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Performance Evaluation of an Anaerobic Stabilization Pond System for Meat Processing Wastes

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PERFORMANCE EVALUATION OF AN ANAEROBIC STABILIZATION POND SYSTEM FOR MEAT PROCESSING WASTES

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

The meat packing industry is decentralizing its processing operations. Many of the large metropolitan packinghouses are being abandoned because they cannot readily assimilate the newer, more efficient processing methods due to the high cost of providing such improvements. These plants are being replaced by small, rural installations which are relatively inexpensive to modify. Shorter livestock haul distances are an additional economic advantage to the small plants.

The advent of the stabilization pond into the meat processing waste treatment field has been due, in part, to the desire for low-cost waste treatment. Also, the new, small abattoirs and packinghouses are locating in rural communities where sufficient land is available for this type of waste treatment. The use of anaerobic stabilization pond facilities for treating these high strength wastes is rapidly increasing.

Furthermore, research on anaerobic fermentation, coupled with recent data regarding the theory, design and performance of the anaerobic contact process have provided the impetus to combine the advantages of anaerobic treatment with those of the stabilization pond.

OBJECTIVES OF THE RESEARCH

Although the literature contains numerous references to anaerobic waste treatment, it is practically devoid of data specifically concerned with anaerobic stabilization ponds for treating meat processing wastes. The publications that do pertain to this subject include little information regarding the effect of extended periods of low air temperatures upon the treatment process.

The objectives of this research were threefold.

a.) to determine the unit pollutional contribution for a small, modern abattoir in terms of the number of animals processed.

b.) to evaluate the design and performance of an anaerobic stabilization pond system ostensibly adapted to the severe climatic conditions of the north central United States.

c.) on the basis of this evaluation, to suggest certain improvements in the design and operation of these systems.

EXTENT OF THE RESEARCH

This research was conducted on the anaerobic stabilization pond system treating the wastewater from the M.I.D. Packing Co., located at Luverne, Minnesota. Because one of the primary objectives of the research was to ascertain the performance of the treatment system during winter operation, the testing program was conducted in late February and early March. The volume of the wastewater being treated was determined from flow gaging data. Samples of the raw waste and the effluents from the anaerobic units were collected for 12 consecutive days. Recording thermometers were used to obtain the temperatures of the influent waste, treated effluent and ambient air during the test run. Observations of the physical appearance of the treatment installation were also noted. In addition, various data regarding the meat processing plant production, water consumption and reuse were procured for each day during the test period. Laboratory analyses of the wastewater samples included determinations of the biochemical oxygen demand (BOD), chemical oxygen demand (COD), solids, pH, ammonia, phosphorous, chlorides and organic nitrogen. The evaluation of the treatment system was accomplished on the basis of the data so collected.

REVIEW OF LITERATURE

INTRODUCTION

The physical concept of an aerobic stabilization or oxidation pond seems well-established in the literature. According to McKinney (1-239), however, very few engineers clearly understand the theory of the treatment mechanism from which the performance of an installation can be predicted. The situation regarding anaerobic stabilization ponds is somewhat different. A considerable amount of information has been published regarding the mechanics and biochemistry of the anaerobic process. Most of these data were obtained from studies of sludge digestion and the performance of anaerobic contact units. The basic theory upon which anaerobic stabilization pond design is based, relies heavily upon these findings.

The term "anaerobic stabilization pond," currently encompasses a wide range of physical entities. Oswald (2) has stated that most aerobic ponds are actually facultative, i.e., aerobic on top and anaerobic on the bottom. Any aerobic stabilization pond which becomes devoid of dissolved oxygen for prolonged periods due to excessive organic loadings could be labelled an "anaerobic pond." Undoubtedly, many of the early anaerobic ponds evolved from the aerobic lagoon in this manner. Porges (3) defines a waste stabilization pond as, "a basin, natural or artificial, designed or used to treat organic wastes by natural biological, biochemical and physical processes, commonly referred to as self-purification." If the predominant biological and biochemical processes involved in this self-purification phenomenon are carried on by anaerobic organisms, the above definition would represent a concise description of an anaerobic stabilization pond. Throughout this thesis, however, the term, "anaerobic stabilization pond," "anerobic pond," or "anaerobic lagoon," is intended to represent only those basins which are specifically designed to encourage the growth of anaerobic organisms by creating an environment devoid of dissolved oxygen in which they will thrive and thus stabilize the major portion of the applied organic matter.

EVOLUTION OF THE ANAEROBIC POND AS A METHOD OF TREATING MEAT PROCESSING WASTES

The first wastewater treatment facilities to be legitimately classified as stabilization ponds were placed into service during the early 1900's in California, Texas and North Dakota (4). Similar installations, but referred to as "fish ponds" were constructed in Europe and Russia during the 1930's (5). Most of these early installations were products of happenstance (4). The first aerobic lagoon designed by a professional engineer for the specific purpose of providing complete treatment of raw sewage on a permanent basis commenced operation in 1948 in Maddock, North Dakota (4). As previously stated, there are indications that most of these units experienced occasional anaerobiasis during the course of their operation (5,6).

Parker, et al. (7) were among the first to advocate the advantages of a pond system designed specifically to operate as an anaerobic digestion unit. These very significant investigations, conducted in the early 1940's, disclosed the following conclusion concerning anaerobic ponds. "In addition to the examination of the performance of such lagoons, it has been found in the course of the present studies that substantial purification of raw sewage can be obtained in lagoons where conditions are deliberately kept anaerobic." The above facilities, located in Australia, treated raw municipal wastewater exclusively.

In discussing the use of the stabilization pond method for treating industrial wastes, Porges (3) stated that the first installations of this nature could be traced back to the early 1900's. Towne and Horning (6) pointed out, however, that waste stabilization was not the primary objective of these units and that they were usually constructed for use as seepage pits, settling basins or holding ponds to detain the waste until greater dilution was available in the receiving streams. Steffen (8) affirmed the statement postulated above, namely that the early industrial waste lagoons, like those used to treat municipal wastes, "were laid out with very few, if any, design considerations."

Almost every type of industry has used the stabilization pond method in one form or another. The mining, steel, petroleum, pulp and paper, textile and food and milk processing industries are among this group (6,9,10,11). By 1962 there were 827 individual establishments, representing 31 industrial groups using this treatment method. Of this total, 197 ponds were classified as anaerobic, of which 29 were used for treating meat and poultry wastes (3).

In his comments regarding the use of anaerobic lagoons, Coerver (12) has stated that this method has been employed to treat abattoir and packinghouse wastes in Louisiana since 1949. He also reported that the first of these units were not the result of deliberate planning. Subsequent investigations, disclosing favorable treatment results, however, supplied the impetus for the construction of additional anaerobic installations increasing the total number to at least 12 by 1964.

The first anaerobic lagoon installation, which was designed upon the basis of scientific investigation to provide complete treatment for meat processing wastes, was placed in operation in 1955. This pond system (13), located in Moultrie, Georgia, was designed by F. W. Sollo, then employed by Swift and Company. It should be noted that two other anaerobic systems, based on rational designs for treating municipal wastes, were constructed in the late 1950's in Washington (6,14).

THEORY AND MECHANISM OF THE ANAEROBIC POND SYSTEM OPERATION

Prior to a discussion of the theory and mechanism of the anaerobic pond system operation, the character of the waste to be treated should be defined in order to limit the scope to ponds used for treating meat packing wastes only. There are a few industrial wastes that cannot be treated successfully by any method involving biological degradation. In fact, even when biological treatment is feasible, the character of the waste exerts a significant influence on the removal efficiencies and should, therefore, be reviewed in order to properly evaluate the performance of any proposed treatment process.

Character of the Waste

According to Babbitt and Baumann (15-654), "The slaughter of animals and the preparation and packing of meat products result in the production of wastes with high polluting characteristics, from 10 to 15 times stronger than normal domestic sewage, as measured by the total solids and the BOD." In addition, there is a considerable variation in the strength of the wastewater. This variance not only occurs throughout each day, but also on a weekly and seasonal basis, depending upon the nature of the plant (15-654). Rudolfs (11-87) states that these wastes are chemically similar to domestic sewage. The waste is substantially free of pathogenic organisms, readily amenable to biochemical treatment and extremely high in pollutional characteristics (15-654)(16). The principal deleterious effects manifest themselves in oxygen depletion, sludge deposits, discoloration, scum formation, odors and general nuisance conditions (11-92)(16).

The constituents that contribute to the composite waste include manure, blood, grease, fleshings and dirt (11-87)(15-654).

There is relatively little published data regarding the strength and quantity of these wastes. Table 1 shows the approximate flows, analyses and strengths of waste for 3 types of establishments.

TABLE 1. (16)
Approximate Range of Flows, Analyses, and Waste Loadings for Stockyards, Slaughterhouses, and Packinghouses.

Operation	Unit	Waste flow gallons per unit	Typical analysis mg/l BOD	Typical analysis mg/l Suspended Solids	Waste loading lbs. per unit BOD	Waste loading lbs. per unit Suspended Solids
Stockyard	Acre	23,070-36,600	64-100	175	13.4	36
Slaughter-house	1,000 lbs. live wt.	435-1,100	650-2,200	930-12,200	8.4-20.0	3.5-11.0
Packing-house	1,000 lbs. live wt.	750-4,350	100-3,000	233-720	5.2-23.5	2.9-22.1

It should be noted that slaughterhouses are establishments primarily involved in the killing and dressing of meat whereas packinghouses are equipped to process the meat to a much greater extent (16).

The data included in Table 2 represent the averages for the waste produced in 16 and 38 packinghouses respectively. These plants processed hogs, cattle or both.

TABLE 2. (16)
Average Unit Packinghouse Losses and Analyses of Combined Packinghouse Wastes

Measurement	BOD	Suspended Solids		Nitrogen		Grease	No. of Plants Surveyed
		Total	Volatile	Organic	Ammonia		
Conc. in mg/l	909	645	582	113	24	-	38
Lbs./1000 lbs. live wt.	14.6	12.0			1.7	1.63	16

Anaerobic Digestion

Because the underlying treatment mechanism of the anaerobic stabilization pond system is based on the theory of anaerobic digestion, it would be very difficult to formulate a reliable diagnosis of its performance without having a basic knowledge of this theory.

Buswell (17) in his writings concerning the fundamentals of anaerobic treatment stated that, "Sewage purification consists essentially of the removal of unoxidized carbon-hydrogen compounds. When reduced to these simple terms, all stabilization processes can be classified under two simple types of reactions, aerobic and anaerobic."

Anaerobic digestion occurs in 2 stages or phases: liquefaction (acid phase) and gasification (methane phase)(18). McCarty (19) succinctly describes the microbiology and biochemistry of these two stages.

In the first stage, there is no methane production and hence no waste stabilization. In this stage, the complex organics are changed in form by a group of facultative and anaerobic bacteria commonly termed the 'acid formers.' Complex materials such as fats, proteins and carbohydrates are hydrolized, fermented and biologically converted to simple organic materials. For the most part, the end products of the first stage conversion are organic fatty acids. Acid forming bacteria bring about these initial conversions to obtain the small amounts of energy released for growth and a small portion of the organic waste is converted to cells. Although no waste stabilization occurs during the first stage of treatment, it is required to place the organic matter in a form suitable for the second stage of treatment.

It is in the second stage of methane fermentation that real waste stabilization occurs. During this stage, the organic acids are converted by a special group of bacteria termed the 'methane formers' into the gaseous end products, carbon dioxide and methane. The methane forming bacteria are strictly anaerobic and even small quantities of oxygen are harmful to them. There are several different groups of methane formers and each group is characterized by its ability to ferment a relatively limited number of organic compounds. Thus, in the complete methane fermentation of complex materials, several different methane bacteria are required. The methane formers which use materials such as formic acid and methanol grow very rapidly and can thrive at sludge retention times of less than 2 days. However, the most important methane formers, which live on acetic and propionic acids, grow quite slowly and sludge retention times of 4 days or longer are required for their growth. These bacteria carry out the major portion of waste stabilization. Their slow growth and rate of acid utilization normally represents the limiting step around which the anaerobic treatment process must be designed.

McKinney (1-250) relates that because of the sensitivity of the methane bacteria to pH, the determination of volatile acids is considered as a significant test in ascertaining digester performance. He also states that a rise in volatile acids, which are not in themselves toxic to the methane formers, to above 2,000 mg/l will normally depress the pH to a level where operational difficulties should be anticipated.

The advantages of anaerobic treatment may be summarized as follows (19).

1. A high degree of waste stabilization is possible. From 80 to 90 per cent of the degradable organics in the waste can be stabilized through conversion to methane gas. Aerobic systems stabilize a much lower portion; ordinarily around 50 per cent.

2. Excess sludge is substantially reduced since only a small portion of the waste is converted to cells.

3. Less nutrients such as nitrogen and phosphorous are required. This is of significance in treating industrial wastes which lack these elements.

4. The treatment rate is not dependent upon oxygen transfer since anaerobic organisms do not require free oxygen.

Anaerobic Contact Process

A brief review of the anaerobic contact process with respect to its use in treating meat packing wastes should provide a clearer understanding of the operation and performance of the anaerobic pond system because the two methods are quite similar. The greater volume of published data regarding the contact process may also provide a better insight into the operating mechanisms of the pond system by extrapolation.

In the anaerobic contact process developed to its present form by G. J. Schroepfer and others, the treatment actions are separated into a contact phase and a separation phase with the operation and performance being similar to the aerobic activated sludge treatment method (20). The anaerobic bacteria are retained with the system and not lost with the effluent (19). A schematic flow diagram of the process is shown in Figure 1.

A general description of the process (21) indicates that initially, the flow enters a tank in which the raw wastes are brought into contact with biologically active sludge under anaerobic conditions. It is in this digester or "contact" tank that coagulation and bioprecipitation occur. The sludge particles consisting, in part, of bacteria, are then subjected to vacuum degasification to reduce the "gas-lifting" effect thereby increasing sedimentation efficiency. These particles are subsequently separated from the mixed liquor in the settling tank, and recycled back to the contact tank. Sludge is constantly washed by the incoming wastewater which prevents the accumulation of soluble waste products.

The anaerobic contact process is designed to economically treat organic wastes (22). Because of the recycling system, a short hydraulic detention time can be used while maintaining the long solids retention time required for adequate treatment (22).

McCarty (22) suggests that the anaerobic contact process should be used to treat wastes with organic concentrations less than

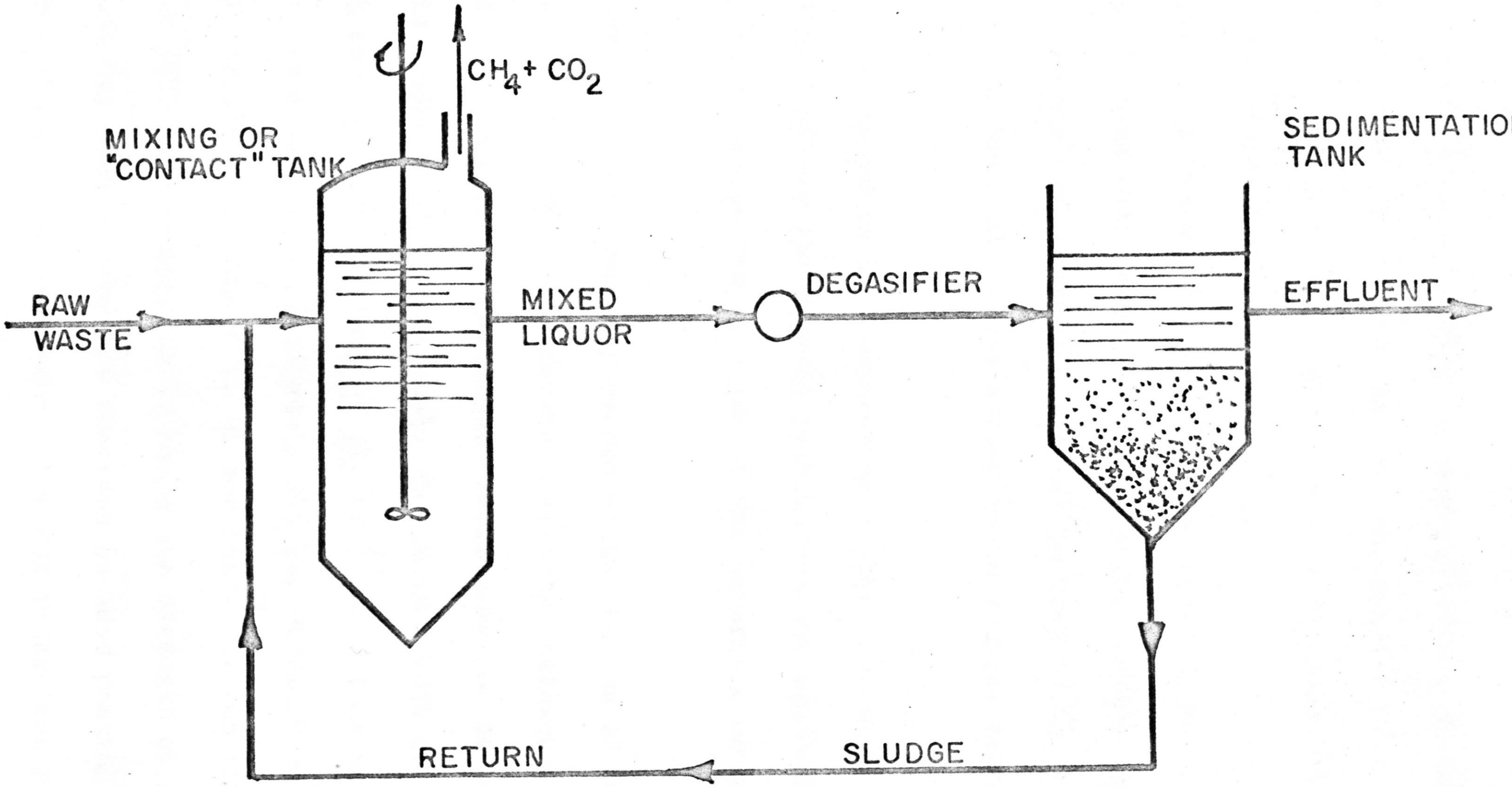

Figure 1. Schematic flow diagram of the anaerobic contact process (19)

one per cent and at organic loadings somewhere between 50 and 250 lb./1000 cu. ft./day. He also states that the recycle rates used for return of biological solids range between 2 to 1 and 4 to 1 based on recycle flow rate to raw waste flow rate.

Although this system has been used for treating municipal wastes (23), research data reveal that much higher solids and BOD removal efficiencies are obtainable when it is used to treat warmer, nutritionally well balanced wastes conducive to maximum bacterial growth (24).

Efficient and economical separation of the bacterial solids from the effluent stream for recycle back to the contact tank has been the major problem arising from the use of the anaerobic contact process (22).

The data shown in Table 3 provides an indication of the treatment efficiencies that have been found in various instances. It is evident from the table that satisfactory reductions can be obtained using organic loadings of approximately 150 lb. BOD/1000 cu. ft. of contact tank per day. Schroepfer, et al. (24) noted that when BOD loadings were increased to approximately 240 lb. BOD/1000 cu. ft. per day, removal efficiencies dropped to 91 per cent. It was also found by Schroepfer (27) that variations in the waste strength of as much as three times the average were not uncommon in meat packing establishments and that these variations lowered the BOD reductions from 1 to 2 per cent. In addition, under nearly constant loading conditions,

TABLE 3
Performance of Anaerobic Contact Process

Hydraulic Detention Time Days	Digestion Temperature °F	Raw Waste mg/1	BOD - 5 day - 20°C lb./1000 cu. ft./day Added	Removed	Stabilized	Per cent Removed	Suspended Solids - Per cent Removed Total	Volatile	Reference
-	77	-	50-100	-	-	80-90	-	-	20
1.3	92	2,000	110	104	77	95	-	-	22
0.5	95	1,430	164	156	-	95	92	79	24
0.5	85	1,310	152	143	-	94	78	72	24
0.5	75	1,110	131	119	-	91	59	64	24
0.5	92	1,380	156	142	66	91	80	83	25
-	91	2,000	120	-	-	95	-	-	26

the effectiveness of the process gradually decreased during the week, but would recover quickly after the weekend rest. Based on these findings and additional pilot plant data, it was concluded that weekend rest periods or periods of low feed are generally beneficial to efficient operation, but not necessarily essential (27).

It is also apparent from Table 3 that the process is temperature sensitive (24). Other studies have shown that the rate of anaerobic stabilization is increased about 2.5 times for packing plant wastes for a 10°C temperature rise (27). Coulter, et al. (21) found that during colder periods, removals ranged between 55 and 80 per cent, and averaged approximately 67 per cent with municipal wastes. At 68°F, the removals averaged 82 per cent, ranging between 80 and 90 per cent. Schroepfer, et al. (24), in 1955, offered the following comments regarding temperature,

> This series (of studies) also suggests the desirability of a test to determine the effect of allowing the raw waste temperatures to control the process temperature without the addition of external heat, or at least none beyond what the process produces. Temperatures might then vary in the typical plant from 70° to 75° F at night to 90° to 95° F during the day. Although the effluent would admittedly be somewhat inferior, subsequent treatment by trickling filters and final sedimentation to recover the solids and return them to the process, might make an overall economical process. Land disposal (deep lagoons, oxidation ponds or irrigation) might also be satisfactory alternatives following anaerobic treatment for reducing the total costs in special applications.

In a later report Schroepfer, et al. (20) suggests that the application of the process was feasible at lower temperatures if the loadings were somewhat reduced. This contention was based on tests using several different wastes at a temperature of 77°F in which BOD removals of 80 to 90 per cent were obtained at loadings of 50 to 100 lb./1000 cu. ft./day.

The importance of mixing was revealed in Schroepfer's early research (27), "It appears to a significant extent, that this process involves the physical action of adsorption as contrasted with purely biological phenomenon; a bio-flocculation action; therefore mixing is very important to the process." Through evaluation of the activated sludge process, McKinney (28) found that a completely mixed aerobic biological reactor or contact tank without a sludge return does not have as high microbial population as a reactor where sludge is returned to the system continuously. It was also shown that the active microbial population decreased as the detention period increased for a given organic loading. From these findings, McKinney states that the concepts of the complete mixing activated sludge system holds true for the complete mixing anaerobic system.

Schroepfer, et al. (27) found that the gas produced by the anaerobic contact process was composed of 70 to 90 per cent methane and 10 to 30 per cent carbon dioxide.

Schroepfer, et al. (27) also states that the most important factor in deciding whether or not to use the anaerobic contact process in a given situation is the thermal requirement. The most desirable waste, he contends, is one that is warm and has a high volatile solids concentration. The least desirable waste would obviously be cold and very dilute.

Anaerobic Stabilization Pond

As previously implied, the operational theory and mechanisms of the anaerobic stabilization pond are quite similar to the anaerobic contact process which has been termed by McCarty (19) as one of the two basic process designs of anaerobic fermentation. The other is the "conventional process" as represented by the heated digester of a trickling filter plant.

A brief statement regarding the mechanism of the anaerobic pond system has been recorded in the pioneer work of Parker, *et al.* (7) concerning their investigations of an installation near Melbourne, Australia, treating municipal wastes. They reported that,

> The high efficiency of the anaerobic lagoon in removing BOD is dependent on the development of digestion in the sludge layer. Organic matter is converted to methane and carbon dioxide under anaerobic conditions and the gassing of the sludge layer seeds the sewage flowing over it.....
>
> ....substantial conversion of organic compounds to gaseous end products also occurs in the supernatant sewage and this is responsible for the high BOD reductions that occur in the absence of dissolved oxygen.

According to Howe, *et al.* (29) in discussing the use of an anaerobic lagoon for treating industrial wastes, simplicity is the primary advantage of the lagoon process. Biological stabilization and solids separation by simple sedimentation are carried on simultaneously in one unit, thereby obviating the need for degasification equipment and separate settling basins.

PHYSICAL CHARACTERISTICS OF THE ANAEROBIC POND SYSTEM

Differences in general layout, number of cells and geometrical configuration of the anaerobic pond installations for treating meat processing wastes found in the literature are quite apparent (3). These dissimilarities may be attributed, at least in part, to the absence of a uniform design criteria as well as the variance in local topography, geographical-climatic factors and waste characteristics (6).

Significant data regarding the physical detail of the anaerobic ponds treating meat and poultry wastes in the U. S. in 1962, as compiled by Porges, are presented in Table 4.

It may be observed from Table 4, that most of the anaerobic pond units were one-cell installations with the majority of the multiple-cell systems operating in series. The surface areas ranged from 0.06 to 12 acres; the median being 1.0 acre. It is also evident that the most often encountered operating depth approximated seven feet. The table also includes similar data regarding the combined anaerobic-aerobic systems because the anaerobic units of this latter group would be performing in a manner similar to the cells of the solely anaerobic ponds.

A tabulation of the layout and dimensions of certain installations discussed in the literature is presented in Table 5.

It is apparent from both Table 4 and 5, that surface area is prominently mentioned for every installation reported. Dornbush and

TABLE 4. (3)
Summary of Layout and Dimensions of Anaerobic Ponds Treating Meat and Poultry Wastes in U.S. - 1962

	Anaerobic	Combined Anaerobic-Aerobic
1. Number	29	11
2. Cell Arrangement		
a. One Cell	20	0
b. Multiple Cell		
1) Series	6	10
2) Parallel	2	0
3) Combined	1	1
3. Physical Dimensions		
a. Area (Acres)		
1) Max.	12	20.6
2) Min.	0.06	0.05
3) Median	1.0	0.8
b. Depth (Ft.)		
1) Max.	14	9
2) Min.	2	2
3) Median	7.3	4
4. Detention Time (Days)		
a. Max.	326	1,304
b. Min.	1.9	14
c. Median	16	43

Andersen (33) in their investigations of anaerobic livestock lagoons in South Dakota, have made the following observation concerning the use of the surface area parameter with respect to anaerobic pond design, ".....this measure of loading is unrealistic. The areal basis is a throwback to the aerobic stabilization pond where available sunlight is important to the algal oxygen supply. It would appear more desirable to place the design on a volumetric basis." Mute

TABLE 5.
Summary of Layout and Dimensions of Selected Anaerobic Pond Systems

		Werribee,	Redmond,	Stony Point,	Moultrie,	Houma,	Gonzales,
1.	Location	Australia	Wash.	Alberta	Ga.	La.	La.
2.	Year of Construction	1940	--	--	1955	1948	1962
3.	Type of Waste		Municipal			Meat Packing	
4.	Anaerobic Ponds						
	a. No. of Cells	2	2	3	1	2	2
	b. Surface Area (Acres)	1.77 2.00	0.33	0.052 0.052 0.15	1.41	0.24 0.28	0.54 0.45
	c. Volume (1000 cu. ft.)	25.5 29.2	--	--	561	--	--
	d. Depth (ft.)	3	5	4-6	14	2	8 4
	e. Detention Time (Days)	2.5	2.0	4.5	6	--	--
5.	Aerobic Ponds						
	a. No. of Cells	1	6	0	1	1	1
	b. Surface Area (Acres)	3.62	0.89	--	19.2	0.28	1.12
	c. Operating Depth (ft.)	3	3	--	3	2	4
6.	Flow Pattern						
	a. Anaerobic Cells in Series	No	No	Yes	--	Yes	Yes
	b. Anaerobic Cell in Parallel	Yes	Yes	No	--	No	No
	c. Anaerobic and Aerobic-Series	Yes	Yes	--	Yes	Yes	Yes
	d. Recirculation	No	No	No	Yes[a]	No	No
7.	Reference	7	30	31	13	32	32

[a] Raw waste is mixed with recirculated flow of anaerobic pond contents at rate of 1500 gpm.

substantiation of this view is found in the published data regarding the anaerobic contact process in which none of the loading parameters are related to surface area.

PERFORMANCE OF THE ANAEROBIC STABILIZATION POND

In reviewing the performance of the anaerobic stabilization pond for treating meat processing wastes, the information presented by Porges (3) represents the broadest compilation found in the literature reviewed. Table 6 contains a listing of these data.

It is interesting to note from Table 6, that 90 per cent of the anaerobic pond owners reporting whether or not an odor nuisance was created by their facility replied in the affirmative. Odors were not a problem in the combined anaerobic-aerobic installations. It is also noteworthy that the range of BOD removal is much narrower and the median removal is significantly higher for the combined systems.

Information regarding the performance of the six installations for which layout and dimensional data have been previously recorded (Table 5), is presented in Table 7. As indicated by this tabulation, the BOD removals for the anaerobic units ranged between 65 and 70 per cent for those units treating municipal wastes and above 90 per cent for those treating meat packing wastes. This difference is very likely due to the lower temperatures at which these municipal treatment facilities operate (13), for not only are they located in a much colder region, but also the influent to these units would be significantly cooler than the usual 90 to 95°F temperatures of the meat

TABLE 6. (3)
Summary of Loadings and BOD Removals of Anaerobic Ponds Treating Meat and Poultry Wastes in U.S. - 1962

	Anaerobic	Combined Anaerobic-Aerobic
1. BOD Loading		
a. No. Reporting	16	10
b. lb.BOD/day/acre		
1) Maximum	6,060	1,885
2) Minimum	175	19
3) Median	1,260	267
2. BOD Removal		
a. No. Reporting	18	7
b. No Discharge	9	0
c. Removal (per cent)		
1) Maximum	92	99
2) Minimum	65	83
3) Median	80	94
3. Odor		
a. No. Reporting	10	2
b. Reported Odors	9	0

processing wastes. It is important to note, however, that even in the severe climate of Canada, anaerobic ponds treating relatively cool wastes, have obtained rather significant BOD reductions.

The performance data pertaining to the aerobic stage of anaerobic-aerobic stabilization pond systems have been included in Table 7 to emphasize the importance of this stage in obtaining a high degree of treatment. It is interesting to note the relatively insignificant reductions obtained by the aerobic ponds in Louisiana, as contrasted with the substantial improvement of the anaerobic effluent attributed to these units in the colder climates of

TABLE 7.
Summary of Performance Data of Selected Anaerobic Pond Systems

	Werribee, Australia	Redmond, Wash.	Stony Point, Alberta	Moultrie, Ga.	Houma, La.	Gonzales, La.
1. Location	Werribee, Australia	Redmond, Wash.	Stony Point, Alberta	Moultrie, Ga.	Houma, La.	Gonzales, La.
2. Year of Construction	1940	--	--	1955	1948	1962
3. Type of Waste	Municipal	Municipal	Municipal	Meat Packing	Meat Packing	Meat Packing
4. Anaerobic Ponds						
a. No. of Cells	2	2	3	1	2	2
b. BOD						
1) Influent (mg/l)	530	--	--	1100	2328	1860
2) Effluent (mg/l)[a]	160	--	--	--	83	83
3) Loading						
a) lb./1000 cu. ft./day[b]	7.0	5.7	22.5	14.0	10.9	--
b) lb./acre/day[b]	1230	1000	4920	4780	950	--
4) Removal (per cent)[c]	70	65	70	--	96.4	95.6
5. Aerobic Ponds						
a. No. of Cells	1	6	0	1	1	--
b. BOD						
1) Influent (mg/l)	160	--	--	--	83	83
2) Effluent (mg/l)	51	--	--	67	44	43
3) Loading (lb./acre/day)	65	40-60	--	50	71	--
4) Removal (per cent)[c]	20	--	--	--	1.7	2.1
6. Overall Reduction[c]	91	85	70	94	98.1	97.7
7. Reference	7	30	31	13	32	32

[a] Represents effluent from final pond only if more than one is listed.
[b] Loading to first pond only if more than one is listed.
[c] Based on reduction in concentration.

Werribee, Australia and Redmond, Washington. Parker (7) and Sollo (13) also claim that, since the anaerobic effluent is unstable, a combination of anaerobic and aerobic ponds is the logical choice for providing a complete treatment system. As evidenced by the loadings and reductions of the anaerobic and aerobic stages in Table 7 and as noted by Parker, et al. (7), the anaerobic lagoon is a much more efficient purification device than its aerobic counterpart.

FACTORS INFLUENCING THE TREATMENT PROCESS

Comments regarding the influence of various factors such as temperature, loading and mixing upon the anaerobic process have been included in previous sections of this review. In that the anaerobic stabilization pond represents a similar application, its reactions to these influencing factors would be expected to be analogous. Additional investigations relative to the influence of these various factors on anaerobic lagoons is needed.

BOD Loading

A specific study of the effect of increasing or decreasing the BOD loading to an anaerobic lagoon could not be found in the literature. Parker, et al. (7) stated that the purification capacity of the anaerobic pond is affected by the BOD volumetric loading, but does not provide an experimental basis for this conclusion.

Temperature

Many investigators were aware of the effect of temperature on the anaerobic lagoon. Unfortunately, their comments, in general, are based on limited studies. Parker, et al. (7) observed that, "....in contrast to aerobic lagoons, there is a considerable difference in BOD reduction through the anaerobic lagoon in winter and summer." Sollo (13) found that a much lower treatment efficiency occurred when the pond temperature dropped below 75°F for prolonged periods. McIntosh and McGeorge (34) reported that the low BOD removal efficiencies of an anaerobic pond during winter operation were increased by 50 to 60 per cent by covering the pond surface with a 3-inch layer of foam insulation; thereby maintaining the pond temperature above 70°F. From studies conducted in California, Oswald (2) concluded that the system was definitely affected by temperature since gas production doubled for each two degrees increase in temperature above 15°C.

Mixing

Again, very little could be found in the literature concerning the mixing of the anaerobic pond contents during treatment. The anaerobic-aerobic lagoons studied by Sollo (13) in Georgia, employed systems to recirculate the sludge in the anaerobic pond and the aerobic effluent in the aerobic pond. Although it was stated that the purpose of the recirculation system was to provide better mixing of the pond contents, the influence of the improved mixing action on the treatment efficiency was not given.

Although specific reference to recirculation with respect to its function in the anaerobic lagoons studied by Wilson, et al. (14) was not included in the report of their investigations, such a system might have been employed since it was apparently a part of the piping layout.

Two observations relative to mixing included in the report on livestock waste lagooning by Dornbush and Andersen (33) seem pertinent to anaerobic lagoons in general. The first emphasizes that effective mixing action can be obtained from the bubbling action originating from sludge deposits on the lagoon bottom. Secondly, it was also postulated that adequate mixing would eliminate the low pH that may exist in the solids accumulations due to excessive volatile acids production (36).

Depth and Detention Time

In the discussion of these factors by Parker, et al. (7), it was concluded that detention times up to five days in the anaerobic lagoons were desirable with little additional advantage obtained by exceeding this time interval. They also noted that the purifying capacity of the anaerobic units appeared to be dependent on detention time or volume and not on surface area. This position is also supported by Coerver (32), who also noted that there was some advantage in minimizing the surface area in order to hasten the formation of the "crust" on the pond surface.

A study of four anaerobic lagoons in Canada by Hogge, et al. (31) revealed the apparent optimum detention time based on maximum BOD reductions to be about five days. Berschauer (30) in Washington, found that a 2 to 5 day detention time appeared reasonable, but for maximum BOD reductions, a 2 to 3 day period was most suitable. He also found that depth did not affect the treatment except as it was related to detention time. The anaerobic lagoons studied by Coerver (12) were operating at detention times of 3 to 4 days.

Oswald (2) stressed the desirability of providing sufficient depth to protect the methane fermentation reaction from oxygen and ambient air temperature changes.

Sludge Accumulation

Parker, et al. (7) in studying two similar, equally-loaded anaerobic lagoons, one devoid of sludge and the other containing a 16-inch accumulation, found much greater BOD reductions in the lagoon containing the sludge, despite the fact that the detention time in this unit was shorter. They also found that it required approximately nine months for the desludged lagoon to attain the same reductions.

Approximately two and one-half years after start-up, Sollo (13) found it was necessary to remove sludge from the anaerobic lagoon to prevent carry over. The surplus sludge was pumped to a nearby field where it was dried without nuisance.

Coerver (12) found in Louisiana, that sludge removal was necessary after 3 to 5 years of operation. This sludge did not create a nuisance after removal and was easily dewatered. He advocated the use of long, narrow anaerobic ponds, with lengths at least three times the width in order to facilitate cleaning.

Miscellaneous Factors

According to Coerver (12)(32) one of the most important factors in the successful performance of an anaerobic lagoon is the formation of a "crust" on its surface. During the time the crust was forming, usually from 6 to 12 months, the pond would not reach peak efficiency in BOD removal. He also suggested that the addition of paunch manure to the pond played an important role in forming this crust.

Oswald (2) found that the rate of gas production varied within the anaerobic lagoon, with the highest production rate occurring near the center. He also noted that whenever an odorous condition developed, the methane production dropped off while hydrogen production increased. In contrast, as the odors disappeared, the methane production increased.

DESIGN AND CONSTRUCTION OF THE WASTE TREATMENT PONDS

THE MEAT PROCESSING PLANT

The anaerobic stabilization pond facilities studied were designed to treat the wastes from the Minnesota-Iowa-Dakota (MID) Packing Plant constructed near Luverne, Minnesota, in 1962. This meat processing operation is essentially that of a slaughterhouse. The plant was initially constructed to process approximately 400 beeves per day based on an estimated average live weight of 1,130 pounds per animal. The beeves are killed, dressed, placed in cold storage for 24 hours and then shipped. The hides are defleshed and shipped after brine curing. All by-products of economic value such as blood, hooves, hearts, livers and tongues are recovered and marketed. The inedible offal is rendered into tallow, grease and tankage. A program of encouraging numerous "in-plant" waste-saving procedures was in progress at the time of these studies. The wastes, consisting of process liquids and wash waters, were derived from the kill floor, carcass dressing, hide room, rendering plant, cooling room and laundry.

HYDRAULIC AND ORGANIC LOADINGS

Because the slaughter house was being constructed concurrently with the design and construction of the waste treatment ponds, the design loadings had to be obtained indirectly.

It was estimated by the slaughterhouse management that the meat processing operation would produce an average daily waste flow of approximately 330,000 gallons. This estimate, based on existing flow data obtained from a similar dressed beef establishment, was used in the design.

None of the activities involved in the plant operation were expected to alter the character of the waste from that usually encountered in slaughterhouse waste treatment. However, the management intended to incorporate numerous waste-saving procedures into the plant operation and to screen the plant waste effluent prior to its entering the waste treatment facilities. Therefore, they were reluctant to accept the average unit BOD values of approximately 15 lb. per 1000 lb. live weight of kill as found in the literature, for use in establishing the design loading.

In an attempt to justify the use of a lower unit BOD for calculating the total waste load, a sanitary survey was conducted at a dressed pork plant in Sioux City, Iowa, which was operating under procedures and conditions similar to those anticipated at Luverne. A BOD value of 7.74 lb. per 1000 lb. live weight was computed from the survey data. Based on this finding, a value of 10 lb. per 1000 lb. live weight was accepted to represent an equitable compromise and was used in all subsequent design computations. On this basis, the estimated BOD to the waste treatment facility was calculated to be 4,520 lb. per day. This loading represented an equivalent population of 27,100 based on the BOD.

DESIGN

There were very little published data available in 1962 regarding the use of stabilization ponds for treating meat packing wastes. The performance of an anaerobic-aerobic pond system in Moultrie, Georgia, along with operation data from a pilot plant built in Perry, Iowa had been reported by F. W. Sollo (13). After preliminary study and considerable discussion of this information, a decision was made to design a treatment plant adapting this anaerobic-aerobic system to the relatively severe climatic conditions of Minnesota.

Description of the Anaerobic-Aerobic Pond Treatment System

A flow diagram of the waste treatment system is shown in Figure 2. The plant obtains its water supply from the city system. After being metered, a portion of the water is used as cooling water with the remainder flowing directly to the kill floor. The cooling water is also used on the kill floor. Because separate disposition of the whole blood and paunch manure are provided, these constituents are not a part of the process wastes. The composite slaughterhouse wastewater, therefore, consists primarily of processing and wash waters from the slaughterhouse plus the recirculation from Anaerobic

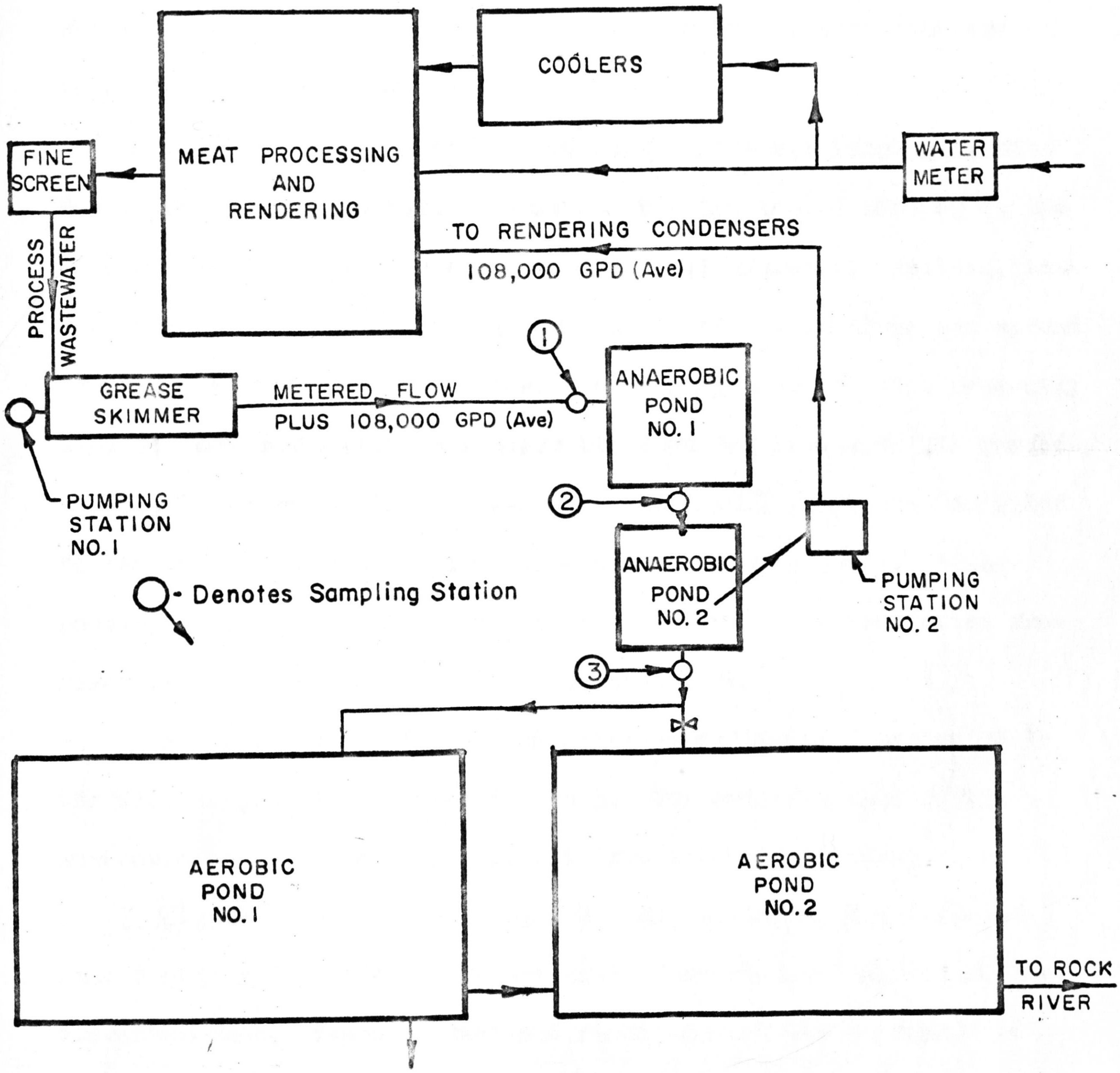

Figure 2. Flow diagram of the anaerobic-aerobic pond waste treatment system

Pond No. 2 which is used for the rendering plant condensers. After being collected at one location for screening through a 20-mesh rotary fine screen, the composite waste flows through the grease skimmer (catch basin), the anaerobic and aerobic ponds which are all in series and on to the Rock River.

Two pumping stations are provided. Although Pumping Station No. 1 was designed to return sediment from the grease skimmer to the fine screen, this procedure had not yet been employed. Instead, both the grease skimmings and sludge are pumped to a tank truck and spread over adjacent agricultural lands. Pumping Station No. 2 is presently used to pump wastewater from Anaerobic Pond No. 2 back to the rendering plant for use in the condensers. Additional pumps are installed to remove sludge accumulations from both anaerobic ponds. This pumping station has also been designed to provide recirculation from Anaerobic Pond No. 1 back to its influent line.

An aerial view of the facilities symbolically represented in the flow diagram is shown in Figure 3. The relative size of the anaerobic ponds is readily apparent from this aerial view.

Figure 4 includes a topographic map of the entire tract of land owned by MID Packing Company with a superimposed layout of the slaughterhouse, grease skimmer and stabilization pond system. It should be noted from Figure 4, that there is a 25 to 30 foot elevation differential between the slaughterhouse site and the location of the aerobic ponds. This arrangement was not accidental. In fact,

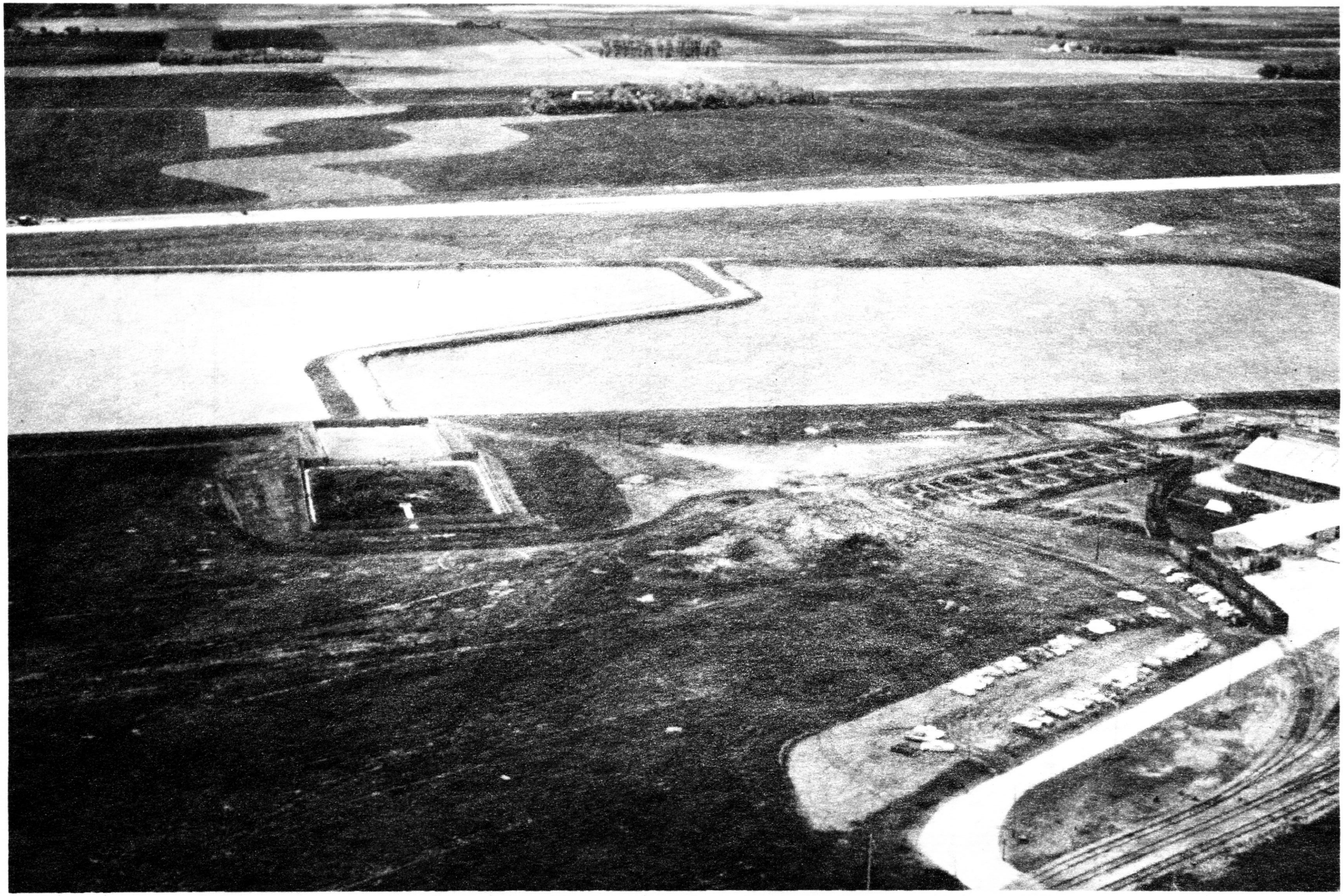

Figure 3. Aerial view of anaerobic-aerobic pond system

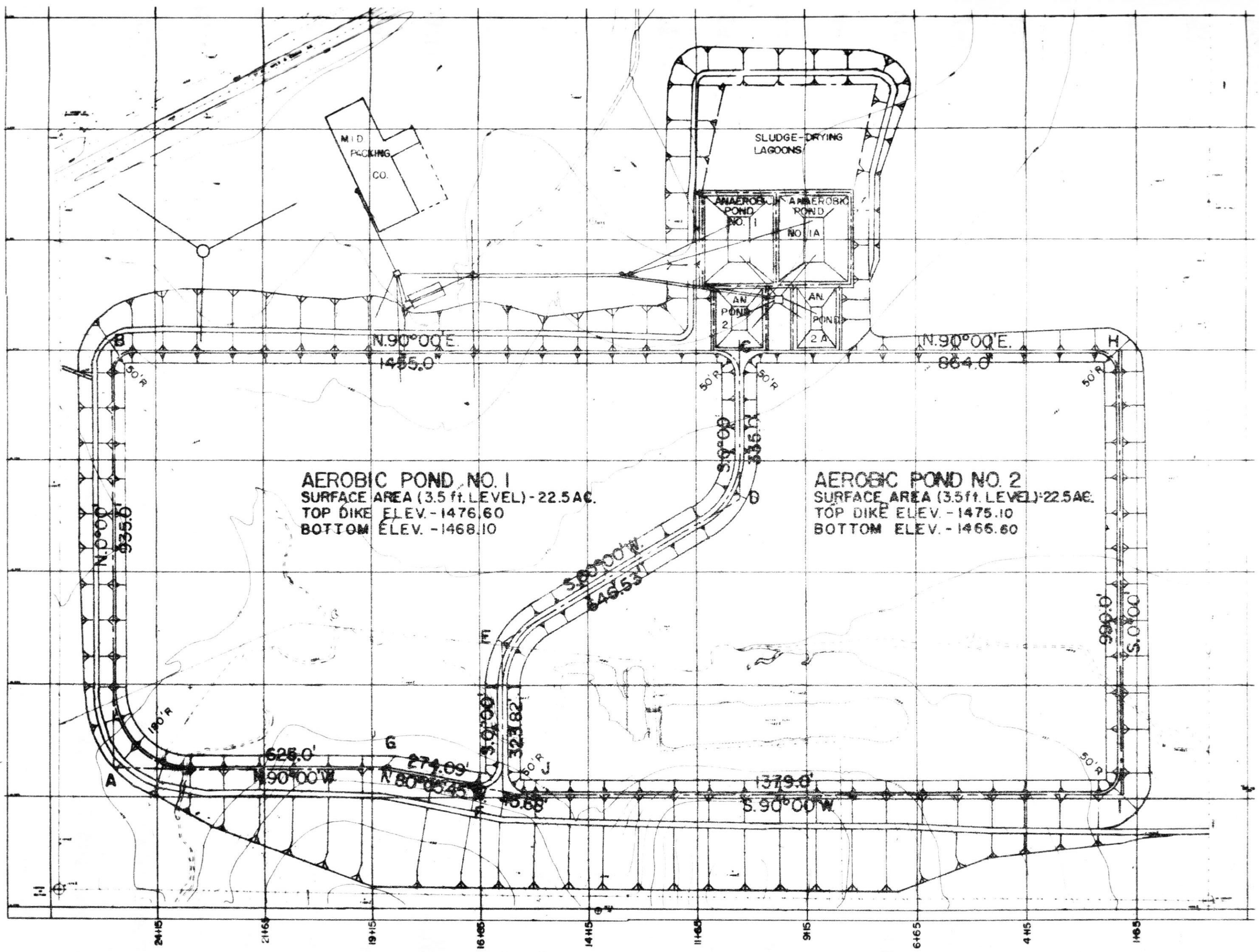

Figure 4. Topographic map of slaughterhouse and proposed waste treatment pond site

one of the primary considerations in purchasing this property was its adaptability to the waste stabilization pond method of treatment. This differential made it possible to use gravity flow throughout the entire treatment system.

Figure 4 contains the proposed layout of a second grease skimmer and an additional set of anaerobic ponds to operate in parallel with the existing set. Although these facilities were included in the original design, it was intended that they would be constructed only upon a substantial increase in slaughterhouse production. Also shown in this figure is an area reserved for future sludge dewatering facilities which will be constructed when excessive solids accumulations warrant such action.

A photographic illustration of many of the physical details of Anaerobic Pond No. 1 is shown in Figure 5. This photograph was taken shortly after waste flow was diverted to this unit. The reinforced concrete structure in the background was designed and constructed to support a gas-fired heater. After considering the high temperatures of the wastes, it was decided to delay the installation of the heating equipment until actual operational data could be obtained to determine whether or not external heat was necessary. A polyurethane foam covering for this pond was also considered as a possible method of maintaining a 75°F minimum temperature. Two large pipes are shown in Figure 5. The one in the foreground is the influent line to future Anaerobic Pond No. 1A (Figure 4). The other is the influent

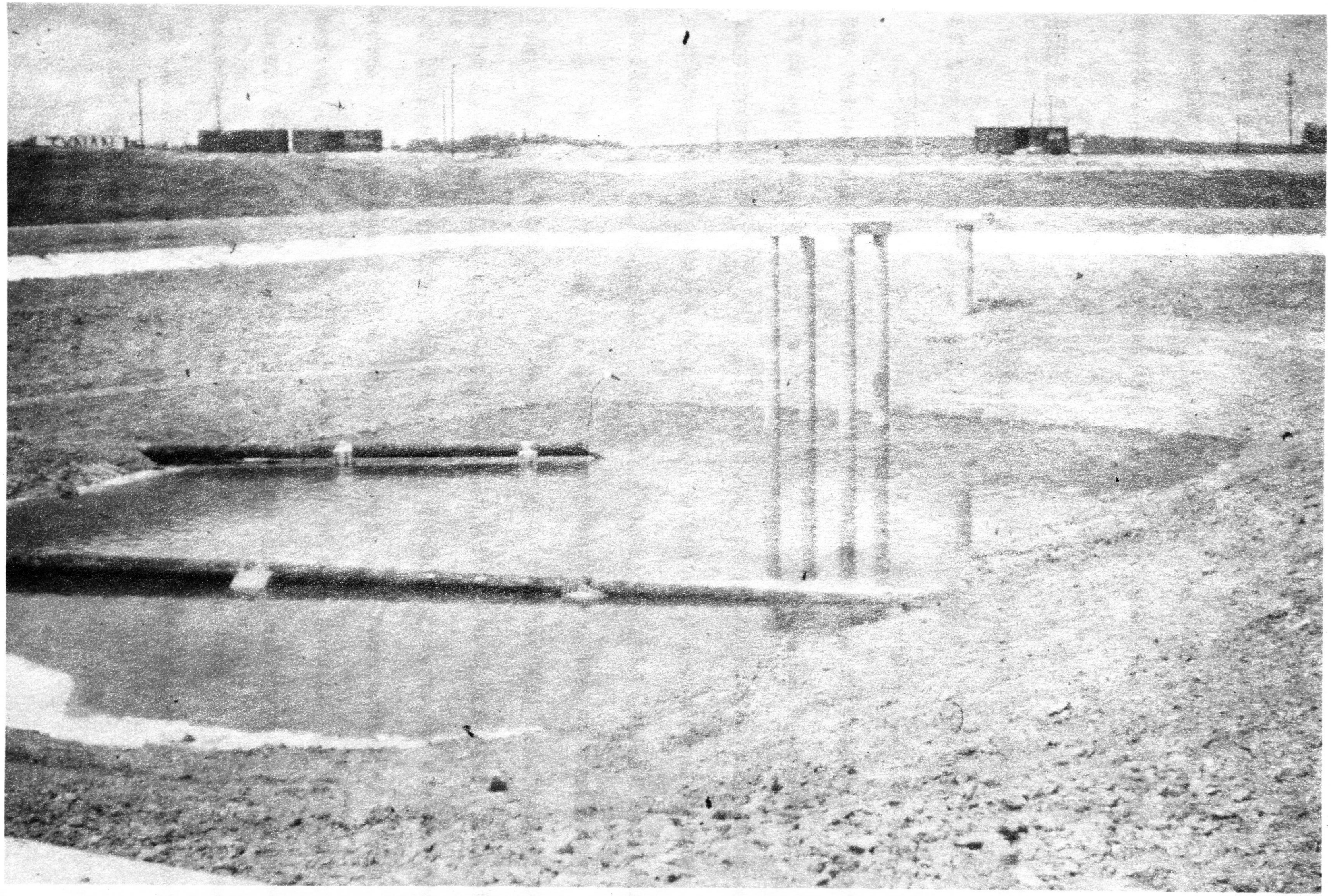

Figure 5. Anaerobic Pond No. 1 showing construction details

line to the existing Anaerobic Pond No. 1 and discharges near the heater support platform. Also shown is the concrete apron constructed at the operating liquid level to prevent erosion and weed growth. A similar apron was provided for Anaerobic Pond No. 2.

Basis of Design

A summary of the criteria used in designing the various units of the waste treatment facilities are presented in Table 8.

The grease skimmer referred to in this table, is identical to the rectangular primary clarifier of a conventional treatment plant. It is approximately 70 feet long by 15 feet wide with an average liquid depth of 6 feet. An electrically-driven sludge collector and surface skimmer were installed in the tank. The entire unit was sheltered to prevent heat loss and facilitate cold weather servicing.

Anaerobic Pond No. 1 was designed to operate at a minimum temperature of 75°F. The soil stability limited the side slopes to 3 to 1, although steeper slopes would have been desirable. A depth of 15 feet was used to minimize heat losses by reducing the surface area. This surface area, of 0.59 acres, was rectangular in shape having a length of 179 feet and width of 143 feet at the operating liquid level. A freeboard of 3 ft. was provided to reduce air turbulence at the liquid surface. The detention time in the unit, based on the design average flow was 5.12 days. Its volume is approximately 226,000 cubic feet.

TABLE 8.
Waste Treatment Units - Basis of Design

Treatment Unit	Design Basis
Grease Skimmer	
Surface Loading	1 gpm/sq. ft.[a]
Detention Time	1 hour
Anaerobic Pond No. 1 (To be maintained at 75°F min. temp.)	
Organic Loading	20 lb. BOD/1000 cu. ft./day
Liquid Depth	15 feet
Slopes	3 to 1
Freeboard	3 ft.
Detention Time	5.12 days[b]
Anaerobic Pond No. 2 (unheated)	
Detention Time	1.5 days[b]
Liquid Depth	10 ft.
Slopes	3 to 1
Freeboard	3 ft.
Aerobic Ponds (two cells to operate in series or parallel)	
Organic Loading	25 lb. BOD/acre/day[c]
Operating Depth Range	2 to 5.5 ft.

a/ Based on average flow during operating period
b/ Based on design average flow
c/ Based on a 3.5 ft. depth and an anticipated 75% BOD reduction in anaerobic ponds

Anaerobic Pond No. 2 was designed to function as a settling basin. It was intended that this unit would reduce the expected high solids concentration of the effluent of Anaerobic Pond No. 1. This unit has an approximate volume of 66,300 cubic feet, and a rectangular surface area of 0.26 acres. It is 119 feet long and 95 feet wide at the liquid surface and also has a 3-foot freeboard for wind protection.

The area at the water surface of each aerobic pond is 22.5 acres measured at the 3.5-foot level. The combined storage volume of these two ponds between the 1-foot and 5.5-foot levels is approximately 4,385,000 cubic feet which provides a total detention time of about 35 weeks, based on the design average flow.

CONSTRUCTION COSTS

The final construction cost of the anaerobic-aerobic treatment system is tabulated in Table 9. Construction was started in August, 1962, and completed in May, 1963.

It is estimated, based on the cost of the completed work, that an additional expenditure of $17,000 will be required to complete the sludge dewatering facilities and other miscellaneous minor improvements. This would result in a total cost of approximately $190,000 for the project. This cost represents an outlay of approximately $7.00 per capita based on the BOD equivalent population.

TABLE 9.
Summary of Final Construction Costs

Work Item	Cost
1. Excavation (400,000 cu. yd.)	$ 86,624.65
2. Grease Skimmer and Sludge Collector Equipment	5,300.00
3. Control Gates	3,272.68
4. Valves and Fittings	1,247.31
5. Wastewater	2,020.20
6. Pipe Costs	10,784.24
7. Electrical Equipment	2,822.00
8. Precast Concrete Materials	4,520.27
9. Reinforced Concrete, Trench Excavation, Sewer Construction	34,776.64
Total Construction Cost	$151,367.99
Administration, Engineering, Inspection, Field Surveys and Construction Staking	22,083.06
Total Project Cost	$173,451.05

START-UP AND OPERATION

Meat processing operations were initiated in December, 1962. Because the anaerobic system was only partially constructed at that time, the process wastewater was discharged to Aerobic Pond No. 1 which was used as a temporary holding pond. On May 10, 1963, after the anaerobic cells were completed, the slaughterhouse waste flow was diverted to Anaerobic Pond No. 1. Flow over the effluent weir of this unit occurred on May 15. During this period, 50,000 gallons of seed sludge obtained from the municipal treatment plant digester was added. This amount of "seed" was calculated on the basis of 0.1 lb. dry solids per gallon per day of average flow.

Although it was expected that the grease skimming unit would be operative within one week after start-up of the anaerobic system, three weeks elapsed before it could be used. Anticipated odor difficulties in the anaerobic cells due to excessive grease accumulations did not occur. In fact, there are now indications that the resultant rapid grease-scum layer development may have been beneficial to the start-up and continued operation.

The foresight of the slaughterhouse management in assigning a full-time operator to the treatment system has provided a significant amount of helpful information regarding response to ambient air temperature. Through the daily temperature records taken by the operator, it was revealed that the temperature drop through Anaerobic Pond No. 1 would be as much as 10°F more on days when high winds would disturb the continuity of the scum blanket. After a six-foot board fence was erected around the anaerobic ponds, and made wind-tight, no further difficulties were experienced in preserving a scum layer over the entire pond surface.

Throughout the first year of operation, the scum build-up on Anaerobic Pond No. 2 was insufficient to cover its entire surface. This condition may be observed from Figure 6 which shows the condition of this pond surface (in foreground) in early February, 1964. Additional scum has since been hauled from the grease skimmer to this unit resulting in a reduced temperature drop.

Since this start-up, no serious operational difficulties have developed and the anaerobic-aerobic system has been essentially odor-free. In addition, sludge dewatering facilities have not been needed.

The operator's duties consist primarily of collecting temperature data, weed and erosion control, routine pump maintenance and hauling the grease skimmings and skimmer sediments (approximately 3600 gallons per day) to agricultural lands.

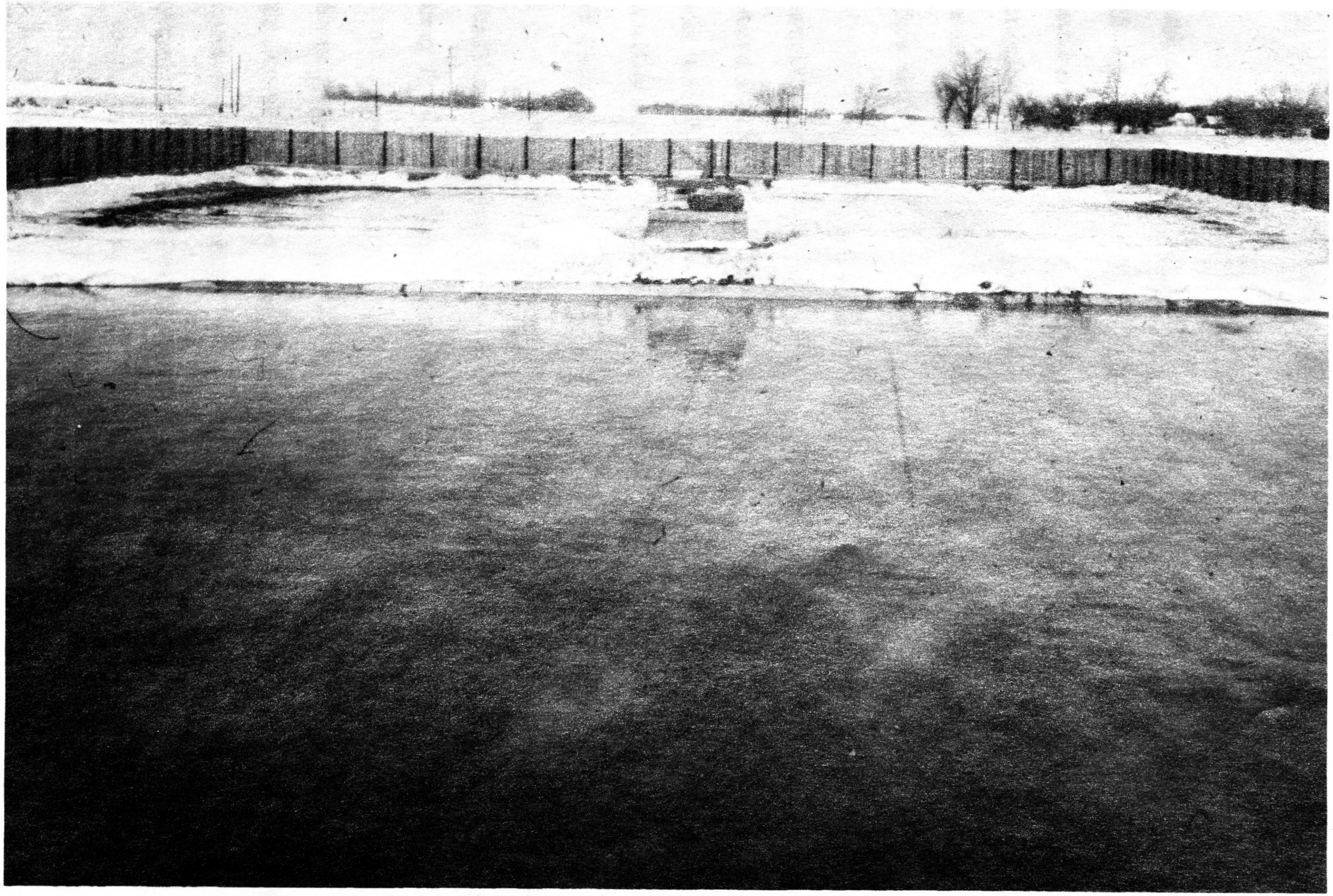

Figure 6. Anaerobic Ponds No. 1 and 2 in operation

FIELD PROCEDURES

Three sampling stations were used in obtaining data regarding the performance of the anaerobic system. Station No. 1 (See Figure 1) was located at the manhole through which the slaughterhouse wastewaters flowed immediately prior to entering Anaerobic Pond No. 1. Station No. 2 was established at the overflow structure between the anaerobic ponds and Station No. 3 at the Anaerobic Pond No. 2 overflow weir.

Recording capillary tube thermometers were installed at sampling stations No. 1 and 2 to obtain the temperatures of the raw waste and the effluent of Anaerobic Pond No. 1. A Trebler sampler was used to obtain 24-hour composite samples of the raw waste at Station No. 1. Grab samples were taken at Stations No. 2 and 3 daily at 7:00 A. M.

Weirs and stage recorders for continuous flow gaging were installed at Stations No. 1 and 3. The recirculation rate was determined from the pumping rates and operating times.

Samples were collected continuously for a 12-day period from March 1 through March 12, 1964. Sample analysis was performed by Minnesota Department of Health personnel in their laboratory facilities located in Minneapolis. Approximately six hours were required to transport the samples to the laboratory.

TABLE 10.
Summary of Analytical Determinations

Analysis[a]	March Test-Run Averages Sta. No. 1[b]	Sta. No. 2[c]	Sta. No. 3[d]	Random Analyses[e] Aerobic Pond No. 1 Effl.	Aerobic Pond No. 2 Effl.
5-Day BOD	940	502	458	90	20 & 13[f]
COD	1285	642	587	500	380
Suspended Solids	457	158	128	140	88
Suspended Volatile Solids	394	143	116	130	48
Total Volatile Solids	805	495	450	270	170
Total Solids	2480	1850	1750	1600	1600
pH	6.5-7.0	6.4-6.8	6.5-7.0	--	--
Chlorides	492	448	423	460	560
Total Phosphorous	6.2	6.2	6.0	5.2	1.7
Ammonia	34	63	64	6.9	1.0
Organic Nitrogen	46	15	14	13	7.6
Deoxygenation Constant (K)	--	--	0.23	--	--

a/ In mg/l except for pH
b/ Raw waste after grease removal
c/ Anaerobic Pond No. 1 effluent
d/ Anaerobic Pond No. 2 effluent
e/ Samples collected on 9/5/63 and analyzed by Minnesota Dept. of Health
f/ Filtered for algae removal

Minnesota Department of Health. The sulfate content of the municipal water, obtained from these same analyses, varied from 65 to 110 mg/l. These sulfates probably contributed to the production of hydrogen sulfide gas which was evident in the anaerobic basins.

It is apparent from Table 10, that the reduction of the suspended solids concentration occurred primarily in the first anaerobic cell. Very little additional reduction was accomplished in the second cell. The "gasing effect" referred to by Schroepfer, et al. (27) could be responsible for this inefficient settling performance, as well as the inherent error in grab sampling.

The COD provides an indication of the amount of oxygen required to stabilize the carbonaceous or organic material present in the waste (35-285), but does not differentiate the biologically inert organics. Because the BOD reflects the amount of oxygen required by the bacteria while stabilizing the biologically oxidizable organics only (35-270), the difference between the BOD and COD should be small in order to achieve satisfactory treatment using biological methods. The waste analyses shown in Table 10 indicate that this difference was small.

The nitrogen data reveal that organic nitrogen was being broken down to ammonia in the first anaerobic pond.

From the aspect of treatment evaluation, the BOD and suspended solids data shown in Table 10 are most important. This information has been related to waste flow and meat production in

TABLE 11.
Summary of Operational Data During Period of Study

	Average
Kill	
Kill; beef/day	409
Weight per animal; lb. live wt.	1255
Kill; 1000 lb. live wt./day	513
Flow	
Raw waste flow; 1000 gal./day	408
Recirculation from Anaerobic Pond No. 2 to rendering plant; 1000 gal./day	108
Unit raw waste flow; gal./1000 lb. live wt.	800
BOD	
Unit BOD; lb./1000 lb. live wt.	7.1
Loading to Anaerobic Pond No. 1; lb./day	3645
Loading to Anaerobic Pond No. 1; lb./acre/day	6180
Loading to Anaerobic Pond No. 1; lb./1000 cu. ft./day	16.1
Aerobic Pond No. 1; lb./day	1523
Aerobic Pond No. 1; lb./acre/day	67.7
Removed by Anaerobic Ponds; lb./day	2122
Reduction through Anaerobic Ponds; %	58.2
Suspended Solids	
Unit suspended solids; lb./1000 lb. live wt.	3.5
Loading to Anaerobic Pond No. 1, lb./day	1870
Loading to Aerobic Pond No. 1, lb./day	417
Removed by Anaerobic Ponds; lb./day	1403
Reduction through Anaerobic Ponds, %	76.9

Appendices II, III and IV, to make it more meaningful. A summary of the data presented in these Appendices is presented in Table 11.

Both the unit BOD and suspended solids values indicated in Table 11, 7.1 and 3.5 lb. per 1000 lb. live wt. respectively, are about the same as the lowest values shown in Table 1 and substantially below the values contained in Table 2. Since the concentrations shown in Table 10 and those of Tables 1 and 2 are quite similar, the low BOD and suspended solids unit values are probably the result of fine screening, grease removal and the efforts of the management to minimize waste flows.

It should be noted that the unit BOD of 7.1 lb. per 1000 lb. live weight compares favorably with the 7.74 lb. value obtained from preliminary investigations at the Sioux City plant. These determinations were all on wastewater samples collected after grease removal and consequently reflect the BOD reductions through the grease skimmer units.

It is significant to note that the daily BOD loading to Anaerobic Pond No. 1 of 6180 lb. per acre or 16.1 lb. per 1000 cu. ft., shown in Table 11, is almost five times the median value, 1260 lb. per acre, shown in Table 6. Of the installations included in Table 7, only Stony Point, Alberta, with 22.5 lb. per 1000 cu. ft., has a higher loading. It would therefore appear that the facility under investigation had a higher organic loading than most of the similar installations reported in the literature. However, when compared to the loadings of anaerobic contact process units, the situation is reversed since the anaerobic pond loading of 16.1 lb. per 1000 cu. ft., is approximately one-tenth of the anaerobic contact process loadings shown in Table 3.

The anaerobic pond efficiency was computed on a basis of pounds of BOD removed considering the recirculation to the rendering condensers. The 58.2 per cent BOD reduction obtained through the anaerobic ponds shown in Table 11 is substantially below the 90 per cent reductions obtained by the anaerobic contact process indicated in Table 3. This reduction is also lower than the minimum reported for the anaerobic ponds included in Table 6. The reductions through the anaerobic pond systems located in the colder regions as tabulated in Table 7, however, are only slightly higher than the 58.2 per cent found from the survey.

The suspended solids removal of 76.9 per cent shown in Table 11 is slightly above the mid-point of the 59 to 92 per cent reductions obtained by the anaerobic contact process as shown in Table 3.

It would appear from the above, that the BOD reduction through the anaerobic system is lower than might be anticipated and that the suspended solids removal approaches the usual level.

A summary of the temperature data is presented in Table 12. It may be observed that the average air temperature for this period was 25.4°F. The influent waste temperature of 82.0°F represents the average, weighted in accordance with the flow rate of the waste at the time the temperature was measured. It was found that the average Anaerobic Pond No. 1 effluent temperature, computed on the same basis as the influent, was 76.9°F. The resultant average temperature drop through this unit was 5.1°F. The average drop through Anaerobic Pond No. 2 was 9.5°F. Expressed in terms of the quantity of heat entering and leaving each anaerobic cell, these temperature drops represent

TABLE 12.
Summary of Temperature Data

Factor	Anaerobic Pond No. 1	Anaerobic Pond No. 2
Average Ambient Air Temperature; °F	25.4	25.4
Average Influent[a] Temperature; °F	82.0	76.9
Average Effluent Temperature; °F	76.9	67.4
Average Temperature Drop Through Pond; °F	5.1	9.5
Average Quantity of Heat Entering Pond; million BTU per day	353.8	331.5
Average Quantity of Heat Leaving Pond; million BTU per day	332.0	291.0
Average Quantity of Heat Lost Through Pond; million BTU per day	21.8	40.5
Area of Liquid Surface; sq. ft.	25,600	11,300
Wetted Contact Area of Pond; sq. ft.	25,600	11,300
Average Detention Time; days	3.3	1.0

[a] Influent = Raw waste after grease removal

heat losses through Anaerobic Pond No. 1 and 2 of 21.8 and 40.5 million BTU's per day respectively.

Further observation of Table 12 reveals that the liquid surface and wetted ground contact areas of the first anaerobic cell are approximately twice those of the second. This greater liquid surface and wetted ground contact area of Anaerobic Pond No. 1 and its longer detention time would be expected to result in substantially higher heat losses from this cell than from the No. 2 pond. The heat loss data shown in Table 12 reveal the opposite condition, however. In fact, the heat loss through Anaerobic Pond No. 2 was almost double that of Anaerobic Pond No. 1. A logical explanation of this apparent incongruity involves the scum-crust layer on the surface of the first anaerobic cell.

From the heat loss standpoint, the anaerobic ponds differ most conspicuously in depth and liquid surface condition. Although additional heat conservation probably results from the greater depth of Anaerobic Pond No. 1, the insulation value of its grease-scum cover appears to be the primary factor in preventing heat loss as indicated by Figure 7. This photograph, taken during the test-run, illustrates the surface condition of Anaerobic Pond No. 1. It may be observed that despite the 76.9°F temperature of the liquid waste below this layer, the snow on the surface did not melt. The thickness of this "crust" was approximately nine inches.

Figure 8 presents visual evidence of the heat loss from Anaerobic Pond No. 2 as represented by the vapors rising from its open liquid surface.

A rough computation of the coefficient of thermal conductivity of this scum-crust surface covering is presented in Appendix V. A coefficient of 8.3 BTU per hour per sq. ft. of surface per °F difference in air and liquid waste temperature was obtained from these calculations. This conductivity coefficient is approximately five

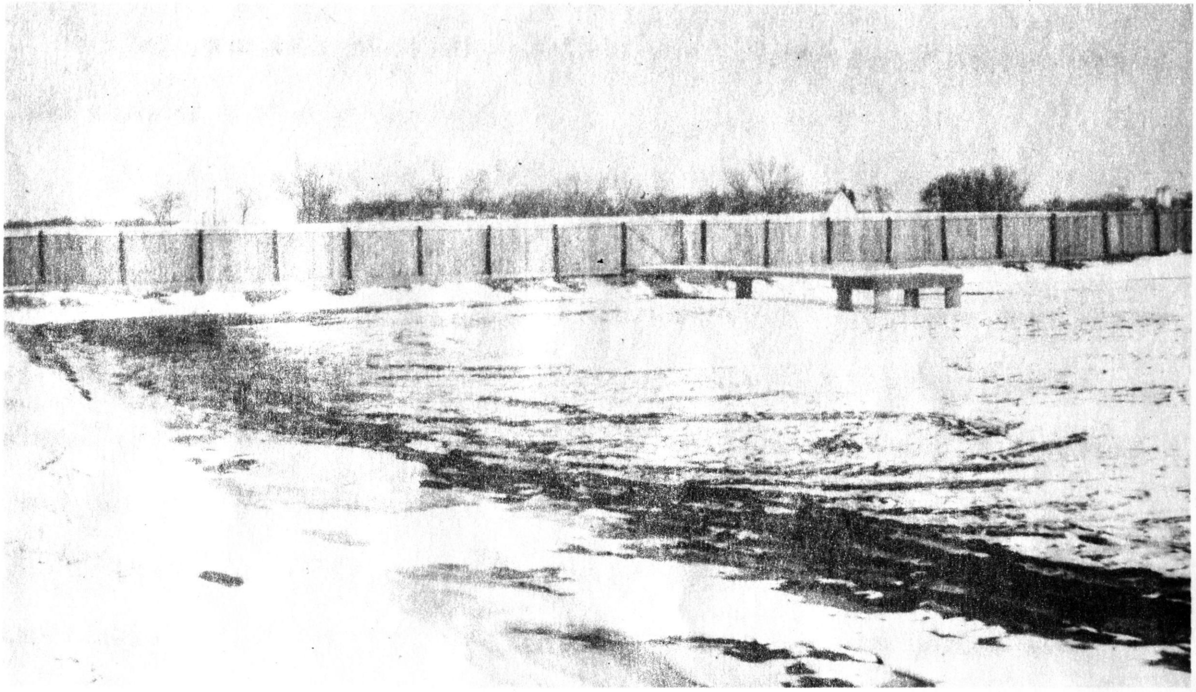

Figure 7. Anaerobic Pond No. 1 showing scum and crust formation

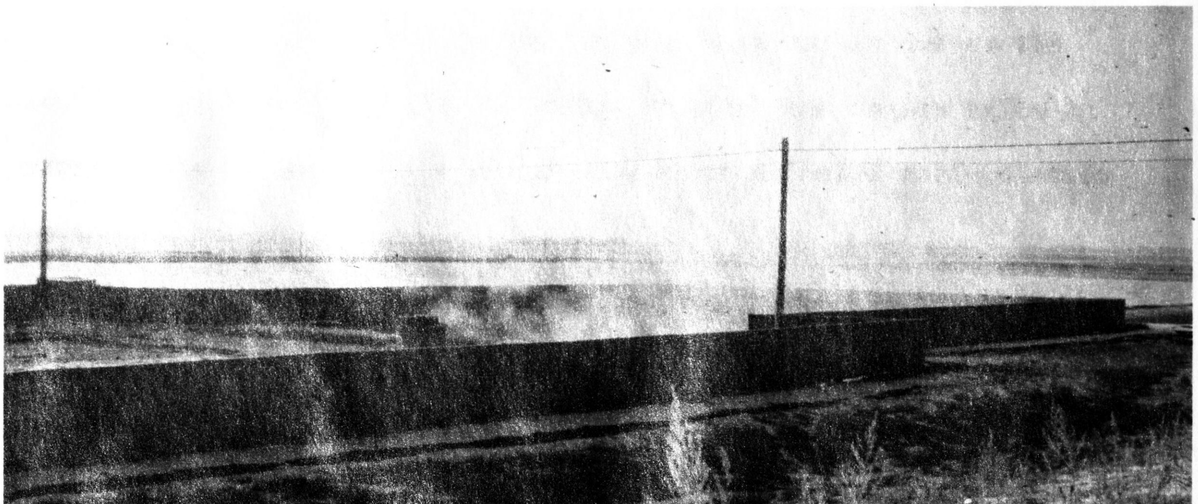

Figure 8. Evaporation and heat loss from Anaerobic Pond No. 2

times less than that of Anaerobic Pond No. 2 which has a liquid surface exposed directly to the air.

The temperature of the influent to the ponds dropped to between 50 and 60°F on Sundays. Because of the low flows, this drastic one-day drop in temperature did not exert a serious detrimental effect on the pond effluent temperature. Since the Sunday flow is almost exclusively clear water from the coolers, it could be diverted from the treatment ponds.

The data in Table 13 has been presented to aid in comparing the anaerobic-aerobic pond performance during the test period with that anticipated from its design.

From Table 13, it may be calculated that the total volumetric loading to the anaerobic ponds was found to exceed the anticipated value by 24 per cent. This larger volume was probably due to the somewhat higher beef production, which exceeded the design value by approximately 11 per cent, and a greater-than-expected recirculation rate to the rendering plant.

The actual influent waste BOD shown in Table 13, is below the design value. Although it would consequently appear that a lower value could be used, the original 10 lb. BOD per 1000 lb. live weight is probably justified on the basis of loading variations and the trend toward gradual increases in production.

Table 13 also indicates that the anaerobic ponds experienced an organic loading approximately 19 per cent less than the 20 lb. of

TABLE 13.
Evaluation of Anaerobic-Aerobic Pond Treatment System

	Anticipated	Actual
Design Information		
Kill; 1000 lb. live wt.	452	513
BOD; lb. per 1000 lb. live wt.	10	7.1 a/
Flow; 1000 gal.	330	408
Anaerobic Pond System		
BOD loading of Pond No. 1; lb. per 1000 cu. ft.	20	16.1
Minimum temperature Pond No. 1; °F	75	75
Detention time Pond No. 2; days	1.5	1.2
BOD removal efficiency; per cent	75	58.2
Aerobic Pond System		
BOD loading; lb. per acre per day	25	33.8
Effluent BOD; mg/l	30	13-30 b/

a/ After grease removal
b/ Recorded during periods of discharge only

BOD per 1000 cu. ft. per day upon which the design was based. This decreased loading may have a detrimental effect on the efficiency of the anaerobic units. McKinney (1-253) points out the significance of maintaining high organic loadings in anaerobic digestion systems and states:

> One of the major fallacies in biological engineering problems is the calculation of unit sizing and then doubling the size as a safety factor. Excess capacity does not act as a safety factor, but rather acts as a retarding factor since it reduces the microbial population below that required for good stabilization.

Although Table 13 indicates a small difference between the actual and design detention times of Anaerobic Pond No. 2, this unit, designed primarily as a settling basin, was found to remove less than 20 per cent of the suspended solids. This disclosure suggests that it might be advantageous to degasify the influent to this cell to eliminate the bouyant effect caused by the gases and thereby increase the settling efficiency of this unit. This could possibly be accomplished by sealing the Anaerobic Pond No. 1 outlet structure to make it air-tight and then applying a vacuum to it thereby reducing the pressure on the effluent. Since this process has been successfully employed in anaerobic contact systems (27), it would appear to merit consideration for use in anaerobic lagoon systems. If degasification were not practical from an economic standpoint, this cell could be considered as a second stage digester or "transitional" pond as advocated by Coerver (32) rather than a sedimentation basin.

The 58.2 per cent BOD reduction in the anaerobic system was below the 75 per cent anticipated. Since the test data indicate that the desired minimum temperature was maintained, the lower-than-expected BOD reductions may be due to factors other than temperature. The importance of thorough mixing in the anaerobic process has been stressed by many writers (1-254)(27)(28)(33)(36). Although provisions were included for recirculation of the Anaerobic Pond No. 1 contents in the design, these facilities have not yet been operated nor their effect evaluated.

The BOD loading imposed upon the aerobic system would appear to be approximately 35 per cent above the anticipated value of 25 lb.

per acre per day. However, these loadings were based on parallel operation of the aerobic ponds. Since the aerobic ponds have operated in series instead of parallel, the load to Aerobic Pond No. 1 was 67.7 lb. per acre per day as shown in Table 11. In spite of this high loading, nuisance conditions have not developed. The success of operating this cell at a loading of nearly three times the design value might be attributed to a change in the nature of the organic material making it more easily assimilated by aerobic organisms. This can be substantiated by the high deoxygenation constant, 0.23, of the anaerobic pond system effluent.

The importance of preceding an aerobic pond system with an anaerobic process was pointed out by Ludwig (37):

> It is a good idea to include in the design a preliminary anaerobic digestion chamber or septic tank.....because, in effect, this is a guarantee that the subsequent oxidation pond will function without the production of odors.

The reported final effluent BOD concentration included in Appendix I and Tables 10 and 13 were obtained from samples collected during the warmer months when discharge to the receiving stream occurred. As shown in the above-mentioned tabulations, these concentrations ranged from 13 to 30 mg/l. This represents an overall reduction of 95 per cent through the entire anaerobic-aerobic system. The 35-week storage capacity was provided in the aerobic system in order to eliminate the necessity of discharging treated wastes during the winter months. This provision is apparently justified since, a BOD concentration in excess of 200 mg/l was found to occur under ice cover in the aerobic cells.

SUMMARY AND CONCLUSIONS

Several important observations have been made from a survey of the literature relative to anaerobic-aerobic stabilization ponds.

1. Although the term "anaerobic stabilization pond" presently encompasses a wide variety of physical forms represented by different depths, shapes, etc., the one factor common to all such units is that the basic treatment process employed is anaerobic digestion.

2. The amount of published data regarding the anaerobic digestion process is sufficient to obtain a basic understanding of the theoretical aspects of the treatment mechanisms.

3. The wastewater produced by most meat processing establishments is readily amenable to anaerobic digestion.

4. The response of the anaerobic contact process to certain variations in loading, temperature, etc., has made it possible to roughly anticipate the response of the anaerobic stabilization pond to these same variations.

5. There is very little published information available regarding anaerobic ponds.

6. Reductions in BOD ranging from 65 to 92 per cent have been reported for anaerobic stabilization ponds treating meat processing wastes.

7. Combined anaerobic-aerobic pond systems treating these wastes have produced BOD removals ranging from 83 to 99 per cent.

8. Based on BOD reductions, there is an apparent advantage in employing a combination of anaerobic and aerobic ponds.

Investigations of the anaerobic-aerobic stabilization pond performance at the M.I.D. Packing Co. abattoir near Luverne, Minnesota, have resulted in several disclosures which might be of value to those designing similar facilities.

The wastewater from this establishment, which represents a medium-sized slaughterhouse employing numerous methods to reduce the amount and strength of its processing wastes, can be expected to produce the following unit pollutional contribution in terms of the number of animals processed.

Unit	Per 1000 lb. live wt.
Waste Flow	800 gal.
5-Day BOD	7.1 lb.[a]
Suspended Solids	3.5 lb.[a]

[a] Following grease removal

The treatment system appears to be providing acceptable suspended solids reductions. However, the BOD reduction through the anaerobic ponds is lower than desired. A heavier BOD loading to Anaerobic Pond No. 1 and recirculating the contents of this unit to provide better mixing could possibly increase this treatment efficiency.

The apparently substantial insulation value of the grease-scum layer covering Anaerobic Pond No. 1 has been one of the most encouraging findings regarding the anaerobic system. The need for applying external heat to the wastewater in order to maintain the desired 75°F temperature is probably not required, even in the severe climate in which this system is located.

Although Anaerobic Pond No. 2 was designed to function as a settling basin, it appears to be of little value in reducing the solids concentration of the wastewater. This poor performance could possibly be attributed to the bouyant effect exerted on the solids due to gas evolved in the system. The efficiency of this unit might be increased by removing the gases from the liquid before it enters Anaerobic Pond No. 2 by applying a vacuum to the first anaerobic pond outlet structure.

This study indicates that the aerobic ponds when preceeded by the anaerobic system can successfully handle BOD loadings that are much higher than normally considered necessary to maintain odor-free performance.

In conclusion, the anaerobic-aerobic pond system as investigated appears to be an efficient and economical slaughterhouse waste treatment method. At an initial cost of about $7.00 per BOD population equivalent, it has provided comparatively nuisance-free operation along with overall removal efficiencies of approximately 95 per cent.

AREAS FOR FUTURE STUDY

This study suggests certain factors which would be worthy of investigation.

1. It has been suggested that the effect of mixing and higher BOD loadings on Anaerobic Pond No. 1 would be to increase the treatment efficiency of this unit. Investigation to verify this hypothesis would be of significant value to future designers.

2. It was shown that the grease-scum layer over the first anaerobic pond has substantial insulation value. A study to determine a reliable numerical value of the coefficient of thermal conductivity of this layer would be a tangible contribution to the rational design of units.

3. Degasification by vacuum methods may be a means of increasing the solids reduction efficiency of the second anaerobic cell. An investigation to ascertain the effect of Anaerobic Pond No. 1 effluent degasification on the solids reduction through the second anaerobic cell would resolve the question of whether or not it is economically feasible to adapt this process to an anaerobic lagoon.

4. It would be advisable to obtain performance data throughout an entire year on a bi-weekly or monthly basis to extend the information obtained and to determine the seasonal variations in treatment efficiency.

5. Performance data of the aerobic ponds should be obtained on a regular basis to more clearly define the relationship between the anaerobic and aerobic ponds.

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APPENDIX I

TABLE A-1

ANALYTICAL DETERMINATIONS

Station No. 1 - Raw Waste After Grease Removal

M.I.D. Packing Co. - March 4-12, 1964

Analysis[a]	Date[b] 4	6	7	8	9	10	11	12	Ave.[c]
5-Day BOD	790	980	1100	66	1000	780	950	980	940
COD	1200	1400	1300	160	1400	1200	1200	--	1285
Suspended Solids	430	540	430	67	520	400	420	--	457
Sus. Volatile Solids	380	460	380	50	440	340	360	--	394
Total Volatile Solids	710	860	830	220	870	760	800	--	805
Total Solids	1800	2000	2100	980	3500	3200	2300	--	2480
pH	6.6	6.7	6.8	6.8	6.5	7.0	6.5	6.8	6.7
Chlorides	290	260	350	150	790	750	510	--	492
Total Phosphorous	6.1	6.8	7.4	1.1	6.0	6.2	4.8	--	6.2
Ammonia	32	31	32	5.8	34	34	40	--	34
Organic Nitrogen	44	50	50	8.4	41	49	44	--	46

a/ In mg/l except for pH

b/ March, 1964

c/ March 4 through 12, excluding Sunday, March 8.

APPENDIX I

TABLE A-2

ANALYTICAL DETERMINATIONS

Station No. 2 - Anaerobic Pond No. 1 Effluent
Anaerobic Pond No. 2 Influent

M.I.D. Packing Co. - 1963-64

	Date[b]											
Analysis[a]	7/24/63[c]	9/5/63[e]	2/19/64[e]	4	6	7	8	9	10	11	12	Ave.[f]
5-Day BOD	491	250	600	480	500	540	490	480	500	400	610	502
COD	--	500	810	630	660	630	560	640	640	650	--	642
Suspended Solids	176	78	230	170	170	150	110	160	150	150	--	158
Suspended Volatile Solids	164	66	200	150	150	140	100	140	140	140	--	143
Total Volatile Solids	452	200	570	490	530	470	420	460	510	510	--	495
Total Solids	1900	1200	2100	1800	1600	1600	1500	1900	2000	2200	--	1850
pH	6.8	--	6.8	6.5	6.5	6.7	6.4	6.4	6.8	6.4	6.8	6.6
Chlorides	--	370	550	440	350	350	270	410	510	630	--	448
Total Phosphorous	--	3.3	7.0	6.1	6.7	6.6	6.0	5.9	6.2	5.8	--	6.2
Ammonia	53.5[d]	30	70	64	65	65	68	61	60	65	--	63
Organic Nitrogen	--	5.6	--	16	15	14	14	12	16	16	--	15
Settleable Solids	1.1	--	--	--	--	--	--	--	--	--	--	--

a/ In mg/l except for pH
b/ March, 1964, except as noted
c/ Samples collected on this date and analyzed by Robert O. Knutson, Chemist, Austin, Minnesota
d/ Kjeldahl
e/ Samples collected on this date and analyzed by Minnesota Department of Health
f/ March 4 through 12 excluding Sunday, March 8

APPENDIX I
TABLE A-3
ANALYTICAL DETERMINATIONS
Station No. 3 - Anaerobic Pond No. 2 Effluent
M.I.D. Packing Co. - 1963-64

	Date[b]											
Analysis[a]	7/24/63[c]	9/5/63[e]	2/19/64[e]	4	6	7	8	9	10	11	12	Ave.[f]
5-Day BOD	411	220	370	350	530	490	520	470	430	340	595	458
COD	--	510	650	590	630	560	530	550	580	610	--	587
Suspended Solids	176	88	174	140	150	120	92	110	120	130	--	128
Suspended Volatile Solids	150	74	150	130	130	110	86	96	110	120	--	116
Total Volatile Solids	384	200	490	450	460	450	440	400	440	500	--	450
Total Solids	1635	1400	1900	1800	1700	1500	1500	1700	1800	2000	--	1750
pH	6.9	--	6.8	6.6	6.6	6.7	6.5	6.5	6.9	6.5	7.0	6.7
Chlorides	--	350	500	490	460	350	300	370	410	460	--	423
Total Phosphorous	--	3.6	7.8	6.0	6.6	6.5	6.4	6.0	5.7	5.5	--	6.0
Ammonia	53.2[d]	32	70[d]	64	65	65	65	63	61	66	--	64
Organic Nitrogen	--	7.0	--	16	14	14	12	10	16	14	--	14
Settleable Solids	1.5	--	--	--	--	--	--	--	--	--	--	--

a/ In mg/1 except for pH
b/ March, 1964, except as noted
c/ Samples collected on this date and analyzed by Robert O. Knutson, Chemist, Austin, Minnesota
d/ Kjeldahl
e/ Samples collected on this date and analyzed by Minnesota Department of Health
f/ March 4 through 12 excluding Sunday, March 8

APPENDIX I
TABLE A-4
ANALYTICAL DETERMINATIONS
Aerobic Pond
M.I.D. Packing Co. - 1963-64

Analysis[a]	Aerobic Pond No. 1 - Effluent			Aerobic Pond No. 2 - Effluent		
Date	7/24/63[b]	9/5/63[d]	2/19/64	7/24/63[b]	9/5/63[d]	2/19/64[d]
5-Day BOD	101	90	230	30	20 & 13[e]	280
COD	--	500	380	--	380	450
Suspended Solids	38	140	76	110	88	--
Suspended Volatile Solids	30	130	62	102	48	--
Total Volatile Solids	324	270	360	343	170	--
Total Solids	1846	1600	1800	2193	1600	--
pH	7.2	--	7.3	8.1	--	--
Chlorides	--	460	440	--	560	930
Total Phosphorous	--	5.2	7.4	--	1.7	9.2
Ammonia	49.6[c]	6.9	63[c]	19.6[c]	1.0	61[c]
Organic Nitrogen	--	13	--	--	7.6	--
Settleable Solids	0.15	--	--	Trace	--	--

a/ In mg/l except for pH
b/ Samples collected on this date and analyzed by Robert O. Knutson, Chemist, Austin, Minnesota
c/ Kjeldahl
d/ Samples collected on this date and analyzed by Minnesota Department of Health
e/ Filtered

APPENDIX II

TABLE B-1

BEEF KILL & FLOW DATA

M.I.D. Packing Co. - March 4-12, 1964

Date	24 Hr. Ave. Flow Rate GPM[d]		Ave. Total Daily Flow MGD[e]		Kill	Ave. Live Wt.	Total Live Wt.	Gal/1000 Lb. of Live Wt.	
March	Raw	w/Recirc[a]	Raw	w/Recirc[a]	Beef	Lb.	1000 Lb.	Raw	w/Recirc[a]
4(Wed)	295	370	0.424	0.532	423	1215	513.95	82.5	104.0
6(Fri)	278	353	0.400	0.508	427	1260	538.02	74.4	94.5
7(Sat)	279	354	0.402	0.510	380	1210	459.80	87.5	111.0
8(Sun)	136	136	0.196	0.196	0	0	0	0	0
9(Mon)	291	366	0.419	0.527	403	1319	531.56	78.8	99.0
10(Tues)	257	332	0.370	0.478	400	1271	508.40	72.8	94.0
11(Wed)	269	344	0.388	0.496	427	1244	531.19	73.0	93.5
12(Thurs)	317	392	0.456	0.564	401	1269	508.87	89.6	110.5
Average w/Sun[b]	2655	331	0.3820	0.4760					
Average w/oSun[c]	2840	359	0.4080	0.5160	409	1255	513.0	79.7	101.0

[a] With rendering plant recirculation included
[b] With Sunday included
[c] Without Sunday
[d] Gallons per day
[e] Million gallons per day

APPENDIX III
TABLE B-2
BOD DATA
RAW WASTE BOD

Date March (1)	Anaerobic Pond No. 1 Influent: 24 Hr. Ave. Flow (w/recirc)[a] MGD[b] (2)	BOD Mg/1 (3)	Lb. BOD/Day (4) 8.34(2)(3)	Anaerobic Pond No. 2 Effluent: 24 Hr. Ave. Flow MGD[b] (5)	BOD Mg/1 (6)	Lb. BOD/Day (7) 8.34(5)(6)	Recirculation: Recirc. Rate MGD[b] (8)	Lb. BOD/Day (9)	Raw BOD Mg/1 (10) (4)-(9)
4(Wed)	0.5320	790	3500	0.3870	350	1130	0.1080	315	3185
6(Fri)	0.5080	980	4160	0.3780	530	1670		477	3683
7(Sat)	0.5100	1100	4680	0.3638	490	1485	0.1080	441	4239
8(Sun)	0.1960	66	1079	0.1223	520	530	--	--	1079
9(Mon)	0.5270	1000	4400	0.4485	470	1758	0.1080	423	3977
10(Tues)	0.4780	780	3110	0.3653	430	1310		387	2723
11(Wed)	0.4960	950	3930	0.3945	340	1120		306	3624
12(Thurs)	0.5640	980	4610	0.4410	595	2190	0.1080	536	4074

[a] With rendering plant recirculation included
[b] Million gallons per day

APPENDIX III

TABLE B-3

BOD DATA

BOD/1000 LB. LIVE WEIGHT AND REDUCTIONS THROUGH ANAEROBIC SYSTEM

Date (1)	Raw BOD Lb./Day (2)	Total Live Wt. Lb./Day (3)	Lb. BOD/10^3 Lb. of Live Wt. (4)	Anaerobic No. 2 Effluent BOD Lb./Day (5)	Percent Reduction Through Anaerobic System (6)
4(Wed)	3185	513.95	6.20	1130	64.5
6(Fri)	3683	538.02	6.85	1670	54.6
7(Sat)	4239	459.80	9.21	1485	65.0
8(Sun)	1079	0.0	-	530	50.9
9(Mon)	3977	531.56	7.48	1758	55.7
10(Tues)	2723	508.40	5.36	1310	51.9
11(Wed)	3624	531.19	6.81	1120	69.1
12(Thurs)	4074	508.87	8.01	2190	46.3
Average w/Sun[a]	3320	449.0	6.24	1400	57.3
Average w/o Sun[b]	3645	513.0	7.13	1523	58.2

[a] With Sunday included

[b] Without Sunday

APPENDIX IV
TABLE D-1
SUSPENDED SOLIDS DATA
Raw Waste Suspended Solids

Date March (1)	Anaerobic Pond No. 1 Influent: 24 Hr. Ave. Flow (w/recirc)[a] MGD[b] (2)	Anaerobic Pond No. 1 Influent: Suspended Solids Mg/1 (3)	Anaerobic Pond No. 1 Influent: Lb. Suspended Solids/Day (4) 8.34(2)(3)	Anaerobic Pond No. 2 Effluent: 24 Hr. Ave. Flow MGD (5)	Anaerobic Pond No. 2 Effluent: Suspended Solids Mg/1 (6)	Anaerobic Pond No. 2 Effluent: Lb. Suspended Solids/Day (7) 8.34(5)(6)	Recirculation: Recirculation Rate MGD (8)	Recirculation: Lb. Suspended Solids/Day (9) 8.34(6)(8)	Raw Waste: Lb. Suspended Solids/Day (10)
4(Wed)	0.5320	430	1910	0.3870	140	452	.108	126	1784
6(Fri)	0.5080	540	2280	0.3780	150	472	.108	135	2145
7(Sat)	0.5100	430	1830	0.3638	120	364	.108	108	1722
8(Sun)	0.1960	67	109	0.1223	92	94	0	0	109
9(Mon)	0.5270	520	2280	0.4485	110	411	.108	99	2181
10(Tues)	0.4780	400	1590	0.3653	120	365	.108	108	1482
11(Wed)	0.4960	420	1740	0.3945	130	433	.108	117	1623
12(Thurs)	0.5640	--	--	0.4410	--	--	.108	--	--

[a] With rendering plant recirculation included
[b] Million gallons per day

APPENDIX IV
TABLE D-2
SUSPENDED SOLIDS DATA
SUSPENDED SOLIDS/1000 LB. LIVE WEIGHT AND REDUCTIONS THROUGH ANAEROBIC SYSTEM

Date (1)	Raw Suspended Solids (2)	Total Live Wt. Lb./Day (3)	Lb. Suspended Solids/1000 Lb. of Live Wt. (4)	Anaerobic Pond No. 2 Effluent Lb./Day (5)	Per cent Suspended Solids Reduction (6)
4(Wed)	1,784	513.95	3.46	452	74.6
6(Fri)	2,145	538.02	3.98	472	78.0
7(Sat)	1,722	459.80	3.76	364	78.7
8(Sun)	109	0.0	--	94	13.7
9(Mon)	2,181	531.56	4.10	411	81.1
10(Tues)	1,482	508.40	2.92	365	75.4
11(Wed)	1,623	531.19	3.06	433	73.3
Totals w/Sun[a]	11,046	3082.92	21.28	2591	474.8
Totals w/o Sun[b]	10,937	3082.92	21.28	2497	461.1
Average w/Sun	1,576	441.0	3.04	370	67.9
Average w/o Sun	1,820	514.0	3.54	417	76.9

a/ With Sunday included
b/ Without Sunday

APPENDIX V

THERMAL CONDUCTIVITY COEFFICIENT OF ANAEROBIC LAGOON SURFACE

NOTE: This calculation is based on the following formula (15-598):

$$H_2 = A_t (T_t - T_e)(C_1)$$

Where:

H_2 = BTU lost from cell, per day

A_t = surface area of cell; top, bottom and sides, sq. ft.

T_t = temperature inside cell, °F

T_e = temperature outside cell, (Air temp.), °F.

C_1 = coefficient of thermal conductivity in BTU per hour per square foot of surface per °F difference of temperature

<u>Anaerobic Pond No. 1</u> (From Table 12).

$$21.8 \times 10^6 = 51.2 \times 10^3 (76.9 - 25.4) C_{A1}$$

$$C_{A1} = 8.25$$

<u>Anaerobic Pond No. 2</u> (From Table 12).

$$40.5 \times 10^6 = 22.6 \times 10^3 (67.4 - 25.4) C_{A2}$$

$$C_{A2} = 42.7$$

<u>Coefficient Comparison</u>

$$\frac{C_{A2}}{C_{A1}} = \frac{42.7}{8.3} = 5$$