S&A-TSB-8

DESIGN CONSIDERATIONS FOR AEROBIC DIGESTERS

U.S. ENVIRONMENTAL PROTECTION AGENCY
SURVEILLANCE AND ANALYSIS DIVISION
TECHNICAL SUPPORT BRANCH
REGION VIII

DESIGN CONSIDERATIONS FOR AEROBIC DIGESTERS

by

BOB A. HEGG[1]

and

KERWIN L. RAKNESS[2]

(1) At the time this report was prepared, Mr. Bob A. Hegg was employed as Chief of the Operation and Maintenance Section, USEPA, Denver, Colorado. At present, he is employed as Chief Sanitary Engineer, M & I Incorporated Consulting Engineers, Fort Collins, Colorado.

(2) At the time this report was prepared, Mr. Kerwin L. Rakness was employed as Sanitary Engineer, Operation and Maintenance Section, USEPA, Denver, Colorado. At present, he is employed as Sanitary Engineer, FMC Corp., Environmental Equipment Division, Englewood, Colorado.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

I. INTRODUCTION

In recent years aerobic digestion of sludge has become an increasingly popular method of stabilizing sludges prior to ultimate disposal. Many of the design requirements, however, have been based on laboratory studies and many of the parameters that affect operation and performance of aerobic digesters have not been studied in detail. As a result, specific design requirements that would insure consistently good performance from all aerobic digesters have not been developed.

Formerly, the Technical Investigation Branch of the Surveillance and Analysis Division, and presently, the Operation and Maintenance Section of the Air and Water Division, provides as one of its functions technical assistance concerning the operation and maintenance of wastewater treatment facilities. This assistance normally is in the form of on-site operator training and plant evaluation. Another specific objective of this program is to provide "feedback" concerning various design and training deficiencies based on actual operational experiences and observations. The following data on aerobic digesters represents the result of such experience plus a summarization of other pertinent design data.

II. PURPOSE AND SCOPE

The purpose of this report is to summarize information concerning the design of an aerobic digester.

The parameters presented are based on information from various literature sources and from actual plant operating experiences.

III. SUMMARY OF DESIGN CONSIDERATIONS

Aerobic digestion of sludges has become an increasingly popular method of sludge handling, especially in smaller plants. This method of sludge treatment competes favorably with the anaerobic digestion process because aerobic digestion does not require extensive process control or equipment (i.e. controlled temperatures, pH, alkalinity, etc.). This does not mean that aerobic digesters will perform satisfactorily without some process control or without proper design. The emphasis in the following summary will be to provide design considerations to insure satisfactory results using aerobic digestion.

A. GENERAL INFORMATION

1. Process Description

Aerobic sludge digestion is a process in which waste sludges are subjected to aeration by various means to oxidize the organic matter thus reducing the amount of sludge and making it less objectionable aesthetically. The process uses primarily the endogenous respiration (auto-digestion) phase of metabolism to convert cell protoplasm and other biologically degradable matter to carbon dioxide, water, and ammonia. Ammonia is further converted sequentially to nitrite (NO_2^-) and nitrate (NO_3^-).

After a period of time (days) a final material is produced that consists of inorganic solids and organic solids that resist further biological destruction. This material or sludge, is suitable for ultimate disposal (land application, land fill, incineration, etc.). All types of sludges have been subjected to aerobic digestion including primary sludge, waste activated sludge, trickling filter humus, combinations of primary and secondary sludges and industrial sludges.

2. <u>Process Operation</u>

Sludge is normally wasted to an aerobic digester from either the primary or secondary clarifier or both. In some instances a sludge thickener is used to concentrate the sludge prior to discharge to the digester. In most secondary plants, secondary sludge is wasted to the primary clarifiers and the combined secondary sludge and primary sludge is then wasted to the aerobic digester.

Sludge can be wasted to an aerobic digester continuously or intermittently (batch operation). If sludge is wasted to an aerobic digester continuously, normally constant supernatant removal is required. To obtain constant supernatant removal a quiescent zone in the digester must be provided to allow for solids liquid separation.

In practice effective, continuous removal of supernatant is difficult to achieve due to the turbulence caused by aeration in the aerobic digester which can effect the quiescent zone. Solids liquid separation can become inefficient in these cases and as a result many solids are contained in the supernatant. To avoid the adverse effects that can be associated with continuous supernatant removal, many aerobic digesters are operated on the batch process approach. The air to the digester is shut off to allow time for solids liquid separation. Supernatant is then decanted from the digester and the air is turned back on. If diffused air or floating mechanical aerators are used, the liquid level in the aerobic digester is not critical and the digester may be refilled with waste sludge in increments until it reaches a level where supernatant drawoff is again required. If fixed mechanical aeration is used, the digester must be refilled to an established level so that aeration is effective.

Operational problems are encountered when supplying oxygen to aerobic digesters. In diffused air systems clogging is frequently encountered in batch operated aerobic digesters because of the on-off operation associated with supernatant removal. Clogging is also encountered in continuously operated digesters because of the high concentration of sludge solids. In both instances, routine maintenance is required to insure a continuous adequate supply of oxygen from a diffused air system. Mechanical aeration systems become less effective when rags and other debris collect on the blades of the aerators. This also represents a maintenance problem and requires routine attention in order to insure that adequate oxygen is supplied to the digester.

Usually digested sludge is withdrawn from an aerobic digester when a clear supernatant can no longer be decanted following a period of settling. Other criteria which indicate that the sludge has been stabilized can be determined by laboratory testing. These criteria are discussed later in the report.

3. Process Reactions

The reactions that take place in an aerobic digester depend in part on the type of sludges wasted to the system. When primary sludges are added to an aerobic digester, non cellular organic solids are converted to activated sludge prior to undergoing auto digestion. In other words, solids (cells) growth will occur before endogenous respiration or cell destruction can proceed.

Sludges wasted from activated sludge processes have already been converted to cellular material and do not require a preliminary growth phase before endogenous respiration or cell destruction can proceed. This important concept must be considered when designing an aerobic digester.

The following discussion includes the effect of primary sludges, on the reactions that occur in the aerobic digestion process. Aerobic bacteria require oxygen and organic matter in order to live and reproduce. A simplified equation of this growth process is:

O_2 + microorganisms + organic matter =

activated sludge + CO_2 + H_2O

As aerobic digestion proceeds, the available food is depleted and becomes inadequate for net activated sludge production. At this point the aerobic bacteria begin to feed on cell protoplasm. The rate of cell destruction exceeds the rate of cell synthesis and endogenous respiration (auto digestion) becomes the predominant metabolic reaction. The organic matter derived from cell protoplasm is converted to CO_2, H_2O, and NH_4^+. The ammonium ion is further converted to nitrites ($NO2$) and nitrates (NO_3).

The two end products removed from the aerobic digester are the supernatant liquor and the digested sludge solids. The supernatant liquor from the aerobic digestion process is quite different than the supernatant liquor produced from the aerobic digestion process. A well digested sludge supernatant from an aerobic digester will have a low suspended solids content and will be quite clear. The 5-day biochemical oxygen demand (BOD_5) of an aerobic digester's supernatant is normally low (less than 100 mg/l) since most of the BOD_5 is used as food by the "starving" aerobic bacteria. This low BOD_5 content reduces the impact of the supernatant liquor that may be returned to the treatment system. The nutrient content is generally quite high with the nutrients being in the form of nitrates and phosphates.

The digested sludge drawn from an aerobic digester should be dark brown, have a musty odor, and have good settling characteristics. The solids content of the digested sludge varies with the type of sludge fed to the digester. Ranges have been reported (1) from 1.5 percent to 6.0 percent solids by weight. The drainability (ability to dewater on drying beds) of well digested aerobic sludges is generally better than that of anaerobically digested sludges. However, when sludge is aerobically digested for short periods of time (less than ten days) it has poor drainability characteristics.

Changes in various parameters can be used to determine the degree of sludge digestion in aerobic digesters. Conversion of ammonium ion to nitrates will occur, therefore a decrease in NH_4^+ concentration and an increase in the nitrate concentration should occur. Biological activity will decrease the alkalinity of the digester contents. Also the pH of the contents will decrease. The volatile solids concentration of the sludge will decrease due to the endogenous respiration (auto digestion) that takes place. All of these reactions will occur if digestion is proceeding satisfactorily.

4. Design Factors

Many factors affect the design of an aerobic digester. Some of the more important factors are: The type of sludge(s) wasted to the digester; the size of the digestion facility; the temperature of the digester contents; and the quantity of oxygen required. These factors are discussed in detail later.

Other factors affecting design are sludge loading rates, ultimate disposal considerations, water quality criteria (i.e. required nutrient removal), and various operational considerations.

5. Advantages of Aerobic Digestion

   a. Capital costs are normally lower than those of an anaerobic system or other methods of handling sludge.

   b. The end product has no objectionable odors and is biologically stable.

   c. Supernatant liquors have a lower BOD_5 than those from an anaerobic system, thus recycling of supernatant liquors does not have as great an impact on the performance of the treatment facility.

   d. Extensive process controls are not required and therefore operational problems are generally reduced.

6. Disadvantages of Aerobic Digestion

   a. High power costs are required to supply the dissolved oxygen.

   b. Methane gas is not produced and thus a useable end product is not available.

   c. Temperatures greatly affect the performance by causing increases or decreases in biological activity.

d. Little information has been available on such important design parameters as loading rates, air requirements, ultimate disposal methods, effects of varying sludge characteristics, sludge age requirements, and others. This limits the use of aerobic digestion in many facilities because engineers would not design a system based on the limited information.

B. UNIT SIZES

The following section describes the rational used in selecting the criteria for sizing an aerobic digester. A summary of this criteria is presented in the various tables.

1. Design Factors

Several parameters have been used as a basis for designing the size of an aerobic digester. Two of these parameters are loading rate (lbs. VSS/day/cu. ft.) and solids residence time (days). Of these parameters sufficient solids residence time (sludge age) is generally accepted as the major criteria for obtaining satisfactory sludge digestion. Although high loading rates appear to affect the performance of the aerobic digester, limited information is available on this parameter. Loading rates have been studied (5) in the range of 0.05 to 0.25 lbs. VSS/

day/cu. ft. When designing an aerobic digester, the loading rate should be determined but normally an overloading problem will not occur unless thickened sludge is fed to the aerobic digester.

Solids residence time (sludge age) is the major criterion selected for sizing an aerobic digester. Sludge age is defined in many different ways making it difficult to compare various values presented by different authors. The method used to calculate sludge ages for this paper is outlined below. The difference between sludge age and hydraulic detention time is also discussed.

Figure 1 shows a typical flow schematic for an aerobic digester and the symbols used to describe each parameter. The sludge age is defined as the ratio of the weight of solids in the digester to the weight of solids leaving the digester daily. Therefore, during "steady state" conditions the equation for sludge age using the symbols shown in Figure 1 is:

$$\text{Sludge Age (days)} = \frac{\text{ADV} \times \text{ADC}}{(\text{SPF} \times \text{SPC}) + (\text{USF} \times \text{USC})}$$

It is noted that if the digester is working properly, a minimum amount of solids should leave the digester in the supernatant liquor. Therefore, the term (SPF x SPC) should approach zero

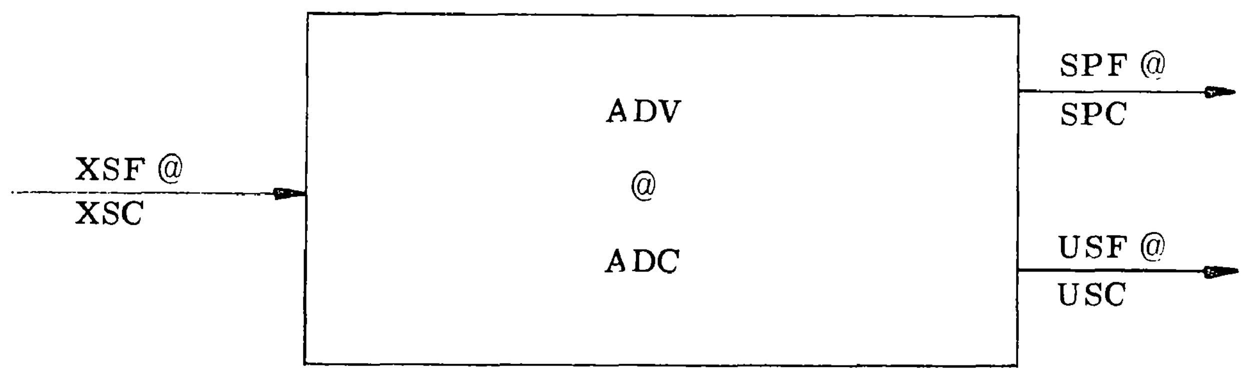
FIGURE 1

SUGGESTED DESIGN CONSIDERATIONS
FOR AEROBIC DIGESTERS

August 1974

DIGESTER FLOW SCHEMATIC

SINGLE STAGE
AEROBIC DIGESTER



WHERE:

XSF = waste sludge flow (gpm or gpd)
XSC = waste sludge concentration (mg/l)
ADV = aerobic digester volume (gal)
ADC = mean aerobic digester solids concentration (mg/l)
SPF = supernatant flow (gpm or gpd)
SPC = supernatant solids concentration (mg/l)
USF = sludge flow to ultimate disposal (gpm or gpd)
USC = sludge solids concentration (mg/l)

and the equation for sludge age simplifies to:

$$\text{Sludge Age} = \frac{ADV \times ADC}{USF \times USC}$$

The sludge age or solids residence time will always be equal to or greater than the hydraulic detention time due to the effect of solids destruction by digestion and solids accumulation by drawing off supernatant. Hydraulic detention time can be calculated as:

$$\text{Hydraulic Detention Time (days)} = \frac{ADV}{SPF + USF} \text{ or } \frac{ADV}{XSF}$$

Since:

$$XSF \approx SFL + USF$$

The XSF will normally be greater than the sum of SPF + USF due to evaporation.

Since sludge age is an important parameter in determining whether an aerobic digester performs satisfactorily or not, and since it is difficult to accurately predict the parameters required to calculate sludge age, the most common parameter used in the design of an aerobic digester is hydraulic detention time. Therefore, if a sludge age is selected and a digester is sized using the hydraulic detention time equal to the selected sludge age, the design should be adequate since the sludge age will always be greater than or equal to hydraulic detention time.

It is suggested that an aerobic digester be sized using the hydraulic detention time equal to a selected sludge age.

Many factors affect the selection of the sludge age to be used in designing an aerobic digester, and as a result, numerous values have been reported. Some authors have used total sludge age (i. e., sludge age in the secondary process plus the sludge age in the aerobic digester). Others (11, 15) consider only the sludge age in the aerobic digester.

In order to select the appropriate sludge age, two important factors which significantly affect sludge digestion should be considered. These factors are temperature and the type of process preceding the digester.

Low temperature reduces biological activity and increases the length of time required to stabilize sludge aerobically. Since these cold temperature portions of the year are critical, it is important to incorporate these conditions in the design of the digester. Lawton (5) noted that temperature has an appreciable effect with short detention times, but this effect decreased considerably as the detention time lengthened. Experience at the Trinidad, Colorado, Wastewater Treatment Plant (6) showed that a 5^{o} C decrease in sludge temperature, (from 15^{o}C to 10^{o}C) greatly inhibited biological activity as evidence by an increase in the dissolved oxygen concentration from almost zero to 2-3 mg/l, and by the fact that solids liquid separation could no longer be accomplished. Thus when low temperatures are encountered either increased sludge age accomplished by increasing the volume of the digester or additional equipment to maintain the temperature at 15^{o}C or greater should be provided.

The second factor which significantly affects sludge digestion is the type of process preceding the digester (i. e., the type of sludge wasted to the digester). For example, a digester that receives both primary and secondary sludge must be larger and provide a longer detention time (sludge age) in order to produce a stabilized sludge. A longer detention time is required because the primary solids must first be converted to "activated solids" before auto-digestion can proceed. Even if primary sludge is not wasted to an aerobic digester, care must be taken in selecting the required detention time because various activated sludge processes yield sludges that have experienced varying degrees of endogenous respiration. For example, a high rate process (normally associated with solids having a low sludge age) produces a sludge that has undergone a limited amount of endogenous respiration; whereas, the extended aeration processes (normally associated with solids having a high sludge age) produces a sludge that has undergone a considerable degree of endogenous respiration. To include these varying degrees of endogenous respiration, some authors suggest using the total sludge age as the design parameter (i.e., sludge age in the secondary process plus the sludge age in the aerobic digester). Ahlberg and Boyko (1) suggest that a minimum total sludge age of 45 days may be acceptable for the design of an aerobic digester.

The more conventional requirement for detention time in the aerobic digester has been 15 days hydraulic detention time. Others (2, 11) have suggested that 10 - 15 days hydraulic detention time is satisfactory if thickened activated sludge is wasted to the digester. Twenty days hydraulic detention time has been recommended when the waste sludge contains primary sludge solids. Table 1 presents a summary of suggested aerobic digester hydraulic detention times (i.e., minimum sludge ages) for various types of processes and various combinations of waste sludges.

TABLE I

SUGGESTED DESIGN CONSIDERATIONS

FOR AEROBIC DIGESTERS

AUGUST. 1974

HYDRAULIC DETENTION TIMES

Treatment Process and Type of Sludge	Suggested Detention Time in Aerobic Digester (Days)	Remarks
Waste Activated Sludges Alone	(Temperature effects not included - see 1 below)	
High Rate Processes	20-25	If a minimum total sludge age of
Conventional	15-25	45 days can be established with a
Step aeration	15-25	lesser hydraulic detention time in
Contact stabilization	15-20	the digester, then the lesser time
Extended aeration	15-20	in the digester may be used.
Primary + Waste Activated	20-30	
Primary Sludge Alone	>20	
Trickling Filter Sludge	20-30	
Other Sludges (industrial, etc.)	-----	It is recommended that pilot studies be conducted on unique sludges to ensure adequate digestion facilities.

1) If sludge temperatures are expected to be lower than 15°C, then additional detention time should be provided. It is suggested that an additional 5 to 10 days hydraulic detention time be included in the design when low temperature operations are expected. Also it is suggested that design steps be taken to minimize the periods of low temperature operation.

2. Estimating Digester Loadings

Once the hydraulic detention time has been selected, the next step in determining the unit size of an aerobic digester is to determine the volume of sludge that will be wasted to the digester (hydraulic loading). Hydraulic loading is a function of two factors: the quantity of solids produced by the treatment process, and the concentration at which these solids are wasted to the digester.

For a given wastewater stream, the quantity of solids produced (sludge yield) by a treatment process depends on the type of process used. Two of the most common types of treatment systems will be analyzed for sludge yields. The first system is the conventional type of plant that includes primary and secondary treatment, and the second system will include such processes as extended aeration where no primary treatment is provided.

The quantity of sludge wasted to the digester from a conventional (primary plus secondary) plant is equivalent to the total quantity of primary sludge plus the total quantity of secondary sludge. The total quantity of primary sludge is normally equal to 55 to 75 percent of the incoming suspended solids. The quantity of sludge from the secondary process depends on the strength of the incoming sewage and the type of secondary treatment process. Table 2 shows yield figures (lbs of suspended solids produced per lbs of BOD_5 removed) for various types of activated sludge processes. These values can be used as a guide if pilot data is not available.

The second type of system associated with aerobic digestion are the contact stabilization and extended aeration processes that normally don't have primary treatment preceding the secondary facilities. The sludge yield for these processes are outlined in Table 2. However, if these processes do not have separate primary treatment, additional sludge must be handled as a result of biologically inert volatile and suspended matter that enters the plant in the influent. One author (7) suggests that normal domestic sewage contains about

TABLE 2
SUGGESTED DESIGN CONSIDERATIONS
FOR AEROBIC DIGESTERS
AUGUST, 1974

SLUDGE YEILD FOR VARIOUS ACTIVATED SLUDGE PROCESSES (1)

	Avg. MLSS Concentration (mg/l)	Avg. Aeration Time (hrs.)	Avg. Loading Factor lb. BOD_5/ lb. MLVSS/day	Predicted (2) Process Yield lbs. TSS Produced lb. BOD_5 Removed	Suggested Design Yield lbs. TSS Produced lb. BOD_5 Removed
High Rate Processes	500	3	0.5-5.0	0.70-0.80	0.75
Conventional	2000	6-8	0.2-0.5	0.50-0.70	0.60
Step Aeration	2500	3-4	0.2-0.5	0.50-0.70	0.60
Contact (3) Stabilization	Contact 3000 Reaeration 6000	0.25-0.5 2-6	0.2-0.5	0.50-0.70	0.60
Extended Aeration	4000	24	0.05-0.2	0.15-0.50	0.35

(1) Values were calculated using following assumptions:

Y = yield coef. = 0.65 lb. VSS produced per lb. of BOD_5 removed.
K_d=endogenous coef. = 0.05 lb. VSS destroyed per lb. of VSS system.

VSS/TSS = 0.80

Waste is typically domestic with limited industrial.

(2) Industrial wastes may differ drastically and pilot studies are recommended in order to determine sludge yield.

(3) If these processes are not accompanied by primary treatment additional sludge must be handled as a result of the biologically inert volatile and suspended matter that enters the plant in the influent.

125 mg/l of inert suspended solids. Another (8) states that 20-40% of the volatile influent suspended solids plus 20-30% of the total influent suspended solids are biologically inert. Therefore, to determine the quantity of sludge produced by a process that does not have separate primary treatment both the quantity of biologically inert solids that enter the plant and the quantity of solids produced by the process must be calculated. The sum of these is equal to the total quantity of sludge produced by the system.

The next important step in determining the hydraulic load to the aerobic digester is determining the concentration at which the solids are wasted to the digester. For primary sludges the underflow concentration usually varies from 3 percent (30,000 mg/l) to 10 percent (100,000 mg/l) by weight. Normally a 5 percent (50,000 mg/l) underflow concentration for a primary sludge is assumed as a typical value. If industrial wastes, chemicals, or waste secondary sludges are added to the primary clarifier, then the resulting underflow concentration may either increase or decrease. This change in underflow concentration must be considered in design. For example, if waste activated sludge is added to the primary clarifier influent, the underflow concentrations of primary plus secondary sludges have been found in the range of 1.5 (15,000 mg/l) to 5 (50,000 mg/l) percent. For design it is suggested that an underflow concentration of 2 (20,000 mg/l) to 3 (30,000 mg/l) percent be used.

Little information is published giving clarifier underflow concentrations that can be expected with the various modifications of the activated sludge process. However, most sources give typical values for return sludge flow rates, sludge volume index, and mixed liquor suspended solids concentrations. Using the values and the physical mixing formulas, underflow concentration can be predicted. Table 3 summarizes the various underflow concentrations associated with several modifications of the activated sludge process. In addition, suggested design underflow concentrations are given. Processes whose parameters differ from the mixed liquor concentrations, loading rates, or detention times shown should be re-evaluated to determine the expected underflow concentration. When the required hydraulic detention time, quantity of solids produced, and underflow

TABLE 3
SUGGESTED DESIGN CONSIDERATIONS FOR AEROBIC DIGESTERS

AUGUST 1974
CLARIFIER UNDERFLOW CONCENTRATIONS FOR VARIOUS ACTIVATED SLUDGE PROCESSES

Treatment Process (Activated Sludge)	Avg. ML Concentration (mg/l)	Avg. Aeration Time (hrs.)	Avg. Loading Factor lb. BOD_5/ lb. MLVSS/day	Avg. Sludge Vol. Index (ml/gm)	Avg. Return Sludge Rate % of Flow	Predicted Range of Underflow Conc. (mg/l)	Suggested Design Underflow Conc. (mg/l)
High Rate	500	3	0.5-5.0	156-1000(1) 100- 300(2)	10-50(3) Avg. 20	1000-10,000	3500
Conventional	2000	6	0.2-0.5	63-156 80-150	15-75 Avg. 30	4700-15,800	7000
Step Aeration	2500	3-4	0.2-0.5	63-156 80-150	20-75 Avg. 50	5800-15,000	7000
Contact Stabilization	Contact Zone 3000 Reaeration Zone 6000	0.25-0.5 2-6	0.2-0.5	63-156 80-150	50-150 Avg. 100	5000-12,500	6000
Extended Aeration	4000	24	0.05-0.2	54-170 Avg. 100	50-200 Avg. 100	5900-25,000	9000

(1) Top valves taken from reference (8)

(2) Bottom valves taken from reference (9)

(3) Valves taken from reference (10)

concentration are determined, the size of the aerobic digester can be calculated. An example calculation is presented in the next section.

It is noted that the data presented in this section of the report assumed that no thickening device was being used. If sludge thickeners (i. e., air flotation units, centrifuges, gravity thickeners, etc.) are used, an increase in solids concentrations wasted to the digester can be expected and the digester capacity can be reduced accordingly.

3. Example Calculations

The following calculations are presented to demonstrate a method of determining the required size of an aerobic digester as suggested in this report.

Problem:

Design the unit size of an aerobic digester for a one million gallon per day treatment plant that has primary treatment followed by a conventional activated sludge system.

Given Parameters:

Influent flow = 1 mgd (0.044 m^3/sec)

Influent BOD_5 = 200 mg/l

Influent TSS = 250 mg/l

Allowable Effluent BOD_5 and TSS = 20 mg/l

Sludge Temperature in Digester = 15^o C

Design - Alternative #1:

Assume separate waste sludge streams from the primary and secondary clarifiers.

a) Determine the volume of sludge removed from the primary clarifier each day.

Assume 65% removal of influent TSS

Assume 5% (50,000 mg/l) underflow concentration.

Therefore, the quantity of TSS removed in the primary clarifier each day equals:

(1 MGD) (250 mg/l) (8.34 lb/gal) (0.65) = 1355 lb TSS/day (614.6Kg)

The volume of sludge wasted to the digester per day to remove 1355 lb. TSS at 5% underflow concentration equals:

(1352 lb TSS/day) (1/50,000 mg/l) (1/8.34 lb/gal) = 0.0032 MGD = 3250 gal/day (1.43×10^{-4} m^3/sec)

b) Determine the volume of excess activated sludge to be wasted from the secondary clarifier each day.

Assume sludge yield of $\frac{0.6 \text{ lbs TSS produced (Table 2)}}{\text{lb BOD}_5 \text{ removed}}$ $\left(\frac{0.6 \text{ Kg}}{\text{Kg}}\right)$

Assume 7000 mg/l underflow concentration (Table 3)

Assume 35% removal of BOD_5 in primary clarifier

The quality of BOD_5 removed in the secondary process equals (the quantity of BOD_5 in the influent) - (the quantity of BOD_5 removed in the primary + the quantity of BOD_5 in the effluent) or:

(1 MGD) (200 mg/l) (8.34 lb/gal) - (1 MGD) (200 mg/l) (8.34 lb/gal) (0.35) + (1 MGD) (20 mg/l) (8.34 lb/gal) = (1668 lb/day) - (584 lb/day + 167 lb/day) = 917 lb/day (415.9 Kg)

The quantity of sludge produced in the secondary process equals:

(917 lb BOD_5 removed/day) (0.6 lb TSS produced per lb BOD_5 removed) = 550 lb TSS produced/day (249.5 Kg)

The volume of sludge wasted to the digester per day to remove 550 lb TSS at 7000 mg/l underflow concentration equals:

(550 lb TSS/day) (1/7000 mg/l) (1/8.34 lb/gal) = .009420 MGD = 9420 gal/day ($4.13 \times 10^{-4} m^3/sec$)

c) Determine the volume of sludge wasted to the digester each day.

The total volume of sludge wasted to the aerobic digester is the sum of the volume wasted from the primary clarifier and the volume wasted from the secondary clarifier or:

$= (3250 \text{ gal primary/day}) + (9420 \text{ gal secondary/day})$

$= 12,670 \text{ gal/day } (5.56 \times 10^{-4} m^3/\text{sec})$

d) Determine the required size of the aerobic digester.

Assume Hydraulic Detention Time equals 25 days, (Table 1). The required volume of the digester equals: $(12670 \text{ gal/day})(25 \text{ day}) = 317,000 \text{ gal } (1200 \text{ m}^3)$

Design - Alternative #2

Assume that the secondary sludge is wasted to the primary clarifier and that the combined primary and secondary sludge is then wasted to the digester.

a) Determine the total pounds of sludge wasted to the digester each day.

The total pounds of sludge wasted to the digester each day is equal to the quantity of sludge removed by the primary clarifier (see Alternative #1) plus the quantity of sludge produced by the secondary process (see Alternative #1), or:

(1355 lbs TSS/day) + (917 lbs TSS/day) =

2272 lbs TSS/day (1030 Kg)

b) Determine the total volume of sludge wasted to the digester each day.

Assume 2.5% (25,000 mg/l) underflow concentration for the combined sludges.

The total volume of sludge wasted to the digester to remove 2272 lbs. TSS/day at 2.5% underflow concentration equals:

(2272 lbs. TSS/day)(1/25,000 mg/l)(1/ 8.34 lb/gal) =

.0109 MGD = 10,900 gal/day ($4.78 \times 10^{-4} m^3/sec$)

c) Determine the required size of the aerobic digester. Assume Hydraulic Detention Time equals 25 days, (Table 1). The required volume of the digester equals:

(10,900 gal/day)(25 days) = 273,000 gal (1034 m^3)

Summary:

Based on the above analysis, the minimum volume for the aerobic digester is obtained by using the primary clarifier as a "thickener" for the secondary sludge and the unit should be designed using this method of operation. It is important that the flexibility to waste separately from both primary and secondary clarifiers directly to the aerobic digester be provided (alternative #1). In addition, flow control and measurement should be provided for the waste activated sludge from the secondary process.

An alternative that could alter the volume of the aerobic digester would be to provide for a thickener to handle the secondary sludge prior to discharge to the digester. The important aspect of a thickener is the flexibility it provides the operator in controlling his plant. It is noted that in showing the example calculations an assumption was made that the sludge temperature in the digester would always be greater than 15^{o} C. If this plant were to be constructed in a colder climate and equipment was not provided to maintain a temperature in the digester of at least 15^{o} C, then additional capacity would be required.

C. OXYGEN REQUIREMENTS

Numerous parameters influence the oxygen requirements for an aerobic digester. Parameters such as process preceding the digester, solids concentration in the digester, two stage versus single stage digestion, sludge detention time in the digester, temperature, altitude, etc., must all be considered when designing the air supply requirement. In this ection of the report, these parameters will be discussed and values for oxygen requirements for various treatment processes will be given.

1. Efficiency Considerations

An aeration system oxygen transfer efficiency (Te = ratio of oxygen transferred to the liquid to the oxygen supplied to the system) greatly influences the adequacy or inadequacy of the supply system. Table 4 shows the actual quantity of oxygen that is supplied to the liquid at air (volume) flow rates of 20 cfm and 90 cfm per 1000 ft^3 (9.4 m^3/sec and 42.5 m^3/sec per 28.3 m^3) of digester capacity and at various transfer efficiencies.

TABLE 4

SUGGESTED DESIGN CONSIDERATIONS
FOR AEROBIC DIGESTERS

AUGUST 1974
VALUES FOR OXYGEN TRANSFER
AT SELECTED AIR SUPPLIES

Assumed Transfer Eff. (1) Te %	Oxygen Transfer at 20 cfm supply per 1000 ft of digester (2) mg/l/hr	Oxygen Transfer at 90 cfm supply per 1000 ft^3 of digester (2) mg/l/hr
5	16.3	73.4
10	32.6	146.9
15	49.0	220.4
20	65.3	293.8
25	81.6	367.2

(cfm x 0.472 = m^3/sec) and (ft^3 x 0.0283 = m^3)

(1) Te = ratio of oxygen transferred to the liquid to the oxygen supplied to the system.

(2) Assumed:

Air Temperature = 32^o F (0^o C)

Ratio of oxygen to air = 21%

Altitude = Sea Level

Not Considered:

Different altitudes, pressures, temperatures, "alpha" coefficients and "beta" coefficients.

It is important to note that the values presented in Table 4 do not include the expected decrease in oxygen transfer due to the high solids concentration of the digester contents or other characteristics of the wastewater. In addition, the increase or decrease in oxygen transfer due to variations in temperature and altitude are not considered.

The expected decrease in oxygen transfer due to the high solids concentration of the liquid in the digester and other characteristics of the wastewater is normally considered in the form of "alpha" and "beta" coefficients. The "alpha" coefficient is the ratio of the overall oxygen transfer coefficient, $K_L a$, of the waste to that of water. The "beta" coefficient is the ratio of the total solubility of oxygen in the waste to the solubility of oxygen in water. Specific values for these coefficients are not presented in this report.

It is suggested that the design of an aeration system specify the quantity of oxygen to be supplied to the liquid in the digester in terms of mg/l/hr. Once this quantity has been established, the designer may select the size and type of aeration equipment.

In most cases different equipment has different transfer efficiencies, and if the quantity of oxygen as mentioned above is selected, then it does not matter which piece of equipment is furnished because that quantity of oxygen should be attained. (Note: The design should insure that adequate mixing is also provided.)

2. <u>Waste Sludge Considerations</u>

The type of sludge wasted to an aerobic digester also affects the oxygen requirement. For example, if waste activated sludge only is wasted to an aerobic digester, the quantity of air required to provide adequate oxygen and mixing is reported to be 15 - 20 cfm per 1000 ft^3 (7.07 - 9.43 m^3/sec per 28.3 m^3) of digester capacity (2, 11). However, if primary sludge is wasted to the digester along with waste activated sludge, then additional air is required to satisfy the oxygen demand due to the increased activity in the digester. Loehr (12) reports that the volume of air required increases almost ninefold. Burd (11) suggests that a minimum supply of 90 cfm per 1000 ft^3 (42.5 m^3/sec per 28.3 m^3) of digester capacity be provided.

The type of secondary process preceding the digester also influences the quantity of oxygen required because in some cases the sludge wasted to the digester is more stabilized and requires less oxygen (i. e., sludge from an extended aeration process) than in other cases (i. e., sludge from a high rate activated sludge process). Other factors may explain the broad range of oxygen utilization rates reported in the literature.

3. <u>Mode of Operating Considerations</u>

The mode of operation influences the quantity of oxygen required because in most cases sludge that has just been wasted to the digester has a high oxygen demand. Barnhart (13) reports initial oxygen utilization rates of 60 mg/l/hr. He also shows that the oxygen utilization rate decreases rapidly during the first two days of digestion and decreases much slower after the second day. Rates less than 20 mg/l/hr after 10 days digestion were reported. Specific oxygen utilization rates (i. e., the oxygen utilization rate divided by the volatile or suspended solids concentration of the digester contents) were reported by Barnhart to range from 10 mg/l/hr per 1000 mg/l of volatile suspended solids to 4 mg/l/hr per 1000 mg/l of volatile suspended solids after 10 days digestion.

This apparent high initial oxygen demand becomes increasingly important when designing a two-stage digestion system or when designing a plug flow digestion system. In both cases attempts should be made to satisfy the high initial oxygen demand in the first stage of a two-stage digester or the head end of a plug flow unit.

The solids concentration of the liquid in the digester also influences the quantity of oxygen required in that higher solids concentrations require more oxygen. Attempts have been made to include the effect of the solids concentration on the quantity of oxygen required by reporting specific oxygen utilization rates (i.e., oxygen utilization rate divided by the suspended or volatile solids concentration of the digester contents). Smith (14) reports specific oxygen utilization rates of 3 mg/l/hr per 1000 mg/l of suspended solids. Benedict and Carlson (15) report specific oxygen utilization rates during endogenous respiration of 5.0 mg/l/hr per 1000 mg/l of suspended solids at a temperature of 32^{o} C, 3.5 mg/l/hr per 1000 mg/l of suspended solids at a temperature of 17^{o} C, and 1.0 mg/l/hr per 1000 mg/l of suspended solids at a temperature of 4^{o} C. Unfortunately, only a limited amount of information is available on the specific oxygen utilization rate, but this does not decrease the importance of solids concentration on the oxygen requirement.

4. Summary of Oxygen Requirements

Many different parameters have been used to describe the air or oxygen requirements for an aerobic digester. These parameters have units varying from "ft^3/min" of air to mg/l/hr of oxygen per 1000 mg/l of suspended solids. Perhaps the most common design criteria requires that the dissolved oxygen in the aerobic digester be between 1 - 2 mg/l and that adequate mixing be provided to keep the solids in suspension. This criteria, like a volume requirement given in ft^3/min per 1000 ft^3 of digester capacity, does not necessarily insure an adequate oxygen supply. Therefore, all units given in this report will be described in units of mg/l/hr of oxygen (oxygen utilization rates) that must be supplied to the liquid in the digester.

Many different values for oxygen utilization rates have been reported. Barnhart (13) indicated values from less than 20 to 60 mg/l/hr. Ahlberg and Boyko (1) show values from approximately 6 to 45 mg/l/hr. Standard design values indicate requirements of 16 to 82 mg/l/hr (see Table 4). Values at the Trinidad Wastewater Treatment Plant (6) ranged between 35 and 50 mg/l/hr.

Suggested design values for oxygen requirements for various types of treatment processes preceding the aerobic digester are presented in Table 5. The broad ranges presented are necessary because of the limited data available. Specific remarks concerning the use of the Table are also indicated.

Settling characteristics of digesting sludge deteriorate with low residual dissolved oxygen levels and with increasing solids concentrations. The effect low D. O. may have on settling should be considered when sizing the aeration equipment. Good settling characteristics are a must if the aerobic digester is to be successful. This is especially true if the aerobic digester is the only method of sludge disposal.

D. SUPERNATANT REMOVAL

Separation of the supernatant liquor and the digested sludge solids is normally accomplished in smaller plants (less than 1 MGD or 0.044 m^3/sec) by using the entire digester or a portion of the digester as a sludge thickener. Larger plants may have separate sludge thickening facilities in the form of gravity thickeners, centrifuges, etc.

An important criterion in good aerobic digester operation, is obtaining a relatively clear supernatant that has a low suspended

TABLE 5

SUGGESTED DESIGN CONSIDERATIONS

FOR AEROBIC DIGESTERS

August 1974

SUMMARY OF OXYGEN REQUIREMENTS

Treatment Process and Type of Sludge	Suggested Range of Values for Oxygen Supply(mg/l/hr)	Remarks
Waste Activated Sludges (alone)		Digesters operating at high solids concentrations should use upper portion of range (i. e., solids concentration greater than 25,000 mg/l).
High rate processes	30 - 75	First stage digesters of a two-stage system should provide a higher oxygen supply.
Conventional	25 - 70	
Step aeration	25 - 70	Mixing requirements must also be met when selecting aeration equipment.
Contact stabilization	20 - 60	Complete mix digesters may consider the lower values for oxygen supply.
Extended aeration	15 - 60	
Primary + Waste Activated	> 75	Primary sludge greatly increases the oxygen demand and therefore requires a higher oxygen supply (see Table 4 values for 90 cfm supply per 1000 ft^3).
Other Sludges (industrial)	- -	It is recommended that pilot studies be conducted on unique sludges to insure that an adequate oxygen supply is provided.

solids concentration. In most cases, the quality of the digester supernatant can be directly related to the settleability of the digesting sludge solids (i.e., poor settling characteristics result in poor quality supernatants). The main factors that affect the settleability of the sludge solids are the dissolved oxygen concentration, the suspended solids concentration, and the degree to which the sludge has been stabilized. Low D. O. concentrations and high solids concentrations have an adverse effect on the settling characteristics of the digesting sludge. Partially digested or unstabilized sludges normally do not settle as well as waste activated sludges that have not undergone any digestion, or as well as thoroughly digested sludges. Since a high quality supernatant is dependent upon these factors, it is important to design the digester to achieve these conditions prior to considering the design of supernatant removal facilities.

Supernatant removal facilities should have a flow measuring device to measure the amount of supernatant withdrawn. A flow measuring device is necessary in order for the operator to conduct a flow and solids balance on his digester and thus determine the solids residence time.

Scum removal is recommended as part of the supernatant removal facilities to retain the heavy brown scum and grease that accumulates on the surface of the digester during quiescent periods. Scum sprays are not recommended because the water added to the digester displaces volume that could be used for digesting sludge solids.

Supernatant drawoff facilities should be located as far as possible from the point where undigested waste sludges are added to the digester. This decreases the chances of short circuiting, and decreases the turbulence near the drawoff facility which can adversely affect supernatant quality. Many types of drawoff facilities are available. The more common facilities are multiple port drawoff tubes, hinged tubes that can be raised or lowered manually, baffled weirs, etc.

Table 6 shows typical digester supernatant characteristics as reported in various sources.

E. TANK CONSTRUCTION CONSIDERATIONS

Two important items that should be considered when designing the location and configuration of an aerobic digester are temperature and mixing.

TABLE 6

SUGGESTED DESIGN CONSIDERATIONS

FOR AEROBIC DIGESTERS

August 1974

CHARACTERISTICS OF DIGESTER SUPERNATANTS

(1, 6)

Parameter	Reported Range of Values	Typical Average Value
pH (units)	5.5 - 7.7	< 7.0
BOD_5 (mg/l)	9 - 1700	< 200
TSS (mg/l)	46 - 11,500	< 1000
Ammonia Nitrogen (mg/l)	- - -	< 10
Nitrate Nitrogen (mg/l)	- - -	> 25
Total P (mg/l)	19 - 241	> 10

Heat losses in winter months normally have the most adverse affect on aerobic digester performance. To minimize these heat losses digesters could be constructed with a common wall (i.e., steel which allows heat transfer) with the activated sludge aeration tanks. Earthen embankments or constructing the tank below grade would aid in maintaining higher sludge temperatures. Heat can also be added through the air supply where a diffused air system is used for oxygen supply. Perhaps the most important method of controlling heat loss is covering the aerobic digester.

Mixing is an important factor that is influenced by the tank configuration. For example, surface mechanical aerators are not recommended for deep tanks unless bottom mixers are included.

Another tank construction consideration which would improve operational flexibility is using multiple aerobic digestion tanks when feasible. If two tanks are constructed, they should be interconnected to allow for either series or parallel operation.

F. OPERATIONAL CONSIDERATIONS

Several features should be included in the design of an aerobic digester for operational control. These are flow measuring devices and sampling points on the influent waste sludge flow and the effluent waste sludge and supernatant liquor flows.

These features would enable the operator to monitor the quantity and quality of the flow streams entering or leaving the digester. With this information, the operator would be able to select and control an optimum mode of operation.

To insure adequate operation and control of the aerobic digestion process, certain laboratory facilities and equipment should be provided. One of the most important tests is to determine the dissolved oxygen concentration of the digester contents. The high solids concentration of the digester, however, makes it difficult to routinely measure D. O. using the Winkler method. Therefore, a portable dissolved oxygen meter and probe is recommended to enable the operator to monitor the D. O. concentration.

Another monitoring test is the determination of the pH of the digester contents. The pH test can be used to indicate if digestion is proceeding since during the process of aerobic digestion, the pH will normally decrease from greater than 7. 0 to less than 6. 0.

Historically, a reduction in the VSS of the sludge has been used to indicate the stability of the sludge and to monitor the performance of the digester. Ahlberg and Boyko (1) have proposed that rather than use the volatile suspended solids reduction, the specific oxygen uptake rate be used to determine the stability of sludge. They have suggested that a well digested sludge has a specific oxygen uptake rate in the range of 0.5 to 1.0 mg/l/hr of oxygen per 1000 mg/l of VSS.

Other tests and parameters which can be used to monitor and control the operation of an aerobic digester are alkalinity, nitrates, BOD_5, TSS, and ammonia. In general, as digestion proceeds, alkalinity, ammonia, and BOD_5 will decrease and nitrates will increase. Total suspended solids test results are used to monitor increases or decreases in digester solids concentrations and to determine the concentration at which solids are withdrawn for ultimate disposal.

G. ULTIMATE DISPOSAL CONSIDERATIONS

At small plants most aerobically digested sludges are disposed in drying beds, in sludge lagoons, or hauled and spread directly on the land. Each of these disposal methods are temperature and weather dependent with problems being frequently encountered during winter months. During the same winter period, aerobic digesters are least efficient. This combination of decreased efficiency during the winter, coupled with the problems of disposal has caused many operational difficulties in small plants. When determining the method for ultimate disposal of the sludge, it is important that critical periods, such as winter operation, be considered when sizing the disposal unit(s) or site(s). Inadequate sludge handling facilities, even for short periods of the year, can adversely affect the performance of the entire wastewater treatment facility.

Larger plants have the same winter problems as the smaller plants, but in many cases additional equipment is provided such as sludge thickeners, centrifuges, filters, etc., to help alleviate some of the sludge handling and disposal problems.

When selecting and sizing an ultimate disposal unit or site several factors must be considered. Two important factors are quantity and volume of sludge to be disposed. Table 7 presents the range of values for suspended solids reduction and concentration of gravity thickened sludge to aid in determining the quantity and volume of sludge that must be disposed.

Flow control devices, flow measuring devices, and sampling locations should be provided on the ultimate disposal drawoff lines from an aerobic digester enabling the operator to selectively control the quantity of sludge removed from the digester.

TABLE 7

SUGGESTED DESIGN CONSIDERATIONS

FOR AEROBIC DIGESTERS

August 1974

SUMMARY OF ULTIMATE DISPOSAL CONSIDERATIONS

(1, 3, 4, 5, 6, 16)

Characteristics	Reported Range of Values	Suggested Design Values (winter operation)
Total Suspended Solids Reduction - %	5 - 45	5 - 15 (1)
Solids Concentration of Gravity-Thickened Aerobic Sludge mg/l	20,000 - 60,000	25,000 (2)

(1) If adequate provisions are made for controlling heat losses, higher values may be considered.

(2) If provisions are made for additional thickening equipment (centrifuges, vacuum filters, air flotation, etc.) higher concentrations can be achieved.

IV APPENDICES

APPENDIX A

REFERENCES

1. Ahlberg, N. R. and Boyko, B. I., "Evaluation and Design of Aerobic Digesters," Journal-Water Pollution Control Fed., Vol. 44, No. 4, 634 (April 1972).

2. Dreier, D. E. and Obma, C. A., "Aerobic Digestion of Solids," Walker Process Equipment Co. Bulletin No. 26-S-18194, (January 1963).

3. Ritter, Lewis E., "Design and Operating Experiences Using Diffused Aeration for Sludge Digestion," Journal-Water Poll. Control Fed., Vol. 42, No. 10, 1782 (October, 1970).

4. Aerobic Digestion of Organic Waste Sludge, U. S. Environmental Protection Agency, Water Pollution Control Research Series, No. 17070 DAU, (December 1971).

5. Lawton, G. W., Norman, J. D., "Aerobic Sludge Digestion Studies," Journal-Water Poll. Control Fed., Vol. 36, No. 4, 495 (April 1964).

6. "Technical Assistance Project - Trinidad Wastewater Treatment Facility - Trinidad, Colorado," Report by Region VIII of the U.S. Environmental Protection Agency, Denver, Colorado, No. S & A/TSB-9.

7. McKinney, R. E., Outline for Course Entitled - Biological Treatment Technology, Sponsoroed by U. S. Environmental Protection Agency, Water Programs Operations, National Training Center, Cincinnati, Ohio, October 30 to November 10, 1972.

8. Goodman, B. L. and Foster, J. W., "Notes on Activated Sludge," Smith and Loveless Corp., Division of Union Tank Car Company, Lenexa, Kansas, Second Edition (1969).

9. Stewart, M. J., "Activated Sludge Process Variations - The Complete Spectrum," Water and Sewage Works, Vol. III, No. 4, (April 1964).

10. Montgomery, J. A., "An Outline - Activated Sludge Waste Treatment Process Variations and Modifications," U. S. Environmental Protection Agency, Pacific Northwest Lab., Corvallis, Oregon.

11. Burd, R. S., "A Study of Sludge Handling and Disposal," prepared for U. S. Dept. of the Interior, FWPCA, Publication #WP-20-4, (May 1968).

12. Loehr, R. C., "Aerobic Digestion - Factors Affecting Design," Paper Presented at 9th Great Plains Sewage Works Design Conference, (March 1965).

13. Barnhart, E. L., "Application of Aerobic Digestion to Industrial Waste Treatment," Proc. of the 17th Purdue Industrial Waste Conference, 126-135, (1962).

14. Smith, A. R., "Aerobic Digestion Gains Favor," Water and Wastes Engineering, Vol. 8, No. 2, 24-25, (1971).

15. Benedict, A. H., Carlsen, D. A., "Temperature Acclimatization in Aerobic Bio-oxidation Systems" Journal-Water Pollution Control Fed., Vol. 45, No. 1, 10, (January 1973).

16. "Process Design Manual for Upgrading Existing Wastewater Treatment Plants," prepared for U. S. Environmental Protection Agency by Roy F. Weston, Inc., Contract No. 14-12-933, (October 1971).

APPENDIX B

ADDITIONAL REFERENCES

1. Dreier, D. E., "Aerobic Digestion of Solids," Proc. of the 18th Purdue Industrial Wastes Conference, 123-140, (1963).

2. Jaworski, N., Sawton, G. W., and Rohlich, G. A., "Aerobic Sludge Digestion," International Journal Air and Water Poll., Vol. 4, 106, (1961).

3. Eckenfelder, W. W. Jr., "Studies on the Oxidation Kinetics of Biological Sludges," Sewage and Industrial Wastes, Vol 28, 983, (August 1956).

4. Reynolds, T. D., "Aerobic Digestion of Waste Activated Sludge," Water and Sewage Works, Vol. 113, 37-43, (1967).

5. Jenkins, D., Garrison, W E., "Control of Activated Sludge by Mean Cell Residence Time," Journal-Water Poll. Control Fed., Vol. 40, No. 11, 1905, (November 1968).

6. Lawrence, A. W., McCarty, P. L., "Unified Basis for Biological Treatment Design and Operation," Journal of the Sanitary Engineering Division, ASCE, No. SA 3 Proc. Paper 7365, 757-777, (June 1970).

7. Walker, J. D., "Aerobic Digestion of Waste Activated Sludge," Presented at the Ohio Water Pollution Control Conference, Cleveland, Ohio (June 15. 1967).