# SWINE OPERATIONS: COMPARISON OF BIOLOGICAL FILTER MEDIA FOR ODOR CONTROL AND WASTEWATER TREATMENT

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## INTRODUCTION

Odor is an increasing concern in many agricultural locations across the United States, in particular, odor generated by waste and wastewater from confined animal housing/feeding operations (CAFO'S). Perception of an odor is a psychological response to an odorant, the actual molecule or molecules that cause the neurological response. The olfactory receptors transmit sensations directly to the olfactory bulb of the cerebral cortex. This portion of the brain, formerly called the "smell brain", is part of the limbic system which is now known to be the center for basic emotional drives and motivation (Fox 1993). Increasing public concern associated with nuisance odor and potential environmental problems associated with untreated or partially treated wastewater from CAFO's has relegated the legislatures of both Mississippi and North Carolina to place moratoriums on the expansion of the swine industry in their respective states (Hayes 1999).

Odors from CAFO's have been identified from three major sources: (1) building and facilities, (2) outside storage systems, and (3) land application of manure and wastewater (Nicolai et al. 1998). Modern swine production facilities in the Southeast United States utilize large fans to ventilate the housing systems. While these fans serve to regulate the interior environment of the house, they force large volumes of odorant laden air directly in the local atmosphere. VanDevender (1998), found a statistically significant relationship between distance from the facility and odor intensity. Depending on atmospheric conditions, his study found that odor from swine production facilities could be detected by humans up to 0.48 km (0.3 miles) down-wind. Odor from land application sites was detected at distances up to 0.8 km (0.5 miles) in the same study. Further, high loading rate and low labor requirements associated with flush-style waste removal has resulted in the widespread adoption of anaerobic lagoons for wastewater treatment in most confined livestock facilities. Anaerobic digestion of waste can release ammonia, hydrogen sulfide, and volatile fatty acids such as organic acids, alcohols, aldehydes, fixed gases, carbonyls, esters, amines, sulfides, mercaptans, and nitrogen heterocycles as a result of the biological treatment process. Subsequent land application of this wastewater can release these odorants into the air, thereby exacerbating odor complaints.

Although there are known methods for odor reduction, no current technology has proven to be cost-effective on a commercial production scale. Accordingly, the goal remains to design a treatment system that reduces odor and biologically treats wastewater from organic waste streams in a cost-effective manner. This prompted the development of the Swine Odor Reduction Bioreactor System (SORBS).

## MATERIALS AND METHODS

### Physical Apparatus

The SORBS uses kenaf as an attached growth medium. In order to evaluate the characteristics associated with the attached growth biological treatment process, a plywood support frame was constructed to hold 10 bench-scale bioreactors. (see Figure 1). The frame is constructed of standard 1.9 cm (0.75 in.) plywood and the bioreactor vessels are constructed from 10.2 cm diameter (4 in.) sewer and drain grade PVC pipe cut to 61 cm (24 in.) lengths. When filled with media to a 50.8 cm (20 in.) height, the treatment volume for each bioreactor vessel is approximately 4,157 $cm^3$ (254 $in.^3$). In addition, a smaller kenaf bioreactor (SK) was constructed out of 20.3 cm diameter (8 in.) PVC pipe to explore geometric relationships. It was filled to a depth of 12.8 cm to equal the volume of the standard kenaf

bioreactor (4,157 $cm^3$). A wire screen was constructed and secured via hose-clamps to the bottom of the bioreactor vessel to provide a stable base for the media without sacrificing flow capability. Sections of 2.54 cm (1 in.) PVC piping, subsequent fittings, and two ball valves were used to create the wastewater distribution system. A small sump-pump was used to continuously re-circulate the effluent. A 17 L (5 gal) bucket was used as the effluent holding reservoir (EHR). Each bioreactor vessel is supported by separate EHRs, recirculating pumps, and distribution systems. Each bioreactor was operated at a flow rate of approximately 0.95 L/min (15 gal/hr).

**Media Selection**

In order to properly evaluate the potential of kenaf as a viable attached growth media, bioreactors filled with kenaf [standard (K) and small kenaf (SK)] were compared with two conventional attached growth mediums [river rocks (R) and synthetic biorings (BR)], one non-conventional biological medium [pine chips (PC)], and a standard treatment [anaerobic pit (Pit)]. The simulated anaerobic pit (a 17 L bucket containing the standard wastewater solution) was used as the control treatment. This yielded six treatments [kenaf (K), small kenaf (SK), biorings (BR), rocks (R), pine chips (PC), and anaerobic pit simulator (Pit)] with two replications of each treatment.

**Swine Waste Solution**

A swine waste solution including both feces and urine was prepared immediately before the experiment began. The swine waste was collected from the Mississippi Agricultural and Forestry Experiment Station (MAFES) Swine Unit located in Starkville, MS.

Modeling the system for large scale swine production facilities, the mass of swine manure and urine excreted by a 90 kg finishing pig is approximately 5.9 kg per day (MWPS-18, 1985). Hereafter, the term "manure" will represent the total mass of feces and urine from the animal per unit of time. A typical finishing facility contains approximately 880 animals. Therefore, the daily manure production from a typical finishing house is 5,192 kg per day (880 x 5.9 kg/day = 5,192 kg/day). Finishing barns, in Northeast region of Mississippi, typically utilize a pit-recharge type of waste storage/removal. A typical facility has about 340,687 L of wastewater beneath the slatted floor. While the pit volume can be fresh water, the general practice is to use recycled anaerobic lagoon effluent in the pits. By dividing the daily manure production (5,192 kg) by the volume of wastewater (340,687 L) in the pits beneath the slats, a manure to pit volume ratio of 0.015 kg manure/L of pit wastewater is calculated.

The bench-scale SORBS has a capacity of 18.9 L [5 gal] of wastewater in the effluent holding reservoir (EHR). Using the manure (kg)/pit volume (L) ratio calculated above, it follows that 0.29 kg of swine manure must be added to 18.9 L to achieve a manure/pit volume ratio for one day of operation. To make certain that the concentration of manure in the EHR was representative of an actual swine finishing facility, 0.35 kg (120% of the 0.29 kg) of swine manure was added to each EHR (18.9 L) for all batch runs reported in this experiment.

The waste solution was prepared by first collecting a bulk quantity of swine waste from the Mississippi State University (MSU) Swine Unit. Ten individual bioreactors were used in this test. In order to create a homogenous waste solution, 3.5 kg [7.9 lb] of waste was weighed in a 18.9 L bucket using a Circuits and Systems Model SX-1002 Electronic Scale. Water was added to the manure and stirred to create a slurry (breaking up most of the fecal solids). The slurry was then strained using a #8 U.S. Standard Sieve with openings of 2.36 mm [0.937 in.]. This operation removed undigested feed (cracked corn, etc.) and other large solids. The strained slurry was then mixed with water to a volume of 18.9 L. Each EHR was filled with tap water to 17 L. The strained slurry solution was divided into 1.9 L volumes while vigorously stirring the contents. This helped ensure that the initial concentration of manure in each EHR was homogeneous.

**Olfactory Evaluation Procedures**

Odor evaluations were completed for each batch-run experiment during this study. Odor evaluations were conducted using accepted sensory descriptive practices (Meilgaard et al., 1991). All odor evaluations were done within 2 hours of retrieving the samples from the bench-scale SORBS.

Approximately 10 mL of wastewater from the effluent holding reservoir (EHR) of each lab-based SORBS was placed in individual 250 mL Nalgene Teflon FEP One-Piece Wash Bottles. These bottles are highly resistant to absorption/adsorption of liquids or gases (odorants). The internal draw tube was removed from each bottle to keep the liquid portion of the treatment sample from escaping into the cap (neck). The bottles were then wrapped in aluminum foil and randomly numbered (i.e., double-blind study). A small piece of glass wool was inserted into the neck of the stem each time the Teflon bottles were used. In order to reduce the effect of olfactory dulling, only 8-10 samples were analyzed during each meeting for both training and testing periods. After each testing period, all bottles were washed with soap and water, thoroughly rinsed, and placed in a 100°C evaporating oven for approximately 15 hours to ensure odor free bottles for the next testing period.

A human olfactory panel consisting of approximately 14 volunteers was established for the study. Panel members were randomly selected from various Departments at Mississippi State University. The panel was trained for approximately 2 months, meeting 3 times weekly. During these weekly meetings, various swine waste samples were introduced to the panel, from which 9 descriptive terms were chosen to describe the odor. The terms chosen were as follows: pleasantness, overall intensity, acridity, sulfurous, earthy, musty, fecal (skatole/cresol complex), cheesy, sweet/grainy, and ammonia. Each term was rated on a 0 to 8 point scale, with 0 being no delectable odor and 8 being a strong odor. Fecal (skatole/cresol complex), ammonia, and sulfur standards (dimethyl trisulfide) were prepared and tested by the panel during the training period. A numerical value 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 unknown odor samples were then graded against the standard. All odor samples taken from the control and treatments were duplicated and assigned different random numbers for olfactory panel analysis.

To evaluate a sample, the panelist swirled the bottles to fill the bottle head-space with odorants and gently squeezed the bottle in a series of small pulses to force the odorant laden air out of the bottle to an area beneath the nose and above the lip (being careful not to allow the bottle to touch any portion of the panelist's face). The panelist then recorded their response to the odorant on the score sheet.

### Wastewater Sampling and Analysis

Wastewater samples were taken from the sumps (EHR) of the laboratory-scale SORBS. Labeled 500 mL Nalgene field sample bottles were submerged approximately 2.5 cm below the waster surface in each respective EHR and allowed to fill with effluent. Samples were analyzed by trained technicians in Agricultural & Biological Engineering (ABE) Water Quality Laboratory at Mississippi State University. The lab performed the following tests: ammonia, $BOD_5$ (5-day biological oxygen demand), COD (chemical oxygen demand), ortho phosphorus (orth-P), pH, total Kjeldahl nitrogen (TKN), total phosphorus (TP) in Kjeldahl digest, total solids (TS), and volatile solids (VS). Table 1 describes the instrumentation protocol for each analylate. When necessary, samples were preserved using concentrated sulfuric acid in combination with refrigeration. Samples were analyzed for $NH_3$, TKN, TP, TS, and VS within 7 days, unless they were stabilized with sulfuric acid, in which case, they were analyzed within 28 days. Wastewater samples were analyzed for ortho-P within 48 hours and COD within 24 hours.

## RESULTS AND DISCUSSION

### Water Quality

Raw water quality data can be viewed in tables 2, 4, 6 and 8 ($BOD_5$, COD, TS and VS). Graphic presentation of $BOD_5$ and COD data, expressed as a ratio of $BOD_5$ or COD at time *t* versus $BOD_5$ or COD initial, can be viewed in figures 2 and 3. Tables 3, 5, 7 and 9 ($BOD_5$, COD, TS and VS) contain treatment efficiencies for each sampling interval.

The $BOD_5$ data is presented in table 2 and shown graphically in figure 2. Observation of the data in figure 2 illustrates that the larger surface area kenaf treatment (SK) operated with a significant lag period, yet endpoint treatment (48 hours) shows little difference between any of the treatments. Further examination of the treatment efficiency data in table

3 suggests that each treatment, excluding SK, achieved an optimum operational treatment efficiency after 24 hours of treatment rather than 48 hours of treatment. This may be due to the fact that a sufficient amount of nutrients had been removed from the wastewater such that the microbial population attached to the media began to lyse due to lack of a nutrient (food) source. This would cause the subsequent increase in $BOD_5$ at the 48 hour sampling interval. Also, the pit treatment shows a $BOD_5$ reduction of approximately 70% which may be attributed to the settling of large solids to the bottom of the 17 L bucket. Recall that the wastewater samples were retrieved at a depth of 2.5 cm from the water surface, thus none of the settled solids would be retrieved in the sample.

The COD data is presented in table 4 and shown graphically in figure 3. Examination of the data represented in figure 3 shows virtually no lag period associated with any of the treatments. Further, the steep slopes from time t = 0 to 4 hours shows that each treatment achieved at least a 40% reduction in COD during this time-period, with the PC treatment having the best treatment efficiency. This can be attributed to the tightly packed pine chips in the reactor vessel providing excellent mechanical filtration for larger solids that would directly affect the COD results. An increase in COD is observed in the anaerobic pit simulator (Pit) between sampling intervals t = 24 and 48 hours, shown in table 4 and figure 3. This increase may be attributed to sampling error, e.g. the Pit container was agitated while taking the 48 hour sample. This would re-suspend settled solids and potentially cause the resulting increase in measured COD. Therefore, the treatment efficiencies of the anaerobic pit (Pit), as presented in table 4, show no effective COD treatment at t = 48 hours. The data presented in table 4 and figure 2 show that there is little difference in endpoint treatment of any of the attached growth treatments (K, BR, R, PC, and SK).

Total solids (TS) data is presented in tables 6 and 7, and volatile solids (VS data is presented in tables 8 and 9. The TS data shows that the PC and SK treatments achieved the highest treatment efficiencies during the first 2 hours of treatment. This can be attributed to the tightly packed matrix of the pine chips and the increased surface area of the SK treatment. Further, the BR treatment did not achieve greater than 20 % removal of solids until after 6 hours, while the other treatments exhibited more than 20 % solids removal during the same time period. This can be attributed to the large voids present in the loosely packed and less dense bioring media. The VS data was generally similar to the TS, $BOD_5$, and COD data, e.g., higher treatment efficiencies were observed after the 24 hour sampling period, excluding the SK treatment. After 48 hours, there was virtually no difference in the VS removal efficiency.

**Olfactory Panel Response**

Duncan's Multiple Range test was used to compute all statistical inference within each time period block. All statisticsl inferences were completed using $\alpha$ = 0.05. Mean panelist response and statistical inference of the olfactory panel data are presented in tables 10, 11, and 12.

Olfactory evaluation results at t = 0 hours of treatment are presented in table 10. The data shows no significant difference for the components pleasant, intensity, acrid, sulfur, earthy, musty, cheesy, and ammonia for this time period. The fecal and sweet components of the odor character were significantly different in the treatments. Mean panelist response for these components ranged from 0.2955-1.667 for fecal, and between 0.0566-0.3333 for sweet.

Olfactory evaluation results at t = 24 hours of treatment are presented in table 11. The data shows no significant difference in the treatments for the odor categories acrid, sulfur, musty, sweet, and ammonia. The kenaf treatment (K) scored in the lower mean response groups for the categories pleasant, fecal, and cheesy. Further, the data shows the kenaf treatment (K) is not significantly different from any other treatment for the odor component intensity. Most importantly, a change in the character of the odor begins to appear during this phase of the treatment. The data for the component earthy shows that the kenaf treatment (K) was significantly different from all other treatments and scored the highest mean response, 1.8846. Further, the small kenaf treatment (SK) was significantly different from all other treatment and scored in the second highest mean response group, 0.8077. There was no significant difference between the

other treatments (BR, R, PC, C, and Pit) in the earthy category.

Olfactory evaluation results after t = 48 hours of treatment (the endpoint of the experiment) are presented in table 12. There was no significant difference between any of the treatments for the odor components acrid, sweet, and ammonia. The kenaf treatment (K) scored in the highest mean response group in the earthy category, and was not significantly different from the bioring (BR) and rock (R) treatments. Kenaf scored in the highest mean response group for the intensity odor component, and was not significantly different from the small kenaf (SK), rock (R), and control (C) treatments. This elevated intensity level can be directly attributed to the rise in the earthy content of the odor character. The anaerobic pit simulator (Pit) scored in the highest mean response group for the odor component sulfur, and was significantly different from all other treatments.

## CONCLUSION

This research presents a comprehensive comparison of kenaf versus conventional and non-conventional attached growth media for use in the biological treatment of swine wastewater. Water quality data shows that kenaf performed as well, and in some cases better than conventional media (rocks and biorings) used in industrial and municipal waste treatment settings. Further, olfactory data shows that the kenaf medium successfully changed the character of the swine waste odor from an intense, fecal, and somewhat acrid odor to an odor characterized by a lower overall intensity and a pronounced earthy character.

Results from this study show that kenaf may be a viable attached growth media for use in the treatment of livestock waste. Further research is needed to evaluate the economic feasability of implementing SORBS. While the SORBS concept was developed specifically for agricultural applications, it may have a similar utility in the treatment of industrial and municipal wastewater.

## REFERENCES


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**Table 1. Wastewater analysis instrumentation and protocol.**

| Analylate | Instrument | Protocol |
|---|---|---|
| Ammonia | Bausch & Lomb-Spectronic Model 601 | Nessellerization (Colorimetric) |
| $BOD_5$ | YSI Model 5905 BOD Probe, YSI Model 58 DO Meter, and a VWR Scientific Model:2005 Incubator | Standard Methods, 17th Edition, Procedure 52110 B |
| COD | Hach COD Reactor (Model 45600) and Hach DR/890 Colorimeter | Hach Company, COD Digestion Vial Type - High Range (0-1500 ppm) |
| pH | Fisher Scientific Accumet 950 ph.Ion or Orion SensorLink pH/ISE/ORP | Standard Methods, 17th Edition, Procedure 4500-H |
| Ortho Phosphorus | Lachat QuickChem 8000 Auto Analyzer | Lachat QuickChem Method: 10-115-01-1-A |
| Total Phosphorus | Lachat BD-46 Block Digester and Lachat QuickChem 8000 Auto Analyzer | Lachat QuickChem Method: 10-115-01-1-C |
| TKN | Lachat BD-46 Block Digester and Lachat QuickChem 8000 Auto Analyzer | Lachat QuickChem Method:10-107-06-2-D |
| Total Solids | Precision Scientific Model 144 Drying Oven (105°C) | Standard Methods, 17th Edition, Procedure 2540 B |
| Volatile Solids | Precision Scientific Model 144 Drying Oven (105°C) and Blue M Muffle Furnace (550°C) | Standard Methods, 17th Edition, Procedure 2540 E |

**Table 2. Average $BOD_5$ data for treatments expressed in mg/L.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 2853.00 | 1850.40 | 1141.50 | 508.20 | 72.90 | 163.56 |
| BR | 2181.00 | 1676.40 | 1104.00 | 481.20 | 113.30 | 152.82 |
| R | 4425.00 | 2513.40 | 954.00 | 693.90 | 146.40 | 208.46 |
| PC | 1845.00 | 2423.40 | 599.50 | 461.20 | 57.30 | 184.20 |
| Pit | 2489.00 | 1982.20 | 858.00 | 987.60 | 480.50 | 743.10 |
| SK | 1271.00 | 1419.00 | 2439.00 | 1066.20 | 318.20 | 85.20 |

**Table 3. Treatment efficiencies for $BOD_5$ data expressed as % reduction.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 0.00 | 35.14 | 59.99 | 82.19 | 97.44 | 94.27 |
| BR | 0.00 | 23.14 | 49.38 | 77.94 | 94.81 | 92.99 |
| R | 0.00 | 43.20 | 78.44 | 84.32 | 96.69 | 95.29 |
| PC | 0.00 | 0.00 | 67.51 | 75.00 | 96.89 | 90.02 |
| Pit | 0.00 | 20.36 | 65.53 | 60.32 | 80.70 | 70.14 |
| SK | 0.00 | 0.00 | 0.00 | 16.11 | 74.96 | 93.30 |

**Table 4. Average COD data for treatments expressed in mg/L.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 2738.67 | 1653.33 | 1328.00 | 921.33 | 83.33 | 300.00 |
| BR | 3280.00 | 2135.33 | 1493.33 | 948.67 | 204.00 | 190.00 |
| R | 3384.67 | 1603.33 | 1454.00 | 1266.67 | 162.00 | 170.67 |
| PC | 3332.67 | 1447.33 | 1043.33 | 637.33 | 682.67 | 276.00 |
| Pit | 2783.33 | 1657.33 | 1450.00 | 1272.67 | 602.67 | 2924.67 |
| SK | 2480.00 | 1708.00 | 1452.67 | 1387.33 | 504.41 | 113.73 |

**Table 5. Treatment efficiencies for COD data expressed as % reduction.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 0.00 | 39.63 | 51.51 | 66.36 | 96.96 | 89.05 |
| BR | 0.00 | 34.90 | 54.47 | 71.08 | 93.78 | 94.21 |
| R | 0.00 | 52.63 | 57.04 | 62.58 | 95.21 | 94.96 |
| PC | 0.00 | 56.57 | 68.69 | 80.88 | 79.52 | 91.72 |
| Pit | 0.00 | 40.46 | 47.90 | 54.28 | 78.35 | 0.00 |
| SK | 0.00 | 31.13 | 41.42 | 44.06 | 79.66 | 95.41 |

**Table 6. Average TS data for treatments expressed in mg/L.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 1741 | 1597 | 1307 | 856 | 565 | 889 |
| BR | 1864 | 1923 | 1696 | 1504 | 925 | 836 |
| R | 2063 | 1768 | 1397 | 1318 | 777 | 836 |
| PC | 1797 | 1204 | 1073 | 652 | 614 | 874 |
| SK | 1953 | 1399 | 1224 | 1167 | 809 | 640 |
| Pit | 1700 | 1426 | 1269 | 1133 | 1248 | 1407 |

**Table 7. Treatment efficiencies for TS data expressed as % reduction.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 0 | 8.27 | 24.93 | 50.83 | 67.55 | 48.94 |
| BR | 0 | 0 | 9.01 | 19.31 | 50.38 | 55.15 |
| R | 0 | 14.30 | 32.28 | 36.11 | 62.34 | 59.48 |
| PC | 0 | 33.00 | 40.29 | 63.72 | 65.83 | 51.36 |
| SK | 0 | 28.37 | 37.33 | 40.25 | 58.58 | 67.23 |
| Pit | 0 | 16.12 | 25.35 | 33.35 | 26.59 | 17.24 |

**Table 8. Average VS data for treatments expressed in mg/L.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 1311 | 1353 | 1392 | 744 | 129 | 363 |
| BR | 1470 | 1690 | 1650 | 1397 | 460 | 351 |
| R | 1627 | 1545 | 1267 | 1125 | 194 | 352 |
| PC | 1265 | 1041 | 949 | 576 | 198 | 406 |
| SK | 1603 | 1080 | 954 | 859 | 541 | 312 |
| Pit | 1315 | 1276 | 1138 | 1024 | 683 | 894 |

**Table 9. Treatment efficiencies for VS data expressed as % reduction.**

| | Sampling interval (hr) | | | | | |
|---|---|---|---|---|---|---|
| TRT | 0 | 2 | 4 | 6 | 24 | 48 |
| K | 0 | 0 | 0 | 43.25 | 90.16 | 72.31 |
| BR | 0 | 0 | 0 | 4.97 | 68.71 | 76.12 |
| R | 0 | 5.04 | 22.13 | 30.85 | 88.08 | 78.37 |
| PC | 0 | 17.71 | 24.98 | 54.47 | 84.35 | 67.91 |
| SK | 0 | 32.63 | 40.49 | 46.41 | 66.25 | 80.54 |
| Pit | 0 | 2.97 | 13.46 | 22.13 | 48.06 | 32.02 |

**Table 10. Mean response and statistical inference for samples at t = 0 hours of treatment.**

| | Categories and mean response | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trt | Pleasant | Intensity | Acrid | Sulfur | Earthy | Musty | Fecal | Cheesy | Sweet | NH3 |
| K | 5.4091 | 2.875 | 0.3958 | 0.6667 | 0.3333 | 0.5 | 0.8750 | 0.2917 | 0.1667 | 0.5833 |
| SK | 5.5455 | 3.2917 | 0.4583 | 0.8333 | 0.25 | 0.4583 | 1.4792 | 0.5833 | 0.1875 | 0.4792 |
| BR | 5.1818 | 2.4583 | 0.5208 | 0.4583 | 0.1667 | 0.6667 | 0.5 | 0.4167 | 0.1667 | 0.5909 |
| R | 5.825 | 3.0 | 0.5 | 0.5455 | 0.2727 | 0.4091 | 1.3636 | 0.6818 | 0.0227 | 0.2727 |
| PC | 5.1818 | 2.375 | 0.3958 | 0.2917 | 0.3333 | 0.5833 | 0.7917 | 0.2708 | 0.0833 | 0.6364 |
| C | 5.6250 | 3.5 | 0.5556 | 0.8889 | 0.0556 | 0.5556 | 1.6667 | 0.4444 | 0.0556 | 0.4444 |
| Pit | 5.1364 | 2.9792 | 0.6875 | 0.7917 | 0.0625 | 0.5 | 0.2955 | 0.9583 | 0.3333 | 0.5833 |
| | Statistical inference | | | | | | | | | |
| K | a | a | a | a | a | a | abc | a | ab | a |
| SK | a | a | a | a | a | a | ab | a | ab | a |
| BR | a | a | a | a | a | a | c | a | ab | a |
| R | a | a | a | a | a | a | ab | a | b | a |
| PC | a | a | a | a | a | a | bc | a | ab | a |
| C | a | a | a | a | a | a | a | a | ab | a |
| Pit | a | a | a | a | a | a | c | a | a | a |

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

**Table 11. Mean response and statistical inference for samples at t = 24 hours of treatment.**

| | Categories and mean response | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trt | Pleasant | Intensity | Acrid | Sulfur | Earthy | Musty | Fecal | Cheesy | Sweet | NH3 |
| K | 4.2692 | 2.2692 | 0.0385 | 0.1923 | 1.8846 | 0.4615 | 0.1538 | 0.0769 | 0.0385 | 0.0385 |
| SK | 5.4231 | 2.8846 | 0.5385 | 0.6538 | 0.8077 | 0.6154 | 1.2308 | 0.7692 | 0.1923 | 0.1538 |
| BR | 5.2308 | 2.7692 | 0.4808 | 0.4231 | 0.2308 | 0.1731 | 1.0962 | 0.5769 | 0.2692 | 0.1667 |
| R | 5.4583 | 2.9583 | 0.6667 | 0.7083 | 0.1250 | 0.3750 | 1.0833 | 0.7917 | 0.125 | 0.125 |
| PC | 4.1923 | 1.0385 | 0.0769 | 0.2308 | 0.1154 | 0.1538 | 0.4231 | 0.5 | 0.0769 | 0.0769 |
| C | 5.1154 | 1.9423 | 0.7115 | 0.1923 | 0.1923 | 0.6154 | 0.3654 | 0.3462 | 0.0769 | 0.2308 |
| Pit | 4.125 | 1.6458 | 0.3333 | 0.4583 | 0.1667 | 0.1667 | 0.8750 | 0.2803 | 0.3125 | 0.2803 |
| | Statistical inference | | | | | | | | | |
| K | bc | ab | a | a | a | a | c | b | a | a |
| SK | a | a | a | a | b | a | a | a | a | a |
| BR | a | a | a | a | c | a | ab | ab | a | a |
| R | a | a | a | a | c | a | ab | a | a | a |
| PC | bc | b | a | a | c | a | abc | ab | a | a |
| C | ab | ab | a | a | c | a | bc | ab | a | a |
| Pit | c | ab | a | a | c | a | abc | ab | a | a |

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

**Table 12. Mean response and statistical inference for samples at t = 48 hours of treatment.**

| | Categories and mean response | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Trt | Pleasant | Intensity | Acrid | Sulfur | Earthy | Musty | Fecal | Cheesy | Sweet | NH3 |
| K | - | 2.7857 | 0.4286 | 0.1071 | 1.6964 | 0.75 | 0.3393 | 0.1786 | 0.0714 | 0.1786 |
| SK | - | 1.8929 | 0.25 | 0.0714 | 0.7143 | 0.3214 | 0.5 | 0.3214 | 0.1071 | 0.1786 |
| BR | - | 1.8036 | 0.1429 | 0.0 | 1.125 | 0.4464 | 0.0 | 0.0357 | 0.1071 | 0.0357 |
| R | - | 1.8929 | 0.1071 | 0.0 | 1.375 | 0.2679 | 0.4821 | 0.1071 | 0.1786 | 0.0769 |
| PC | - | 0.4231 | 0.0385 | 0.0 | 0.2692 | 0.1538 | 0.0192 | 0.0 | 0.0 | 0.0 |
| C | - | 2.0714 | 0.25 | 0.1071 | 0.4464 | 0.4464 | 0.9286 | 0.5714 | 0.1786 | 0.2143 |
| Pit | - | 1.4821 | 0.1429 | 0.3571 | 0.0714 | 0.2143 | 0.5536 | 0.5 | 0.2143 | 0.0714 |
| | Statistical inference | | | | | | | | | |
| K | - | a | a | b | a | a | ab | abc | a | a |
| SK | - | ab | a | b | bc | b | ab | abc | a | a |
| BR | - | b | a | b | ab | ab | b | c | a | a |
| R | - | ab | a | b | a | b | ab | bc | a | a |
| PC | - | c | a | b | c | b | b | c | a | a |
| C | - | ab | a | b | c | ab | a | a | a | a |
| Pit | - | b | a | a | c | b | ab | ab | a | a |

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

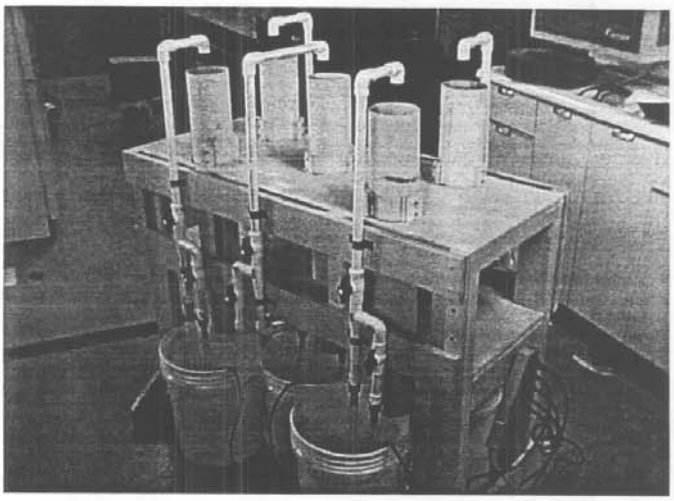

Figure 1. Laboratory-based ORBS (5-cells).

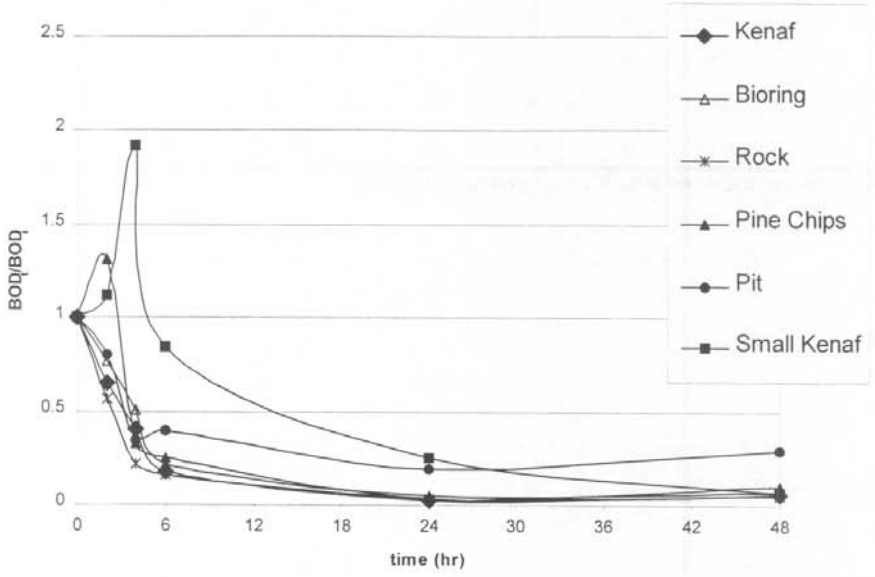


Figure 2. $BOD_{5t}/BOD_{5t}$ vs time.

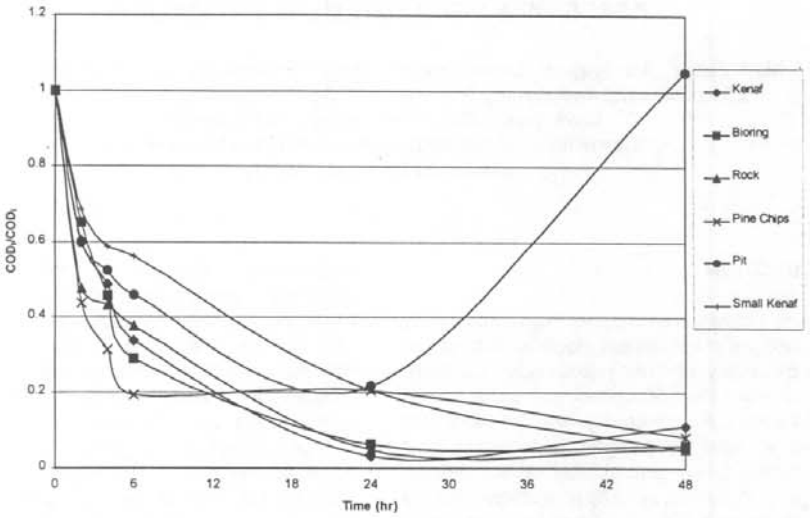


**Figure 3. CODt/CODi vs time.**