THE EFFECT OF ANAEROBIC DIGESTION UPON SWINE MANURE ODORS

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A series of odor panels were established to determine the effect of anaerobic digestion on the odor of swine manure. Samples from digesters of various solids retention time, agitation rates and operating temperatures were tested. Anaerobically digested manure that had been stored for various periods of time and undigested manure samples were also tested. The results indicated that anaerobic digestion was effective in reducing odors but that some negative quality in the odor remained. Anaerobic digestion at 35C was more effective for reducing odor than anaerobic digestion at 25C. In certain cases, increased solids retention times and agitation rates were found to improve the odor-reducing capability of anaerobic digestion.

INTRODUCTION

Odor control is a major factor in determining the success of many livestock operations. This is especially evident in cases where clean air has been considered a property right that is subject to the jurisdiction of nuisance law (Lisoway vs. Springfield Hog Ranch Ltd. 1975; Giblin 1975; Willrich and Miner 1971). At present 42 odorous compounds have been found in offgases from livestock manure facilities (Miner 1974). These compounds include amines, amides, sulfides, disulfides, mercaptans and ammonia. In addition, alcohols such as methanol, butanol and ethanol and acids such as acetate, butyrate and caproate are also present in most anaerobic environments.

The odorous compounds resulting from the anaerobic storage of manure are the result of microbial fermentations. The anaerobic degradation of cellulose, lipids, proteins, and other complex organic materials results in intermediate fermentation products such as those previously mentioned which are responsible for most foul odors. However, under the controlled conditions of anaerobic digestion, these complex materials and intermediate products are further degraded by a selective microbial ecosystem into the odorless compounds CH_4 and CO_2. Thus, anaerobic digestion has been used for many years to stabilize the organic fraction of sewage sludge so as to effectively reduce odors resulting from sludge disposal.

Until recently, anaerobic digestion has been considered too costly to be a practical manure management alternative. Indeed, to the authors' knowledge, no systematic appraisal of the effect of anaerobic digestion on the odors from livestock manure has been reported in the scientific literature. Lapp et al. (1974) have suggested that anaerobic digestion may significantly reduce the odor of livestock manure. If this were true, anaerobic digestion not only could serve as a potential process for lessening the dependence of livestock producers on external energy supplies but also could play a useful role in the manure management strategy of livestock producers. Increasing energy costs are bringing about a reappraisal of the feasibility of anaerobic digestion of livestock manure. The purpose of the project described in this paper was to determine, through olfactory evaluation, the effect of anaerobic digestion on swine manure odors.

PROCEDURES

In the past, the majority of olfactory studies on animal manure odors have involved the determination of the threshold concentration of the odor. It has been suggested that although the odor quantification methodology available favors the determination of threshold concentrations, the most important feature of the sense of smell is the hedonics (Engen 1974). Thus, hedonic rating of the odor of anaerobically digested, undigested and stored swine manure was undertaken by a series of 35 ten-member odor panels which were formed twice weekly over a 4½-mo period. The panelists were selected from a pool of 33 faculty, staff and graduate students of the Department of Agricultural Engineering at the University of Manitoba. As a result of varying work schedules and holidays, five individuals participated in over half of the panels, while the remaining individuals participated in an average of 20% of the panels. No pre-testing of the panelists was undertaken.

The comparisons provided by the panel were those between (a) anaerobically digested swine manure, (b) untreated swine manure and (c) untreated swine manure and anaerobically digested swine manure which both had been stored for various lengths of time. The pilot-plant studies from which the effluent samples were obtained included four separate digesters operating independently of the odor panels assembled for this experiment. Thus the digester effluent samples were classified to match the experimental design of the pilot studies. Accordingly, two experimental periods were involved: (a) that having a constant digester temperature (35C) but varying solids retention times (SRT) and (b) that having a constant SRT (12 days) but two temperatures (25C and 35C). Nine and twenty-two replicate odor panels were obtained from these periods, respectively. This information and additional information regarding the length and temperature of stored influent and effluent samples are given in Table I.

On the day prior to an odor panel, effluent (anaerobically digested swine manure) and influent (untreated swine manure) samples were taken from the pilot-scale anaerobic digesters (Lapp et al. 1975) and were refrigerated at 4C until the following day when they were prepared for the panel. The untreated and digested swine manure samples which were to be stored were also gathered from the pilot-scale facilities, but only at 2-wk intervals. Four air-tight, 10-liter containers were filled with influent and effluent and were placed in storage at 4 and 21C, respectively, for a period which in each case was to last 11 wk. Subsamples were then taken from the appropriate containers so as to simulate various storage time intervals and to replicate these time intervals as often as possible. Accordingly, a minimum of three replicates was obtained for each time interval (Table I). The refrigerated samples of digester influent and effluent and the subsamples of stored influent and effluent were allowed to reach room temperature before presentation to the panelists.

Odorant samples were prepared by placing a 100-ml aliquot of the odorant in a 250-ml (glass) Erlenmyer flask which had been painted black. The flasks were cleaned immediately after each panel by a detergent-wash and then by an acid-wash, followed by a thorough rinse with distilled water. The flasks were then air-dried and stored until preparation began for the next panel.

During the first 10 wk of the study, each panelist received a set of 10 flasks, including a blank containing a 100-ml aliquot of distilled water and two flasks containing 0.5

TABLE I EXPERIMENTAL DESIGN

Sample description	SRT (days)	Digester temperature (°C)	Storage period (days)	Storage temperature (°C)	Number of panels
Digester effluent†					
1	6	35			9
2	10	35			9
3	10	35			9
4	20	35			9
5	12	35			22
6	12	35			22
7	12	25			22
8	12	25			22
Digester influent					
9	—	—			35
Stored effluent					
10			8	4	7
11			15	4	9
12			36	4	5
13			43	4	7
14			72	4	3
15			79	4	5
16			11	21	6
17			18	21	6
18			39	21	5
19			46	21	5
20			75	21	3
21			82	21	3
Stored influent					
22			22	4	6
23			29	4	8
24			25	21	6
25			32	21	6
Distilled water					
26					35
Dried swine manure					
27					10
28					10

†Samples 2, 4, 6 and 8 were mixed 12 min/h; 1 and 7 were mixed 2 min/h; and 3 and 5 were mixed 30 min/day.

and 1.0 g, respectively, of dried swine manure in 100-ml aliquots of distilled water. Digester influent served as the control through the entire experimental period. Analysis of the results from the dried swine manure samples and the control samples at the end of the 10-wk period indicated that the panelists had not altered their ratings significantly (at the .01 probability level) over that period (i.e. the panelists were not being trained with time and the results were not being influenced by panel make-up). Subsequently, the samples which had previously been stored were substituted for the dried-manure samples.

The 10 flasks used for each panel were arranged in random order and were presented simultaneously to a panelist. Each panelist quantified and characterized the samples independently but was allowed to repeat observations if it was felt necessary. The panelists were instructed to swirl the liquid contents of the flask gently before removing the cap and to wait approximately 10 sec between sniffs to prevent olfactory fatigue.

An 11-point hedonic-rating scale (Amerine et al. 1965; American Society of Testing and Materials 1968a, b, c) was utilized to quantify the presence and the offensiveness of the odor. To determine the presence rating, a rating of 0 was used to indicate no odor, while 10 was used to indicate a very strong odor. The numbers 1-9 were taken to be intermediate odor presences. A similar rating system was used to quantify the offensiveness of the odor. The data sheet used was similar to that developed and described by Sobel (1972) and the word descriptions allowed were those utilized by Sobel.

The data were analyzed using the Student's *t* statistic to determine the least significant difference (Steel and Torrie 1960)

TABLE II DIGESTER PERFORMANCE CRITERIA

Sample number	Total volatile acids (as acetic acid)	COD	Nitrogen: Total	Nitrogen: Ammonia-N	Volatile solids	*p*H	Gas production‡ (liters/g/day)	Organic loading rate§ (g/liter/day)
	(g/liter)	(g/liter)	(g/liter)	(g/liter)	(g/liter)			
Digester effluent								
1	0.20	35.3	2.67	2.84	23.6	8.1-8.2	0.42	4.43
2	0.13	32.3	2.74	2.82	22.8	8.1-8.2	0.53	2.66
3	0.15	32.2	2.74	2.64	22.7	8.1-8.2	0.55	2.66
4	0.15	31.6	2.78	2.69	21.3	8.1-8.2	0.70	1.33
5	0.26	42.6	4.36	3.54	29.2	7.8-8.1	0.48	3.10
6	0.23	39.2	4.51	3.47	28.6	8.0-8.1	0.47	3.10
7	0.45	53.3	3.99	3.33	32.5	7.7-7.8	0.29	3.10
8	0.41	52.8	3.78	3.42	32.6	7.7-7.9	0.33	3.10
Digester influent†								
9								
1-4	>1.40	55.7	2.87	2.70	26.6	6.8-6.9	—	—
5-8	>1.40	72.2	4.02	3.02	37.2	6.8-6.9	—	—

†Digester influent for samples 1-4 was of lesser concentration than for samples 5-8 due to different pilot-scale experiments.
‡Data reported as liters biogas per gram volatile solids added per day.
§Data reported as grams of volatile solids per liter of digester capacity per day.

between the presence and offensiveness ratings of a given treatment. Where statistically significant differences did not exist between these ratings, the presence and offensiveness data were averaged and reported as an overall odor rating. Differences between the overall odor ratings of the various treatments were analyzed for statistical significance using Tukey's *w*-procedure for multiple comparisons (Steel and Torrie 1960).

RESULTS AND DISCUSSION

Digester Influent and Effluent Characteristics

Barth et al. (1974) demonstrated that the odor intensity of stored manure was strongly influenced by its content of volatile organic acids (VOA), ammonia (NH_3) and hydrogen sulfide (H_2S). As stated earlier, anaerobic digestion would be expected to reduce the levels of complex organic materials and intermediate fermentation products such as volatile organic acids (VOA). As shown in Table II, the level of VOA in the digester influent (sample 9, untreated manure) was consistently reduced to less than 0.5 g/liter after digestion. Thus some reduction in odor intensity of the digester effluent samples might be expected.

The effect of reduced VOA content on odor intensity is enhanced by the increase in *p*H (Table II). The result of this increase is to shift the equilibrium between the gaseous and the ionized form of H_2S to the right (equation 1).

$$H_2S \rightleftharpoons HS^- + H^+ \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Therefore, relatively less H_2S gas would be dissolved in the digester effluent, and if the total amount of H_2S (ionized and unionized) remained constant or decreased, a lesser odor intensity would be expected.

The data in Table II also indicate that the concentration of NH_3-N increased as a result of anaerobic digestion. The average concentration in the effluent samples 1-4 and 5-8 were 2.75 and 3.44 g/liter, respectively, while the influent to those digesters contained 2.70 and 3.02 g/liter of NH_3-N, respectively. This increase, in combination with the elevated *p*H, partially offsets the effect of the reduced presence of VOA's and unionized H_2S by increasing the presence of NH_3 (equation 2).

$$NH_4 \rightleftharpoons NH_3 + H^+ \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Odor Ratings of Digester Influent and Effluent Samples

The overall odor ratings of the digested effluent samples were an average of 1.9 units lower than that of the digester influent. Insofar as the design parameters — SRT, organic loading rate and digester operating temperature — are concerned, their combined effect on odor ratings should be reflected in the VOA content of the digester influent. Data in Table II indicate that with the exception of the 25C digester effluent (samples 7 and 8), little difference between odor ratings of digested effluent samples might be expected. Indeed, when compared to one another, the odor ratings of digester effluent samples 1 through 8 were not statistically different (Table III).

TABLE III ODOR RATINGS OF DIGESTED AND UNDIGESTED SWINE MANURE

Sample number	Presence		Offensiveness		Odor rating	Statistical† comparison
	μ	σ	μ	σ		
Digester effluent						
1	5.30	1.27	5.18	1.38	5.24	*a, b*
2	4.34	0.88	4.09	0.65	4.22	*a*
3	4.87	0.96	4.70	0.98	4.78	*a, b*
4	4.43	1.45	4.09	1.49	4.26	*a*
5	4.08	0.91	4.03	0.93	4.06	*a*
6	4.03	0.70	3.96	0.71	3.99	*a*
7	5.12	0.88	5.19	0.89	5.16	*a, b*
8	4.97	0.94	5.10	0.88	5.04	*a, b*
Digester influent						
9	6.50	1.06	6.50	0.93	6.50	*b*
Distilled water						
26	0.34	0.51	0.34	0.54	0.34	
Dried swine manure						
27	2.79	0.60	1.68	0.54		
28	2.94	0.75	2.17	0.83		

†Odor ratings having same letters are not significantly different at 0.01 probability level.
μ = mean.
σ = standard deviation.

When the odor ratings of samples 1-8 were compared with those of the influent samples it was evident that some digester designs were, after all, more effective than others in reducing the presence and offensiveness of odors. For example, the odor ratings of samples 1, 3, 7 and 8 were not statistically different (at the 0.01 probability level) than those of the influent, whereas samples 2, 4, 5 and 6 had significantly lower odor ratings than the influent samples (Table III). Since the odor ratings of the influent served as a common basis of comparison for samples 1-8, the differences between samples 1, 3, 7 and 8 and 2, 4, 5 and 6 were ascribed to the design parameters of the digesters from which the samples were obtained.

Samples 7 and 8 had nearly twice the VOA levels of the comparative samples 5 and 6. Thus, greater odor ratings were anticipated for samples 7 and 8 which were taken from digesters operating at 25C as opposed to samples 5 and 6 taken from 35C digesters. Evidently, the lower digester operating temperature resulted in reduced biological activity, which in turn resulted in increased VOA levels and a greater presence and offensiveness of the effluent.

Although samples 1 and 3 had relatively low VOA levels when compared to other digester effluent samples, the odor ratings

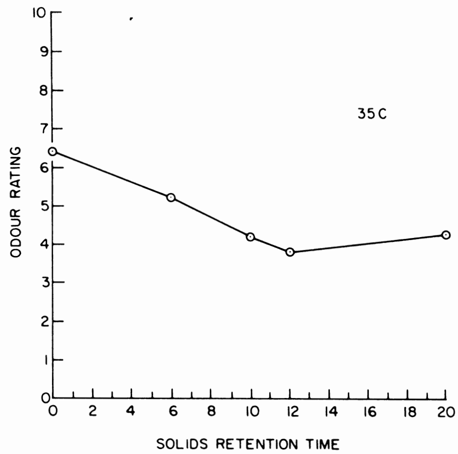

Figure 1. Effect of solids retention time on odor rating.

were higher and in fact were not statistically different than the odor rating of the digester influent. This suggests that the volatile acids alone were not at fault for the high odor ratings. The distinguishing features of samples 1 and 3 were their low SRT's (6 and 10 days, respectively) and the small amount of mixing provided for each. The added facts that samples 2 and 3 differed only in the amount of mixing provided (12 min/h as opposed to 30 min/day, respectively) and that sample 2 reduced odor ratings significantly when compared to digester influent, while sample 3 did not, imply that odor control in heavily loaded anaerobic digesters is enhanced by more frequent mixing.

There is an apparent influence of SRT on digester effluent odor ratings (Fig. 1). But, because of the relatively large standard deviations obtained between replicates, one cannot conclude, for example, that a 12-day SRT brought about a more significant reduction in odors than did a 6-day SRT.

TABLE IV ODOR RATINGS OF STORED SWINE MANURE AND UNDIGESTED SWINE MANURE

Sample number	Presence		Offensiveness		Odor rating	Statistical† comparison
	μ	σ	μ	σ		
Stored effluent						
10	4.80	1.21	4.47	1.16	4.64	*a,d*
11	3.43	0.75	3.33	0.79	3.38	*a, b*
12	3.74	1.04	3.44	1.22	3.59	*a, b*
13	3.40	0.88	3.17	0.87	3.29	*b*
14	3.33	0.67	3.00	0.56	3.17	*b*
15	3.42	1.04	3.42	1.11	3.42	*b*
16	4.00	0.34	4.05	0.29	4.03	*a, c, d*
17	3.65	0.67	3.48	0.88	3.57	*a, b, c*
18	2.91	0.46	3.03	0.47	2.87	*b, c*
19	3.19	1.05	3.15	1.19	3.17	*a, b, c*
20	3.40	0.26	3.63	0.12	3.52	*b*
21	2.67	0.80	2.57	1.17	2.61	
Stored influent						
22	6.00	0.64	6.13	0.53	6.07	*e, f*
23	5.59	1.21	5.61	1.20	5.60	*e, f*
24	5.30	1.34	5.38	1.46	5.35	*e*
25	4.88	0.80	4.93	0.85	4.91	*e, d*
Digester influent						
9	6.50	1.06	6.50	0.93	6.50	*f*

†Odour ratings having same letters are not significantly different at 0.01 probability level.
μ = mean.
σ = standard deviation.

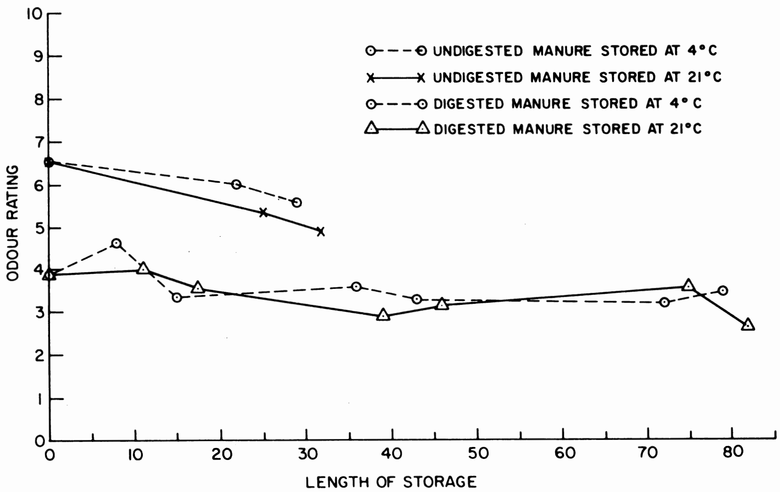

Figure 2. Effect of storage on odor rating.

One can conclude, however, that the odor ratings of effluent from digesters having at least a 10-day SRT and mixing at least once an hour were significantly less than undigested manure.

Odor Ratings of Stored Digester Influent and Effluent

The reduced presence and offensiveness of digester effluent odors remained even after storage for nearly 3 mos (Fig. 2). Storage temperature did not change the relative magnitude of the odor ratings of the effluent samples to any significant extent (Table IV). Likewise, the length of storage and storage temperature did not alter the relationship between odor ratings of stored effluent as compared to stored influent. A reduction in odor ratings did occur as the length of storage increased for both the stored effluent and stored influent samples. Over the 79- and 82-day storage intervals, the stored effluent underwent a gradual though somewhat erratic reduction in odor. The net effect of this gradual decrease was an odor reduction which, for both the 4C and 21C samples, was statistically significant at the 0.01 probability level (Table IV). Although the stored influent samples also appeared to be undergoing a gradual reduction in odor, the storage interval was not sufficient to establish the significance of the trend.

With the exceptions of samples 10 and 16, the odor ratings of the stored effluent were significantly less than those of the stored influent and the digester influent (Table IV). Samples 10 and 16 exhibited increased odor ratings over the corresponding freshly digested samples (Fig. 2). This increase may have been due to an accumulation of VOA and H_2S in the stored effluent during the initial days of storage. This might be expected because of the cessation of methanogenesis resulting from rapidly decreased temperatures. Consequently, VOA's could have increased with a concommittant decrease in *p*H and a subsequent buildup of H_2S gas in the stored effluent. Effluent samples which were stored for longer intervals probably did not exhibit increased odor ratings because more time was available for the microbial population to adapt to the lower temperatures and thus reduce the VOA levels.

Odor Descriptions

The majority of the panelists used one of the qualitative descriptions that were suggested on the data sheet. While a number of panelists volunteered sample descriptions, several were unable to give an adequate verbal description of the odors encountered during the experiments. The panelists' subjective odor experience appeared to play a significant role in determining the qualitative description of the odor. This is similar to the findings of Jonsson (1974).

The major qualitative odor description for all digested and undigested manure samples was "sulfide-like" or "rotten egg." The "ammonia" description and the "sour and fermented" and "mouldy, musty" descriptive terms were also quite popular. The major voluntary descriptive terms given by the panelists seemed to be "manure." Apparently, the type of odor did not significantly alter as a result of anaerobic digestion, but the intensity of the odor had been modified. A second descriptive term that was sometimes used was the term "rotten." This suggests that, despite the treatment, the odor still carried an obnoxious quality.

In a number of cases the panelists attempted to describe the odor in terms of the treatment the sample received. That is, the odor was described as similar, for example, to that of a "digested sample" or a "stored sample." In the majority of cases these attempts were incorrect. This reinforces the observation that though anaerobic digestion reduces the presence and offensiveness of swine manure odor, the effluent retains a quality similar to undigested manure.

SUMMARY AND CONCLUSIONS

Hedonic rating of odors from anaerobically digested swine manure and from undigested swine manure demonstrated that (1) anaerobic digestion reduced the presence and offensiveness of swine manure odors from a rating of 6.5 for undigested manure to an average of 4.6 for digested manure;

(2) anaerobic digestion at 35C was more effective in controlling odors than at 25C provided that agitation was provided at least once an hour and SRT's were 10 days or greater.

(3) digested swine manure that had been stored for approximately 30 days had a significantly lower odor rating than undigested manure that had been stored for an equivalent length of time.

(4) odors from digested swine manure that had been stored for nearly 3 mo were reduced in presence and offensiveness by approximately one additional odor unit when compared to freshly digested manure.

(5) although the odors from anaerobically digested swine manure were considerably reduced in presence and offensiveness, they were still identifiable as manure odors having negative qualities.

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