

AEROBIC SLUDGE DIGESTION

By

BRUCE RAY BARRETT

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Oklahoma State University

Stillwater, Oklahoma

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Name: Bruce Ray Barrett

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Scope of Study: The scope of this study is to determine if sewage sludge can be digested aerobically. The length of time required for digestion is also studied, along with observations of the digested sludge's drainability and odor. The principal measure of digestion is the reduction of volatile solids from the raw to the digested sludge.

Findings and Conclusions: The laboratory results show that sewage sludge can be digested aerobically. It was also observed that the digested sludge drained satisfactorily and had no objectionable odor. It was concluded that reduction of volatile solids is a function of detention time.

ADVISER'S APPROVAL

Quinton B. Graves

AEROBIC SLUDGE DIGESTION

Report Approved:

Quinto B. Gracia

Report Adviser

Louis Hemphill

Dean of the Graduate School

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B.R.B.

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CHAPTER I
THE PROBLEM

1-1 Purpose and Scope of Experiment

The purpose of this project was to determine if sewage sludge could be digested aerobically. Also within the scope of the project was a study of the effects of time and loading rates on the digestion process, to determine if the process was free from objectionable odors, and to ascertain whether or not the sludge would drain satisfactorily.

It was conceived that this type of sludge digestion could be useful in many types of sewage treatment, particularly where odor-free operation was needed, or where space is limited. The information contained herein might also answer some questions about the fate of aerobically digested solids in extended aeration sewage treatment. A unit of this type could be installed in sewage treatment plants already in operation to alleviate bad conditions.

1-2 Deficiencies of Anaerobic Digestion

Among the objections to anaerobic sludge digestion units are the capital investment required and the offensive odors which are so often emitted from them.

High rate digestion by aeration of sludge could decrease the required size of the unit, thereby decreasing the capital investment. Also, it is believed that aeration will eliminate most of the odor.

1-3 Previous Works

Relatively little work has been done in aerobic sludge digestion. Almost all of the studies have been made since 1950.

One of the early studies was made by Coackley (1). In 1950, he subjected to aerobic digestion sludge which had been previously partially digested anaerobically. In one series he aerated sludge without inoculating it with aerobic organisms. In another series he inoculated the sludge with aerobic organisms. These series were aerated at 18° C. and 37° C. He found essentially no reduction of volatile solids in either series at 18° C. after 48 days aeration. However, at 37° C., in the first series, volatile solids were reduced from 2.98% to 1.08% in 47 days, and in the second series volatile solids were reduced from 2.66% to 1.52%. These calculations are based on the weight of dry volatile solids divided by the weight of wet sludge required to produce those volatile solids, quantity times one hundred.

Abel, Moran, and Rouf (2) found that sewage sludges were readily oxidized by oxygen gas at elevated temperatures and pressures. However, they did not investigate conditions at normal temperatures and pressures.

Eckenfelder (3) states in connection with the oxidation rate of sludge: "With increasing times of aeration, the rate progressively decreases and approaches a limit of about 40 to 60 per cent volatile solids reduction." Volatile solids reduction is figured by initial weight minus final weight, all divided by the initial weight, quantity

times one hundred, or

$$\text{Volatile Solids Reduction} = \frac{W_i - W_f}{W_i} \times 100$$

where W_i is the weight of volatile solids in the raw sludge and W_f is the weight of volatile solids in the digested sludge. In an aeration period of seven days at a temperature of 25° C. the volatile solids decreased from 76.5% down to 63.5% of the total solids. These calculations are based on the weight of dry volatile solids divided by the weight of dry total solids, quantity times one hundred.

Jaworksi, Lawton, and Rohlich (4) found a reduction in volatile solids of 21% at a detention time of 5 days at 15° C. At a detention time of 15 days at 20° C., they found a reduction of 43%, while at a detention time of 60 days at a temperature of 20° C. they found a reduction of 46%. They concluded that after a detention time of 15 days, only small increases in the reduction of volatile solids are obtained.

CHAPTER II
THE EXPERIMENT

2-1 Equipment

The equipment used in this project consisted of:

1. Two 8 gallon lucite plastic tanks
2. Four 2 liter glass tanks
3. General Electric 1 HP compressor
4. Aeration devices
5. Two lucite plastic sand drying beds
6. Two 250 watt heat lamps
7. Exhaust unit
8. Precision Scientific Company 600 watt oven
9. Cenco-Cooley 3400 watt electric furnace
10. Dessicator, large
11. Photovolt Electronic pH meter
12. Triple beam balance
13. Evaporating dishes
14. Tongs

The eight gallon lucite plastic tanks were seven feet tall and six inches in diameter. Wall thickness was approximately one quarter inch. Spigots were attached to the tanks at one foot intervals, one near the bottom and every foot up to six feet. These taps had an

opening of about one quarter inch. It was later discovered that this was too small. These tanks were calibrated into gallons and tenths of gallons. The eight gallon mark was approximately at the $5\frac{1}{2}$ foot mark. This allowed $1\frac{1}{2}$ feet for freeboard. The tanks rested on one quarter inch base plates, about eight by twelve inches. One of the tanks is shown in Figure 1.

The glass tanks were fabricated from eighty millimeter glass tubing. One end was necked down to about one half inch inside diameter on a slope of forty-five degrees. Rubber tubing was fastened on the neck and a screw clamp used to regulate flow. The glass tanks were about two feet long, and were held in place by a wooden rack made for that purpose. Four to five inches of freeboard was provided when the tanks were filled to the two liter mark. After much trouble with overflowing, the operating capacity of the glass tanks was reduced to one liter, providing over a foot of freeboard. These units are shown in Figure 2.

The supply of air was delivered by a one horsepower compressor. The compressor was located two rooms away and the air was pumped in through about fifty to sixty feet of three-eighths inch pipe. The compressor tank was maintained between 150 and 200 pounds per square inch pressure, while air leaving the compressor was between 45 and 50 pounds per square inch. The air leaving the transmission pipe was under approximately 40 pounds per square inch pressure.

The air was dispersed in the eight gallon tanks with homemade devices. In one of the large tanks a perforated copper coil was used,

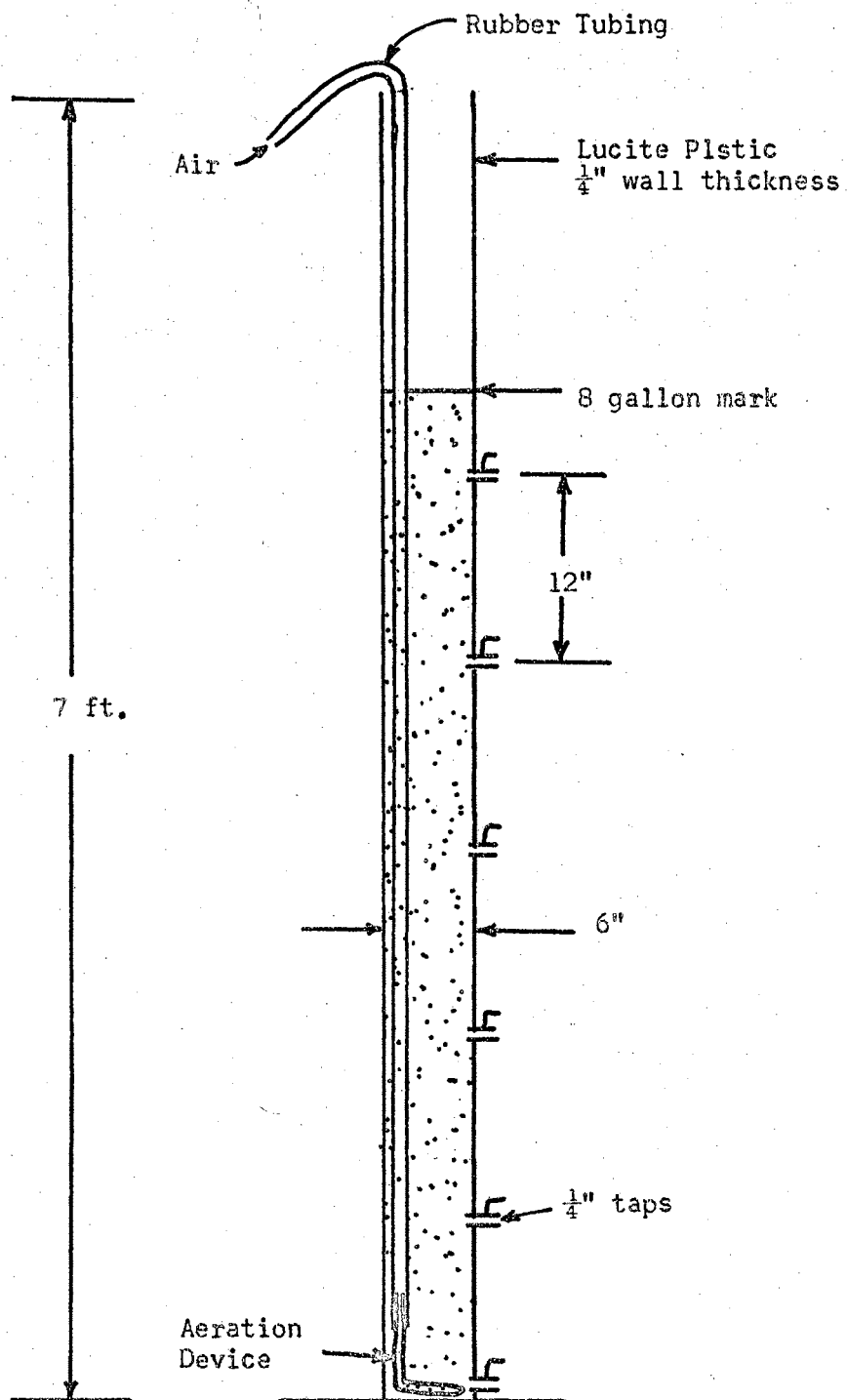


Figure 1

8 gallon Laboratory Aerobic Sludge Digestion Units

Designated in Text as 1L and 2L

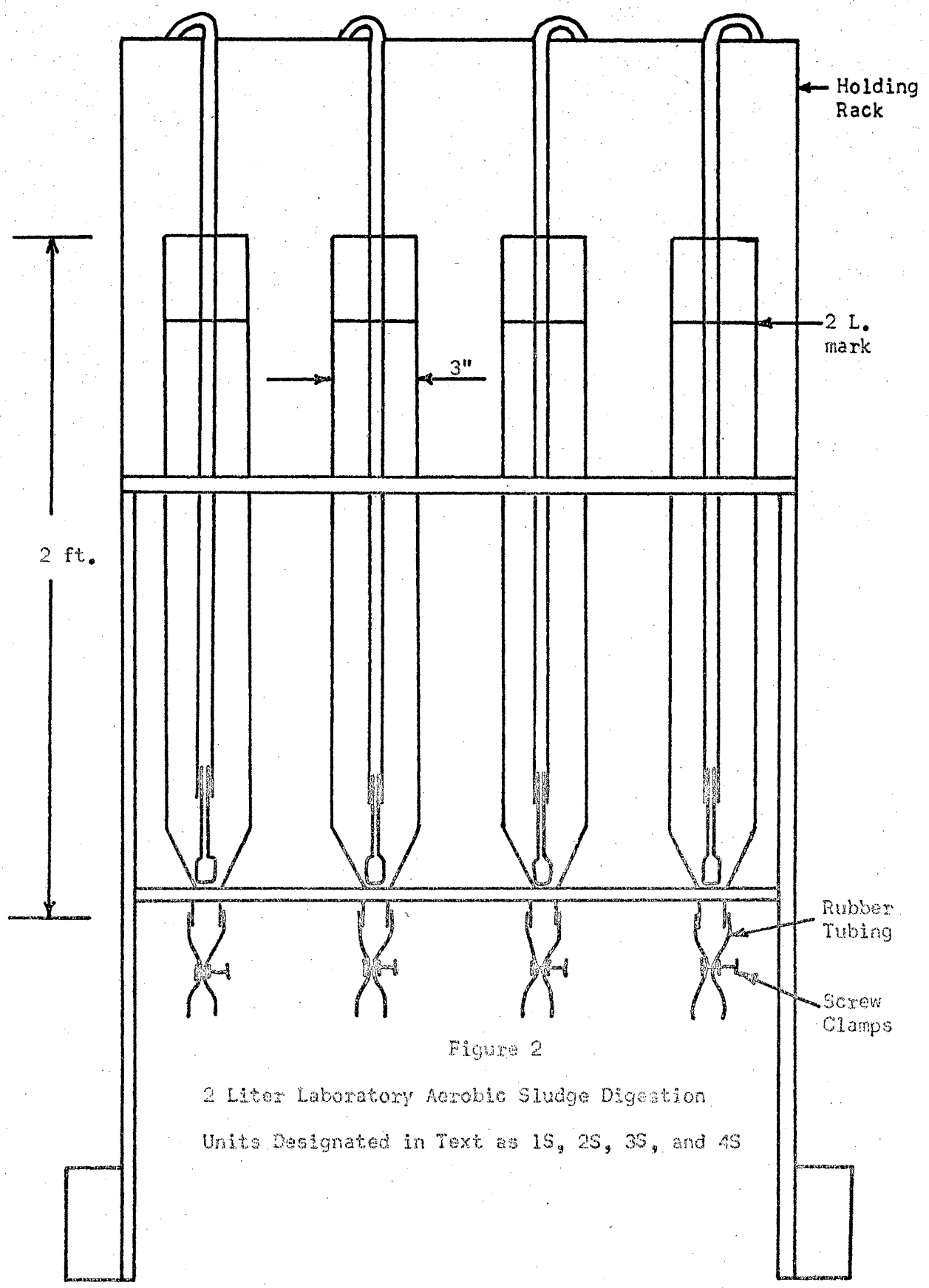


Figure 2

2 Liter Laboratory Aerobic Sludge Digestion
Units Designated in Text as 1S, 2S, 3S, and 4S

while in the other tank a pliable plastic tube was formed into a circle and was perforated on the bottom side. These aeration devices were connected to the air supply by means of three-eighths inch rubber tubing which entered the digesters from the top. Regular gas dispersion tubes were used to distribute air in the small glass tanks. These were connected to the air supply by one-quarter inch rubber tubing, which also entered the digesters through the top.

The two lucite plastic sand drying beds were the same material as the large digesters. They had a bottom plate that was grooved to drain. One of these drying beds was about fourteen inches tall while the other was about two feet tall.

All other equipment was used in testing the sludge. Included was a triple beam balance with a capacity of 111 grams and upon which weights could be estimated to thousandths of a gram, evaporating dishes, tongs, a large dessicator, a large exhaust unit, heat lamps, a 600 watt oven, a 3400 watt furnace, and an electronic pH meter.

2-2 Procedure

The sludge used in the experiment was obtained from the primary settling tanks of the Stillwater sewage treatment plant. The digesters were filled initially with six gallons of water and two gallons of sludge, and aeration was begun. Following this straight sludge was added. The loadings of sludge were varied from time to time and from tank to tank. Air volume was not measured because there was no way readily available to measure it, and also it was not within the scope

of this project. However, more than enough air was supplied to the sludge to keep it saturated with oxygen. The objective type tests run were temperature, pH, and total solids content broken down into fixed and volatile.

There was no attempt to control the temperature of the digesters. Sludge temperature varied from a high of 84° F. during the last part of July to a low of 68° F. during the middle of September.

An electronic pH meter was used for pH determinations. These tests were run on the mixed liquor.

The solids tests were run on sludge drained off at or near the bottom of the tanks. The sludge was drained off to some level, and fresh sludge of equal amount was poured in through the top of the digesters. The amount of sludge drained off each day depended on the loading of that particular digester on a given day.

In the large plastic tanks, the fresh sludge was added in increments during the day. The purpose of this was to reduce the shock of adding cold (40° F.) sludge to the digesters. This practice was altered for the smaller glass tanks. All the required amount of sludge was added at one time each day, but the feed sludge was first heated to the temperature of the sludge in the digesters.

To determine solids content Standard Methods (5) was followed as closely as possible. Tare weight of the evaporating dishes was determined. Then some quantity of sludge was added and the dish and sludge were weighed. These samples were then placed in an exhaust hood under heat lamps, and were allowed to dry. They were then placed in electric oven, at a temperature of 103° C. for a period of one hours. After cooling in a dessicator,

they were weighed again. They were then placed in an electric furnace at a temperature of 600° C. for a period of one hour. After cooling them in the dessicator, they were weighed again. Knowing the weight of the evaporating dish, evaporating dish and wet sludge, evaporating dish and dried sludge, and evaporating dish and ash, it is possible to determine the weight of wet sludge, dried sludge, and ash. These weights were estimated to the nearest one thousandth of a gram. On a weight basis, the per cent of dry solids in the wet sludge was determined. Then the per cents of solids as fixed and volatile were calculated.

2-3 Loading Rates

During the first 35 days of this experiment, no particular loading rate was placed on the digesters. The objective during this period was to determine to what degree digestion would occur in an aerobic environment and to obtain an active sludge. Sludge was added sporadically with no particular displacement in mind. However, after studying the data, it was found that there was a definite displacement period of 80 days, carried on for 15 days. The tanks were fed an average of once every 5 days during this period.

Definite displacement periods were instigated after the first 35 days. In one of the large tanks, a 32 day displacement period was begun, while an 8 day displacement period was begun in the other tank. These loading rates were continued for 12 days.

At this point the smaller tanks were obtained, and all were filled with sludge from the large tanks with the 32 day displacement.

Then certain loading rates were commenced in the 4 small tanks. These rates gave 2, 4, 8, and 16 day displacement. This portion of the experiment continued for 16 days.

2-4 Observations of Odor and Drainability

The observation of odor is a very subjective type observation, an objective type test being difficult if not impossible. Since the digestion tanks were indoors, any noticeable odors were quickly detected. There was no attempt to assign a particular familiar smell to the odors from the digesters. The odors were either objectionable or unobjectionable.

During most of the experiment, the only criterion of drainability was that the sludge would drain or it would not drain. The sludge was poured on sand drying beds and observed. However, at the last of the experiment, a relative type of drainability was recorded. Fifty ml. of the sludge from each of the four small tanks was poured into four funnels into which filter paper had been fitted. The amount of effluent from each was then recorded at various times. This afforded a means of determining the relative drainability of the four sludges.

2-5 Measures of Digestion

In the anaerobic digestion process, the chief measure of digestion is gas production. Secondary measures of digestion are pH, solids content, volatile solids content, volatile acids, color, drainability, and odor.

Since measure of gas production would be quite difficult in the aerobic process, volatile solids content was used as the chief indicator of digestion. Other indicators used included pH, drainability, and odor.

Theoretically, well digested sludge should have a volatile solids content of 50 per cent or less. It's pH should be 7 or greater, it should drain rapidly, with the presence of no objectionable odor.

CHAPTER III

THE RESULTS

3-1 Characteristics and Content of Digested Sludge

Seven different detention times were tried in this experiment. These detention times ranged from 2 to 80 days.

In the first phase of the experiment, no particular loading rate was attempted, but from study of the data, it was determined that an 80 day displacement was actually in progress. The objective of the research during this period was to develop an active sludge and to determine the extent of aerobic digestion. During this period of prolonged aeration, the lowest percentage of volatile solids obtained was 43.3%. At this time the sludge temperature was 84° F. (29° C.), the highest recorded during the experiment. From the general trend of the data, it appears that a decrease in volatile solids content is a function of an increase in temperature, other things being equal.

During the 15 days that the 80 day displacement was in effect, the average digester temperature was 83° F., while the pH averaged 7.48. The digester was being loaded at the rate of 0.031 pounds of dry solids per day per cubic foot of digester capacity, with 0.021 pounds of this being volatile. The percentage of wet sludge as

total solids was reduced from 4.10 to 2.87, while the percentage of total solids as volatile solids was reduced from 66.1 to 50.7, a 46.3% reduction. Figure 3 shows graphically the reduction of volatile solids with time.

In the second phase of the project, planned loading rates were begun in the two large tanks. In tank No. 1L, a 32 day detention time was initiated, while an 8 day detention time was commenced in tank No. 2L.

During the 12 day period in tank 1L, total solids were reduced from 4.10% to 3.29%, of the wet sludge, and volatile solids were reduced from 66.1% to 49.0% of the total solids, a 40.6% reduction. The sludge digester operated at a mean temperature of 77° F. and a mean pH of 7.33, while being fed at the rate of 0.077 pounds of dry solids per day per cubic foot of digester capacity, 0.051 pounds of which were volatile. The relationship of time and solids content is shown in Figure 4. In the same time period, tank 2L had an 8 day displacement. It was loaded at the rate of 0.308 pounds of dry solids per day per cubic foot of digester capacity, of which 0.205 pounds were volatile. Average values of temperature and pH were 77° F. and 7.47, respectively. Total solids were reduced from 4.10% to 2.92%, of the wet sludge, and volatile solids were reduced from 66.1% to 58.2% of the total solids, a 37.3% reduction. Figure 5 shows a plot of time vs. solids for this period.

The third phase of the project consisted of planned loading rates in the small glass tanks. Displacement of 2, 4, 8, and 16 days were tried during this 16 day period.

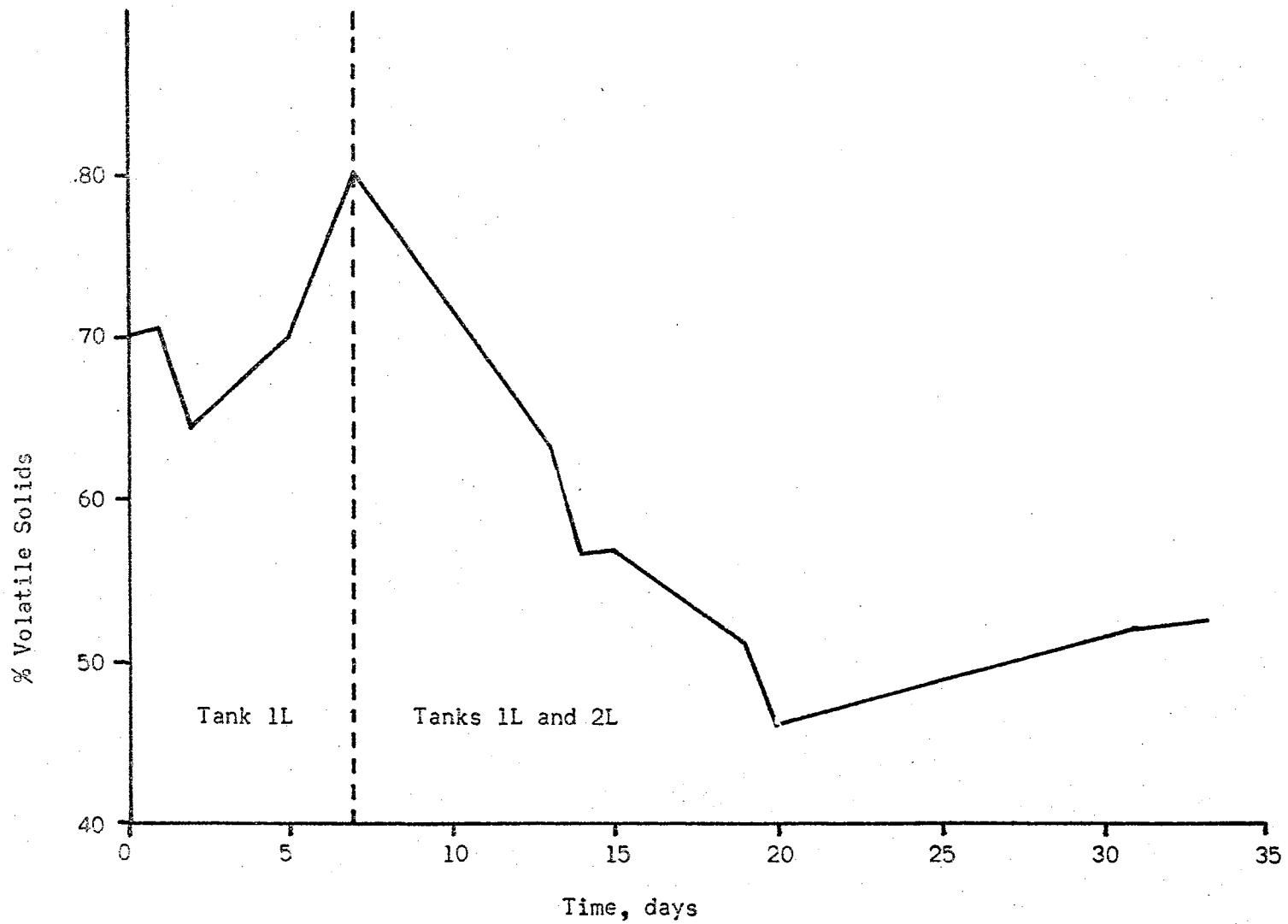


Figure 3

Average Results, Tanks 1L and 2L, July 12 - August 14

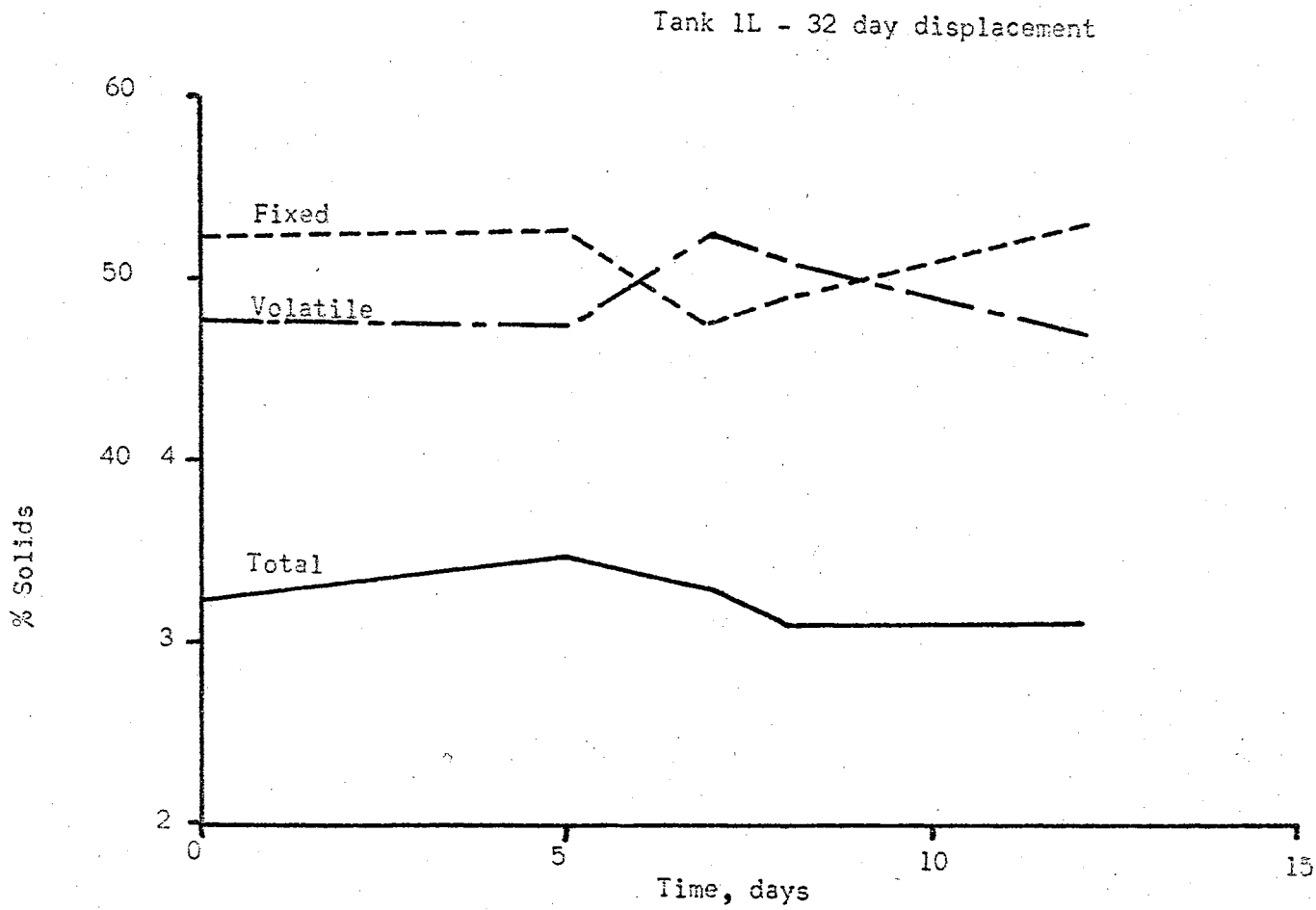


Figure 4

Operation Data, Tank 1L, August 16-28

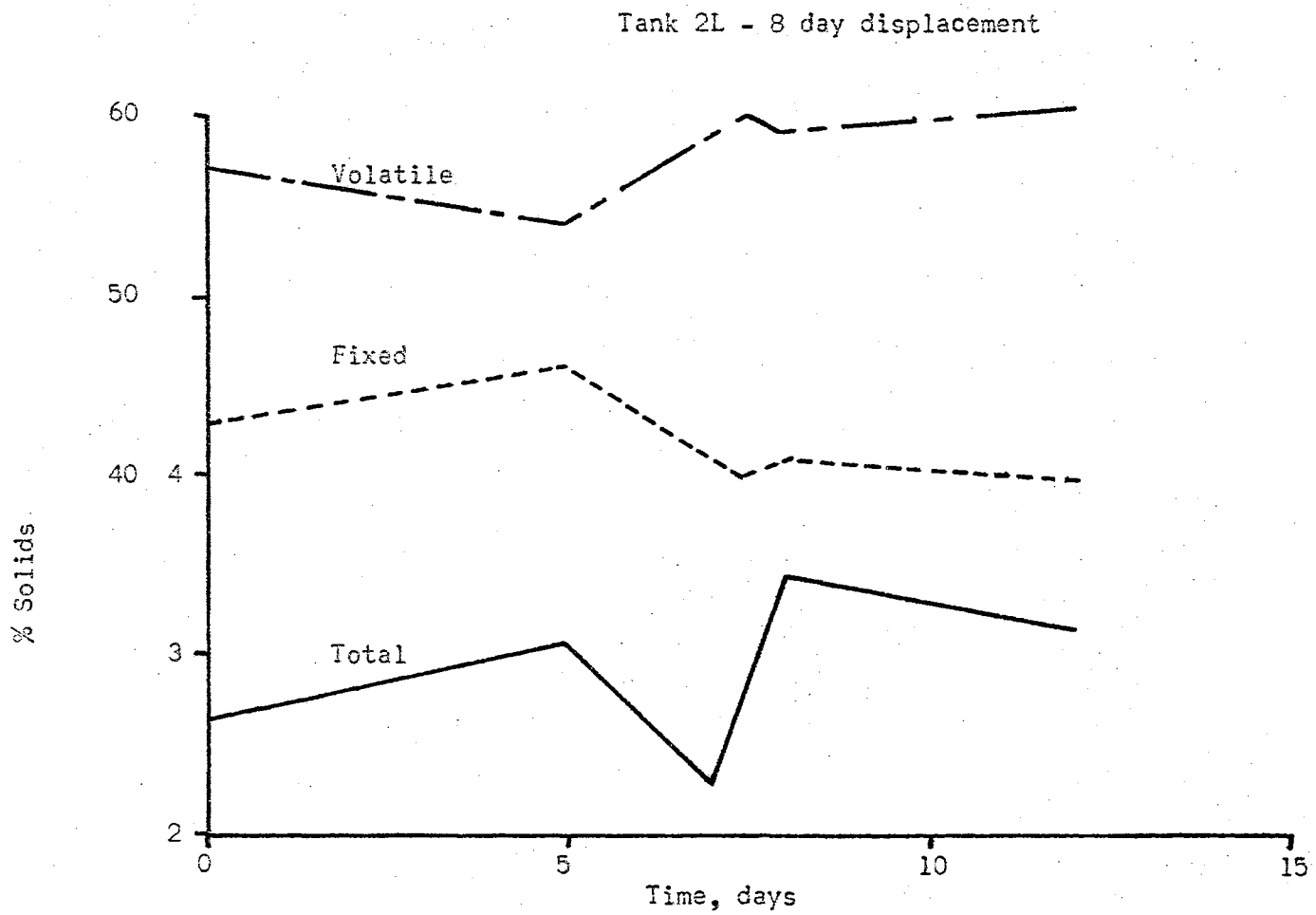


Figure 5

Operation Data, Tank 2L, August 16-28

In tank 1S, a 2 day detention time was used. Temperature averaged 68° F. and pH averaged 8.22. The tank was loaded at the rate of 2.7 pounds of dry solids per day per cubic foot of digester capacity, 1.571 pounds being volatile matter. Total solids decreased from 8.49% to 8.44% of the wet sludge, and volatile solids were increased from 58.2% to 62.6% of the total solids, a 7.1% increase. This small increase is probably due to sampling error.

A 4 day displacement was used in tank 2S. Total solids decreased from 8.49% to 5.66% of the wet sludge, while a reduction in volatile solids from 58.2% to 57.4% of the total solids was achieved, a 34.2% reduction. Operating temperature averaged 68° F. and pH averaged 8.36. Loading was at the rate of 1.35 pounds of dry solids per day per cubic foot of digester capacity, 0.785 pounds being volatile.

Tank 3S had an eight day detention period. The temperature in the digester averaged 68° F., with a mean pH of 8.48. Loading was at the rate of 0.675 pounds of dry solids per day per cubic foot of digester capacity. Volatile matter accounted for 0.393 pounds of this. Total solids decreased from 8.49% to 4.69% of the wet sludge. Volatile solids were decreased from 58.2% to 55.5% of the total solids, a 45.4% reduction.

Detention period was 16 days in tank 4S. Total solids decreased from 8.49% to 4.14% of the wet sludge. Volatile solids percentage decreased from 58.2 to 53.8 of the total solids, a 54.9% reduction. Loading was at the rate of 0.338 pounds of dry

solids per day per cubic foot of digester capacity, 0.196 pounds being volatile solids. Digester temperature averaged 68° F., and the average pH was 8.50.

Figures 6 and 7 show graphically the relationship of time to total and volatile solids, respectively.

In Table 1, digester operations are tabulated for the entire project.

During the first two phases of the project, no objective type tests were run on drainability. However, sludge was poured on the drying beds several times, and in each case drained satisfactorily within one day. Although the sludge was still moist after one day, it was in a cake form.

During the third and final phase of the experiment, objective type drainage tests were run on the sludges from the four digesters. Four funnels with filter papers were set up, and 50 ml. of sludge from each tank were poured into the funnels. Volume of filtrate was then plotted against time in Figure 8. Sludge from tank 1S with the 2 day displacement yielded 1.5 ml. of filtrate by the next day, tank 2S yielded 2 ml., tank 3S yielded 18 ml., and tank 4S yielded 27.5 ml. From this it appears that drainability improved greatly somewhere after 4 day displacement.

Aside from the feedings of raw sludge, objectionable odors were noticed only once. This occurred when the four small glass tanks were first put in operation. The air supply was turned down low, and the heavy loadings of tank 1S and 2S caused those two tanks to emit objectionable odors of slight intensity. During the rest of

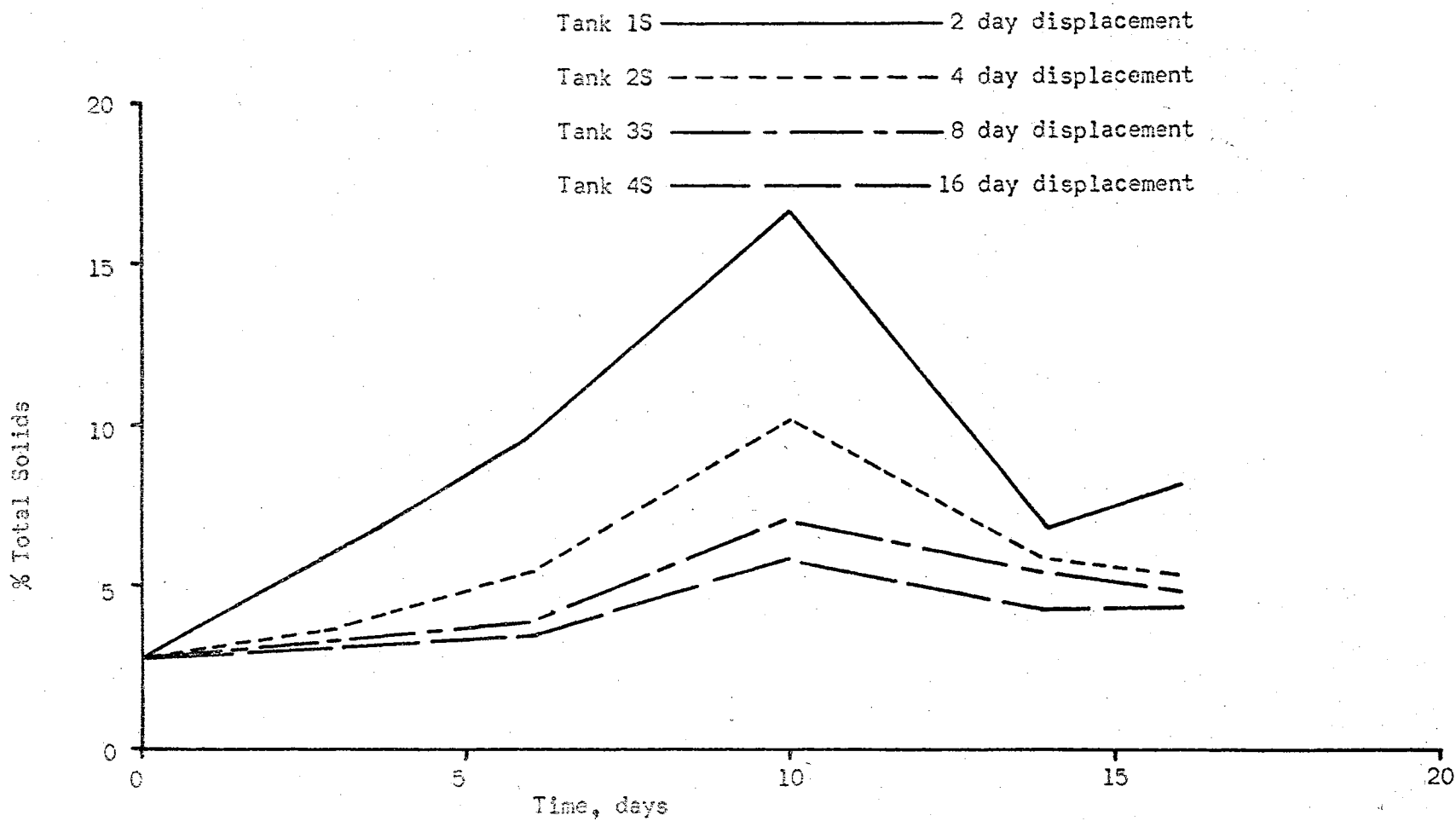


Figure 6

Operation Data, Tanks 1S, 2S, 3S, and 4S, September 2-18

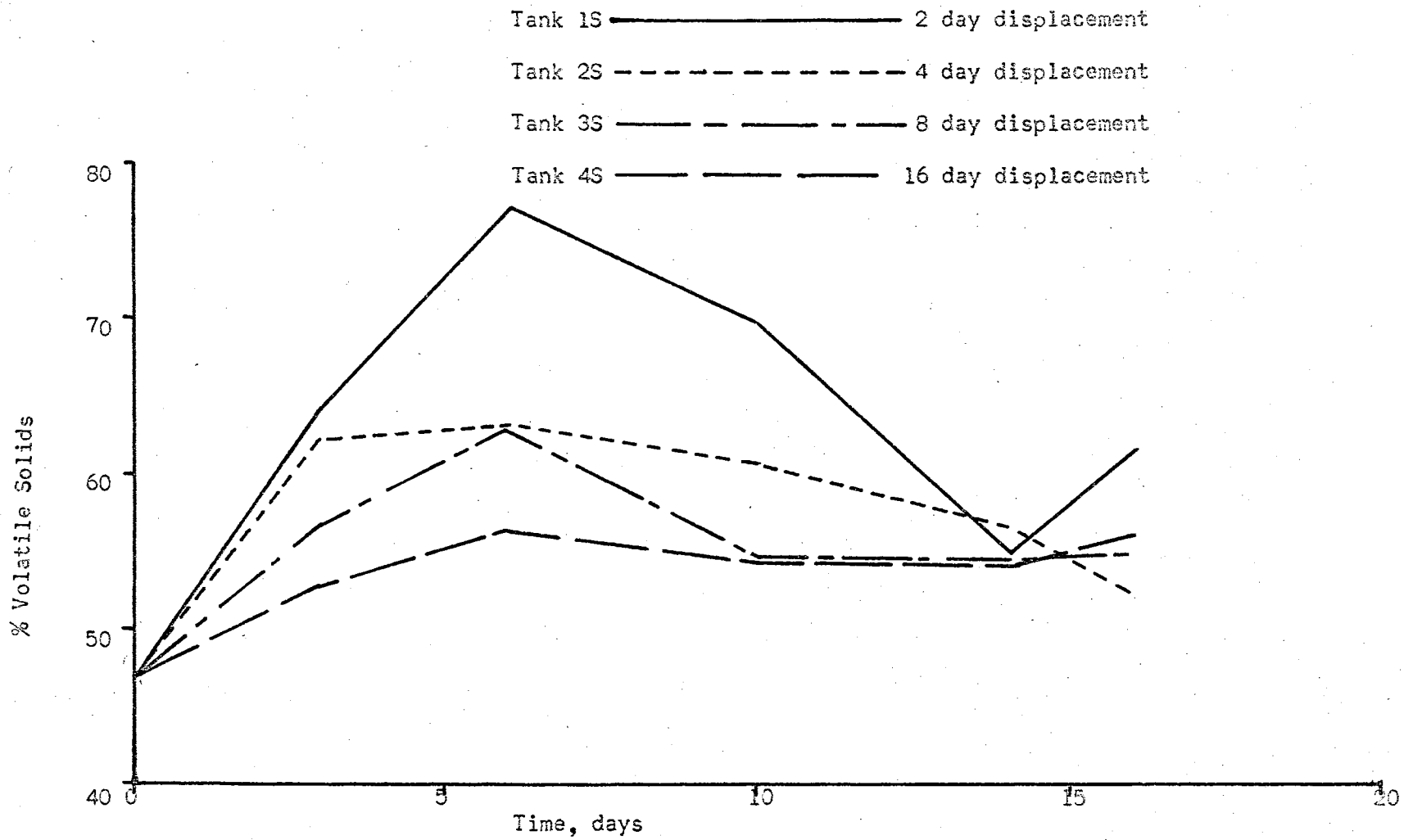


Figure 7

Operation Data, Tanks 1S, 2S, 3S, and 4S, September 2-18

TABLE I Digester Operations

Tabulated Values Are Averages Over Given Period

Tank and Period	Average Large Tanks 1&2 July 28- Aug. 12	Large Tank #1 Aug.16- Aug.28	Large Tank #2 Aug.16- Aug.28	Small Tank #1 Sept.2- Sept.18	Small Tank #2 Sept. 2 Sept.18	Small Tank #3 Sept.2- Sept.18	Small Tank #4 Sept.2-- Sept. 18
Raw Sludge (average results)							
Total Solids (%)	4.10	4.10	4.10	8.49	8.49	8.49	8.49
Volatile Solids (%)	66.1	66.1	66.1	58.2	58.2	58.2	58.2
pH	6.52	6.52	6.52	7.8	7.8	7.8	7.8
Loading							
Total Solids (lb/day/ft ³)	.031	.077	.308	2.700	1.350	.675	.338
Volatile Solids (lb/day/ft ³)	.021	.051	.205	1.571	.785	.393	.196
Displacement (days)	80	32	8	2	4	8	16
Operating Conditions							
Digester Temperature (°F.)	83	77	77	68	68	68	68
pH	7.48	7.33	7.47	8.22	8.36	8.48	8.50
Digested Sludge							
Total Solids (%)	2.87	3.29	2.92	8.44	5.66	4.69	4.14
Volatile Solids (%)	50.7	49.0	58.2	62.6	57.4	55.5	53.8
Volatile Solids (% reduction from raw to digested)	46.3	40.6	37.3	7.1*	34.2	45.4	54.9

*% Increase

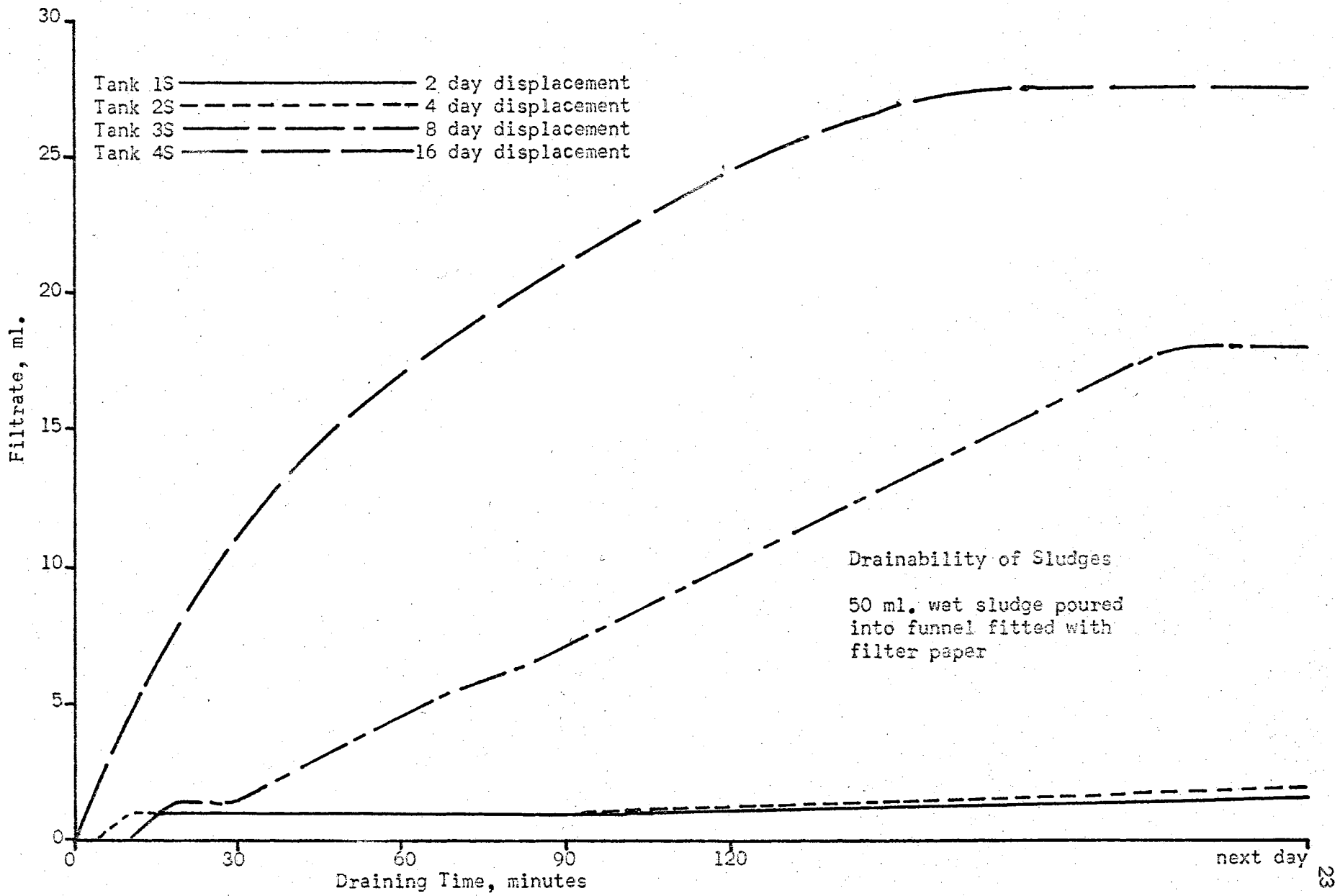


Figure 8

the project, the only noticeable odor was a faint earthy odor. Even after prolonged periods on the drying beds, no objectionable odors could be detected.

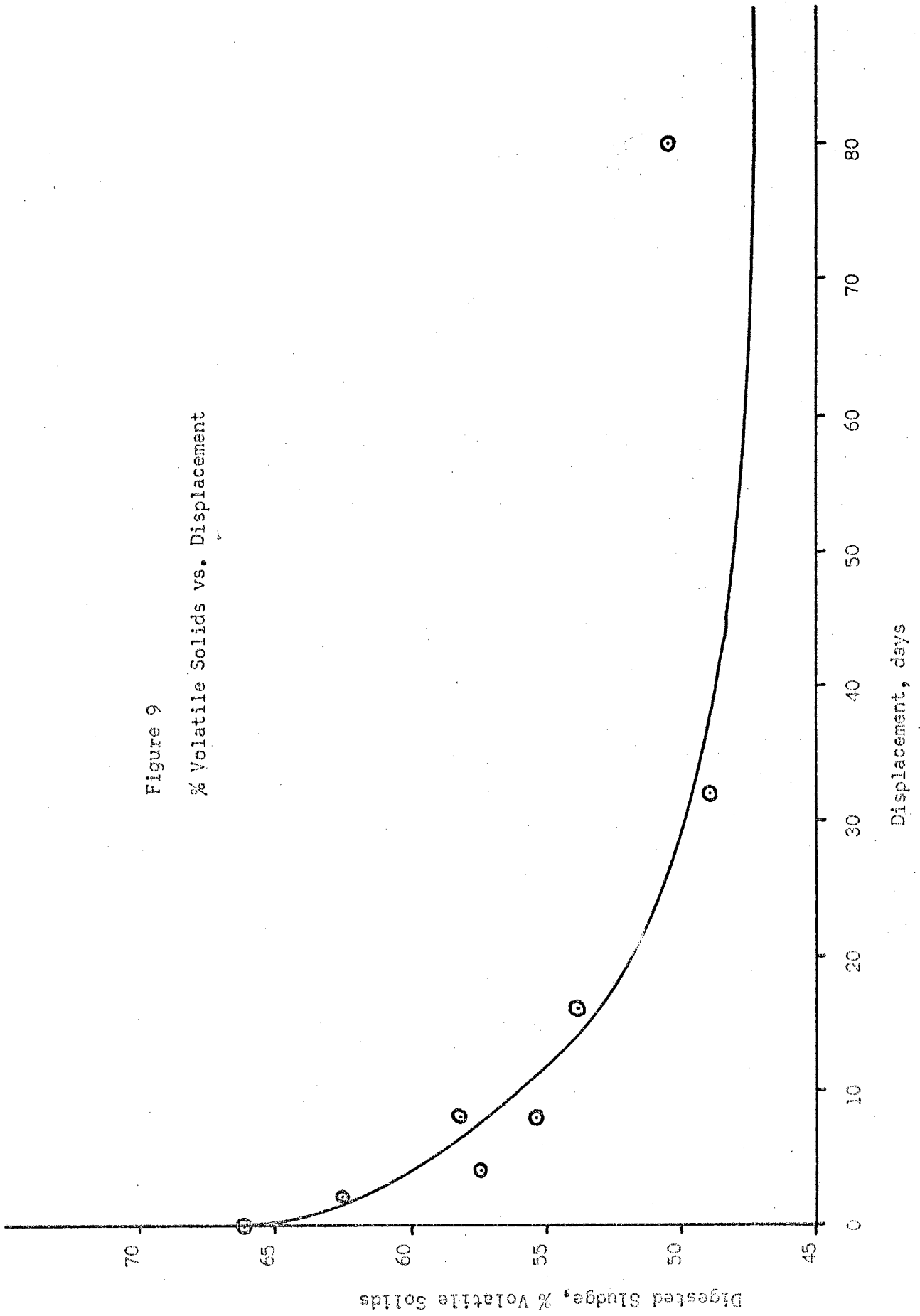
3-2 Effect of Loading Rates

The loading rate, or displacement, of the digesters appears to be the prime variable in the aerobic digestion process. Out of the bounds of certain limits, temperature undoubtedly is another important factor. Aerobic digestion is probably a function of air supply also.

The curve obtained when percentage of volatile solids is plotted against displacement appears to be an exponential curve, apparently reaching a limit somewhere near 45% to 50% volatile solids. Figure 9 shows the curve obtained from data from this project. Although the curve is not well fitted, the data shows the general shape of the curve. To be a true picture, the data should be from digesters at the same constant temperature, and should also have many more points in order to fit the curve better.

After about 30 days detention, very little improvement is shown. More than half of the reduction of volatile solids to be accomplished occurs within 8 days. A curve of this sort with many points plotted could well be used as design criteria for an aerobic digestion unit.

Figure 9
% Volatile Solids vs. Displacement



CHAPTER IV
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

4-1 Summary

The main purpose of this research project was to determine if aerobic digestion would work, and if so, to determine the effect of loading rates on the aerobic digestion process.

It was believed that if the aerobic process was successful, aerobic digesters could be designed into new sewage treatment plants, and installed in old ones where the present anaerobic digesters were overloaded or not working properly. Economic feasibility, beyond the scope of the project, would have to be determined first however.

Very little previous work has been done on this exact subject, and almost all of it has been done since 1950.

Special equipment for this experiment consisted of two 8 gallon capacity tanks, four 2 liter capacity tanks, and aeration equipment.

During the first phase of the experiment, loading was intermittent and light, to determine how far the aerobic digestion process would go. During the remainder of the project, loading was at a specific rate. Tests run on the sludge included total solids, volatile solids, pH, temperature, drainability, and odor.

Loading rates tried were 2, 4, 8, 16, 32, and 80 day displacement. Detention times of 8, 32, and 80 days were tried in the large

tanks while detention times of 2, 4, 8, and 16 days were tried in the small tanks.

The principal measure of digestion used was the reduction of volatile solids, and pH; drainability and odor were secondary measures.

The extremes of digestion were from the 2 day displacement to the 32 day displacement. In the 2 day detention digester, volatile solids were increased from 58.2% to 62.6%. In the 32 day detention digester, volatile solids were reduced from 66.1% to 49.0%. The pH of all digesters was above 7.3 up to 8.5. The average temperatures varied from 68° F. to 83° F.

The sludge from all tanks drained well on sand drying beds, but the drainability of the sludge seemed to improve greatly with a detention time somewhere between 4 and 8 days.

Detention time seemed to be the most important factor of digestibility. However, temperature is probably also very important, and air supply also probably has a bearing on it. The plot of percent of volatile solids versus displacement appears to be an exponential curve, with little improvement in digestion occurring after 30 days detention.

4-2 Conclusions

1. Data collected on aerobic digestion during this study is not of sufficient extent to permit definite conclusions. However, certain trends in the data could be used to guide future experimentation.

2. One of the outstanding features of aerobic digestion units is the absence of objectionable odors.
3. Reduction of volatile solids appears to be a function of detention time.
4. Little improvement in digestion occurs after 30 days detention.
5. Better digestion appears to occur at higher temperatures.
6. A large improvement in drainability occurs between 4 and 8 days detention.
7. Aerobically digested sludge produce little or no objectionable odor while drying.
8. Aerobic digesters run above a pH of 7.

4-3 Recommendations

From the results of this study, it appears that aerobic sludge digestion has its place in sewage treatment. However, much more laboratory and pilot plant work must be done first.

Curves like the one in Figure 9 must be fitted much closer than it is, and there should be a different curve for each temperature. Ideally, each series of tests should be run at a constant temperature to determine the curve for that temperature. After the curve is well defined, another series could be run at a higher temperature, and a new curve determined. With a series of these curves, the economic feasibility of heated aerobic digestion could be determined. If the heating speeds up the digestion process enough, the great reduction in size of the digester might pay for the heating and aerating. For

example, a heated aerobic digester might reduce the detention time to two days or even less, therefore greatly reducing the amount of sludge to heat and aerate, and also reduce the capital investment.

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VITA

Bruce Ray Barrett

Candidate for the Degree of
Master of Science

Report: AEROBIC SLUDGE DIGESTION

Major Field: Sanitary Engineering

Biographical:

Personal Data: Born April 8, 1938 in Ardmore, Oklahoma

Education: Attended grade school in Enid, Oklahoma, and Okmulgee, Oklahoma, and high school at Okmulgee and Will Rogers in Tulsa, Oklahoma; completed requirements for the Bachelor of Science degree from Oklahoma State University, in January 1961; completed requirements for the Master of Science degree in January 1962.

Professional Experience: Engineer trainee, Corps of Engineers. Now a member of A.S.C.E. student chapter at Oklahoma State University.