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Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: DIGESTION OF SEWAGE SLUDGE BY AEROBIC PROCESSES

Pages in Study: 28 Candidate for Degree of Master of Science

Major Field: Sanitary Engineering

Scope of Study: The purpose of this report is to determine the degree to which sewage sludge can be digested using aerobic processes. The degree of digestion is measured as the per cent reduction of volatile solids, reduction of total solids content, and drainability. The influence of the method of feeding is also studied.

Findings and Conclusions: The laboratory results showed that the degree of digestion of sewage sludge that can be accomplished aerobically is dependent on several factors. It was concluded that the reduction of volatile solids is a function of the detention time, temperature of operation, and method of adding raw sludge to the digester.

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DIGESTION OF SEWAGE SLUDGE
BY AEROBIC PROCESSES

By

Benjamin Franklin Ballard, Jr.

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

August, 1961

Submitted to the Faculty of the Graduate School
of the Oklahoma State University
in partial fulfillment of
the requirements for
MASTER OF SCIENCE
August, 1962

DIGESTION OF SEWAGE SLUDGE

BY AEROBIC PROCESSES

Report Approved:

Quintin B. Graves

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Dean of the Graduate School

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B.F.B.

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CHAPTER I

INTRODUCTION

A population increase greater than that expected at the time of design has resulted in the overloading of sludge digester facilities at many sewage treatment plants. This overloading has decreased the detention time as well as increased the loading on the digester, thus many plants are disposing of sludge that does not drain well and has an offensive odor.

The cost of modifing present digesters, or adding new ones to gain the volume for the long detention period required for satisfactory anaerobic digestion is very high.

It is the belief of the author that this cost can be reduced as well as the first cost of new plants by the use of aerobic digestion rather than anaerobic. Aerobic digestion requires an air supply that anaerobic does not, but this cost would be small compared to the savings in digester size. Another saving would come from lower heating equipment and fuel costs since the volume of sludge in the aerobic digester at any time will be much less than that in an anaerobic digester. Also if the anaerobic digester is not heated its volume requirement per capita is larger than in the heated anaerobic digester.

The laboratory experiments detailed in this report were conducted in an attempt to answer the following questions.

1. Can domestic sludge be digested to a satisfactory degree using aerobic digestion?
2. Will the drainability of the sludge be satisfactory?
3. What will be the minimum detention time that will give acceptable results?
4. Will obnoxious odors during digestion or draining be prevalent?

In aerobic digestion the organisms must have dissolved or free oxygen available, whereas anaerobic organisms can utilize the oxygen that is chemically combined in organic matter.

The reactions that take place in an anaerobic digester have been studied by many experimenters and are well defined and documented in the literature, but there is a paucity of information concerning the reactions that occur in the aerobically digested sludge. Also a laboratory anaerobic digester is a closed system in which all mass exchanges, such as sludge fed and removed and gas produced, can be expressed. This is not the case with an aerobic digester since it must be open to the atmosphere to allow the air used for aeration to escape. Along with the air there is water vapor, dissolved gases, volatile acids, gases produced by the metabolic action of bacteria, and other constituents all of which are difficult to seperate qualitatively or quantitatively, but whose loss has an effect on the digester.

Most of the information available on aerobic reactions in sludge has come from studies on the activated sludge process and modifications of this process. The activated sludge process consists of aerating the entire sewage to which has been added sludge settled from previously aerated sewage. Wehn the sludge is continuously aerated after its initial aeration in the activated sludge process it is refered to as sludge reaeration. Several different methods for sludge reaeration have been devised and names such as "Biosorption", "contact stabilization", "Ridgewood biological coagulation process", "extended reaeration", and others have been coined for these processes.

Aerobic sludge digestion differs from the activated sludge process and its derivatives in that it is desired to digest a sludge to the stage that it may be disposed of conveniently, rather than develop it as a seed to add to sewage being digested. Sludge digestion is necessary because all sewage treatment processes develop a sludge that must be disposed of in some fashion.

CHAPTER II

PREVIOUS INVESTIGATIONS

A search of the literature reveals only one treatment plant using aerobic digestion of sludge. Gunson (1) states that aerobic digestion has been used satisfactorily at one of Denver, Colorado's sewage treatment plants for two years. Experiments were conducted prior to the installation of a plant size mechanically aerated digester. He reports that no problem of temperature has resulted other than the freezing of pipes, and that the digested sludge drains well and contains less E. Coli than sludge digested anaerobically. This is reported to be caused by a mold that develops when the operation is properly controlled.

Results from a study of aerobically digested sludge by Jaworski, Lawton, and Rohlich (2) indicate that the process is feasible. They concluded that little additional reduction in volatile solids was obtained after detention periods of 15 days, but up to this limit the reduction was a function of the digestion period. They found that generally greater reductions could be obtained at higher temperatures and at lower loading rates. Little odor is reported produced from drying the digested sludge and its drainability was satisfactory when the detention time was greater than five days.

Abe, Morgan, and Ruof (3) succeeded in stabilizing sewage sludges by chemical oxidation rather than bacterial oxidation with oxygen gas at elevated temperatures and pressures. They demonstrated that sludge lost its slimy character and fecal odor with as little as 10% of its initial carbon converted to carbon dioxide.

The results of oxidation studies of sludge by Eckenfelder (4) revealed that the per cent volatile solids reduction approaches a limit of 40 to 60 per cent with increasing times of aeration. He also stated that for each 10° rise in temperature the oxidation rate would approximately double.

Aerobic digestion with detention times varying from 2 to 80 days was reported by Barrett (5). His findings are in general agreement with those of Jaworski, Lawton, and Rohlich (2). He also states that the aerobic digesters operate at a pH above 7.

Chanin (6) in his discussion on sludge digestion gives several goals that a process should obtain.

1. Reduce the volume of the sludge.
2. Reduce the amount of organic, volatile, solids in the sludge.
3. Render the sludge less obnoxious and more readily disposable.
4. Alter the physical state of the sludge so that the accompanying moisture can be readily removed.
5. Perform the above economically and in a controllable manner.

CHAPTER III

EXPERIMENTAL APPARATUS

Digesters

Six tanks were used as digesters in the laboratory work. Two were made from six inch diameter plastic tubing with a flat bottom. They were seven feet tall and had a one inch diameter tap with pipe and valve $1\frac{1}{2}$ inches from the bottom. Also six 3/8 inch valves were inserted at one foot intervals along the digester length. The large valve at the bottom permitted drawing of digested sludge, without clogging prior to feeding. The small valves were used to take samples at the different levels in the tank and provide an opening for reading the temperature in the tank. A sketch of one of the large tubes is shown in Figure 1.

The air for the digester was provided through a diffuser which lay on the bottom of the tank. The diffusers differed slightly in construction. One being a spiral of $\frac{1}{4}$ inch copper tubing and the other a circle of $\frac{1}{2}$ inch plastic tubing connected to a metal T-joint. Each was approximately 5 inches in diameter and contained many fine holes.

The four smaller tanks were made from 3 inch glass tubing tappered at the bottom to permit a 3/4 inch rubber tubing to be slipped on. The length of the tank was approximately

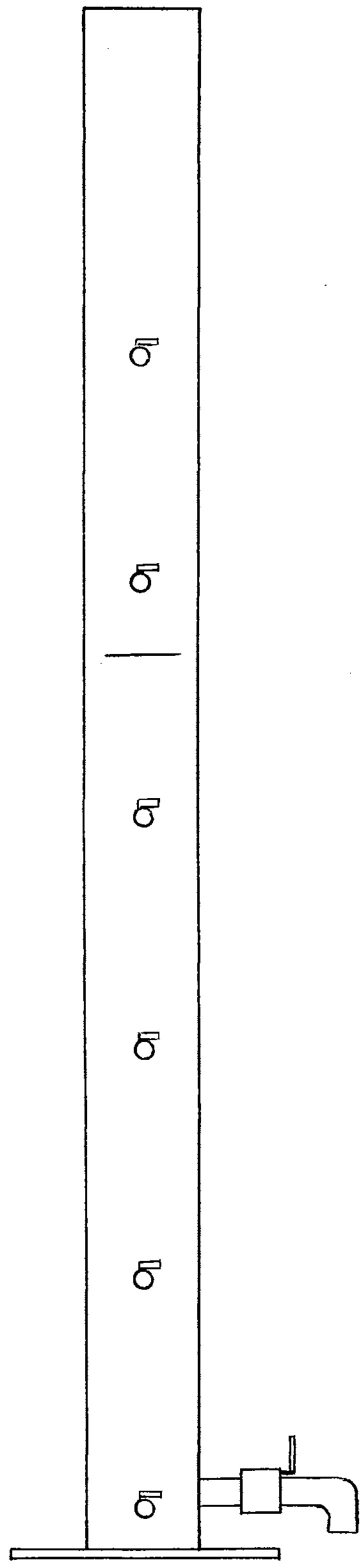

Figure 1

Laboratory Aerobic Sludge Digester, 18.88 liters

2 feet. A screw clamp on the rubber tubing served as a valve to remove digested sludge. Figure 2 is a sketch of the tanks and rack which held them.

Air Supply

Compressed air for the aerobic digesters was supplied by a compressor built by the Kargard Company operating at a tank pressure of 160 p.s.i. An air line regulator was used to decrease the pressure to 20 p.s.i. The air flow to the small tanks was measured with a Fisher laboratory flow meter and the air flow to the large digesters with variable-area flow meters by Fischer and Porter Company. With each flow meter a mercury manometer was used in the line to measure working pressure.

pH Meter

A photovolt, battery-operated, pH meter was used to measure pH to the nearest 0.1. The meter is equipped with a glass electrode in combination with a saturated calomel electrode, and a single operating control with a complete range from 0 to 14, thus pH readings may be taken on either side of the neutral point without range switching.

Ovens

Two ovens were used in the determination of total and volatile residue. One a 115 volt electrical oven made by Precision Scientific Company operating at 103°C., and the other a 230 volt Cenco-Cooley Electrical Muffle Furance

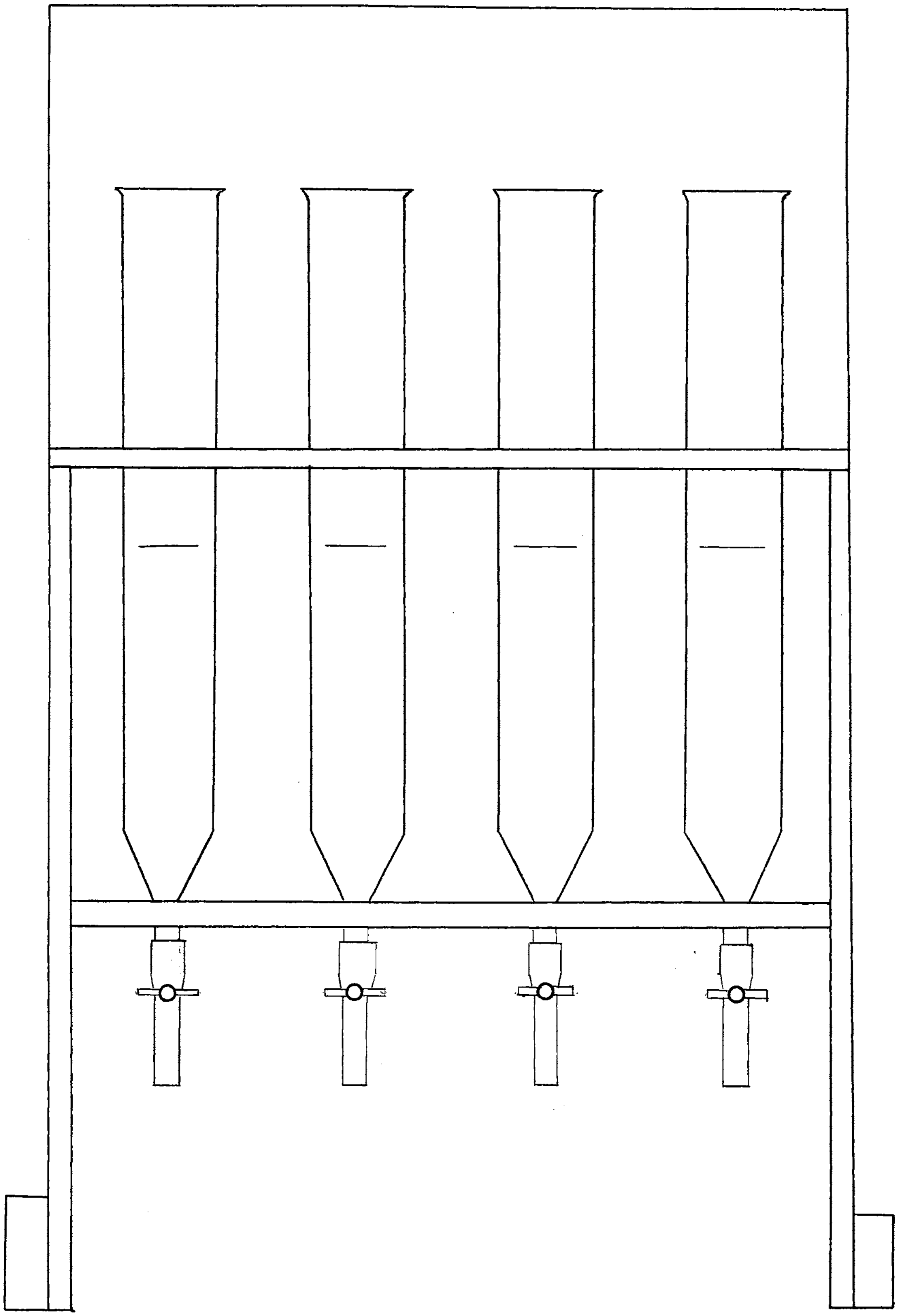

Figure 2

Laboratory Aerobic Sludge Digesters, 1 liter operating at 600°C.

Balance

All weight determinations were made on a 4 place chainomatic analytical balance built by Seederer and Kohlbush, Inc. The weights were recorded to the nearest one thousandth of a gram.

CHAPTER IV

EXPERIMENTAL METHODS

Previous work had shown that the digester and feed material were ready for use. A detention time of 4 days was selected for one set of digesters and 8 days for the other. A "set" consisted of one large and two of the small digesters. The large digesters being denoted in the text by the numbers 1 and 2, and the small digesters by 1A, 1B, 2A, and 2B. The group containing 1's having the 4 day detention time. The 4 day detention time was chosen because previous work by Barrett (5) indicated that this was about the minimum detention time from which satisfactory results could be obtained at room temperature, and it was desirable to use a multiple of the first for the detention time of the second.

It was decided to use a volume of one liter in the small digesters leaving approximately one foot of freeboard. The four were filled with digested sludge from tanks 1 and 2 and feeding of all tanks began on October 9, 1961. A 250 ml. portion of digested sludge was removed from tanks 1A and 1B each day and an equal volume of raw sludge was added. The volume drained from and added to tanks 2A and 2B of digested sludge and raw, respectively, was 125 ml.

A volume of 2/3 cubic feet or 18.88 liters was selected for application in the large digesters. This produced 3 feet of freeboard. The feeding rate for tank 1 was 0.167 cubic feet per day or 4.72 liters per day. For tank 2 the feeding rate was 2.36 liters per day, half the volume used in tank 1.

The raw sludge was obtained from the Stillwater, Oklahoma, Sewage Treatment Plant. The Stillwater anaerobic digester was overloaded and as a measure to solve this problem the raw sludge was pumped from the primary settling tank to an Imhoff tank. The sludge from the Imhoff tank was then pumped to the digester. This sludge from the Imhoff tank was used in the laboratory experiments. One disadvantage of using this sludge, rather than sludge from the primary, was that anaerobic digestion had begun to take place. Raw sludge for several days operation was obtained and stored in a refrigerator at 41°F.

Each day the volume lost from the aerobic digesters due to evaporation was made up with distilled water. After this the sludge was mixed well and a volume of digested sludge, equal to the volume of the digester divided by its detention time, was removed. From this digested sludge representative samples were taken periodically to be tested. The tank was then fed with raw sludge and the aeration continued. Air was supplied to the digesters continuously except for short breaks during the feeding routine, laboratory construction work, and minor problems with the compressor.

Gas production is very difficult to analyze for in an aerobic digester. Therefore, other tests and determinations will have to be used to give an indication of the degree of digestion. Residue determinations, pH, temperature, relative drainability, and odor were used.

Residue determinations consists of tòtal, fixed and volatile solids. Total solids are determined from the weight left after evaporating a sample of sludge to dryness. After igniting the dry sample only the fixed solids and ash are left. The weight of volatile is found by substracting the fixed solids from the total.

The laboratory procedures used follow closely thoses outlined in Standard Methods (7). A porcelain evaporating dish of known weight was filled with a sludge sample and weighed. The sample was evaporated to dryness under a heat lamp in an exhaust hood and then placed in a 103°C. oven for one hour. After cooling in a dessicator the dished and its contents were weighed. Ignition was accomplished by placing the dish in a 600°C. muffle furnace for 30 minutes. The weight was taken after the sample cooled in a dessicator, and the values of total, fixed, volatile and sample weight were determined. With these values the ratios of total, fixed, and volatile solids per sample and fixed and volatile solids per total solids were calculated and expressed as a per cent.

By substracting the per cent total solids per sample from 100% the moisture content could be obtained. An equation is given by Fair and Geyer (8) for calculating the specific gravity of the sludge when it was desired to express the feed as grams of volatile solids rather than as a per cent. The equation: $s = 25000/(250p+(100p)(100+1.5p_v))$, where p_v is the per cent volatile solids and p is the per cent moisture, assumes specific gravity of 1.0 and 2.5 for volatile solids and fixed solids, respectively.

The reduction of volatile solids is calculated by subtracting the total grams of volatile solids discarded in the waste from a digester for a given time from the total volatile solids added in the raw sludge fed over the same time period and dividing this by the total volatile solids in the feed. This reduction is expressed as a per cent for a given period of time.

Several types of filter apparatus were used to test the relative drainability of sludges from different tanks, and digested sludge with the raw. Another good indication of the degree of digestion, although only qualitative, is the odor given off during the draining test.

Two different grades of filter paper were used in glass funnels and both were used without a vacuum. They were Whatman No. 50 and No. 4, the first was a fine texture paper hardened by treatment with nitric acid and resistant to pressure, and the second a rapid unwashed paper for filtration where the precipitates are coarse.

Filters were also made by placing sand in a section of 6 inch diameter plastic tubing with a bottom designed to drain the filtrate into a graduated cylinder. Various depths and gradings of sand were used, therefore it is not possible to compare results made at different times.

The results from the drainability tests are given for only a short time period. They show the relative trend that each sludge was taking, but the conditions of the sludge on the filter media was also noted the day following the test. Detection of possible water ponded on top of the sludge and odor were the main objects of interest.

The per cent moisture at different time intervals is calculated by substracting the weight of filtrate received to that time from the original weight of water present in the sample less the weight of filtrate. The weight of the sample is calculated by multiplying its specific gravity times the initial volume used. The milliliters of filtrate received is taken as grams of water.

Graphs of per cent moisture remaining in the sludge versus time are plotted to show relative drainability when the original moisture contents are similar, otherwise the per cent reduction in moisture content is plotted against time.

Hydrogen ion concentration, expressed as pH, was determined on the samples prior to the solids test. Hydrogen ion concentration measurements were discontinued after November 7, 1961.

Room temperature was measured at the same location in the room through out the experiment although it was necessary to move the tanks to a new location. In the later experiments the temperature was measured within the tank by inserting the thermometer into the tank through a rubber gasket attached to one of the 3/8 inch spigots.

Experimental work with the four 1 liter digesters was discontinued after December 9. 1961. Loading at the same rates was continued with the two large digesters until March 6, 1962, at which time the detention time of tank 2 was changed to 4 days. The feeding rate was then 4.72 liters of raw sludge per day, the same as for tank 1.

This change was made to determine if the rate at which the daily feedings were made had any effect on the digestion. Prior to this all daily loading had been made at one time. The loading of tank 1 proceeded as usual and tank 2 was feed one fourth of its total daily load four times a day. These loadings were made at 7:30 am, 12:30 pm, 5:30 pm, and 10:30 pm. Tests on samples of tank 2 were made from the digested sludge removed before the 7:30 am feeding.

The air flow rate to the digesters was not measured, but an excess of air was used. This flow of air kept the contents of the digester mixed throughly as well as saturated with oxygen.

CHAPTER V

RESULTS AND CONCLUSIONS

Comparing the degree of digestion for tanks 1 and 2 as given in Table I over the period of time for which their detention time was 4 and 8 days, respectively, will give an indication of the increase in digestion due to a lower feeding rate. The increase in digestion with a detention time of 8 days varies from 3.5% to 9.0% greater than the degree of digestion achieved with a 4 day detention period. The mean increase is 6.3% or a 20.5% increase above average per cent digestion for tank 1. The average loading rate for tank 1 was .998 pounds of total solids per day per cubic foot or .64 pounds of volatile solids per day per cubic foot of digester capacity and the loading for tank 2 was .499 pounds of total solids per day per cubic foot or .32 pounds of volatile solids per day per cubic foot of digester capacity.

During the first month of operation the average values of tanks 1A and 1B given in Table II, compared with the results of tank 1. The average results of tanks 2A and 2B are comparable with the results of tank 2 for the 1 liter tanks to give higher values than the large tanks. There could be several reasons for this.

TABLE I

ANALYTICAL DATA AND VOLATILE MATTER DESTRUCTION
FOR TANK 1 AND TANK 2

Date	Raw		Tank 1		Tank 2		Volatile Matter Destruction	
	Total Solids (%)	Volatile Solids (as % of T.S.)	Total Solids (%)	Volatile Solids (as % of T.S.)	Total Solids (%)	Volatile Solids (as % of T.S.)	Tank 1 (%)	Tank 2 (%)
1961								
October	6.91	50.4	4.22	51.8	3.71	49.2	37.2 ~~40.6~~	47.6 49.6
November	7.60	71.2	5.92	69.5	5.42	70.0	30.1 29.9	36.0 33.4
December	5.99	66.7	5.89	67.9	4.59	69.4	20.0	26.6
1962								
January	3.94	67.0	3.67	64.4	2.96	62.4	23.3	28.9
February	7.45	65.6	4.48	57.8	2.59	54.6	39.5	46.5
March *	6.10	65.9	3.50	62.1	3.10	58.7	50.2	52.0

* 4 day detention time for each tank

TABLE II

ANALYTICAL DATA AND VOLATILE MATTER DESTRUCTION
FOR THE AVERAGE OF TANKS 1A AND 1B
AND TANKS 2A AND 2B

Date	Raw		Tanks 1A & 1B		Tanks 2A & 2B		Volatile Matter Destruction	
	Total Solids (%)	Volatile Solids (as % of T.S.)	Total Solids (%)	Volatile Solids (as % of T.S.)	Total Solids (%)	Volatile Solids (as % of T.S.)	Tanks 1A & 1B (%)	Tanks 2A & 2B (%)
1961								
October	6.91	50.4	4.02	53.9	4.18	52.9	37.2 42.3	35.6 44.1
November	7.60	71.2	4.45	68.9	4.99	68.3	43.3 43.2	37.0 36.0

More trouble was encountered with the small digesters as far as foaming was concerned. Once foaming began it went over the top of the small tanks readily because of their small diameter. A small loss in solids would have a large effect on the results because of the small total volume of sludge being investigated. Thus any loss of solids due to foaming would indicate a per cent digestion that was too high. Because of this problem the use of the small tanks was discontinued and all work concentrated on the large digesters.

Foaming occured in the large, 2/3 cubic foot, digesters from time to time, but was not the problem it was in the small tanks because it had to exist for a much longer time to over flow the freeboard available.

The digesters operating with a detention time of 8 days were plagued more with foaming. This was true for the large digesters as well as the small ones. Also in most every case when a loading was missed, due to the lack of raw sludge, on the tank with a detention time of four days foaming would occur on the second day. This cannot be explained from the experimental data obtained.

It is believed that a surface spray system, similar to those used in the elutriation, activated sludge and extended aeration processes, could be used to disperse the foam. The spray would act to release entrained gas from the solid particles permitting them to stay in solution. Such a system was not used in the experiments because it would introduce a volume of water that would have to be measured and accounted for in the calculations.

Temperature readings are not given in Tables I and II because they tend to be misleading. The temperature readings were recorded at the time of feeding and do not reveal the lower temperatures the digesters were subjected to during the nights of the winter months. The per cent digestion, decreases from a relatively high per cent, for two months and then increases steadily until the end of the experiments. Greater digestion occured during the months of overall warm temperature while the poorest occured during the colder winter months. From the information available it can not be stated that temperature is the sole cause of the variation in per cent digestion because there are other variables to be considered, but it appears to be a contributing factor to the degree of digestion accomplished.

The pH value of all the digested sludges were in the range of 8.1 to 8.6. This is well above the 6.8 to 7.4 range which is usual for sludges digested anaerobically.

A fine textured filter paper, Whatman No. 50, was used to determine if and to what extent detention time would affect the drainability of the sludge. A 100 ml. sample of raw sludge and digested sludge from tanks 1 and 2 were filtered and the results plotted on Figure 4 as per cent moisture remaining versus time with the vertical scale exaggerated to show the trend of draining for a short period of time. No objectionable odor was detected from the digested

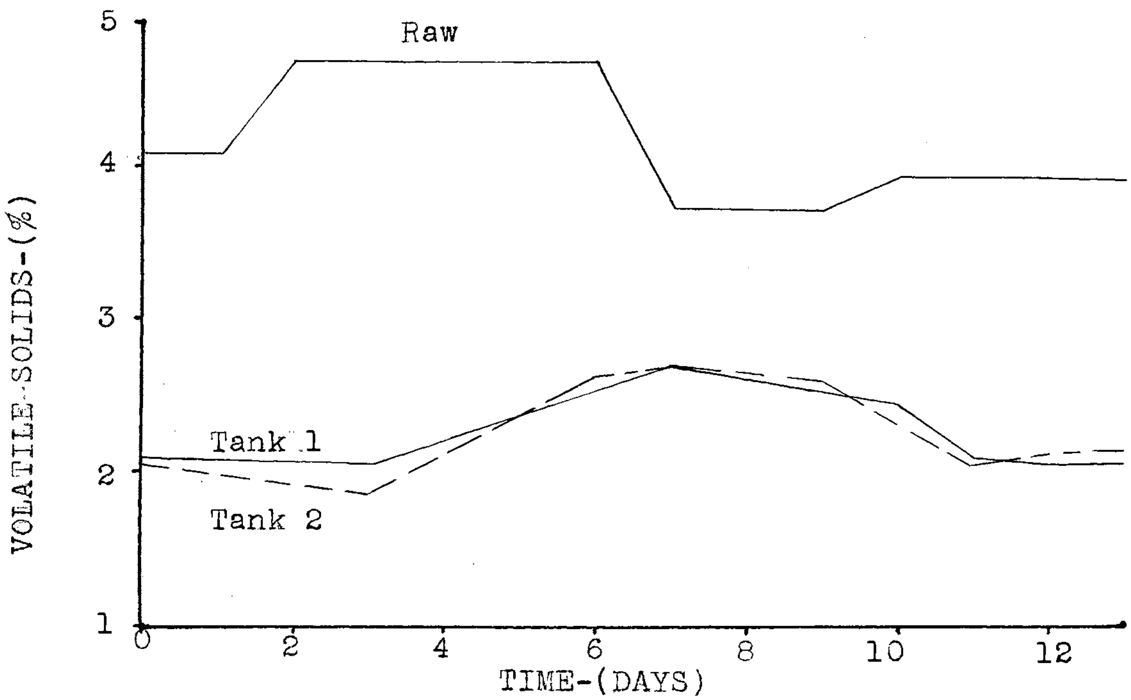

Figure 3

Operation Data for Tanks 1 and 2

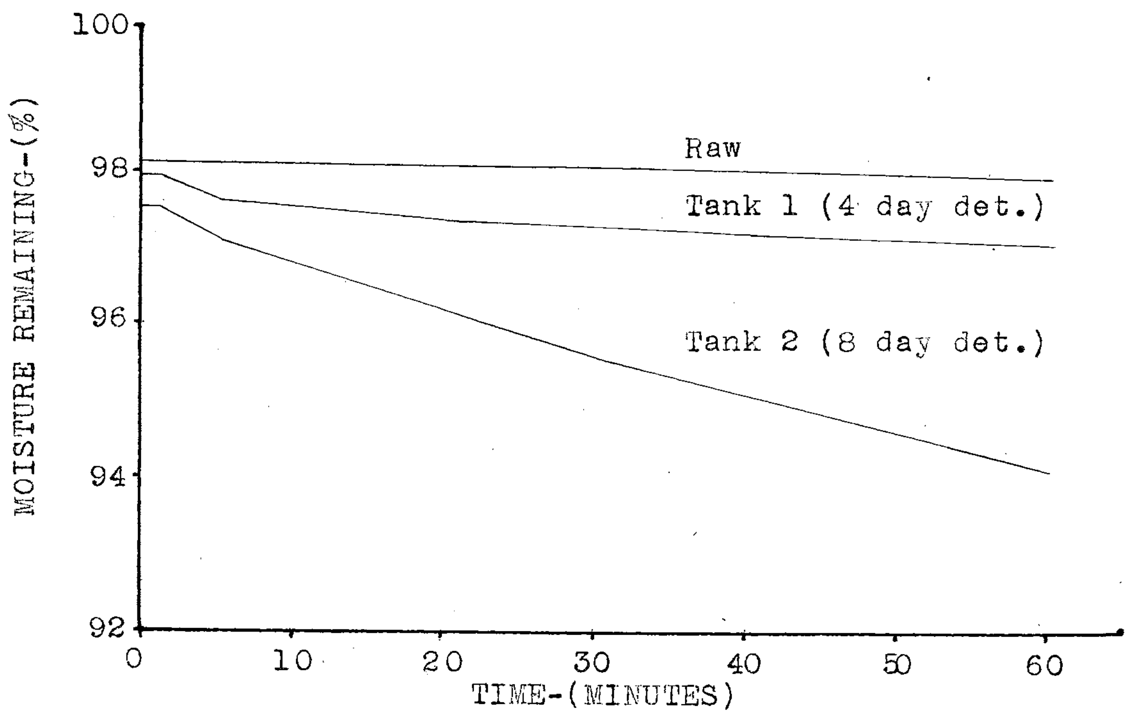

Figure 4

Relative Drainability of Raw Sludge and Digested Sludges from Tanks 1 and 2 sludges, but that of the raw was very strong. The following day the odor of the raw was less, but still obnoxious. The only ponding of water that occurred was on the raw sludge.

In the last phase of the project the influence of more frequent feedings, refered to as a step-wise feeding, was investigated. Tanks 1 and 2 were operated with a 4 day detention. Tank 1 was fed once a day as usual. The feed to tank 2 was divided into four equal quanties and fed step-wise four times a day. The average results are shown in Table I and Figure 3 is a plot of the volatile solids expresses as a per cent of the sample for tanks 1 and 2 and the raw sludge. An increase of 1.8% in the digestion of volatile solids resulted.

The average total solids of the raw for this period was 6.10%. This was reduced to 3.50% in tank 2. Also the average volatile solids expressed as a per cent of the total solids was reduced from 65.9% in the raw to 62.1% and 58.7% in tank 1 and 2, respectively. For this phase of study the average loading was 1952 pounds of total solids per day per cubic foot of digester capacity or .626 pounds of volatile solids per day per cubic foot for each tank.

Another indication that step-wise feeding will increase the digestion is shown by the relatively better drainability that digested sludge from tank 2 exhibits as shown in Figure 6. Whatman No. 4 filter papers and 100 ml. samples of sludge were used. The plot of per cent moisture remaining versus time shows that both digested sludges drain well.

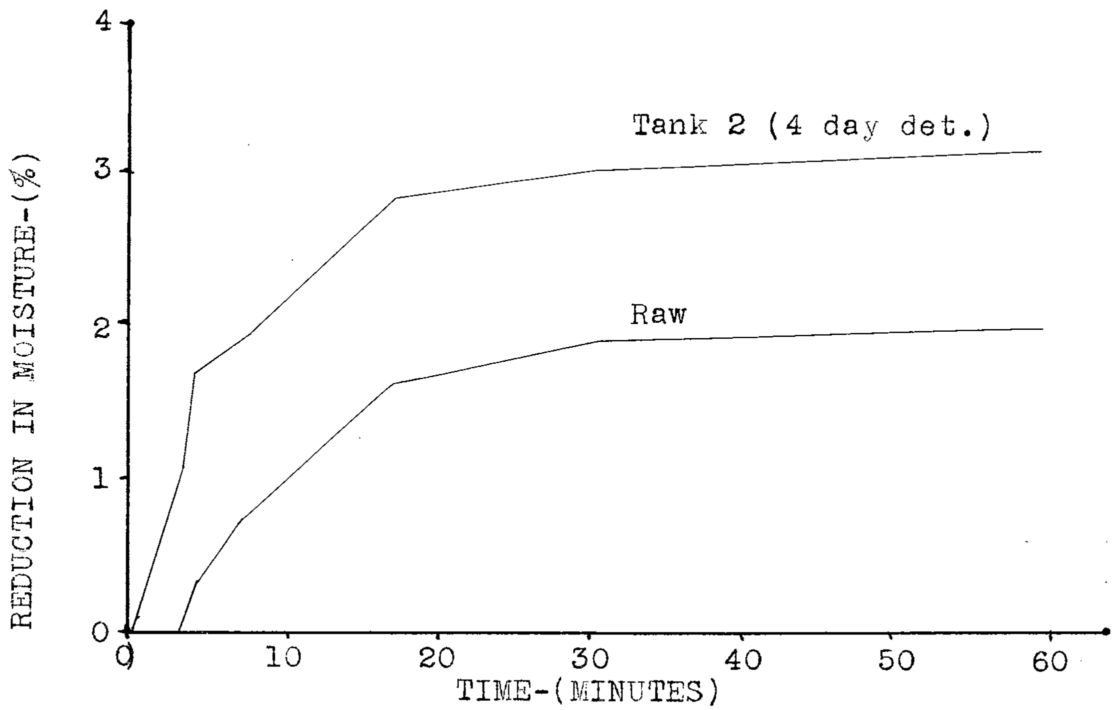

Figure 5

Relative Drainability of Raw Sludge and Digested Sludge from Tank 2

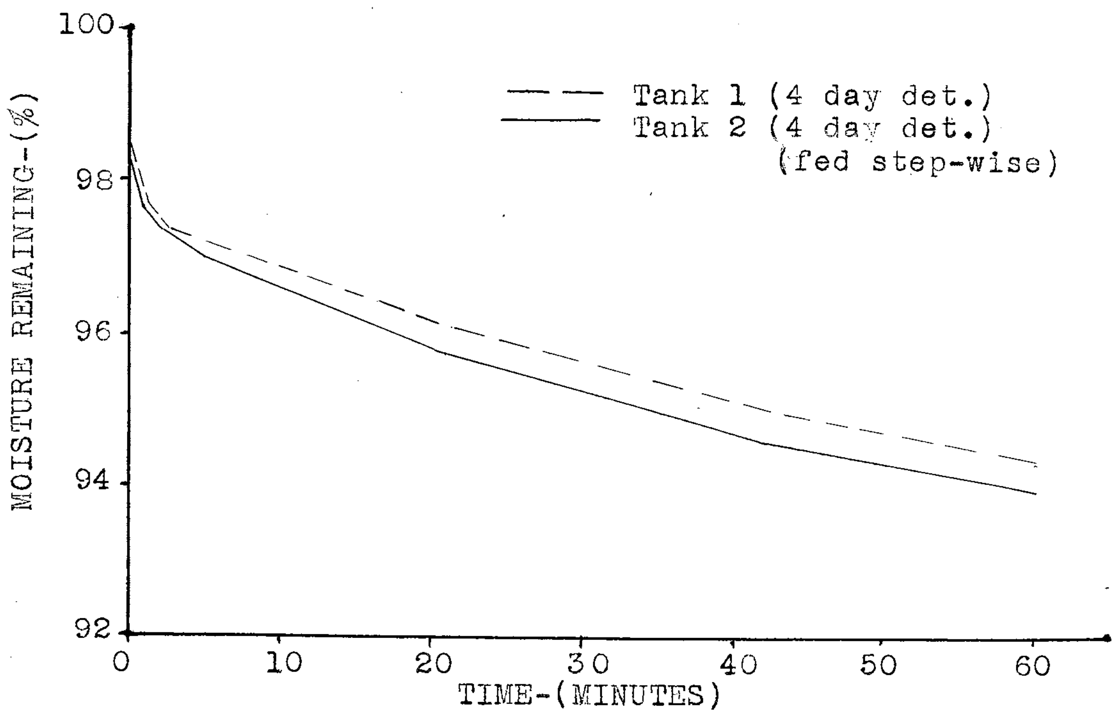

Figure 6

Relative Drainability of Digested Sludges

The vertical scale is somewhat exaggerated to show the trend of draining for a short period of time.

No objectabile odor was noted during the filter test such as had been present when the test was conducted earlier using a sample of raw sludge. Also, there was no water ponded on the filter cake the following day.

Feeding the tank several times a day rather than at once which may result in a shock to the system gives better digestion of the volatile matter as well as better drainability. This step-wise feeding procedure is more applicable to full-scale plant operation because sludge from settling tanks is pumped out several times each day. Theoretically continuous feeding is required, amoung other things, to maintain the organisms in their most active state. As this feeding condition is approached better digestion should be obtained.

The relative drainability of raw sludge and digested sludge from tank 2 is shown in Figure 5. Tank 2 was operating with a detention time of 4 days. A 300 ml. sample was placed over a one inch layer of sand in the plastic tube drying beds. The decrease in moisture expressed as a per cent is plotted against time. Again the vertical scale is exaggerated to show the trend of draining for a short period of time. The odor given off by the filter containing the raw sludge was very strong and obnoxious. If any odor was present from the digested sludge it could not be detected because of the prevailing odor from the raw sludge. The following day the digested sludge appeared drier than the raw and the odor of the raw was still present.

Most of the objectionable odors present occured during the process of feeding the tanks with raw sludge. During the month of December, which showed the lowest degree of digestion it was noted that the sludge drained from tank 1 had a slight odor. After the average temperature increased and better digestion occured no noticeable odors, aside from the feeding period, were detected.

Several definite trends of aerobically digested sludge can be established from this experimental work:

1. The aerobic process will digest sludge to a satisfactory degree for disposal.
2. The reduction of volatile solids is a function of the detention time, in the range investigated.
3. Under conditions of satisfactory digestion there is an absence of objectionable odors.
4. At higher operating temperatures a greater degree of digestion is achieved.
5. The digested sludge drains well, and an increase in detention time increases drainability.
6. Little or no odor is present during the draining of the sludge.
7. Aerobic digesters operate above a pH of 7.

A determination of the minimum detention time required for satisfactory digestion could not be made because of the variation that existed in the temperature.

More experimental work is needed on the subject to allow for the design of plant digesters for a given situation. Curves which give the degree of digestion for a given temperature and loading rate, such as have been determined for anaerobic digestion, would be useful. These could be obtained by conducting experiments at constant temperature and feeding with as near a constant sludge as possible, with a family of temperature and digestion relationships the economical feasibility of using a heated aerobic digester can be determined.

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Education: Graduated from Durant High School, Durant, Oklahoma, May, 1956; attended Southeastern State College, Durant, Oklahoma, in 1956 and 1957; received the Bachelor of Science degree from the Oklahoma State University, with a major in Civil Engineering, in August, 1961; completed requirements for the Master of Science degree, in Sanitary Engineering, in August, 1962.

Professional experience: Graduate Assistant, Oklahoma State University, Stillwater, Oklahoma.