THE EFFECTS OF pH ON AEROBIC SLUDGE DIGESTION

by

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INTRODUCTION

As population and industrialization continue to expand, it becomes necessary to more closely scrutinize the ecology of the world. Increased modernization, higher standards of living, and growth of the population have produced an increase in waste products. If unchecked, these waste products will continue to contaminate our environment until they threaten the very existance of life itself. Until recently, purification of these wastes has been predominantly dependent upon natural phenomena, with minimal efforts on the part of humanity to supplement the natural processes. As man's modern development has progressed, however, nature alone has become unable to maintain a favorable equilibrium. Thus it has become necessary for man to develop waste treatment processes in order to maintain the required balance of activity throughout the chain of biological metabolism.

Biological Aspects of Aerobic Sludge Digestion

Efforts to balance the return of wastes to the environment have relied heavily upon the use of microorganisms. Not only have they proven to be very useful for the treatment of undesirable organic compounds in solution but, since they are plentiful in nature (and usually present in the waste product itself), they are both easily and economically cultivated.

For a specific waste flow, it may be generally stated that a heterogeneous culture of microorganisms can be developed and acclimated that will reduce the colloidal and dissolved organic impurities by absorption and assimilation, resulting in a settleable mass of solids which when separated from the liquid phase produces a water of improved quality. Such a process is the activated sludge process. Optimum removal of impurities is based on a specific food to microorganism ratio. This ratio is maintained by recirculating the settled organisms from the clarified effluent back to the influent end of the aeration tank. Through assimilation, growth, and reproduction, sludge in excess of that required for the optimum F/M ratio is produced and must be wasted from the process for further disposal.

Waste activated sludge consists primarily of a mixture of living cellular material, biologically inert organic material, and a lesser amount of inorganic material. When sludge is wasted, the biological growth will ideally be in the declining growth or endogenous phase. Further oxidation of the sludge without the addition of a nutrient source will result in auto-oxidation of the biological mass. Cellular material has been characterized by the formula $C_5H_7O_2N$ and, theoretically, may be oxidized to the final end products of carbon dioxide, water, and ammonia. This oxidation occurs from cellular metabolism and synthesis. Energy for cellular metabolism is represented by the following reaction of cellular oxidation:

$$C_5H_7O_2N + 5O_2 = 5CO_2 + 2H_2O + NH_3$$

Cell synthesis may generally be represented by the equation:

$$3CH_3COOH + O_2 + NH_3 = CO_2 + H_2O + C_5H_7O_2N$$

From these equations it may be seen that the system oxidizes theoretically to carbon dioxide, water, and ammonia (14).

Purpose of Research Investigation

Probably the single most expensive problem in waste treatment processes is that of sludge conditioning and disposal. Anaerobic digestion has proven to be a satisfactory, though expensive and sensitive, process for the reduction and conditioning of primary waste solids. Although it produces an inoffensive and stable sludge, the resulting supernatant liquor is very high in BOD and suspended solids, and requires still further treatment. By contrast, waste activated sludge is not readily treated by anaerobic digestion as it often increases the suspended solids of the supernatant liquor and the resulting sludge is difficult to dewater. Dewatering of unconditioned waste activated sludge has also been attempted, however, this requires chemical conditioning and special equipment which add not only a great deal to the expense of the process but also to the solids for ultimate disposal.

Where the activated sludge process has been employed, aerobic digestion has proven to be competitive with anaerobic digestion in the stabilization of waste activated sludge and mixtures of primary and waste activated sludge (1, 8, 10, 12, 13). Aerobic digestion has the

distinct advantage over anaerobic digestion of producing both a well stabilized sludge and a purified supernatant. There are no disagreeable odors and the process does not require special heating and gas handling equipment. One disadvantage is that it requires an outside source of energy (aeration) since it produces no combustible gas which may be used as an energy source. It is important to realize, however, that at this time the parameters of aerobic digestion are poorly understood as the process has never been subjected to extensive investigations as the anaerobic process has. Yet it has proven to be competitive with anaerobic digestion for some applications, and further investigation into the nature of the process should indicate ways of optimizing its advantages and reducing its shortcomings. It is the purpose of this research to explore further those parameters deemed important by previous studies and to investigate their relationship with pH during aerobic digestion.

LITERATURE REVIEW

Although many articles appear in the literature on aerobic sludge digestion, most investigations were primarily concerned with the degree of solids reduction and stabilization which could be obtained rather than the parameters which determine the results achieved. In most cases, correlation of results can not be made directly due to the nature and conditions of individual studies. The experiments conducted used either primary sludge, secondary sludge or combinations of the two types of sludge in specified ratios based on solids content. Investigations were conducted on both batch and continuous bases, and each sludge used may have had some initial degree of stabilization. In a good number of cases, however, sufficient data has been presented to indicate parameters which may be significant in the control and optimization of the process.

In 1936, Heukelekian (8) aerobically digested fresh solids and aerated seed material mixed on a dry basis of 7.5 to 1.0, respectively, for a period of 35 days. His results showed a 50 percent reduction in volatile solids, a 99 percent reduction in fat and a total nitrogen reduction of 30 percent. Properly seeded sludge anaerobically digested for the same period of time was not as thoroughly decomposed as that treated aerobically.

Eckenfelder (5) reported in 1956 that waste activated sludge from a conventional activated sludge plant subjected to aerobic digestion for a period of seven days at 25°C showed a 48 percent decrease in

mixed liquor COD, a 38 percent reduction in total suspended solids, and a 49 percent decrease in volatile solids content. First order kinetics were no longer approximated after five days, and the auto-oxidation rate decreased rapidly with increased aeration.

Using batch tests on waste activated sludge from a biosorption plant in Austin, Texas, Reynolds (23) concluded that a 95 percent reduction in biodegradable solids could be achieved in 5 days. His data indicated total solids reduction from 42 to 52 percent and volatile solids reductions from 46 to 63 percent. Initial total solids contents were 7435 to 8360 mg/l, the percent volatile content ranging from 66 to 81 percent, in a series of four digesters. Greater solids reductions were realized with decreasing percent volatile content. After stabilization, the sludge would not further decompose and readily gave up it's water content when poured onto a sand drying bed.

Kehr (12) compared anaerobic digestion to aerobic digestion and concluded that a 77 percent reduction in total dry matter could be achieved for a bacterial sludge subjected to aerobic digestion and that a 60 to 70 percent reduction in organic matter could be achieved for a primary sludge under anaerobic digestion. He recommended a loading rate of 0.05 to 0.10 KgBOD/Kg mixed liquor suspended solids/day for aerobic digestion and a detention time from 3 to 5 days. Aerobic digestion was recommended for plants serving populations of 5,000 to 10,000 persons because of it's simple operation and a 30 percent reduction in digester tank volume could be realized over anaerobic digestion.

In 1961, Norman (19) aerobically digested mixtures of primary and waste activated sludges combined on a dry solids basis of 1.75 to 1.0

respectively. Mixed liquor total solids were around 3.2 percent. Volatile solids were reduced by 35 percent in 15 days and by 53 percent in 30 days. He noted an increase in solids reduction with increasing temperature, detention time and solids loading. Sludge age was found to be a desirable parameter of volatile solids reduction and no significant change in the solids reduction rate was noted for a pH range of 5.0 to 7.0. Frothing in the digesters occurred at times. This was alleviated by adjusting the sparging rate. Frothing did not occur for sludges aerated less than 8 days. pH depression in the latter days of digestion was not due to volatile acids since they could not be detected in the supernatant liquor in sufficient quantity. Norman reported that Ludzak had found that the increase in acidity of sludge during extended periods of aeration was due to increased nitrate concentration and corresponding loss of buffer capacity.

Lawton and Norman (13) studied the aerobic digestion of waste activated sludge from a plant handling one third pretreated meat packing waste and two thirds domestic sewage. They reported volatile solids reductions of 14-20 percent to 39-53 percent in 5 and 30 days of digestion respectively, at a temperature of 20°C. They concluded that increased volatile solids reduction showed a strong correlation with sludge age. The supernatant liquor produced was very low in BOD and sludge digested more than 5 days showed improved drainability. pH values as low as 5.0 had no significant effect on volatile solids reduction.

Irgens and Halvorson (10) acclimated a culture of organisms using primary sludge from the Urbana, Illinois, activated sludge plant and

used it to investigate nutrient removal by aerobic digestion. Their investigation indicated that a significant portion of the carbonaceous matter was oxidized to carbon dioxide and water, the remaining portion being assimilated into microbial protoplasm. With detention time of 20 days at 23°C and a mixed liquor suspended solids concentration of 28,000 mg/l, a 44 percent reduction in total suspended solids was achieved. Primary solids were fed to the unit on a daily basis. Available nitrogen and phosphorus were effectively incorporated into microbial protoplasm, leaving less than 1 mg/l of ammonia nitrogen and less than 10 mg/l of phosphate and total nitrogen in the supernatant. The sludge was easily separated from the supernatant, leaving a clear, slightly colored fluid. It was later discovered that the primary sludge at the Urbana plant was receiving waste activated sludge from the secondary unit. A similar test conducted on primary sludges from Rantoul and Tuscola, Illinois, where the sludge was from primary settling only, produced poor flocculation and settling, although good oxidation was obtained. When seeded with Urbana waste activated sludge, the Rantoul and Tuscola sludges gave satisfactory results comparable to the original tests on the Urbana primary sludge.

Malina and Burton (15) digested primary sludge without seed material on a continuous basis and concluded that a loading rate of 0.14 pound of volatile solids per day per cubic foot of mixed liquor volume produced a 43 percent reduction in volatile solids content. Volatile solids reduction was less at a loading rate of 0.10 pound of volatile solids per day per cubic foot of mixed liquor volume. The sludge produced was well stabilized and the supernatant was low in BOD and ammonia nitrogen.

Nitrogen in the effluent increased with organic loading. The average pH was constant around 8.0, decreasing slightly with organic loading.

Carpenter and Blosser (3) aerobically digested secondary boardmill sludge and concluded that volatile solids reduction nearly doubled when the temperature of digestion was raised from 20°C to 30°C. The addition of a supplementary nitrogen source significantly increased the volatile solids reduction, indicating a nitrogen deficiency in the waste sludge. Thickening and filtering characteristics become less desirable with increased aeration. Filtration could be accomplished with the addition of chemical conditioners such as ferric chloride.

Bruemmer (2) studied the effects of oxygen tension on the aerobic digestion of mixed activated and primary sludges by sparging separate continuous runs with air and oxygen gas. He concluded that normal air sparging is not effective in oxygenating high strength loads of primary sludge for stabilization and that high air sparging rates disintegrate the floc and hinder settling. He found that oxygenation requirements are diminished when the daily organic load is added in multiple portions rather than one slug. High oxygen tension did not adversely affect the removal of nitrogen and phosphorus from the supernatant. The minimum time for digesting raw sludge at 50,000 mg/l COD was found to be 4 days at 30°C.

The aerobic digestion of several domestic and industrial waste sludges was studied by Barnhart (1). He concluded that solids reductions are comparable to those obtained with anaerobic digestion. Temperatures below 20°C were found to be retardant to the digestion process and solids reduction varied greatly with the type of sludge. A detention

time of 15 days appeared to be adequate in all cases. Oxygen requirements were found to be low but aeration rates had to be maintained at a high level to keep the solids in suspension. The pH tended to rise initially, then fell gradually to a level of 5.0 to 6.0 when digestion was continued over an extended period of time.

Viraraghavan (30) conducted four series of experiments digesting raw primary sludge under the climatic conditions at Madras, India, and concluded that a fairly high degree of digestion is obtained under aerobic conditions. The digested sludge had no disagreeable or objectionable odor, volatile solids reduction beyond 15 days was not significant, and substantial nitrification and BOD reductions were realized. An initial rise in pH was noted in the first days of digestion, followed by a gradual decline into the acid range.

Saunders (25) conducted aerobic digestion batch studies on waste activated sludge at various solids concentrations for 30 days and made the following observations:

1. Fixed solids did not accumulate despite high reductions in total and volatile solids.
2. Sludge settleability was poor initially and did not improve with digestion.
3. Drainability was poor initially and did not improve with digestion, although the rate of drainage did improve.
4. Cellular carbohydrate did not accumulate during aerobic digestion.

5. Cellular protein per unit weight of total suspended solids showed an increase with time of digestion.

A typical variation in pH was noted during digestion. An initial rise in pH to about 8.5 and subsequent decline to a value of about 6.0 occurred in the first 15 days of digestion. This trend is similar to that reported by other investigators (1, 19, 30). Microscopic examination of the digesting sludge showed the aerobic digestion process was characterized by the protozoan class, Ciliata. Free swimming ciliates characterized the initial five day period. By the tenth day the free swimming ciliates had decreased in number and motility, and large clusters of stalked ciliates were dominant. Clusters of stalked ciliates characterized the remaining period of digestion, their numbers decreasing significantly by the thirtieth day. Severe frothing was experienced occasionally, but no definite pattern was determined.

Randall, Saunders and King (21), reporting on aerobic digestion studies conducted with waste activated sludges from conventional activated sludge and biosorption plants, concluded that solids reduction was still significant after 15 days of aerobic digestion. The percent of volatile solids was not considered a good indicator of the extent of stabilization except in gross terms. Drastic pH depression to values in the range of 5.6 and below occurred and appeared to cause inhibition and destruction of activated sludge microorganisms. Inhibition of nitrifying bacteria was apparently temporary. Solids reduction occurred at pH values around 5 and less, but appeared to be greater at pH values above 5.6. The carbohydrate fraction of the total suspended solids remained steady with digestion, but the protein fraction steadily

increased. Aerobic digestion does not necessarily improve the drainage characteristics of waste activated sludge. Drainage may be retarded by large amounts of fibrous material and some types of microorganisms. Drainability of aerobically digested sludge was found to be closely related to sludge activity as measured by oxygen utilization.

Turpin (29) studied the drainability of aerobically digested secondary sludges in relation to cellular parameters and reached the following conclusions:

1. Dehydrogenase enzyme activity decreases with aerobic digestion. No direct correlation of the absolute level of enzyme and solids reduction appeared among the sludges during aerobic digestion, but there was a direct relationship between the total change in enzyme activity and the solids reductions accomplished in respective units.
2. Cellular protein per unit weight of total suspended solids increases during digestion, and drainability increases with increasing cellular protein content.
3. Cellular carbohydrate apparently varies in a manner peculiar to a particular sludge.
4. Higher solids reductions occur with sludges having a higher percent of volatile solids. The percent volatile solids showed little change during aerobic digestion, and did not appear to be related to enzyme activity.

5. Detention times of up to 30 days continue to show significant solids reductions.
6. Suspended solids reduction can be accomplished over a wide pH range from slightly more than 5.0 to at least 9.0.
7. Sludge drainability is improved by aerobic digestion and is closely related to the degree of stabilization obtained.

METHODS AND MATERIALS

The objective of this research was to determine the effects of pH on the aerobic digestion of waste activated sludge. To accomplish this, three batch-fed aerobic digesters were monitored for a series of two runs of approximately 20 days each, controlling the pH in selected units at various constant levels and measuring chosen parameters that the effects of such imposed pH control on the digestion process might be determined and the results compared with those obtained by previous investigators. The digestion process was conducted in a constant temperature room where the apparatus and sludge were maintained at a temperature of 20°C ($\pm$ 1.0°C). In the first of the two runs, batch A served as a control unit, the pH of the same being allowed to seek its own level, while batches B and C were maintained at constant pH levels of 7.0 and 5.0 ($\pm$ 0.5) respectively throughout the digestion period. pH control was accomplished by adding 1.0 N sulfuric acid or 1.0 N potassium hydroxide as required. In the second run, batch D served as control while E and F were maintained at pH 9.5 and 3.5 ($\pm$ 0.5) respectively, using concentrated sulfuric acid and 33 percent potassium hydroxide as required. The detrimental effects of the concentrated chemicals on the sludge organisms were minimized by adding slowly with adequate mixing. In each of the series of runs, the initial pH adjustment was accomplished over a minimum period of 24 hours to reduce the shock of such environmental change on the microorganisms.

Experimental Apparatus

The three aeration chambers used were plexiglass cylinders eight inches in diameter, eighteen inches in depth and approximately 13.5 liters in volume. The cylinders were each equipped with a bottom sampling spout and aerator assembly consisting of a cotton filter to minimize contamination by oil or other matter which might come through the air supply, rubber tubing, a piece of bent glass tubing to insure rigid support for the diffuser assembly, and a diffuser assembly made from a short section of plastic tubing fitted to the end of the glass tubing. This arrangement enabled the investigator to remove the diffuser assembly at will to insure proper operation. In addition, the depth of the aeration assembly in each digester could be adjusted to insure equal aeration in each unit. A sketch of the apparatus thus described is presented in Figure 1. No attempt was made to eliminate evaporation losses since it was desirable to obtain sufficient evaporation to enable the investigator to add acid or alkaline solutions as required to maintain pH at the desired level.

Digester F experienced severe foaming when the pH was lowered to 3.5 and it was necessary to install a device to disrupt the foam. A small variable speed motor mounted on a burette stand with a shaft extending from it into the sludge was used for this purpose. A 6" horizontal bar was mounted on the shaft so that it rotated about one inch above the surface of the sludge. This was sufficient to prevent loss of solids from the digester.

Procurement and Handling of Sludge

Activated sludge was obtained from the Roanoke, Virginia, sewage treatment plant which uses the conventional activated sludge process. The sludge was taken from the effluent end of the aeration tanks to

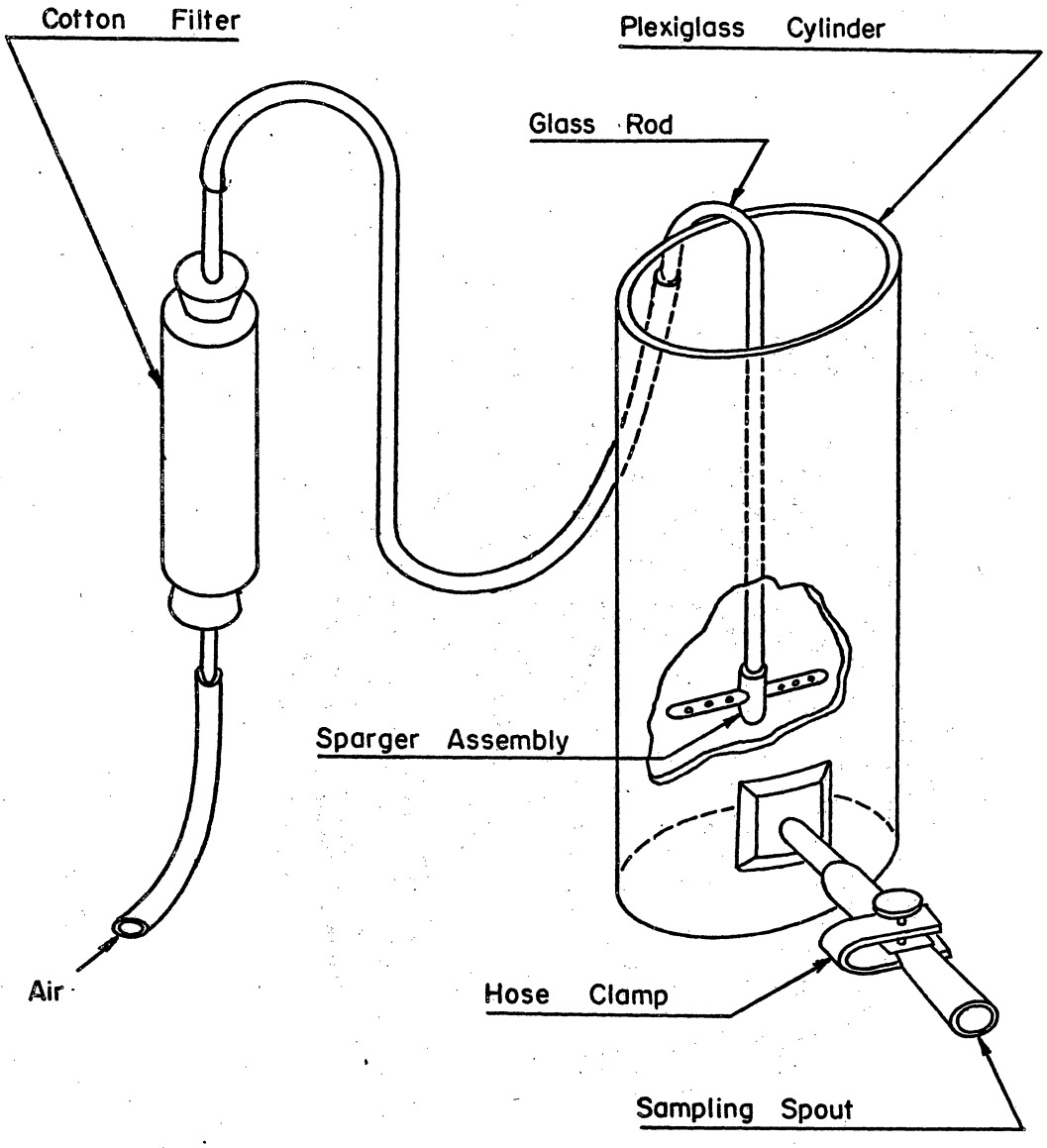

Figure 1: DIGESTION APPARATUS

insure that the microorganisms were in the endogenous phase and to simulate sludge wastage. The collected sludge was allowed to settle and the supernatant liquor decanted to increase the solids concentration. It was desired that the digester sludge concentrations be in the range of 20,000 mg/l total suspended solids which corresponds to the typical solids concentration used by Saunders (25) for his previous investigations on the same sludge. This range was easily reached by allowing the sludge to settle for approximately six hours. After concentration, the sludges were thoroughly mixed to insure uniform solids concentration prior to being placed in the digestion tanks. Following concentration and mixing, the sludges were placed in the digestion tanks, aeration being initiated within ten hours from the time of collection. Approximately eight liters of sludge was placed in each digester, allowing sufficient freeboard to prevent spillage. No specific air flow rates were used but a minimum level of 2.0 mg/l of dissolved oxygen was established and maintained throughout the period of digestion. Initial solids concentrations in the digesters are given in Table 1.

Sampling Procedures

On days of sludge analysis, aeration was discontinued, the digester sides were scraped, and distilled water was added to compensate for evaporation losses. Then aeration was restarted to mix the contents and samples were taken. After sufficient sampling, the new digester volume was marked. Samples for residue, carbohydrate, protein and filterability tests were pipetted directly from the digester, whereas those for BOD, COD, nitrate and phosphate were taken from the sampling spout and collected in a 150 ml. beaker. The beaker was covered with aluminum foil

TABLE I

INITIAL SOLIDS CONCENTRATIONS

Digester	Total Suspended Solids (mg/l)
A	17,820
B	19,647
C	19,797
D	26,550
E	25,200
F	26,850

and cold stored until all tests had been performed. Sludge samples for settleability and pH were returned to the digester following measurement. When the sampling spout was used, the first 150 ml was returned immediately to the digester and the following 100 ml used for analysis to insure that no error due to anaerobic conditions in the sampling spout might occur, and that the sample came from the body of actively digesting mixed liquor. Sampling was frequent during the first 10 days of digestion since it has been shown by previous investigations that the greatest change in solids reduction occurs in this period. pH was measured daily throughout the digestion period since it was the basic control parameter.

Analytical Procedures

The following methods were used to analyze samples taken as previously described:

1. pH

A Leeds and Northrup line operated laboratory model pH meter was used to measure mixed liquor pH.

2. Suspended Solids

Total and volatile suspended solids were determined using Gooch crucibles with glass fiber filters (Reeves-Angel, 2.1 cm). The filters were placed in the crucibles rough side up and seated with distilled water over a vacuum. Crucibles and filters were then dried at 103°C for a minimum of 20 minutes, fired in a muffle furnace at 600°C for thirty minutes, cooled in a desiccator for a minimum of one hour, following which the tare weights were recorded. Sludge samples were diluted with distilled water to a ratio of 1:4 since filtering of the undiluted sludge proved to be a lenghty process. 5 ml. of diluted sample were applied

to each crucible, filtration being aided by a vacuum pump. All solids determinations were initially made using three samples, this was lessened to two after one week since the results showed little variance. The crucibles and samples were dried at 103°C for one hour, cooled and desiccated for a minimum of thirty minutes and weighed. They were then ignited at 600°C in a muffle furnace for 30 minutes, cooled and desiccated for a minimum of one hour, and the final weights recorded.

Smith and Greenberg (26) reported in an evaluation of methods for determining suspended solids that results obtained by the Gooch crucible-glass filter method were not statistically different from those determined by the Gooch crucible asbestos mat method of Standard Methods (27).

3. BOD and COD

BOD and COD were measured on the sludge mixed liquor and supernatant from the sand drying beds in accordance with the procedures outlined in Standard Methods (27). Appropriate BOD dilutions were made in a 1000 ml graduated cylinder, thoroughly mixed as prescribed and transferred to BOD bottles for determination of initial D.O. and incubation at 20°C for 5 days. D.O. determinations for the BOD test were made by the modified Winkler method (27).

4. Ammonia

Tests for ammonia were made at extended intervals to determine the fate of nitrogenous material during digestion. The Direct Nesslerization Method (27) was used since only relative concentrations were desired. Standards were prepared and placed in a Fisher Nesslerimeter for comparison with sample dilutions. Computations were made in accordance with Standard Methods (27).

5. Carbohydrates

Cellular carbohydrates were determined by the Anthrone method as prescribed by Ramanathan, Gaudy and Cook (20). 5 ml of mixed liquor from each digester were filtered through 0.45 micron millipore filters aided by a vacuum pump. About 10 ml of 0.1 N phosphate buffer solution was then drawn through the partially dewatered sludge. The sludge mat was then removed and resuspended in 10.0 ml of 0.1 N phosphate buffer solution and cold-stored for later analysis. Prior to analysis, a Brownwill Scientific "Biosonik III" sonic disintigrator was used to insure complete resuspension of the sludge mat in the phosphate buffer solution. For analysis, appropriate aliquots of samples were placed in test tubes and the total volume was adjusted to 3.0 ml with distilled water. Next, all tubes were placed in an ice water bath and allowed to equililibrate. The contents were then mixed rapidly with 9 ml of ice cold anthrone reagent. The tubes were then covered with glass marbles and boiled in a water bath for exactly fifteen minutes. Upon reaching room temperature, the absorbances (optical densities) read on a Beckman model B spectrophotometer at a wave length of 540 millimicrons ($m\mu$). Standards were prepared with a dextrose solution, aliquots of which were placed in test tubes and processed exactly as the samples. The standard curve is plotted for carbohydrate determination in Figure 3.

6. Protein

Cellular protein was determined by the Folin-Ciocalteu method as prescribed by Ramanathan et al. (20), who stated that although color development is not strictly proportional to concentration and different proteins give different intensities of color, the method is one hundred

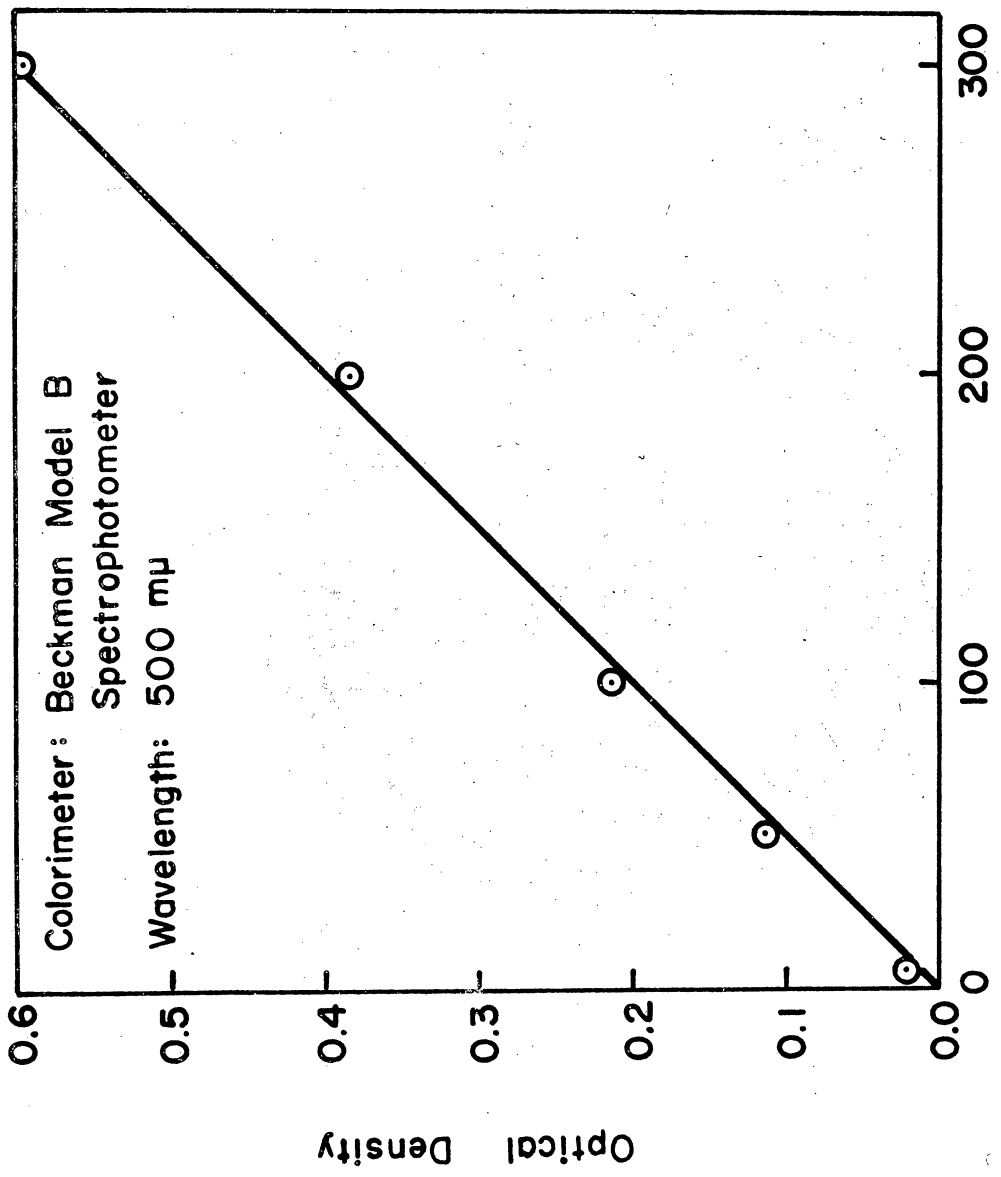

Figure 3: STANDARD CURVE FOR CARBOHYDRATE DETERMINATION ANTHRONE METHOD

times as sensitive as the biuret method and extremely low concentrations may be measured. Tyrosine, tryptophan, most phenols, uric acid, guanine, and xanthine react with the Folin-Ciocalteu reagent to give color. Samples used in this determination were the same as those used for carbohydrate analysis. Aliquots of the samples were placed in test tubes and diluted to a total volume of 1.2 ml with distilled water. Standard protein dilutions were prepared using bovine serum albumin. 6 ml of freshly prepared alkaline copper solution was then added and thoroughly mixed in each tube. After 10 minutes, 0.3 ml of Folin-Ciocalteu reagent was added, and each tube thoroughly mixed. Following a 30 minute period allowed for color development, the absorbances (optical densities) were read using a Beckman model B spectrophotometer at a wave length of 500 mμ. The standard curve for protein determination is shown in Figure 2.

7. Nitrate and Phosphate

Nitrates and orthophosphate were determined using a Hach Chemical Company DR-EL Engineer's Laboratory field water testing kit since only relative determinations were desired and the author has found the accuracy to be sufficient for this purpose. 20 ml of mixed liquor from each digester were centrifuged for 15 to 30 minutes and the supernatant was used for the analysis performed. Following the addition of prescribed chemicals, concentrations were read on the Hach colorimeter provided after 3 minutes for nitrates and 5 minutes for orthophosphates.

8. Sludge Settleability

Sludge settleability was measured by filling a 50 ml graduated cylinder to the 50 ml mark with mixed liquor from each digester and recording the clear supernatant appearing at 30, 60 and 720 minutes

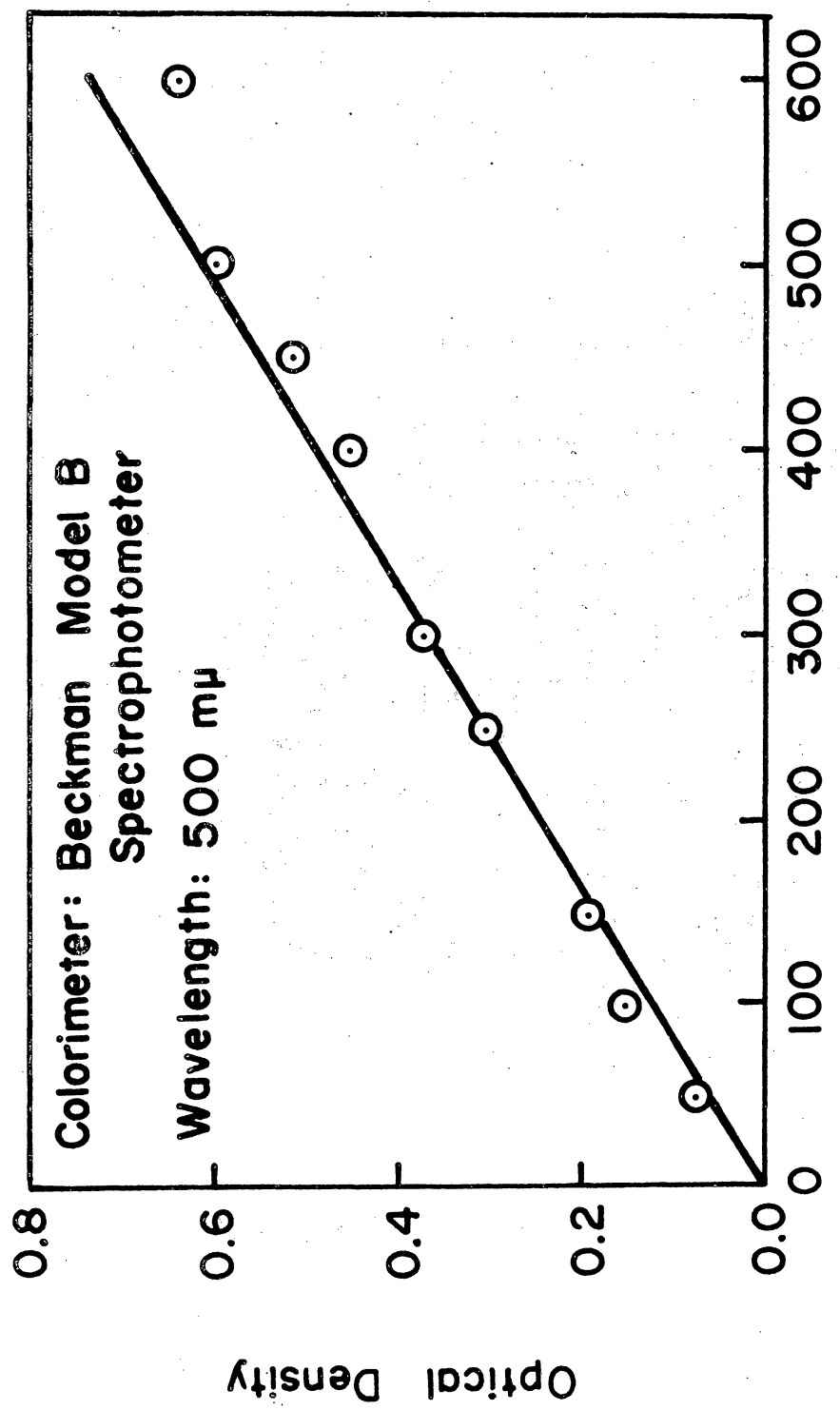

Figure 2: STANDARD CURVE FOR PROTEIN ESTIMATION FOLIN METHOD

(6 hours). The reasons for performing the test in this manner are as follows:

a. Sludge volume index is not useful for digested sludges since it measures only a 30 minute settling time. Digested sludges would ideally be allowed to thicken for more extended periods of time in order to accomplish solids concentration.

b. 50 ml were used since it was not desirable to use larger volumes which might disturb the digestion process when returned to the digester following extended periods without aeration.

c. Only a relative comparison among the digesters was desired.

When sufficient data had been collected, the sludge samples were returned to their respective digesters. Settleability readings were reported as ml of clear supernatant appearing per 100 ml of mixed liquor.

9. Filterability

Filterability determinations were made by applying 100 ml of mixed liquor to a 9.0 cm diameter Buchner funnel fitted with a paper filter. A vacuum of 12.5 inches of mercury was applied and readings were made as ml of filtrate appearing 1, 5, 15 and 30 minute intervals. This test was considered adequate since only relative values for comparison among digesters was desired.

10. Drainability

Drainability was measured on the last day of digestion for batches D, E and F only, since the improvements in filterability and settleability had not been expected and the equipment had not been prepared in advance. Following final sampling, 6 liters of sludge from each digester was applied to each of three sand beds having an area of one square foot. The filter bed consisted of 1" of coarse sand overlaid with 2" of medium sand. Filtrate volumes were recorded at 5, 10, 30 and 60 minute intervals, followed by readings at 2, 12 and 36 hours.

11. Microscopic Examination

Microscopic examinations of the mixed liquor were made frequently to determine the general types of organisms which characterized the different environments during aerobic digestion. A Spencer light microscope and flat glass slides with cover plates were used for making observations.

EXPERIMENTAL RESULTS

The experimental results obtained during the course of this study are presented and briefly discussed in this chapter. The data is presented primarily in graphical form. Each digestion parameter studied is discussed individually with regard to observations made during the conduct of the laboratory research. Since pH was the primary control parameter, all other parameters are discussed with respect to it.

The pH variance of each unit during aerobic digestion is shown in Figure 4. In control units A and D, pH was allowed to seek its own level. An increase from pH 7.5 to a pH of about 8.5 was reached in both of these units during the first 8 days of digestion. Unit A maintained this value until the 14th day when pH showed a sharp decline to a value of 6.2 on the 19th day of digestion. Unit D began to show a more gradual decline on the 9th day, reaching a pH of 6.2 by the 23rd day of digestion. Units B, C, E and F were adjusted to and maintained at constant pH levels ($\pm$ 0.5) of 7.0, 5.0, 9.5 and 3.5 respectively. These units showed little variance in the amount of acid or alkali needed to maintain constant pH once the desired level was established. pH adjustment was required every 2 to 3 days.

Biological Solids

Total and volatile suspended solids for digesters A through F are shown in Figures 5 through 10, respectively. Percent reductions in

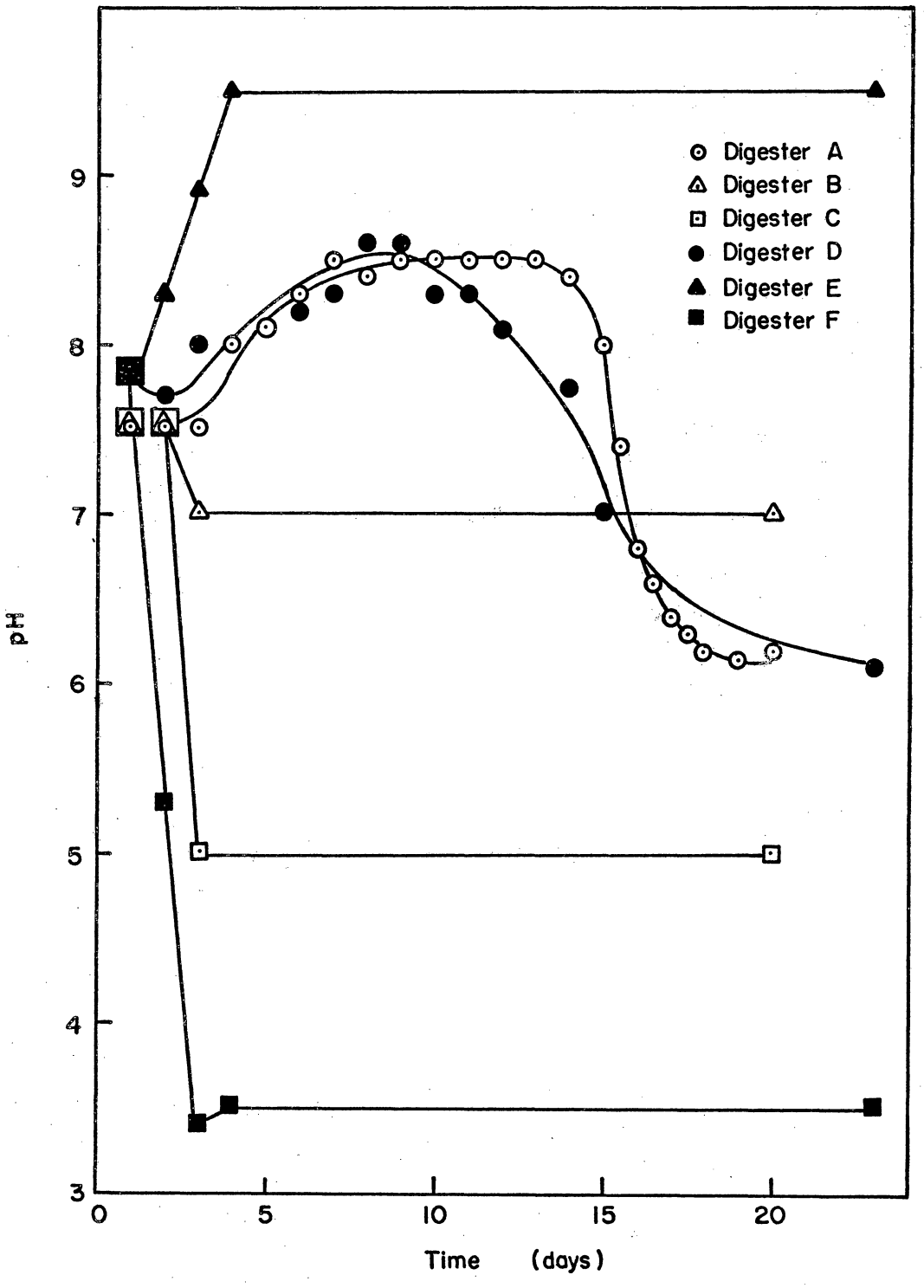

Figure 4: pH DURING AEROBIC DIGESTION

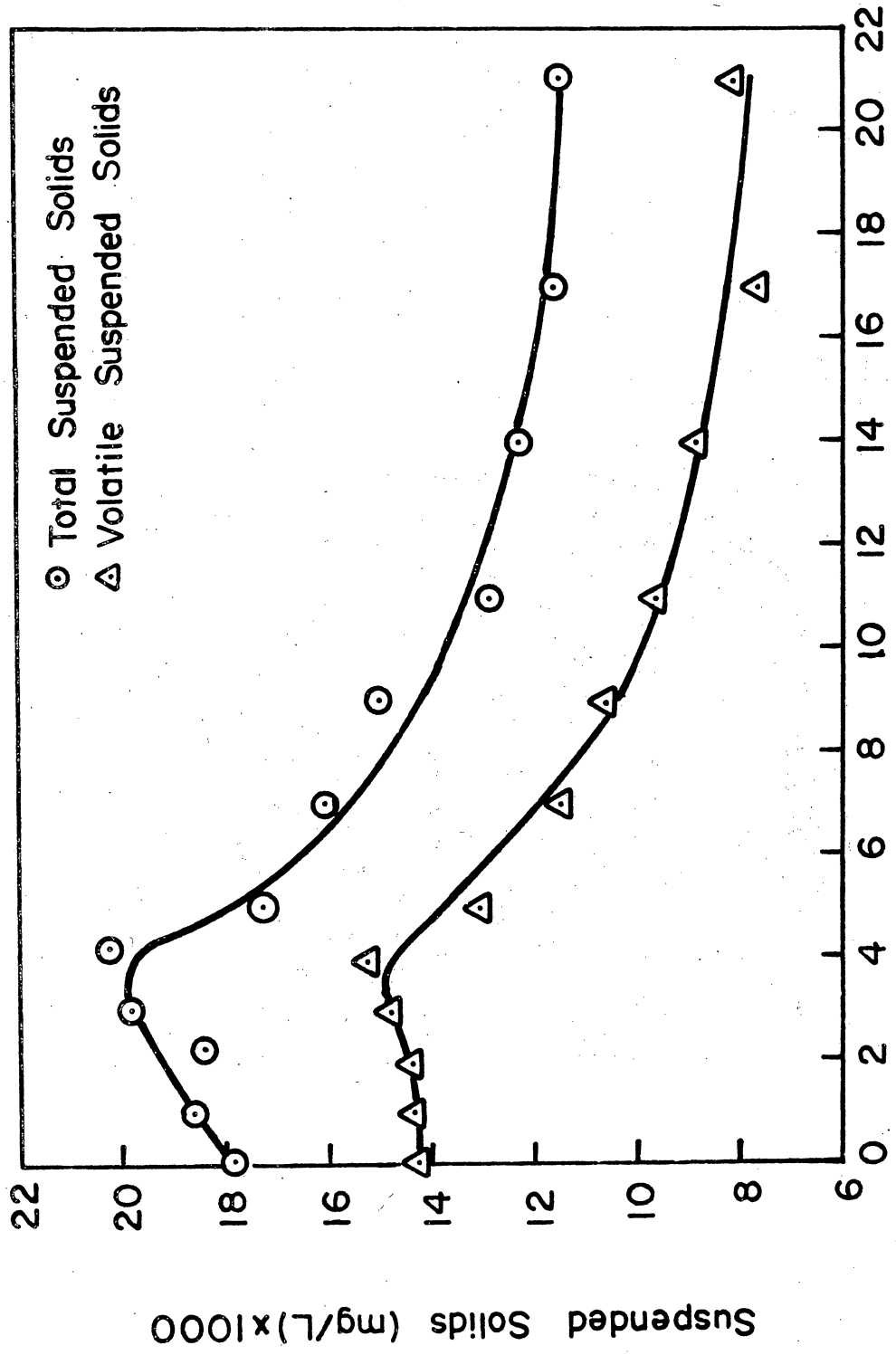

Figure 5: TOTAL AND VOLATILE SUSPENDED SOLIDS OF DIGESTER A

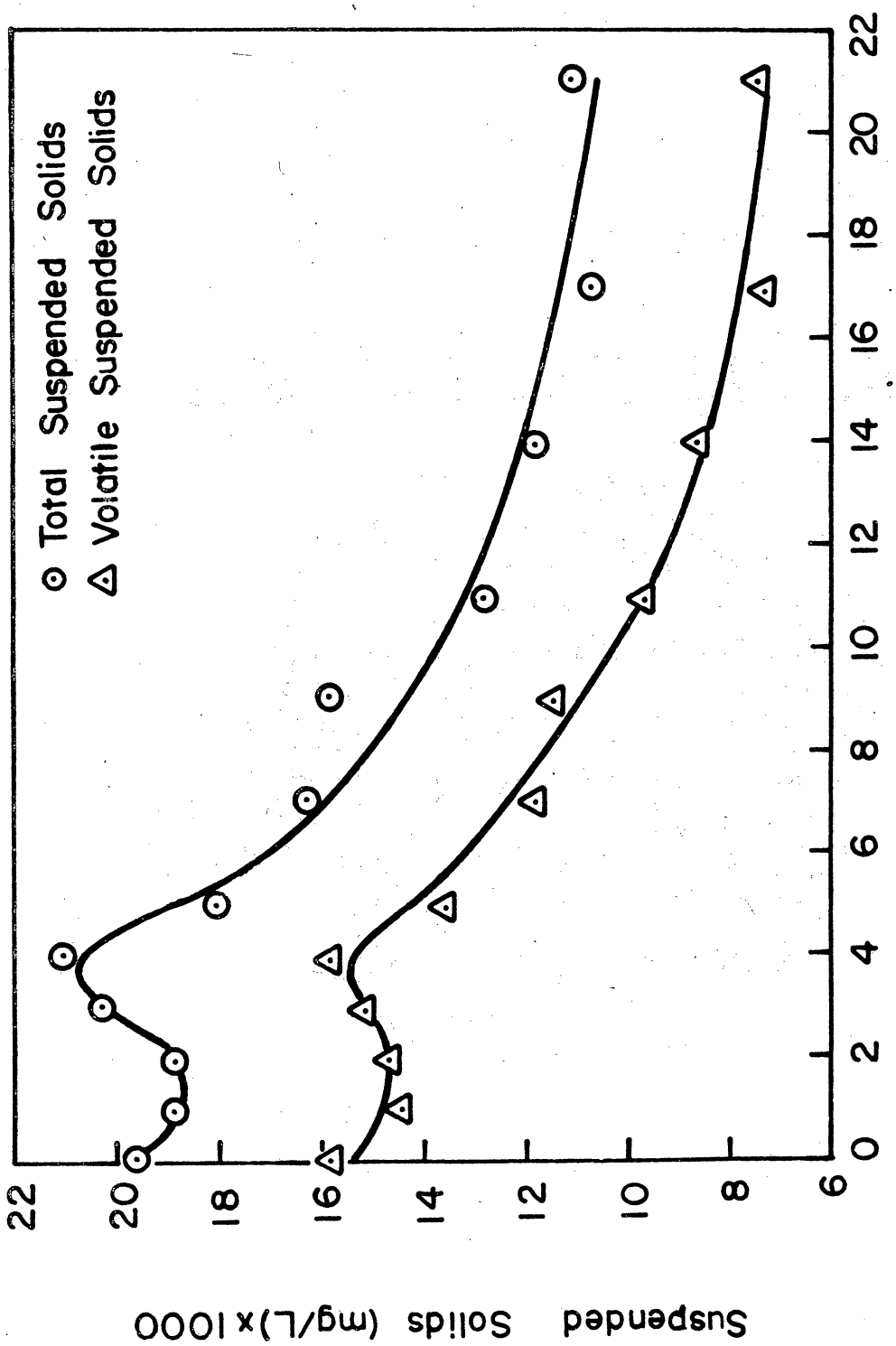

Figure 6: TOTAL AND VOLATILE SUSPENDED SOLIDS OF DIGESTER B

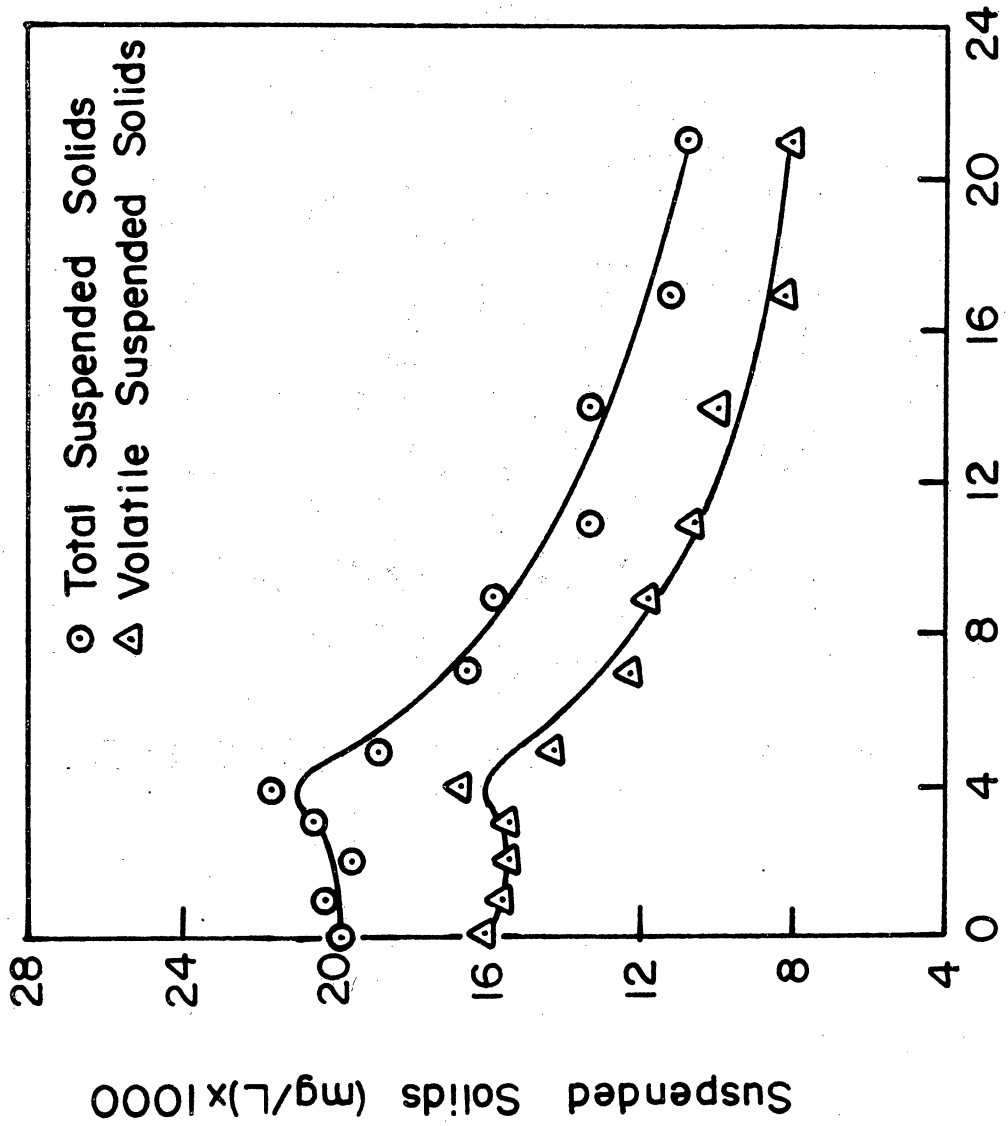

Figure 7: TOTAL AND VOLATILE SUSPENDED SOLIDS OF DIGESTER C

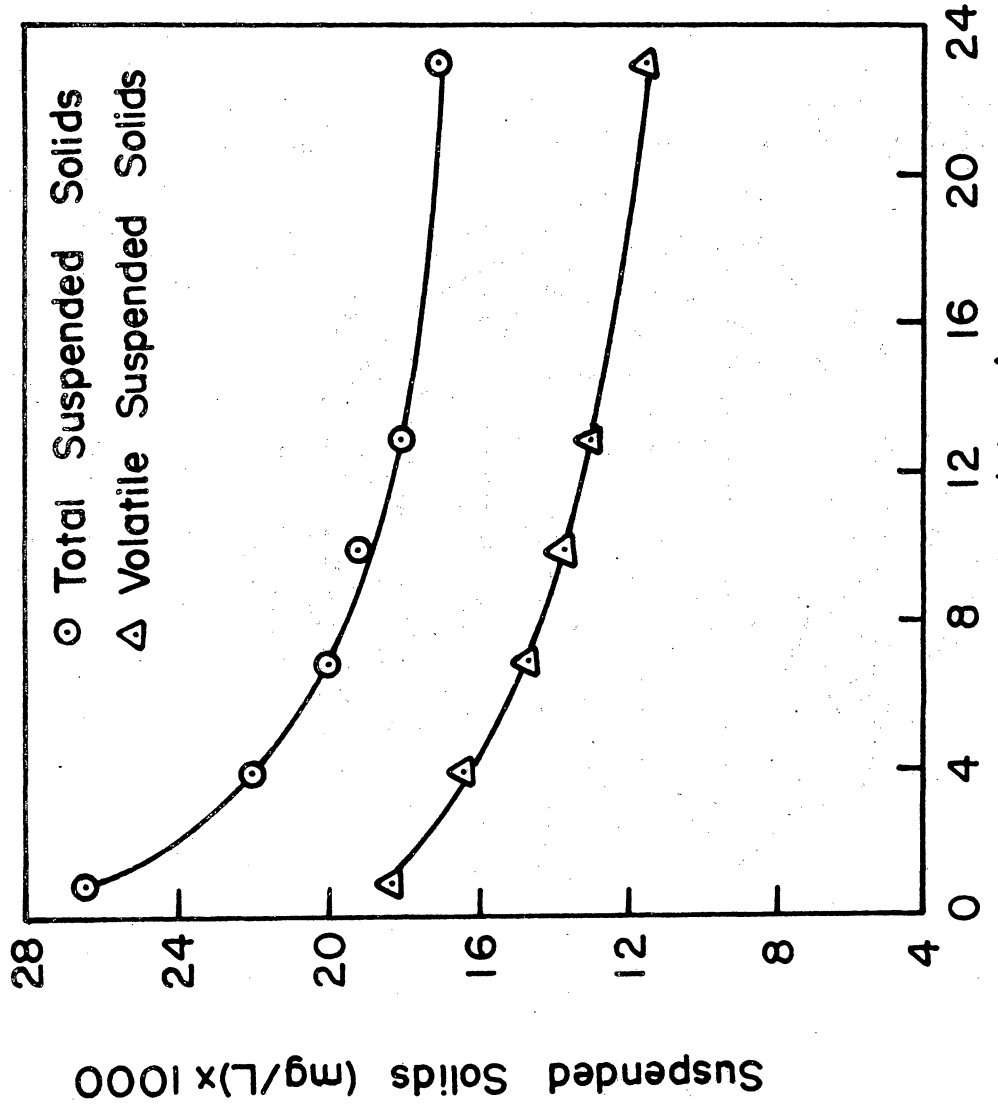

Figure 8: TOTAL AND VOLATILE SUSPENDED SOLIDS OF DIGESTER D

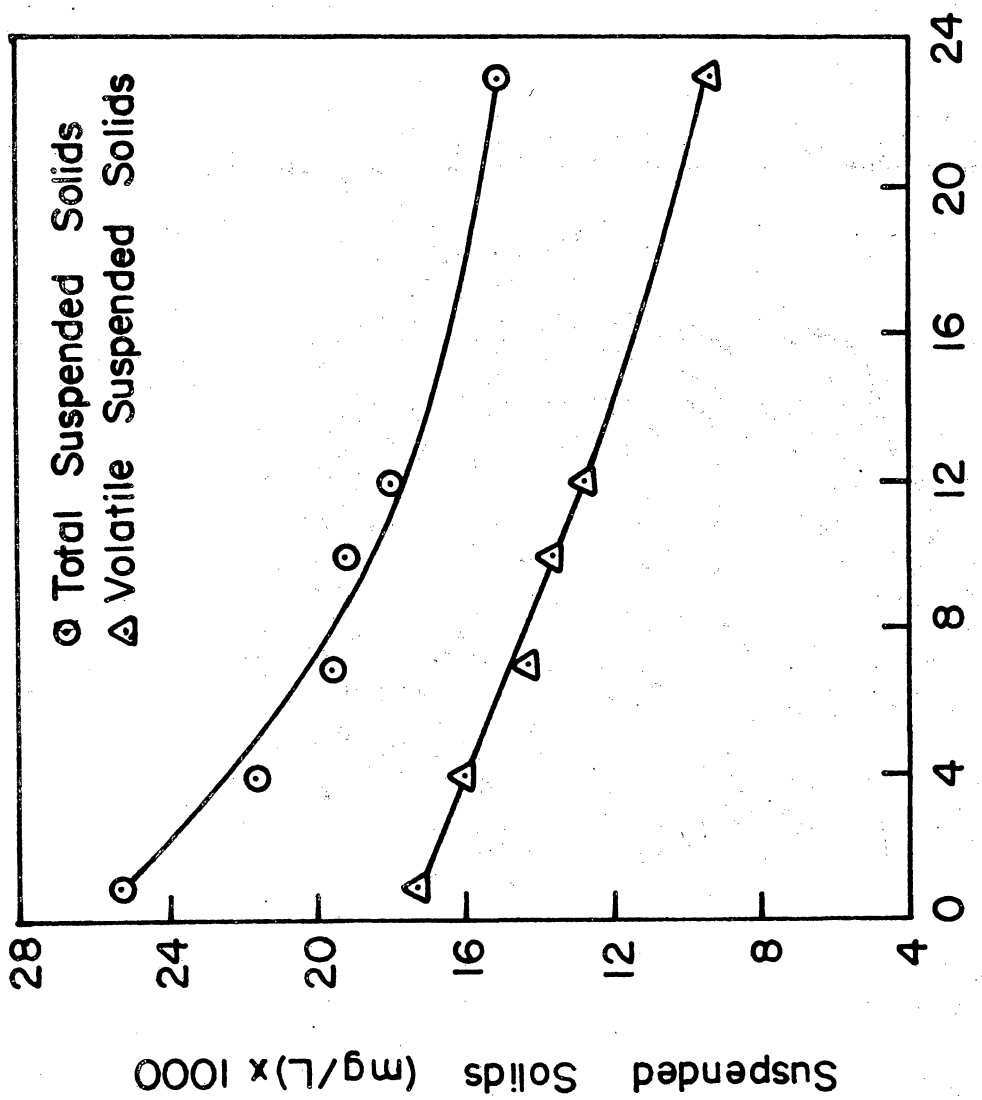

Figure 9: TOTAL AND VOLATILE SUSPENDED SOLIDS OF DIGESTER E

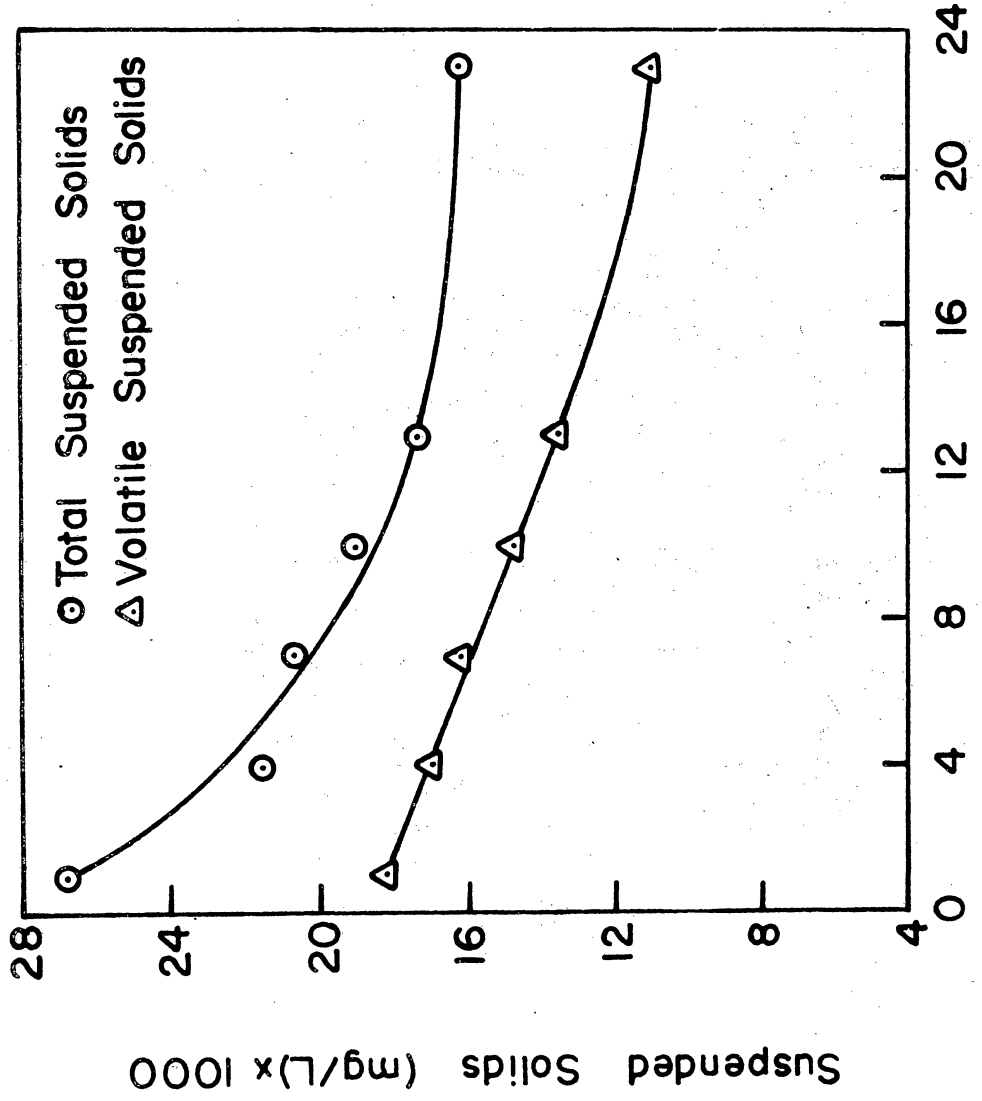

Figure 10: TOTAL AND VOLATILE SUSPENDED SOLIDS OF DIGESTER F

total and volatile suspended solids for the same are presented in Figures 11 through 16. Solids losses due to frothing occurred in digester F on the 4th day of digestion and in digester E on the 21st day of digestion. The losses in each do not appear to have been significant since the plotted data show no appreciable break in the relative values before and after the period of frothing (Figures 9 and 15).

An initial increase in both total and volatile suspended solids was experienced in all three digesters (A, B and C) of the first series. A similar phenomenon was observed by Saunders (25) on day one of his experiment. He attributed the increase to experimental error, although he stated that it could possibly have been a response of the system. During this study solids analyses were made daily during the period of increase and thus the rise in solids could not be attributed to experimental error. Instead, it was probably due to the unstabilized nature of the sludge at the time of sampling. Although daily solids analyses were not performed on sludges D, E and F, it did not appear that an increase occurred since no lag period was observed. Figures 11 through 13 were computed as of day 4 for digesters A, B and C to compensate for the solids increase, since this was the day of maximum solids concentration and endogenous respiration is characterized by a net loss of solids due to auto-oxidation of the microbial cells.

Percent volatile solids reductions were nearly identical for sludges having the same initial solids content and subject to pH control. During each run, the percent reduction in volatile solids in units with constant pH was greater than that in the units without pH control. Volatile solids reduction became almost linear with time for

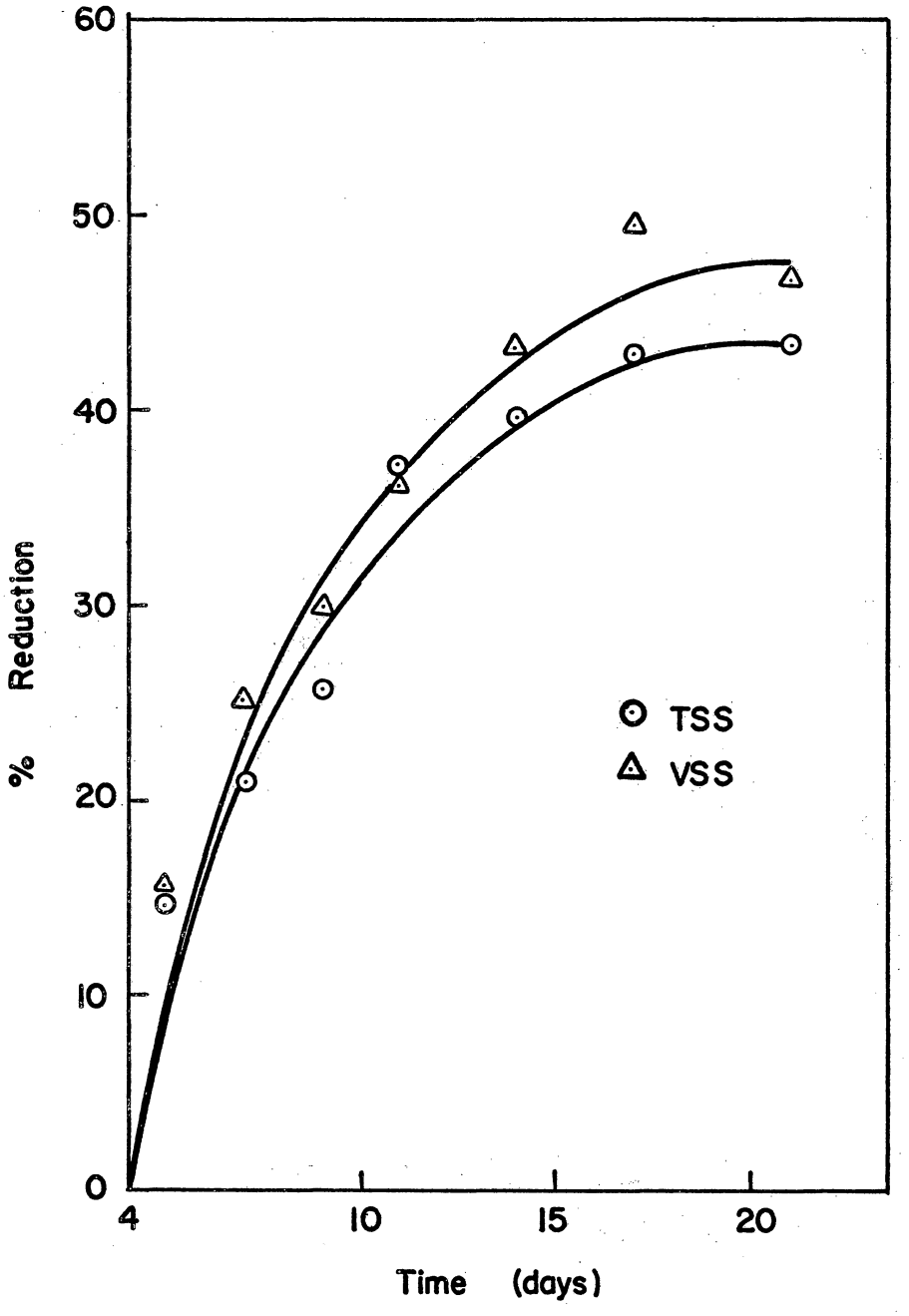

Figure 11: PERCENT SUSPENDED SOLIDS REDUCTION IN DIGESTER A

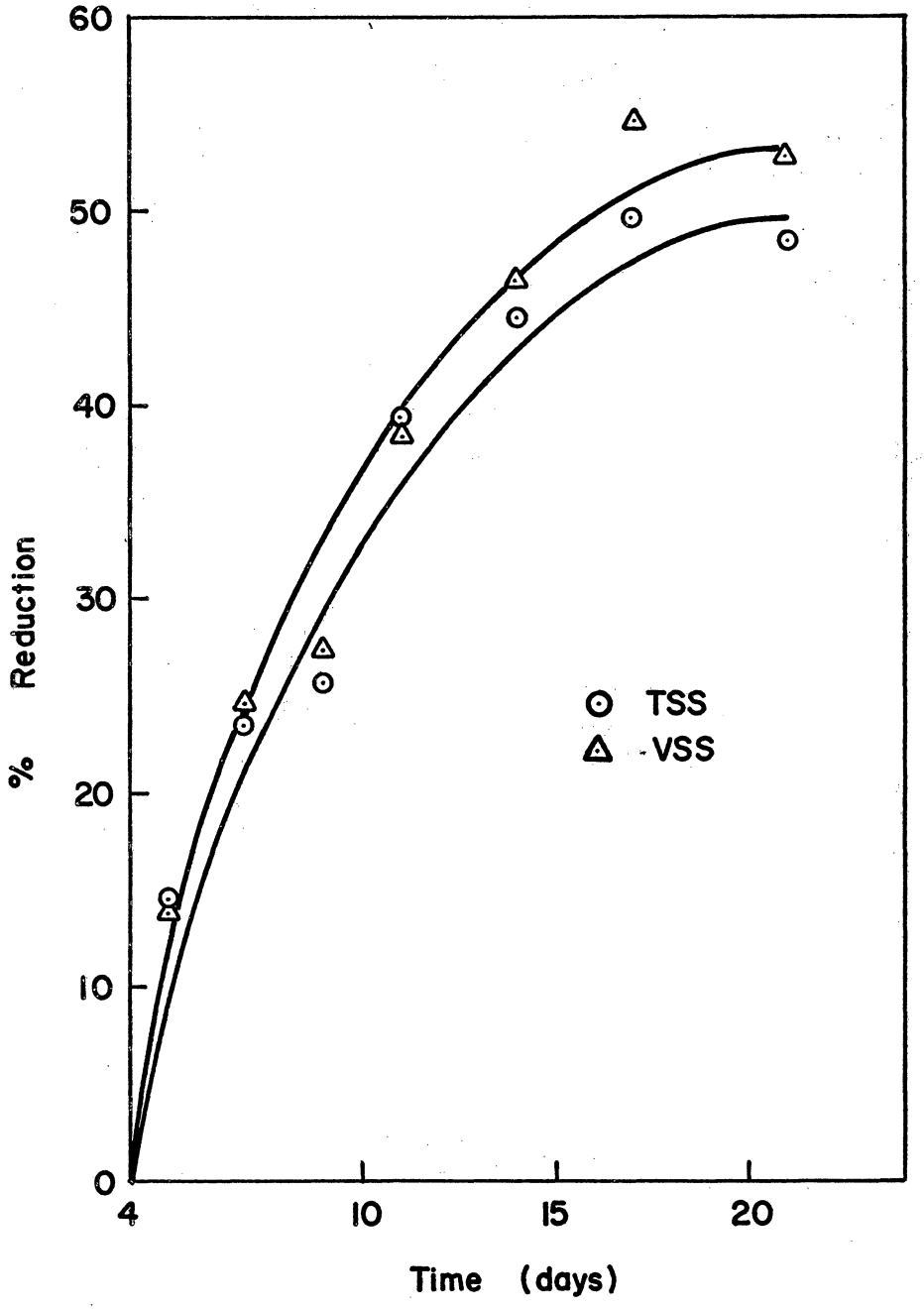

Figure 12: PERCENT SUSPENDED SOLIDS REDUCTION IN DIGESTER B

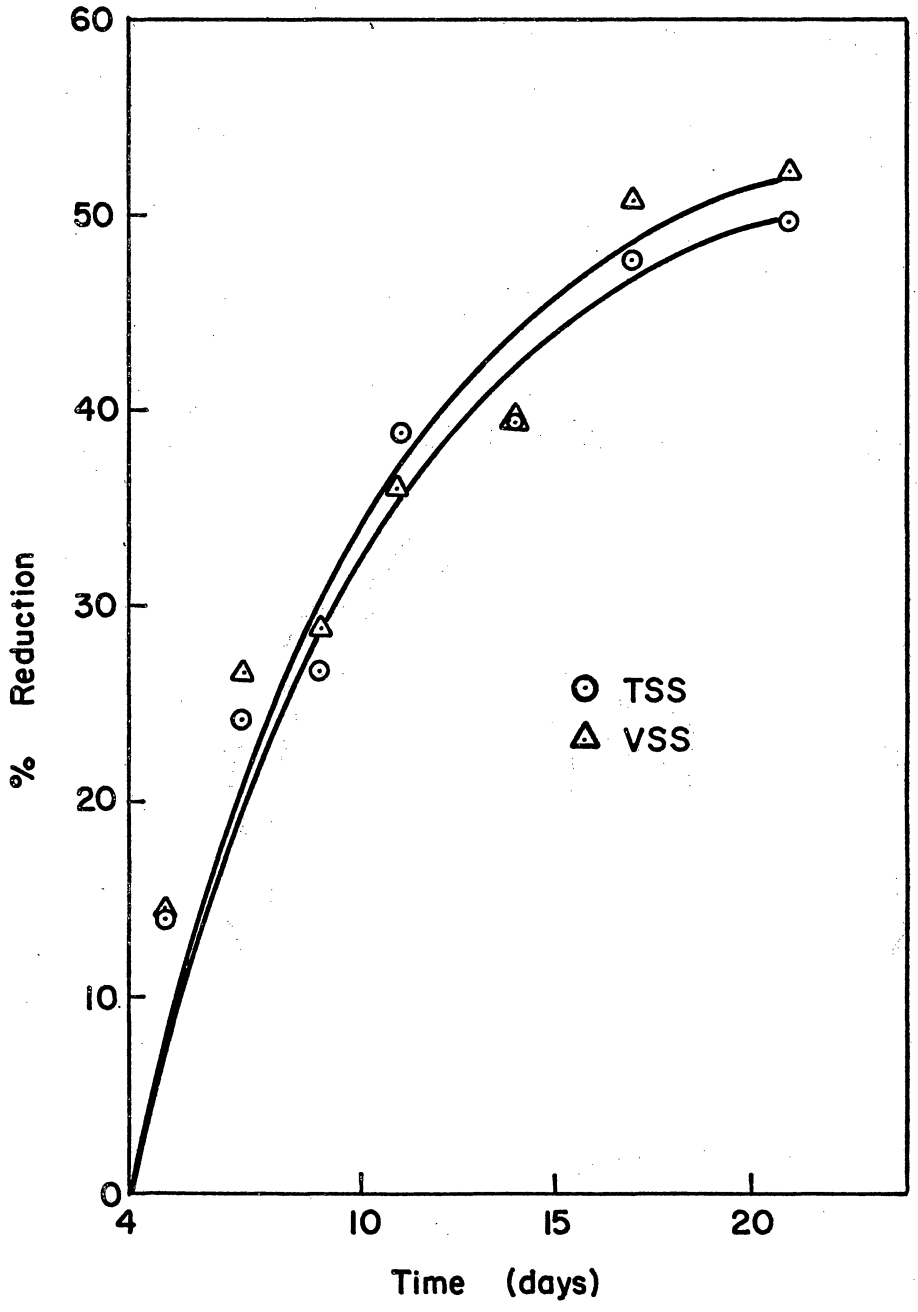

Figure 13: PERCENT SUSPENDED SOLIDS REDUCTION IN DIGESTER C

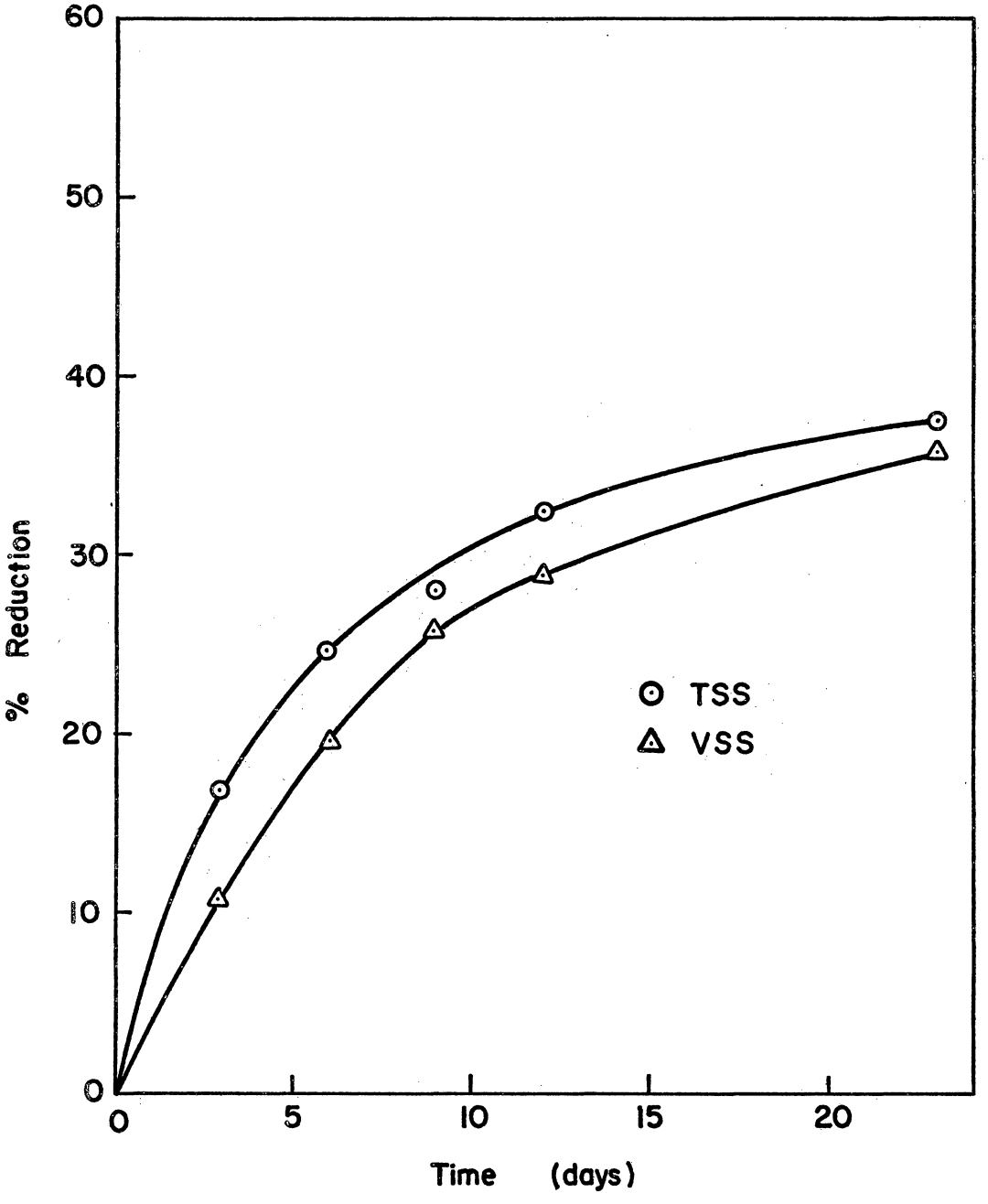

Figure 14: PERCENT SUSPENDED SOLIDS REDUCTION IN DIGESTER D

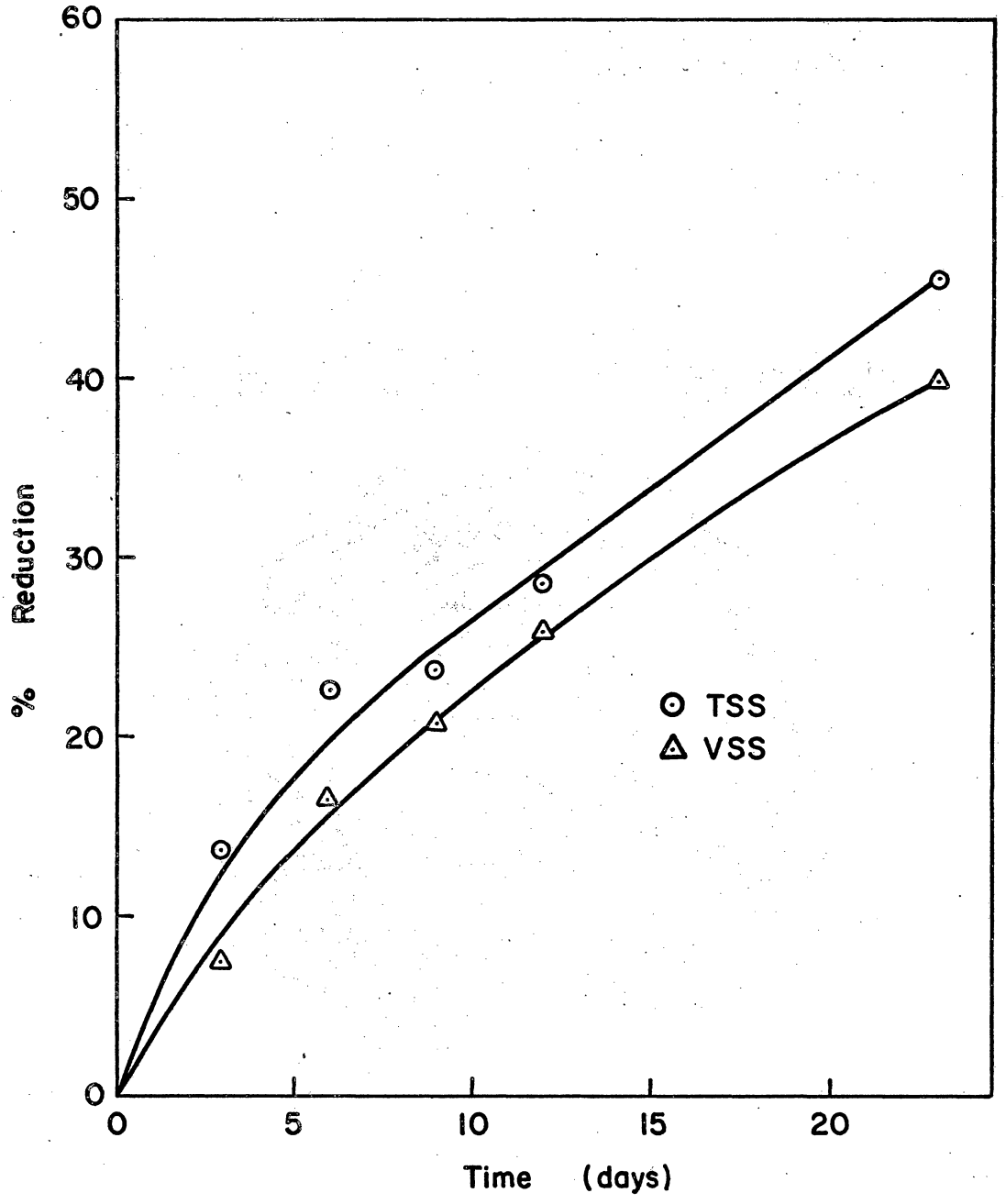

Figure 15: PERCENT SUSPENDED SOLIDS REDUCTION IN DIGESTER E

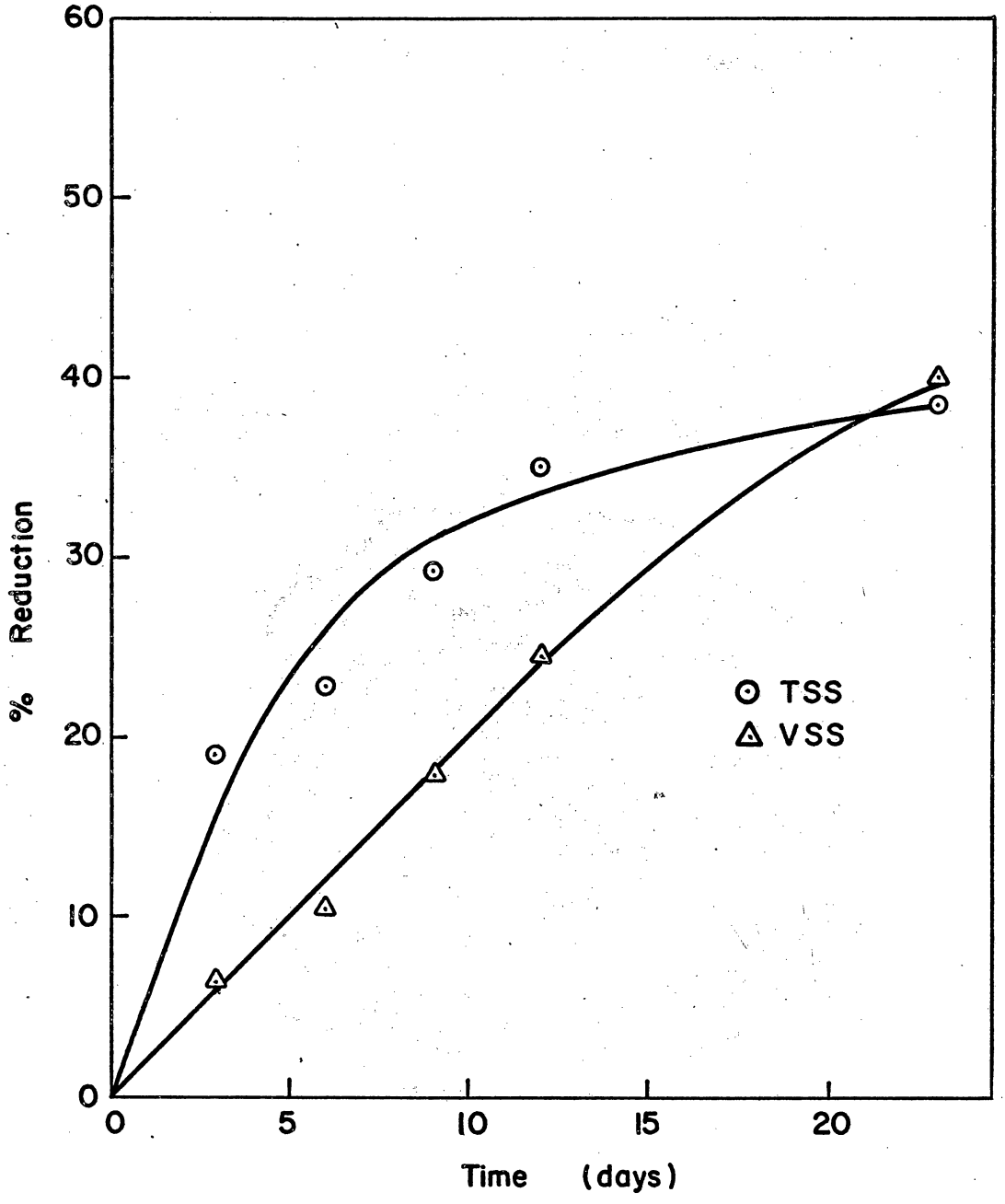

Figure 16: PERCENT SUSPENDED SOLIDS REDUCTION IN DIGESTER F

the digesters with higher initial solids content and controlled pH. By constrast, in unit D, which had similar initial solids concentration but without pH control, the rate of volatile solids reduction tended to become linear after 10 days, but was markedly less than the rates in units E and F. Units with lower solids concentrations showed a decrease in the rate of volatile solids reduction after 15 days. In each individual digester the rates of reduction in total and volatile suspended solids were nearly equal except for unit F. In digester F, the rate of volatile solids reduction was nearly constant throughout digestion, whereas the rate of total solids reduction was significantly higher the first 10 days of digestion, and then showed a drastic decline during the remaining digestion period. This decline in total solids reduction without a corresponding decline in volatile solids reduction resulted in a build-up of fixed solids in the unit. Such mineralization was not observed in the other units.

In units of lesser solids concentration (A, B, C), percent volatile solids reduction was consistently higher than the percent total solids reduction. For the units at higher solids concentration (D, E, F), percent total solids reduction was greater than the percent volatile solids reduction. The only exception to this was in unit F where on day 23 the percent reduction in total and volatile suspended solids was nearly equal (Figure 16). Interestingly, greater percent solids reductions were realized at lower solids concentrations after 20 days, however, the rate of solids reduction was greater at higher solids concentrations with the exception of the rate of total solids reduction in unit F.

During digestion, the percent volatile solids content declined in all units. Some variation in the rate of decline was noted in units C and F, apparently due to the lower pH values maintained in those units. Unit C (pH 5.0) tended to maintain a slightly higher percent volatile solids content than digesters A and B after the first day of digestion through termination. Digester F (pH 3.5) showed a significant rise in percent volatile solids initially, this value remaining relatively constant until termination, when it showed a sharp decline. Percent volatile solids content data for each digester during digestion are shown in Table II.

Nitrates and Ammonia Nitrogen

Extensive nitrification took place in units A, B and D, whereas units C, E and F showed practically no nitrification (Figure 17). Nitrification was most pronounced in unit B where pH was held at 7.0, which is highly favorable to the nitrifying bacteria. However, pH values as high as 9.5 or as low as 5.0, as maintained in units C, E and F, are inhibitory to nitrification. It was noted that the odor of free ammonia gas was obvious about digesters A, D and E during the initial 10 days of digestion, but this was not true of digesters B, C and F during any period of the digestion process. To determine the fate of the nitrogen, ammonia tests were performed on digesters A, B and C at 14 and 20 days. The results are shown in Table II. The higher volatile solids content of digester C may account for the low ammonia content at 14 days, the nitrogen being combined in organic compounds.

TABLE II

PERCENT VOLATILE SOLIDS CONTENT AND AMMONIA NITROGEN

Digester Detention Time (days)	Percent Volatile Solids					
	A	B	C	D	E	F
0	79.8	80.6	81.1	68.7	68.1	67.6
3	77.7	77.7	78.1	73.9	73.1	78.2
6	74.7	75.3	76.9	73.3	73.6	78.7
9	71.5	74.0	74.7	71.0	71.0	78.3
12	71.0	73.2	74.8	72.4	70.6	78.5
20	70.7	68.3	73.4	66.9	61.6	69.0

Digester	NH_3-N/NO_3-N(mg/l as Nitrogen)	
	14 days	20 days
A*	56/52	90/124
B**	185/38	370/145
C	85/2.5	700/3.0

*Loss of ammonia to atmosphere and nitrification

**Loss of ammonia primarily to nitrification

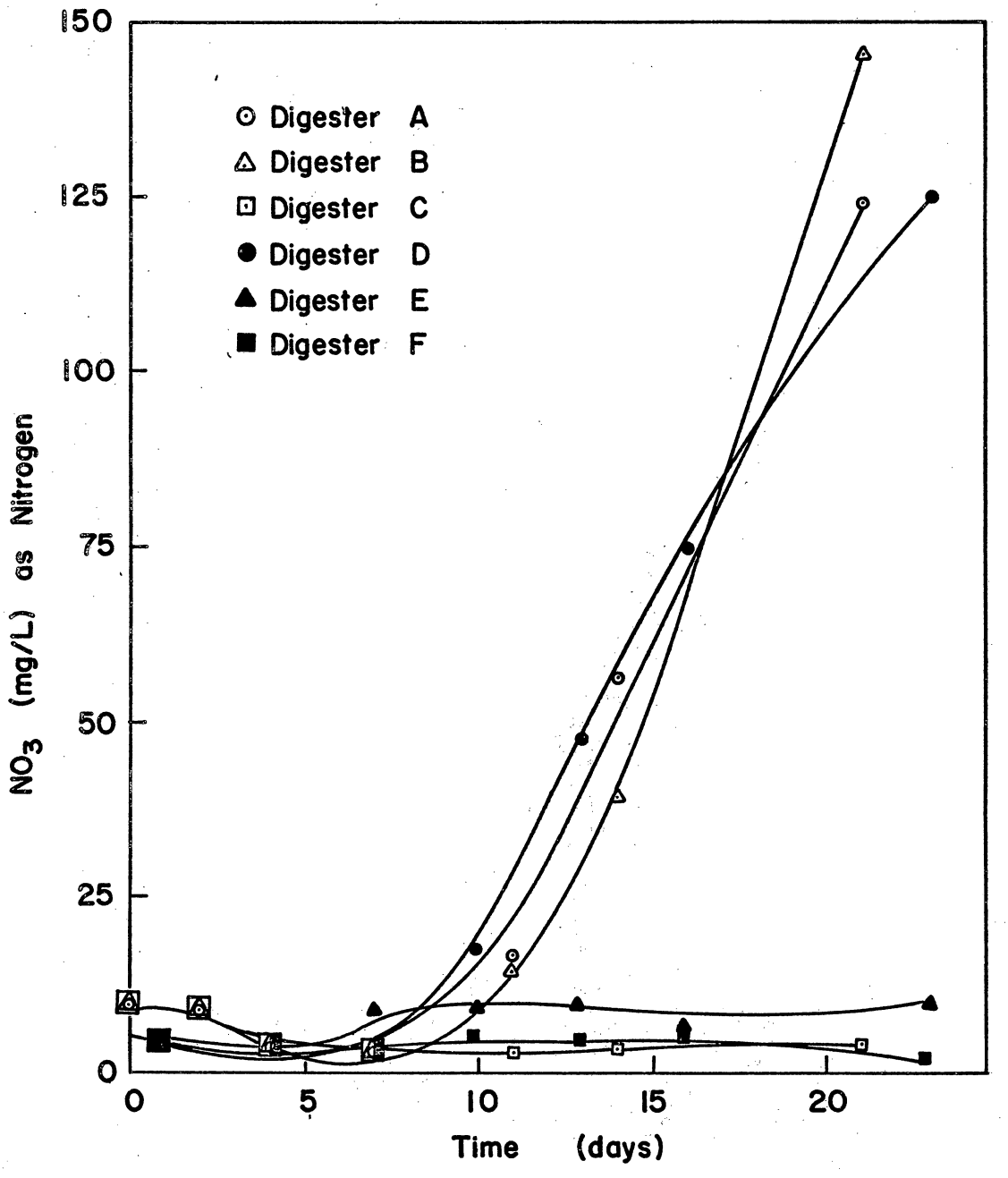

Figure 17: NITRIFICATION DURING AEROBIC DIGESTION

In units without pH control (A and D), the increase in nitrate concentration corresponds with the decline in pH, which concurs with the results of Ludzak as reported by Norman (19).

Orthophosphate

The concentration of orthophosphate in the supernatant showed a definite increase with aeration time and the deviation of pH from a value around 7.0. The release of orthophosphate was apparently retarded in the digesters with higher solids concentrations (Figure 18).

Cellular Protein

In unit A (without pH control) and unit C (pH = 5.0), cellular protein showed a cyclic tendency, whereas in unit B (pH = 7.0), the cyclic effect was more subdued (Figure 19). All units displayed a gradual increase in the weight of cellular protein per unit weight of total suspended solid (Figure 22). The cyclic tendencies of units A and C were again apparent, whereas unit B showed a smooth increase. Tests were made on units D, E and F on the first and last days only, but the gradual increase in grams of cellular protein per unit weight of total suspended solid was apparent. The gradual increase in cellular protein indicates that as cellular constituents are oxidized metabolically resistant proteins of non-living material become a larger portion of the total suspended solids.

Cellular Carbohydrate

Carbohydrate sampling frequency was the same as that used for proteins in all digesters. Total cellular carbohydrate showed a significant variation in units C and F in comparison with other digesters (Figure 20).

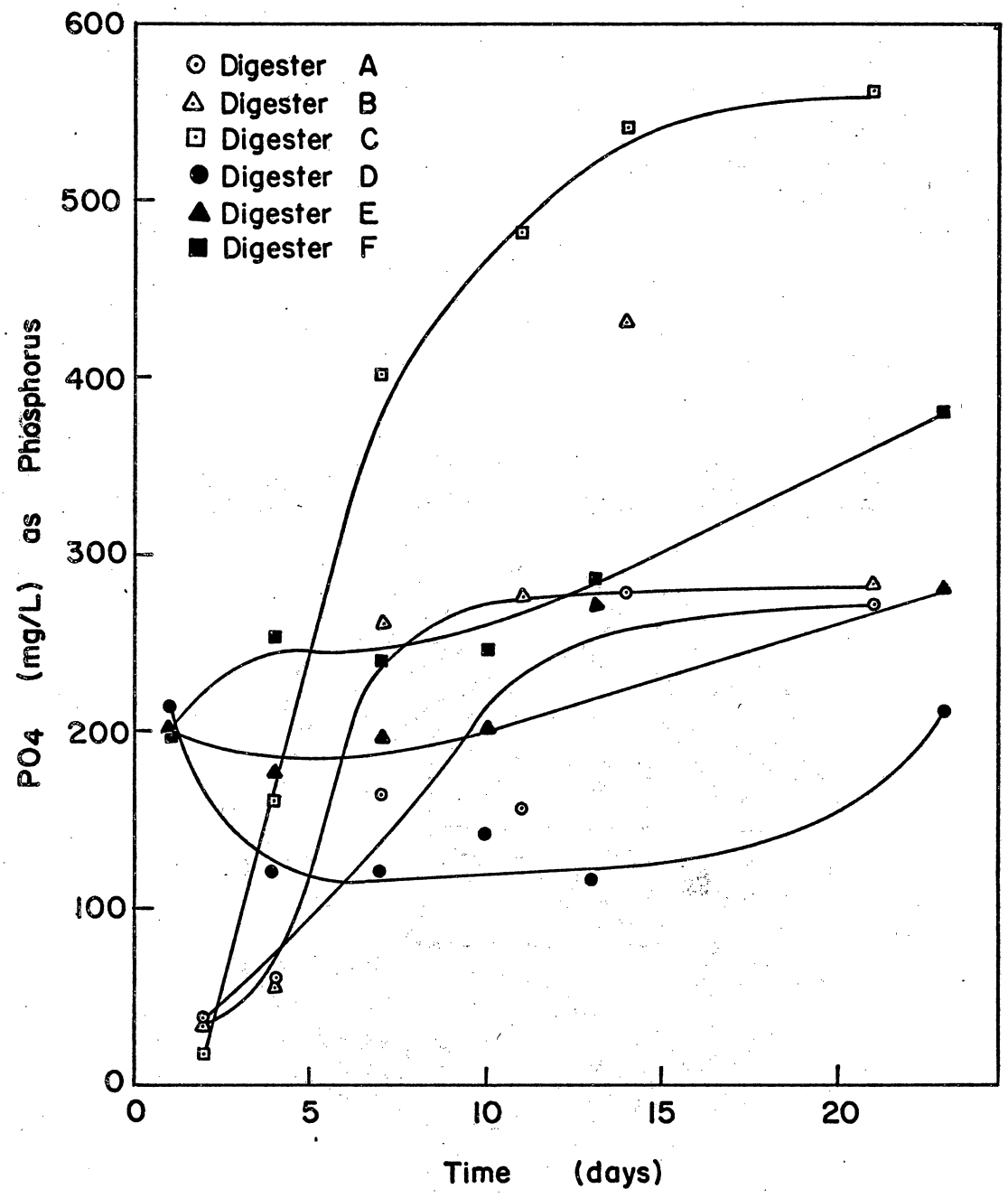

Figure 18: ORTHOPHOSPHATE CONCENTRATION DURING AEROBIC DIGESTION

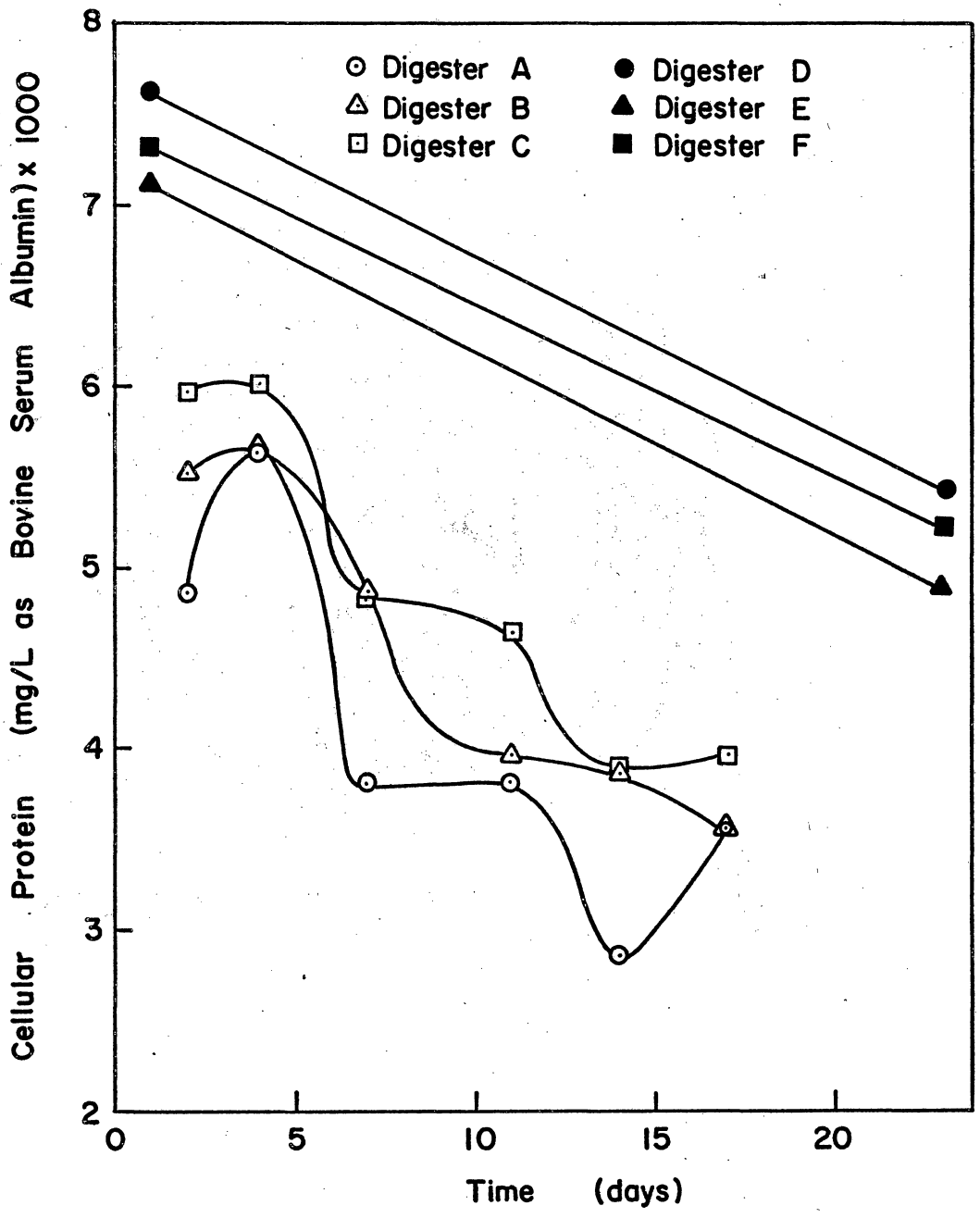

Figure 19: CELLULAR PROTEIN DURING AEROBIC DIGESTION

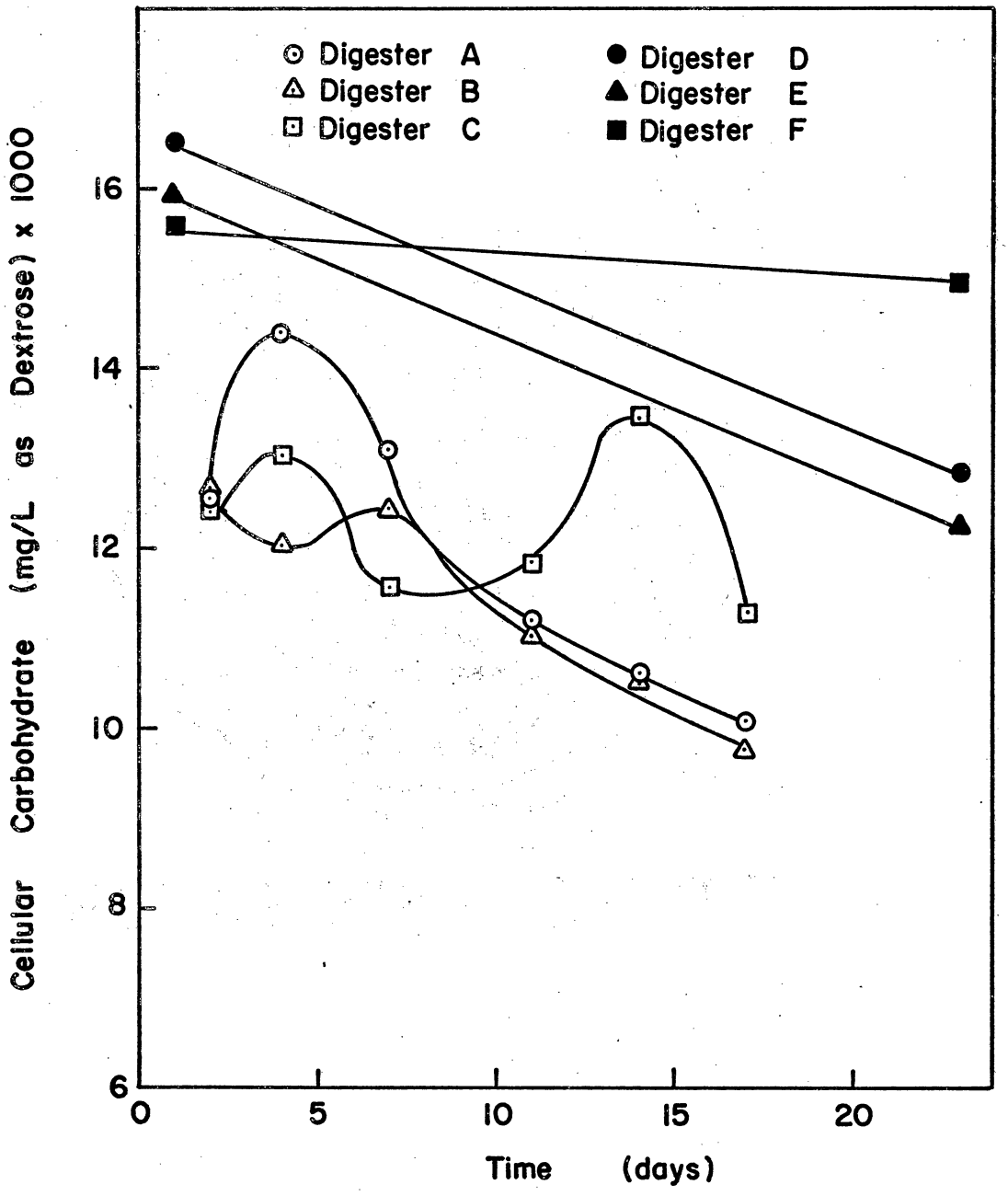

Figure 20: CELLULAR CARBOHYDRATE DURING AEROBIC DIGESTION

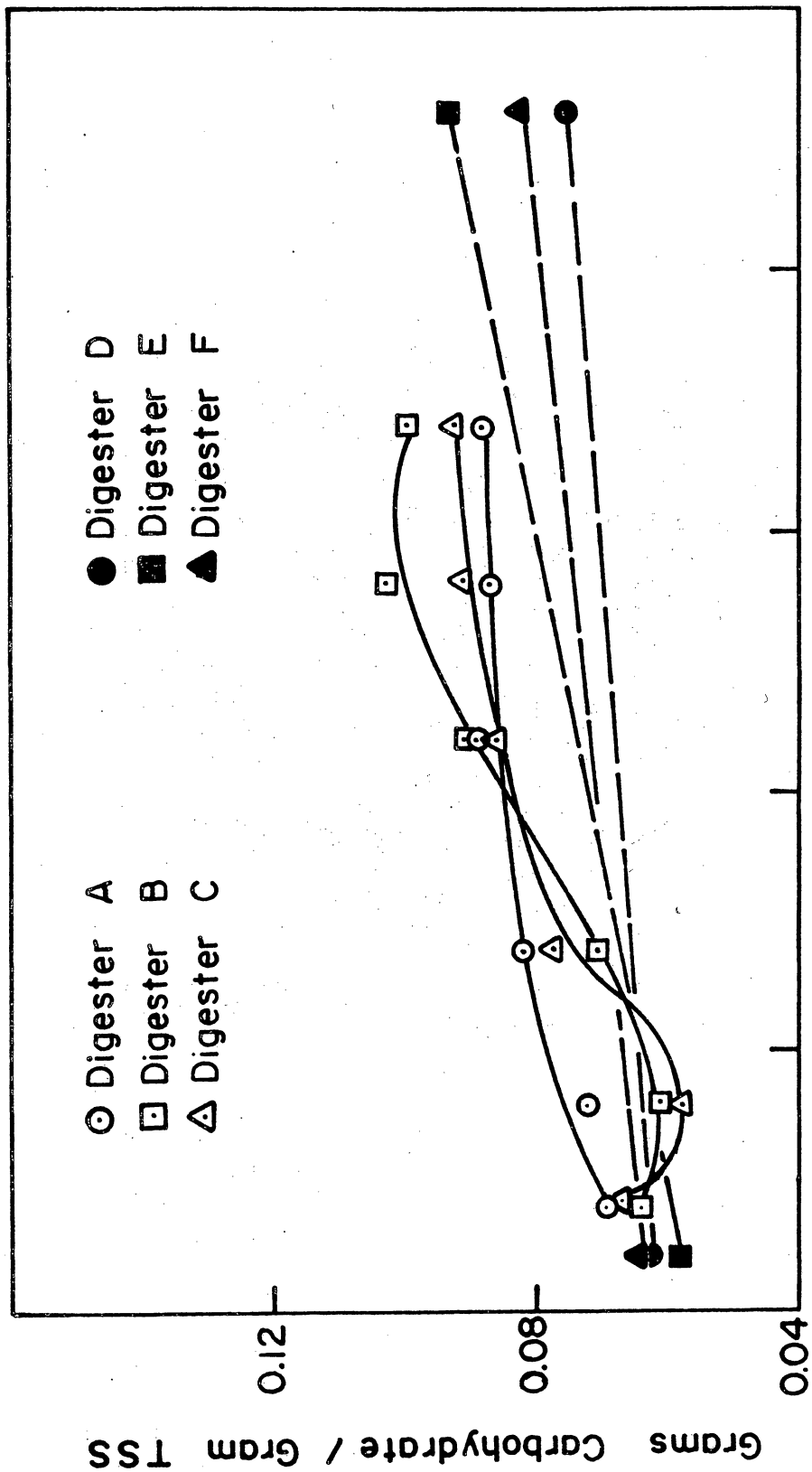

Figure 21: CARBOHYDRATE FRACTION OF TSS DURING AEROBIC DIGESTION

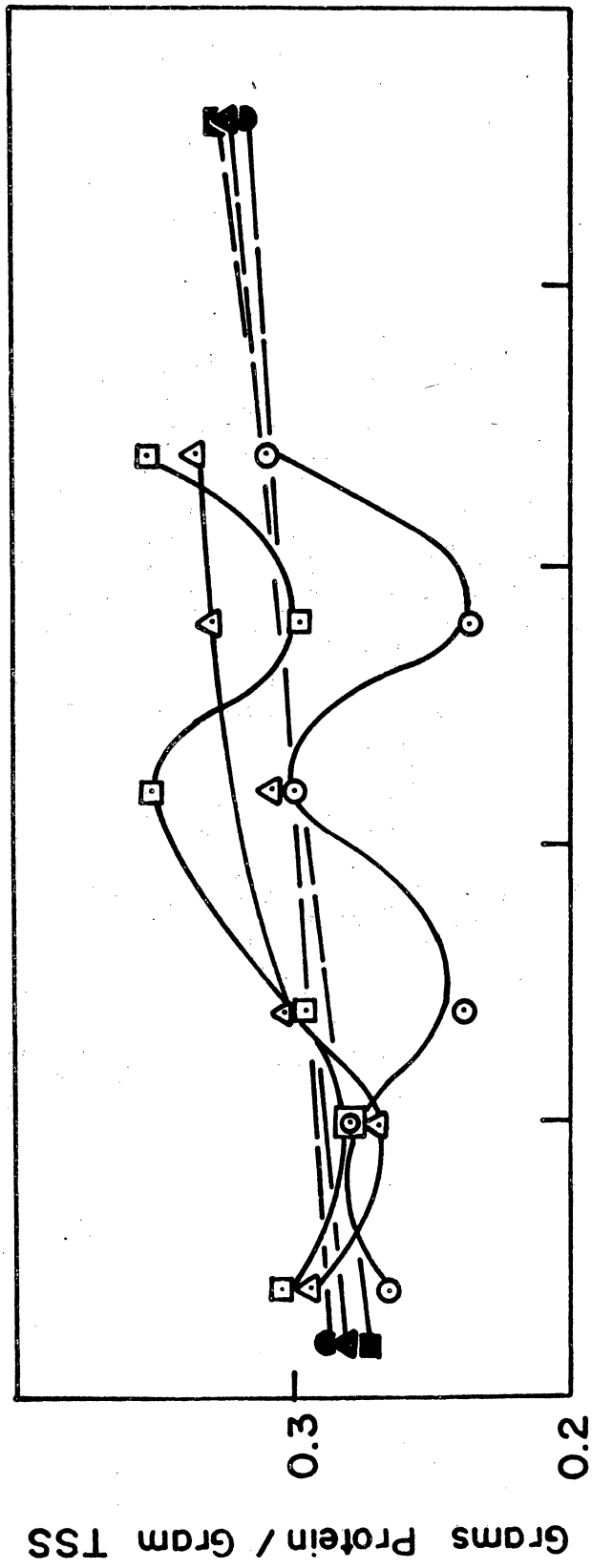

Figure 22: PROTEIN FRACTION OF TSS DURING AEROBIC DIGESTION

This variation is considerably reduced, however, when grams of cellular carbohydrate per gram of total suspended solids is plotted against time (Figure 21). The decrease in total cellular carbohydrate was considerably less with decreasing pH. A mild build-up in grams of cellular carbohydrate per gram of total suspended solids was realized in all digesters and this increases slightly with decreasing pH. A diphasic variation in cellular carbohydrate was noted in digester C. The large increase at 15 days sets it apart from digesters A and B. This rise seemingly corresponds to an observed increase in protozoan activity in digester C.

BOD and COD

The reduction in mixed liquor BOD for all digesters was consistent (Figure 23). Digesters B and C showed a lag in reduction for the first 6 days, but subsequently conformed to the pattern of digester A. Only the initial and final values for digesters D, E and F were determined. The variation in initial BOD determinations for digesters A, B and C are believed to have been subject to experimental error, since all sludges were well mixed prior to being placed in their respective digesters. Improvement in the technique of the investigation is believed to have improved the accuracy of subsequent analyses. COD was not plotted since a 40 percent reduction was consistent in digesters A, B and C at termination of the experiment. COD determinations for digesters D, E and F were not made.

It was assumed that the initial BOD of the mixed liquor in digesters A, B and C was 8,300 mg/l, since this was the average of the three determinations. All digesters showed at least an 86 percent reduction in mixed liquor BOD after 20 days.

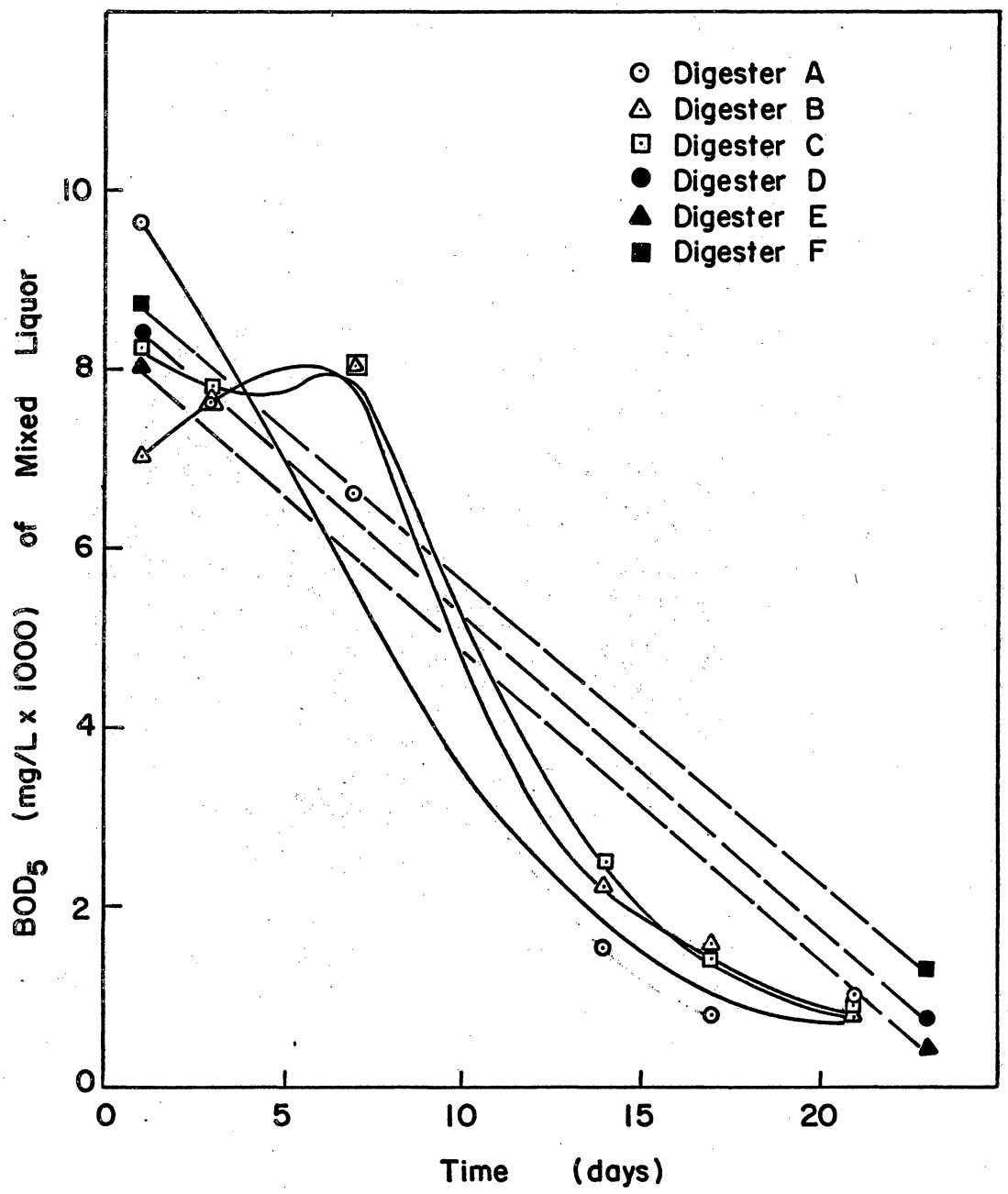

Figure 23: BOD_5 CHANGE DURING AEROBIC DIGESTION

Settleability

Although settleability did improve for all digesters to some degree, digester F (pH = 3.5) showed an overwhelming improvement (Figure 24). At both 13 and 23 days of aeration, active coagulation and flocculation was observed in sludge F after 15 minutes of quiescent settling. Correspondingly, the supernatant of digester F was consistently clearer than that of the other digesters. No coagulating effect was noted in digesters A, B, D or E. It was, however, observed in digester C, but to a lesser extent than in digester F. Eight hours of settling (not shown on graph) was sufficient to concentrate sludge F from approximately 1.7 percent solids content to 5 percent solids content in the settled sludge.

Filterability

Filterability tests were run on digesters D, E and F only, since a change in filterability had not been anticipated in the previous series. Tests were begun when sludge F yielded more quickly to the glass filter in the residue test than did D or E. The changes that occurred are illustrated by Figure 25. At four days of aeration, digesters D and E failed to produce 10 ml of filtrate in 30 minutes and are, therefore, not shown. At 15 days, digester F showed the greatest improvement, filtering 94 percent of the original volume in 8 minutes and forty seconds leaving only a sludge mat on the filter paper. At 23 days of aeration, it was realized that filterability had decreased, and only the time to filter 75 percent of the original volume was recorded. Filterability increased in digesters D and E up to 15 days, but they showed no subsequent improvement. In all tests, the filtrate from D and E was very cloudy, while that from F was clear.

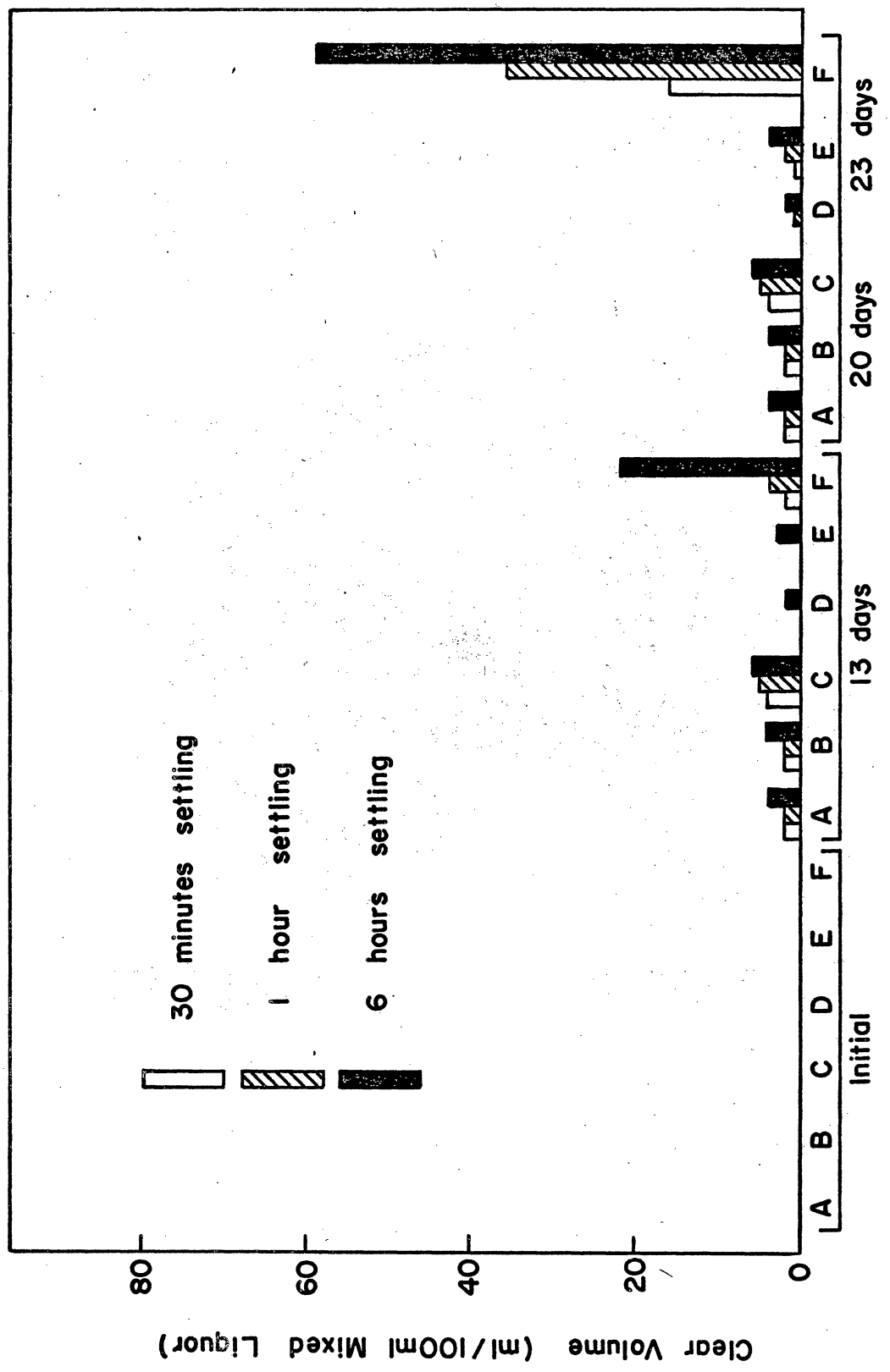

Figure 24: CHANGE IN SETTLEABILITY DURING AEROBIC DIGESTION

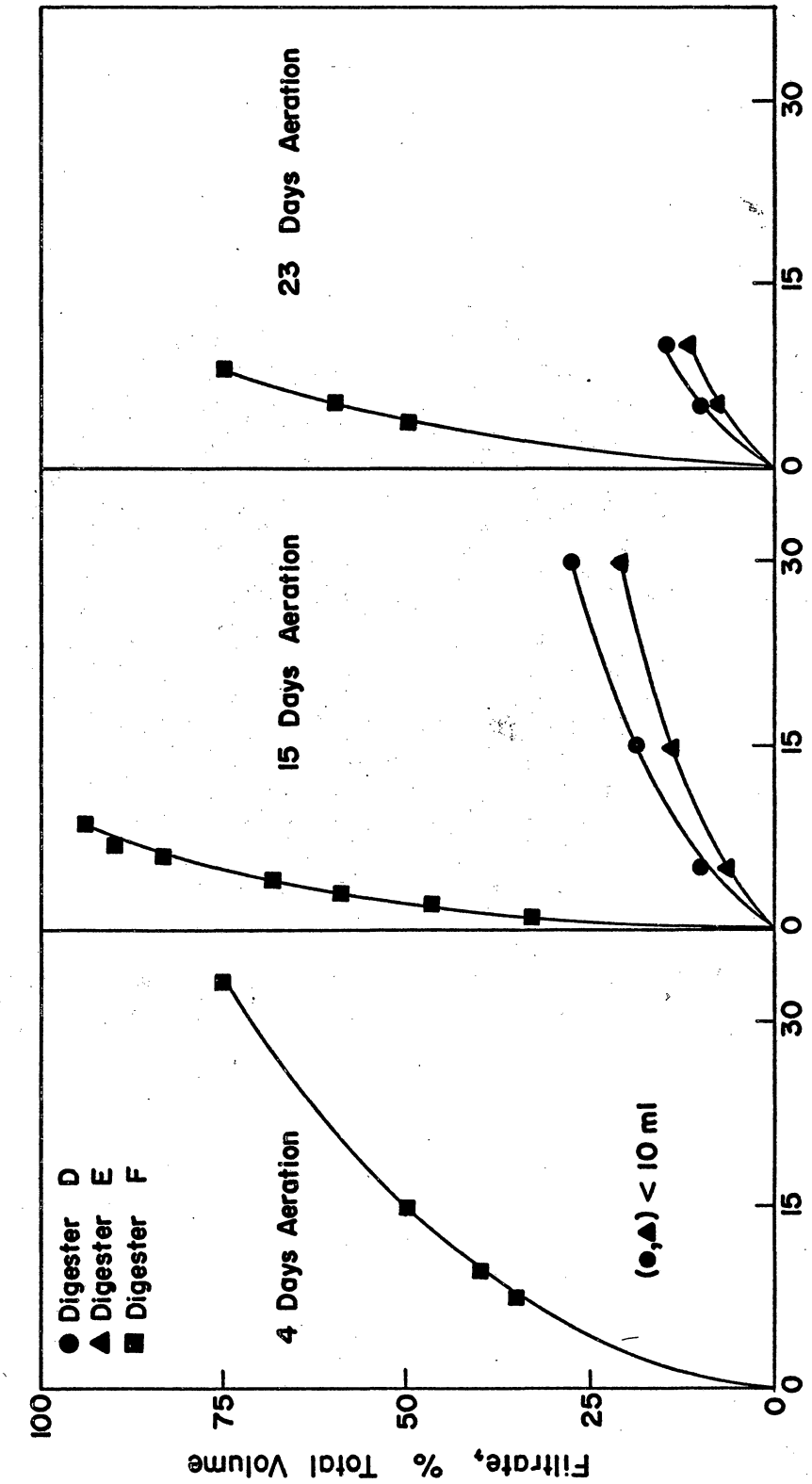

Figure 25: SLUDGE FILTERABILITY

Drainability

Results of the drainability test are shown in Table III. Filtrates from D and E were very dark, while that from F was only slightly cloudy, becoming clear as drainage progressed. The sludge of D and F had a neutral odor, whereas the sludge of E developed a putrescible odor within 24 hours. BOD values of the filtrate from D, E and F were 32, 54 and less than 24 mg/l respectively. BOD samples were collected after a minimum of 2 l of filtrate had drained from the sand beds.

Microscopic Examination

All sludges had a similar appearance initially. Few motile forms were observed. Cell fragments from nematodes and protozoa were apparent among masses of gelatinous organic material. After 6 days, both free-swimming and stalked protozoa of the class Ciliata appeared in Digesters A, B, C and D, with a fewer number of flagellated protozoa. The number of protozoa were decidedly greater in unit C. Digesters E and F were least active, probably due to the sharp change in pH to which they had been subjected. Digester B had some activity, but was decidedly less active than A, D or C. At 10 days, digester A displayed large numbers of free-swimming and stalked ciliates. Forms such as flagellates and other small protozoa were scarce. Digester B was less active, with only a few free-swimming and stalked ciliates appearing. Digester C displayed all the forms of A but in abundance. Large clusters of the stalked ciliate Vorticella and numerous free-swimming ciliates were dominant. Digester D was similar to A, and digester E displayed no life forms larger than bacteria, some motile forms of which were observed at

TABLE III

SLUDGE DRAINABILITY

	Filtrate, Percent Total Volume						
Digester	5 min.	10 min.	30 min.	1 hr.	2 hr.	12 hr.	36 hr.
D	37.5	38.4	41.6	45.0	47.7	59.3	71.0
E	35.4	38.4	43.4	47.5	52.0	70.4	80.4
F	53.4	56.6	67.5	76.6	88.3	96.0*	96.6

*Sludge mat appeared to be drained.

a magnification of 1000. In digester F, many free-swimming ciliates of the species Glaucoma were observed and appeared to be the only living creatures other than bacteria. By the 15th day, only digester F showed significant change. The ciliate Glaucoma was so numerous that as many as 30 to 50 (approximate) could be viewed in the microscopic field at a magnification of 100 times. By the 20th day, all digesters showed few living forms. In digesters A, B, C and D, filamentous forms had appeared, and the ciliates had disappeared except for a few of the stalked forms. Digester A had a few nematodes, and digester C contained some protozoa with rigid, projecting spicules. Digester E showed no signs of life and digester F displayed only a few Glaucoma.

Frothing

Frothing occurred in all digesters at different times, but showed no apparent pattern except in the case of digester F, which experienced severe frothing when the pH was initially adjusted to 3.5. In all other cases, a decrease in the sparging rate alleviated the problem.

DISCUSSION OF RESULTS

It is evident from the results obtained that the reduction in total and volatile suspended solids during aerobic digestion is not severely affected by pH over a range from 3.5 to 9.5. However, the data shows that improved results may be obtained if pH is held constant instead of being allowed to fluctuate. During normal aerobic digestion, pH varies widely from about 8.5 in the early stages of digestion to values of 5 and below for extended periods of aeration. It was found in this study that a different biota resulted from each level of pH control. Further, it is known that pH is a selective characteristic of media which will favor the predominance of different organisms at different levels. It easily follows that the variation in pH which typically occurs during aerobic digestion disrupts the growth of the various aerobic populations, and thereby serves to retard solids reduction. A drastic change in pH generally requires a considerable shift in the population to dominance by different species. During aerobic digestion, the development of the preferred species as pH changes is further retarded by a continuing shortage in the food supply of the system with increased aeration. If pH is held constant, on the other hand, the efficiency of the process is enhanced since a maximum population of optimum organisms is maintained and they are free to respire endogenously in a favorable media to, theoretically, the exhaustion of available energy in the system.

The rate of solids reduction was initially greater in units of the first series (A, B, C) which had lower total solids concentrations.

However, despite the difference in solids concentration, the mixed liquor BOD was nearly the same for both series, indicating a greater initial stabilization in the second series (D, E, F). The initial increase in solids content to day 4 in the first series is further indication of an unstable sludge. This difference in the degree of stabilization probably accounts for the initially higher rate of solids reduction in the first series. After 15 days of digestion, the rate of volatile solids reduction decreased rapidly in the first series while the second series continued to show a significant and nearly constant rate of volatile solids reduction throughout the 23 day run with the exception of digester D. Digester D, the control unit, has a decrease in the rate of volatile solids reduction commensurate with declining pH beginning on the 10th day of digestion, indicating pH toxicity to the dominant population. The rapid decline in solids reduction after 15 days in the first series was probably caused by the exhaustion of the available nutrient in the system.

The rate of reduction in total and volatile suspended solids was nearly the same within each individual digester except for digester F. In that digester the reduction in total solids declined after 10 days but volatile solids reduction continued to be high seemingly indicating the conversion of volatile solids to fixed solids, constituting mineralization. This was possibly caused by the highly developed predator growth of free-swimming ciliates that appeared in the unit in contrast to the other units. Mineralization did not occur in digester C at a pH of 5 which also had a high predator population, however microscopic

counts showed that the ratio of the number of predators in C and F was approximately 1:5. During the study, predators appeared in increasing numbers with decreasing pH. The preference of protozoa, especially those of the class Ciliata, for media in the acid range has been established (6, 7, 9, 24).

The sludge used for this study was typically very difficult to dewater regardless of the stage of digestion. However, filterability tests on the mixed liquor indicated significant improvement with lower pH and increased aeration time up to 15 days, thereafter decreasing slightly by 23 days. This improvement was only slight at pH 5.0, but the improvement at pH 3.5 (unit F) was truly remarkable. The maximum filterability was observed at 15 days which coincided with the maximum active predator growth observed in that unit. It would appear that the predators were largely responsible for the change. A possible reason for such an effect is that the protozoa concentrate bacteria and organic detritus in their larger bodies by ingestion, thus reducing the material with high clogging potential. Then, as aeration time increases, a shortage in food supply causes death of the protozoa, thereby releasing organic detritus to the mixed liquor which tends to clog filter pores. However, the large protozoa tend to flocculate well even after significant decline in their active numbers. It has been reported that flocculation will enhance drainability by the formation of drainage channels through the settled floc. Similar effects would logically improve filterability as long as the floc has a high enough shear strength to resist the force of liquid passing through the drainage channels at high velocities.

The increase in drainability may also be attributed to the flocculent nature of sludge F. The dark, turbid filtrates from D and E attested to the presence of organic detritus and bacteria. This material was apparently consumed by the protozoa in sludge F and a clear supernatant was obtained. The improvement in flocculation and settling of biological sludges due to a well developed predator population has been well established in the literature (11, 16, 17, 28).

Further illustration of the effect of flocculation on drainability and filterability in this experiment was obtained by attempting to draw distilled water through the sludge mat of a dewatered sample from digester F. Even with vacuum assistance, practically no water was able to penetrate the mat in a 30 minute period when the sample originally drained to a mat in about 8 minutes.

Nitrification is commonly used as a measure of stabilization in typical activated sludge systems, however, because of the low pH in digester F, no nitrification occurred. Although nitrification did not occur, the sludge mat which formed on the sand bed during the drainability test had a neutral to slightly earthy odor even after 5 days, indicating good stabilization of organic matter.

Significant mixed liquor BOD reductions were consistently achieved in all units. However, the sludge mat formed by mixed liquor from unit E after 23 days of aerobic digestion at a pH of 9.5 developed a putrescible odor within 24 hours. Since the unit experienced a high reduction in suspended solids and mixed liquor BOD, the reason for this phenomenon is not clear. None of the parameters measured set it apart from other

digesters which achieved good stabilization, but apparently, compounds susceptible to anaerobic breakdown remained in the sludge.

Although total cellular protein showed some variation among the units during digestion, all units had a similar decline in concentration. Cellular protein per unit weight of total suspended solids increased in all digesters, however a cyclic tendency was observed in units A and C in contrast to a smooth increase in unit B. Correlation between cellular protein and other parameters measured was not apparent.

Total cellular carbohydrate declined consistently in all units except for units C and F. These units were operated in the acid range and developed large protozoan populations. Interestingly, they showed a much lower rate in the reduction of cellular carbohydrate. This variance is evident to a lesser degree when grams of cellular carbohydrate per unit weight of total suspended solids is plotted with digestion time since cellular carbohydrate is a relatively small portion of the total suspended solids. All units showed a slight increase of cellular carbohydrate per unit weight of total suspended solids, but it was consistently greater at lower pH (Figure 21). There appears to be, therefore, a correlation between a build-up in cellular carbohydrate per unit weight total suspended and the protozoan population, but the significance of this is not clear from the data obtained during this study. A better evaluation could have been made if extracellular carbohydrates had also been measured.

CONCLUSIONS

The following conclusions have been derived from the results of this investigation:

1. The aerobic digestion process is relatively insensitive to pH level and significant solids reductions can be obtained over a pH range of 3.5 to 9.5. However, solids reduction is greater if the pH is maintained at a constant value within the mentioned range rather than permitting it to vary as occurs under normal digestion conditions.

2. A significant and consistent reduction in mixed liquor BOD can be obtained over the pH range studied, however, sludge digested at pH 9.5 produces a sludge which easily becomes anaerobic. By contrast, aerobic digestion at all other pH values studied produced a well stabilized sludge.

3. Cellular carbohydrates and cellular protein accumulate with aerobic digestion. Although cellular carbohydrate accumulates somewhat more at low pH, the change in accumulation of cellular carbohydrates and cellular protein appears to be relatively insignificant with change in pH.

4. A striking improvement in the flocculation characteristics occurs with digestion at low pH and it corresponds to the development of a very large predator population. The improvement in flocculation

characteristics and the removal of organic detritus and bacteria from the sludge by the predators significantly enhances the settleability, filterability and drainability of the digested sludge.

SUMMARY

The objective of this investigation was to determine the effects caused by pH on aerobic digestion of waste activated sludge. To accomplish this, batch studies were performed on waste activated sludge obtained from the Roanoke, Virginia, sewage treatment plant. The sludge was aerobically digested in three plexiglas cylinders in a series of two runs. During each run, one digester served as a control while constant pH at selected levels were maintained in the remaining digesters. Each run was conducted for a period of at least 20 days and the effects of pH over a range of 3.5 to 9.5 were determined.

The investigation showed that the reduction in total and volatile suspended solids is relatively insensitive to change in pH. A significant and consistent reduction in mixed liquor BOD was obtained indicating good stabilization. However, sludge digested for 23 days at pH 9.5 became anaerobic when aeration was discontinued for 24 hours.

Nitrification has been extensively used as an indication of a well-stabilized sludge, however, since pH of 3.5 is inhibitory to the nitrifying organisms, nitrification did not occur in sludge digested at that pH but a well stabilized sludge was obtained.

Cellular carbohydrates and cellular protein accumulated during digestion of the sludge, cellular carbohydrate showing a slightly greater accumulation at low pH. There appeared to be no significant relation, however, between these parameters and mixed liquor pH during digestion. Some correlation may have been possible had total carbohydrate been measured.

When sludge was digested at pH 3.5, a striking improvement in the flocculation characteristics of the sludge occurred. This was attributed to the development of a very large predator population, which was also believed to be responsible for tremendous improvement in the settleability, filterability and drainability of the digested sludge. It appeared that the predators removed bacteria and organic detritus from the sludge, incorporating this material in their larger bodies which are more susceptible to flocculation, and thus to improved filterability, drainability and settleability of the sludge. The removal of bacteria and organic detritus by the predators was indicated by the clear filtrate obtained when the sludge was placed on a sand drying bed.

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THE EFFECTS OF pH ON AEROBIC SLUDGE DIGESTION

by

Herbert Randolph Moore

ABSTRACT

Batch studies to determine the effects of pH on aerobic digestion of waste activated sludge were performed using a detention time of at least 20 days. Total and volatile solids reductions were not affected over a pH range from 3.5 to 9.5. Somewhat greater solids reductions were realized when pH was held constant rather than allowed to vary as occurs with normal aerobic digestion. High reductions in mixed liquor BOD were consistent among digesters over the pH range investigated, however, sludge digested 23 days at pH 9.5 developed a putrescible odor when aeration was discontinued for 24 hours. Cellular carbohydrate and cellular protein accumulated during digestion, but no distinct relation to pH level was obvious although cellular carbohydrate showed a slightly greater accumulation with lower pH. Striking improvement in the settleability, drainability and filterability of sludge digested at pH 3.5 occurred. This effect was attributed to the development of an overwhelming protozoan population which caused observed improvement in the flocculation characteristics of the sludge.