PILOT-SCALE SWINE ODOR REDUCTION BIOREACTOR SYSTEM (SORBS)

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INTRODUCTION

Odors associated with livestock production, particularly swine production, have drawn much media attention during recent years. The control of odor from livestock facilities is actively being researched. As the concentration of animals at a given site increases, the problems associated with odor control will become more problematic (Burcham 2000). Public concern with regard to odor associated with primarily swine production has resulted in moratoriums on industry expansion in the states of North Carolina and Mississippi (Hayes 1999). These factors resulted in a research effort by the Mississippi Agricultural and Forestry Experiment Station (MAFES) at Mississippi State University (MSU) to develop a cost-effective biological treatment system. This system is now in the pilot-scale development stage and is called the Swine Odor Reduction Bioreactor System (SORBS).

The SORBS was designed with the primary goal of reducing odor associated with large-scale swine production. The SORBS uses "attached growth" biological treatment to reduce the formation of odor compounds. While most "attached growth" reactors use inorganic media (plastic, gravel, etc.), the SORBS uses plant fiber as the attached growth medium. In particular, kenaf (hibiscus cannabis), a plant in the okra family, is being utilized in the SORBS. Microorganisms, that naturally populate the kenaf fiber, process the wastewater and reduce the formation of odor causing compounds.

In 1999, Jones and Burcham developed a 10-cell bench-scale SORBS at the Agricultural & Biological Engineering Department at Mississippi State University to facilitate replicated testing. This system was used to determine loading rates and potential odor reduction for the SORBS concept. Water quality analyses indicated that the SORBS was effective in reducing biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total solids (TS), volatile solids (VS), and other nutrients in the swine wastewater. A human olfactory panel evaluated the treatments for odor reduction. The panel indicated that the SORBS treatment transformed the odor associated with swine waste from a highly intense, acrid odor to a primarily "earthy" odor (Jones et al. 1999). Preliminary results were promising, therefore a pilot-scale SORBS was designed and installed at the MAFES Swine Physiology Facility located near the MSU campus. This manuscript describes the results from the first six weeks of data collection at the facility.

SORBS Process Description

The SORBS is a holistic sustainable wastewater treatment system that can be implemented for treatment of most organic waste streams. The primary design goal of the SORBS is odor abatement and wastewater remediation of organic waste streams. Development of the SORBS has been on high strength wastewater from swine production facilities. The SORBS is composed of five fundamental components:

1. A kenaf fiber-screening filter (KFSF) for removal of debris and settleable solids.
2. A kenaf medium bioreactor vessel (KMBV) designed to function as a modified attached growth biological reactor using chopped whole-stalk bast fiber and core as the attached growth medium.
3. An effluent holding reservoir (EHR) serves as a sump (providing primary clarification).
4. A re-circulating pump to move wastewater through the various stages of the SORBS.
5. A spent kenaf composting facility (SKCF) for stabilization of plugged (spent) kenaf biomass.

The SORBS uses chopped whole-stalk kenaf for both the solids filtration and primary biological treatment. The kenaf plants are harvested with a standard forage harvester adjusted to produce fiber and core material approximately 50.8 mm (2 inches) in length. This length achieves relatively good primary filtration and biological treatment characteristics, while minimizing plugging.

A schematic of the SORBS is shown in figure 1. Wastewater (feces, urine, and process wastewater) is collected in an effluent holding reservoir (EHR), which provides primary clarification through sedimentation and storage of the settleable solids for first stage treatment. The wastewater is pumped from the EHR to the KFSF. The wastewater then moves into the KMBV, which is designed to function as a modified attached growth biological reactor (using chopped whole-stalk kenaf bast fiber and core as the attached growth medium). As the wastewater trickles through the KMBV, it is biologically treated. Wastewater exits the KMBV and falls back into the EHR via gravity. While early testing of the SORBS has used continuous circulation, the system can also function in a batch/sequenced operational mode.

Once the kenaf medium becomes plugged (spent) with accumulated solids or biological slimes, it is replaced with new kenaf medium. The spent kenaf medium is transferred to the SKCF for composting. The spent kenaf material, with its resident microbial slimes and accumulated organic solids, provides the nitrogen and carbon essential for aerobic composting. The SKCF provides a low-cost, low-odor means of stabilizing the spent kenaf medium. The non-toxic stabilized compost is then utilized on-site (for crop production) or exported off-site as a value-added plant fertilizer and/or soil amendment.

MATERIALS & METHODS

A pilot-scale SORBS was installed in the MAFES Swine Physiology Barn (SPB), a small research swine facility located near the MSU campus (see figure 2). The design of the SPB provides 11.15 m^2 (120 ft^2) of pen surface area over each flush alley. The flush alleys were modified to form wastewater collection pits (underdrains) similar to those used in commercial swine production facilities. Both alleys were equipped with the SORBS and the underdrains were fitted with an aeration system powered by a regenerative blower. The SORBS consisted of a 0.85m^3 (30 ft^3) KMBV made from expanded metal (66 x 106.68 x 122 cm, depth, width, height, respectively). The KMBV was filled with chopped whole-stalk kenaf. The underdrains served as the EHRsPumps (373 W [1/2 hp]) were fitted to each EHR to re-circulate the wastewater.

The aeration system includes a 373 W regenerative blower and ceramic diffusers. The aeration system was installed to determine how the addition aeration and of activated sludge might affect SORBS performance.

Based on the commercial stocking rate of 0.93m^2 (10 ft^2) per pig, 12 pigs were placed in each pen, for a total of 24 pigs in the barn. The pigs were fed a standard diet to produce representative quantities of feces and urine for pilot-scale testing. The study began when the pigs weighed approximately 11 - 14 kilograms and will continue until the pigs reach an approximate weight of 100 kilograms (the normal range for grower swine).

Three treatments were evaluated: a control (C), that mimics the conditions currently used by large scale swine production facilities; the SORBS (SRB), as described previously; and SORBS augmented with aeration and activated sludge (SRB/AAS). For each treatment, the experiment was conducted for 168 hours (7-days). During the course of each 168-hour experiment, the pigs were allowed to freely defecate and urinate into the EHR.

For the control (C) treatment, 3785 L of tap water was used to fill the pits at time t = 0 and the underdrains received no augmentation, e.g., they were allowed to remain stagnant with no underdrain circulation. For the SRB treatment, each underdrain was again filled with 3785 L of tap water and the wastewater in the underdrains was continuously circulated through each respective KMBV at a rate of 19 L/min (5 gpm) for 168 hours. For the SRB/AAS treatment, the underdrain was filled with 3785 L of tap water and 38 L (10-gal) of activated sludge (obtained from the Starkville Wastewater Treatment Plant). Atmospheric air was bubbled through the underdrains and wastewater was continuously circulated through each respective KMBV for 168-hours.

In order to provide replication, both sides (each flush alley) were operated with the same treatment. At the end of the 168-hour experiment, another treatment was tested. The treatment scheme for each week reported was as follows:

Week 1 (2/9 – 2/16)	C
Week 2 (2/16 - 2/23)	SRB
Week 5 (3/8 – 3/15)	SRB/AAS
Week 6 (3/15 – 3/22)	C

Wastewater Evaluation

Two wastewater samples were taken from both EHRs at 24, 48 120, and 168 hours. The following wastewater analyses were performed on each sample: pH, volatile acids, phenols, chemical oxygen demand (COD), total solids (TS), and biochemical oxygen demand (BOD_5). Samples were analyzed by trained technicians in the ABE Water Quality Laboratory. Dissolved oxygen (DO) measurements were taken directly from the wastewater in the EHRs (in situ).

Odor Evaluation

An odor panel analysis was conducted to compare the C and SRB/AAS treatments. The odor samples were prepared by placing 10 mL of the wastewater sample in a 250 mL Nalgene Teflon FEP One-Piece Wash Bottle. These particular bottles were chosen for their high resistance to absorption/adsorption of liquids or gases. The bottles were wrapped in aluminum foil and randomly numbered to provide a double blind study. A maximum of 8 – 10 samples were analyzed at any given odor panel session to prevent olfactory dulling.

The odor panel consisted of 20 volunteers that were trained for three weeks prior to the sample analysis. During the training weeks, swine wastewater samples were introduced to the panel. The panel rated each sample based on nine descriptive terms used to describe the odor. The terms are as follows: overall intensity, acridity, sulfurous, earthy, musty, fecal, cheesy, sweet/grainy, and ammonia. Each term was rated on a 0 to 8 scale, with 0 being no detectable odor and 8 being a very strong odor. Fecal (skatole/cresol complex) and ammonia standards were prepared and tested by the panel during the training period. A numerical value of 4 was assigned to the fecal standard (a mixture of p-cresol (210 mg/L) and skatole(12.8 mg/L) in deionized water) and all odor samples were then rated against the standard.

RESULTS & DISCUSSION

Wastewater Analysis

pH and Dissolved Oxygen. The pH of the wastewater from the underdrains ranged from 6.9 to 8.6 for all treatments tested. Most bacteria can tolerate a pH of 4 and 9.5 (Metcalf & Eddy 1991). Therefore, the pH was not considered a limiting factor in the growth of the microorganisms within the SORBS.

Only the SRB/AAS treatment maintained a DO level of 2.0 mg/L or higher for the first 120 hours of treatment. However, after the 120 hour mark the DO level plunged to 0.04 mg/L at 168 hours of treatment. Thus, it appears that the quantity of oxygen supplied by the aeration system was insufficient for the organic loading rate encountered after 120 hours. The wastewater in the EHRs for the SRB and both C treatments was anaerobic. For these treatments, the DO levels in the EHRs never rose above 0.4 mg/L for the C or the SRB treatments.

Data Normalization. Since both flush alleys (both sides) of the barn received the same treatment, two replications were achieved with each 7-day experiment. There were a total of five treatments (three reported in this paper), so the pigs were substantially larger by the time the same treatment regime was repeated. For example, about 79.4 kg of waste entered into the EHRs during the first week of the study and by the sixth week of the study the amount of waste entering the EHRs increased to about 220 kg. Therefore, a methodology to normalize the experiments was developed. The literature indicates that swine produce 2.75, 0.94, and 2.88 kg/d/AU of COD, BOD_5, and TS, respectively (AWMFH 1992)An AU = 454 kg of live animal weight. From this information the theoretical amounts of COD, BOD_5, and TS produced by the pigs could be calculated for any stage of the growth cycle. The data was normalized by dividing the actual quantity (concentration * volume) of a particular constituent (COD, BOD_5, etc.) by the theoretical quantity produced by the pigs.

COD. The normalized data for COD is shown in figure 3. Both the SRB and the SRB/AAS treatments had less COD remaining than the C treatments after 168 hours of treatment. This indicates that both SRB and SRB/AAS treatments are effective in reducing the amount of COD within the wastewater. On a mass basis, the theoretical removal of the dissolved/suspended COD was 39%, 74%, 79%, and 61% for the C (t=1W), SRB (t=2W), SRB/AAS (t=5W), and C (t=6W) treatments, respectively (based on endpoint data)

BOD_5. The BOD_5 graph shown in figure 4 indicates that the SRB/AAS treatment was highly effective in removing BOD_5. The slight increase in the BOD_5 after 120 hours occurs around the same time the DO level began to drop within the system. This drop in DO may have caused the system to go anaerobic, thus reducing aerobic biological treatment. The SRB treatment was also effective in removing BOD_5, however it took approximately 120 hours for the removal to begin. This delay in treatment may have been necessary to allow the microorganisms sufficient time to acclimate to the wastewater. The theoretical removal of the dissolved/suspended BOD_5 was 92%, 88%, 87%, and 68% for the C (t=1W), SRB (t=2W), SRB/AAS (t=5W), and C (t=6W) treatments, respectively (based on endpoint data). The first week C treatment showed good removal efficiency; however, this is probably due to the low loading exerted on the system (very small pigs). The sixth week C treatment was not nearly as effective in removing BOD_5 when compared to the other treatments.

TS. From the TS graph shown in figure 5, it appears that the SRB and SRB/AAS treatments had no real affect on the TS concentration when compared to the C treatments. The high TS value for both the SRB and the SRB/AAS at 24 hours may be due to the dislodging of kenaf fines into the EHR.

Volatile Acids & Phenols. The volatile acids and phenols data was not normalized; therefore, figures 6 and 7 represents the actual concentration versus time. From figures 6 and 7, it is clear that the SRB/AAS treatment is effective in removing volatile acids and phenols from the wastewater. This is a significant finding, since both volatile acids and phenols have been found to be contributors to the generation of odor from swine waste (Zhu, Riskowske, and Torremorell 1999). Therefore, if the SORBS process can reduce the concentration of volatile acids and phenols in the underdrains, it may be effective in reducing the odor associated with large swine production facilities.

The SRB treatment was effective in removing phenols, but actually indicated an increase in the volatile acid concentration. This increase was surprising and did not correlate with the Fall 1999 findings.

<u>Fall 1999</u>

For the most part, the above results correspond to the findings from the Fall 1999 Pilot Scale SORBS study. The average pig weight at the beginning of the fall experiment was approximately 150 pounds. During the 1999 study, the SRB was directly compared to the C treatment (same waste loading into the underdrains). Summarized results of the endpoint (168 hours of treatment) data for BOD_5, COD, TS, VS, and volatile acids, for both C and SRB treatments, are shown in figure 8. The SRB treatment was effective in reducing all parameters shown, especially BOD_5, COD, and volatile acids. The phenol concentration (not shown in figure 8) of the SRB treatment was 46% less than the C.

<u>Odor Analysis</u>

The odor panel analyzed the endpoint wastewater samples from the control at 6 weeks and from the SRB/AAS treatment at 5 weeks. Mean responses and statistical inferences are shown in Table 1. Data was analyzed using SigmaStat and means were separated by performing the Mann Whitney Rank Sum Test. There was no significant difference ($\alpha = 0.05$) between the SRB/AAS and the control treatments with regard to the acridity, cheesy, musty, and sulfurous characteristics. For the control treatment, the odor response means were higher and significantly different than the SRB/AAS means for intensity, ammonia, fecal, and sweet/grainy characteristics. The mean "earthy" odor response for the SRB/AAS (0.47) treatment was higher than the control (0.30) and significantly different. The results indicate that the SORBS process can reduce the overall intensity, ammonia, and fecal components of the wastewater. This data is also representative of the results found in the 1999 study.

CONCLUSION

This study compared the SORBS to a traditional pit recharge system (the C treatment) and looked at the affect of the addition of aeration and activated sludge on the SORBS process. Water quality analysis indicated that the SRB/AAS treatment performed as well or better than the SRB treatment in reducing concentrations of BOD_5, COD, phenol, and volatile acids. With the exception of TS, both the SRB and the SBR/AAS treatments performed better than the C treatment (week 6) in all parameters tested. The odor analysis indicates that the SRB/AAS is capable of reducing the overall intensity and the fecal, ammonia, and sweet/grainy characteristics of the swine wastewater when compared to the C treatment. All results indicate that the SORBS process does reduce odor associated with swine wastewater and biologically treats the wastewater.

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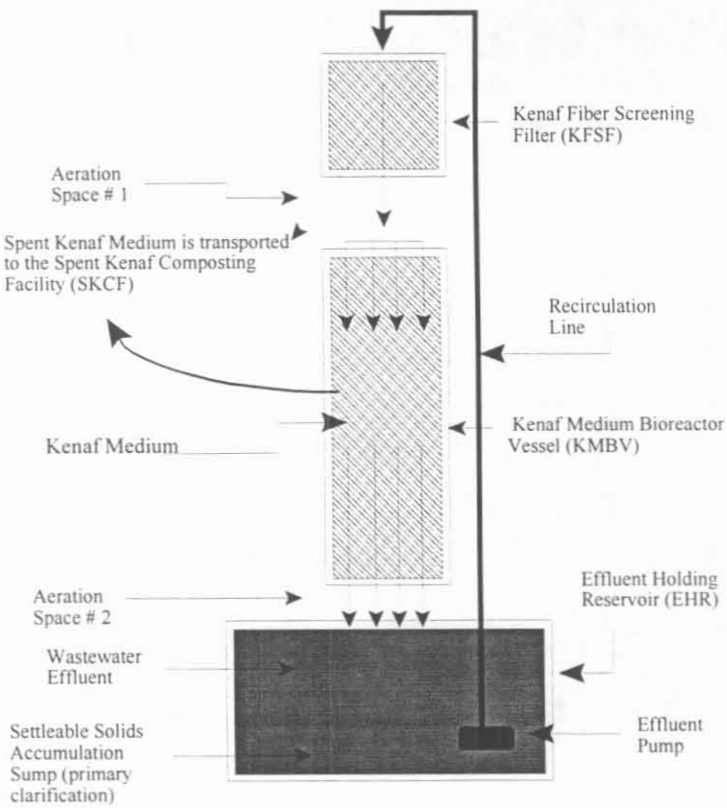

Figure 1. Schematic view of the SORBS.

Figure 2. Pilot-scale Swine Odor Reduction Bioreactor System (SORBS).

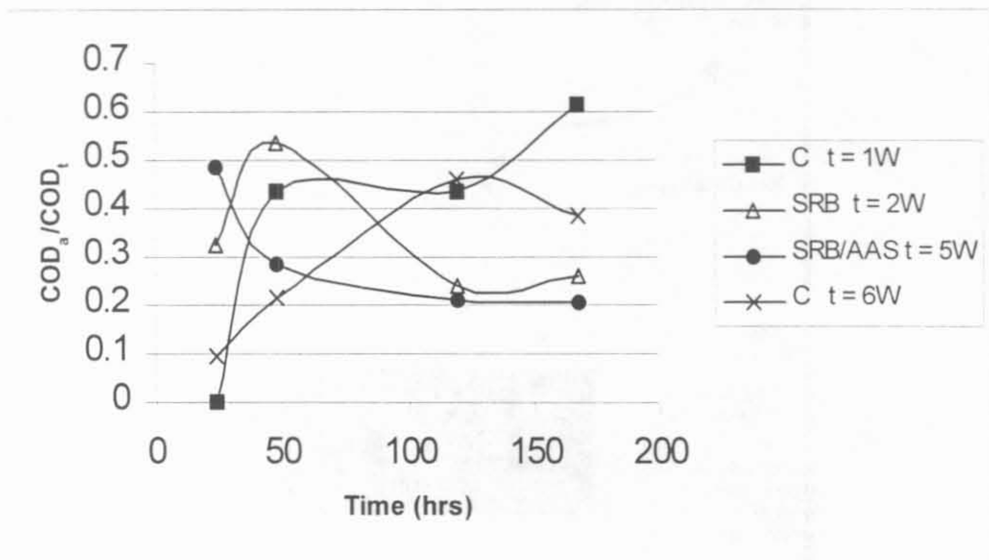

Figure 3. COD vs time.

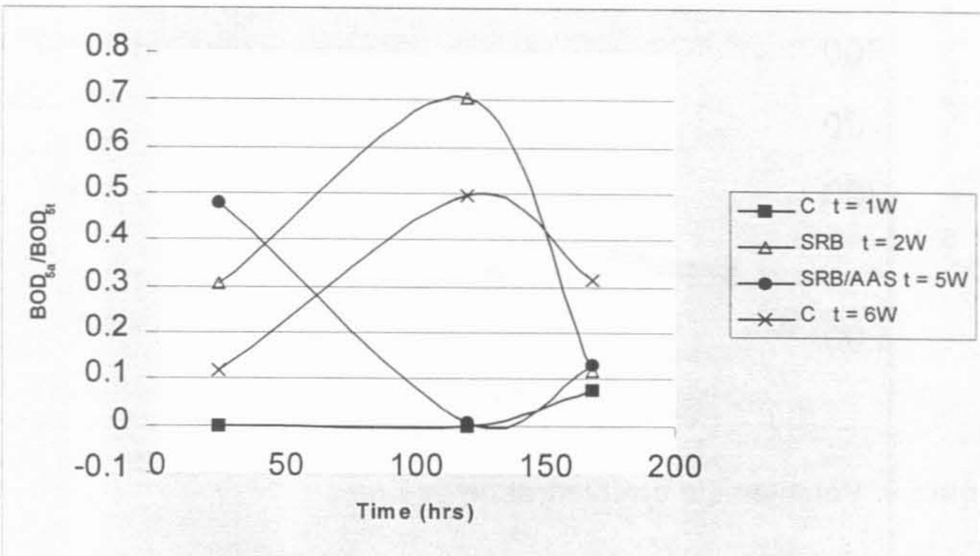

Figure 4. BOD_5 vs time.

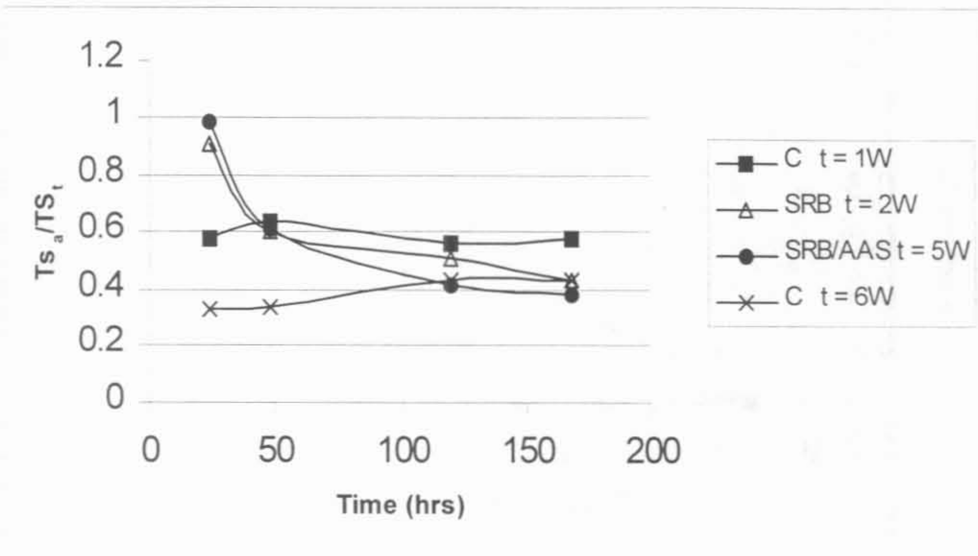

Figure 5. Total solids vs time.

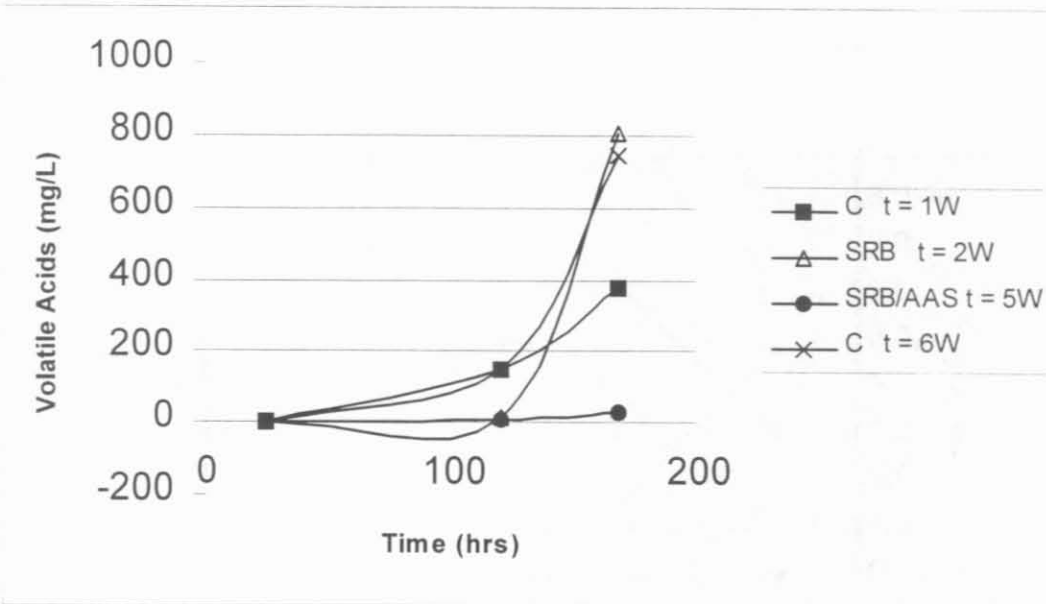

Figure 6. Volatile acid concentration vs time.

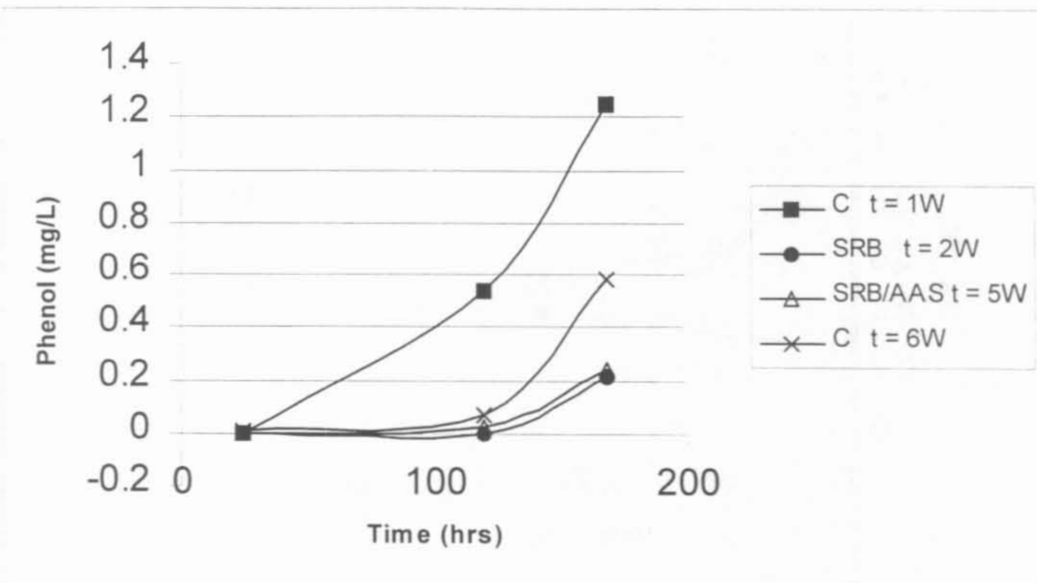

Figure 7. Phenol concentration vs time.

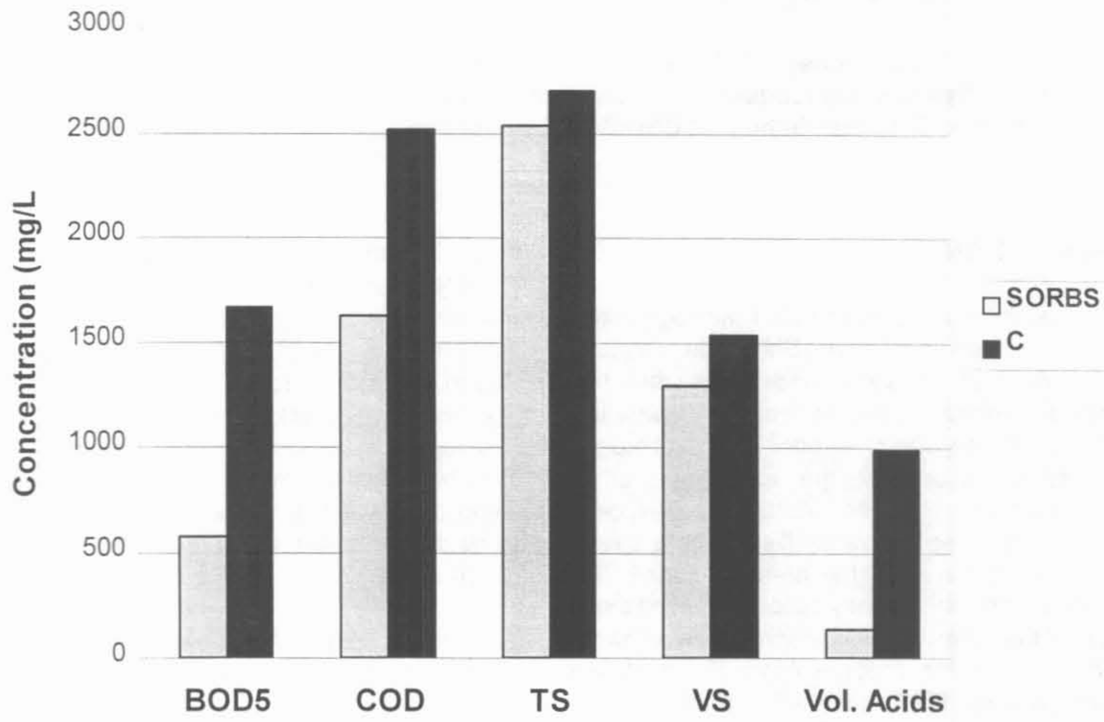

Figure 8. 1999 SORBS data.

Table 1. Mean odor response and statistical inference for C and SRB/AAS treatments.

	Odor Components								
Trts	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	Ammonia
Control	3.77b	0.52a	0.57a	0.30a	0.60a	1.56b	0.75a	0.57b	0.67b
SRB/AA	2.16a	0.24a	0.21a	0.47b	0.55a	0.95a	0.47a	0.10a	0.08a

Note: Means with the same letter are not significantly different.