EFFECT OF DISSOLVED OXYGEN CONCENTRATION ON THE AEROBIC STABILIZATION OF SWINE WASTE

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Most aerobic waste treatment system designs recommend that the dissolved oxygen concentration be maintained at 0.5 - 2.0 mg/l. This design parameter may not be applicable to high strength wastes. Swine wastes (initial chemical oxygen demand (COD), 30,000 mg/l) were batch-digested at three levels of dissolved oxygen (0.5-2.0 mg/l, 5-8 mg/l, and 15-20 mg/l) over 14-day treatment periods. The results indicate that dissolved oxygen concentrations greater than 2 mg/l produce a significant increase in the rate of aerobic stabilization of the waste. For this waste, the bacteria were able to remove the organic compounds responsible for the soluble COD from solution within 2 days at all oxygen levels but they were able to oxidize these chemicals more rapidly at the higher oxygen concentrations. This increase in the rate of stabilization with oxygen concentration could have a direct effect on the design of waste treatment systems for other high strength animal and food processing wastes.

INTRODUCTION

Intensified livestock production has resulted in large volumes of animal manures being produced on small land areas. In many cases there is insufficient land available to use the nutrients in these manures optimally through a normal crop production program. This surplus has stimulated research to develop treatment methods that will enable producers to find alternate reuse or disposal systems. Many of these systems involve the aerobic treatment of manures for conversion into a form suitable for use as an animal feed or to reduce their oxygen demand before final disposal. Much of the work to date in aerobic animal waste treatment systems has been based on applying principles that were originally developed for the treatment of municipal sewage. Because of the differences in the characteristics of animal wastes and municipal sewage, such as solids concentration, biodegradability, settleability and bacterial population, it is quite possible that many of these principles are not directly applicable.

One of the areas where the differences encountered could have a significant effect on systems design is in the concentration of dissolved oxygen required for satisfactory aerobic oxidation. Most systems that are designed for the aerobic treatment of municipal wastes recommend the dissolved oxygen concentration be maintained in the range of 0.5 - 2 mg/l and this is supported by the work of Thabaraj and Gaudy (1971). Oxygen concentrations greater than this have been reported to give no significant improvement in biochemical oxygen demand (BOD) removal efficiency for animal wastes (Loehr 1971).

Recent studies on the use of pure oxygen in waste treatment systems have indicated that oxygen concentrations from 1 to 14 mg/l resulted in no change in substrate removal kinetics (Ball and Hunenick 1973). But, in activated sludge floes with a diameter greater than 500μ, calculations showed that oxygen concentrations greater than 2.5 mg/l would be required to maintain completely aerobic conditions (England and Eckenfelder 1973). Other research using oxygen concentrations of 8-10 mg/l in an activated sludge system indicated that a dissolved oxygen concentration of 1 ppm in the control experiment might be leading to anaerobic conditions inside the bacterial flocs (United States Department of the Interior 1970).

Irgens and Day (1966) in their studies on aerobic stabilization of swine waste maintained a dissolved oxygen level of 1 mg/l during treatments. They recommended that a dissolved oxygen level of 0.5 - 2 mg/l be used in the design of oxidation ditches and this is supported by work of others (Jones et al. 1970).

The purpose of this study was to determine whether the rate of stabilization of high strength swine wastes is affected by dissolved oxygen concentration.

MATERIALS AND METHODS

A series of batch tests were conducted to evaluate the effect of dissolved oxygen concentration on the aerobic stabilization of swine wastes. The batch tests were conducted over a 15-day period and changes in the chemical oxygen demand (COD), and the total organic carbon (TOC) were monitored daily. Three 1/4-capacity digesters were used and were held at the following dissolved oxygen concentrations: high 0; level (15-20 mg/l); medium 0; level (5-8 mg/l); and low 0; level (0.5-2 mg/l).

The wastes used throughout the study were collected from an anaerobic holding tank in a commercial hog-finishing operation. Prior to entering the holding tank, the waste had undergone limited anaerobic decomposition within the barns over a 6-wk period and then passed through an overflow system to the tank. The wastes were collected and transported to a laboratory where they were stored at 4°C until they were used in the experiments. The wastes were aerated at room temperature (20-23°C) using three specially constructed 5/l polyethylene digesters. Inverted T-bars located close to the bottom of each digester and connected to variable speed motors were used to stir the contents of the digesters. Aeration was provided by a small air pump or pressurized cylinders of pure oxygen. The gases were passed through submerged porous stones to maintain the dissolved oxygen concentration in the digesters at preset levels.

Analytical Methods

The chemical oxygen demand (COD) was performed as outlined in Standard Methods (American Public Health Association (APHA) 1971) for the 20-ml sample size. A 20-ml sample was taken from the digester and a 5:1 dilution prepared using a volumetric flask. For soluble COD determinations, the 5:1 diluted sample was filtered using No. 1 Whatman filter paper and 20 ml of the filtrate used in the analysis. For total COD determination, the 5:1 sample was diluted to 10:1 and a 20-ml portion was used in the analysis.

Values for total residue and total volatile residue were obtained as outlined in Standard Methods (APHA 1971) with the following modification. An exact volume of sample was not used. A sample of the digester contents was transferred to a graduated cylinder and the volume recorded. This sample was then transferred to an evaporating dish and the analysis done in the normal manner. This modification avoided the problems of settling which are common with high particulate wastes when exact volume measures are taken.

The oxygen concentration of the digesters was monitored using an oxygen meter and probe (Yellow Springs Instrument Co., Model 54). The system was periodically calibrated against a known dissolved oxygen concentration as determined by the Azide Modification of the Winkler Method (APHA 1971).
**Digester Test Trial**

An initial test trial was carried out on the three digesters to determine whether the digesters acting under the same conditions would produce the same biodegradation of the animal wastes.

Each of three digesters was filled with 5 l of anaerobic swine waste (COD, 24,000 mg/l on a wet weight basis). The waste was oxidized over a 15-day period and the rate of breakdown of the material was evaluated using daily COD determinations. The oxygen concentration in each of the digesters was maintained at a level of 6 - 8 mg/l.

For each of the subsequent trials the low, medium and high oxygen level in each digester was chosen randomly. The results of the experiments have been reported in the same sequence for ease of reading.

**Batch Tests A and B: Oxygen Concentration Effects**

At the start of each test, each digester was filled with 5 l of anaerobic swine waste. Throughout the test, one digester was maintained at a low dissolved oxygen concentration; 0.5 - 2 mg/l. A second digester was maintained at a medium dissolved oxygen concentration; 5 - 8 mg/l; and the third digester was maintained at a high dissolved oxygen concentration; 15 - 20 mg/l. The desired oxygen concentration was maintained by manually adjusting the proportions of air and pure oxygen being supplied by the digesters with the total flow rate being kept constant. Samples were taken daily from the digesters throughout the 15-day experiment and were analyzed for COD, total residue, and total volatile residue.

**Batch Test C — Effect of Oxygen Concentration on Waste Stabilization after Seeding with Aerated Swine Waste**

This test was carried out to determine if seeding the digesters with previously aerated swine waste would alter the effect that different levels of dissolved oxygen had on the rate of stabilization of the waste. An initial seed with an active aerobic bacterial population was established in a sample of swine waste by maintaining the dissolved oxygen at 5 ppm for 3 days. The three digesters were each filled with 4 l of anaerobic swine waste, aerated for 4 h to remove the dissolved gases; 1 l of the previously aerated waste was added to each of the digesters, and the waste then aerated for a 15-day period.

The dissolved oxygen concentration was monitored for each of the three digesters as before and maintained at the low, medium and high concentrations as in tests A and B. Oxygen uptake rates were determined periodically for the three digesters.

To determine oxygen uptake rates, the oxygen probe was inserted into the digester, the rotor speed was increased to provide good agitation and the oxygen supply was shut off. The level of dissolved oxygen was recorded at various time intervals and plots were prepared using this data. The oxygen uptake rates in mg/min were determined from these plots. In the digesters where pure oxygen was being used, the digester contents were purged with air so that the three digesters all had the same initial oxygen concentration at the beginning of the rate determination.

Daily COD determinations were made on samples from each of the digesters before and after filtering using a No. 1 Whatman filter paper.

Viable organism concentrations were determined at various times using the standard plate count with serial dilution and plate plate inoculation techniques (APHA 1971).

**RESULTS AND DISCUSSION**

**Digester Test Trial**

The initial test trial was run to determine if there were any differences among the digesters when they were operated under essentially identical conditions. The pH of the digesters started at 7.5 and rose to 8.9 and then remained constant throughout the experiment. The temperature in the digesters was allowed to fluctuate with the laboratory temperature (24.5 + 3°C).

The rates of COD reduction in the three digesters were similar to each other. The COD vs. time curve for the medium oxygen concentration in batch test A (Fig. 1) was typical of all three digesters in this trial run.

A least squares linear regression on the change in COD with time was calculated from the data from each digester. A covariance analysis was made on this COD data and the regression lines for the three digesters compared for differences in levels and slopes (Snedecor 1956). There was no difference in the % significance level between digesters II and III. However, digester I had a lower rate of COD reduction than digesters II and III. An examination of the daily COD analysis showed that there was very little change in the COD for digester I from day 3 to day 5.

This lag phase did not show up in digesters II or III. The records showed that the dissolved oxygen level in digester I had dropped to less than 0.1 mg/l sometime after 1600 h on day 2 until 1000 h on day 3. This low level of oxygen appears to have caused the lag in COD reduction. An analysis of the data indicated that a 24-h lag phase could account for the difference in slope down to the 1% significance level between digester I and the other two digesters. This indicated that the aerobic treatment of wastes in the digesters should operate in the same manner under similar conditions but that low oxygen concentrations could adversely affect treatment rates.

**Batch Tests A and B**

Batch tests A and B were run to determine what effect the level of dissolved oxygen would have on COD removal. The three digesters were maintained at different levels of dissolved oxygen throughout the oxidation period. The TOC analyses carried out on the same samples as the daily COD tests showed a positive correlation and provided a check on the COD analyses. The relationship between COD and TOC for both filtered and unfiltered samples has been reported previously (Bulley and Husdon 1974). The COD values for the two batch tests are summarized in Table I.

There was a definite effect of oxygen concentration on the COD reduction with 48.7% reduction after 7 days at the high oxygen and a 15.7% reduction at the low oxygen. After 14 days, the percentage reductions had increased to 57.8% at the high oxygen and 38.9% at the low oxygen. The changes in COD with time for the three oxygen treatments for batch test A are shown in Fig. 1. The slow COD reductions at the low and medium O₂ concentrations appear to be due to a lag phase which occurred for the first 7 days at the low oxygen and for about 3 days at the medium oxygen concentration.

It can be seen in Fig. 1 that for the high oxygen treatment, the COD vs. time relationship could be approximated by two different linear functions, one for the first 6 days and the second for the last 8 days. It was not possible to describe them by the same linear function throughout. Since the main difference in COD between oxygen levels occurred during the first 7 days (see Table I), the data was adjusted to consider this in the best straight line to approximate the data. This was done by including only COD values over 16,000 mg/l, since it was below this level that the rate of COD reduction dropped off sharply for the high oxygen treatment. With this adjustment, COD values were included for the first 6 days for the high oxygen treatment, for the first 12 days for the medium oxygen treatment, and...
TABLE I. EFFECT OF OXYGEN CONCENTRATION, ON THE CHANGE IN COD (mg/l) OF SWINE WASTE DURING AEROBIC STABILIZATION

<table>
<thead>
<tr>
<th></th>
<th>Batch test A</th>
<th>Batch test B</th>
<th>Batch test C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High oxygen (15-20 mg/l)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>30,400</td>
<td>30,313</td>
<td>36,000</td>
</tr>
<tr>
<td>After 7 days</td>
<td>15,880</td>
<td>15,256</td>
<td>20,140</td>
</tr>
<tr>
<td>Percentage reduction</td>
<td>47.8</td>
<td>49.6</td>
<td>48.7</td>
</tr>
<tr>
<td>After 14 days</td>
<td>13,014</td>
<td>12,616</td>
<td>19,090†</td>
</tr>
<tr>
<td>Percentage reduction</td>
<td>57.2</td>
<td>58.4</td>
<td>47.0</td>
</tr>
<tr>
<td><strong>Medium oxygen (5-8 mg/l)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>31,776</td>
<td>30,993</td>
<td>32,120</td>
</tr>
<tr>
<td>After 7 days</td>
<td>21,629</td>
<td>18,972</td>
<td>24,000</td>
</tr>
<tr>
<td>Percentage reduction</td>
<td>32.0</td>
<td>38.8</td>
<td>25.3</td>
</tr>
<tr>
<td>After 14 days</td>
<td>15,886</td>
<td>15,061</td>
<td>20,000†</td>
</tr>
<tr>
<td>Percentage reduction</td>
<td>50.0</td>
<td>51.4</td>
<td>37.7</td>
</tr>
<tr>
<td><strong>Low oxygen (0.5-2 mg/l)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>32,180</td>
<td>30,896</td>
<td>38,600</td>
</tr>
<tr>
<td>After 7 days</td>
<td>28,568</td>
<td>24,645</td>
<td>30,800</td>
</tr>
<tr>
<td>Percentage reduction</td>
<td>11.2</td>
<td>20.2</td>
<td>20.2</td>
</tr>
<tr>
<td>After 14 days</td>
<td>17,800</td>
<td>20,730</td>
<td>26,600†</td>
</tr>
<tr>
<td>Percentage reduction</td>
<td>44.7</td>
<td>32.9</td>
<td>31.1</td>
</tr>
</tbody>
</table>

115 days

TABLE II. PERCENTAGE REDUCTION TOTAL VOLATILE RESIDUE

<table>
<thead>
<tr>
<th></th>
<th>Batch test A</th>
<th>Batch test B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High oxygen</strong></td>
<td>19.1</td>
<td>32.6</td>
</tr>
<tr>
<td><strong>Medium oxygen</strong></td>
<td>11.8</td>
<td>23.1</td>
</tr>
<tr>
<td><strong>Low oxygen</strong></td>
<td>17.4</td>
<td>21.1</td>
</tr>
</tbody>
</table>

for the entire oxidation period for the low oxygen treatment. With these limitations, a linear regression analysis was made for the reduction of COD with time, combining the results of batch tests A and B.

A statistical analysis of the data showed that the slopes of the daily COD determinations were found to be different at the 1% level of significance. These plots are shown in Fig. 2.

The reduction of total volatile residue after 14 days, in batch tests both A and B, was greater for the high dissolved oxygen treatment than for the medium and low levels. The reduction of total volatile residue at the medium and low level was not consistent. The low level reduced a greater percentage than the medium level in batch test A but less than the medium level in batch test B. These reductions are summarized in Table II.

**Batch Test C**

It was felt that the lag in the removal of COD that was evident in the low and medium levels of dissolved oxygen was possibly due to the lack of a suitable biological culture. Batch test C was run to determine the effect of oxygen concentration on the rate of biological breakdown of swine wastes that had been seeded with aerated swine waste. The COD of the contents of the digesters was analyzed daily (Fig. 3) and the overall reductions in COD are summarized in Table I. The daily COD values for the filtrate from the filtered samples are also shown (Fig. 3). The lines on Fig. 3 have been hand drawn and are included to show trends during the digestion of the waste.

Seeding of digesters did not affect the rate or degree of treatment significantly. The rate of COD removal at each of the oxygen concentrations was similar to the rates observed in experiments A and B. A least squares linear regression was calculated for the pooled data of experiments A, B and C, and a covariance analysis was made on this data. The slopes of the lines were significantly different at the 1% confidence level.

A study of the filtered COD vs. time data, as compared to the unfiltered COD vs. time data (Fig. 3), may shed more light on the cause of the reduced oxidation rate at the lower oxygen concentration.

During day 2 there was a rapid decrease in soluble COD followed by a slow decline over the next 12 days. The high removal of soluble COD on day 2 was accompanied by a corresponding decline in total COD at the high and medium oxygen concentrations but not at the low oxygen concentration.

This would indicate that even though about 40% of the soluble COD was rapidly removed in all three digesters, it was only being stored within the micro-organisms at the low O₂ concentration. This would account for the fact that there was no corresponding decrease in total COD. This interpretation is supported by the work of Robarts and Kempton (1971) who studied the removal of C₁₄ glucose by activated sludge. Their studies showed that large amounts of the substrate could be removed and stored within the cell and that this storage was separate from the oxidation process. This initial decrease in soluble COD can also be, in part, attributed to the "initial
TABLE III. BATCH TEST C, OXYGEN UPTAKE RATES AND BACTERIA COUNTS

<table>
<thead>
<tr>
<th>Day</th>
<th>(Low O₂) O₂ uptake (mg/l/min)</th>
<th>Bacteria count (colonies/ml)</th>
<th>(Medium O₂) O₂ uptake (mg/l/min)</th>
<th>Bacteria count (colonies/ml)</th>
<th>(High O₂) O₂ uptake (mg/l/min)</th>
<th>Bacteria count (colonies/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.8</td>
<td>1,380X10³</td>
<td>1.3</td>
<td>1,440X10³</td>
<td>3.2</td>
<td>1,380X10³</td>
</tr>
<tr>
<td>5</td>
<td>3.0</td>
<td>900X10³</td>
<td>2.4</td>
<td>1,620X10³</td>
<td>1.0</td>
<td>2,100X10³</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>1,000X10³</td>
<td>.4</td>
<td>1,200X10³</td>
<td>.4</td>
<td>1,500X10³</td>
</tr>
</tbody>
</table>

This high COD removal rate was sustained for only a relatively short time before a much slower oxidation process took over. Whether a continuous digester could be operated at the high oxygen levels and remove 45% of the COD in 7 days can not be predicted from these results. The seeding of the digesters did not help the COD removal rates at the medium and especially at the low oxygen concentrations as might have been expected. This would indicate that the level of dissolved oxygen in the digesters is very significant in determining the rate of oxidation for these concentrated wastes.

Although this work was carried out using swine wastes, the oxidation of other animal and food processing wastes with a high solids content may also be restricted by the maintained level of dissolved oxygen.

With the increase in interest in refeeding of wastes to livestock, the partial or complete oxidation of wastes into a form suitable as a livestock feed source should be investigated.

The capital costs of waste treatment systems using pure oxygen are high but are partially offset by the reduction in treatment time, equipment size, and process control.

Based on this research, further studies should be carried out using both batch and continuous treatment systems to determine the feasibility and practicability of increasing the dissolved oxygen concentrations in aerobic treatment systems for concentrated organic wastes.

CONCLUSIONS

1. During the batch aerobic stabilization of swine waste, the oxygen concentration does affect the rate of COD reduction.
2. For the unseeded batch treatment, the rate for COD reduction during the first 7 days of treatment was highest at high O₂ (15-20 mg/l), removing 49% of the COD. At the medium oxygen concentration (5-8 mg/l), 35% of the COD was removed after 7 days. The low oxygen digester (0.5-1.5 mg/l) had a definite lag phase during the first 7 days, reducing the COD by only 15%.
3. For seeded treatment, the rate of COD reduction was highest at high O₂ (15-20 mg/l).
4. There is a rapid uptake of organic compounds by the bacteria soon after treatment begins, resulting in a reduction in soluble COD. At high (15-20 mg/l) and medium (5-8 mg/l) O₂, this uptake of soluble COD is accompanied by a rapid oxidation with accompanying reduction in total COD. At low O₂ (0.5-2 mg/l), the rapid uptake of organic compounds was followed by a slow steady oxidation process.
5. After about 40% of the original COD has been removed, the rate of COD removal appears to be less dependent on the oxygen concentration.

ACKNOWLEDGMENT

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