RESEARCH REPORT
ENVIRONMENT

Title: Evaluation of Boric Acid and Sodium Tetraborate to Reduce Ammonia and Hydrogen Sulfide Emissions from Swine Facilities – **NPB #05-112**

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Industry Summary

Hazardous gas emissions from stored livestock manure can pose environmental and health issues for both farm workers and animals. Ammonia and hydrogen sulfide emissions have risen sharply with more intensive livestock production and are especially being targeted as gases of concern. Numerous management strategies, technologies and chemicals have been tried to reduce the production of these gases. However, nothing really seems to work well, or they are either too toxic to animals, not cost effective, or not environmentally sustainable. Borates have long been used in a number of commercial products for cleaning and controlling odors. With support from NPB, previous studies in our laboratory showed that boric acid and borax are highly effective in inhibiting both ammonia and hydrogen sulfide emissions from stored swine manure slurry. The objective of this continuing research project was to test the efficacy of boron (20 Mule Team Borax) in reducing ammonia and hydrogen sulfide emissions in a normal operating swine facility. Shallow, pull plug manure storage pits beneath nursery rooms at the Michigan State University Swine Teaching and Research Facility were treated with borax powder, and the air quality in the rooms were monitored for ammonia and hydrogen sulfide emissions over 4-5 weeks. There was a significant reduction in hydrogen sulfide emissions, amounting to about 80% of the control with borax treatment. This is the first demonstration that boron can suppress hydrogen sulfide production. In contrast, ammonia emissions from the shallow manure pits treated with borax were not different from the control, so the inhibition of ammonia by borax in the laboratory was not confirmed. Further studies are being planned to investigate this difference in response. This research was supported by the National Pork Checkoff.

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Scientific Abstract

Borates have long been used in a number of commercial products for cleaning and controlling odors. However, they have not been examined for controlling hazardous gas emissions from stored livestock manure. The objective of this study, based on previous laboratory in vitro incubation studies, was to test the efficacy of boron (20 Mule Team Borax) in reducing ammonia and hydrogen sulfide emissions from stored manure in an operational swine facility. Shallow, pull plug manure storage pits beneath nursery rooms at the Michigan State University Swine Research and Teaching Facility were treated with borax powder or left untreated as control, and the air quality in the rooms were continuously monitored for ammonia and hydrogen sulfide concentrations using a continous emissions 1314 photoacoustic multi-gas monitor (CEM) and Jerome hydrogen sulfide detector with data logger. Manure pits were treated weekly with a quarter of the borax dose needed to attain a 1 and 2% final treatment based on the anticipated volume of manure accumulating in 4 weeks. Data on pig numbers, estimated pig weights and pit depth measurements were collected weekly. Issues with ventilation differences, pig numbers and weights, manure accumulation rates, and other variables associated with normal operations of the facility were encountered. Based on a comparison of the hydrogen sulfide concentrations in the treated and control nursery rooms, borax treatment significantly decreased hydrogen sulfide emissions from stored swine manure. Hydrogen sulfide concentrations measured at the time the pull plugs were opened and the stored manure drained from the manure pits, indicate that this inhibition was about 80%. Measurements of ammonia concentrations in the treated and control nursery rooms, indicated that borax treatment did not inhibit ammonia emissions from the store manure. These results confirm our laboratory in vitro studies for the inhibition of hydrogen sulfide, but not for the inhibition of ammonia by borax. Further studies are being planned to explain this difference in response.

Introduction

Production of toxic gases (i.e. ammonia, hydrogen sulfide, nitrous oxide, carbon monoxide and carbon dioxide) can pose a serious health risk for farm workers and animals. The presence of these hazardous gases in livestock facilities is well documented and their concentrations have been increasing sharply with more intensive livestock production (**Chang et al., 2001**). Federal agencies (**OSHA, NIOSH, and EPA**) have set occupational exposure limits in the workplace for these toxic gases. The EPA has received approval to have animal feeding operations (**AFOs**) voluntarily monitored for air emissions and to ensure compliance with environmental air laws. Some states, such as Minnesota, already have air quality standards for livestock facilities.

The NPB has identified technological and biological means of improving air quality and reducing ammonia and hydrogen sulfide emissions from stored swine manure in swine facilities as a major environmental issue of the industry which needs to be addressed. Although there are a number of effective chemical treatments to control ammonia and hydrogen sulfide emissions from stored swine manure, many of these treatments are either too toxic to animals, not very cost effective, or not environmentally friendly for sustained use (**Singh et al., 2005)**. Nothing really seems to work particularly well. Panetta et al. (**2005**) concluded that prevention of ammonia release is a key intervention point for management strategies, since substantial ammonia emissions occur during storage of manure (**Lorimor et al., 2000)**. The problem is complex in that ammonia is released very rapidly (i.e. hours), once urine is excreted by the animal, while hydrogen sulfide production takes a considerably longer (i.e. days) time to occur until anaerobic conditions are established in the stored manure. Given this timeframe, identifying a chemical that can inhibit both ammonia and hydrogen sulfide simultaneously is a formidable task.

Literature Review

Borates have been used in a wide variety of commercial products such as laundry detergent, bleaches, makeup, preservatives, dispersal and buffer agent in industry, and for the production of ultra thin LCD

screens, heat resistant glass and fiberglass, flame retardants, wood preservative, and fertilizer for optimum plant growth. The laundry detergent (20 Mule Team Borax) has been marketed since 1891.

Boric acid and borax have also been used for many years as an insecticide, herbicide and bacteriocide, but are virtually non-toxic to humans, birds, fish, aquatic invertebrates and relatively non-toxic to beneficial insects (**Boron. Mineral Tolerances of Animals**, **2005**). Boric acid is the oldest continually registered pesticide in the U.S. The **LD_{50}** of boron toxicity is in the range of table salt and it is non-carcinogenic (**Chemical Watch Factsheet**, **2003)**. The EPA has issued a general exemption for tolerance (i.e. acceptable residues) of boric acid in raw agricultural commodities, but does set a limit in foods and additives. Boron is an essential micronutrient for plants and is routinely added to fertilizers for optimum plant growth. Certain areas of the U.S. are deficient in boron in the soil (**Kelling, 1999**). Boron is a known competitive inhibitor of bacterial urease by interfering with the Ni 2+ catalytic site of the enzyme (**Breitenbach and Hausinger, 1988**). Boron is also a potent inhibitor of hydrogenase, a key bacterial enzyme involved in electron transfer from hydrogen gas (**Hausinger, 1987**). Boric acid is the major ingredient for controlling urea hydrolysis and ammonia production from excreted urine in commercial cat litter. Use of boric acid is recommended for providing an odor free environment for laboratory animals (**NRC Guideline for Care and Use of Laboratory Animals, 1985).**

Boron is nutritional important for animals, enhancing bone growth, facilitating calcium absorption and brain function. Boron has not been established as an essential nutrient for humans, since no specific biochemical function has been identified. However, there is strong evidence that it is essential. Food and water are the primary sources of boron ingested by humans (**Parks and Edwards, 2005**). Boron (boric acid and borax) have not been extensively studied for use in controlling ammonia and hydrogen sulfide emissions from stored swine manure slurry.

Previous Research

Supported by NPB **(#04-147**), we demonstrated in laboratory studies that boric acid and sodium tetraborate decahydrate (borax) are highly effective in inhibting the production of ammonia and hydrogen sulfide by anaerobic bacteria in stored swine manure. Depending on the dose, addition of boric acid to swine manure slurry delayed the hydrolyis of urea to ammonia by **48-144** hours (i.e. **2-6** days) in comparison to control incubations. Addition of **1%** boric acid resulted in virtually complete inhibition (>**95%** of control) of ammonia release from urea for up to **7** days. Similarly, depending on the dose, addition of sodium tetraborate decahydrate (20 Mule Team Borax) resulted in a delay of **24-120** hours (i.e. **1-4** days). Addition of **1%** borax resulted in almost complete inhibition (>**94%** of control) of ammonia release from urea for up to 7 days of incubation. The timing of the borate treatment in these incubations is crucial as only fresh swine manure slurry will show a response, as ammonia release from the urea contained in urine occurs very rapidly once excreted by the pig and acted upon by ureolytic bacteria in the environment.

In contrast to ammonia production, hydrogen sulfide production is not detectable for several days in swine manure slurry until anaerobic conditions are well established and there is hydrogen gas available from the fermentation. We found that boric acid and borax were also effective in inhibiting hydrogen sulfide emissions in swine manure slurry. H_2S emissions in untreated nursery manure slurry peaked at **100** ppm after **96** hrs of incubation. In contrast, addition of **1%** boric acid almost completely inhibited (**99.93%**) H_2S emissions for up to **7** days of incubation. Addition of borax also inhibited H_2S emissions. Hydrogen sulfide emissions peaked at **140** ppm in untreated nursery manure slurry after **96** hours of incubation. In contrast, addition of **1%** borax inhibited H_2S emissions by **99.96**% (i.e. **0.06** ppm) after **96** hours of incubation, and concentrations remained low for up to **7** days.

During these studies, we detected a significant improvement in the odor of the treated incubations in comparison to the pungent, ammoniacal odor of the control incubations. We also observed that mold growth was significantly inhibited on the surface of the boric acid and borax treated nursery manure slurry incubations, the practical significant of which is still unclear. We also observed a decrease in the numbers of E.coli in the nursery manure slurry with boric acid and borax treatment. Borates are know to have fungicidal and bacteriocidal properties.

Objectives

Based on the encouraging results of our laboratory studies, during the second year of this project, we proposed the following objectives:

a. **To evaluate the effectiveness of boric acid (and sodium tetraborate) in reducing ammonia and hydrogen sulfide emissions in an operating facility with a sloped floor with scraper, liquid-solid separation system and a pull plug system.**

b. **To determine the usage cost of boric acid (and sodium tetraborate) on the results of this study.**

Because it appeared that boric acid and borax were about equal in their response on the basis of their boron content, we decide to focus only on the use of borax in this study. Borax is also much cheaper than boric acid, more readily available to farmers, and has better solubility properties in water than boric acid. Preliminary studies indicated that the sloped floor with scraper, liquid-solid separation system did not generate enough ammonia and hydrogen sulfide to serve as a viable site for testing the borax treatment, so we focused on the shallow manure storage pits of the nursery rooms at MSU.

Materials and Methods

Facility. All of the studies were conducted at the Michigan State University Swine Research and Teaching Facility. This is an environmentally controlled, total confinement, shower in and shower out facility located about two miles from the main campus of MSU. All normal operations were conducted during the experiments. Two adjacent nursery rooms in the facility were used for the research, with one room treated with borax and the other serving as the control (**Photo 1**). The treatment and control rooms were switched for each experiment conducted. There were three manure holding pits with pull plug systems beneath each nursery room. Two pits were **44** ft long x **44** inches wide x **2** ft deep on either side of the room with a third pit that was **40** ft x **88** inches wide x **2** ft deep in the middle of the room. The pits had a slight slope toward both ends where the pull plugs were located.

Pigs. An attempt was made by the swine farm manager to keep the numbers and sizes of pigs about equal in both rooms throughout the study, so that the volume of manure accumulating in the pits was about equal throughout the experimental period. Pigs were fed their standard starter diet with some antibiotic supplementation.

Treatment. Sodium tetraborate decahydrate (20 Mule Team Borax) was purchased from a local grocery store at **$3.79** for a box containing **4.73** lbs (i.e. **2.15 kg**) (**Photo 2**). We obtained a small discount by buying by the case. The amount of borax added to each pit was calculated based on an estimate of the manure volume accumulating in the pit over **4** weeks, which is about the maximum amount of time that pigs were kept in the nursery rooms. The pits were initially flushed out with water, and the borax powder was sprinkled through the slatted flooring directly into the manure pit (**Photo 3**). The pull plugs were not opened for the entire treatment period. The borax was applied at weekly intervals by hand sprinkling to provide a quarter of the amount needed to attain a final treatment dose of either **1%** or **2%** after **4** weeks.

Collection of Data. Pig numbers and their estimated weights data was collected weekly in the treated and control nursery rooms. The depth of the accumulated manure was measured at three points, at both ends and the middle of each pit using an aluminum yardstick. Pit volume was calculated by the formula **V = l x a x (b + c)/2).** At the termination of the experiment, the pull plugs of the three manure pit in each room were sequentially opened and the stored manure allowed to drain out of the pits. During this period, the air quality of the room was continuously monitored by the CEM and the Jerome hydrogen sulfide detector (**Photo 4**). Since we were monitoring air quality in an operational swine facility, factors influencing the variability of the data (e.g. ventilation, open doors, automatic feeding, workers in the facility, movement of pigs in and out of rooms, dust, etc) were not easily controlled. To correct for some of this day to day variation, we normalized the air quality data on the basis of CO_2 concentration, pig numbers and weights. Since pig numbers and weights were also difficult to control, we felt that standardizing on the basis of CO_2 concentration would give us the most reliable air quality data (**Ni et al., 1999**).

Monitoring of Ammonia and Hydrogen Sulfide. Ammonia, methane, carbon dioxide, carbon monoxide and water were monitored continuously every **10** minutes using a Continuous Emission **1314** Photoacoustic Multi-Gas Monitor (CEM) with computer software program (Innova Air Technology Instruments, California Analytical Instruments) (**Photo 5**). Hydrogen sulfide was monitored every **15** minutes using a portable Jerome hydrogen sulfide detector (Model **631-X,** Arizona Instruments) with a data logger (**Photo 6**). The Jerome hydrogen sulfide detector has a detection range of **0.003-50** ppm. The portable Jerome was moved between rooms at intervals, and the CEM was switched between rooms by flipping the air sampling switches between rooms. When the pull plugs were opened at the end of each experiment and the stored manure emptied from the pits, the Jerome was manually operated with sampling every **2** minutes for the detection of hydrogen sulfide emissions.

Results

Inhibition of Hydrogen Sulfide by Borax

Borax treatment was effective in inhibiting hydrogen sulfide production and emissions from swine manure stored beneath nursery rooms, which confirms our laboratory in vitro incubation data.

Graph (3/9/07-3/13/07) shows the H_2S/CO_2 concentration ratio curves for the borax treated and untreated control nursery rooms in **Expt. 2.** The H_2S/CO_2 graph shows the H_2S/CO_2 and the CO_2 concentrations in the treatment room (**3/9/07-3/12/07**) and control room (**3/12/07-3/13/07**). The paired t-test of treatment means shows that the control room had significantly higher H_2S/CO_2 concentrations than the treatment room (**3.91E-05 vs 2.45E-05).** Although not statistically significant, H_2S/ lbs of pig was also higher for the control room over the treatment room (**1.44E-05 vs 1.39E-05**).

Graph (3/26/07-9/0/07) shows the H_2S / CO_2 concentration ratio curves for the borax treated and untreated control nursery rooms in **Expt. 3.** The graph shows the H_2S/CO_2 and CO_2 concentrations in the treatment room (**3/26/07-3/28/07**), (**3/30/07-4/1/07**), (**4/5/07**) and (**4/9/07**) and control room (**3/28/07-3/30/07**), (**4/1/07-4/5/07**), (**4/5/07-4/9/07**). Paired t-test comparison of treatment means showed that the control room had higher hydrogen sulfide concentrations than the treatment room (**0.1489 vs 0.1032** ppm) . When the data was normalized for CO_2 concentraton, the H_2S/CO_2 ratio was higher for the control room over the treatment room (**9.08E-03 vs 6.05E-03**).

Graph (4/9/07-4/17/07) shows the H_2S /CO_2 concentration ratio curves for the borax treated and untreated control nursery rooms at the end of **Expt. 3** after the last borax treatment (**4/6/07**). H_2S concentration in the control and borax treated rooms were not different (**0.0226 vs 0.0224**). H_2S /CO_2

concentration was higher in the control than the treated room (**1.12E-05 vs 8.12E-06**) but the paired t-test comparison of treatment means was not statistically significant. H_2S / lb of pig was higher for the control over the treated room (**2.66E-06 vs 2.22E-06**), but also not statistically significant.

The effectiveness of borax treatment in inhibiting H_2S production was most evident at the time that the pull plugs were opened and the pits drained of the stored manure after **4-5** weeks. Graphs **Experiment 2 Plug Pulls** and **Experiment 3, Plug Pulls** shows the H_2S concentration in the borax treated and control nursery rooms monitored at two minute intervals, when the pull plugs were opened and the four pits drained of the stored manure at the end of the experiment. In **Expt 2,** the hydrogen sulfide concentration curve increased sharply in the untreated control room within **10** minutes of pulling the plugs, and peaked at close to **6** ppm within **15** minutes, and remained elevated, with a gradual decline in concentration out to **60** minutes. The odor of hydrogen sulfide was very noticeable in the room during this period. In contrast, the hydrogen sulfide concentration curve in the borax treated room showed considerably smaller peaks, which barely exceeded **1** ppm at only **5** and **10** minutes, and gradually declined in concentration to background level to **60** minutes. During this period of time the exhaust fans in the rooms were in operation, which may account for some of the fluctuations in the concentration curves. In **Expt. 3,** hydrogen sulfide concentrations were not as high as in **Expt. 2.** However, the hydrogen sulfide concentration curve sharply increased within **7** minutes of pulling the plugs to about **1.6** ppm in the untreated control room, followed by a sharp decline, and a second peak of about **1.3** ppm at **21** minutes. In the borax treated room, hydrogen sulfide concentration peaked at **14** minutes at a concentration close to **1** ppm, and then slowly declined out to **60** minutes.

Using the highest peak concentration of H_2S detected in the treatment and control rooms during the period that the pull plugs were opened and the pits drained, it was calculated that borax inhibited H_2S production in the stored manure by about 81-83 %.

Inhibition of Ammonia by Borax

Borax treatment did not appear to inhibit ammonia production and emissions from stored swine manure beneath nursery rooms, so we could not confirm the results of our vitro incubation data.

Graph (3/9/07-3/12/07) shows the Ammonia/CO_2 concentration and Methane/CO_2 concentration of the treatment room (**3/9/07-3/12/07**) and the control room (**3/12/07**) during **Expt 2.** Paired t-test comparisons of treatment means indicates that the control room had a higher ammonia concentration than the treated room (**3.52 vs 2.79 ppm**), which was significantly different. However. when the data was normalized to the CO_2 concentrations (Am/CO_2 ratio), the control room had a lower ammonia concentration in comparison to the treated room. The difference was that the CO_2 concentration was higher in the treatment room than the control room (**2016 vs 1679 ppm**). Am/CO_2 (lower), M/CO_2 (higher) , and H_2S/CO_2 (higher) were all significant for the untreated control room over the treated room. Total pig weight was also significantly higher for the control room (**4510 vs. 3535**). Ammonia/ lbs of pigs and H_2S/lbs of pigs were not significantly different between the treatment and control rooms.

Graph (3/26/07-4/9/07) shows the Ammonia/ CO_2 concentration and Methane/CO_2 concentration of the treatment and control room during **Expt. 3.** Paired t-test comparisons of treatment means indicates that the treatment room had significantly higher ammonia concentrations than the control room (**4.43 vs 3.37 ppm**) and the control rooms had significantly higher carbon monoxide (**3.75 vs 1.91 ppm**) When the data was normalized to the CO_2 concentration (Am/CO_2 ratio), the treatment room was significantly higher in ammonia concentration than the control room (**2.11E-03 vs 1.67E-03**),. Total lbs of pig was significantly higher for the control room **(8408 vs 8248**). Ammonia / lb of pig higher for the treatment room and H_2S/lb of pig was higher for the control room.

Graph (**4/9/07-4/17/07**) shows the Ammonia/CO_2 and Methane/CO_2 concentration of the treatment and control rooms at the end of **Expt. 3.**
Paired t-test comparisons of treatment means indicate that ammonia concentration was higher for the treated room than the control room (**4.75 vs 3.75 ppm**). Methane was higher in the treated room than the control room (**16.63 vs 15.80 ppm**), but it was not statistically significant. Ammonia/CO_2 concentration was higher for the treated room, but not significantly (**2.19E-03 vs 2.04E-03**). Ammonia/lb of pig was the same for the treated and control rooms (**4.48E-04 vs 4.48E-04**). Total pig weight was significantly higher in the treatment room than the control room (**10749 vs 8398 lbs**), which was reflected in a significantly higher CO_2 concentration for the treated room than the control (**2243 vs 1894 ppm**).

Cost of Using Borax

Borax (20 Mule Team Borax) retails for **$3.79** per box (**4.75 lb @ $0.80/lb**), so in **Expt. 2,** in which we used **5** boxes/week to treat the pits, the cost was **$18.95**/ week or **$75.80** for **4** weeks of treatment. The average number of pigs in treatment room was **163** during this period, so the cost/pig is about **$0.46** or **$ 0.03/lb** of pig. In **Expt. 3,** we used **8** boxes/week to treat the pits, so the cost was **$30.32**/week or **$151.60** for **5** weeks of treatment. The average number of pigs in the treatment room was **196** during this period, so the cost/pig is about **$ 0.77**/pig or **$ 0.02**/lb of pig. If the borax is purchased in bulk, it probably would be considerably cheaper than its retail cost.

Discussion

Our data clearly shows that borax is effective in inhibiting H_2S production in stored swine manure. This is the first report that boron in the form of borax has the capability of suppressing hydrogen sulfide production in stored livestock manure. During the **4** weeks of **Expt. 2**, we treated the four pits in the treatment room with **5** boxes (e.g. **23.75 lbs**) of borax per week based on the volume of manure which was anticipated to be produced by the pigs in the room. This amounted to a total treatment dose of **95 lbs** of borax. During **Expt. 3,** we treated the four pits in the treatment room with **8** boxes (e.g. **38.0 lbs**) of borax per week for 5 weeks. This amounted to a total treatment dose of **190 lbs** of borax. Weekly measurements of pit depth indicated that we did not attain the volume of stored manure that we had anticipated, and consequently the amount of borax used to treat the pits was higher than the projected **1%** and **2% .** Based on the accumulated pit volumes of stored manure in **Expt 2,** we treated with an average of **1.8%** of borax, and in **Expt 3,** we treated with **3.2%** of borax. This is a much higher treatment dose than we had anticipated in using, and probably could be scaled back considerably. Based on the H_2S data collected during the period the pull plugs were opened and drained in **Expt 2** and **3**, excess amounts of borax did not seem improve the inhibition of H_2S beyond a certain dose level.

Boron may be influencing hydrogen sulfide production by inhibiting the bacterial enzyme, hydrogenase, a key Ni containing enzyme possessed by some anaerobic bacteria, which catalyzes the reversible oxidation of hydrogen gas for electron transfer. Sulfate reducing bacteria use hydrogenase to produce the electrons needed to reduce sulfate to sulfide in stored swine manure slurry. Other bacteria, such as methanogens, use hydrogenase to reduce CO_2 to CH_4, and are in competition with sulfate reducing bacteria for electrons generated from H_2 gas. So, the possibility exist that boron treatment of stored swine manure, besides reducing hydrogen sulfide, could be either stimulating or inhibiting methanogenesis, when it is use to treat stored swine manure. We are presently setting up **55** gallon barrel experiments with boric acid and a combination of boric acid and borax to test this hypothesis.

The effect of borates to inhibit ammonia release from urea is well documented in the literature and is

already being commercially exploited. Boric acid is the key ingredient in cat litter for controlling the odor of ammonia released from urine excretion. Boron (Br) works by interfering with bacterial enzymes, containing nickel (Ni) at the catalytic site of the reaction. The bacterial enzyme, urease, which is involved in ammonia hydrolysis from urea is a Ni containing enzyme. Urease is a cell bound enzyme, so the boron must come into contact and be taken up by the microbial cell to inhibit its catalytic activity.

Our data did not confirm that borax treatment inhibited ammonia production in stored swine manure. It is surprising that borax did not work very effectively in inhibiting ammonia emissions in the shallow manure pits of the nursery rooms at a concentration that was very effective in previous laboratory in vitro incubations. There were confounding issues as previously mentioned in accurately monitoring the air quality in an operating swine facility which we attempted to minimize as much as possible. These issues may have partially affected the data. Another possible issue could be the manner in which the borax was applied and frequency of application. Ammonia hydrolysis occurs very rapidly once urine is voided by the pig and the borax powder might not have been adequately distributed by hand sprinkling in the manure pit to inhibit the ureolytic bacteria from releasing the ammonia. Better mixing of the borax or more frequent application might have resulted in better results. Another possibility is that the boron was not in the proper form (i.e. acid versus salt) for the conditions (i.e. pH, solubility, ionic balance) of the stored swine manure to be taken up by the bacteria. We decide to only treat the pits with borax in this study, but our earlier studies showed that boric acid appeared to be more effective in inhibiting ammonia, while borax was more effective in inhibiting hydrogen sulfide. We attributed this difference in response to their boron content, since boric acid contains **17%** boron, while borax contains **11%** boron. However, it might be that the acid form (boric acid) is more effective than the salt form (borax) of boron in inhibiting ureolytic bacteria in stored swine manure. The demonstrated effective inhibition of hydrogen sulfide by borax would lead credence to this hypothesis (e.g. that the form of boron is important for different bacterial species). We are presently setting up **55** gallon barrel experiments to reexamine the effects of boric acid and the combination of boric acid and borax in inhibiting ammonia release from fresh swine manure.

Hand sprinkling of the powdered form of borax is labor intensive and not very uniform in getting the borax well distributed in the manure pits. Pelletizing, solubilizing or emulsifying the borates might prove to be more efficient in distributing the boron in a manure pit and might result in a better response at a lower treatment dose. In this context, the **2%** borax treatment of this study reduced H_2S production by about **80%**, and if a lower target reduction is sought (i.e. **30-50%)** than a much lower treatment dose could be used. In conjunction with the use of borax, a management strategy might also involve reducing the amount of supplemental sulfate in the diet of pigs, thus, decreasing the amount of substrate for hydrogen sulfide production by the sulfate reducing bacteria in the stored manure.

Two hypothetical risks regarding the environmental sustainability of using borax to treat stored swine manure is that of phytotoxicity when the manure is applied to the land as fertilizer or composted, and the possibility of excessive amounts accumulating in the soil. While there is concern about boron accumulating in the environment, its use to treat stored livestock manure would not be as problematic as the issues of phosphorus or zinc overload. Boron is routinely added to fertilizers as a micronutrient and plants require a certain amount of boron for optimum growth. Certain areas of the country, such as the Midwest, are boron deficient in their soils. Many factors influence the boron concentration in soils, including soil type, pH, precipitation, industrial sources, etc (**Parker and Edwards, 2005**). Crops vary in their need for boron and the range between essentiality and toxicity is narrow. For agronomic crops, such as corn, wheat, oats, soybeans, alfalfa and grasses, high levels of boron is usually not a problem. There are certain crops (e.g. Indian mustard, tall fescue, birds foot trefoil, kenaf and poplar trees) which are efficient in removing soil boron (**Robinson et al., 2003**). There are water treatment processes which can remove boron from water (**Parks and Edwards, 2005**). An environmental impact

assessment should be made to evaluate the effect of boron in treating livestock manure and appropriate management options identified.

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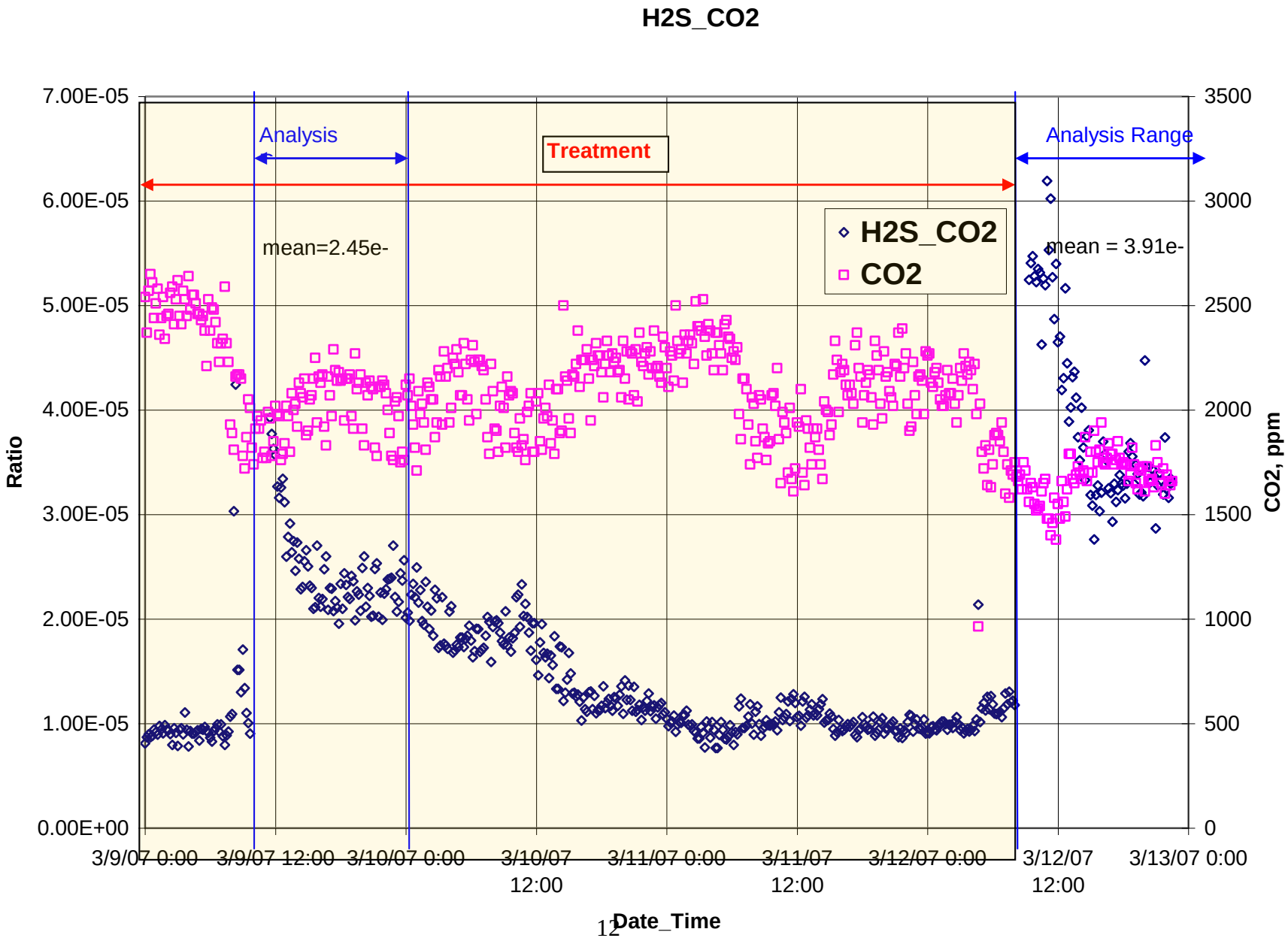
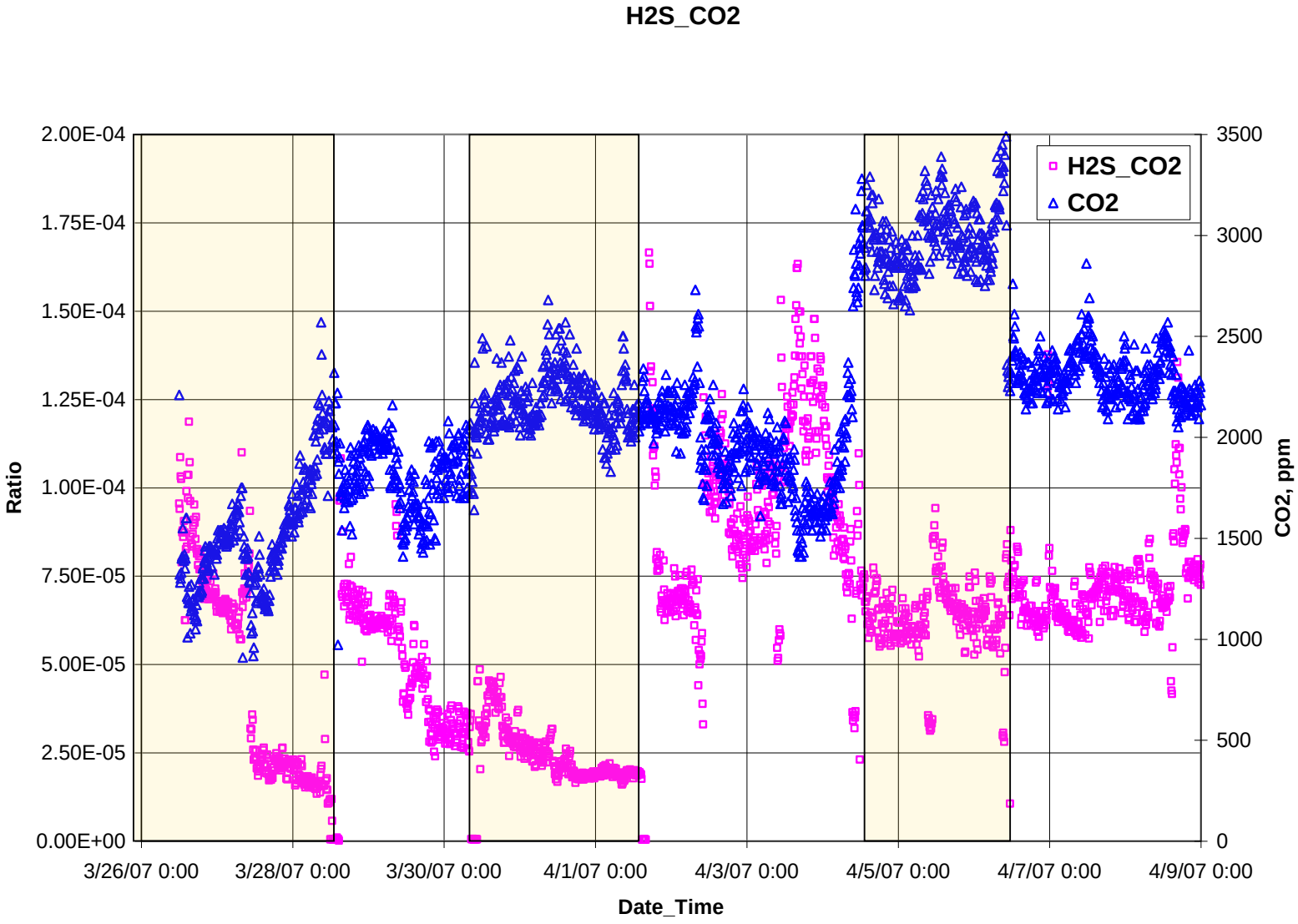
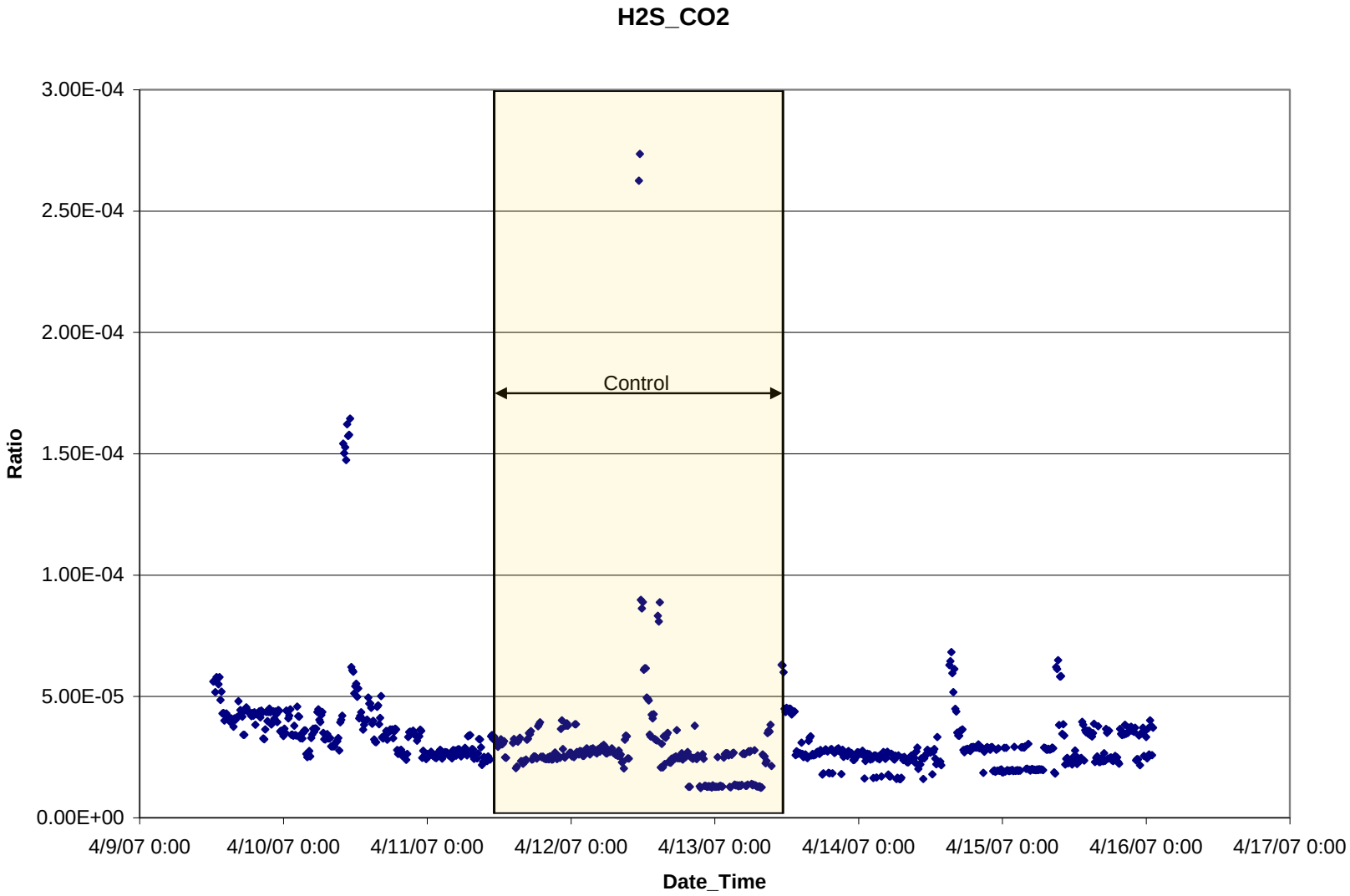
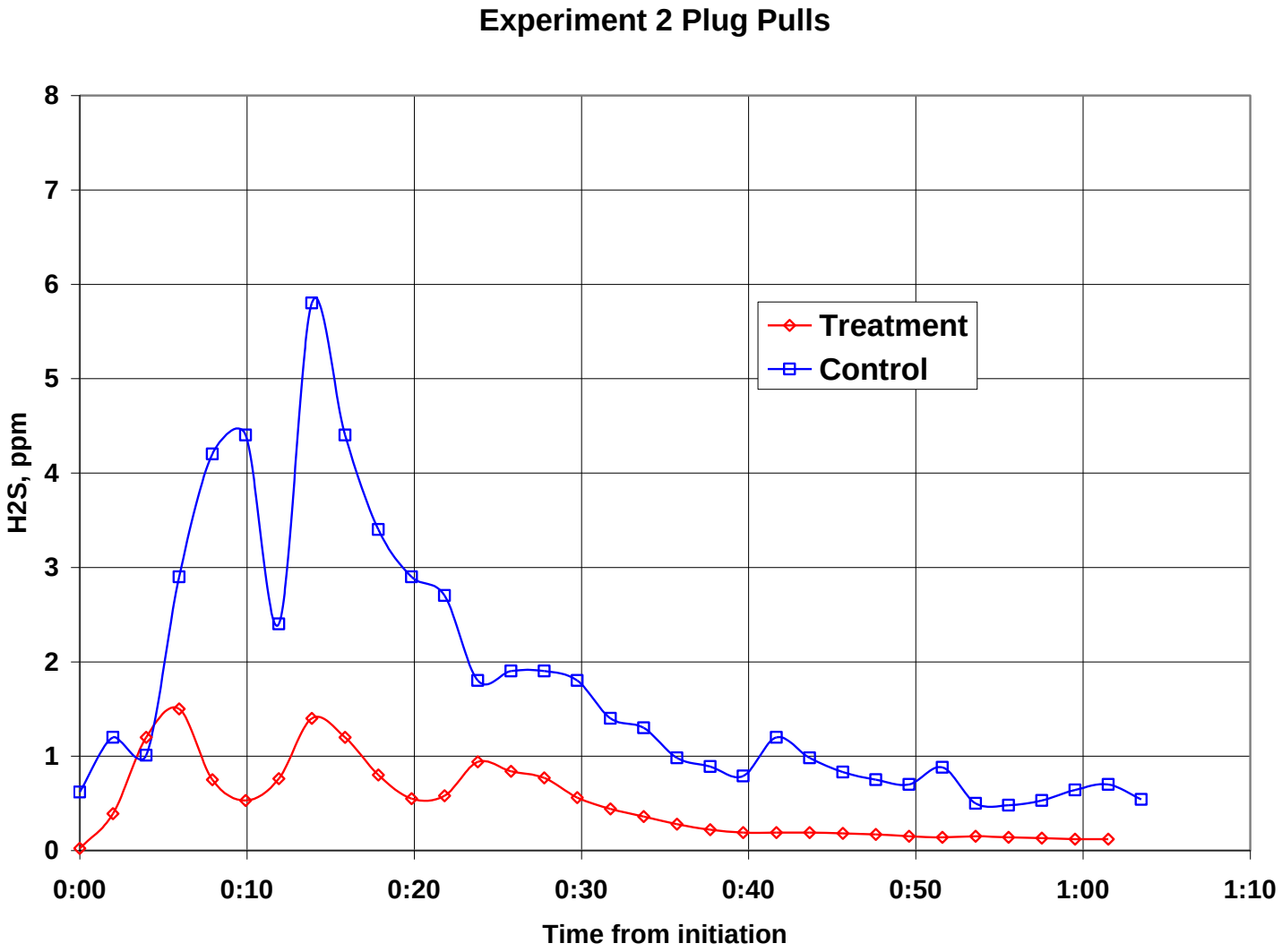
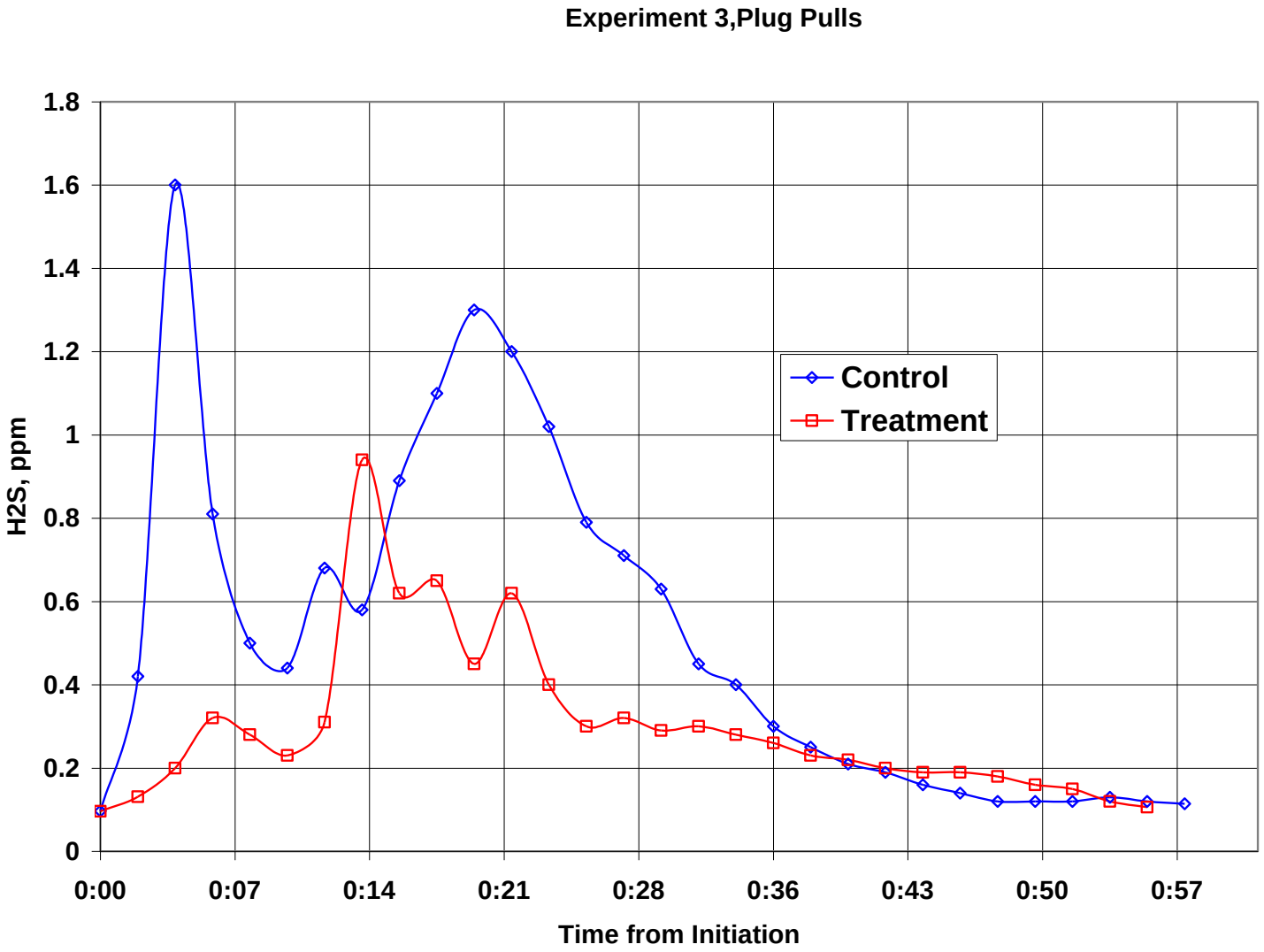
X. Appendices

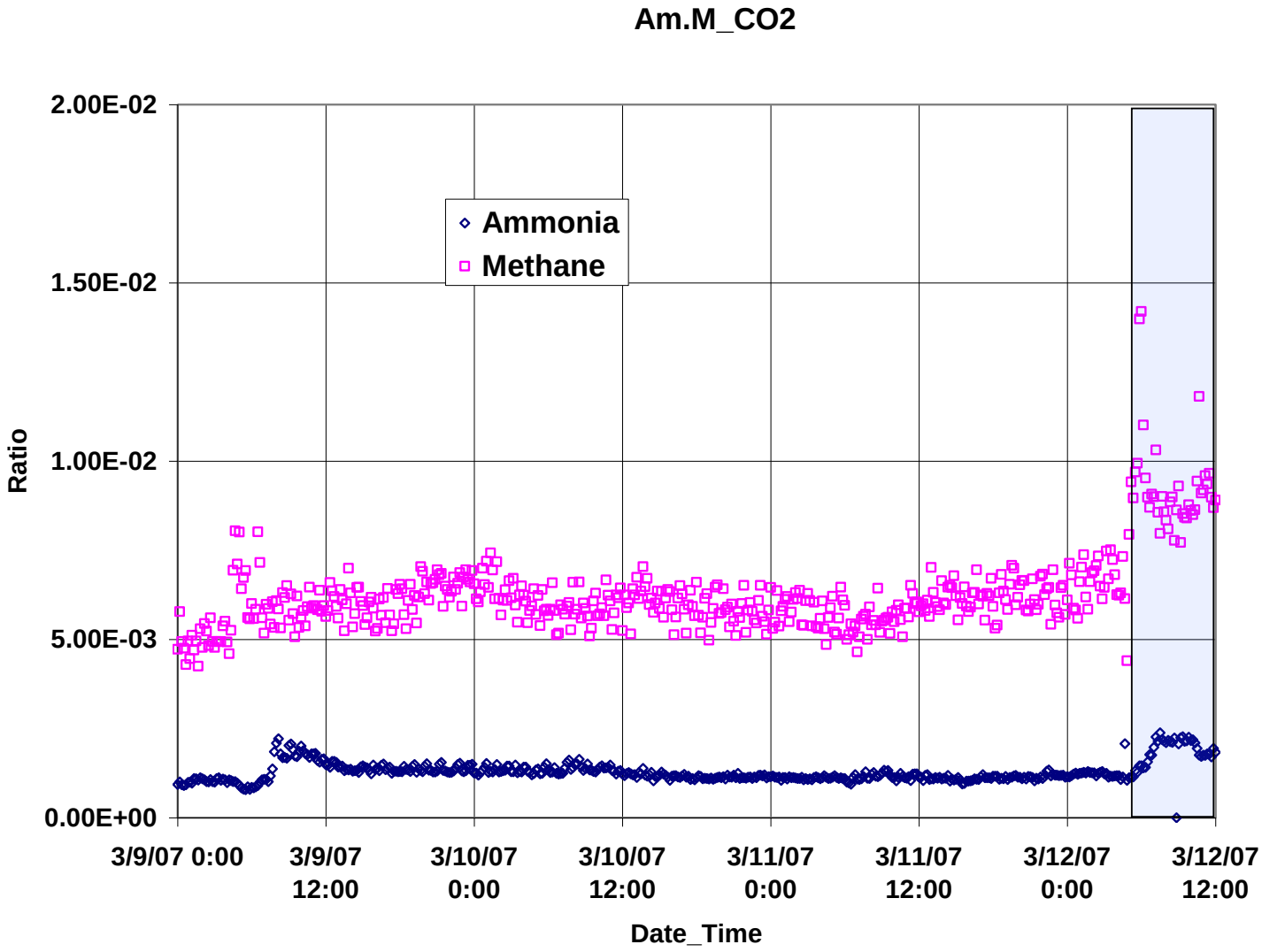

H2S_CO2
Analysis
Treatment
Analysis Range
mean=2.45e-
mean = 3.91e-
H2S_CO2
CO2
Ratio
CO2, ppm
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
3500
3000
2500
2000
1500
1000
500
0
3/9/07 0:00
3/9/07 12:00
3/10/07 0:00
3/10/07 12:00
3/11/07 0:00
3/11/07 12:00
3/12/07 0:00
3/12/07 12:00
3/13/07 0:00
Date_Time

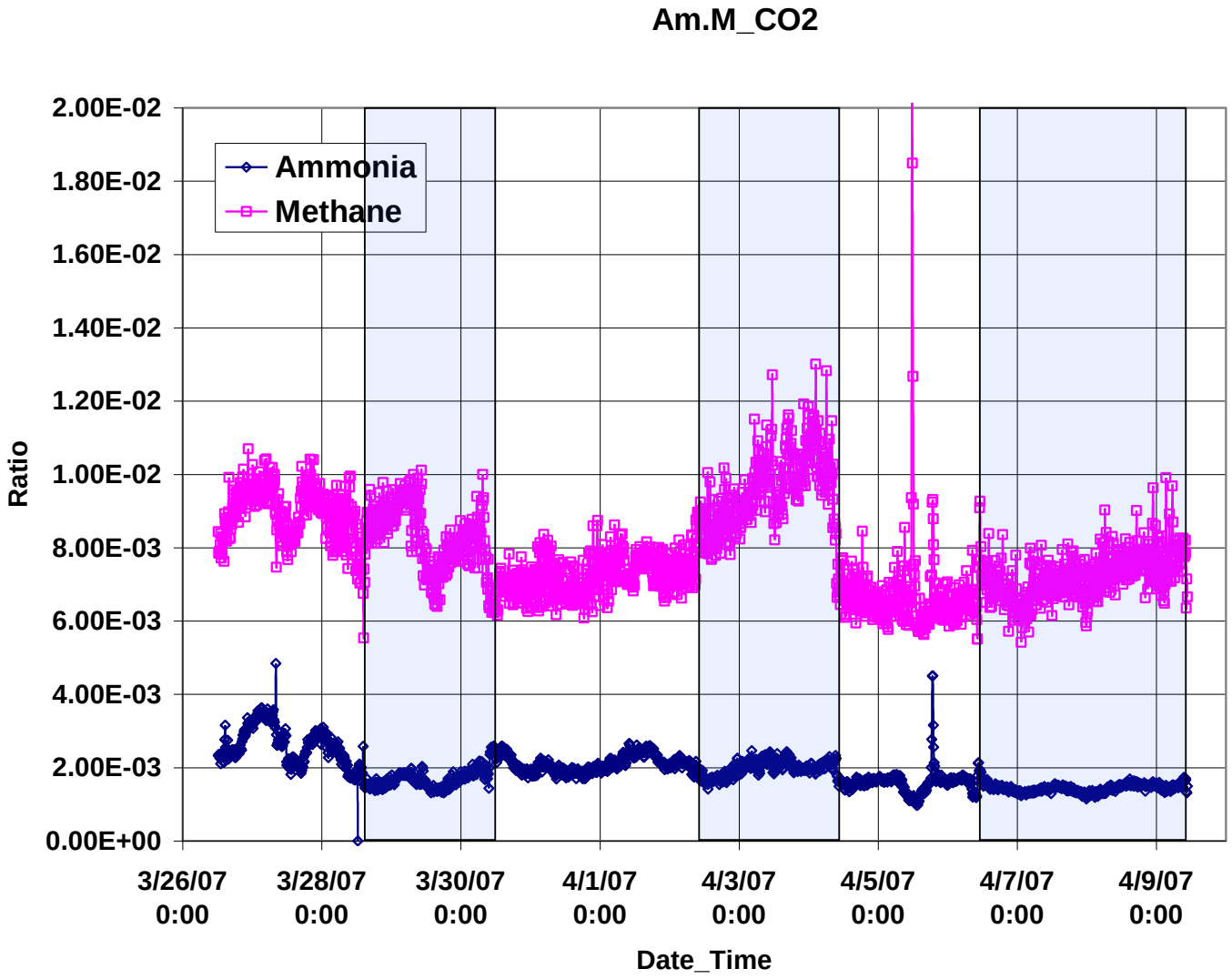

H2S_CO2
H2S_CO2
CO2
Ratio
CO2, ppm
Date_Time
2.00E-04
1.75E-04
1.50E-04
1.25E-04
1.00E-04
7.50E-05
5.00E-05
2.50E-05
0.00E+00
3500
3000
2500
2000
1500
1000
500
0
3/26/07 0:00
3/28/07 0:00
3/30/07 0:00
4/1/07 0:00
4/3/07 0:00
4/5/07 0:00
4/7/07 0:00
4/9/07 0:00

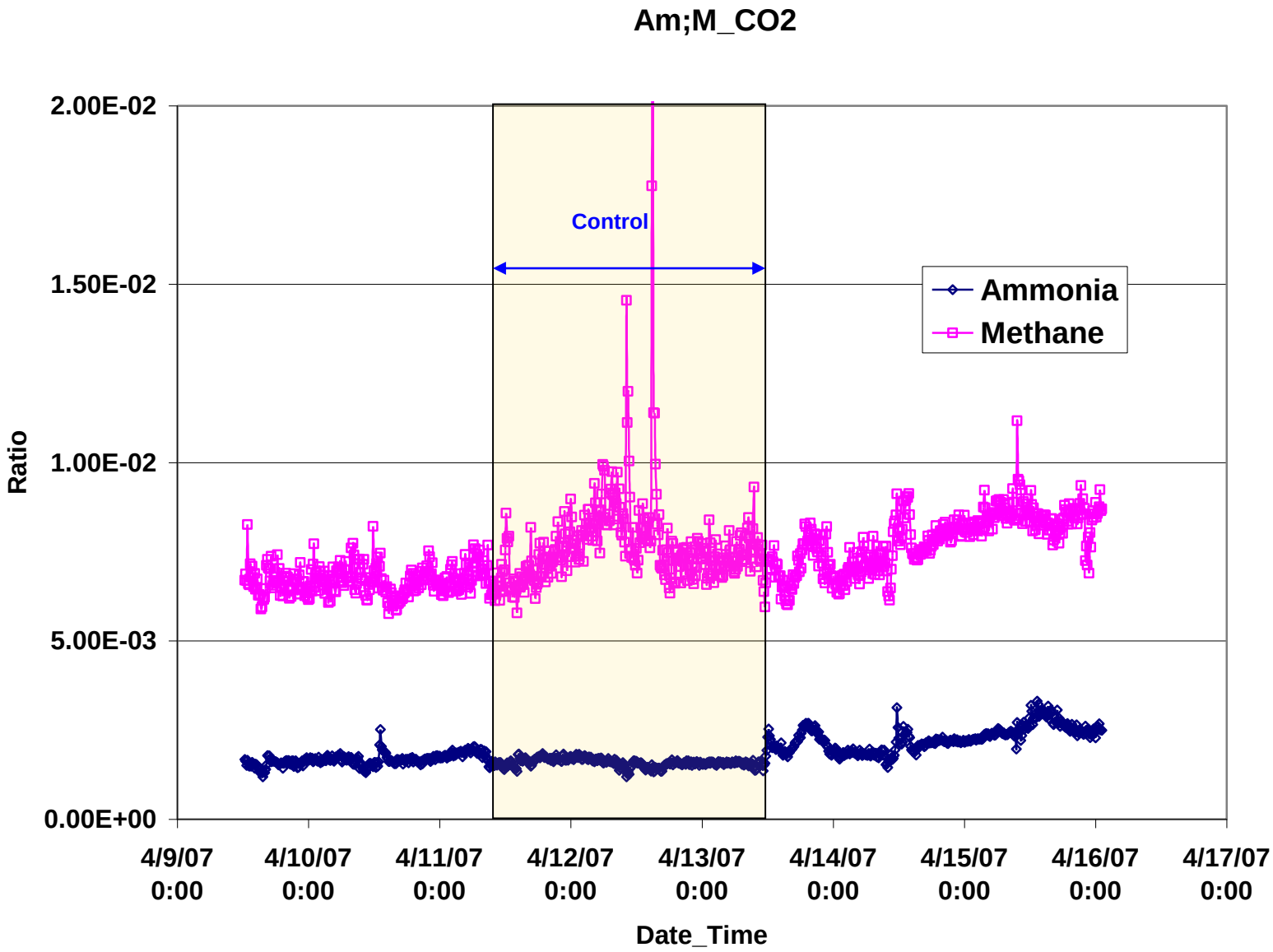

H2S_CO2
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
Ratio
Control
4/9/07 0:00
4/10/07 0:00
4/11/07 0:00
4/12/07 0:00
4/13/07 0:00
4/14/07 0:00
4/15/07 0:00
4/16/07 0:00
4/17/07 0:00
Date_Time


Experiment 2 Plug Pulls
H2S, ppm
8
7
6
5
4
3
2
1
0
0:00
0:10
0:20
0:30
0:40
0:50
1:00
1:10
Time from initiation
Treatment
Control


Experiment 3,Plug Pulls
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
H2S, ppm
0:00
0:07
0:14
0:21
0:28
0:36
0:43
0:50
0:57
Time from Initiation
Control
Treatment


Am.M_CO2
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Ratio
Ammonia
Methane
3/9/07 0:00
3/9/07 12:00
3/10/07 0:00
3/10/07 12:00
3/11/07 0:00
3/11/07 12:00
3/12/07 0:00
3/12/07 12:00
Date_Time


Am.M_CO2
Ammonia
Methane
Ratio
2.00E-02
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
3/26/07 0:00
3/28/07 0:00
3/30/07 0:00
4/1/07 0:00
4/3/07 0:00
4/5/07 0:00
4/7/07 0:00
4/9/07 0:00
Date_Time


Am;M_CO2
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Ratio
Control
Ammonia
Methane
4/9/07 0:00
4/10/07 0:00
4/11/07 0:00
4/12/07 0:00
4/13/07 0:00
4/14/07 0:00
4/15/07 0:00
4/16/07 0:00
4/17/07 0:00
Date_Time

		Am	Meth	NO	CO	CO2	H2O		H2S	Am	M	H2S	H2S	Total	Am/#	H2S/#
	B	C	D	E	F	G	H	I		CO2	CO2	CO2	Meth	Pig #		
Global	3/9/07-3/13/07															
Mean		**3.52**	**14.63**	**0.75**	**4.17**	**1679**	**7.51**	**0.00**	**0.0649**	**2.09E-03**	**8.72E-03**	**3.91E-05**	**4.48E-03**	**4510**	**7.80E-04**	**1.44E-05**
Std Dev		**0.43**	**1.16**	**0.03**	**0.69**	**111**	**0.69**	**0.00**	**0.0107**	**2.07E-04**	**5.95E-04**	**8.62E-06**	**9.50E-04**	**28**	**9.08E-05**	**2.47E-06**
Mean		**2.79**	**12.43**	**0.85**	**5.48**	**2016**	**8.44**	**0.00**	**0.0491**	**2.39E-05**	**6.18E-03**	**2.45E-05**	**3.99E-03**	**3535**	**7.89E-04**	**1.39E-05**
Std Dev		**0.13**	**1.15**	**0.04**	**0.66**	**141**	**1.34**	**0.00**	**0.0069**	**5.72E-06**	**4.80E-04**	**4.30E-06**	**7.91E-04**	**35**	**4.11E-05**	**2.07E-06**

C C C C C C C C C
S S S S S S
T T T T T

	Am	Meth	NO	CO	CO2	H2O	H2S	Am	M	H2S	H2S	Total	Am/#	H2S/#
	C	D	E	F	G	H		CO2	CO2	CO2	Meth	Pig #		
Global	3/26/07-4/9/07													
Mean	**3.37**	**16.51**	**0.73**	**3.75**	**2046**	**8.40**	**0.1489**	**1.67E-03**	**8.18E-03**	**7.37E-05**	**9.08E-03**	**8408**	**4.03E-04**	**1.70E-05**
Std Dev	**0.43**	**1.87**	**0.05**	**1.11**	**188**	**1.84**	**0.0249**	**1.82E-04**	**8.47E-04**	**1.45E-05**	**1.73E-03**	**120**	**5.18E-05**	**4.64E-06**
Mean	**4.43**	**16.30**	**0.72**	**1.91**	**2212**	**12.25**	**0.1032**	**2.11E-03**	**7.59E-03**	**4.33E-05**	**6.05E-03**	**8248**	**5.38E-04**	**1.08E-05**
Std Dev	**0.72**	**2.50**	**0.07**	**0.73**	**197**	**1.79**	**0.0457**	**3.35E-04**	**7.86E-04**	**2.32E-05**	**3.11E-03**	**144**	**8.75E-05**	**6.22E-06**

C C C C C C C C C
S S S S S S
T T T T T
S S S

	Am	Meth	NO	CO	CO2	H2O	H2S	Am	M	H2S	H2S	Total	Am/#	H2S/#
4/9/2007	C	D	E	F	G	H		CO2	CO2	CO2	Meth	Pig #		
Global														
Mean	**3.75**	**15.80**	**0.73**	**1.04**	**1894**	**9.02**	**0.0226**	**2.04E-03**	**8.37E-03**	**1.12E-05**	**1.47E-03**	**8398**	**4.48E-04**	**2.66E-06**
Std Dev	**0.48**	**4.36**	**0.08**	**0.60**	**323**	**1.89**	**0.0192**	**2.70E-04**	**1.58E-03**	**9.36E-06**	**1.22E-03**	**69**	**5.77E-05**	**2.20E-06**
Mean	**4.75**	**16.63**	**0.77**	**0.87**	**2243**	**11.74**	**0.0224**	**2.19E-03**	**7.49E-03**	**8.12E-06**	**1.14E-03**	**10749**	**4.48E-04**	**2.22E-06**
Std Dev	**0.69**	**2.71**	**0.08**	**0.63**	**335**	**1.81**	**0.0205**	**3.83E-04**	**9.44E-04**	**6.88E-06**	**1.02E-03**	**0**	**6.05E-05**	**2.04E-06**
				C			**C**		**C**	**C**	**C**		**C**	**C**
	T	**T**	**T**		**T**	**T**		**T**				**T**		
	S				**S**	**S**						**S**		