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EFFECT OF SOLID-LIQUID SEPARATION ON BOD AND VFA IN SWINE MANURE

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ABSTRACT

Fresh swine manure was sieved into seven different particle size categories, i.e., <0.075 mm, < 0.15 mm, < 0.25 mm, < 0.5 mm, < 1.0 mm, < 1.4 mm, and < 2.0 mm. Manure was stored in seven PVC columns and sampled every 5 days up to 30 days. Manure samples were analyzed for total volatile fatty acids (VFAs), 5-day biochemical oxygen demand (BOD_5), total solids (TS), total suspended solids (TSS), and total volatile solids (TVS). Two parameters (VFAs and BOD_5) were used to determine the odor generation potential of the test manure. The results showed that total VFAs correlated well with BOD_5 ($R^2 = 0.8297$). The levels of TSS only explained 40% of BOD_5 and 46% of VFAs, both of which increased with storage time, regardless of solid particle sizes. Also, the data inferred that most of the odorous compounds (measured by VFA and BOD levels) were contained in manure solid particles less than 0.075 mm. These cannot be removed by commercial mechanical separators with screen size ranging from 0.5 to 3.0 mm. With an average separation efficiency of 25% for most commercially available mechanical separators, the removal efficiencies of BOD_5 and VFAs were as low as 10% and 12%, respectively. These findings cannot justify the use of solid-liquid separation to control odor. Data also showed that for swine manure, it is critical to run separation treatment within the first ten days after the manure is excreted to potentially improve the separation efficiency. After ten days, the degradation of TSS was accelerated due to the increased biological activities, which may greatly reduce the separation efficiency.

Keywords: Separation; swine manure; odor control; particle size; volatile fatty acids

INTRODUCTION

It is commonly recognized that solid-liquid separation provides a feasible approach to concentrating organic solids and nutrient elements in manure into a small fraction for utilization. However, only a few studies have been directed at determining whether solid-liquid separation can reduce odor emission from the treated pig slurry. Yasuhara et al. [1] reported that the solids component of manure is more important than the liquid fraction in terms of odor generation because they found that volatile fatty acids (VFA) were mainly formed from fiber and protein, most of which were contained in manure solids, by microbial degradation. Kroodsma [2] reported successful reduction of odor from a swine facility after solids were separated from the liquids immediately after the manure and feces were voided. Pain et al. [3] used a brush screen/roller-press separator to evaluate the effects of solid-liquid separation and aerobic treatment of swine manure on the reduction of odor emissions after land application. They found a reduction of odor emissions by about 20 to 30% due to the separation treatment compared with the untreated pig slurry. Regardless of the above studies, Zhang and Westerman [4] concluded, through a thorough review of the available literature, that quantitative information about the odor reduction by solid-liquid separation is lacking. Since the public concern about odors that may be generated at large animal operations are increasing, a close examination of the solid-liquid separation as a method to help reduce manure odors deserves serious attention.

The key to studying odor generation potential is to identify odor indicator compounds in the manure. There has been extensive research done by numerous researchers in determining major odor indicators for swine manure. Merkel et al. [5] found alcohols were unimportant in determining the nature of swine odors and the major odor constituents were from the amine and sulfide groups. Barth and Polkowski [6] reported that the volatile organic acids correlated best with the odor intensity. Ammonia was thought to be useful as an indicator for malodor, but in spite of the relatively high concentrations and the easy determination, ammonia was proved to be a poor parameter in evaluating odor intensities [7-10]. A study conducted by Spoelstra [11] showed that indole and skatole could not be recommended as indicators for malodor because the concentrations of these two compounds might decline during storage. Later, Spoelstra [12] reported in another study that neither ammonia nor hydrogen sulfide was a suitable indicator for the smell. He stated that the most pungent and the greatest variety of obnoxious smelling compounds originate from the decomposition of proteins. Ammonia does not reflect this degradation kinetic of the manure because a major part of ammonia in manure originates from urea hydrolysis. Moreover, ammonia remains unchanged by methanogenesis and shows a retarded reaction to aerobic treatment compared with organic volatiles. Hydrogen sulfide formation also does not reflect manure degradation kinetics because a relatively large part is derived from sulfate reduction. Therefore, Spoelstra [12] concluded that volatile fatty acids (VFAs) seemed to be useful indicators to test whether an effect has occurred from odor-abatement methods. Williams [9] found that the most widely applicable indicator was soluble biochemical oxygen demand (BOD) both during aerobic treatment and post-treatment storage; VFAs, total organic acids, indoles and phenols can indicate acceptable and unacceptable limits of offensiveness during aerobic treatment and post-treatment storage; sulfide is a misleading indicator during aerobic treatment but is a useful indicator during post-treatment storage; and ammonia is of no value as an indicator. A study conducted by Zahn et al. [13] reported that the volatile organic acids with carbon numbers from 2 to 9 specifically demonstrated the greatest potential for the manure odor. Therefore, according to the above researchers, it appears that VFAs could be used as suitable odor indicators for swine manure. Thus VFAs were used in this study to indicate the odor generation potential for swine manure under solid-liquid separation treatment.

The objective of this study is to investigate the possibility of using solid-liquid separation to control odor generation based upon the relationship between the settleable solids and the VFAs in manure. The relationship between VFAs and total BOD was also studied. Practicability of this technique in controlling odor is evaluated based on the size of manure solid particles that may contain most of the odorous compounds measured by the VFA concentrations as opposed to the pore size of commercial mechanical, screen-type separators. In addition, the optimum time to achieve the best efficiency for solid-liquid separation treatment is suggested.

MATERIALS AND METHODS

Manure Source

Fresh, clean swine feces (no conspicuous external materials such as straw beddings) were collected from the floor of a swine grow-finishing hoop building, which is a deep straw-bedded, vault-shaped structure with roof and sides but open ends for much of the year. The manure was then diluted with tap water to about 8% total solids content 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 [14]. 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 < 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 opening of 2.0 mm, 1.4 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.15 mm, and 0.075 mm (Cole Parmer Company, Chicago, Illinois, USA). Two 132-liter 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. Manure samples were collected every five days up to 30 days. During each sampling phase, each column was thoroughly stirred using a motorized paddle-stirrer and a sample of 100 ml drawn from the homogenized slurry. Whenever it was not possible to analyze the samples immediately, the samples were deep-frozen to minimize bacterial activities of producing VFA during storage, 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), 5-day biochemical oxygen demand (BOD_5), and VFAs by distillation according to the Standard Methods for the Examination of Water and Wastewater [14].

RESULTS AND DISCUSSION

Total Solids (TS), Total Suspended Solids (TSS), and Total Volatile Solids (TVS)

The percentages of TS and TSS reduction were tabulated in Tables 1 and 2. For manure with a maximum particle size equal to or greater than 0.5 mm, the reductions of TS (Table 1) and TSS (Table 2) were relatively small within the first 10 days of test. Similar results were obtained for manure with a maximum particle size equal to or greater than 1.0 mm. Therefore, increasing decomposition rates of both TS and TSS were observed. These trends suggest that the breakdown and liquefaction of TS and TSS by microbes may not proceed at an appreciable rate for manure less than 10 days old in these particle size ranges. Since TSS account for about 85% of TS in fresh swine manure [15] and solid-liquid separation only affects TSS, to increase the separation efficiency, it is necessary to remove as much of the TSS as possible. It is

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

Sampling day	Particle size (mm)						
	< 2.0	< 1.4	< 1.0	< 0.5	< 0.25	< 0.15	< 0.075
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

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

Sampling day	Particle size (mm)						
	< 2.0	< 1.4	< 1.0	< 0.5	< 0.25	< 0.15	< 0.075
5	-2.86	2.00	-8.57	4.29	-0.70	2.13	9.40
10	-0.71	2.00	-1.92	15.34	16.08	19.15	33.56
20	31.43	26.00	20.24	35.58	30.77	40.43	31.54
25	42.14	44.00	31.31	44.79	43.36	48.94	49.66
30	33.57	38.00	35.75	44.79	39.16	42.55	47.65

therefore recommended, according to Table 2, that solid-liquid separation treatment should be performed within the first 10 days of manure storage to potentially improve separation efficiency.

No lag phases in TS and TSS breakdown were observed for manure with particle size ranges equal to or less than 0.25 mm and 0.5 mm, respectively, indicating that they were attacked by microbes immediately after excretion. It is interesting to note from Table 1 that the particles for TS 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, suggesting that for particle size of 0.25 mm and smaller, the liquefaction rate became irrelevant to particle size. Also, it can be seen from Table 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, implying that most of the large particles may have broken down to finer particles. The situation for TSS was slightly different compared with TS. For particle size ranges of < 0.5 mm, < 0.25 mm, and <0.15 mm, the decomposition rates were similar for the first 20 days of storage. While for the particle size range of < 0.075 mm, substantial breakdown of TSS was already observed within the first ten days of storage. These observations implied that manure, once excreted from animals and stored anaerobically, would rapidly undergo decomposition. Similar results were reported by Oleszkiewicz [16]. The production of large quantities of fine particles certainly will increase the separation difficulties. 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), it may be more efficient and economical to conduct separation on manure less than 10 days old. The above findings have not been reported anywhere in the available literature.

Table 3 listed the percentage reduction for TVS. 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 according to this study.

Table 3. The percentages of reduction in total volatile solids during the 30-day storage period (%).

Sampling day	Particle size (mm)						
	< 2.0	< 1.4	< 1.0	< 0.5	< 0.25	< 0.15	< 0.075
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

Biochemical Oxygen Demand (BOD_5) and Volatile Fatty Acids (VFAs)

It can be seen that the biochemical oxygen demand correlated well with the volatile fatty acids contents in the manure with a linear correlation coefficient of 0.911 (Figure 1). This reveals that total BOD_5 could also indicate overall odor offensiveness of swine manure. Since only Williams stated that soluble BOD was a good indicator (9), more research is needed to determine if total BOD may have the same merit to be an odor indicator. Based on the relationship between the VFA and total BOD observed in this study, the potential for using total BOD as an odor indicator does exist. Therefore, in the remainder of the discussion, these two parameters will be used to determine whether solid-liquid separation will have an effect on odor reduction from swine manure.

The Relationship of BOD_5 and VFAs with TSS

Figures 2 and 3 present information on the relationship of BOD_5 and VFAs with TSS. A correlation analysis revealed that the TSS accounted for about 40% of total BOD_5 (R^2 = 0.3979) and 46% of VFAs (R^2 = 0.4575) in the test manure. It follows that even if the separation efficiency can be achieved

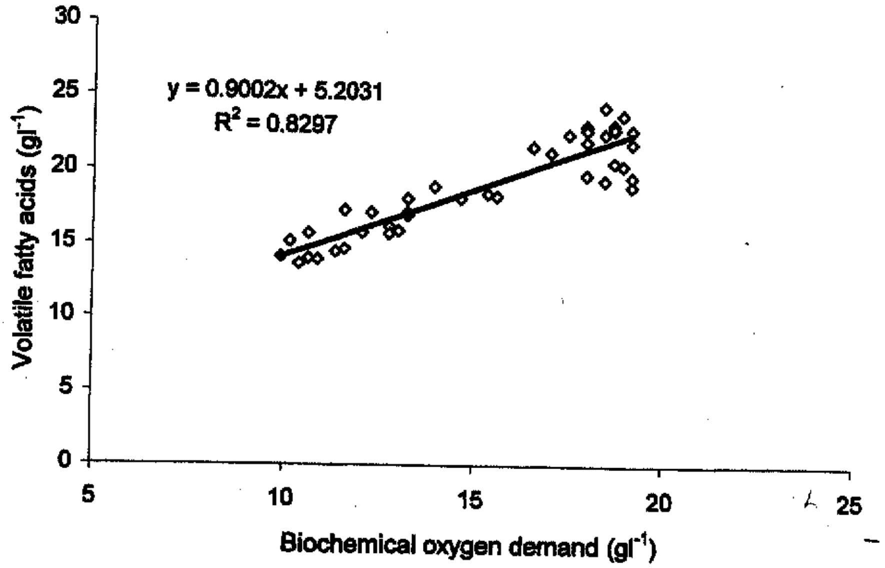

Figure 1. The relationship between biochemical oxygen demand and volatile fatty acids.

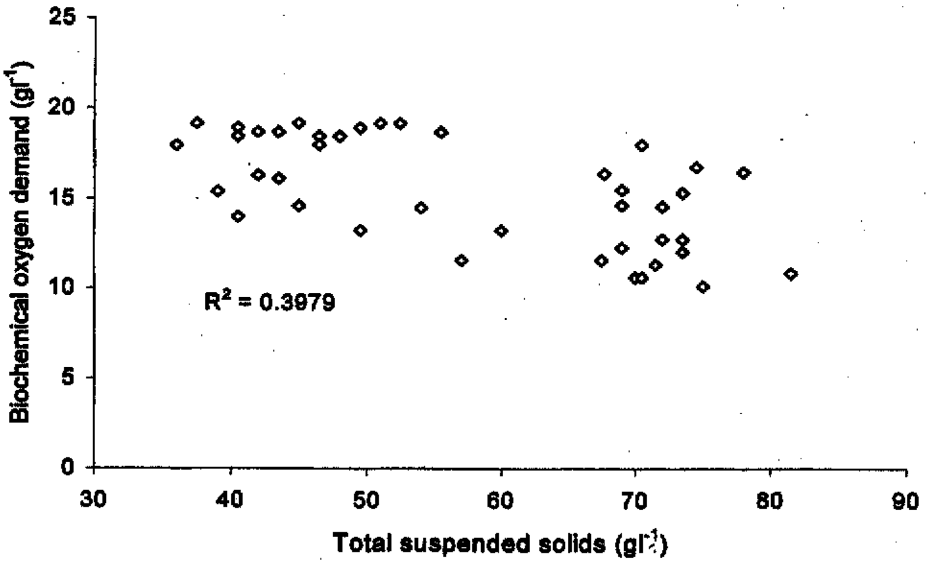

Figure 2. The relationship between total suspended solids and biochemical oxygen demand.

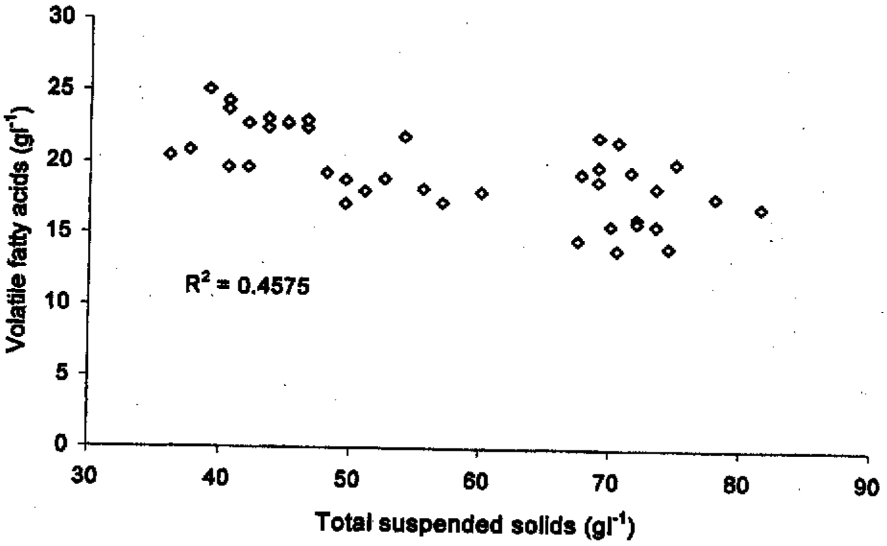

Figure 3. The relationship between total suspended solids and volatile fatty acids.

at a 100% level, only about 40% of BOD_5 and 46% of VFAs will be removed from the manure. As a matter of fact, according to the performance summary provided by Zhang and Westerman [4], the separation efficiency of various mechanical separators ranged from around 0 to 69% for chemical oxygen demand removal. Assuming that all separators can achieve 69% separation efficiency, the removal efficiencies of BOD_5 and VFAs will be around 28% and 32%, respectively, based on the data from this study. Furthermore, if the average separation efficiency of 25% among different separators is used [4], the removal efficiencies of BOD_5 and VFAs will be significantly reduced to about 10% and 12%. Obviously, these removal efficiencies may not be able to reduce the odorous substances in manure to the extent at which the odor generation potential is reduced during the storage period for manure that receives solid-liquid separation treatment. The finding from this study may explain why Pain et al. [3] only found a reduction of odor emission by about 20 to 30% due to the separation treatment compared to the untreated pig slurry. Therefore, it may be concluded that solid-liquid separation may not be able to substantially reduce manure odor based on VFA/BOD analysis in this study.

The Particle Size Effect on BOD_5 and VFAs

Figure 4 illustrates the variations of VFAs for all the particle size ranges during the test period. First, although

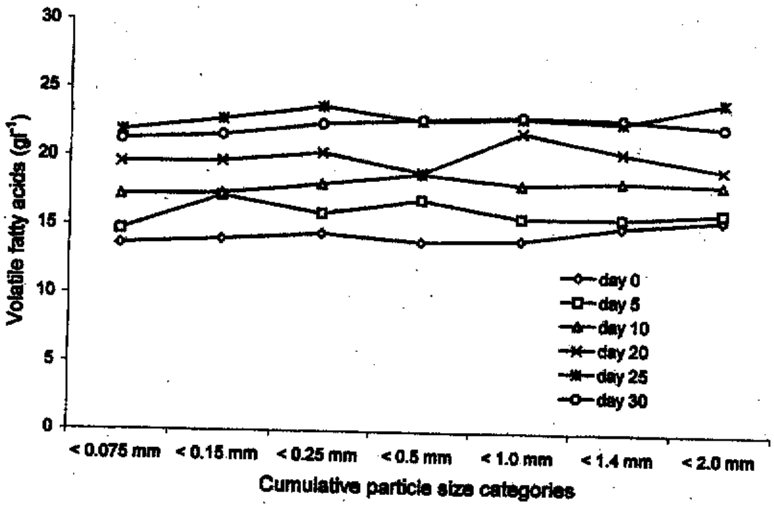

Figure 4. Variations of VFAs for different accumulative particle size ranges over the test period.

VFA concentrations fluctuated somewhat for each sampling phase (day), there was little difference among different particle size ranges for manure samples collected within each sampling phase. Since the size ranges are cumulative, i.e., each range consists of all the ranges that are smaller than the current one, it may be reasonable to assume that most of the VFAs are contained in the smallest particle size range (< 0.075 mm). This observation confirms the hypothesis proposed by Zhang and Westerman [4] that odorous compounds are usually contained in fine particles, although they did not articulate the extent of fineness of those responsible particles. Second, the levels of VFAs in the test manure apparently increased with increased storage time, which, again, indicated the biological conversion of large particles into fine particles during the storage time.

Similar trends were observed for BOD_5 (Figure 5). The above discussions indicate the difficulty in using solids-liquid separation to control odor because most odorous compounds are contained in particles smaller than 0.075 mm. As discussed earlier, commercially available screen-type separators have screen sizes ranging from 0.5 to 3.0 mm. It is therefore apparent that solids-liquid separation by using this type of separator will not be able to reduce odor since none of these separators can remove particles of size smaller than 0.075 mm.

CONCLUSIONS

According to this study, the breakdown rates for total solids with particle sizes equal to or greater than 0.5 mm greatly increased after fresh manure was stored for more than 10 days. The same time frame applied to total suspended solids with particle sizes equal to or greater than 1.0 mm. Therefore, to potentially improve separation efficiency, separation treatment should be performed within the first ten days after the manure is produced. For total volatile solids, such rules may not apply.

The levels of biochemical oxygen demand in the manure correlated well with the levels of volatile fatty acids (with a correlation coefficient of 0.911). Therefore, total BOD may also have the potential to become an odor indicator. More research in this area is needed before reaching any conclusions.

According to the data, the total suspended solids explained only about 40% of BOD_5 and 46% of VFAs. Considering the fact that the average separation efficiency is around 25% for different mechanical separators, the removal efficiencies for BOD_5 and VFAs by separation could be as poor as 10% and 12%, respectively. Therefore, separation treatment to remove total suspended solids may not be able to significantly reduce the odor generation potential from pig slurry.

Since most of the VFAs and BOD_5 may be contained in particles smaller than 0.075 mm and commercially available screen-type separators have screen sizes ranging from 0.5 – 3.0 mm, solids-liquid separation alone using these types of separators may not be an effective method in mitigating odor problems. Hence, chemical treatment causing coagulation and flocculation of finer particles may be considered for solid-liquid separation. However, since large particles will break down due to biological activities during the storage period, the timely removal of large particles using commercial mechanical separators may help reduce the production of fine particles, thus reducing odor generation potential.

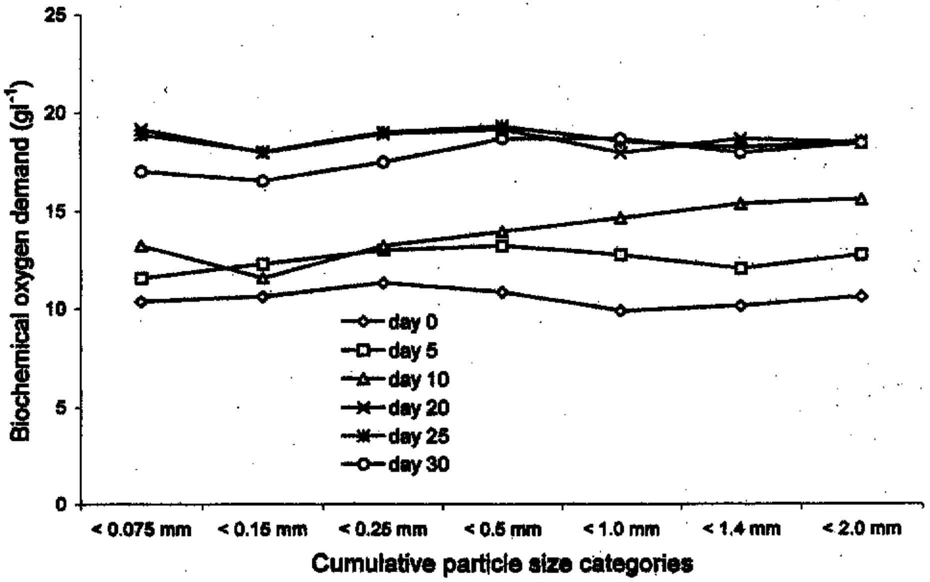

Figure 5. Variations of BOD_5 for different accumulative particle size ranges over the test period.

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