Changes in Swine Manure Solids During Storage May Affect Separation Efficiency

J. Zhu, P. M. Ndegwa, A. Luo

Abstract. *A laboratory study revealed the dynamic changes of solids in swine manure during storage in order to determine the best time for efficient solid-liquid separation treatment. Data showed that separation should be conducted within 10 days after manure excretion for particle sizes equal to or greater than 0.5 mm and within five days for particle sizes smaller than 0.5 mm. After the first 10 days of storage, the total suspended solids tended to be decomposed at a higher rate, thus reducing separation efficiency. Particles equal to or smaller than 0.25 mm were biologically decomposed at the same rate without relevance to the particle size during the first 20 days of storage. The level of total volatile solids in liquid manure was linearly correlated with the total solids content with a correlation coefficient of 0.9850 in the 30-day period.*

Keywords. *Separation efficiency, Particle size, Storage time, Swine manure.*

Solid-liquid separation has been widely used for treating municipal and industrial wastewaters. However, it has not become a popular unit operation for swine manure management, although past researchers have intensively focused on developing and testing different types of separation equipment with swine manure (White, 1980; Hegg et al., 1981; Moore, 1989; Powers et al., 1995; Zhang and Westerman, 1997). The major hindrance of using this technique rests with the high capital and operational costs and low separation efficiency. To date, there is little indication that swine producers will accept this technique unless improvements in either cost reduction or efficiency enhancement are made.

Research has already shown that swine manure solids characteristics may have an effect on separation processes (Zhang and Westerman, 1997). However, how these chemical constituents interact with the separation process has not been well studied. The total solids of swine manure is the sum of total suspended solids (TSS) and total dissolved solids (TDS). Both TSS and TDS can be divided further into total volatile solids (TVS) and total fixed solids (TFS). Separation only affects TSS with little effect on TDS which are usually removed by biological treatment or coagulation. Therefore, to increase the separation efficiency, it is necessary to remove as much of the TSS as possible. The prerequisite of achieving this requires that the major portion of TS in liquid manure should be present in the form of TSS. If TDS dominates, separation will no longer be efficient to remove solids from liquid manure.

Fresh swine manure contains high levels of suspended solids and low levels of dissolved solids (Evans et al., 1978). Once excreted from animals and stored anaerobically, the manure will naturally undergo decomposition. Since dissolved solids are easily degradable organic materials and suspended solids are slowly degradable substances, bacteria will first consume the dissolved solids and, at the same time, hydrolyze and convert the suspended solids into dissolved solids to obtain a continuous food supply for their growth. This decomposition process will lead to the increase of TDS and the decrease of TSS. As a result, separation efficiency will be reduced. Therefore, it can be assumed that the maximum separation efficiency may be achieved if separation is performed before the bacteria in manure have fully established their growth.

The objectives of this research are to (1) examine the dynamic changes in solids composition of fresh swine manure with different particle size ranges during storage for 30 days; and (2) determine the most efficient separation time after manure is excreted based on the data collected from this study.

Materials and Methods

Manure Source

Fresh, clean swine feces were collected from the floor of a swine growing-finishing hoop building and diluted with tap water to about 8% total solids content. The total solids content was determined by a series of bench top sampling and analysis of manure at different dilution levels using the methods provided by the American Public Health Association (APHA, 1998). The pigs in the hoop building were fed a regular corn soybean ration.

Experimental Procedure

The above prepared liquid manure was separated into seven different liquid portions with particle size ranges of

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< 2.0 mm, < 1.4 mm, < 1.0 mm, < 0.5 mm, < 0.25 mm, < 0.15 mm, and < 0.075 mm, respectively. The separation was effected by successive sieving of the fresh swine manure through a series of seven ASTM standard wire screen sieves with openings of 2.0 mm, 1.4 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.15 mm, and 0.075 mm (ColeParmer Company, Chicago, Illinois). Two 35-gal containers were used to transfer manure back and forth for each sieving. After each stage of separation, a sump pump was used to mix the sieved manure to keep solids suspended and, at the same time, one of the seven 91.62-cm-tall simulation Plexiglas columns (15.27 cm in diameter) was filled up with manure of that specific particle size range, leaving approximately 10.18 cm of headspace. Once all the columns had been filled, each column was thoroughly stirred using a motorized paddle-stirrer and a sample drawn from the homogenized slurry. This sampling technique was used at each sampling time for the 30-day test period at a five-day interval. Whenever it was not possible to analyze the samples immediately, the samples were frozen at –20°C and only thawed when samples were needed for analyses. The columns were set up in a dark room to simulate the conditions in storage pits and the room temperature was maintained between 18 and 22°C. For each sampling, manure solids parameters analyzed included total solids (TS), total suspended solids (TSS), total volatile solids (TVS), and total volatile suspended solids (TVSS). The total dissolved and fixed solids were determined by subtracting TSS and TVS from TS, respectively.

Results and Discussions

Total Solids (TS) and Total Volatile Solids (TVS)

The variations of TS for all the particle size ranges during the 30-day storage period are presented in figure 1. The percentage of TS reduction was tabulated in table 1. For manure with a maximum particle size equal to or greater than 0.5 mm, the reduction of TS was relatively small within the first 10 days of test and there appeared to be increasing decomposition of TS thereafter. Since no duplicate data are available in this study, more research employing statistical design of the experiment is needed to verify the findings. During the decomposition process, the reduction of TS is mainly due to the loss of volatile solids generated by the biological activities in the manure. The above observation implies that the breakdown and liquefaction of TS by microbes may not proceed at an appreciable rate for manure less than 10-days-old in these particle size ranges. Therefore, it is recommended (according to the TS) that solid-liquid separation treatment should be performed within the first 10 days of manure storage to potentially improve efficiency.

Table 1. The percentages of reduction in total solids during the 30-day storage period (%)

Sampling Day	Particle Size < 2.0 mm	Particle Size < 1.4 mm	Particle Size < 1.0 mm	Particle Size < 0.5 mm	Particle Size < 0.25 mm	Particle Size < 0.15 mm	Particle Size < 0.075 mm
5	2.33	5.43	0.74	1.96	3.93	6.03	4.59
10	4.47	5.63	3.81	5.17	8.29	11.29	8.94
20	15.27	17.67	14.48	16.84	19.13	20.29	18.24
25	19.07	21.22	19.87	23.24	28.27	21.93	24.52
30	20.23	23.99	19.77	21.80	21.57	27.41	27.66

For manure with particle size ranges equal to or less than 0.25 mm, no lag phases in terms of total solids breakdown were observed, indicating that they were attacked by microbes immediately after excretion. Also, it is interesting to note that the particles in the three lowest ranges (< 0.25 mm, < 0.15 mm, < 0.075 mm) were decomposed virtually at the same rate from the very beginning for the first 20-day test. This suggests that when the particle size reached 0.25 mm and smaller, the liquefaction rate became irrelevant to particle sizes. Finally, it can be seen from figure 1 that after 10 days, the solids breakdown rates for the top four particle size ranges were similar to those for the bottom three ranges. This implies that most of the large particles possibly were broken down to small particles with sizes equal to or less than 0.25 mm within that period. The production of large quantities of fine particles certainly will increase the difficulties for separation. Thus, it may be more efficient and economical to conduct separation on manure less than 10 days old since most of the commonly used screen type separators have pore sizes ranging from 0.5 to 3 mm (e.g., rotary screen: 0.5-2.0 mm; inclined screen: 1.0-3.0 mm). The above findings have not been reported anywhere in the available literature.

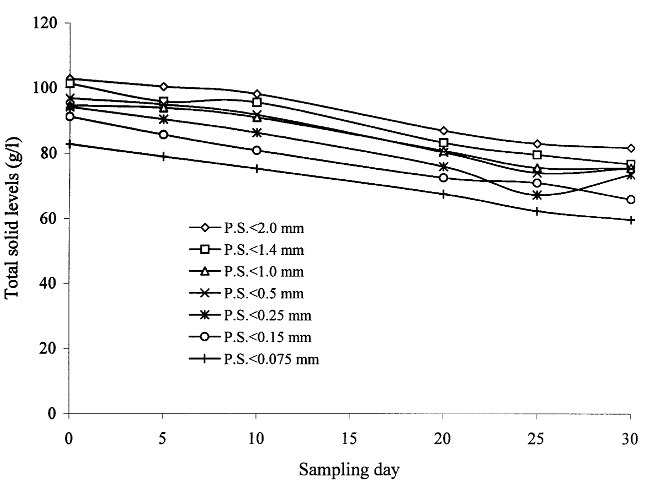

Figure 1–Variations of total solids during the sampling period (P.S. = particle size).

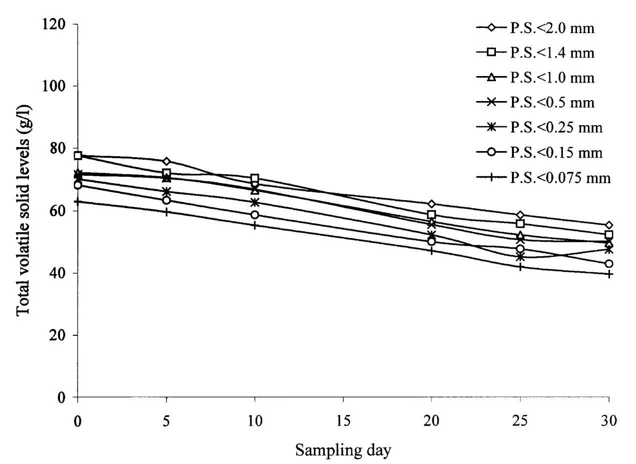

Figure 2–Variations of total volatile solids during the sampling period (P.S. = particle size).

Table 2. The percentages of reduction in total volatile solids during the 30-day storage period (%)

Sampling Day	Particle Size < 2.0 mm	Particle Size < 1.4 mm	Particle Size < 1.0 mm	Particle Size < 0.5 mm	Particle Size < 0.25 mm	Particle Size < 0.15 mm	Particle Size < 0.075 mm
5	2.57	7.22	2.22	1.68	5.71	7.18	5.25
10	11.71	9.41	7.77	6.70	10.70	14.08	12.08
20	20.08	24.36	21.64	22.49	25.53	26.69	25.12
25	24.58	28.09	27.60	29.19	35.52	30.06	33.39
30	28.70	32.60	31.21	30.03	32.10	37.10	37.04

Figure 2 showed the data for TVS and table 2 listed the related percentage reduction. It appears that there were no clear lag phases in decomposing volatile solids after the manure was excreted. The effect of timing on separating this portion of solids may not be critical. Again, more research producing statistical data is needed to verify the findings in this study.

An anomaly was observed in figure 1, i.e., there was a slight increase in TS for size range "< 0.25 mm" by the end of test. This is impossible and could be caused by manure sampling errors. Similarly, figure 2 demonstrated the same scenario. Due to the non-homogeneous properties of swine manure, to obtain a well-mixed, representative sample is extremely challenging. One way to check the sampling method for reliability is to examine the total fixed solids (TFS) concentrations (also called "ash content") at each sampling time. Since TFS is neither chemically reactive nor biologically degradable, it theoretically should stay unchanged for manure samples collected throughout the entire storage period. The information of TFS presented in figure 3 did indicate the existence of a fluctuation for samples (< 0.25 mm range) collected from day 25 and 30, suggesting a likelihood of errors during sampling.

If the ratios of TVS to TS are plotted against the sampling days, an interesting fact is unveiled (fig. 4). An approximately linear relationship was observed for all particle size ranges over the entire test period. In general, linearity can be expressed by a linear equation, y = kx + b. Substituting TVS/TS for y yields the following equation:

$$TVS/TS = kx + b \qquad (1)$$

Rearranging equation 1 yields:

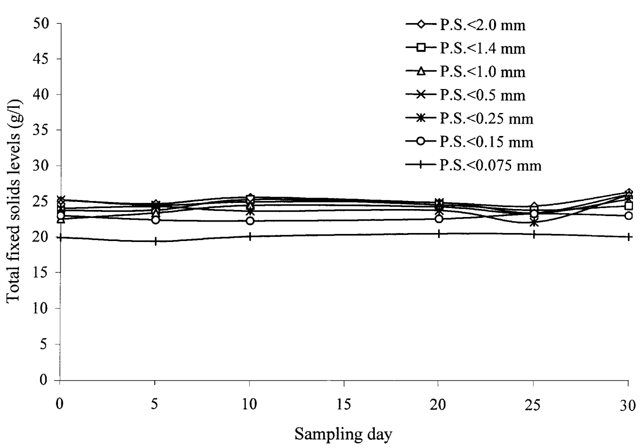

Figure 3–Variations of total fixed solids during the sampling period (P.S. = particle size).

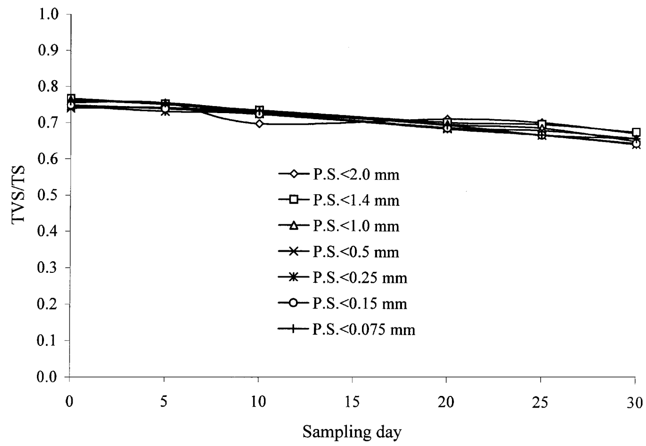

Figure 4–Variations of the ratio of total volatile solids to total solids during the sampling period (P.S. = particle size).

$$TVS = (kx + b)\, TS \qquad (2)$$

Since k and b are constants, equation 2 suggests that TVS may be linearly correlated with TS regardless of the particle size in the 30-day storage time. This may offer an opportunity to develop a general formula to estimate TVS based on TS. By lumping together the data from this study, this relationship can be expressed in equation 3 with a linear correlation coefficient of 0.9850 (fig. 5):

$$TVS = 0.9207 \times TS - 17.156 \qquad (3)$$

With this equation, the TVS can be easily calculated according to TS. However, manure from pigs at different growing stages may present different relationships for TS with TVS. In addition, extremely long storage time may affect the accuracy of the equation derived above due to complete degradation of TVS. Further research is needed to determine if a universal equation exists to account for these variables.

Research on how TVS affects odor generation has not been conducted in sufficient depth. One past study showed that volatile solids may contribute to manure odor intensities so the control of TVS could be of significance in

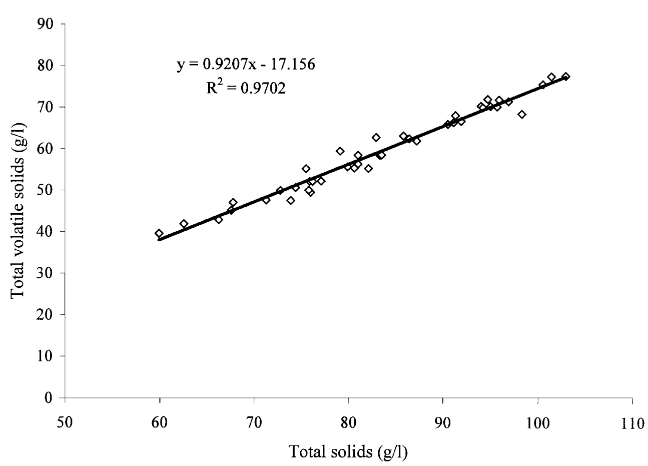

Figure 5–The relationship between total solids and total volatile solids in the 30-day period.

reducing the emission of volatile substances (Zhu et al., 1997). Since the data in this study indicated that TVS was proportionally related to TS, manure with low TS contents should have a lower potential of generating volatile substances than manure with high TS contents, as indicated by Williams et al. (1984). Therefore, it could be inferred that a good separation would very likely contribute to the reduction of odor emissions from the liquid fraction of manure during storage period because of the reduction in emitting substances. Further research is needed in this area.

TOTAL DISSOLVED SOLIDS (TDS)

Figure 6 presents information on the variations of the ratios of total dissolved solids (TDS) to TS for different particle size ranges during the storage. It appears that the ratios either decreased or remained nearly unchanged only within the first five days (except for ranges: < 2.0 mm, < 1.4 mm, and < 1.0 mm, which stayed unchanged up to 10 days). After that period, they tended to increase, indicating that more solids were dissolved due to microbial activities. Once the solids are dissolved, they will no longer be separated from liquid. As a result, separating solids from liquid will become difficult and the separation efficiency of mechanical separators will drop dramatically. Based on the data in this study, it will be advantageous to perform separation treatment within five days of excretion for manure with particle sizes less than 1.0 mm and 10 days for manure containing particles larger than 1.0 mm.

TOTAL SUSPENDED SOLIDS (TSS) AND TOTAL VOLATILE SUSPENDED SOLIDS (TVSS)

The ratios of TVSS to TSS are presented in figure 7. It can be seen that the TVSS accounted for about 75 to 85% of TSS, implying that most of the TSS were volatile regardless of the particle size. Therefore, to use solid-liquid separation for reducing the emission of volatile substances from manure, it becomes critical to remove as much of TSS as possible. In seeking for the improvement of separation efficiency of separators, a further examination of the characteristics of TSS during storage may provide some insights.

Figure 8 shows the changes of TSS over the entire test period. For all the particle size ranges, the levels of TSS did not vary much during the first five-day storage. After that, the decomposition of TSS for all ranges (except for < 2.0 mm, < 1.4 mm, and < 1.0 mm) proceeded at increased rates with the increase in total dissolved solids (fig. 6). For the ranges of < 2.0 mm, < 1.4 mm, and < 1.0 mm, the stable periods for TSS were extended to 10 days of storage before an appreciable reduction was observed. As discussed previously, the increase in dissolved solids content will increase the difficulty in separation and decrease the separation efficiency of separators. Thus, it appears that the time to achieve the best separation is when the dissolved solids are at the lowest level. According to this study, since fresh manure contains particles in all size ranges, the best time frame to perform separation will be within the first ten days of storage in order to maximize the separation efficiency for a particular separator. Any separation work done after the first 10 days would expect decreased separation efficiency.

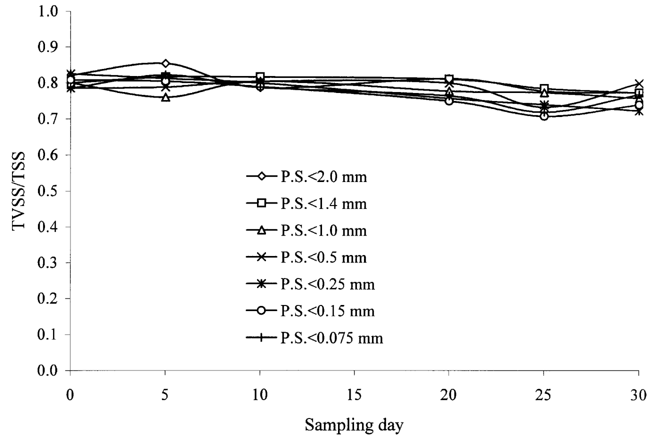

Figure 7–Variations of the ratio of total volatile suspended solids to total suspended solids during the sampling period (P.S. = particle size).

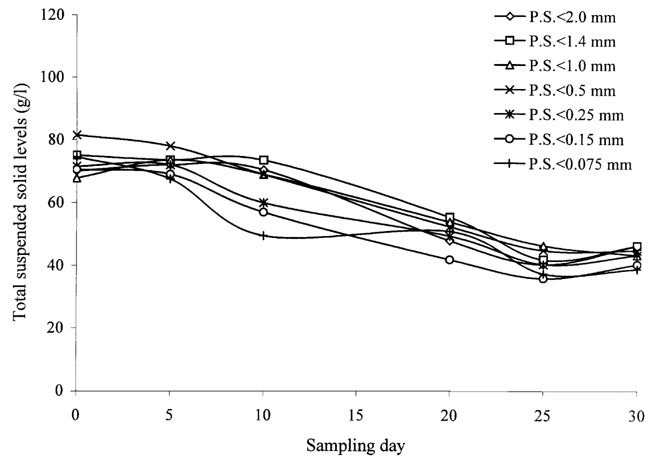

Figure 8–Variations of total suspended solids during the sampling period (P.S. = particle size).

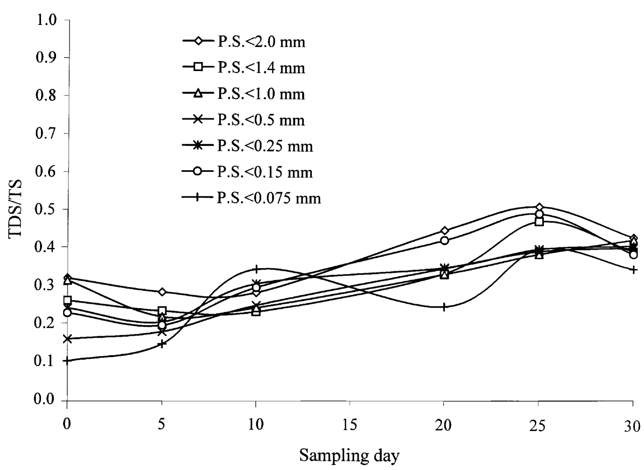

Figure 6–Variations of the ratio of total dissolved solids to total solids during the sampling period (P.S. = particle size).

SUMMARY AND CONCLUSION

According to this study, the solid-liquid separation technique, if applied to the treatment of swine liquid manure with solids particle sizes equal to or greater than

0.5 mm, should be performed within the first 10 days after the manure is excreted in order to potentially improve separation efficiency. Although no apparent lag phases were observed in terms of solids decomposition by microbes for particle sizes equal to or less than 0.25 mm, it is still advantageous to run separation treatment as early as possible to avoid further breakdown of solids, which may result in a reduction in separation efficiency. It also should be noted that since statistical analysis was not performed here because of lacking duplications in data, more research that will encompass statistical analysis is needed to verify the findings in this article.

Since TVSs accounted for about 75 to 85% of TSS, timely removal of TSS could help reduce the emission of volatile substances from the manure, hence a potential for reducing odor generation. Quantitative effects of TVS removal on odor reduction were not determined in this study and need further research.

There was a linear relationship between total volatile solids and total solids during the entire test period. In this study, this relationship can be expressed as $TVS = 0.9207 \times TS - 17.156$, with a correlation coefficient of 0.9850. Since TVS may contribute to manure odor emissions, the relationship may provide a simplified method to estimate the potential of odor generation from manure based only on TS. Further research is needed to verify the linear relationship for manure from different species with varying storage times that should be longer than 30 days.

REFERENCES

American Public Health Association. 1998. *Standard Methods for the Examination of Water and Waste,* 20th Ed. Washington D.C.: APHA.

Evans, M. R., R. Hissett, M. P. W. Smith, and D. F. Ellam. 1978. Characteristics of slurry from fattening pigs, and comparison with slurry from laying hens. *Agriculture & Environ.* 4(1): 77-83.

Hegg, R. O., R. E. Larson, and J. A. Moore. 1981. Mechanical liquid-solid separation in beef, dairy and swine slurries. *Transactions of the ASAE* 24(1): 159-163.

Moore, J. A. 1989. Dairy manure solid separation. In *Proc. Dairy Manure Manage. Symp.,* 178-192, Syracuse, N.Y., 22-24 February. NRAES-31. Ithaca, N.Y.: Cornell University.

Powers, W. J., R. E. Montoya, H. H. Van Horn, R. A. Nordstedt, and R. A. Bucklin. 1995. Separation of manure solids from simulated flushed manures by screening or sedimentation. *Applied Engineering in Agriculture* 11(3): 431-436.

White, R. K. 1980. The role of liquid-solid separation in today's livestock waste management systems. *J. Animal Sci.* 50(2): 356-359.

Williams, A. G., M. Shaw, and S. J. Adams. 1984. The biological stability of aerobically-treated pig slurry during storage. *J. Agric. Eng. Res.* 29: 231-239.

Zhang, R. H., and P. W. Westerman, 1997. Solid-liquid separation of animal manure for odor control and nutrient management. *Applied Engineering in Agriculture* 13(3): 385-393.

Zhu, J., D. S. Bundy, X. Li, and N. Rashid. 1997. A procedure and its application in evaluating pit additives for odor control. *Canadian Agric. Eng.* 39(3): 207-211.