UTILIZING ELECTRIC HEAT FOR THE OPERATION OF A WASTE SLUDGE DIGESTER

By

DONNY FRANK KINCANNON

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1959

Submitted to the Faculty of the Graduate School
of the Oklahoma State University of
Agriculture and Applied Science
in partial fulfillment of
the requirements for
the degree of
MASTER OF SCIENCE
1960

UTILIZING ELECTRIC HEAT FOR THE OPERATION

OF A WASTE SLUDGE DIGESTER

Thesis Approved:

Quintin B. Graves
Thesis Adviser

Harry M Wyatt Jr.

Robert MacVicar
Dean of the Graduate School

PREFACE

This study is the first of a series of investigations to determine if an electrical heating element is feasible for heating a waste sludge digester.

The author wishes to acknowledge and express his indebtedness to Professor Quintin B. Graves for his invaluable assistance and constructive criticism in the preparation of this thesis and for acting as the writer's major adviser. Acknowledgement is due Professor Harry M. Wyatt, Jr. who, as the writer's second adviser, made many grateful contributions to the project. Ronald Waters, a graduate student in Civil Engineering, offered many invaluable suggestions.

The author expresses his gratitude to the Faculty in the School of Civil Engineering for appointing the author Graduate Assistant, and for their many contributions to his education.

The author wishes to thank Miss Willie Cannaday for her careful typing of the manuscript.

D. F. K.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1-1 The Process of Sludge Digestion

Digestion of sewage sludge is accomplished by biological action in which the solid organic matter undergoes liquefaction and gasification, and the condition of the sludge is so changed that its volume is reduced, valuable gas may be produced, the fertilizing qualities of the sludge may be improved, and it renders the sludge fit for easy disposal by lagooning, dilution, or similar means. This is accomplished in digesters by an anerobic fermentation process under controlled conditions. The digestion of fresh sludge starts with an acid reaction which is slowly replaced by putrefaction and an alkaline reaction. In some tanks both acid reaction and putrefaction may take place simltaneously.

The conditions that may affect the operation of a sludge digester may include temperature, digestion period, degree of mixing tank contents, manner of feeding, the pH, the volatile acids content of the digesting mixture, and the amount and kind of added chemicals. Indices that may be used to measure digestion include:

1. The pH of the digested sludge is between 6.8 to 7.4
2. Digested sludge has 10% dry solids of which 50% are volatile
3. Volatile acids do not exceed 2000 p.p.m.
4. The methane content of gas produced lies between 55 and 75

per cent and carbon dioxide makes up to about 95 per cent of the gas volume.

5. The digested sludge is black, quickly drainable, and inoffensive in odor.

Unsatisfactory digestion is indicated by the presence of hydrogen sulfide, skatol, mercaptans, and other foul smelling substances, mere traces of which will impart intense, characteristic, highly offensive odors.

1-2 Temperature of Digestion

Sludge digestion may be accomplished in two different temperature zones, these being the mesophilic zone and the thermophilic zone. The optimum temperature of sludge digestion in the mesophilic zone is about 95° F., while in the thermophilic zone it is about 128° F. Although the optimum sludge digestion temperature may vary somewhat with local conditions, the temperature generally adopted for sludge digestion falls within the range of 85° F. to 95° F.

The evidence from plant trials shows that thermophilic digestion increases somewhat the methane content of the gas. The pH of sludge digested at 120° F. is about the same as that of sludge produced from mesophilic digestion. Tests have also indicated that reduction of total solids and volatile matter in the thermophilic zone is 5 to 10% greater than for digestion in the mesophilic zone.

Temperatures below 75° F. to 80° F. are not usually considered because the digestion rate and gas production fall off rapidly at the lower temperatures until at about 50° F. it practically ceases. No permanent harm is done to the bacteria life even at temperatures slightly below freezing. With an increase in temperature, digestion will

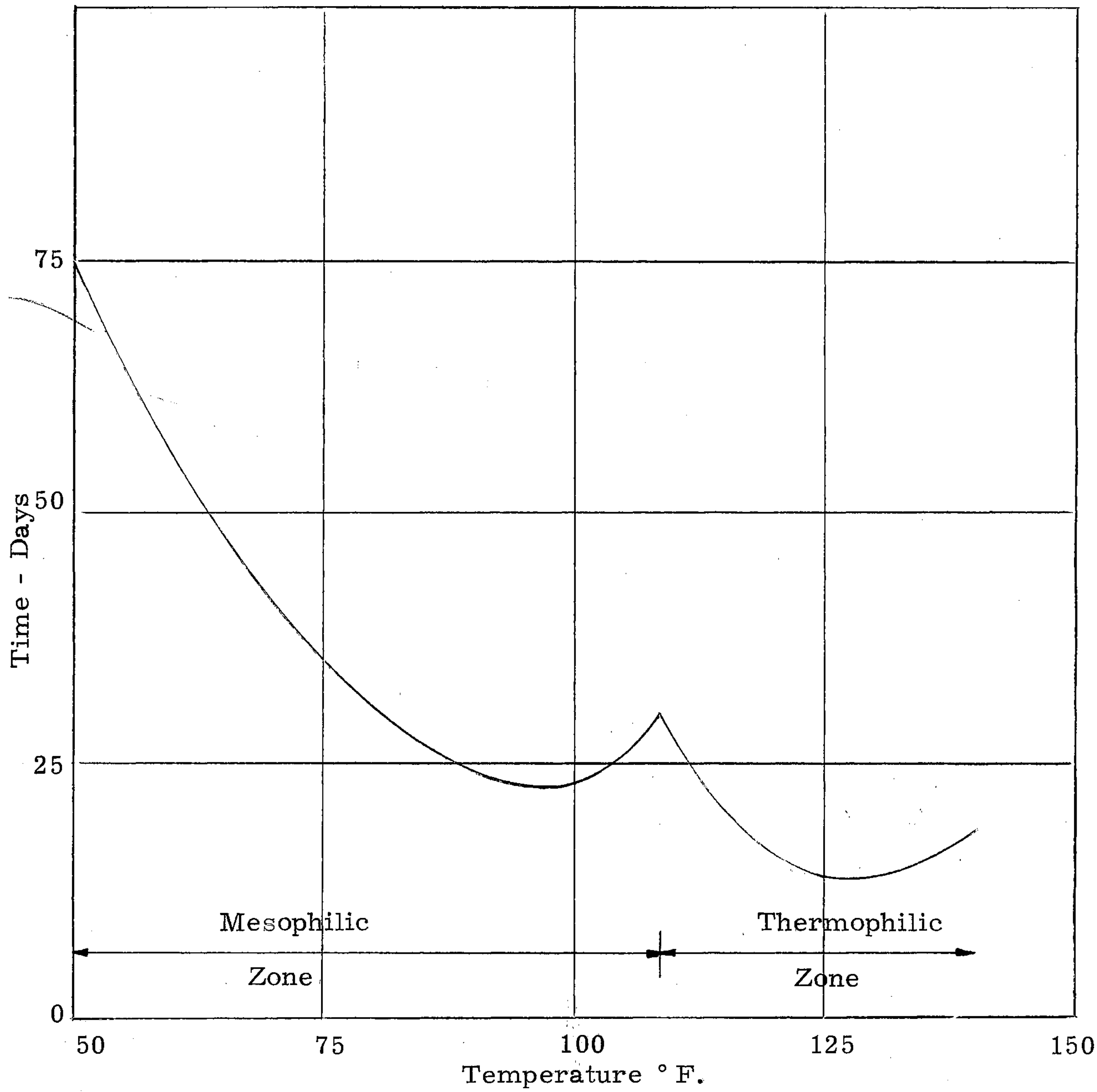

Figure 1

Time required for digestion of Sewage
Sludge at different Temperatures

proceed in a normal manner. As the temperature rises above 95° F. there is a slight falling off in biological action until about 109° F., when it begins to increase to attain a theromophilic optimum of 128° F. Digestion is more rapid in the thermophilic zone, so that changes requiring weeks at 60° F. can be accomplished in days at 128° F.

The relationship between temperature and time required for digestion is given in Figure 1. Starting at low temperatures, the time of digestion decreases until a temperature of 95° F. is reached. At this point an increase in temperature causes an increase in digestion time until about 109° F. and again with an increase in temperature will cause a decrease in digestion time. This is due to the change in biological action mentioned in the preceding paragraph.

1-3 Method of Heating

In the last few years a method of heating has been sought that not only is adequate, but also provides maximum flexibility. This has been brought about due to the increase utilization of the gas produced from digestion and the importance of temperature as being one of the main factors affecting digestion. The heating systems devised have been tried not only as to their ability to meet the requirements of the digestion process, but also as to the efficiency of the particular heating devices themselves. In operating a sludge digester the operator is interested in meeting the heat requirements of the digestion process with the lowest total amount of B. T. U.'s being used. Also the operator is interested in the flexibility of the heating system, and of the maintenance cost.

In selecting a method for applying heat we must consider the methods of heat transfer which are:

1. Radiation - the transmission of heat through space by wave motion in a manner similar to the travel of light waves.
2. Convection - the transfer of heat accomplished by the motion of the fluid from a locality where it receives heat to a locality where it gives up heat.
3. Conduction - the transfer of heat from one part of a continous material to another part of the same material, or from one material to another material in physical contact with it.

In applying a method of heating we may use either one of these three methods of heat transfer or we may use them in combination.

The common methods of applying heat to digesters are:

1. Internal heating
   - (a) Horizontal pipe coils
   - (b) Vertical pipe coils
2. External heating
3. Direct Flame
4. Direct steam

Hot water circulated in horizontal pipe coils within the digestion tank was the first method used for the heating of sludge, and has been more widely used than any other type of heating system. In most cases it has proven to be a good method of heating, but it has enough disadvantages that in recent years the wide acceptance of this heating method has been effectively challenged. This includes both horizontal and vertical pipe coils. One of the main problems with this method is sludge caking on the coils. With caking on the coils the heat transfer from coils to digester contents is cut down, therefore, it has become almost self-evident that the hot water entering heating coils should be kept below 140° F. to avoid this caking. An additional disadvantage of horizontal pipe coils is that when trouble is encountered with the coils, their location makes repairs on them a major task. The digester must be emptied to make the repairs, thus taking the digester out of operation. The vertical type coils are better concerning this matter, in that, they are usually inserted at the top of the digester tank. This allows the coils to be removed for inspection, repair, and replacement if necessary.

The seriousness of the breakdown of coil heating systems has caused plant operators and designing engineers to look in the direction of the external heater as an answer to these problems. External heaters have been used in English sewage treatment plants since 1923, and have more recently started replacing internal coils in the newer plants in the United States.

Higher velocities of the heating medium are used in external heat exchangers than in internal heating coils. The higher velocities result in higher heat-transfer coefficients and, therefore, in higher heating efficiencies. Also, all operating parts are located outside the digester, where the necessary maintenance and repairs can be made.

The common types of external heating are a heat exchanger with a separate gas heater or boiler furnishing hot water. Usually some type of oil or gas is used as the fuel for heating. Smith and Morris [1] in 1953 introduced the use of a "Heat pump" as an external heat exchanger. Heat pump is a name usually used to designate a set of refrigerating equipment when utilized for heating purposes. They maintain that in localities where the cost of electrical energy is less than $0.01 per kilowatt hour, the heat pump may prove to be a more economical means of digester tank heating than by oil or gas. As yet this method has not been extensively used.

Direct flame heating has been used in some locations. Philadelphia is one such place. Here sewage gas is burned in a specially designed combustion chamber and the hot combustion gases are diffused into the sludge in small heating tanks. The sludge is pumped into the heating tanks and then to the digesters. The temperature of the combustion gases in about 2,400° F., and the escaping gases have a temperature of about 125° F. Over-all thermal efficiency is reported to be 85 to 90 per cent.

Steam has been injected directly into sludge digesters with favorable results. In most cases it requires softening of the boiler water supply and 100% boiler make-up water is required. It also requires considerable attention, and for these and other reasons this method has never gained wide acceptance.

One disadvantage of all of the general methods of digester heating is that they provide no economical method of heating small capacity digesters. As a consequence, small communities, National Parks, or anyone requiring small capacity digesters have to use unheated digesters. Digestion requires about 24 days at 90° F. and about 48 days at 65° F. (Fig. 1). From this we can see that unheated digestion requires approximately twice as long as heated digestion. From Table I, we can see that the Ten-State Standards requires the digester capacity to be doubled for unheated digestion. This causes an added expense on the community in having to double the size of their digester, plus the fact that in many localities no digestion takes place during the winter months due to the cold climate. As we have learned earlier practically no digestion takes place below 50° F.

TABLE I

TEN-STATE STANDARDS FOR DIGESTION TANK CAPACITY

Type of Plant	Volume in Cubic Feed per Capita Heated	Unheated
Imhoff tanks		3 to 4
Primary	2 to 3	4 to 6
Primary + low-rate filter	3 to 4	6 to 8
Primary + high-rate filer	4 to 5	8 to 10
Activated Sludge	4 to 6	8 to 12

This paper is concerned with developing a method of electrical heating for a sludge digester. The development will be for small capacity tanks. Ones, that are being designed at the present time are usually unheated tanks, because no satisfactory method of heating is available for small tanks.

1-4 High Rate Digestion

The main reason engineers have stayed away from electrical heating of digestion tanks has been the cost. One important thing that may reduce this cost is high rate digestion. Since the advent of separate sludge digestion in 1923, and the application of heat to a sludge digester in 1927, very little advancement has been made in this field. It has only been during the past 5 - 6 years that some developments have been demonstrated that resulted in appreciable economy and improvement in performance.

The new developments in this field have been directed toward the reduction of volume required for satisfactory sludge digestion and increased production rates and economy in the field of sludge dewatering. This paper is interested in reduction of volume requirements, thus high rate digestion.

From reports published, it is apparent that full scale digestion units have been operated satisfactorily in the range of 11 to 14 day detention periods at volatile solids loadings ranging from 0.18 to 0.25 lb. per cubic foot per day. Torpey(2) demonstrated on a plant scale that volatile solids loading five times that of conventional standards and detention times as low as eleven days were practical with the end results equal to those formerly obtained when using 54 days of digester detention. Morgan (3) has reported on pilot scale studies of one year's duration in which satisfactory digester operation was obtained with volatile solids loadings of 5 to 7 times those normally used and with detention periods as low as 7 to 8 days. Sawyer and Roy, (4) have also shown on a laboratory scale that digestion is feasible at loadings of five to seven times conventional at detention periods as low as six days. Numerous other investigators have made similar studies with similar results. The author feels no need to mention them here. The few references used, were to show that high rate digestion has been proven workable.

After reviewing the reports of these investigations, and having a laboratory digester in operation for 42 days, it is concluded that the successful operation of a high rate digester depends upon the following critical requirements:

1. Feeding on as much a continuous basis as possible.
2. Feeding as concentrated a sludge as possible.

3. Continous mixing of the entire contents of the digester, to keep scum broken up and to mix incoming sludge throughout the digester.
4. Careful control of the temperature.

If these requirements are maintained in a digester, operators will be able to achieve high rate digestion, which means engineers can design digesters on the basis of 1 to 2 cubic feet per capita instead of the present standard of 3 to 4 cubic feet per capita. This is a reduction in size of digester of one-half or greater. This reduction in volume is what makes high rate digestion so important to the use of electrical heating in a digester. This will be taken up in more detail when the cost of operation of an electrical heating element for digestion operation is discussed.

CHAPTER II

STATEMENT OF THE PROBLEM

Sludge digestion is desired for the following reasons:

1. Production of inoffensive sludge for disposal
2. Reduction of quantity of sludge to be handled for disposal
3. Production of sludge that will dry readily
4. Production of sewage sludge gas.
5. Production of sludge for use as a soil conditioner.

In small communities the first three are the most important reasons for digestion tanks. In communities of 1,500 to 5,000 range unheated digesters are competitors of Imhoff tanks, but there are few heated digesters. It has been pointed out earlier that to obtain digestion that will meet the requirements of reasons two and three, the unheated digester requires at least twice as much volume as a heated digester. It is also known that odors are kept under better control with a heated digester than with a septic tank or Imhoff tank.

In communities of 5,000 or greater they can make use of the gas produced during digestion to operate heating equipment for their digesters, but small communities are unable to produce enough gas to be of value. Therefore, some method must be developed that can be employed in small communities to heat their digesters. As an example of the problem in these small localities, in Sequoia National Park an Imhoff tank is used to provide sludge digestion, but even the summer temperatures at this location are too low to provide enough heat for digestion. Therefore, the sewage sludge accumulates each year with little or no digestion taking place.

In this research paper the author will attempt to show that an electrical heating element can be utilized to provide heating in digester tanks for small communities. The problems that have to be considered include:

1. Can good digestion be accomplished?
2. Will cost be such that the process will be economically feasible?
3. Will caking occur on the heating element?

CHAPTER III

PROCEDURE AND EQUIPMENT

3-1 General

A detention time of 30 days was picked for the laboratory digester. This detention time was decided upon due to the fact many operators use this time as a rule of thumb for their digesters. A temperature of 90° F. was set as the digestion temperature. Most plants are able to obtain this temperature and it is very close to the optimum for the mesophilic zone of digestion.

The digester was constructed out of a five gallon glass water bottle by "popping" the top off of the bottle. The diameter of the bottle was 10.45 inches with a volume of 14.2 liters. A plastic top was made and all mechanisms of the digester was placed through this top. This included the heating element, mechanical mixing device, recording thermometer probe, a thermoswitch for regulating the temperature, and tubes for adding raw sludge and drawing off digested sludge.

3-2 Special Equipment

A 500 watt, 115 volt immersion heater was selected as the heating element. This element was purchased from Sargent Scientific Laboratory Supplies. The element was placed in a vertical position through the plastic top, such that it could be easily removed for inspection and maintenance.

A Fenwal Thermoswitch was used as the device to control the

Fig. 2

Laboratory Sludge Digester

temperature of the digester contents. The thermoswitch is adjustable from minus 100° F. to plus 400° F., with a sensitivity of $\pm$ 0.1° F.

For measuring the kilowatt-hours a small 5 ampere, 115-120 voltage house meter was used. The meter was one formerly used by the city of Stillwater and calibrated by them before being used in this research.

For determining the temperature of the digester contents a 24 hour recording thermometer was used. The chart could be read to the nearest 1° F.

To be able to hold the voltage constant, a Powerstat variable transformer was used. The primary voltage is 120 volts with an output voltage of 0-140 volts.

For measuring the pH a Photovolt battery-operated pH meter was used. The meter is equipped with a single operating control with a complete range from 0 to 14. The pH may be read to the nearest 0.1, and readings may be taken continuously through the neutral point without range switching.

For the mechanical mixing a kitchen type hand mixer was used. The mixer was equipped with three variable speeds. The only modification was to lengthen the shaft and make a propeller blade for the mixing.

3-3 Procedure

Before any sewage sludge was added to the digester, the digester was filled with water and all equipment was calibrated. The variable transformer was set so that the heating element would not heat to a higher temperature than 125° F. It was found that line voltage could be used without over heating. The thermoswitch was then calibrated

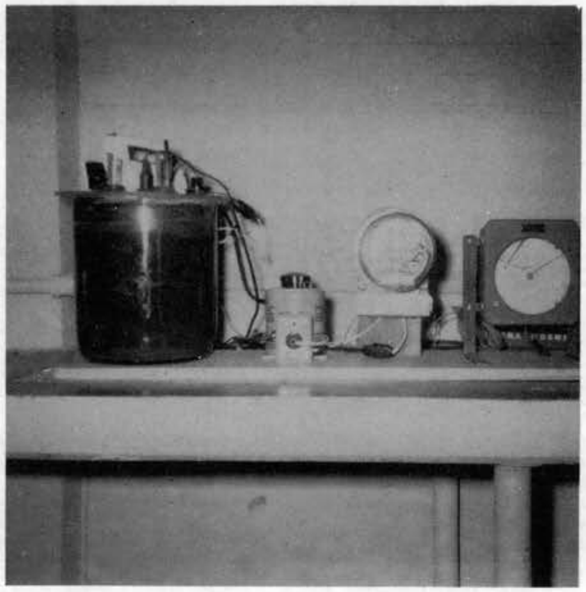

Fig. 3

Special Equipment

Sludge Digester
Variable Transformer
Watt-Hour Meter
Recording Thermometer

to maintain a constant temperature of 90° F.

After calibration approximately 12 liters of sludge was obtained from the Stillwater, Oklahoma sewage treatment plant to be used as seed for the laboratory digester. The sludge was obtained as the operators were drawing off from the digester and should have been well digested sludge. The Stillwater plant was in an overloaded condition and therefore the sludge was in a poor condition. The pH of the sludge was only 5.3 and the sludge had a strong odor.

The seed sludge was placed in the laboratory digester on February 1, 1960, and raw sludge feeding began on February 2. The raw sludge feed consisted of 470 ml. added once each day. The raw sludge was obtained from the primary settling tank of the Stillwater plant. In the beginning the raw sludge was obtained fresh each day from the sewage treatment plant. A sample was taken to be stored in a refrigerator at 41° F. to determine how long the raw sludge could be stored without becoming septic. It was found it could be kept at least one week and possibly longer without septic conditions. After this the samples were obtained for a one week supply and stored at 41° F.

The digested sludge and supernatant liquor had to be drawn off approximately every three days. Controlling the level of the sludge in the digester determined the time of drawoff. Due to the mechanical mixing, the level of the sludge had to be under careful control to insure complete mixing of the digester contents. Approximately 1.0 liter was drawn off every third day. Of this, 500 ml. was digested sludge and 500 ml. was supernatant liquor. At times the drawoff consisted of the mixed contents of the digester. This was done to obtain a sample of the mixed contents where tests could be run on it.

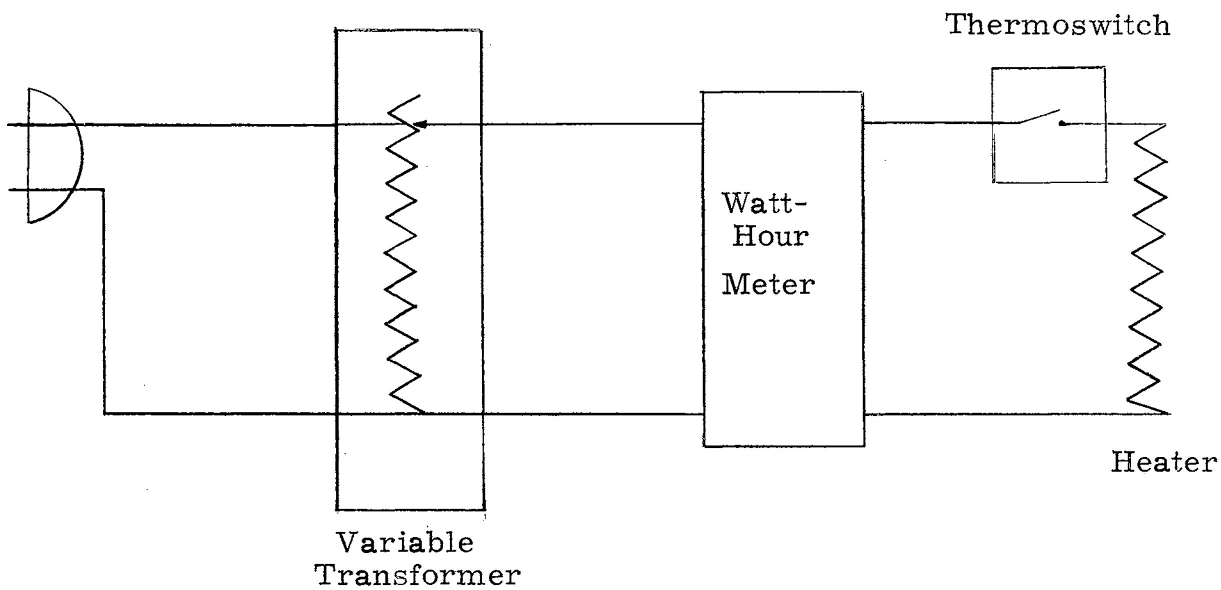

Figure 4

Electrical Wiring Diagram

To obtain the settled digested sludge, the mechanical mixing was stopped one hour before the sludge was drawn off. This allowed the sludge to settle to the bottom of the tank leaving the supernatant in the center portion of the tank and the gas lifted particles at the top of the tank. This was done to try and overcome the disadvantages, that in drawing off a "mixed liquor" the mixture leaving the digester is essentially the same as that left in the unit. Thus the discharge is in an actively digesting condition.and contains a significant fraction, $\frac{1}{t}$, of sludge of residence time of 1 day or less (t = detention time). The fraction of sludge of any age contained in the mixed drawoff is: [5]

$$X = \frac{1}{t}\left(\frac{t-1}{t}\right) n - 1$$

n = whole days

At periodic times the pH of the mixed sludge, supernatant liquor, and settled sludge was taken. The method of determining pH followed the method outlined in "Standard Methods." [6] Since the sludge used as seed had a low pH of around 5.3, the pH was watched closely at first to be sure the pH was increasing to an expected pH of 7.0.

Total and volatile solids determinations had to be made to obtain the composition of the raw sludge, mixed, and digested sludge. Standard Methods was followed as closely as possible, but due to a lack of equipment some deviations had to be made.

To make the solids determinations, 50 ml. of the sample was weighed in an evaporating dish, of known weight, and then placed in an oven for 1 hour at 103° C. The sample was then placed in a desiccator to cool and then weighed. From this the percent total solids was determined.

To determine the percent volatile solids the dish with the total

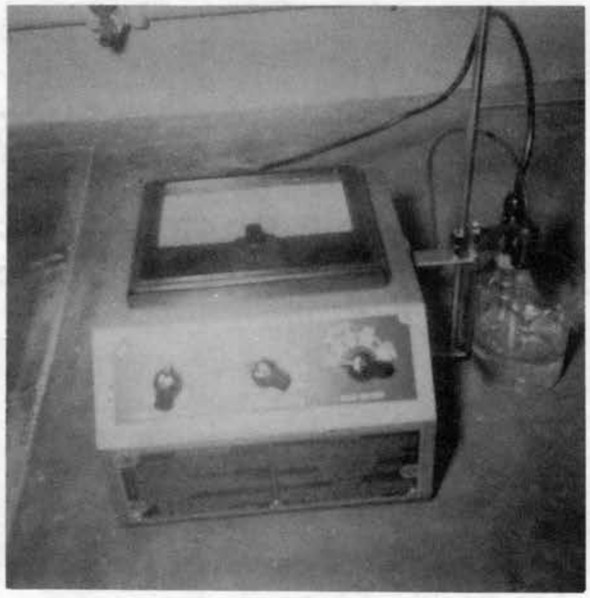

Fig. 5

Electronic pH Meter

solids was placed over a Fisher burner and heated to a cherry red color for 30 to 40 minutes. The sample was then cooled and weighed. The percent volatile solids was then determined from the difference between total and fixed solids. This method is somewhat different than the method recommended in Standard Methods, but it did give satisfactory results.

Determinations of volatile acids and the amount of gas production were not made due to the unavailability of the necessary equipment to run these tests.

After five weeks of continuous digester operation the first operational problem arose. Hair from the sludge had been collecting on the shaft of the electric mixer. Finally enough hair collected to freeze the shaft and almost burned the electric motor up. The effect of the damage was that the motor will now run for only a short period of time before overheating.

At this point, it was decided that enough data had been obtained to prove that satisfactory digestion had taken place. Also a long enough record of power consumed was available to determine a fair average of daily power consumption. It had also been determined that at the voltage the heating element was operating no caking occurred.

The only test left was to determine at what voltage caking would occur on the heating element. To determine this the variable transformer was set at a specified reading, and the voltage read at the heating element with a volt-meter. After the contents in the digester had been cooled to 80° F. the heating element and mixer were turned on. The heating element was left on until the contents in the digester reached 90° F. The heating element was then inspected for signs of caking.

The voltage was then increased and the same procedure was followed until caking occurred.

CHAPTER IV

RESULTS AND CONCLUSIONS

4-1 Significance of Results

The results from tests made during the operation of the laboratory digester shows that satisfactory digestion can be obtained in the laboratory using an electrical heating element and mechanical mixing. The author realizes that an actual digester will not necessarily operate in the same manner that a laboratory model will, but all indications point to the fact that a digester built for a community of 1,500 to 5,000 capita would obtain just as good digestion as the laboratory model.

In Chapter I, it was pointed out that the indices that may be used to measure digestion included:

1. The pH is between 6.8 to 7.4
2. Digested sludge has 10% dry solids of which 50% are volatile
3. The digested sludge is black, quickly drainable, and inoffensive in odor.

Comparing the results obtained from the laboratory digester with these indices will give an indication of what degree of digestion was obtained in the laboratory.

In comparing the pH values, it is found that the sludge started out with a pH of 5.3 which shows the sludge used as a seed was in very poor condition. As mentioned before, this was due to the Stillwater plant being in an overloaded condition. They were just recovering from the flood of the fall of 1959.

TABLE II

SLUDGE pH READINGS

DATE	SETTLED	MIXED	SUPERNATANT LIQUOR
Feb 8	5.3	5.6	
9		6.1	
15		6.5	
16	6.6		6.6
19	6.5	6.8	
22	6.8		6.7
26	6.5	6.5	
27		6.5	
29	6.7	6.2	
Mar 3		6.1	6.0
7	6.1		

Operation started February 1, 1960

TABLE III

SLUDGE COMPOSITION

DATE	FEED			MIXED		SETTLED	
	% Solids	% Volatile Solids	lbs./vol. solids/ ft^3/day	% Solids	% Volatile Solids	% Solids	% Volatile Solids
Feb. 18	5.1	51.5	0.046				
22						10.0	37.5
22	5.9	62.0	0.064				
26				5.7	32.5	5.9	44.0
26	5.7	58.0	0.060				
29				3.05	50.0	3.2	50.0
29	5.3	67.0	0.063				
Mar. 5				3.5	40.0	4.15	35.0
5	2.6	69.0	0.046				

Detention time 30 days

Digester started operating February 1, 1960

A very interesting observation here is that the pH went from this low 5.3 to 6.8 in a very short time. This gives an indication that high rate digestion took place. In the beginning of the project, high rate digestion was not planned. The digester was only fed once a day and with raw sludge direct from the plant. Whereas, high rate digestion calls for continuous feeding of a concentrated sludge. The one criteria of high rate digestion used was continuous mixing of the entire contents of the digester.

After reaching a pH of 6.8 the pH dropped a little. This drop is unaccounted for. One possible answer is that some stronger wastes were in the sludge causing the trouble. When using a raw sludge from a city sewage treatment plant, there is no control over the composition of the raw sludge.

Though it was desired to reach and maintain a pH of 7.0 - 7.2, a pH of 6.0 - 6.8 still gives indication of acceptable digestion. Many plants operate at a pH even lower than this.

In looking at the solids content it is found that the total solids content should be consolidated from 2 - 5% in raw sludge to 5 - 10% in the digested sludge. Also volatile matter should be reduced from 75% of dry solids in raw sludge to 50% of dry solids in the digested sludge.

In the laboratory digester operation, it was found that over a five week period the average total solids content was consolidated from 4.92% in the raw sludge to 5.8% in the digested sludge. The volatile matter was reduced from 61.5% of dry solids in raw sludge to 41.6% of dry solids in the digested sludge.

The sludge composition over the five week period is given in Table III and the average values of laboratory digester operations is

TABLE IV

LABORATORY DIGESTER OPERATION

Average Results

February 1, 1960 - March 7, 1960

RAW SLUDGE	
Total solids %	4.92
Volatile solids %	61.5
pH	5.5
LOADING	
Total solids lb./day/cu.ft.	0.0906
Volatile solids lb./day/cu.ft.	0.0558
Displacement days	30
OPERATING CONDITIONS	
Digester temperature	90°F.
pH	6.7
MIXED SLUDGE	
Total solids %	4.1
Volatile solids %	40.8
SETTLED DIGESTED SOLIDS	
Total solids %	5.8
Volatile solids %	41.6

given in Table IV.

The digested sludge had a dark black color. The change in color was very evident in observing the digester. When the seed sludge was placed in the digester it was gray in color. As time elapsed the contents of the digester became darker and darker. It was evident enough that people not even related to the project noticed the change in color.

The odor of the digester made a noticeable change also. When the digester was first put in operation, it had a very strong odor. As better digestion started taking place the odor disappeared.

The digested sludge easily met the indices of color and odor.

To make use of an electrical heating element in a sludge digester, there must be no caking on the heating element. Electrical heating can be expensive even at best operating conditions, but with caking of sludge on the heating element the transfer of heat from element to digester contents will be greatly lowered. This would make the cost of operation much greater.

The heating element was checked throughout the operation of the digester and it showed no signs of caking. The element was operated on line voltage which varies between 113 - 117 volts. After completion of digester operation, tests were made to see at what voltage caking would occur. This voltage turned out to be 120 volts. This is not conclusive for all cases. Conditions could change this value and it should be determined for each case before being used.

4-2 Cost of Operation

The cost of operation is one of the most important factors in determining if an electrical heating element should be used in small capacity digesters.

The design of the heating equipment to maintain a desired temperature in the digestion tank requires a study of the heat balance in the tank. Two sources of heat dissipation are (a) the heat required to raise the temperature of material added (b) radiation of heat through the bottom, walls, and top. The heat lost from the digestion tank can be expressed as

$$Q = \frac{k}{x} A (T_2 - T_1)$$

where Q = heat loss in B. T. U. 's per hour

k = thermal conductivity of the material in B. T. U. 's per hour per square foot per degree Fahrenheit per inch thickness

x = thickness of material in inches

A = Area in square feet

T_1 and T_2 = boundary temperatures in degrees Fahrenheit.

In actual practice most structures are considered to consist of compound wall members. For compound walls, such as concrete with insulation, the heat-flow equation takes the form:

$$Q = U A (T_2 - T_1)$$

in which

$$U = \frac{1}{\frac{1}{K_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \ldots + \frac{1}{K_o}}$$

where $x_1, x_2 \ldots x_m$ = thickness of materials in inches

$k_1, k_2 \ldots k_m$ = thermal conductivity of materials

K_i = surface conductance at the air-surface area inside the tank in B. T. U. 's per hour per square foot per degree

Fahrenheit

K_o = surface conductance at the surface-air or surface-ground area outside the tank in B. T. U.'s per hour per square foot per degree Fahrenheit.

The factor $\frac{1}{K_i}$ becomes zero if liquid is touching the surface of the wall members.

Heat transfer data for materials involved in sewage plant construction are given in Table V (7) and Table VI (8).

In addition to the heat losses from the digester, heat is also required to raise the raw sludge temperature to digestion temperature. The formula for obtaining this heat requirement is

$$Q = W C (T_2 - T_1)$$

where Q = the amount of heat required to raise the temperature of the sludge from the temperature of the raw sludge to the temperature of digestion in B. T. U.'s per day

W = pounds of raw sludge added to the digester per day

C = mean specific heat of raw sludge, usually taken as 1.0

T_1 = temperature of raw sludge in degrees Fahrenheit

T_2 = temperature of digestion in degrees Fahrenheit.

With the use of these equations the theoretical power consumption may be determined for the digester. Which in turn may be compared with the power consumption measured during the project by the watt-hour meter.

The laboratory digester was a glass cylinder with a diameter of 10.45 inches and a height of 11.30 inches. The walls of the cylinder were 0.15 inches thick with the bottom being 0.3 inches thick. The

TABLE V

HEAT TRANSFER COEFFICIENTS - k
Btu/hr/sq. ft./°F/in

Kind of Material	Coefficients
Asbestos	1.48
Brick masonry	5.0
Cement mortar	12.0
Cinder concrete	5.4
Concrete (typical)	12.0
Concrete blocks	0.8 to 1.0
Glass wool	0.27
Mineral wool	0.27 to 0.30
Corkboard	0.25 to 0.30
Fiber (flexible blanket)	0.27 to 0.29
Roofing	
Asphalt composition	6.7
Built up bitumen and gravel surface	1.5 to 3.0
Plaster board, gypsum fiber concrete, 3 ply	0.5 to 0.6
Air space, over $\frac{3}{4}$ in. thick	1.1
Wood	0.7 to 1.0
Soils	4 to 14

TABLE VI

HEAT TRANSFER COEFFICIENTS - K
Btu/hr/sq. ft. / °F

Material	Coefficients
Concrete to or from still air	1.65
Concrete to outside moving air (15 mph)	6.00
Brickwork to or from still air	1.65
Brickwork to outside moving air (15 mph)	6.00
Steel to or from still air	1.00
Steel to outside moving air (15 mph)	3.00
Composition roofing to outside moving air	10.50
Concrete to dry earth	1.00
Concrete to wet earth	2.00

top was made out of 0.25 inch plastic. The digester was sitting on a 0.5 inch board which was on a 3.0 inch concrete bench.

Pertinent areas of the laboratory digester are:

Surface area of walls = A_W = 2.575 sq. ft.

Bottom area = A_B = 0.595 sq. ft.

Roof area = A_R = 0.595 sq. ft.

For theoretical heat lost through the digester walls

$$Q = \frac{1}{\frac{x_1}{k_1} + \frac{1}{K_o}} A_w \, (T_2 - T_1)$$

where x_1 = 0.15 inches (wall thickness)

k_1 = 6.00 B.t.u./hr./sq.ft./°F./inch

K_o = 1.65 B.t.u./hr./sq.ft./°F.

A_w = 2.575 sq.ft.

T_2 = 90 °F.

T_1 = 70 °F.

$$Q = \frac{1}{\frac{0.15}{6.00} + \frac{1}{1.65}} 2.575 \, (90 - 70)$$

$$Q = 80.0 \text{ B.t.u. per hour}$$

The theoretical heat lost through the roof would be

$$Q = \frac{1}{\frac{1}{K_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{K_o}} A_R \, (T_2 - T_1)$$

where K_i = 1.6 B.t.u./hr./sq.ft./°F.

x_1 = 1.1 inches (air space)

k_1 = 1.1 B.t.u./hr./sq.ft./°F./inch

x_2 = 0.25 inches (roof thickness)

k_2 = 6.00 B.t.u./hr./sq.ft./ °F./inch

K_o = 1.65 B.t.u./hr./sq.ft./ °F.

A_R = 0.595 sq.ft.

T_2 = 90 °F.

T_1 = 70 °F.

$$Q = \frac{1}{\frac{1}{1.6} + \frac{1.1}{1.1} + \frac{0.25}{6.00} + \frac{1}{1.65}} \; 0.595 \; (90 - 70)$$

$$Q = 5.23 \text{ B.t.u. per hour}$$

The theoretical heat lost through the bottom would be

$$Q = \frac{1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{K_o}} \; A_B \; (T_2 - T_1)$$

where x_1 = 0.3 inches (bottom thickness)

k_1 = 6.0 B.t.u./hr./sq.ft./ °F./inch

x_2 = 0.5 inches (board thickness)

k_2 = 1.0 B.t.u./hr./sq.ft./ °F./inch

x_3 = 3.0 inches (concrete)

k_3 = 12.0 B.t.u./hr./sq.ft./ °F./inch

K_o = 1.65 B.t.u./hr./sq.ft./ °F.

A_B = 0.595 sq.ft.

T_2 = 90 °F.

T_1 = 70 °F.

$$Q = \frac{1}{\frac{0.3}{6.0} + \frac{0.5}{1.0} + \frac{3.0}{12.0} + \frac{1}{1.65}} \; 0.595 \; (90 - 70)$$

$$Q = 8.47 \text{ B.t.u. per hour}$$

The total theoretical heat lost from the digester would then be

$$Q_{TOTAL} = 80.0 + 5.2 + 8.4 = 93.6 \text{ B.t.u. per hour}$$

The heat required to raise the sludge from the temperature of the raw sludge to the temperature of digestion could be found by using

$$Q = W\,C\,(T_2 - T_1)$$

where $W = 0.935$ pounds per day

$C = 1.0$

$T_2 = 90\,^\circ F.$

$T_1 = 41\,^\circ F.$

$$Q = 0.935 \times 1.0\,(90 - 41)$$

$$Q = 45.75 \text{ B.t.u. per day}$$

The total theoretical power consumption for one day would be

$93.6 \times 24 \text{ hr.} + 45.7 = 2291$ B.t.u. per day

or 0.671 kilowatt-hours per day

The actual power consumption measured by the kilowatt-hour meter was 0.531 kilowatt-hours per day. This was the average over a nineteen day period. The actual power used was 20.9% less than the theoretical power consumption. It is hard to say whether or not this has any real significance. It is practically impossible to predict how an actual full size digester will act in comparison with a laboratory model. Therefore, the cost of operation of an electrical heating element in an example digester will be figured by theoretical power consumption. Comparison between the measured and theoretical power consumption shows the theoretical to be greater. So any cost that is figured will be greater than the actual cost.

The example digester is shown in Figure 6. The digester is designed for a population of 2, 000 on the basis of 3.01 cu.ft. per capita. The actual volume of the tank is 6, 019 cubic feet. It is constructed of reinforced concrete with at least a 10 foot fill of soil on the sides.

Due to the variation in outside temperature, a tabulation of heat lost values will be made for the varying outside temperature.

Pertinent areas of the example digester are:

Surface area of walls $= A_w = 934$ sq. ft.

Bottom area $= A_B = 452$ sq. ft.

Roof area $= A_R = 380$ sq. ft.

For the theoretical heat lost through the walls

$$Q = \frac{1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{K_o}} A_w (T_2 - T_1)$$

where x_1 = 12 inches (thickness of walls)

k_1 = 12.0 B.t.u./hr./sq.ft./ °F./inch

x_2 = 120 inches (inches of earth)

k_2 = 10.0 B.t.u./hr./sq.ft./ °F./inch

K_o = 1.0 B.t.u./hr./sq.ft./ °F.

T_2 = 90 °F. (temperature of digestion)

T_1 = varies (outside conditions)

For the theoretical heat lost through the bottom of the digester

$$Q = \frac{1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{K_o}} A_B (T_2 - T_1)$$

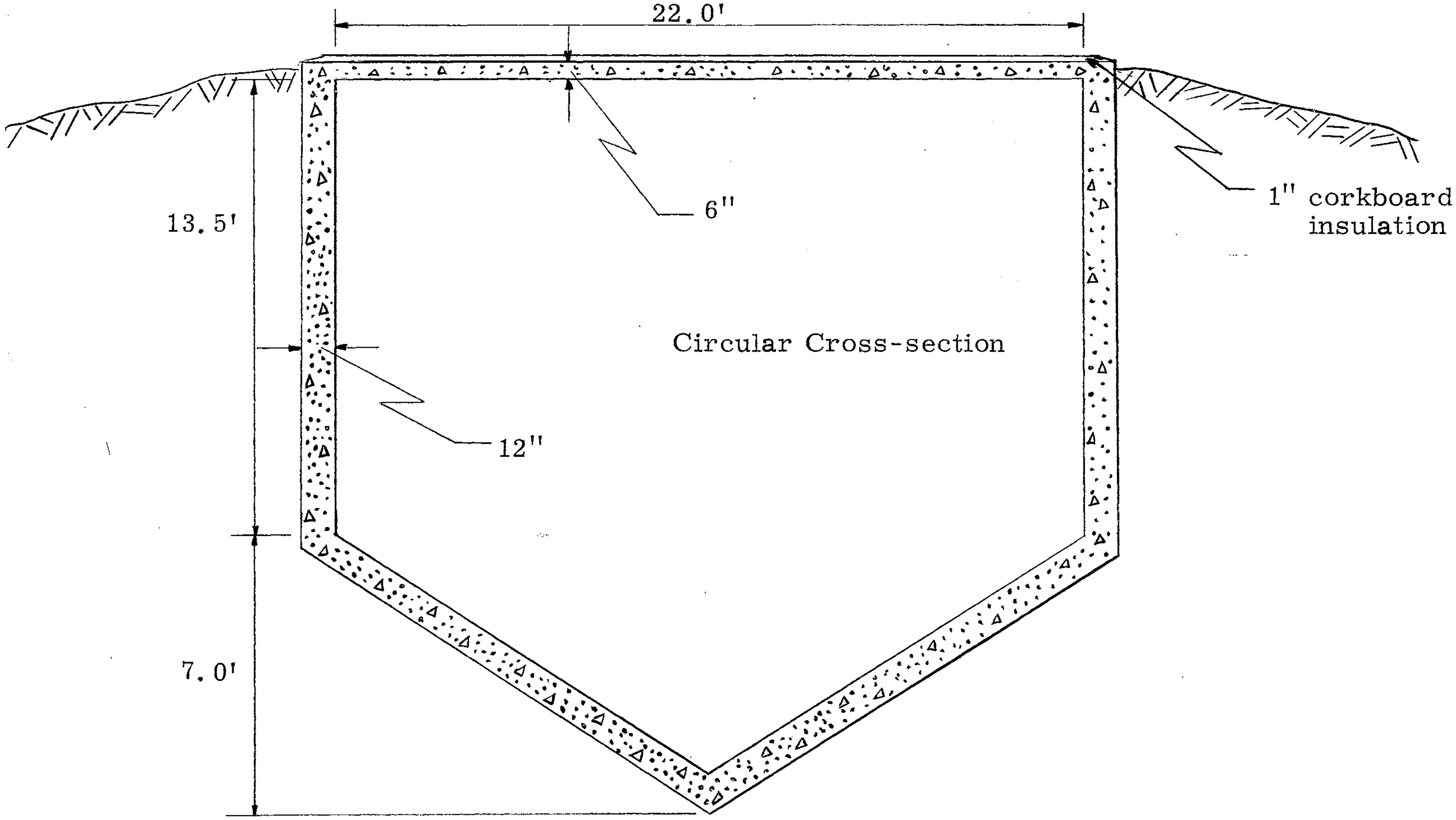

Figure 6

Example Sludge Digester

where x_1 = 12 inches (bottom thickness)

k_1 = 12.0 B.t.u./hr./sq.ft./°F./inch

x_2 = 120 inches (wet earth)

k_2 = 14.0 B.t.u./hr./sq.ft./°F./inch

K_o = 2.0 B.t.u./hr./sq.ft./°F.

T_2 = 90 °F. (digestion temperature)

T_1 = varies (outside conditions)

For the theoretical heat lost through the roof of the digester

$$Q = \frac{1}{\frac{1}{K_i} + \frac{1}{K_a} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{K_o}} A_R (T_2 - T_1)$$

where K_i = 1.6 B.t.u./hr./sq.ft./ °F.

K_a = 1.1 B.t.u./hr./sq.ft./°F. (For air space)

x_1 = 6.0 inches (roof thickness)

k_1 = 12.0 B.t.u./hr./sq.ft./°F./inch

x_2 = 1.0 inches (corkboard roof insulation)

k_2 = 0.25 B.t.u./hr./sq.ft./°F./inch

K_o = 6.00 B.t.u./hr./sq.ft./°F.

T_2 = 90°F. (digestion temperature)

T_1 = varies (outside conditions)

The values of heat lost for different outside temperatures are tabulated in Table VII.

For determing the heat requirements for raising the temperature of the sludge from the raw sludge temperature to digestion temperature a loading of 0.0906 lbs./day/cu.ft. will be used. This is the average loading of the laboratory digester. This is also an

TABLE VII

TABULATION OF HEAT LOST

Digester Temperature = 90° F.

Outside Temp. ° F.	Q - Btu per hour			Total Q
	Walls	Bottom	Roof	
0	6000	4060	5540	15600
10	5350	3620	4930	13900
20	4670	3170	4310	12150
30	4000	2710	3700	10410
40	3340	2260	3080	8680
50	2680	1810	2470	6960
60	2020	1355	1850	6225
70	1350	905	1230	3285
80	670	452	615	1737

average value for the Stillwater treatment plant. A dry solids loading of 0.0906 lbs./day/cu.ft. and a total solids content of 4.92% will give a loading of 11,100 lbs./day for the example digester. The heat required to raise the temperature of the raw sludge would be

$$Q = W C (T_2 - T_1)$$

where W = 11,100 lbs. per day

C = 1.0

T_2 = 90 °F. (digestion temperature)

T_1 = temperature of raw sludge

The temperature of the raw sludge will vary with the time of year so a tabulation will be made for different temperatures of raw sludge.

TABLE VIII

TABULATION OF HEAT REQUIRED TO RAISE THE TEMPERATURE OF RAW SLUDGE

RAW SLUDGE TEMP. °F.	Q - B.t.u. per day
20	777,000
30	666,000
40	555,000
50	444,000
60	333,000
70	222,000
80	111,000

For average conditions the outside temperature may be considered to be 40 °F. and the temperature of the raw sludge as 50 °F. This would give a total daily power consumption of 8680 x 24 + 444,000 = 652,000 B.t.u. per day or 191 kilowatt-hours per day. At a cost of

\$0.01 per kilowatt-hour, the cost of operating the digester with electric heating would be \$1.91 per day.

Under winter conditions the outside temperature may be considered to be 0 °F. and the temperature of the raw sludge as low as 40 °F. This would give a total daily power consumption of 15,600 x 24 + 555,000 = 929,000 B.t.u. per day or 271 kilowatt-hours per day. Again at a cost of \$0.01 per kilowatt-hour the cost of operation would be \$2.71 per day.

Under average conditions the cost of operating a sludge digester for a population of 2,000 with electric heating would be approximately \$2.00 per day, while under the coldest conditions the cost of operation would be \$2.70 per day.

An oil furnace operating at 75 % efficiency with an oil having 137,000 B.t.u. per gallon and a cost of \$0.15 per gallon would cost approximately \$1.00 per day for average conditions. This is one-half as much as an electrical heating element. The author admits that oil heating is cheaper than electrical heating, but oil heating has not been adapted for small installations due to the equipment required for oil heating. This fact must be kept in mind when considering electrical heating for small communities.

Electrical heating can be adapted very easily for communities of populations between 1,500 and 5,000. At the present, communities of this size are having to use unheated digesters, which calls for twice the volume of a heated digester. For only \$2.00 a day or \$730 a year operating expenses the communities could use an electrical heating element for sludge digestion.

Where unheated digesters are in operation, the communities would be able to double their capacity by installing an electrical heating element. The cost of this installation would depend upon what type of mixing was used, but the heating elements could be purchased for approximately $150. This cost would be for a digester the size of the example digester. Unheated digesters could be converted to heated digesters with electrical heating at very little cost.

In construction of new treatment plants the cost of construction of the digester should be considered. For a heated digester for a community of 2,000, the cost of construction would be approximately $6,000. This is figuring a cost of $100 per cubic yard of concrete for construction. The cost of an unheated digester for the same size community would cost approximately $9,500. The cost of the heating equipment would have to be added to the construction cost, but even so, there would be a savings of approximately $3,000 in the construction of a digester and the community would have heated digestion, at an operating expense of approximately $700 PER YEAR.

High-rate digestion may be the answer to the cost of electrical heating. As it was pointed out in Chapter I, high-rate digestion may cut the detention period from 30 days to 11 or 14 days. This would mean the engineer could design the digester on the basis of 1.5 cubic feet per capita instead of 3.0 cubic feet per capita. Making at least a one-half reduction in volume of the digester. A part of high rate digestion is "Sludge Thickening." In this process the concentration of solids in sludge is increased. This will have as a direct result, a daily decrease in the total pounds of sludge added to the digester. This will require a lesser amount of heat to raise the daily loading of raw sludge to digestion temperature. By considering these reductions the heat required for digestion could be reduced as much as one-half or more. Instead of an average cost of $2.00 per day, the cost would only be $1.00 per day or less. This would definitely make electrical sludge heating a worth while process.

4-3 Conclusions

Utilizing an electric heating element for operation of a waste sludge digester should be given more consideration by designing engineers. It definitely has a place in the 1,500 to 5,000 population communities, which includes our national parks.

It has been shown that:

(a) good digestion can be accomplished by using an electrical heating element as the source of heat

(b) no caking occuring on the element when operated below 120 volts

(c) the cost of electric heating is in the range where it could be economically feasible to use.

One important observation that should be mentioned here is the excellent temperature control that was reached using the electric heating element and continuous mixing. The temperature never varied more than 2 F. during the operation of the digester. With this control the operators would have no worry of the bacterial activity being upset by a change in temperature.

4-4 Recommendations

During the operation of the laboratory sludge digester, certain problems and possible solutions of these problems were encountered. Further research on the problems and possible future equipment developments could lead to better operation of an electric heating element in a digester.

One of the main problems that was mentioned earlier was the collection of hair on the shaft of the mixer. With mechanical mixing the hair would be a continuous maintenance problem. One answer to this could be the recirculation of the gas produced during digestion to provide mixing. One recommendation is that a study be made to determine if sufficient gas is produced in small community digesters to provide complete mixing of digester contents.

A possible method of decreasing the cost of digestion discovered during the operation of the laboratory digester was that of high-rate digestion. Problems for future work would be to determine how short a detention period can be obtained and how great a concentrated loading can be applied. An important point to consider is, would the concentrated sludge tend to cause caking on the heating element.

After these tests are made on the small scale digester, tests should be made on a larger scale. It is known that large scale digesters will not always act the same as their small scale counterparts. This would have to be done before it could absolutely be said that electric heating was the answer to small communities problems of sludge digestion.

A future possibility for utilizing this operation is the development of a combination unit, consisting of an electrical heating element and a means of continuous mixing.

SELECTED BIBLIOGRAPHY

1. Smith, G. S. and Morris, J. A. Jr., "Use of the Heat Pump For Digester Heating," Sewage and Industrial Wastes, 1953, Vol. 25, No. 12.

2. Torpey, W. N., "High Rate Digestion of Concentrated Primary and Activated Sludge," Sewage and Industrial Wastes, 1954, Vol. 26.

3. Morgan, P. F., "Studies of Accelerated Digestion of Sewage Sludge," Sewage and Industrial Wastes, 1954, Vol. 26.

4. Sawyer, C. N. and Roy, H. K., "A Laboratory Evaluation of High Rate Sludge Digestion," Sewage and Industrial Wastes, 1955, Vol. 27, No. 12.

5. Sawyer, C. N., "Evaluation of High-Rate Digestion," Water and Sewage Works, 1958, Vol. 105, No. 6.

6. "Standard Methods for the Examination of Water and Sewage," 10th. Edition, American Public Health Association, New York, N. Y. (1955).

7. "Sewage Treatment Plant Design," ASCE - Manuals of Engineering Practice - No. 36 (1959).

8. Wittwer, N. C., "Theory and Practice of Sewage Sludge Digestion Tank Heating," Water Works and Sewerage (1943) Vol. 90, No. 6.

9. Greene, R. A., "Sludge Heating Methods," Sewage and Industrial Wastes, 1949, Vol. 21, No. 6.

10. Schreiber, H. A., "Experimental Installations to Increase Digester Capacity," Civil Engineering 1960, Vol. 30, No. 2.

11. Babbitt, H. E., Sewerage and Sewage Treatment, New York, John Wiley and Sons, 1953.

VITA

Donny Frank Kincannon

Candidate for the Degree of

Master of Science

Thesis: UTILIZING ELECTRIC HEAT FOR THE OPERATION OF A WASTE SLUDGE DIGESTER

Major Field: Sanitary Engineering

Biographical:

Personal Data: Born January 17, 1933 in Olustee, Oklahoma.

Education: Attended grade school in Amarillo, Texas, and high school in Altus, Oklahoma; completed requirements for the Bachelor of Science degree from Oklahoma State University, in January 1959; completed requirements for the Master of Science degree in May 1960.

Professional Experience: Served in the U.S. Army from April 1953 to January 1956. Student Civil Engineer, Corps of Engineers. Hydraulic Engineer, Bureau of Reclamation. Graduate Assistant, Oklahoma State University, Stillwater, Oklahoma. Now an Associate member of A.S.C.E. and an E.I.T. Member of O.S.P.E. and N.S.P.E.