrations continuously over a 9-day period in a filtered-air, positive pressure ventilated poultry breeder house. The study involved filtering air for a house that held 400 breeder chickens, 1.5 years old on a 9.2 x 9.2 m floor covered with pine shavings. Ventilation air into the house was forced through two filters before it entered the house through dampers. The first filter removed between 30 and 35% of respirable air particles. The second filter removed 90 to 95% of the particles ranging from 1-3 μm.

Particle numbers were determined using a Climet CI-226 Particle sensor. Respirable air concentrations were recorded by taking a 10 minute air sample every 30 minutes over a 9-day period. Air was pulled into the sampler from a tube that protruded 0.2 m into the house 0.9 m above the floor.

Results showed that the mean particle concentration over the 9-day period was 140.3 particles/mL with a standard error of 58.4 particles/mL. These concentrations were lower than conditions in turkey barns during the summer in Minnesota and in commercial broiler houses, but were not lower than conditions reported by Van Wicklen et al. (1986) for curtain wall broiler housing during warm weather.

Van Wicklen et al. (1986) studied the effect of bird activity, temperature, relative humidity, and day/night differences on respirable particle concentrations in Georgia broiler houses. For this study, particle concentrations were compared between two similar curtain-walled houses. One house was 10.4 m x 122.0 m, while the other house was 10.4 m x 91.5 m. The houses had curtain sidewalls with ventilation fans to circulate air into and out of the houses.

Dry bulb, dew point, total (inert + viable) respirable particle concentration, and viable respirable particle concentration were the environmental parameters monitored. Thermocouples measured the dry bulb, and dew point temperatures. A Climet 226 Particle Sensor, placed 0.3 m above the litter, measured the particle concentrations for a range between 0.3 and 10.0 microns. The sampler collected a 7.08 L sample every 15 minutes. The viable particle concentration was measured using an Anderson Viable Sampler with TSA agar.

These studies revealed that 86 percent of the particles were between 0.3 and 0.5 microns in diameter. The other 14 percent of the particles were from one to 2.0 microns. Over the sampling period the mean indoor concentrations of particles in the one to 2.0 micron range were more than 14 times greater than the outdoor particle concentrations. A 39 percent increase in concentrations during natural daylight hours versus nighttime hours was found. Relative humidity had no significant effect on concentrations in the 0.5 to 5.0 micron range.

A study of the effect of respirable particle concentrations for broilers was conducted by Van Wicklen et al. (1994). Broilers at four weeks of age were treated with different respirable aerosol particle concentrations. The experiment was set up as a split plot design. Broilers in environmental chambers were exposed to one treatment from four to seven weeks of age.

Litter from previous trials was used to increase the levels of particles beyond normal concentrations. The levels were increased from 60 to 90 each day during the growout. A MetOne Model 237A Particle Counter was used to measure the particle concentrations during each test. Concentrations were measured twice weekly for a one-hour period.

After the test the broiler lungs were examined for damage from the particle concentrations. Test results showed that the mean RAC level for chamber one was 9.2 particles/mL compared with 10.2 particles/mL for chamber two. For test two the mean RAC was 97.7 particles/mL in chamber one with a maximum RAC of 572.6 particles/mL. Conditions in chamber two that did not have the particle generator had a mean RAC level of 37.3 particles/mL and a maximum RAC level of 78.3 particles/mL. RAC treatment had no significant effect on mortality as most of the deaths occurred the first four weeks before the treatments. Broiler weights were also not affected by dust levels. Feed conversion ratios were not affected. The group of birds exhibiting the lowest feed conversion ratio (1.33) was exposed to the highest mean RAC of (98 particles/mL). A similar feed conversion ratio of 1.31 was exhibited by the birds exposed to the lowest mean RAC (9 particles/mL). Post mortem studies on the respiratory tracts of the birds revealed no adverse effects from exposure to particles.

Czarick and Lacy (1990) studied the effect of curtain machines on broiler house environments. Air quality measurements were taken at bird level 100' feet from one end of the house. Parameters measured were: temperature, relative humidity, ammonia, carbon dioxide, and oxygen. Temperature measurements were taken with a Fluke hand-held thermometer. Oxygen levels were found by using a G C Industries electrochemical oxygen monitor/alarm meter. Ammonia and carbon dioxide measurements were determined using a Matheson Kitagawa hand pump with gas detector tubes.

The effect of the curtain machines was determined by observing the cyclic nature of the curtain machine during mild and cold weather conditions. Indoor and outdoor temperatures were recorded and plotted with time to calculate to the average cycle time. The curtains on the same commercial broiler house were closed for 20 minutes while monitoring the air quality conditions every five minutes.

The results of the tests showed that the curtains did have a distinct cycle based on outdoor temperature and this cycle was 15 to 45 minutes long. Closing the house completely revealed that critical conditions were reached within 20 minutes of curtain closure. The conditions were critical because of high temperature and relative humidity, not because of toxic gas levels. Ammonia levels in the houses increased linearly throughout the closure. Two of the farms had a threefold increase in levels and one farm had a fourfold increase during the 20 minute closures. Carbon dioxide levels rose from 750 ppm to 3600 ppm during the test.

Ross and Daley (1986) tested two different electronic chemical sensors. These two types were a metal oxide semiconductor (MOS) and an electrochemical sensor. The MOS sensors operate by measuring the change in resistance of a material. As the material is exposed to the gases, the material is oxidized and reduced changing the conductive properties of the material. The MOS sensor was tested in the lab and then in the field. Lab tests included exposing the sensor to increasing concentrations of ammonium hydroxide while measuring the resistance of the material. Field tests were conducted by exposing the sensor to field conditions and then comparing the expected results with actual lab tests.

Field test results revealed that the MOS sensor was instable upon the start of testing. The sensor was allowed to warm up for three days. Two of the same sensors were placed in the same general location of the house. The two sensors did not show the same readings. The sensors were returned to lab for calibration and the were found to follow different calibration curves as compared to initial calibrations.

The second sensor tested by Ross and Daley (1986) was an electrochemical sensor. The electrochemical sensor is composed of a cell and current divider. The cell contains a gas specific liquid exposed to air by a gas permeable membrane. There are two electrodes in the cell, a reference electrode and an unknown electrode. The potential is converted to a 4-20 mA current.

This sensor's response time was tested in the laboratory under varying physical conditions. The electrochemical sensor was compared with Gastec diffusion tubes, Dräger diffusion tubes, and a MIRAN 1B miniature infrared analyzer. The electrochemical sensors were consistently high when exposed to concentrations of 10 and 45 ppm, but the difference was attributed to an inadequate warm-up period. The diffusion tubes were close to the correct values. Sensor response and decay tests were performed. The electrochemical sensor reached only 80% of the 10 ppm exposure concentration. The sensor was removed from the exposure concentration and the sensor decayed to zero after eight minutes. Humidity and temperature did not affect the sensor. The authors noted that under field conditions an adequate warmup period is necessary to obtain accurate readings.

Hansen and Fischer (1986) investigated methods of reducing ammonia concentrations in broiler houses. The methods of reduction discussed were the use of: chemically treated brooding paper, ferrous sulfate hepthydrate applications, wood fiber pellets for litter, and ammonia detection coupled with fan control systems. Ammonia detection was accomplished using a Matheson-Kitagawa gas detection gun and detector tubes, a Gastec gun and 3M ammonia detection tubes. The detector tubes performed satisfactorily during the test. The ammonia detection systems coupled with fan controllers drifted out of calibration during use in the house. Carbon monoxide from the propane brooders was suspected to interfere with ammonia detection.

Van Wicklen and Allison compared the aerosol and ammonia concentrations in two different types of broiler houses, naturally ventilated (NV), and mechanically ventilated (MV). The effects of housing style, bird age, and time of day on respirable aerosol concentration (RAC) were investigated. Sampling was done in each house at days 24, 25, 32, and 33 days of age. Aerosol sampling was accomplished using a Climet CI-226 Particle Analyzer at the center of the house 0.3 m above the floor. Concentrations were determined on 15 minute intervals on each day of sampling. Outdoor concentrations were measured before an initial setup of the sampler in each house.

Mean daily RAC levels ranged between 34.9 and 44.1 particles/mL for the MV house and mean RAC levels for the NV house were between 9.0 and 15.5 particles/mL. Statistical analysis concluded that significant differences in mean daily RAC levels occurred between the hours of 0600 and 0800 in the NV house and the hours of 1000 and 1600 hours in the MV house. The authors concluded that ventilation rates larger than those necessary to remove moisture and maintain thermal balance were necessary to reduce RAC levels.

Dust levels in mechanically ventilated swine barns were measured by Meyer et al. (1986). Dust particle size distributions were determined using Anderson Ambient Air Samplers. The samplers sampled air at a rate of 0.00047 m^3/s (1cfm). Sample times ranged from 115 minutes to 342 minutes with an average of 244 minutes. Ammonia, relative humidity, inside temperature, and outside temperature were also recorded.

Total dust levels in the nine farrowing rooms ranged between 0.44 and 2.99 mg/m^3. Ammonia measurements taken with a sample pump and amine detector tubes ranged from 12 to 105 ppm. Variations in ventilation type produced more variations in dust and ammonia levels than production phase.

Van Wicklen et al. (1994) conducted an evaluation of the environment within a caged brooding system. The system was comprised of two houses each having levels of cages to be used for brooding unlike a floor brooding system where chicks are housed on the floor. Air temperature, ammonia levels, and RAC levels in the caged brooding system were compared to levels in a typical brooding system.

Met One Model 237A Particle Counters were used to count respirable aerosol particles between 0.5 and 5 μm. Samples were taken on 10 minute intervals over a 21 day period. The samplers were placed in the center of the house and at the sidewall of the house. In the caged system house (CSH) the center sampler was 2.13 m (7 ft) above the floor. The sidewall sampler was located 1.83 m (6 ft) above the floor. In the floor system house (FSH) aerosol concentrations were measured at the center of the house and along the sidewall. Ammonia concentrations in both houses were measured using a Gastec volumetric hand pump and detector tubes.

Ammonia concentrations in the CSH were between 1. 5 and 3.0 ppm during the monitoring period. In the FSH concentrations of ammonia ranged from 7 to 22 ppm. It was concluded that the lower ammonia levels of the CSH are a real benefit of the housing system. Results from RAC measurements showed that concentrations in the CSH were higher near the sources of dust generation (i.e manure belts, floor cleaning), but there was no significant difference among concentrations for different times of the day. Increases in RAC were noted in the third week of production and was attributed to the development of feather coats by the chicks.

CHAPTER III

METHODS AND PROCEDURES

Two different environmental management systems were evaluated. Two naturally ventilated houses in Greene County, and two tunnel ventilated houses in Bradley County were monitored. Air quality within the confinement units was determined by sampling air for dust levels and continuously monitoring the levels of oxygen, carbon monoxide, ammonia, and hydrogen sulfide.

1. Gas Measurement

Four electrochemical sensors were used to measure ammonia, carbon monoxide, hydrogen sulfide, and oxygen concentrations. The Polytron SE brand units, manufactured by Dräger Inc., included a cell containing a gel or liquid exposed to air through a permeable membrane. The cell contained two probes between which electricity flowed. As gases diffused through the membrane, the chemical properties of the liquid or gel changed thus varying current flow between the two probes. This produced a variable output corresponding to the concentration of gas in the air.

The 12 V power source required by the Dräger sensors was provided by a deep-cycle 12 V battery. The output signal of the sensors was a 4-20 milliamp current. This current was converted to voltage using a 240 ohm shunting resistor (Figure 1) to utilize almost all of the 5000-millivolt range of the Campbell Scientific 21X datalogger used to

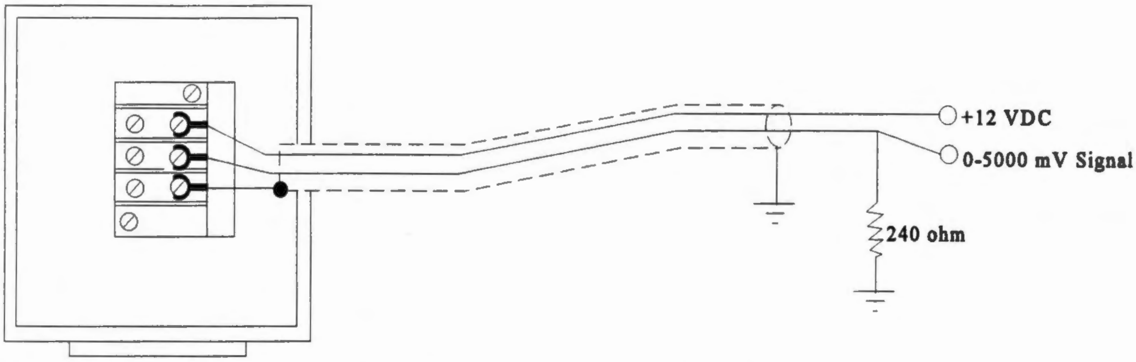

Figure 1. Wiring schematic for connection of sensors to datalogger.

record the data. The voltage drop across the shunting resistor was read by the datalogger as a single-ended voltage.

The gas sensors were initially mounted in a 91 cm (36 in) x 25 cm (10 in) diameter PVC tube (Figure 2). Adapters were machined so that the sensors would hang 20 cm (8 in) apart in the center of the tube. One end of the tube was covered with a flat cap having a 7 cm (3 in) diameter air outlet covered with a brass screen. The opposite end had a similar cap with a 7 cm (3 in) diameter AC box fan fastened to the inside of the cap. Affixed to the outside of the cap was an adapter that allowed 3M brand HEPA filters to thread into the end cap. The fan pulled air through the filter creating a positive pressure environment inside the tube while providing the sensors dust-free air. The air passed the length of the tube and exited through the screen at the opposite end from the fan.

Preliminary test results indicated that this housing design was unsuitable for accurate ammonia measurements. The filters became laden with dust, which absorbed ammonia from the incoming air and reduced sampling accuracy. Thus, the tube housing

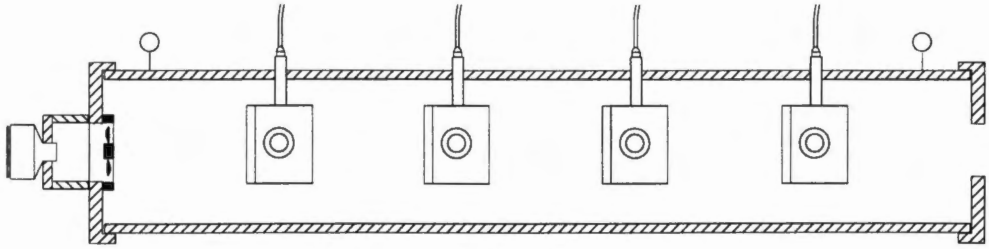

Figure 2. Original configuration of sensor enclosure.

was replaced with a simple protective hood that permitted natural air currents over the sensors.

This protective hood was constructed of 6.35 mm (0.25 in) PVC sheeting (Figure 3). The overall dimensions were 91 cm (36 in) x 20 cm (8 in). The sensor spacing was the same for this configuration as for the tube (20 cm, 8 in). The hood was fabricated so that the sensors would be protected from the top and sides. The hood was open on the bottom. The upper 10 cm (4 in) of each end was open for improved air circulation through the ends of the covering. The sensor enclosure and sensors were placed in the center of the houses during the monitoring cycle.

Sensor Calibration

All sensors were calibrated prior to use with each flock. The sensors, connected to the datalogger, were connected to the power source and allowed to warm up for the necessary time (>24 hours) in a laboratory environment. After warm-up, the sensors were exposed to 100% N_2 using procedures specified by the manufacturer. After appropriate settling time, the sensor displays were zeroed by adjusting the offset potentiometer on the sensor circuit board. The voltage drop created by the current flow

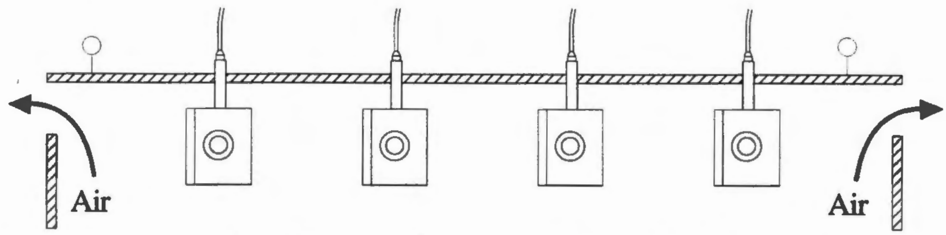

Figure 3. Second and final configuration of sensor enclosure.

through the resistor was then recorded at the datalogger. The sensors were then exposed to their respective calibration gases (table F-1) to produce a near full-scale reading and the displays on the sensors were adjusted by turning the slope potentiometer to give the appropriate reading. Once the displays were adjusted, the voltage drop was once again recorded. The sensors were then transported to the farms fully powered to avoid warm-up time once installed.

At initial calibration, the sensors were exposed to heat from a heat lamp to determine if temperature affected sensor output. No temperature effect was found.

A linear regression model was used to obtain a straight line equation for the calibration of each sensor. Post-processing of the data was completed using the equations representing the calibration lines.

2. Environmental Parameters

One Campbell Scientific model 107 temperature and relative humidity probe was used to measure the temperature and relative humidity at the gas sensors. Another probe was located outside to monitor outdoor conditions. The probes were connected directly to the datalogger.

A Licor LI-200SZ pyronometer was located outside to record solar radiation. The pyronometer was also directly connected to the datalogger.

A Campbell Scientific AM416 multiplexer was used to permit temperature measurements at multiple locations using type T thermocouples. Temperatures were recorded at the point of gas measurement and at 15 m (50 ft) intervals, 1.5 to 2.0 m above the floor along the center of the house. Measurements were taken at a total of nine positions.

All sensors were read every minute by the datalogger and averaged for each thirty minute period. These averages were recorded in permanent storage for later retrieval.

3. Dust Sampling

Total dust concentration samples were obtained using two SKC model 224-43XR universal flow air sampling pumps. The total systems consisted of: the sampling pump, cartridge holder, and 37 mm cartridges. An adjustable stand held the sampling pumps 1 m (3.3 ft) above the floor of the houses. Each cartridge contained a 37 mm support pad and a 37 mm PVC filter with $0.5\mu m$ poresize. Before initial weighing, the filters were equilibrated in an environmental chamber maintained at 20° C (68° F) and 50% relative humidity for two days. The filters were weighed and the cartridges were assembled and sealed with cellulose bands.

The sampling pump batteries were charged using the supplied chargers until the indicator light on the chargers indicated a full charge. Personnel at the National Institute for Occupational Safety and Health suggested, in a telephone inquiry, the pumps be set to a flow rate between 1.5 and 2.0 L/min. The suggested total volume of air collected was to be between 25 and 133 Liters. The pumps in this study were set to a flow rate of 1.6-1.7 L/min using an SKC model 712 electronic bubble film calibrator. The flow rates of the pumps could be adjusted by turning a potentiometer on the pump to adjust the voltage supplied to the diaphragm pump inside each housing. Each pump had internal circuitry to adjust the speed of the pump to maintain a stable flow rate under variable pressure conditions.

Before sampling at the broiler houses, the cartridges were placed in the cartridge holders and attached to the stands. The stands were then placed approximately 30 m (100 ft) from each end of the houses. The pumps were allowed to operate for approximately one hour. Start and stop times were recorded to calculate total run time for each pump.

The cartridges were returned to the laboratory and placed in the environmental chamber (20° C (68° F), 50% RH) for a minimum of 48 hours. After reaching equilibrium the filters were carefully removed from the cartridges and weighed. The final weight was then recorded. The total dust per liter of air was calculated using the equation:

$$\frac{\textit{Total Dust}}{\ell} = \frac{\textit{Final Weight} - \textit{Start Weight}}{\textit{Time}\ (\text{min}) \times \textit{Flow Rate}\ (\ell/\text{min})}$$

4. Chronology of Events

Farm A

Farm A was located in upper east Tennessee near Morristown. The house was a 12 m (40 ft) x 122 m (400 ft) curtain-sided poultry house. The East-West oriented house was naturally ventilated using only 1.2 m (4.0 ft) circulating fans on the interior to move air toward each end of the house. The house was constructed of poles and had a steel gable ceiling, styrofoam insulation, and tin roof painted with reflective roof coating.

Instrumentation was installed in this house on October 5, 1994. Preliminary data were collected on October 10, 1994 to evaluate the operation of the sensors. Day-old chicks were placed in the house on October 11. The following week the oxygen sensor was removed due to loss of sensitivity. The sensor was sent to the manufacturer for analysis and was found faulty because of age. Normal data collection, excluding oxygen measurements, was resumed weekly. Two dust samples were collected on November 18, 1994. Monitoring equipment was removed on November 21 and the birds were picked up for processing on the 22nd of November at an age of seven weeks.

The original tube enclosure for sensors was used during these tests. Questionable ammonia readings occurred as dust collected on tube intake filters. This led to further tests that indicated increased ammonia concentrations after the replacement of the filters. Analysis of the data also revealed decreased ammonia concentrations after the filter had been in place for 2-3 days. Use of this system was discontinued and a new hooded system that utilized the natural movement of air was constructed (Figure 3).

Farm B

Farm B was located in Bradley county Tennessee. The houses on this farm were 12.2 x 152.4 m (40 x 500 ft) tunnel ventilated houses. The house had post-type construction with wooden rafters and 10.2 cm (4 in) batten-type insulation between the rafters. A plastic liner protected the insulation from moisture damage by the interior environment. During the winter months (0.9 m, 3 ft) fans were used to exhaust the house pulling air in through inlets along the eaves of the building. Propane brooders were used to supply heat to the chicks.

On December 7, 1994, calibration of the monitoring system revealed that the ammonia sensor was losing sensitivity. Birds were placed on this farm on December 20, 1994. Equipment was not installed until January 4, 1995. The ammonia sensor could not be replaced during this collection. Two dust samples were collected on January 9, 1995. The equipment was removed on the 30th of January and the birds were removed later that night. Because ammonia concentration data was not collected, another test was performed at this farm.

On February 16, 1995, the hydrogen sulfide sensor failed calibration testing. The system was installed without the H_2S sensor into the same house at Farm B on the 18th of February. Two dust samples were collected on February 23, 1995. Preliminary evaluation of the data revealed a sharp rise in ammonia concentration in the house on Wednesday, March 1, 1995. This increase in concentration was due to a cracked water line leaking onto the floor of the house saturating a 6.1 x 6.1 m (20 x 20 ft) section of the floor. Battery failure on March 3 caused the system to cease sampling and all subsequent data were lost. Dust samples were collected on March 2 and March 18. The birds were removed from the house on March 31, 1995.

Farm C

This farm was located in the same general area as Farm B and had the same building construction and management system as Farm B. Day-old chicks were placed at the farm on July 6, 1995 and monitoring was resumed. Two dust samples were collected on July 21, 1995. Increased summer temperatures warranted the use of tunnel ventilation, evaporative cooling pads, and misting nozzles reducing the concentrations of all gases to nearly zero. Because of these conditions the equipment was removed on August 3, 1995 when the birds were at four weeks of age.

Farm D

Farm D was located within 10 miles of Farm A and near Morristown, Tennessee. The house measured 12.2 m (40 ft) x 130.0 m (400 ft) and had curtain sides. Natural ventilation was the management system used in the house. Eight 1.22 m (4 ft) circulating fans were used to push air toward each end of the house, and ten ceiling fans were spaced evenly throughout the house. Steel gables supported the 2.54 cm (1 in) styrofoam insulation and tin roof, painted with a reflective coating.

Sensor calibration was carried out on November 29, 1995. Day-old chicks were placed in the house on November 29, 1995. Instrumentation was installed in this house on the November 30, 1995. Data from the sensors were downloaded each week for five consecutive weeks. Dust samples were collected on December 15 and 20, 1995. The instrumentation was removed from the house on January 3, 1995.

4. Statistical Analysis

Weekly values for maximum, minimum, average, and median for each monitored gas were calculated. Each of these variables for each gas was tested using a general linear model to determine if there was statistically significant difference between management system (mechanical or natural), between farms (A, B, B2, C, D) with the same management system, between production weeks (1, 2, 3, 4, 5, 6), and between weeks with the interaction of the management system. SAS® was used to run the analysis (Appendix E).

CHAPTER IV

RESULTS AND DISCUSSION

This research project was undertaken to first, continuously monitor the air quality within naturally and mechanically ventilated poultry houses and second, to determine the overall effectiveness of the management system (natural or mechanical). Four different houses were studied with two of those being naturally ventilated and two houses with a mechanical ventilation system. The parameters studied within each house included the gas concentrations, the total dust levels, and the thermal environment. Production parameters considered included net feed efficiency, percent livability, and average daily gain.

1. Production Results

Production data were obtained for each monitored growout cycle (Table 1). Farm A had a longer growout because of scheduling problems with the processing facility. The remaining farms had similar production cycles and data. Statistical tests were not performed to model any of the production parameters as a function of the management system because of the small number of data points.

Table 1. Production results from each growout period.

Farm	Date Placed	Age at Slaughter	Net Feed Eff.	% Live	Avg Daily Gain
A	10/11/94	7 Wks 1 Day	1.75	97.3	0.083 lbs
B	12/20/94	5 Wks 6.5 Days	1.90	95.8	0.093 lbs
B2	2/17/95	6 Wks 0 Days	1.80	99.6	0.094 lbs
C	7/6/95	5 Wks 6 Days	1.78	96.1	0.096 lbs
D	11/29/95	*	*	*	*

*Production results for Farm D were unavailable at the time of publication.

2. Gas Measurements

Graphical analysis of the data for select times showed daily variations in gas levels in the naturally ventilated houses. During the warm periods of the day, the curtains would cycle for longer periods allowing more air to enter the house. This cycling created a greater air exchange affecting interior temperatures and ammonia levels. The interior temperature would increase, and, as a result, the rate of ammonia release from the litter also increased. Ammonia level increases normally occurred between 1000 and 1230 hours in the naturally ventilated houses (Figures 4 and 7). This increase corresponded with an exterior temperature increase.

This daily variation was not as prevalent within the mechanically ventilated houses (Figures 5 and 6). The ventilation system on these houses was set to operate on a preprogrammed cycle instead of relying on natural currents for air exchange.

Carbon Monoxide Results

Carbon monoxide is a by-product of improper combustion of propane. Insufficient oxygen results in the production of CO instead of the less harmful compound CO_2. Maximum carbon monoxide levels were between 16.3 and 30.0 ppm for the first

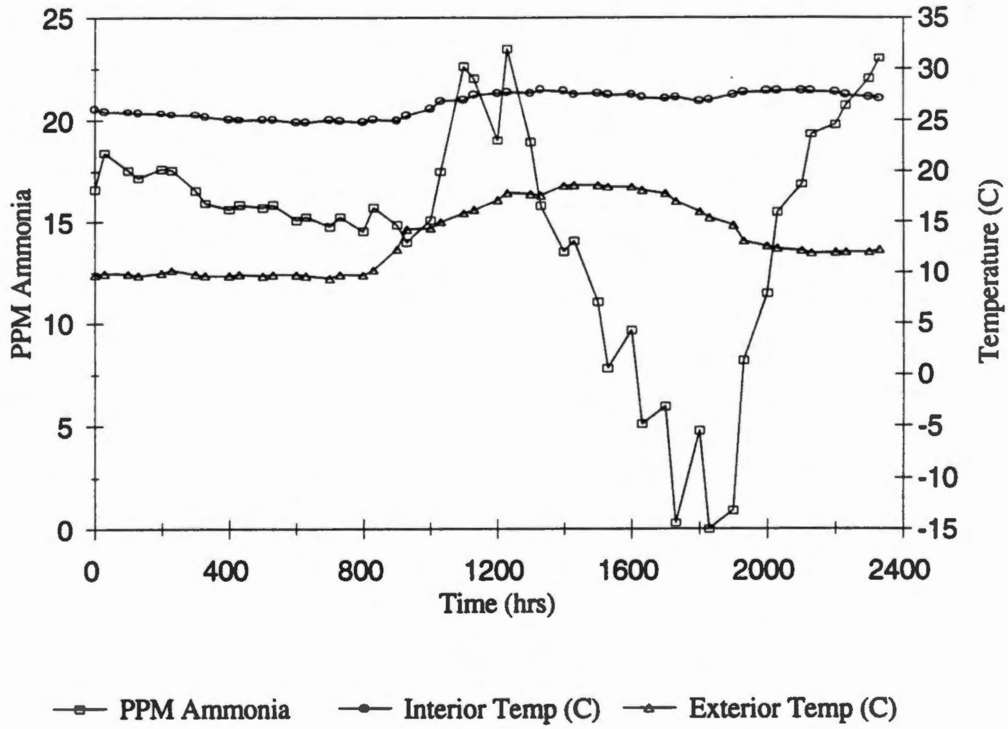

Figure 4. Ammonia levels and temperatures October 25, 1994 at Farm A (naturally ventilated).

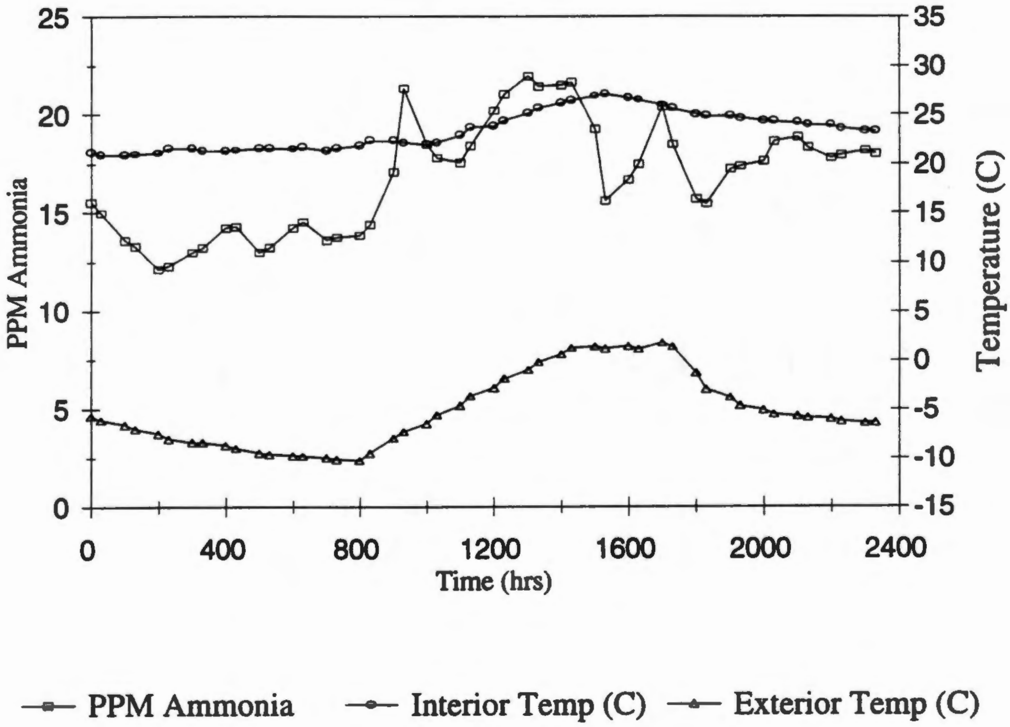

Figure 5. Ammonia levels and temperatures January 5, 1995 at Farm B (mechanically ventilated).

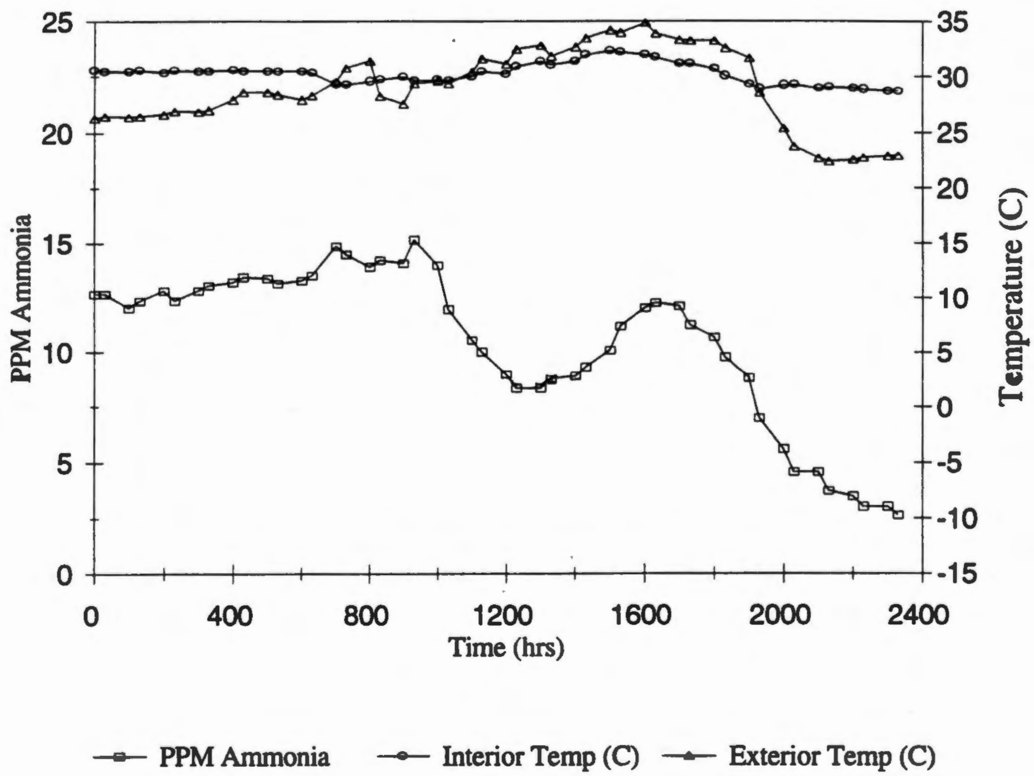

Figure 6. Ammonia levels and temperatures July 7, 1995 at Farm C (mechanically ventilated).

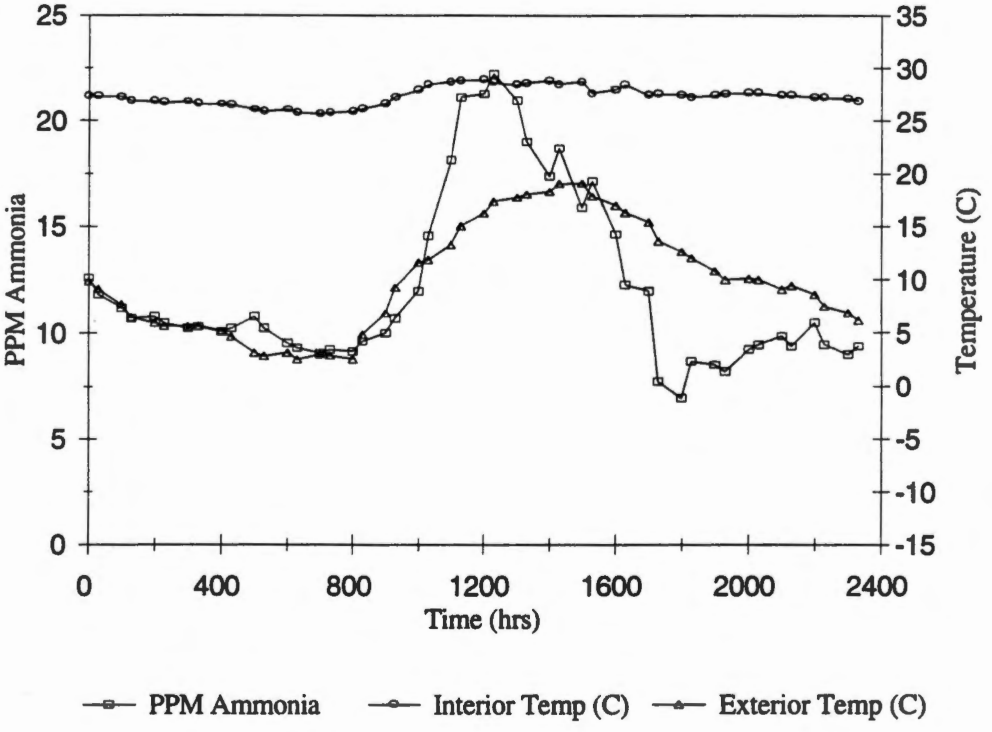

Figure 7. Ammonia levels and temperatures December 2, 1995 at Farm D (naturally ventilated).

week of production at each house. Levels dropped to near zero as the need for alternate heat sources decreased throughout the production cycle.

Oxygen Results

The oxygen sensor failed at Farm A, therefore data were not collected during the production cycle for this naturally ventilated house. A new sensor was calibrated and installed at the next farm, Farm B, a mechanically ventilated house. For this production cycle the minimum value occurred during week 2 (19.1, Table A-3). A second production cycle was monitored at Farm B from now on designated as Farm B2. Data was collected only during the first two weeks of the cycle and monitoring was halted because of battery failure. This production cycle had a minimum value for oxygen in week 2 of the production cycle (19.8%, Table A-5). The lowest oxygen levels were recorded during the fourth week of the production cycle at Farm D (18.0%, Table A-10).

Maximum weekly oxygen levels ranged from 19.5% to 21.1%. Values more than 20.9%, the atmospheric concentration of oxygen, were considered sampling error and not conclusive to the test. Weekly average oxygen levels ranged from 18.6% to 20.4%.

Figure 8 shows variation in oxygen levels during portions of four growout periods. The most significant feature of this data is the wide fluctuations in oxygen levels for Farm C. The effect of mechanical ventilation is clearly visible. Daily differences of more than 1.5% in oxygen level are common. Oxygen levels follow changes in exterior temperature throughout the day. The high levels occur during the afternoon periods of higher temperatures and higher ventilation rates, while the lower

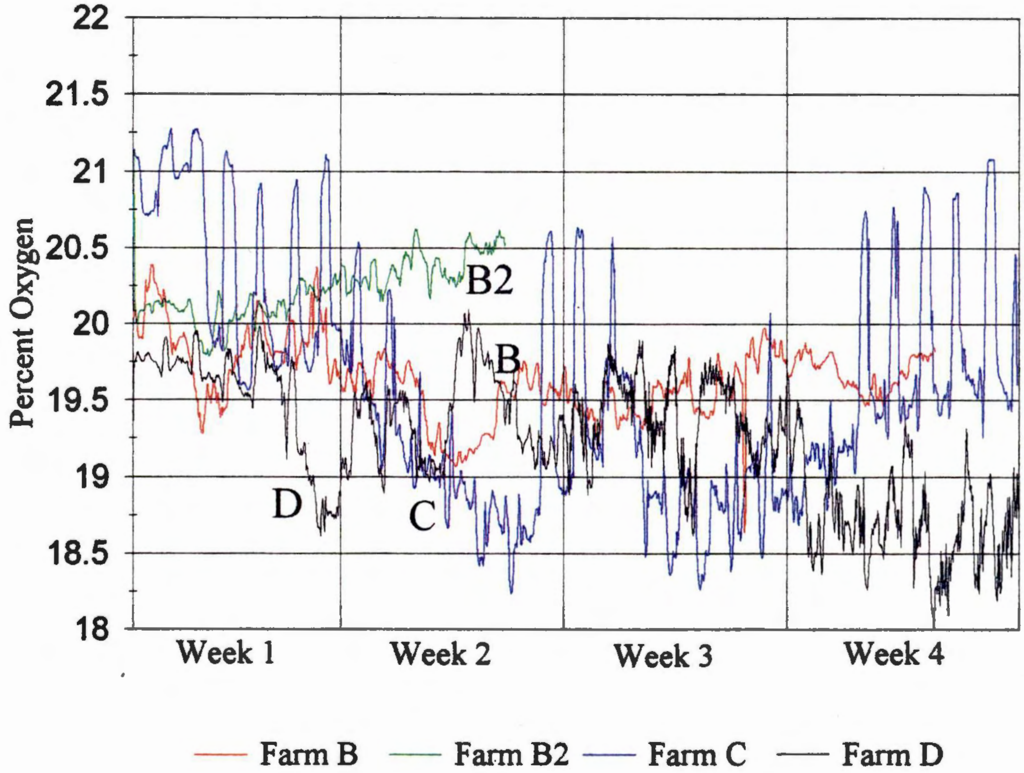

Figure 8. A composite graph of oxygen levels during each growout cycle at each farm.

levels occur during the late night hours of lower temperature and reduced ventilation. Oxygen levels follow changes in exterior temperatures throughout the day. These wide daily changes in oxygen level are not present in the naturally ventilated houses, although variation over longer periods are present for all houses. This longer term variation follows weather changes with lower outside temperatures resulting in lower oxygen levels.

Ammonia Results

Weekly average ammonia levels ranged from 0.9 ppm, recorded in week 4 at Farm C, to 47.4 ppm, recorded in week 4 at Farm D. The ammonia sensor failed during the first growout at Farm B. This failure is evident in the calibration equation for ammonia obtained on 12-12-94 (Table D-1). The sensor was replaced and another growout (B2) in the same house was monitored. An initial reading of 55.7 ppm (Table A-5) was recorded during the first week of monitoring at B2. Ammonia concentrations began to decline at Farm B2, but a water supply line burst inside the house wetting the litter in the center of the house. Due to the high humidity outside and inside (Table A-6), the water could not be removed from the litter. The ammonia concentration rose to about 45 ppm (Figure 9) where it remained throughout the production cycle. Ammonia levels did not drop below 16.1 ppm during the production cycle. These high concentrations of ammonia were due to the high humidity conditions outside and inside the house.

Farm C had no extreme rise in ammonia concentration throughout the production cycle. Weekly maximum ammonia levels ranged from 6.5 ppm to 21.9 ppm. Weekly

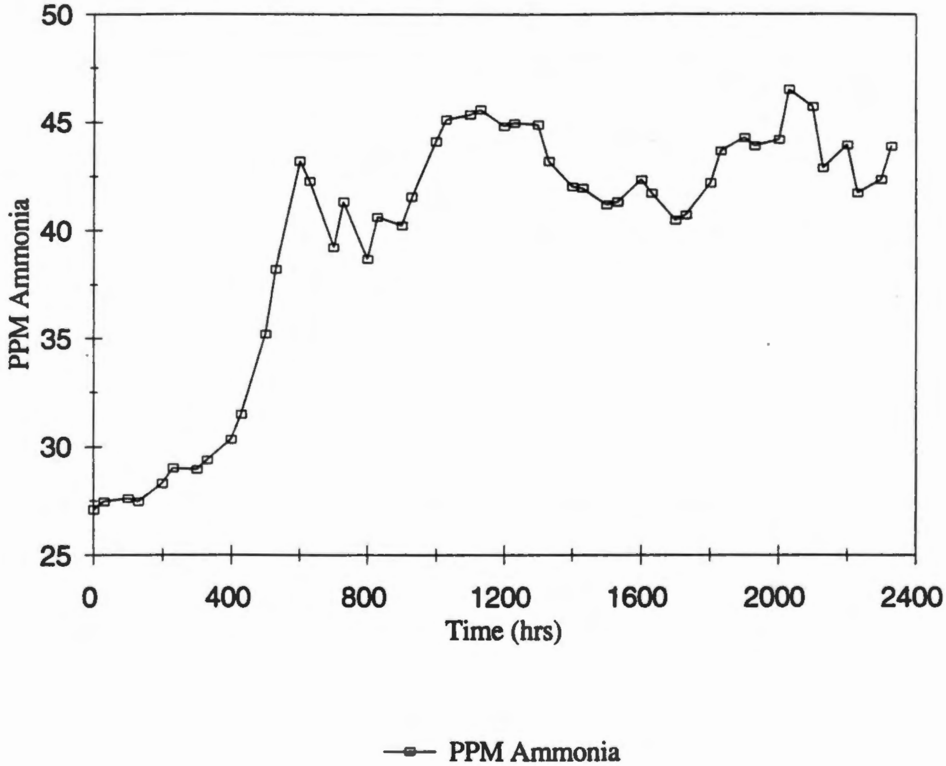

Figure 9. Ammonia levels during flood on February 28, 1995 at Farm B2 (naturally ventilated).

averages ranged from 0.9 ppm to 6.6 ppm. These low values were attributed to extreme outdoor temperatures (31° C, 88° F, an average of weekly temperatures, Table A-8).

High levels of ammonia were recorded during monitoring at Farm D. A maximum value of 62.3 ppm (Table A-9) was recorded during week 3 of production. High humidity inside the house (86%, Table A-10) and minimized ventilation were the suspected causes of these conditions. During the third and fourth weeks of production the concentration of ammonia did not drop below 15.9 ppm (Table A-9). Weekly averages for the third and fourth weeks were 32.2 and 47.4 ppm, respectively. These levels were due to cold temperatures (6° C, 43° F, an average of weekly temperatures, Table A-10)

Hydrogen Sulfide Results

Hydrogen sulfide is rarely found in poultry houses. One source of hydrogen sulfide is the decomposition of swine manure. During this study hydrogen sulfide remained very low throughout all monitoring cycles.

3. Temperature and Relative Humidity

Average weekly values for interior and exterior are included in Tables A-2, A-4, A-6, A-8, and A-10. The information included in these tables was used to prove some of the statements in the analysis of results. The information in the tables was not statistically analyzed during this study.

4. Sensor Lifespan

All of the sensors were guaranteed for one year from the date of purchase. The original sensors were purchased in the spring of 1993. At the time of failure the oxygen sensor was about 18 months old, the ammonia sensor was about 22 months old, and the hydrogen sulfide sensor was about 24 months old. The sensors remained packaged until their initial calibration and testing during the summer months of 1994. All of the sensors were replaced during the study at ages of 6 to 18 months and the replacements were operational in January of 1996. It is unknown whether the operational environment affected the lifespan of the original sensors. From this study it appears that the sensor lifespans are limited to slightly more than one year even if the sensors are never removed from their original packaging.

5. Statistical Analysis

Statistical analyses of the maximum, minimum, average, and median for each gas were performed using the SAS® program in Appendix E. All parameters were tested at the 0.05 level of significance. Significant differences ($p<0.05$) were found for weekly maximum oxygen level for the terms Vent and Farm(Vent) (Table B-1). The differences found between management systems were attributed to the apparent differences shown in Figure 8. There was also variation between farms with the same management system. Although, this difference was not as significant as the differences between management systems. No differences were found for weekly minimum, average, or median oxygen levels.

Analysis of ammonia levels revealed significant differences ($p<0.05$) for weekly maximum, minimum, average and median levels (Table B-2). A significant difference was found between management systems and between farms with the same management system for maximum weekly level. The variation in weekly maximum level between farms with the same management systems was more significant than the difference between management systems. There were significant differences between farms with the same management system for minimum, average, and median ammonia levels.

The significant differences ($p<0.05$) found among the terms for hydrogen sulfide (Table B-3) were probably due to variations in the low levels at two farms and the lack of data for the other three farms.

A significant difference ($p<0.05$) between weeks was found for maximum and average carbon monoxide level. Higher maximum levels were recorded during the early stages of production due to the intensive use of propane brooders. Again, there were significant differences between farms with the same management system for minimum, average, and median carbon monoxide levels.

6. Dust Measurements

Means were calculated for all dust sampling events during the monitoring periods at each farm (Table 2). These means were calculated from the data listed in Appendix F. Although the means seem different, they are difficult to summarize because sampling dates were not consistent throughout all production cycles. Farm C, having the lowest mean concentration, had the highest ventilation rates due to extreme outdoor temperatures. Farm D, sampled during December of 1995, had the highest total dust concentration of all farms sampled (0.0076 mg/L, appendix G). The data indicates a trend that as exterior temperature increases, total dust concentrations decrease.

Table 2. Mean total dust concentration at each farm.

Farm	Management System	Mean Concentration	Mean Ext. Temp.
A	Natural	0.0020 mg/L	16° C
B	Mechanical	0.0041 mg/L	8° C
B2	Mechanical	0.0023 mg/L	16° C
C	Mechanical	0.0010 mg/L	31° C
D	Natural	0.0056 mg/L	6° C

CHAPTER V

SUMMARY AND RECOMMENDATIONS

1. Summary

The purpose of this project was to continuously monitor the environment within poultry houses and evaluate the differences between environmental management styles. Results of the study suggested that there was a statistically significant difference ($p<0.5$) between management systems (natural or mechanical) for weekly maximum levels of oxygen, ammonia, and hydrogen sulfide (Tables B-1, B-2). Statistically significant differences existed between different houses of the same management system. This suggested that the differences were due to different management practices among the growers. These practices included, but were not limited to, operation of curtain systems, operation of fan systems and, removal of litter. These different practices were too numerous to evaluate in this study. An extensive environmental parameter data set was obtained for reference in future studies. Sensor failure was a problem that plagued the study.

2. Procedural Comments

It was difficult to completely analyze the difference between housing environments of commercial broiler houses. Variability in weather patterns made it impossible to analyze two different housing environments under the same environmental conditions. Scheduling houses to be monitored was also a problem during this study.

As the instrumentation was removed from one house, the next scheduled house was typically in mid-production. Time would also elapse between the completion of one production cycle and the placement of the next flock on the farm. These time constraints and their effect on the time periods for monitoring was detrimental to the analysis of the management practices.

Total dust concentration analysis is inadequate for comparing management practices in commercial broiler houses. A continuous dust sampling system should be used to compare concentrations among different houses. Having only two portable dust samplers made it difficult to collect sufficient samples at each farm. Farm location was also a major factor in collection of the samples. Travel time to each farm was more than one hour. This excessive travel time cut down on time that could be spent collecting samples at the farm. A particle counter, such as the one used by Van Wicklen (1994) would be better suited to compare dust levels among the houses. A counter of this nature would permit a more thorough comparison of the variations of dust levels between days and production cycles. Variations due to interior and exterior environments could be coupled with the data for comparison.

Ammonia, carbon monoxide, and oxygen levels could be controlled using a ventilation system equipped to monitor and adjust the rate of air exchange. Evidence from this study (Figures 4, 5, 6, 7) revealed an increase in ammonia levels during the warm periods of the day. Using an appropriate system, ventilation rates could be increased during the warmer periods to remove the abundant ammonia.

Satisfying objective two was more difficult than expected. No one management style, natural or mechanical, prevailed for the control of toxic gases. Mechanical ventilation was expected to be superior in the removal of unwanted constituents and was not found to be because of the events that occurred. Minor adjustments to the environmental management systems could be made to all of the houses examined to improve interior conditions. Propane burners could be calibrated more often to reduce production of carbon monoxide. Routine maintenance may have avoided the flood observed at Farm B2, that lead to the extremely high concentrations of ammonia. High levels of ammonia at Farm B2, however, did not affect the growth of the birds. The flock had the best feed efficiency among all farms at the processed during that week for the particular integrator. Examination of results such as these made it difficult to pinpoint detrimental environmental conditions.

3. Conclusions

- The farm manager, not the ventilation system, had the largest role in maintaining the quality of air inside the poultry house.
- Electrochemical gas sensors work well for research, but they would not be acceptable in the development of a toxic gas control system, due to the high cost and short lifespan.

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APPENDICES

APPENDIX A

Table A-1. Gas level values recorded at Farm A

Farm A Natural Ventilation

Week 1	10-10-17-1994			
Gas	Max	Min	Avg	Med
CO	30.0	0.0	2.5	2.0
O2		Malfunction		
NH3	21.6	0.0	12.6	15.1
H2S	1.2	0.4	0.9	0.9

Week 2	10-17-24-1994			
	Max	Min	Avg	Med
CO	6.5	0.0	1.2	0.5
O2		Malfunction		
NH3	28.6	0.0	14.2	16.2
H2S	1.1	1.0	0.3	1.3

Week 3	10-24-31-1994			
	Max	Min	Avg	Med
CO	1.7	0.0	0.3	0.0
O2		Malfunction		
NH3	28.6	0.0	13.3	14.8
H2S	1.5	0.4	0.9	1.0

Week 4	10-31-11-7-1994			
	Max	Min	Avg	Med
CO	0.5	0.0	0.0	0.0
O2		Malfunction		
NH3	30.0	0.0	10.2	8.8
H2S	1.2	0.3	0.7	0.6

Week 5	11-7-14-1994			
	Max	Min	Avg	Med
CO	0.9	0.0	0.0	0.0
O2		Malfunction		
NH3	21.1	0.0	8.8	9.9
H2S	1.0	0.3	0.6	0.6

Week 6	11-14-21-1994			
	Max	Min	Avg	Med
CO	0.1	0.0	0.0	0.0
O2		Malfunction		
NH3	20.9	0.0	7.0	6.4
H2S	0.7	0.2	0.4	0.4

Note: Concentration of O_2 is percent, all others are parts per million.

Table A-2. Mean weekly temperatures and relative humidity for Farm A.

	Inside		Outside	
Week	Mean Temp (°C)	Mean % rh	Mean Temp (°C)	Mean % rh
1	29	65	16	79
2	30	74	19	89
3	29	69	14	82
4	29	65	15	78
5	28	63	14	73
6	26	61	15	78

Table A-3. Gas level values recorded at Farm B.

Farm B Mechanical Ventilation

Week 1	1-4-8-1995			
	Max	Min	Avg	Med
CO	28.0	1.5	11.6	11.4
O2	20.4	19.3	19.8	19.9
NH3	26.8	11.3	18.8	18.6
H2S	Malfunction			

Week 2	1-9-15-1995			
	Max	Min	Avg	Med
CO	18.0	0.0	3.0	1.9
O2	20.4	19.1	19.6	19.7
NH3	26.1	4.8	16.7	16.7
H2S	Malfunction			

Week 3	1-16-22-1995			
	Max	Min	Avg	Med
CO	2.1	0.0	0.8	0.7
O2	19.8	19.2	19.5	19.5
NH3	17.2	2.9	9.0	8.9
H2S	Malfunction			

Week 4	1-23-29-1995			
	Max	Min	Avg	Med
CO	1.9	0.0	0.4	0.2
O2	20.0	18.6	19.4	19.7
NH3	17.2	0.0	6.6	6.4
H2S	Malfunction			

Note: Concentration of O_2 is percent, all others are parts per million.

Table A-4. Mean weekly temperatures and relative humidity for Farm B.

	Inside		Outside	
Week	Mean Temp (°C)	Mean % rh	Mean Temp (°C)	Mean % rh
1	27	70	2	79
2	27	79	15	90
3	24	75	9	89
4	22	74	7	85

Table A-5. Gas level values recorded during a second production cycle at Farm B.

Farm B Mechanical Ventilation

Week 1	2-18-23-1995			
	Max	Min	Avg	Med
CO	28.4	1.4	19.2	21.0
O2	21.1	19.8	20.1	20.1
NH3	55.7	12.5	36.2	36.3
H2S	Malfunction			

Week 2	3-2-1995			
	Max	Min	Avg	Med
CO	25.2	1.8	9.3	20.1
O2	20.6	20.1	20.3	20.3
NH3	46.5	16.1	29.2	16.1
H2S	Malfunction			

Note: Concentration of O_2 is percent, all others are parts per million.

Table A-6. Mean weekly temperatures and relative humidity for Farm B.

	Inside		Outside	
Week	Mean Temp (°C)	Mean % rh	Mean Temp (°C)	Mean % rh
1	29	53	11	77
2	20	68	20	77

Table A-7. Gas level values recorded at Farm C.

Farm C Mechanical Ventilation

Week 1	7-6-13-1995			
	Max	Min	Avg	Med
CO	20.9	0.0	3.8	0.7
02	21.3	19.6	20.4	20.5
NH3	21.9	0.0	6.6	6.5
H2S	Malfunction			

Week 2	7-13-21-1995			
	Max	Min	Avg	Med
CO	0.8	0.0	0.0	0.0
02	20.6	18.2	19.2	19.0
NH3	15.1	0.0	2.5	0.0
H2S	Malfunction			

Week 3	7-21-26-1995			
	Max	Min	Avg	Med
CO	0.0	0.0	0.0	0.0
02	20.6	18.3	19.0	18.9
NH3	6.5	0.0	0.9	0.0
H2S	Malfunction			

Week 4	7-26-8-3-1995			
	Max	Min	Avg	Med
CO	0.0	0.0	0.0	0.0
02	21.1	18.8	19.8	19.6
NH3	6.9	0.0	0.9	0.0
H2S	Malfunction			

Note: Concentration of O_2 is percent, all others are parts per million.

Table A-8. Mean weekly temperatures and relative humidity for Farm C.

	Inside		Outside	
Week	Mean Temp (°C)	Mean % rh	Mean Temp (°C)	Mean % rh
1	32	67	30	82
2	32	69	31	79
3	31	78	31	85
4	31	78	32	83

Table A-9. Gas level values recorded at Farm D.

Farm D Natural Ventilation

Week 1 11-30-12-5-1995	Max	Min	Avg	Med
CO	16.3	1.6	10.6	11.8
O2	20.0	18.6	19.5	19.7
NH3	23.5	0.0	11.9	10.8
H2S	0.5	0.2	0.4	0.4

Week 2 12-5-13-1995	Max	Min	Avg	Med
CO	16.5	5.0	12.5	13.2
O2	20.0	18.9	19.4	19.4
NH3	51.7	6.4	24.2	22.5
H2S	0.6	0.3	0.5	0.4

Week 3 12-13-20-1995	Max	Min	Avg	Med
CO	12.7	0.8	4.4	3.7
O2	19.9	18.6	19.4	19.4
NH3	57.8	15.9	32.2	30.7
H2S	0.5	0.1	0.3	0.2

Week 4 12-20-27-1995	Max	Min	Avg	Med
CO	8.9	2.0	4.5	4.3
O2	19.5	18.0	18.7	18.7
NH3	62.3	25.1	47.4	48.9
H2S	0.5	0.2	0.3	0.3

Note: Concentration of O_2 is percent, all others are parts per million.

Table A-10. Mean weekly temperatures and relative humidity for Farm D.

	Inside		Outside	
Week	Mean Temp (°C)	Mean % rh	Mean Temp (°C)	Mean % rh
1	29	52	10	76
2	29	73	1	70
3	30	74	12	86
4	29	86	-1	75

Appendix B

Table B-1. Statistical results for oxygen.

Oxygen

Variable	Term	F-Value	Pr>F
Max	Vent	28.52	0.0059
	Farm(Vent)	12.07	0.0202
	Week	1.96	0.2616
	Week*Vent	1.66	0.3110
Min	Vent	4.62	0.0981
	Farm(Vent)	2.57	0.1918
	Week	0.71	0.5934
	Week*Vent	0.41	0.7573
Avg	Vent	3.32	0.1424
	Farm(Vent)	0.64	0.5730
	Week	0.86	0.5292
	Week*Vent	0.67	0.6128
Med	Vent	2.55	0.1856
	Farm(Vent)	0.72	0.5416
	Week	1.04	0.4665
	Week*Vent	0.68	0.6108

Table B-2. Statistical results for ammonia.

Ammonia

Variable	Term	F-Value	Pr>F
Max	Vent	11.70	0.0111
	Farm(Vent)	16.94	0.0014
	Week	0.70	0.6440
	Week*Vent	6.90	0.0169
Min	Vent	0.00	0.9702
	Farm(Vent)	4.74	0.0414
	Week	0.22	0.9419
	Week*Vent	1.73	0.2471
Avg	Vent	2.27	0.1754
	Farm(Vent)	7.66	0.0130
	Week	0.20	0.9546
	Week*Vent	2.19	0.1770
Med	Vent	3.15	0.1191
	Farm(Vent)	3.55	0.0759
	Week	0.16	0.9701
	Week*Vent	1.59	0.2763

Table B-3. Statistical results for hydrogen sulfide.

Hydrogen Sulfide

Variable	Term	F-Value	Pr>F
Max	Vent	151.65	0.0012
	Farm(Vent)	69.27	0.0036
	Week	4.17	0.1348
	Week*Vent	0.23	0.8699
Min	Vent	8.07	0.0656
	Farm(Vent)	5.91	0.0932
	Week	0.96	0.5511
	Week*Vent	0.71	0.6066
Avg	Vent	13.48	0.0350
	Farm(Vent)	4.45	0.1254
	Week	0.35	0.8559
	Week*Vent	0.13	0.9340
Med	Vent	29.09	0.0125
	Farm(Vent)	20.18	0.0206
	Week	1.99	0.3031
	Week*Vent	0.51	0.7043

Table B-4. Statistical results for carbon monoxide.

Carbon Monoxide

Variable	Term	F-Value	Pr>F
Max	Vent	0.03	0.8622
	Farm(Vent)	1.84	0.2287
	Week	4.94	0.0296
	Week*Vent	0.16	0.9181
Min	Vent	1.44	0.2696
	Farm(Vent)	5.03	0.0362
	Week	0.66	0.6626
	Week*Vent	1.12	0.4027
Avg	Vent	0.94	0.3637
	Farm(Vent)	14.18	0.0023
	Week	3.82	0.0548
	Week*Vent	2.11	0.1869
Med	Vent	3.78	0.0930
	Farm(Vent)	17.21	0.0013
	Week	1.48	0.3070
	Week*Vent	0.36	0.7864

APPENDIX C

Appendix C. Datalogger program.

```
Program:
Flag Usage:
Input Channel Usage:
Excitation Channel Usage:
Continuous Analog Output Usage:
Control Port Usage:
Pulse Input Channel Usage:
Output Array Definitions:

*   1      Table 1 Programs
 01: 60     Sec. Execution Interval

01:  P10    Battery Voltage
 01: 1      Loc [:BATT V   ]

02:  P17    Panel Temperature
 01: 2      Loc [:PANEL T  ]

03:  P1     Volt (SE)
 01: 4      Reps
 02: 5      5000 mV slow Range
 03: 1      IN Chan
 04: 3      Loc [:SIGNAL #1]
 05: 1      Mult
 06: 0.0000 Offset

04:  P11    Temp 107 Probe
 01: 2      Reps
 02: 7      IN Chan
 03: 2      Excite all reps w/EXchan 2
 04: 7      Loc [:ProbeT #1]
 05: 1      Mult
 06: 0.0000 Offset

05:  P12    RH 207 Probe
 01: 2      Reps
 02: 9      IN Chan
 03: 2      Excite all reps w/EXchan 2
 04: 7      Temperature Loc ProbeT #1
 05: 9      Loc [:ProbRH #1]
 06: 1      Mult
 07: 0.0000 Offset

06:  P2     Volt (DIFF)
 01: 1      Rep
 02: 2      15 mV slow Range
 03: 8      IN Chan
 04: 11     Loc [:Pyronomet]
 05: .09434 Mult
 06: 0.0000 Offset

07:  P86    Do
 01: 41     Set high Port 1

Page 2  Table 1

08:  P87    Beginning of Loop
 01: 0000   Delay
 02: 10     Loop Count

09:  P86    Do
 01: 72     Pulse Port 2

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

11:  P14    Thermocouple Temp (DIFF)
 01: 1      Rep
 02: 1      5 mV slow Range
 03: 3      IN Chan
 04: 1      Type T (Copper-Constantan)
 05: 2      Ref Temp Loc PANEL T
 06: 12--   Loc [:TC #1    ]
 07: 1      Mult
 08: 0.0000 Offset

12:  P95    End

13:  P20    Set Port
 01: 0      Set low
 02: 1      Port Number

14:  P92    If time is
 01: 0000   minutes into a
 02: 30     minute interval
 03: 10     Set high Flag 0 (output)

15:  P77    Real Time
 01: 0110   Day,Hour-Minute

16:  P71    Average
 01: 20     Reps
 02: 1      Loc BATT V

17:  P      End Table 1
```

Appendix C. Datalogger program continued.

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

01: P      End Table 2

*   3      Table 3 Subroutines

01: P      End Table 3

*   4      Mode 4 Output Options
 01: 00     Tape/Printer Option
 02: 00     Printer Baud Option

*   A      Mode 10 Memory Allocation
 01: 28     Input Locations
 02: 64     Intermediate Locations

*   C      Mode 12 Security (OSX-0)
 01: 00     Security Option
 02: 0000   Security Code

 Input Location Assignments (with comments):


Key:
T=Table Number
E=Entry Number
L=Location Number

T: E: L:
1: 1: 1: Loc [:BATT V  ]
1: 2: 2: Loc [:PANEL T  ]
1: 3: 3: Loc [:SIGNAL #1]
1: 4: 7: Loc [:ProbeT #1]
1: 5: 9: Loc [:ProbRH #1]
1: 6: 11: Loc [:Pyronomet]
1: 11: 12: Loc [:TC #1   ]
```

Input Location Labels:

1:BATT V	7:ProbeT #1	13:TC #2	19:TC #8
2:PANEL T	8:ProbeT #2	14:TC #3	20:TC #9
3:SIGNAL #1	9:ProbRH #1	15:TC #4	21:TC #10
4:SIGNAL #2	10:ProbRH #2	16:TC #5	22:TC #11
5:SIGNAL #3	11:Pyronomet	17:TC #6	23:TC #12
6:SIGNAL #4	12:TC #1	18:TC #7	24:________

APPENDIX D

Table D-1. Calibration equations for gas sensors.

10-4-94

Sensor	Equation
CO	ppm=-78.2585 + 0.077637 * (mV)
O_2	%=-5.8807 + 0.006477 * (mV)
NH_3	ppm=-74.8000 + 0.077273*(mV)
H_2S	ppm=-12.5355 + 0.013058 * (mV)

12-12-94

Sensor	Equation
CO	ppm=-77.9467 + 0.077689 * (mV)
O_2	%=-6.2635 + 0.006491 * (mV)
NH_3	ppm=-91.2475 + 0.077394 * (mV)
H_2S	ppm=-12.6356 + 0.013094 * (mV)

2-18-95

Sensor	Equation
CO	ppm=-65.7344 + 0.065538 * (mV)
O_2	%=-6.2524 + 0.006493 * (mV)
NH_3	ppm=-76.3853 + 0.078667 * (mV)
H_2S	Malfunction

7-6-95

Sensor	Equation
CO	ppm=-78.2582 + 0.077869 * (mV)
O_2	%=-6.4039 + 0.006595 * (mV)
NH_3	ppm=-75.6002 + 0.078180 * (mV)
H_2S	Malfunction

11-29-95

Sensor	Equation
CO	ppm=-77.8216 + 0.077666 *(mV)
O_2	%=-6.3057 + 0.006501 * (mV)
NH_3	ppm=-76.1703 + 0.078284 * (mV)
H_2S	ppm=-12.7656 + 0.013174 * (mV)

APPENDIX E

Appendix E. Statistical analysis program.

```
data one;
options ls=72 ps=55;
infile 'c:\stats.txt';
input farm $ week vent $ gas $ max min avg med;
proc sort; by gas;
proc glm; by gas;
        class farm week vent;
        model max min avg med = vent farm(vent) week week * vent;
        means vent farm(vent) week week*vent
        output out = rrr r = rmax rmin ravg rmed;
run;
proc univariate plot normal;
var rmax rmin ravg rmed;
run;
```

APPENDIX F

Table F-1. Concentrations of calibration gases.

Calibration Gases		
Gas Mix	Suggested Concentration	Actual Concentration
NH_3 in N_2(#1)	200 ppm	187 ppm
NH_3 in N_2(#2)	200 ppm	177 ppm
CO in air	200 ppm	209 ppm
H_2S in N_2	25 ppm	23.7 ppm
N_2 UHP grade	99.999%	99.999%

Appendix G

Appendix G. Table of dust sampling results.

Farm	Date	Flow Rate (L/min)	Time (min)	Start WT (grams)	End WT (grams)	Total Air (Liters)	Concentration (mg/L)
A	02/22/94	1.62	75	0.0378	0.0381	121.50	0.0025
A	02/22/94	1.63	74	0.0405	0.0407	120.62	0.0017
A	02/22/94	1.67	33	0.0377	0.0377	55.11	0.0000
A	11/18/94	1.68	66	0.0162	0.0165	110.88	0.0027
A	11/18/94	1.74	69	0.0159	0.0163	120.06	0.0033
B	01/09/95	1.75	50	0.0162	0.0166	87.50	0.0046
B	01/09/95	1.67	50	0.0161	0.0164	83.50	0.0036
B	02/23/95	1.73	60	0.0165	0.0168	103.80	0.0029
B	02/23/95	1.65	60	0.0162	0.0167	99.00	0.0051
B	03/02/95	1.75	60	0.0163	0.0166	105.00	0.0029
B	03/02/95	1.68	60	0.0162	0.0164	100.80	0.0020
B	03/18/95	1.74	63	0.0163	0.0163	109.62	0.0000
B	03/18/95	1.67	62	0.0147	0.0148	103.54	0.0010
C	07/21/95	1.72	63	0.0153	0.0154	108.36	0.0009
C	07/21/95	1.62	63	0.0146	0.0147	102.06	0.0010
D	12/15/95	1.71	61	0.0150	0.0156	104.31	0.0058
D	12/15/95	1.63	62	0.0150	0.0153	101.06	0.0030
D	12/20/95	1.72	61	0.0147	0.0155	104.92	0.0076
D	12/20/95	1.64	61	0.0152	0.0158	100.04	0.0060

Vita

Scott D. Snyder was born in Malone, New York on November 15, 1971. Scott attended elementary school in Titusville, Florida, and high school at Hiwassee Dam High School in Murphy, North Carolina. He graduated from high school in 1989.

Upon entering the University of Tennessee in the fall of 1989, he pursued a degree in Agriculture with a major in Animal Science. Scott graduated with a Bachelor of Science degree in Agriculture in December 1993. During his undergraduate career he was active in many campus activities such as: FarmHouse Fraternity, Poultry Club, and Alpha Zeta.

Scott began his graduate career immediately at the University of Tennessee, in the Department of Agricultural Engineering. During his assistantship he became a member of Gamma Sigma Delta National Honor Society. Scott completed his Master of Science Degree in Agriculture, with a major in Agricultural Engineering Technology, in May of 1996. He is currently employed with John Deere Company.

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MJ