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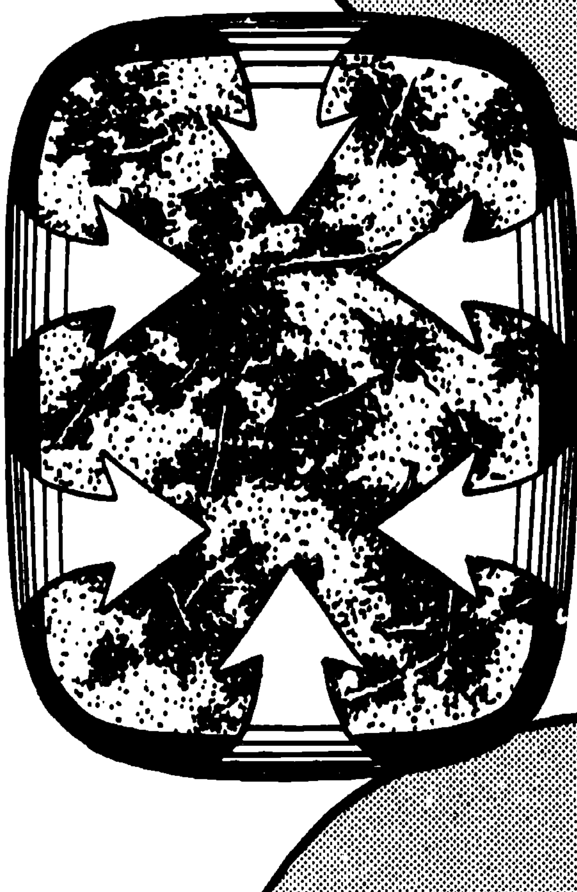
ABSTRACT

This student manual contains the textual material for a four-lesson unit on anaerobic digestion control. Areas addressed include: (1) anaerobic sludge digestion (considering the nature of raw sludge, purposes of anaerobic digestion, the results of digestion, types of equipment, and other topics); (2) digester process control (considering feeding and loading, control of supernatant quality and effects, use of laboratory tests and other information for process control, chemicals used in digester control, and other topics); and (3) troubleshooting assistance (for loading supernatant, digested sludge, sludge pumping and pipelines, sludge temperature control using internal coils, sludge temperature control using external heat exchangers, sludge mixing--gas mixers, sludge mixing--mechanical mixers, scum blanket, digester gas system, digester covers--fixed, digester covers--floating, digester covers--gas holder type, and toxicity). A list of objectives, glossary of key terms, list of references, and worksheets are included. (JN)

Biological Treatment Process Control

Anaerobic Digestion



Linn-Benton Community College
Albany, Oregon
1984

BIOLOGICAL PROCESS TREATMENT CONTROL

ANAEROBIC DIGESTION

Student Manual

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ANAEROBIC DIGESTION

Student Manual

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ANAEROBIC DIGESTION

Objectives

Upon completion of these lessons, you should be able to:

1. Identify the roof type:

    a. Fixed
    b. Floating cover
    c. Gas dome

2. Identify the following components:

    a. Flame arrestor
    b. Sedimentation trap
    c. Moisture trap
    d. Thermal valve
    e. Pressure regulator
    f. Pressure vacuum relief valve
    g. Heat exchanger
    h. Mixing equipment
    i. Sludge line - gas lines/excess gas burner
    j. Boiler

3. Do the following calculations:

    a. Solids detention time
    b. Volatile solids to volume ratio
    c. Volatile solids to volatile solids ratio
    d. % reduction
    e. Lbs of anhydrous ammonia needed to neutralize a set amount of VA

4. Describe the digestion process. Name the types of organisms involved, their relationship to each other and their by-products.

5. Define the following:

    a. Volatile solids
    b. Anaerobic bacteria
    c. Facultative bacteria
    d. Psychrophilic
    e. Mesophilic
    f. Thermophilic

6. Give normal operational parameters for the following:

   a. VA/Alk ratio
   b. Loading VS/ft^3 VS/VS<5%
   c. Temperature
   d. pH
   e. Concentration of raw sludge 5-8%
      WAS 1.5-2%
      Mixture 3-5%

7. Describe the effect and give a possible cure for the following problems:

   a. Sludge feed pump accidentally left running all night
   b. Low concentration of solids to digester
   c. High organic loading - Increase VA, could reduce digester capacity by excess scum or grit

8. Name the six factors that affect operation of an anaerobic digester:

   a. Bacteria
   b. Food
   c. Loading
   d. Mixing
   e. Environmental factors
   f. Time

9. Recall four purposes of digestion.

10. Recall one advantage and one disadvantage to anaerobic and aerobic digestion.

11. Recall sampling sites.

12. Recall normal operational test.

Glossary

Acid forming bacteria - The group of bacteria in a digester that produce volatile acids as one of the by-products of their metabolism. The acids are used as a food source by the methane forming bacteria.

Alkalinity - The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate.

Anaerobic digestion - Wastewater solids and water (about 5% solids, 95% water) are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen. At least two general groups of bacteria act in balance: (1) Saprophytic (acid forming) bacteria break down complex solids to volatile acids, and (2) Methane Fermenters break down the acids to methane, carbon dioxide, and water.

Manometer - An instrument for measuring pressure; usually it consists of a U-shaped tube containing a liquid, the surface of which in one end of the tube moves proportionally with changes in pressure on the liquid in the other end. The term is also applied to a tube type of differential pressure gage.

Methane - An odorless, colorless, flammable gas, CH_4, that is the major constituent of natural gas. It is used as a fuel and is an important source of hydrogen and a wide variety of organic compounds.

Methane forming bacteria - The group of bacteria in a digester that use volatile acids as a food source and produce methane as a by-product.

Mesophilic digestion - Digestion by biological action at or below 113 degrees Fahrenheit.

Orifice - An opening in a plate, wall, or partition. In a trickling filter distributor the wastewater passes through an orifice to the surface of the filter media. An orifice flange set in a pipe consists of a slot or hole smaller than the pipe diameter. The difference in pressure in the pipe above and below the orifice may be related to flow in the pipe.

Psychrophilic digestion - Digestion by biological action at or above 68 degrees Fahrenheit.

Stabilize - To convert to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.

Stabilized waste - A waste that has been treated or decomposed to the extent that, if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

Supernatant - Floating on surface, like oil on water. Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface on an anaerobic digester.

Thermophilic digestion - Digestion by biological action at or above 113 degrees Fahrenheit.

Thief hole - A digester sampling well on top of the digester.

Volatile acids - Fatty acids which are produced by acid forming bacteria and which are soluble in water. They can be steam-distilled at atmospheric pressure. Voaltile acids are commonly reported as equivalent to acetic acid.

Volatile solids - The quantity of solids in water, sewage, or other liquid, lost on ignition of the dry solids at 600° C.

ANAEROBIC SLUDGE DIGESTION

INTRODUCTION

Natural decomposition of organic material has occurred for millions of years. This natural decaying process breaks organic material such as leaves and grass, animal waste, dead carcasses, rubbish and refuse of all kinds into simple elements or compounds that return to the soil as nutrients. These materials are broken down biologically by bacteria which come in all types, sizes and shapes. Some live and work in almost any environment, while others are extremely sensitive. Some use any type of organic material as food, while others are very selective. In a manner of speaking, bacteria eat the organic material as food, digest it, and convert it into end products consisting of liquids, gases and stabilized solids.

Bacterial decomposition can occur with or without air (oxygen). The bacteria that need air use it in the same way we do. These are called aerobes, or **aerobic bacteria**. Bacteria that live without oxygen are called **anaerobic** bacteria. Some bacteria can live under either condition and are called **facultative** bacteria.

Man is perhaps the greatest producer of waste materials. Since man is also an inventive animal, he has discovered that one of the best and cheapeast ways of getting rid of his waste is to put these millions upon millions of bacteria to work for him. All man needed to do was collect his waste material in one place, put it in a container, create the right environment, and let nature take its course. Water is used to carry waste materials from hundreds of sources to a central point where these materials can be removed from the water for treatment. A typical wastewater treatment facility has several "container" processes, each designed to remove or treat these wastes.

WHY DIGEST ORGANIC SOLIDS?

The organic solids removed from the wastewater produce offensive odors when they decompose. These sludges also may contain **pathogenic** (disease-causing) organisms harmful to man.

Sludge also contains water held within the sludge particle which makes it difficult to dewater. It is, therefore, necessary to contain and treat these wastes so that:

1. The treated sludge is stabilized, which means that the sludge is decomposed and further bacterial activity is minimal.

2. The offensive odors are eliminated.

3. Many pathogenic bacteria are eliminated.

4. The disposal problem of sludge is minimized by converting a large percentage of sludge to gases and liquid. Gases can be used as fuel.

5. The sludge is easily dewatered and will dry readily. It has value as a soil conditioner when recycled back to the land.

WHAT MATERIALS ARE REMOVED FROM WASTEWATER?

Figure 4-1 shows that the incoming wastewater contains two basic types of material classified as being about 70 percent organic and 30 percent inorganic. The **organic** portion of the sewage is used as food for bacteria, while the **inorganic** portion passes on through the entire treatment process unaffected. Inorganic material includes rock, grit, rags, plastic, metal, etc.

These materials are normally removed in pretreatment units such as bar screens, rock traps, and grit collectors. Material passing through these collectors contains solids too large to be effectively treated. These must be reduced in size by other pretreatment units such as comminutors and barminutors, which shred the material and allow it to pass through the treatment units. All of these units must operate continuously at top efficiency if the subsequent plant processes are to work properly. The material removed from the wastewater in this phase is usually sent to a landfill site.

After pretreatment, the remaining solids are either settleable, suspended or dissolved. **Settleable solids** are those which are heavy enough to settle out when the wastewater flow is slowed down and enough time is allowed for them to settle. These solids are removed in primary clarifiers and are called raw primary sludge.

The remaining solids are either **suspended** in the water or dissolved just as sugar is **dissolved** in coffee. Most of this material passes on to some form of biological treatment process where it is converted to biological solids heavy enough to settle. These solids are removed from the wastewater flow in secondary clarifiers. Figure 4-1 shows that both raw sludge and biological sludge are sent to the anaerobic digester for natural decomposition.

Of the materials reaching a digester, only the organic portion can be decomposed by the bacteria. The inorganic materials are unaffected by biological treatment; however, they can

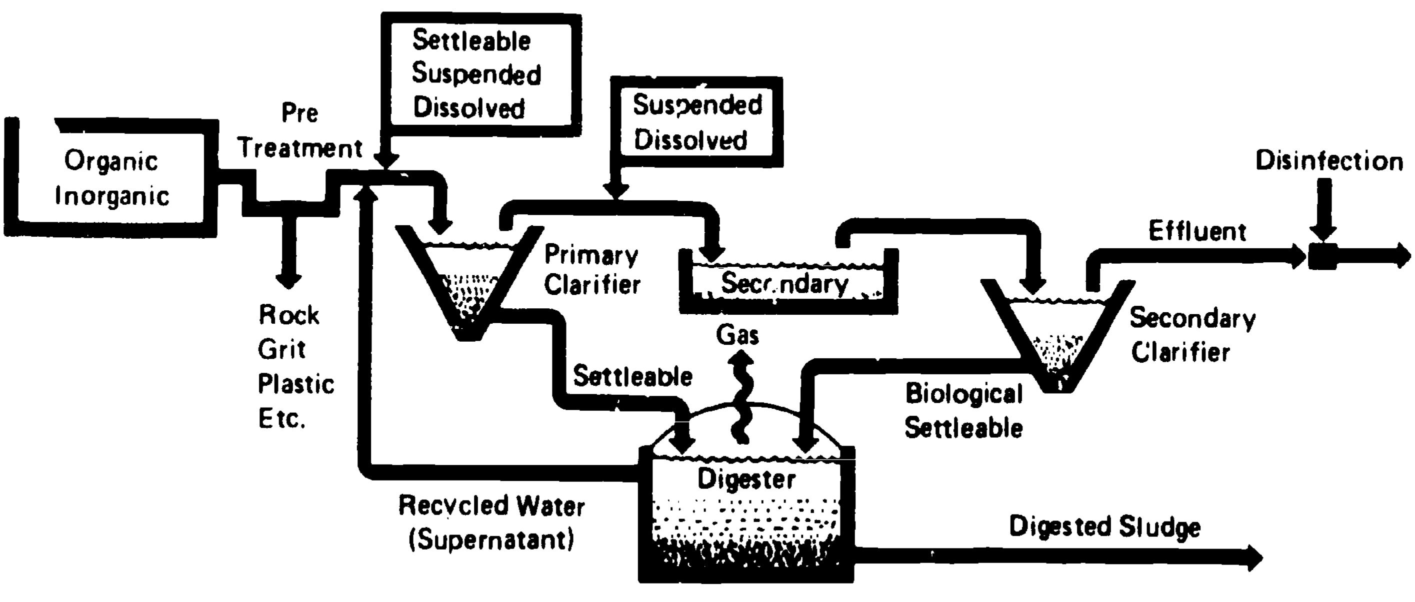


FIGURE 4-1
DIAGRAM OF MATERIALS REMOVED FROM WASTEWATER

cause severe problems, such as reducing digester volume.

Several methods are used to concentrate digester feed sludges. Primary clarifiers, gravity thickeners, flotation thickeners and centrifuges are commonly used.

Primary clarifiers are the only sludge-thickening devices in many plants. Biological sludges, such as activated sludge or trickling filter humus, are often wasted to the primary clarifier and settled with the raw sludge. The sludge concentration developed in the primary clarifier is controlled by the frequency, duration and rate of sludge withdrawal.

Gravity-type thickeners are used in plants which remove raw sludge continuously from the primary clarifier. They yield 4 to 8 percent solids concentration. Waste-activated sludges may be thickened with the raw sludge in these units, but difficulties occur when the waste-activated sludge is young and slow-settling.

Flotation thickeners are often used to thicken waste-activated sludges. These lightweight sludges tend to float, which makes air flotation a practical means to concentrate them to about 3 to 4 percent. The use of centrifuges is another method for thickening waste-activated sludge. Both units will thicken the waste-activated sludge to about 3 to 4 percent.

Regardless of the sludge source, the concentration of total solids fed to a digester should be as thick as possible. Normal ranges are from 3 to 8 percent. This is necessary:

1. To prevent dilution of the **alkaline buffer** which could cause a pH change. NOTE: A buffering material is the amount of alkalinity in the digester needed to offset the acids and keep the pH near neutral.
2. To prevent dilution of the food material. This would make it more difficult for the workers to utilize the food.
3. To reduce the amount of heat required in a heated digester.
4. To provide the maximum **hydraulic loading time** in the digester. NOTE: This is the amount of time in days that the liquid stays in a digester.
5. To prevent washout of solids and organisms.

WHAT TYPE OF DIGESTION: AEROBIC OR ANAEROBIC?

Both types of digestion will do the job when properly loaded and operating in the right environment. The anaerobic digestion process has been used for many years because of its low operating cost, its proven effectiveness on raw primary sludges, and its production of a useful by-product, a burnable gas. This gas has been used as a fuel for boilers, gas engines and heating. But the anaerobic process has some disadvantages. The slow rate of bacterial growth requires long periods of time for starting and limits the flexibility of the process to adjust to changing waste loads, temperatures and other environmental conditions.

The aerobic digestion process has been used successfully to treat waste-activated sludges from secondary treatment plants. These sludges may become a loading problem with anaerobic digesters. The principal disadvantages of aerobic digesters are higher operating costs, high energy demands, and an inability to produce a burnable gas to recover energy.

The remainder of this section will describe the anaerobic digestion process, its operation, and its problems.

WHAT HAPPENS INSIDE AN ANAEROBIC DIGESTER?

Anaerobic sludge digestion is a continuous process. Fresh sewage sludge should be added continuously or at frequent intervals. The water separated from the sludge (**supernatant**) is normally removed as sludge is added. Digested sludge is removed at less frequent intervals but it must be removed. The gas formed during digestion is removed continuously.

The stabilization of organic wastes by anaerobic sludge digestion must always result in the production of methane gas which is insoluble in water and escapes as a gas. Thus, if no methane gas is produced there can be no waste stabilization.

Anaerobic sludge digestion is considered a two-stage process as shown in Figure 4-2. This diagram shows organic material as food is changed in the first stage by **acid-forming bacteria** to simple organic material, chiefly organic acids. The **methane-forming types** of bacteria then use the acids as food and produce carbon dioxide and methane gas. It is important to understand that no waste stabilization occurs in the first stage. Real stabilization occurs only in the second stage.

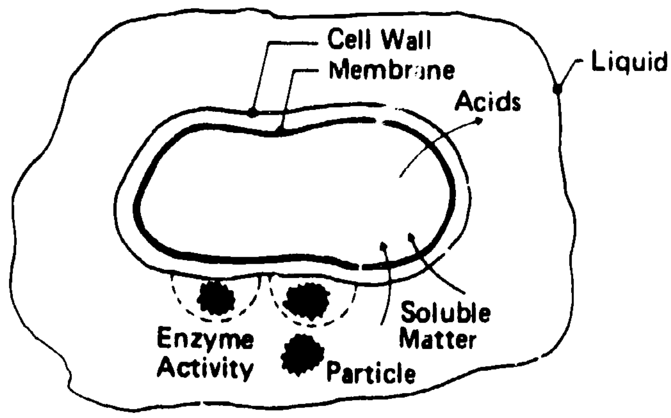


FIGURE 4-3
TYPICAL ACID-FORMING BACTERIA

One of the major considerations is the type of food available to the acid-forming bacteria. Food may be in two forms, soluble and insoluble. In the soluble form it is readily removed (like sugar in water). Insoluble forms, such as fats or complex solids, are more difficult to use. They must first be broken down into a soluble form. This is accomplished, in part, by **enzymes** which are produced by the bacteria. The bacteria can only directly use the soluble solids as food since it must be in this form to pass through the cell wall and the membrane as shown in Figure 4-3. The cell wall acts as a sieve to screen out the large particles, while the membrane selects and guides material both in and out of the inner cell.

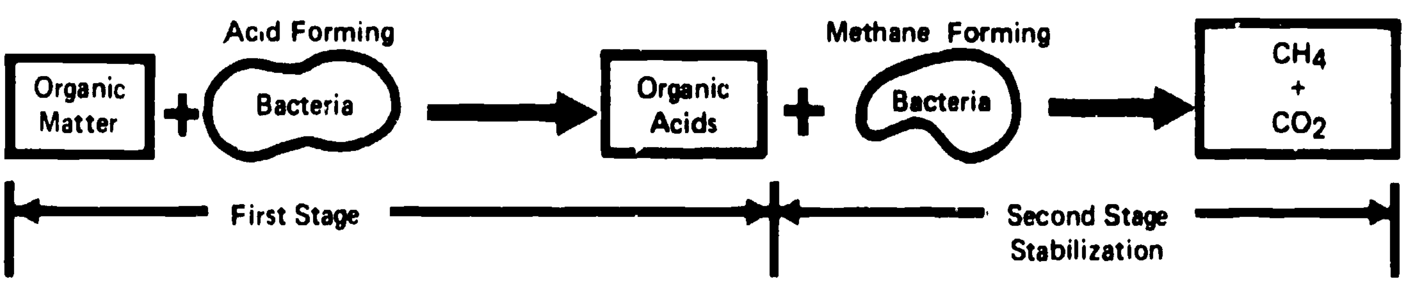


FIGURE 4-2
DIAGRAM OF WASTE STABILIZATION

Not all of the organic solids are completely broken down nor does all of the material pass into the cell. These materials contribute to that portion of digested sludge which is not **degradable** (poor food for bacteria) and that fraction called **inert solids** (not food for bacteria).

The bacteria use the food for energy and produce organic acids also called **volatile acids** or fatty acids. The production of these acids completes the first stage of the digestion process and is commonly known as the acid phase.

In a normal or healthy digester, acids will be used as food by the second group at approximately the same rate as they are produced. The volatile acid content of the digesting sludges usually runs in the range of about 50 milligrams per liter (mg/l) to 300 mg/l, expressed as acetic acid.

If the acid phase was the only step occurring in digestion, the process would be incomplete, resulting in a continuing drop in pH caused by an overproduction of acids. This does occur for a period of time when a digester is first started or when a digester has lost a large amount of its methane formers. ***Digestion can only be completed when the second phase is occurring at the same time as the acid phase.***

The second phase in anaerobic digestion occurs because of another bacterial group called the methane formers, which use the volatile acids produced by the acid formers as food The acids are then converted to carbon dioxide (CO_2) and methane (CH_4) gases as major end products. This step completes the work of the two principal forms of bacteria and results in stabilizing between 40 and 60 percent of the organic waste in domestic sludge.

The methane formers, which are responsible for waste stabilization, grow quite slowly compared to the acid formers since they get very little energy from their food. This causes the methane formers to be very sensitive to slight changes in loading, pH and temperature. Since the methane formers are strictly anaerobic bacteria, they are also extremely sensitive to air (oxygen).

The acid formers have a decided edge over the methane formers since they are rapid growers and are not as sensitive to environmental changes. ***Thus, the operation of anaerobic digesters depends largely upon keeping methane formers happy.***

The objective of good digester operation, then, is to control the food supply, the temperature and the pH, thus keeping the acid formers and the methane formers in balance. These subjects are discussed later in this section.

WHAT ARE THE PRODUCTS?

Gases

The major gases produced in any anaerobic condition are methane (CH_4) and carbon dioxide (CO_2). These gases are usually collected, and compressed. The methane portion is used as a fuel gas for boilers, gas engines and other auxiliary uses.

Most of us have seen bubbles rising to the surface of a swamp, especially on a warm day. These bubbles are gases formed by the same kind of methane groups as in a digester. Maybe you have noticed that, as the gases rise to the surface, they carry small chunks of bottom sludge and there is a little turbulence in the water--similar to boiling water The same thing happens inside a digester. In fact, the only mixing in many digesters occurs in this natural manner.

Scum

Scum blankets form in digesters as the result of this upward lift of the gas. The formation of scum presents a special problem to many operators who have unmixed tanks. The scum in these tanks tends to concentrate the food material, the working bacteria are generally concentrated in the bottom sludge. If mixing doesn't bring the two together, there will not be much digestion occurring in the scum layer. In an unmixed tank, the supernatant layer provides a physical barrier between the two.

In unmixed tanks, it is necessary to keep the scum blanket moist so that the gases can get through. However, if the blanket dries, the operator must break it up so that the gases can escape. Methods for breaking up scum blankets are discussed in Part I, Trouble-shooting Guide No. 9.

Supernatant

The water or liquid inside the digester comes from two sources: carrier water entering the digester and water formed as solids are broken down. A certain amount of this liquid leaves the digester as supernatant. In most cases, supernatant is displaced as fresh sludge enters the digester. However, in some digesters, it is taken out before sludge feeding.

Supernatant is often normally recycled through the plant and is high in suspended solids and BOD. Many secondary plants have experienced process problems due to the addition of supernatant. The major problems seem to be a buildup of solids in the system and insufficient aeration to accomplish the necessary BOD reduction. Both of these conditions result in a deterioration of the plant's final effluent. One common method practiced by many plants to help correct this problem is to release supernatant frequently and in small amounts to prevent shocking the system. Other suggestions are given in the Operations Section, Part II, page 2-4.

Supernatant quality is affected by the type of digester system, the efficiency of digestion and by the type of waste and its settling capacity. For example, waste-activated sludges tend to thin out the digester contents, resulting in less time for digestion to occur. Mixers tend to homogenize the sludge, making supernatant removal difficult if sufficient settling time is not allowed. ***Good settling conditions are a must.*** The digested sludge must have enough time under quiet, undisturbed conditions to be allowed to settle. This is normally accomplished either by shutting mixers off or by transferring the digested sludge to a second settling tank

Operators generally use the results from two tests: total solids and volatile solids, to indicate the quality of the supernatant as described later in Digester Control.

Digested Sludge

The inorganic and volatile solids that are not easily digested make up the final product—digested sludge. ***A well digested stabilized sludge must drain easily or be dewaterable and not have a noxious odor.*** The characteristics of the sludge are:

1. Some of the water in the sludge particles is released as the particles are broken down. This makes the sludge easier to dewater.

2. The amount of the well digested sludge leaving the digester is less than the amount of raw sludge entering the digester because the complex organic material has been broken down into simpler substances such as liquid acids, water and gases.

3. The sludge should have a lumpy appearance.

4. The sludge turns black. Light gray streaks indicate a "green" undigested sludge.

5. The original offensive odor changes to a less objectionable odor.

6. Volatile solids in the stabilized sludge should be 40 to 60 percent less than the feed sludge.

Stable (digested) sludge can be disposed of on approved land or landfills after it has been dewatered.

HOW IS DIGESTION AFFECTED BY TYPES OF DIGESTERS?

Single, Unheated and Unmixed Digesters

The simplest digester is a circular or rectangular, unheated, open-top tank, whose contents are mixed naturally by rising gases. This type of digester includes Imhoff tanks and Clarigesters which are two-story units with the top portion serving as a clarifier where the solids settle and then drop through a slot into the lower digester portion. In these unmixed digesters, the sludge arranges itself in layers as illustrated in Figure 4-4.

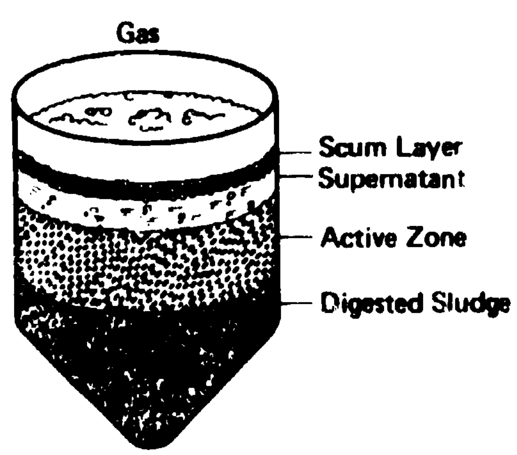


FIGURE 4-4
OPEN-TOP, UNHEATED, UNMIXED DIGESTER

Sludge enters the center of the active zone where digestion takes place and water is released to form a supernatant zone. The decomposed solids are heavier than the liquid and settle to the bottom. As gases are formed, they rise to the surface, pass through the scum layer and escape into the atmosphere. The rising gases carry the lighter sludge particles to the surface above the supernatant and form a dense layer of scum. This scum layer, in time, can become quite thick and be tough enough to walk on.

Figure 4-5 shows the same digester after three to six years of operation.

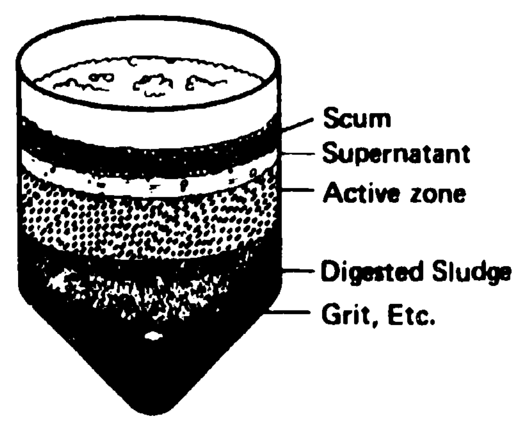


FIGURE 4-5
OPEN-TOP, UNHEATED, UNMIXED DIGESTER AFTER 3 TO 6 YEARS

Deposits of grit and other material on the bottom and a thicker scum layer greatly reduce the effective capacity of the tank. Problems occur more frequently. It may be difficult to obtain a well digested sludge, or the supernatant layer may be hard to find. The unit is easily overloaded and has more frequent upsets.

This type of digester is no longer being built although several remain in use.

Single, Heated-Mixed and Covered Digesters

Now, let's take the same digester, add a cover to collect gas, add a heat exchanger and a pump to pull sludge from the tank bottom, pump it through the heat exchanger and return it to the uppe level as shown in Figure 4-6

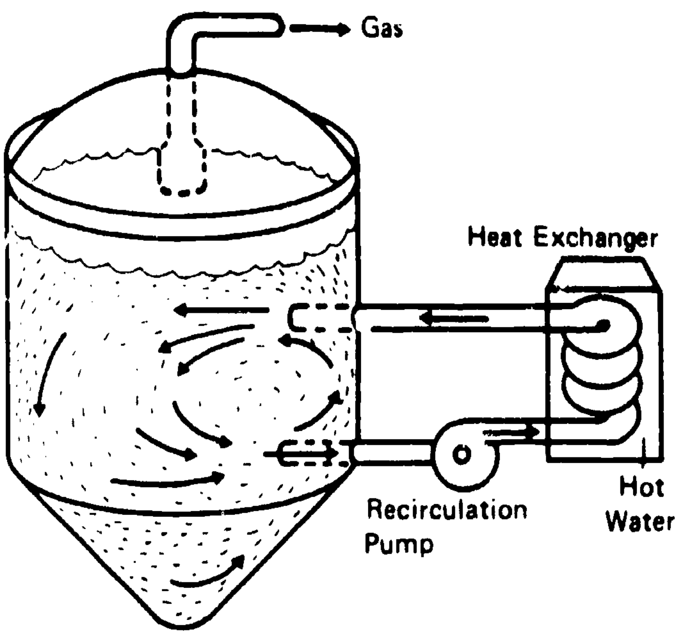


FIGURE 4-6 SINGLE COVERED DIGESTER WITH RECIRCULATION

What changes have occurred? First, the pump is acting like a mixer and sets up a current inside the tank. More bacteria are exposed to the food, and a faster reaction takes place. The heat exchanger raises the temperature of the sludge. The operator can control the temperature to help the bacteria do a better job. In addition, the collected gas can be used as fuel for a hot-water boiler to supply the heat exchanger. Thus, the addition of heating and recirculation equipment reduces the layering effect seen in the unmixed units, complete digestion occurs in less time and a smaller digestion tank can be used.

There are many types of mixers, many ways to heat the sludge, and many ways to collect gases, but they perform the same functions. The major differences are mechanical. These systems are discussed later in this section.

When withdrawing supernatant in these tanks, it is necessary to shut the mixers off and allow the solids to settle before withdrawal begins. The operator should also find the supernatant zone and carefully select the clearest liquid.

Two-Tank Systems

Next are those digestion systems using two tanks: one for active mixing and digestion, and the other serving as a quiet settling tank as shown in Figure 4-7.

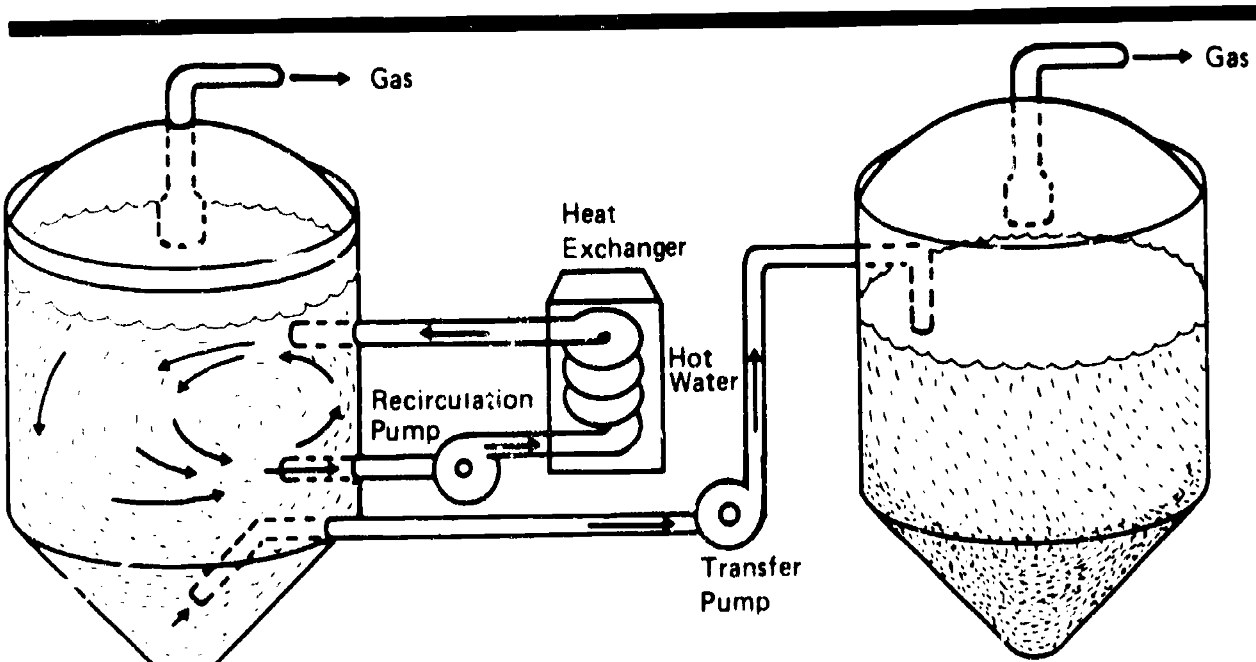


FIGURE 4-7 TWO-TANK SYSTEM

Two-tank systems were designed to shorten the total digester detention time by utilizing one mixed tank (the primary) to provide for active mixing and digestion while the second tank is used to provide settling. These systems are referred to as two-stage digesters.

Operationally, the primary tank can be mixed continuously, since the mixers do not have to be shut off and the contents allowed to settle before withdrawing supernatant or sludge. Generally, more efficient mixing is obtained in these units. Both tanks are covered, and the gas system cross-connected between them. The secondary tank, however, does not produce much gas because most of the gas production occurs in the primary tank.

The secondary tank has another beneficial use. It contains a large volume of good active sludge (bacteria) which can be transferred to the primary when the digestion process is fouled. This seed sludge can be used to correct pH and toxicity problems by using "natural recovery" instead of adding chemicals such as lime.

Conventional Versus High Rate Digesters

The basic difference between these two systems is their loading rates:

- Conventional–0.03 to 0.10 lbs. per cubic foot (0.48 to 1.60 kg/m^3) of volatile solids loaded per day.
- High Rate–0.10 to 0.40 lbs. per cubic foot (1.60 to 6.40 kg/m^3) of volatile solids loaded per day.

The high rate units achieve their higher loadings because their design includes uniform temperature and greater mixing capacity. The tanks are also usually deeper. Operationally, the high rate system will be fed on a more nearly continuous basis.

WHAT FACTORS AFFECT SLUDGE DIGESTION?

Five basic factors affect digestion: bacteria, food, loading, contact (mixing) and environment. The acid and methane formers can only do their best job as a team when the right conditions are provided. The purpose of this section is to describe the factors needed for good digestion. All of these affect the process and all can be monitored and controlled by the operator.

Bacteria

The digesting and digested sludge contains all of the necessary bacteria to stabilize the sludge. Thus, the operator must keep as much good digested sludge as possible in his digester to have enough workers on hand to do the job. ***Do not remove any more digested sludge than is necessary, but some digested sludge must be removed at regular intervals***. A good guideline is to have about 20 times as much seed sludge as feed sludge expressed as volatile solids.

In single tank digesters, liquid (supernatant) is displaced as fresh sludge is added. Digested sludge is withdrawn under strict control. In two-tank systems, where the primary tank is mixed, many of the bacteria are trapped in the supernatant from the primary tank and are moved to the secondary tank. The secondary tank contains an abundance of bacteria often called "seed" sludge.

This is good seed material which can be recycled or transferred back to the primary digester. This is a good technique to use when organic overloading or a potential toxic load is expected or has already occurred. This technique is often used by plant operators who favor the "natural process" for recovery. A similar technique can be used for single tanks except that seed sludge would have to be obtained from another installation, hauled to the site and then fed into the digester.

Food

Volatile solids in primary and waste secondary sludges are the food for the bacteria.

Raw primary sludges, compared to biological sludges, produce the clearest and best supernatant and the most easily dewaterable sludge from a digester. When biological sludges are added, good supernatant quality becomes more difficult to obtain. In fact, some plants separately treat biological sludges in aerobic digesters and primary sludge only in the anaerobic digesters to improve total plant performance.

Vegetable fats and oils, such as cooking oils, are readily decomposed in anaerobic digesters, but mineral oils such as fuel oil, automotive oils and greases, and paraffins will cause toxicity problems.

Loading

Feeding is one of the things under the control of an operator. Each operator must consider:

- The **concentration** of the incoming sludge, which is the amount of solids in a given volume of water.
- The amount of **volatile solids** in the incoming sludge, which tells how much of the material can be used as food by the bacteria and indirectly the amount of grit.
- The amount of volatile solids per unit to digester volume, which is used as a **loading factor** in much the same way as the "food to microorganism ratio" is used in activated sludge.
- The **hydraulic loading** (hydraulic detention time) which is related to the organism growth and washout.

These are described in detail beginning on page 4-20

Contact (Mixing)

Sludge stabilization cannot occur unless the bacteria are brought into **contact** *with the food.*

The goals are to expose the bacteria to the maximum amount of food and also to reduce the volume occupied by settled inorganic material, such as grit, and organic material, such as scum. The benefits of mixing are speeding up the process of the volatile solids breakdown and increasing the amount of gas production.

This is done two ways:

1. **Gas Evolution.** As gas is produced, it forms in pockets, then breaks loose and rises to the surface. This action creates a boiling effect resulting in some mixing. This method is controlled by feeding. When conditions allow a fairly constant loading, which may be higher than normally designed in conventional digesters, internal mixing will occur. A loading of about 0.4 pounds cubic foot per day is needed for natural mixing. As long as loading can be sustained at this level, no other mixing may be required; however, if prolonged periods of low loading are experienced, mixing may be interrupted and scum blankets may form. On the other hand, increased loading may cause organic overloads with resulting slower gas production. Conditions which cause natural mixing are somewhat unstable but do afford an inexpensive method of mixing if the operation is closely controlled.
2. **By Artificial Means.** Many types of mixing devices are used to stir or mix the digesting sludge. The amount and frequency of mixing are controlled by the operator. These have been described beginning on page 4-27.

Environmental Factors Affecting Digestion

The methane bacteria, which cause the final conversion of digesting sludge into a stable waste, are very sensitive to conditions in the digester. Their activity slows down unless optimum conditions are maintained. The following table summarizes the best conditions for anaerobic digestion.

Table IV-1
OPTIMUM CONDITIONS FOR ANAEROBIC DIGESTION

Anaerobic Conditions	No oxygen (air)
Temperature*	85-100 deg. F. (29-37 deg. C.)
pH	6.8-7.2
No Toxic Materials	

** Temperatures between 85-100 degrees F. (29-37 degrees C.) are in the MESOPHILIC RANGE. Temperatures between 120-135 degrees F. (48-57 degrees C.) are in the THERMOPHILIC RANGE. Most digesters operate at mesophilic temperatures.*

The operator must understand the basics of each condition below because they must be controlled to obtain the most efficient treatment.

Anaerobic Conditions. *No air can be admitted to the digestion tank if anaerobic conditions are to be maintained.* The methane formers cannot tolerate even small amounts of oxygen. Closed tanks with covers designed to collect the methane gas are used to keep air out. Operators must not allow air into the digesting sludge since an explosive mixture will result when air comes into contact with methane gas. See also Safety section, page 3-6. If air is admitted into a digester, be extremely cautious about possible ignition.

Temperature. *Temperature controls the activy of the methane bacteria.* They can function best in the 85-100 degree F. (29-37 degree C.) range or, in another range, 120-135 degrees F. (49-57 degrees C.) Outside these ranges, the bacteria's activity is severely reduced. For example, activity is almost nonexistent at 50 degrees F. (10 degrees C.). It should be noted that, although bacterial actions stop, the bacteria themselves are not harmed but are simply inactive until the temperature increases again.

The methane-formers are affected by changes in temperature of as little as 1 degree Fahrenheit per day, but the acid formers are not as sensitive to temperature changes. Temperature changes greater than 2 degrees Fahrenheit will reduce methane former activity while acids are still forming. This results in losing the buffering capacity and possibly incapacitating the digester. The best bacterial activity will occur in digesters operating at a *constant temperature* somewhere between 90 and 98 degrees Fahrenheit (32 and 36 degrees centigrade).

Once the best temperature for the individual digester is found, based on the highest gas production and ability to hold the pH near 7.0, this temperature should be held within 1 degree Fahrenheit. If heating capacity is limited and it is not possible to hold this temperature in winter months, it is better to drop down from 95 degrees F. (35 degrees C.) to 90 degrees F. (32 degrees C.) and hold this value constant than to fluctuate between 92 and 98 degrees F. (33 and 36 degrees C.) over a two- to three-day period in an attempt to reach the higher temperature.

Various statistics are available showing the value, effects and the necessity of heating the digester contents to allow the most efficient use of the process. When the subject of temperature is discussed, the element of time cannot be ignored because solids stabilization can be accomplished at low temperatures if enough time is available. Table IV-2 relates time and temperature to illustrate this point.

These data show that even at 77 degrees F. (25 degrees C.), digestion can occur in about 5½ weeks. However, approximately 60 percent more digester capacity would be

Table IV-2
EFFECT OF TEMPERATURE ON DIGESTION TIME

Temperature (Deg. F.)	Digestion Time (Days)
59	67.8
68	46.6
77	37.5
86	33.3
95	23.7
104	22.7
113	14.4
122	8.9
140	12.6

(NOTE: Deg. C. equals deg. F minus 32 times 0.55)

needed to reach the same efficiency as when the temperature is held at 95 degrees F. (35 degrees C.).

Operation of the heating system will vary with geographical location, size of digester, degree of loading, and in some cases type of industrial waste mixed with the sludge. The following discussion considers some of the important principles of sludge heating.

CONSTANT TEMPERATURE CONTROL. The optimum temperature range for normal digestion is cited at 90-98 degrees F. (32-36 degrees C.). If the digester cannot be heated to 90-98 degrees F. (32-36 degrees C.), it is better to maintain control at a lower temperature (at a constant value) than to fluctuate between high and low temperatures over a short period of time.

CHANGES IN TEMPERATURE. Temperature should not be changed more than 1 degree Fahrenheit per day once the operating temperature has stabilized. During start-up or after recovery from other difficulties which cause the temperature to drop more than 10-15 degrees F. (5-8 degrees C.) the temperature can be brought up to normal at a faster rate, but should be stabilized and held when the normal temperature level is reached. This is particularly true when starting the digester because it may be necessary to raise from 60-95 degrees F. (15-35 degrees C.) in seven or eight days.

THERMOPHILIC TEMPERATURES. Temperatures above approximately 102-110 degrees F. (39-43 degrees C.) cause a change in the major type of methane bacteria and can result in unstable operation if temperatures fluctuate in this region. In the northern part of the nation, where temperature fluctuations affect heating capabilities of the plant, even greater problems will be encountered than in the southern part of the nation. A limited number of plants have operated units for extended periods of time in this range, but the practice is not widespread enough and will not be discussed in detail in this manual. The reader is referred to the City of Los Angeles Hyperion plant article in the WPCF Journal for more information on the subject, as several years of experience have been gained at this plant. See Appendix B, "References."

General methods of sludge heating have been described in this section beginning on page 4-25.

pH. One of the most important environmental requirements is the proper pH. For example, the acid workers can function satisfactorily at any pH level above 5, but the methane workers are inhibited when the pH falls below 6.2. In digester operation, slight decreases in pH will seriously inhibit the activity of the methane workers.

Best Operating Range: 6.8 to 7.2
Tolerable: 6.4 to 7.4

Cases are known where efficient digestion occurs at pH's lower than 6.4, probably due to development of a strain of bacteria able to live in this environment.

The pH of the liquid undergoing anaerobic digestion is controlled by the amount of volatile acids produced and the alkalinity in the digester.

Volatile Acids. The production of organic acids is largely dependent upon the volume of sludge fed to the digester. In a normal or healthy digester, acids will be used as food by the methane formers at about the same rate as they are produced. Under these conditions, the volatile acid content of the digesting sludge usually runs in the range of 50 mg/l to 300 mg/l, expressed as acetic acid.

If the same amount of sludge is fed daily, a population balance between the acid group and the methane group will be maintained easily. On the other hand, if a large amount of readily digestible organic matter were added suddenly, excess amounts of acids would be produced and lower the pH. When this occurs, the methane formers slow down, can't keep up with the acid formers and acids accumulate in the digester.

Buffers in the digester keep the process from becoming upset every time there is overfeeding.

Buffers. Process stability depends largely on a digester's ability to resist a change in pH. This is commonly known as its **buffering capacity** measured as alkalinity. Buffers are essential in digesters. During the digestion process. the methane workers also produce some buffering material, such as bicarbonates, carbonate and ammonia, which goes into solution. The amount of buffer produced in this stage is usually enough to balance the acid produced by the acid workers so that the pH will remain at a constant level.

Alkaline buffers come from two sources:

1. Those already present in the incoming sludge, and
2. Those created as part of the digestion process.

Incoming sludges in communities with hard water supplies or with alkaline wastes from industries have a higher buffering alkalinity, sometimes as high as 6,000 mg/l. These digesters can absorb much higher swings in organic acids before pH is affected. Digesters operating in areas with very little alkalinity in the incoming wastes may need to add a caustic material such as lime, soda ash, or agricultural ammonia to raise the alkalinity.

Changes in the acid production rate or the amount of buffering material can cause changes in pH. Here is what happens when the digester pH suddenly starts to change.

Assume a digester which usually runs at a pH of 6.7 or 6.8 suddenly changes to a pH of 6.5. This means that the natural alkaline buffer in the digester has been reduced, that acids are being made faster than a neutralizing buffer, and that the methane formers can't keep up. First, the operator needs to get the pH back to normal. This gives him time to find the cause of the problem and correct it. pH control continues until the process returns to normal. Typical causes of downward trends in pH are:

1. Sudden changes in organic loading, temperature or type of waste.
2. Lack of pH control.
3. Presence of toxic materials.
4. Slow bacterial growth during start-up.

Volatile acids and alkalinity are measured to indicate the progress of digestion and to control the digester. These test results are normally used as the volatile acids to alkalinity ratio

(VA/Alk) which is the concentration of volatile acids (VA) divided by the alkalinity (Alk). The digester works best if the VA/Alk is less than 0.25, and many operators prefer to keep the VA/Alk less than 0.15 to be safe. This means that there is four to ten times more alkalinity than volatile acids, and the digester will be well buffered to keep the pH from changing.

Toxic Materials. It is important to keep toxic substances out of a digester since they inhibit bacterial activity and can cause complete failure. It is also important for operators to recognize potential toxicity problems and to apply the right corrective measures. All too often, operators have treated a toxic problem as an overload problem and added tons of lime only find that the problem was still there. Toxic problems and their cures are described in detail in Part III of this manual.

DIGESTER CONTROL

No process can be operated without having adequate control and an indication of its progress. In digester operation, how are controls and indicators defined? ***Controls are short term and used for correction.*** They are tests that can be run to confirm satisfactory operation or to indicate an action that would bring about change. Indicators are tests run, recorded and used for forecasting purposes. Control examples are shown in Figure 4-8.

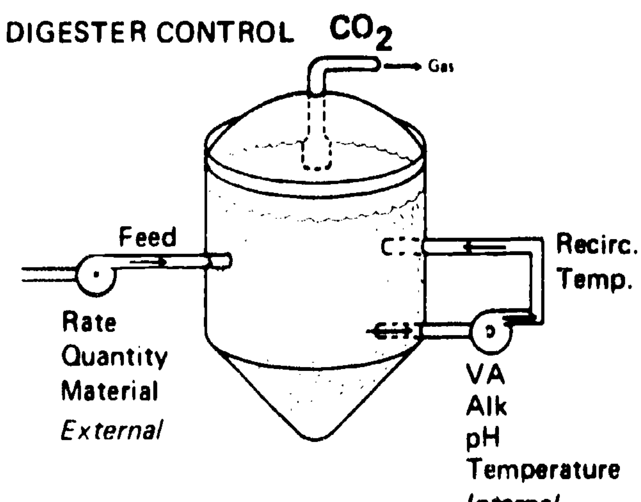


FIGURE 4-8
DIGESTER CONTROL TEST DIAGRAM

External Control

External control tests are used to help the operator control what is coming into the digester. As an example, in normal operation the operator should control the concentration of solids in the feed to avoid diluting the digester contents. To do this, the operator takes a composite sample of the incoming sludge and runs a **total solids** test. This test measures all solids and what percent of the liquid is in solid form. The test and application is described under "Indicators" on page 4-20. Best operation is obtained when the feed sludge concentration is kept as high as possible, preferably in the range of from four to eight percent.

Other external control tests are quantity of sludge handled in pounds per day and tests which describe the characteristics of the incoming sludge. In the latter case, the operator can use this information to tell:

1. Whether the existing grit removal system is operating as well as it should or whether new equipment is needed.

2. Whether toxic materials are present.

3. Whether the sludge is fresh or stale.

4. How much heat will be needed and if the digester operating temperature can be maintained.

Internal Controls

Internal controls, illustrated in Figure 4-8, show what is happening inside the digester. **Four tests are recommended for best control: temperature, volatile acids, alkalinity and pH.**

TEMPERATURE. Temperature directly affects the work of the methane bacteria as explained earlier on page 4-13. **Variations in temperature should never exceed more than one degree per day**. The best temperature range lies between 85 and 100 degrees Fahrenheit (29.37 degrees centigrade). However, the best temperature for any given digester is based on:

1. The highest gas production.
2. Ability to hold the volatile acids to alkalinity ratio between 0.1 and 0.25.
3. Maintaining the pH near neutral (6.8 to 7.2).

Thermometer locations vary according to the design of the digester. Some are inserted into the digester wall, or in the sludge recirculation line. Many operators must take temperatures from samples drawn from the supernatant overflow or from thief holes.

VOLATILE ACIDS/ALKALINITY. The major internal control combines two lab tests: volatile acids and alkalinity. The alkalinity of a digester is important because it represents the ability of the digester to neutralize the acids formed during digestion or present in the incoming waste. The results of these two tests expressed in mg/l (milligrams per liter) are combined as a ratio (volatile acids divided by alkalinity) and expressed as a single number. For example, 140 mg/l of volatile acids per 2,800 mg/l alkalinity is shown as:

$$\frac{140 \text{ mg/l}}{2{,}800 \text{ mg/l}} = 0.05$$

These two tests are run on sludge samples from the primary digester. Typical sampling points are from the recirculated sludge line and from special sampling pipes located at different tank levels. (NOTE: It is important to let the sludge in the line run for a few minutes in order to obtain a representative sample.) Other sample points are from flowing supernatant drawoff tubes or thief holes. Do not take a sample immediately after adding sludge to a digester because of possible short circuiting. Mix the contents thoroughly first.

The concentrations of volatile acids and alkalinity are the first measurable changes that take place when the process of digestion is becoming upset. As long as the volatile acids remain low, compared to alkalinity, the digester can be considered healthy with good digestion taking place. The volatile acid/alkalinity relationship can vary from less than 0.1 to about 0.35 without significant changes in digestion. Each plant will have its own characteristic ratio for good digestion. An increase in the ratio is the first warning that trouble is starting in the digester and that serious changes will occur unless the increase is stopped. If the ratio increases, the following changes will occur:

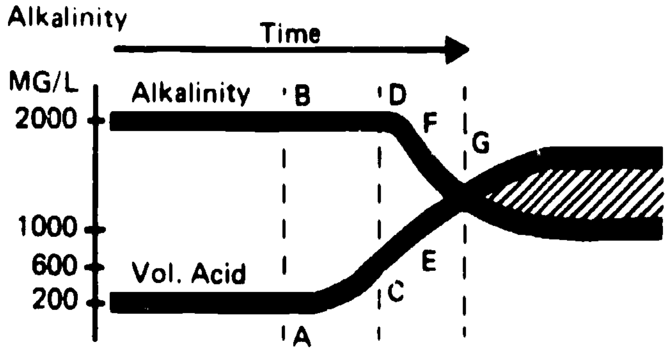
1. The CO_2 content of the gas will increase.
2. The gas production rate will decrease.
3. The pH of the digester will drop and the digester will go sour.

pH. The pH is one of the simple tests that can be run to indicate the progress of digestion and should be run frequently (at least once per operating shift). The danger lies in depending too much on pH as a process control. Because of the alkalinity in the digester, the pH changes very slowly. In fact, the digester may be completely upset before the pH changes.

Frequent monitoring of the volatile acids and the alkalinity and plotting the VA/Alk ratio provides the best information for controlling digesters because these indicators are the first to show a change when the process begins to become upset.

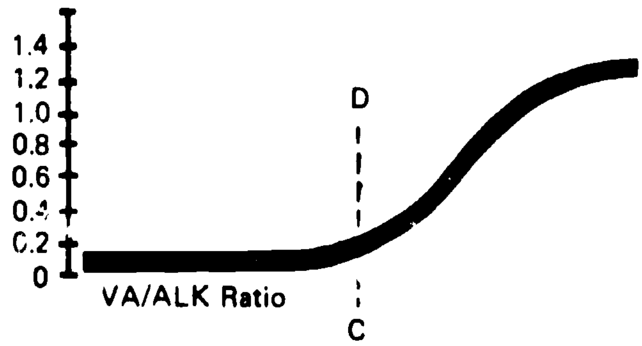
The graphs in Figure 4-9 illustrate the sequence of the change within the digester.

I Relationship Of Volatile Acids To Alkalinity



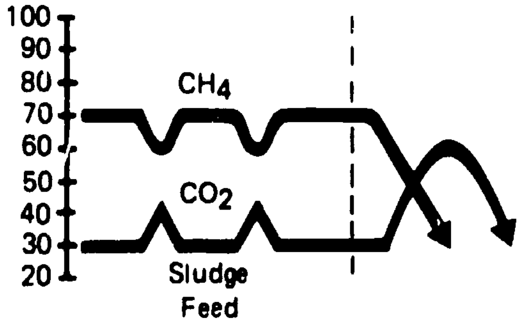
This graph shows a digester operating with a good buffering capacity (the low volatile acids 200 mg/l compared to an alkalinity of 2,000 mg/l. At Point A, something has happened to cause the volatile acids to increase followed by a decrease in alkalinity at Point D. At Point G, the digester has become sour.

II Volatile Acids/ Alkalinity Ratio



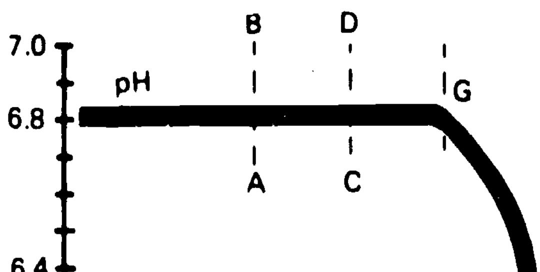
This graph continues the same digester performance by showing the volatile acids/alkalinity ratio. Notice that at Points CD, the increase in volatile acids produces an increase in the ratio from 0.1 to 0.3.

III Relationship Of The Change In Ratio Of CO_2 To Methane (CH_4) As [illegible] Of "I"



By comparing this graph with Graph II, methane production begins to drop with a corresponding increase in CO_2 when the ratio in Graph II reaches about 0.5.

IV Relationship Of pH Change To Change In "I"



pH doesn't change in this graph until the digester is becoming sour at Point G.

FIGURE 4-9 GRAPH OF CHANGE SEQUENCE IN A DIGESTER

Digesters respond slowly once they are upset. Therefore, the best operation is obtained by **preventing upsets**. The following general guidelines are given for best process control.

1. Routine volatile acids and alkalinity determinations during any startup process are a must in bringing a digester to a state of satisfactory digestion.

2. Measure the volatile acid/alkalinity ratio at least twice per week during normal operation, plot against time and watch for trends. NOTE: An example of this is found in Appendix G.

3. Measure the volatile acid/alkalinity ratio at least daily when a digester is approaching trouble such as an increased solids load from waste discharges or a storm.

4. CO_2 and pH tests may be substituted for volatile acids/alkalinity control in those cases where the loading is uniform and predictable and process upsets are infrequent. It is important, however, to realize that failures are costly in terms of both money and time.

The following suggestions are given for corrective response when the volatile acids/alkalinity ratio exceeds 0.35.

1. Extend the mixing time of digester contents.

2. Control heat more evenly.

3. Decrease sludge withdrawal rates.

4. Pump some seed sludge from the secondary digester to the primary using the following guidelines.

   a. Draw down the primary digester to make room for the sludge addition.

   b. Use the volatile acid/alkalinity ratio as a guide to determine how much seed sludge should be added. Hold the ratio to less than 0.25.

Several methods are available for performing the volatile acids test.

1. **Silicic Acid or Chromatographic Method.** This is the preferred method when high accuracy is required. The test can identify up to 95 percent of the organic acids present in the sample. It is the only test recommended by *Standard Methods for the Examination of Wastewater*. The test requires about one hour to run. The disadvantages include the need for more special equipment and more chemicals than the other methods.

   Appendix E.
   Standard Methods, 13th Edition, page 577

2. **Straight Distillation Method.** This is one of the most commonly used tests since the procedure is fairly straightforward and does not require any special equipment. The test is not for accurate work but is satisfactory for digester control. The disadvantages are the test's dependency on lab techniques to obtain good results and it requires about an hour to run.

   Appendix E.
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3. **Titration or Nonstandard Method.** This test was originally developed by R. DiLallo and O.E. Albertson and is listed in the WPCF Manual of Practice. The test takes about ten minutes to run and is reported good when volatile acids exceed 250 mg/l.

   Appendix E.
   MOP No. 18, *Simplified Laboratory Procedures for Wastewater Examination*
   WPCF Journal, Volume 33, April 1961, page 356

Process Indicators

Process indicators are those tests used for forecasting purposes rather than control. Test results are always recorded and best use is made when they are graphed. Procedures for graphing are described in Appendix G. The most common tests used are shown on Figure 4-10 and described below.

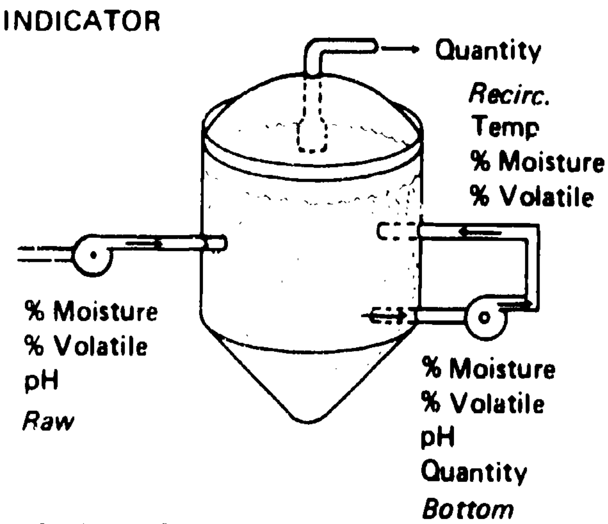


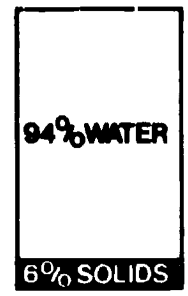
FIGURE 4-10
DIGESTER INDICATOR TEST DIAGRAM

Solids. Several points in the digestion process are sampled and tested for solids—both **total solids** and **volatile solids**. These points are raw sludge feed, recirculated sludge, supernatant and digested sludge.

These tests are needed to gain information on such things as concentration, loading rate, pounds of solids handled through the process and the percent reduction of volatile solids.

TOTAL SOLIDS. Sludge concentration is determined by drawing a sample from a well mixed point for each source, such as raw sludge feed, digester mixed sludge and supernatant, and then performing a **total solids** test. Total solids is obtained by evaporating all of the water from a weighed sample and weighing the residue. The results are expressed in percent of solids (dry basis). The percent of solids can be converted to mg/l as follows:

10,000 mg/l equals 1 percent solids
20,000 mg/l equals 2 percent solids
and so on . . .
5,000 mg/l equals 0.5 percent solids



To convert mg/l per million gallons into pounds:

mg/l times volume in million gallons times 8.34 equals pounds (OR)
mg/l x MG x 8.34 = lbs.

The effect of sludge concentration on digestion time can be seen in the following example. Suppose an operator pumps 12,800 gallons (48400 l) of raw sludge with 2 percent (0.02) solids and then changes the method of pumping sludge to increase the concentration to 4 percent (0.04). The reduced amount to be pumped can be found by setting up the following ratio:

$$\frac{0.02}{12{,}800 \text{ gals.}} = \frac{0.04}{X \text{ gals.}} \text{ then}$$

$$\frac{0.02}{0.04} \times 12{,}800 = 6400 \text{ gpd } (24000 \text{ l/day})$$

The same amount of food would be added. For example:

1. 0.02 x 12,800 gpd x 8.34 lbs./gal.
   = 2,135 lbs./day (968 kg/day)

2. 0.04 x 6400 gpd x 8.34 lbs./gal.
   = 2,135 lbs./day (968 kg/day)

VOLATILE SOLIDS. *Volatile solids tests are used to indicate* ***organic loading*** *to the digester and* ***digester efficiency***.

Digester operators need to know what percent of the total solids entering the digester is coming in as food matter to be decomposed by the bacteria. This is found by a volatile solids test. The residue from the total solids test sample is burned at 550 degrees centigrade until a white ash remains in a dish. The ash is then weighed, and this weight is subtracted from the total solids weight. The difference between the two weights represents the volatile or organic portion and the residue after burning represents the ash or the inorganic portion. This is shown in Figure 4-11.

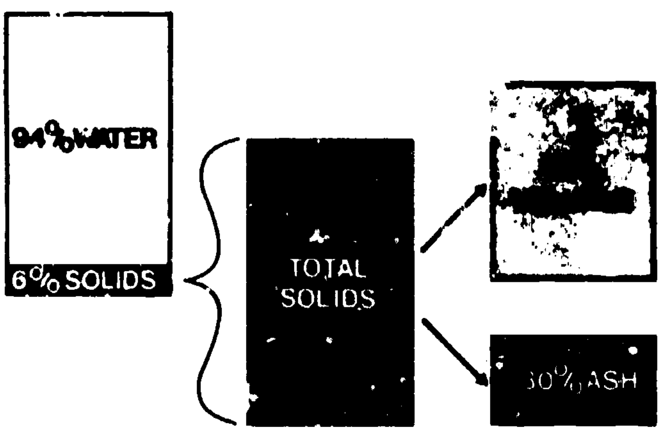


FIGURE 4-11 SLUDGE FEED DIAGRAM

Volatile solids is usually expressed as a **percent of total solids**. The numbers in these examples were used only to illustrate relative proportions and may be different than actual plant conditions.

Let's carry the example one more step and find out what typically happens to the sludge fed to a digester as shown in Figure 4-12.

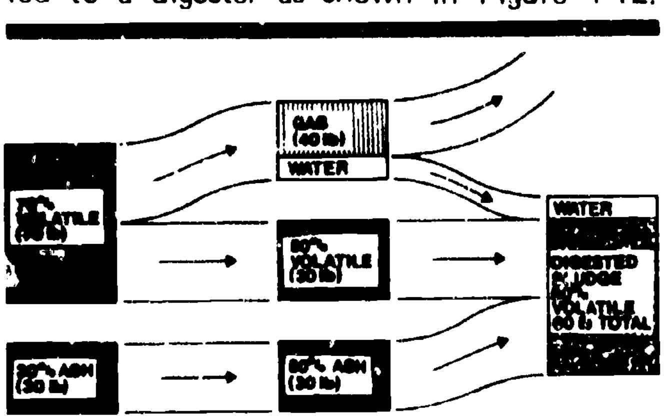


FIGURE 4-12
HOW VOLATILE SOLIDS ARE CONVERTED TO STABILIZED SLUDGE

For example, assume 100 pounds (45.4 kg) of total solids coming into a digester. Then 70 pounds (31.8 kg) of this material is volatile solids and 30 pounds (13.6 kg) is ash or inert material. As the volatile solids portion undergoes digestion, it is converted into 40 pounds (18.1 kg) of gas and water and 30 pounds (13.6 kg) remain as undigested volatile solids. Notice that the ash portion has been unaffected by digestion and remains as 30 pounds (13.6 kg).

It is desirable to feed the digester with the highest volatile solids content sludge possible. This is done with an efficient grit removal system. The volatile content is an indirect way of measuring the amount of grit material in the incoming sludge as well as directly measuring the amount of food available to the bacteria. It has been found that the volatile content of incoming sludges should be above 70 percent. This means that the plant's grit removal facilities must always operate at top efficiency to prevent filling a digester with grit and reducing its capacity. Figure 4-5, on page 4-9, illustrates an inefficient digester condition resulting from grit accumulation. Typical grit removal equipment includes grit channels, detritus tank and cyclonic grit separators.

Now that we've discussed solids and what happens to them in a digester, let's look at loading and efficiency.

Two different loading factors, organic load and hydraulic load, are important process indicators.

ORGANIC LOADING. Organic load is the amount of food (volatile solids) fed to the digester each day and is normally calculated as pounds of volatile solids fed per day per cubic foot of active digester volume.

The method most commonly used to express loading is to relate the amount of volatile solids in the feed sludge to the active volume in the digester. This figure is calculated by: (1) averaging the volatile solids content of the raw sludge, (2) knowing the total pounds of sludge pumped into the digester in a given period; (3) measuring or calculating the volume of the digester, (4) dividing the digester vo ıme into pounds of volatile solids.

$$\frac{\text{lbs. raw sludge/day} \times \text{\% volatile content}}{\text{available digester volume}}$$

The number that results can be expressed as pounds of volatiles per cubic foot of digester capacity, or as pounds of volatile solids per 100 or per 1,000 cubic feet (2.83-28.3 m^3) of capacity. This number is similar to the expression used in activated sludge known as the F/M ratio, except that this is an expression of the amount of food to the volume of the digester.

The amount of active volume before digestion takes place is affected by both the amount of scum that is on the surface of the tank and the amount of grit and inorganic material on the bottom. When the tank starts out in a clean condition, the active volume is essentially equivalent to the total volume of the tank. As time progresses, this active zone is reduced more and more, causing a higher loading ratio. Looking at it another way, less volume is available to treat the same or an increased amount of solids compared with what was available originally.

The following example will help to illustrate changes in loading. The volume when a digester is first put into operation is compared with the volume four years later without cleaning the tank.

Needed information:

Digester volume (**available volume**)
Pounds of raw sludge feed
Volatile content

Example:

Assume the available volume of a new 50-foot diameter (15.2 m) digester is 50,000 cubic feet (1416 m^3), raw sludge is 8,000 (3630 kg) pounds per day, volatile content is 74 percent.

Then

8,000 pounds/day x 0.74
= 5,920 lbs. (2687 kg) VS per day

Loading:

$$\frac{\text{5,920 pounds/day}}{\text{50,000 cu. ft.}} = \text{0.11 lbs. VS}$$

per cu. ft. per day (1.76 $kg/m^3/day$)

Let's continue the example to see what changes have occurred to the same digester four years later with the same loading rate. The operator measures the scum blanket and grit layer (as described in Part III, page 3-31), and finds the scum averaging 5 feet (1.5 m) deep and the grit 3 feet (0.9 m) deep. The available volume has been reduced by a total of 8 feet (2.43 m) which represents a loss of

$$\frac{8 \text{ ft.} \times \pi \times \text{dia.}^2}{4} = \frac{8 \times 3.14 \times (50)^2}{4}$$

$$= \text{15,700 cu. ft. } (445\ m^3)$$

Loading now is

$$\frac{\text{5,920 lbs./day}}{(\text{50,000} - \text{15,700 cu.ft.})}$$

$$= \text{0.17 lbs. VS/cu.ft./day}$$
$$(2.72\ kg/m^3/day)$$

This change in loading from 0.11 to 0.17 pounds of VS per cubic foot per day (1.76 to 2.72 $kg/m^3/day$) will make the digester harder to operate and may cause more frequent upsets.

HYDRAULIC LOADING. ***The hydraulic loading is the average time in days that the liquid stays in the digester and is related to digester capacity.*** Hydraulic loading is calculated as follows:

Hydraulic loading equals
Digester Volume/Feed Volume

For example, at an average pumping rate of 12,800 gallons per day into a 250,000-gallon digester, the detention time would be:

$$\frac{250{,}000 \text{ gallons}}{12{,}800 \text{ gal./day}} = 19.5 \text{ days}$$

There is a minimum time required by a digester to convert the solids into an acceptable sludge. The minimum hydraulic loading varies with the type of digester and the type of solids (up to six months for a single unheated unit to as low as ten days for a high-rate system).

If the time is too short, the methane formers will not have enough time to convert the acids produced by the acid formers to methane gas. Some wastes need a longer time. For example, a purely domestic waste needs a fairly short time to complete the decomposition of solids, but the same kind of municipal waste with cellulose added by an industry would need a much longer period.

Treatment plants located in agricultural communities where food processors operate on a seasonal basis have other problems because the amount of sludge produced suddenly increases when the food processing plant starts up. The increased volume of sludge produces an immediate overload on the digester. The operator must watch the digester and add lime or other caustic to keep the buffering capacity high. Often the good sludge in a secondary digester is used to accomplish the same purpose.

The hydraulic loading time can be increased by prethickening the feed to reduce the amount of water fed. Too much water in the feed causes a hydraulic washout of both feed and organisms.

QUANTITY OF RAW SLUDGE. Amounts of raw sludge pumped may be found by several means, but should be recorded even if it is an educated guess as to the amount. The amount may be measured by reading a magnetic flow meter output, by measuring the volume of a piston pump barrel and counting the number of strokes per minute, by calculating the volume of a sump or pit from which sludge is pumped and recording the number of pits full or sumps full pumped in a day, or by measuring the distance traveled by a floating cover on a primary digester. One or more of these methods may be available to the operator; even an educated guess as to amount is better than no information at all.

When more than one means exists for making this determination, it is a good idea to compare two different methods. For instance, if measurements are made by estimating the amount pumped out of a pit and into a digester with floating cover, estimate the volume of each and compare results over several days to see how close they are.

DIGESTER EFFICIENCY. The "In-Out" test using volatile solids indicates digester efficiency. Normally samples are drawn from the digester feed sludge and from the digested or bottom sludge. However, the active digester sludge can be substituted for the bottom sludge.

Digester efficiency can be calculated using the volatile solids test results in the following formula:

$$P = \frac{(\text{In} - \text{Out})}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

Where **In** represents the percent of volatile solids entering the digester and **Out** represents the percent of volatile solids leaving the digester and **P** is the percent reduction of volatile solids.

Example:

Assume that the volatile solids entering a digester is 70 percent and that a test showed 50 percent volatile solids leaving the digester.

In = 70% = 0.70

Out = 50% = 0.50;

Then,

$$P = \frac{(.70 - .50)}{.70 - (.70 \times .50)} \times 100\% = \frac{.20}{.70 - .35} \times 100\% = \frac{.20}{.35} \times 100\%$$

$$P = .57 \times 100\% = 57\%$$

The In-Out tests can be used for indication purposes. For example, if the trend shows a decrease in percent reduction, then, this might mean that the:

1. Volume of the digester has decreased.
2. Throughput has increased.
3. Temperature is not high enough.
4. An inhibitory or toxic material has entered the digester.

CO_2. This is a most easily measured major component in the digester gas. Because the sum of the CO_2 and CH_4 (methane) is approximately 100 percent, the amount of CH_4 can be roughly estimated by measuring the CO_2. The CO_2 content of the gas in well-operating digesters ranges from 25 to 35 percent. ***The percent of CO_2 can be an early indicator of problems.*** When the percent of CO_2 begins increasing, trouble may be on the way. It is important, however, to realize that the percent of CO_2 will increase soon after feeding if sludge is fed into the digester intermittently. If sludge is fed to the digester only two or three times a day, information should be obtained at different times during the day to find normal values for the plant.

The best procedure for taking the CO_2 test is to take it the same time after feeding.

Gas Production. ***Gas production from a digester should be fairly constant if the feed is constant.*** Gas production should range between 7 and 12 cubic feet for each pound of volatile matter destroyed.

pH. ***pH run on raw feed may indicate the presence of toxic material and whether the incoming sludge is septic or fresh.*** Tests on the digester contents indicate the balance of neutralizing buffer. Changes show the need for making caustic additions. The normal range for pH in digesting sludge is from 6.8 to 7.2.

Summary: Process Control Indicators. As a summary, some early indications of problems are given by graphing the following parameters: pH, CO_2, alkalinity and volatile acid ratio and gas production. Direction of the parameter compared to time is more important than absolute numbers. Table IV-3 below illustrates how direction of several of these parameters can indicate possible problems.

Table IV-3

DIRECTION OF PROCESS INDICATORS OCCURRING SIMULTANEOUSLY INDICATE POSSIBLE DIGESTER PROBLEMS

Indicator		pH	CH_4	CO_2	Alk.	Vol. Acid
	Trend of graph					
pH	down		down			
CH_4 (amount)	down	down		up	down	up
CO_2 (percent)	up		down			
Alk	down	down				
Vol Acid	up		down			

TYPES OF EQUIPMENT

Sludge Heating

Submerged Burners. There are two general types of these devices, one of which discharges hot gas and flame directly into the sludge (see Figure 4-13). The other type has a burner that is enclosed in a ductwork tubing arrangement which allows the flame to heat the interior of the tube, while the tube passes through the contents of the digester. Hot gases are exhausted through an opening in the roof (see Figure 4-14).

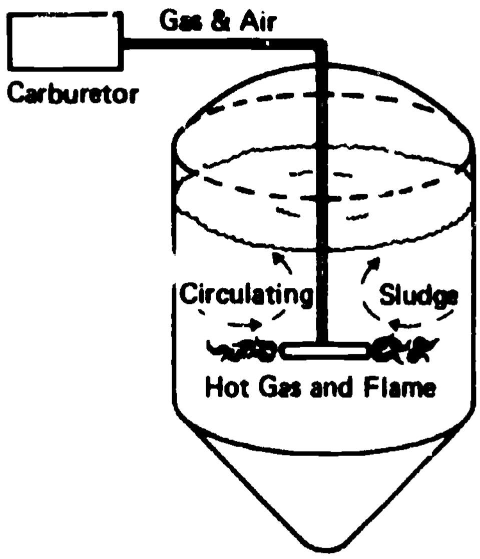


FIGURE 4-13 INTERNAL SUBMERGED BURNER

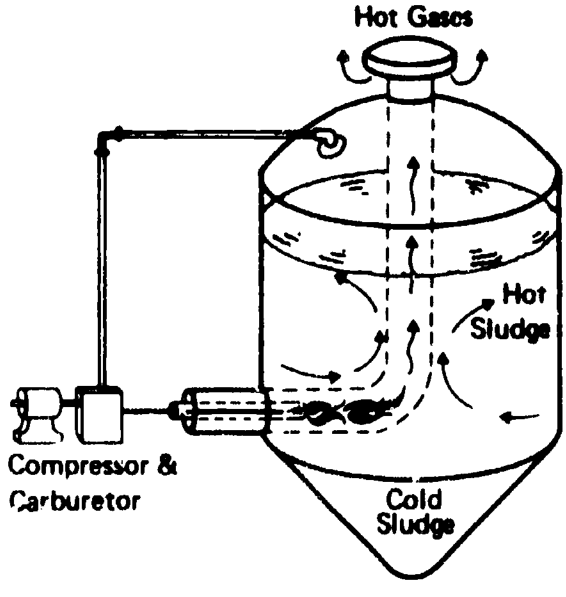


FIGURE 4-14 EXTERNAL SUBMERGED BURNER

Steam Injection Into the Digester. Digester gas or other fuel is used to fire boilers which supply steam to be injected into the digester. Generally, multiple steam feed points are used—either as pipes that extend to some point below the sludge surface or are connected into sludge feed lines. Several companies make steam injection devices that are mounted in the sludge pipeline downstream of any valves.

This type of system adds water to the tank contents and, because boilers must be continuously fed, boiler water conditioning is an important operational consideration.

Equipment that is standard with steam-injection systems includes:

1. Boiler water conditioning.
2. Steam lines which require safety precautions.
3. Check valves which prevent sludge backing up in the lines.
4. Pressure gauges and steam line controls.

Particular care must be taken that check valves function correctly in lines that connect with sludge under pressure. A check valve failure in one plant with this type of heating system caused sludge to be transferred into the boiler. Fortunately, the boiler was not hot at the time of the discharge or a serious explosion could have occurred. After this accident occurred a second check valve was placed in the line backing up the first one as an added safety measure.

Steam Injection Into Preheat Tank. A system similar to that described for "Steam Injection Into The Digester" allows raw sludge to be heated in a separate tank before being pumped to the digester. Steam is injected into the tank until a preset temperature is reached.

Digester sludge may also be recirculated through the tank, or both raw and digested sludge may be introduced simultaneously.

Hot Water Transferred to Internal Digester Heat Exchanger. Hot water from gas-fired boilers or cooling water from gas-driven engines may be pumped through several different types of devices located inside the digester. Each type is described below:

1. Coils of pipe placed inside the tank and normally secured to the wall allow hot water to circulate around the walls and return to the heat source. Various types of mixers cause the sludge to move past the hot water pipes. In some older installations, natural convection currents caused by rising hot sludge may provide the only mixing available (see Figure 4-15).

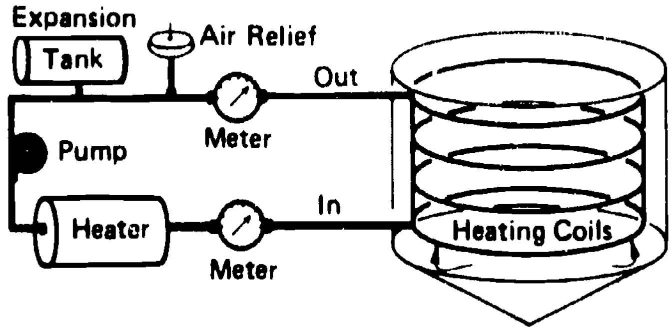


FIGURE 4-15 INTERNAL HEAT EXCHANGER

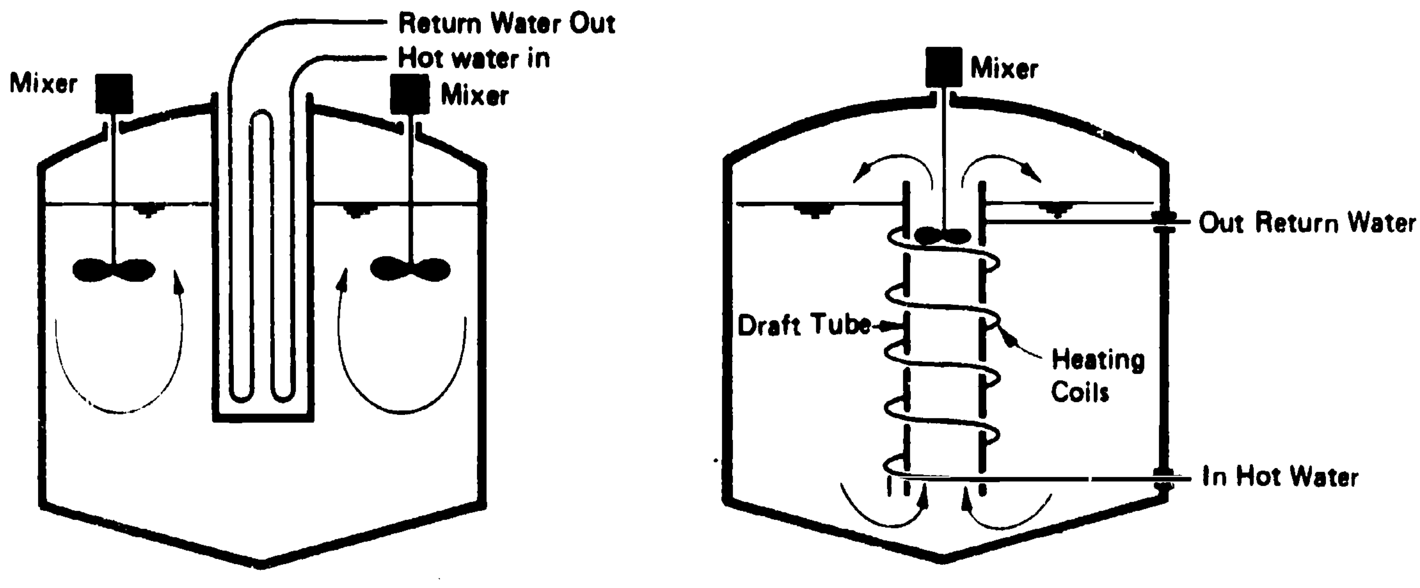


FIGURE 4-16 INTERNAL HEAT EXCHANGERS

2. Several different systems with heat exchangers surrounding draft tubes are used. The principle is to move sludge to pass heated surfaces to increase heat transfer (see Figure 4-16).

Common equipment is listed as follows:

1. Hot water source (boiler or engine jacket).
2. Heat exchanger circulation pump.
3. Heat exchanger submerged in tank.
4. Expansion tank.
5. Water meters.
6. Air relief valve.
7. Temperature gauges for monitoring the water and sludge systems.
8. Temperature gauges for controlling the heater and circulation pump.

External Heat Exchanger. Many of the major pieces of equipment are the same as those discussed for internal heat exchangers. In this system, sludge is circulated from the digester through the exchanger and back to the tank rather than transporting water to a point inside the tank. Raw sludge may also be heated in this system, either separately or with the digester recirculated sludge.

It is common practice to locate the heat exchanger near the boiler to reduce heat loss in transporting the water to the exchanger. Sludge is pumped through a series of pipes submerged in a hot water bath or through coils close to pipes carrying hot water in a spiral heat exchanger (see Figure 4-17).

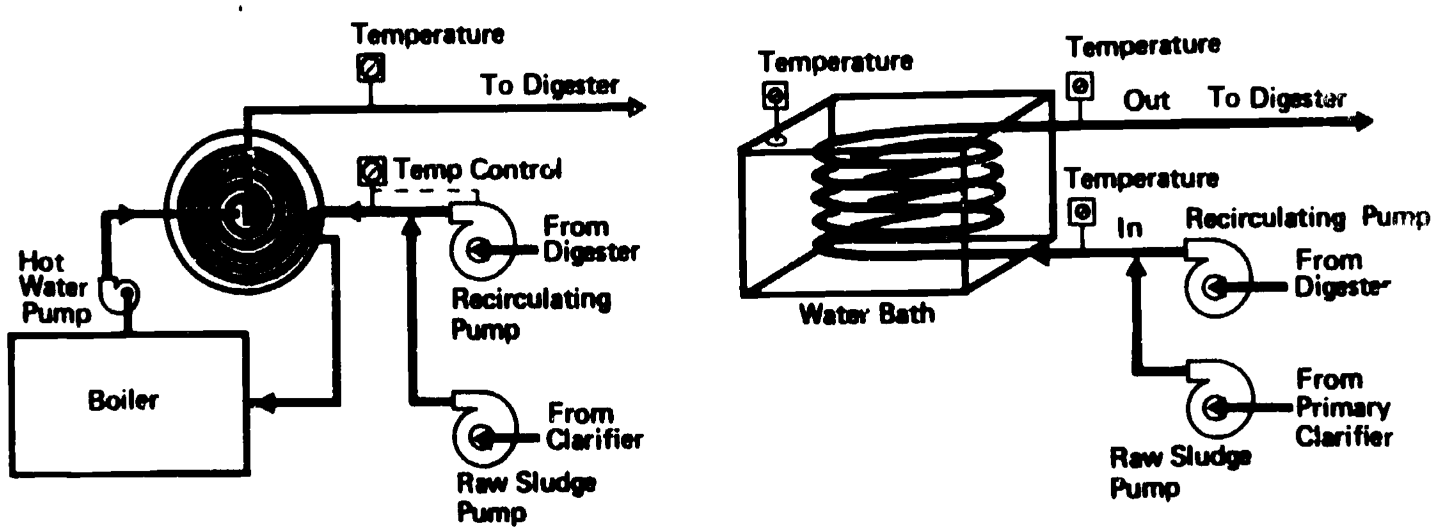


FIGURE 4-17 EXTERNAL HEAT EXCHANGERS

Temperature Control Systems. Temperature control systems should be checked for accuracy, such as temperature probes located in digester walls or in sludge pipelines. In the case of probes in sludge pipelines, the operator should consider that:

> Accurate temperatures can only be obtained after the recirculation pump has been running for several minutes. The operator is cautioned not to take readings until the pump has been running long enough for the temperature to stabilize.

Sludge Mixers

Internal Fixed Mixers. A major method of mixing is accomplished by discharging steam, hot gas, or digester gas under the sludge surface and allowing the buoyancy of the rising gas stream to cause movement (see Figure 4-18).

Components of these systems are: a compressor or other device to create pressure higher than the head in the digester, delivery piping, diffusers, and safety and process controls.

Internal Moving Mixers. These mixers use propellers, impellers and turbine wheels to move the sludge, as shown in Figure 4-19.

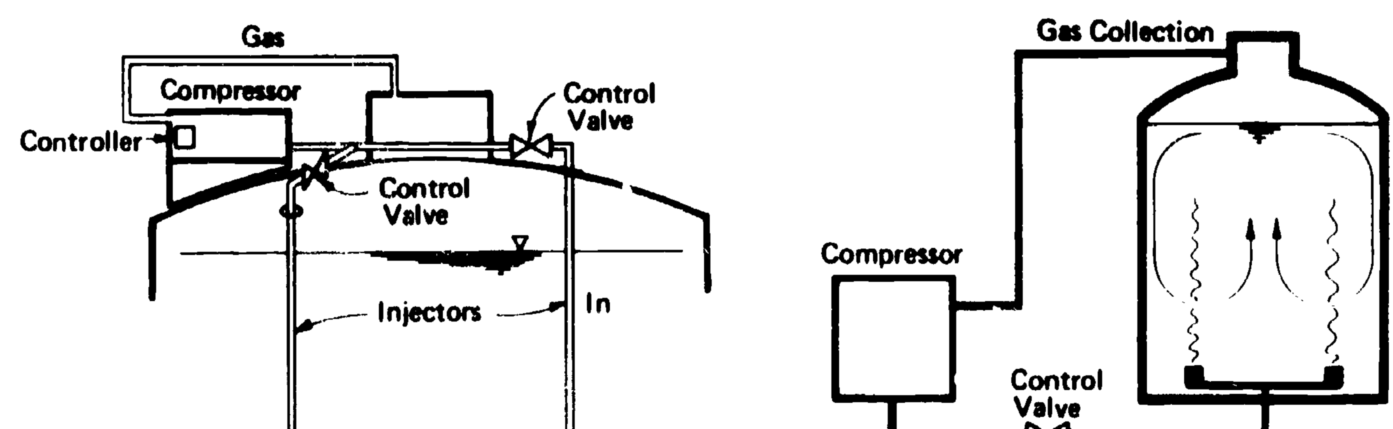


FIGURE 4-18 INTERNAL FIXED MIXERS

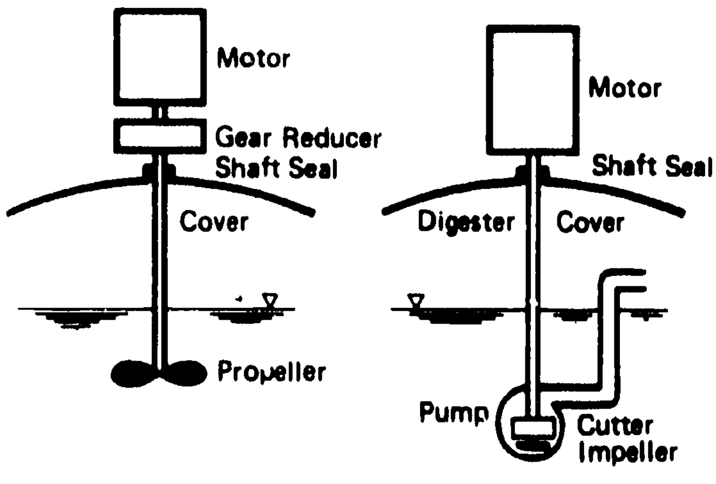


FIGURE 4-19
INTERNAL MOVING MIXERS

An important factor related to this method of mixing is the exposure of moving surfaces to grit and debris. Material that collects around shafts and impellers can cause vibration due to imbalance, and grit wears away impellers. Generally, as the diameter of the rotor increases, the debris problem increases, but wear from grit decreases. On the other hand, small diameter pump impellers or mixing propellers are subject to rapid wear in heavy grit conditions.

Recirculation. Recirculation demands the use of a pump, which may be centrifugal or piston type, and which is located externally from the digester. The total capacity of the pump is generally less than the circulating capacity of mixers. However, some plants use recirculation as the only means of mixing.

Digester Covers

The top surface or cover of a digester has some unique features which merit discussion. Personnel must be aware of how variation in pressure, contents and level inside the tank may affect the cover. Three major types are discussed; fixed, floating and gas holder.

General Comments. The cover on the digester serves several purposes: superstructure for mixing equipment, access to the tank, support for safety devices, space for accumulation and collection of gas and variable storage space for the gas produced. The operator should recognize that precautions must be taken to prevent damage due to excess pressure which may occur when the sludge lines plug and/or gas control devices fail. Damage may also result when vacuum devices fail and movable covers are on the corbels. Fixed covers are vulnerable when the rate of sludge being drawn out exceeds the feed rate, or vacuum devices fail.

Fixed Covers. The biggest hazard in fixed cover operation is encountered when the pressure relief device fails, supernatant overflow line plugs and the liquid level continues to rise. The pressure inside the tank can lift the fixed cover off the walls causing serious damage. The covers may either be concrete structure rigidly fixed to the walls, or metal with anchor bolts securing the cover in one position (see Figure 4-20). In either case, separation from the top of the wall will require

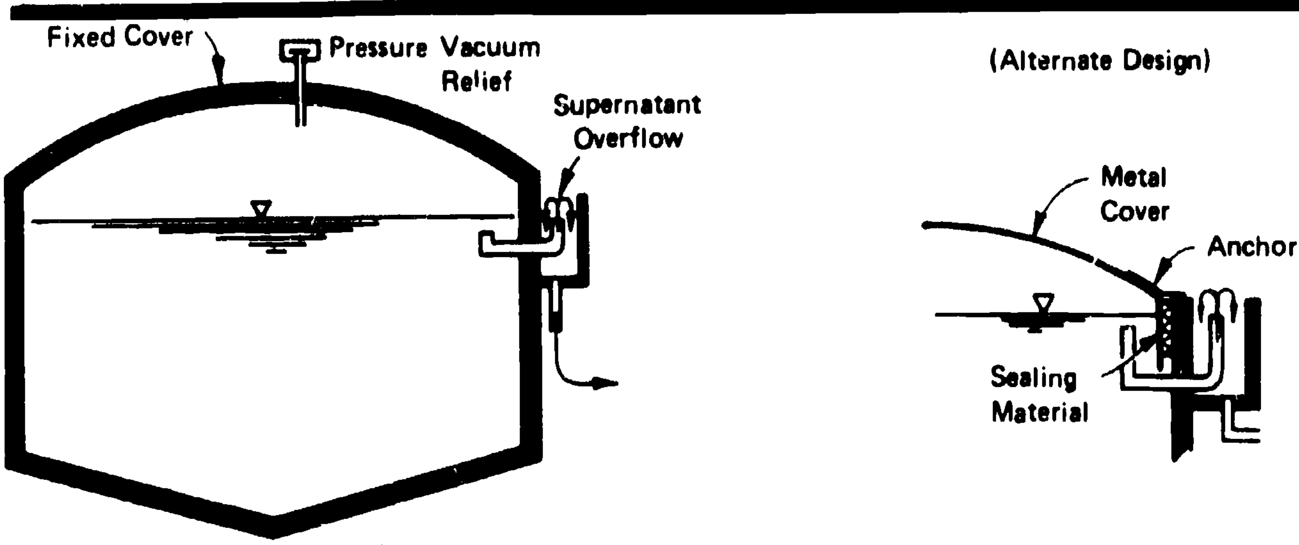


FIGURE 4-20 FIXED COVER

tank draining and expensive repairs.

Floating Covers. Various types of floating covers are in use; however, they have many of the same characteristics and operational problems. Figure 4-21 shows one type. Generally, the cover floats on the surface of the sludge which varies as feeding and supernatant removal rates change.

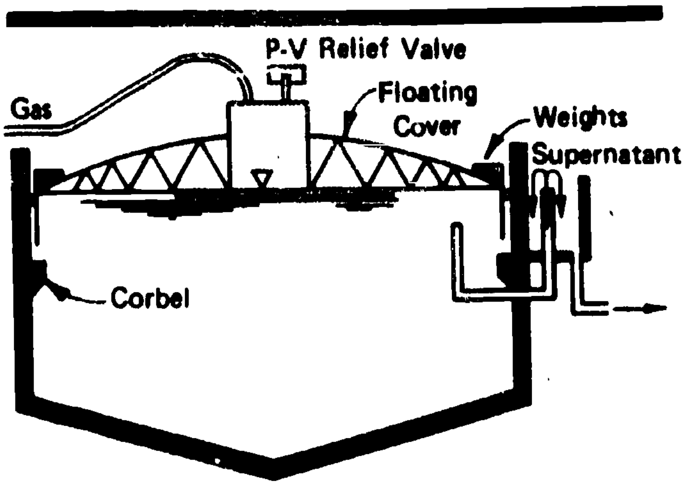


FIGURE 4-21 FLOATING COVER

Maintaining cover guides in smooth operating condition and keeping the cover level are the two main operational concerns with floating covers. For covers with wooden superstructures, replacing the deck and repairing or recovering roofing may also be necessary.

Care must be taken not to pump in excessive amounts of sludge, particularly if plugging of the overflow line is a problem. There have been instances where covers have floated over the wall because of high sludge levels. Covers have also been known to collapse when the vacuum relief failed and the covers were setting on the corbels. Failures of this type are most prevalent during freezing weather.

Gas Holder Covers. The third major type of cover is used to store gas as it is produced. The pressure developed inside the tank causes the cover to lift as much as six feet or more above the minimum height. The cover has a much longer skirt than the floating type (see Figure 4-22).

Stiff metal guides and rollers are mounted between the cover and the wall superstructure

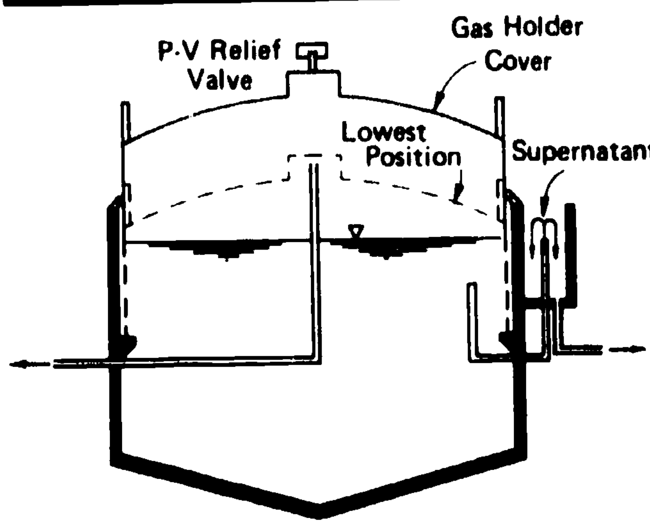


FIGURE 4-22 GAS HOLDER COVER

to allow the cover to travel up and down without binding. Accumulation of heavy scum around the edge between the cover and the walls can cause excessive friction and prevent free travel. Pressure and vacuum relief valves must also be kept in good operating condition to maintain the desired pressure.

Gas Handling Equipment and Control Devices

Figure 4-23, Typical Flow and Installation Diagram—Digester Gas System, shows many of the major pieces of equipment in a gas collection and distribution system.

1. **Pressure Relief Device.** The pressure relief device allows excess pressure to escape from the digester in the event that a blockage occurs and pressures build up above a safe level. Troubleshooting information has been given in Part I, Troubleshooting Guides 10 and 11 on digester covers.

2. **Vacuum Breakers.** The vacuum breaker functions opposite to the pressure relief valves and allows air to enter the tank in the event that sludge is drawn out of the tank too rapidly or the level of the sludge changes suddenly with relation to the floating cover. Troubleshooting information is given in Troubleshooting Guides 10 and 11.

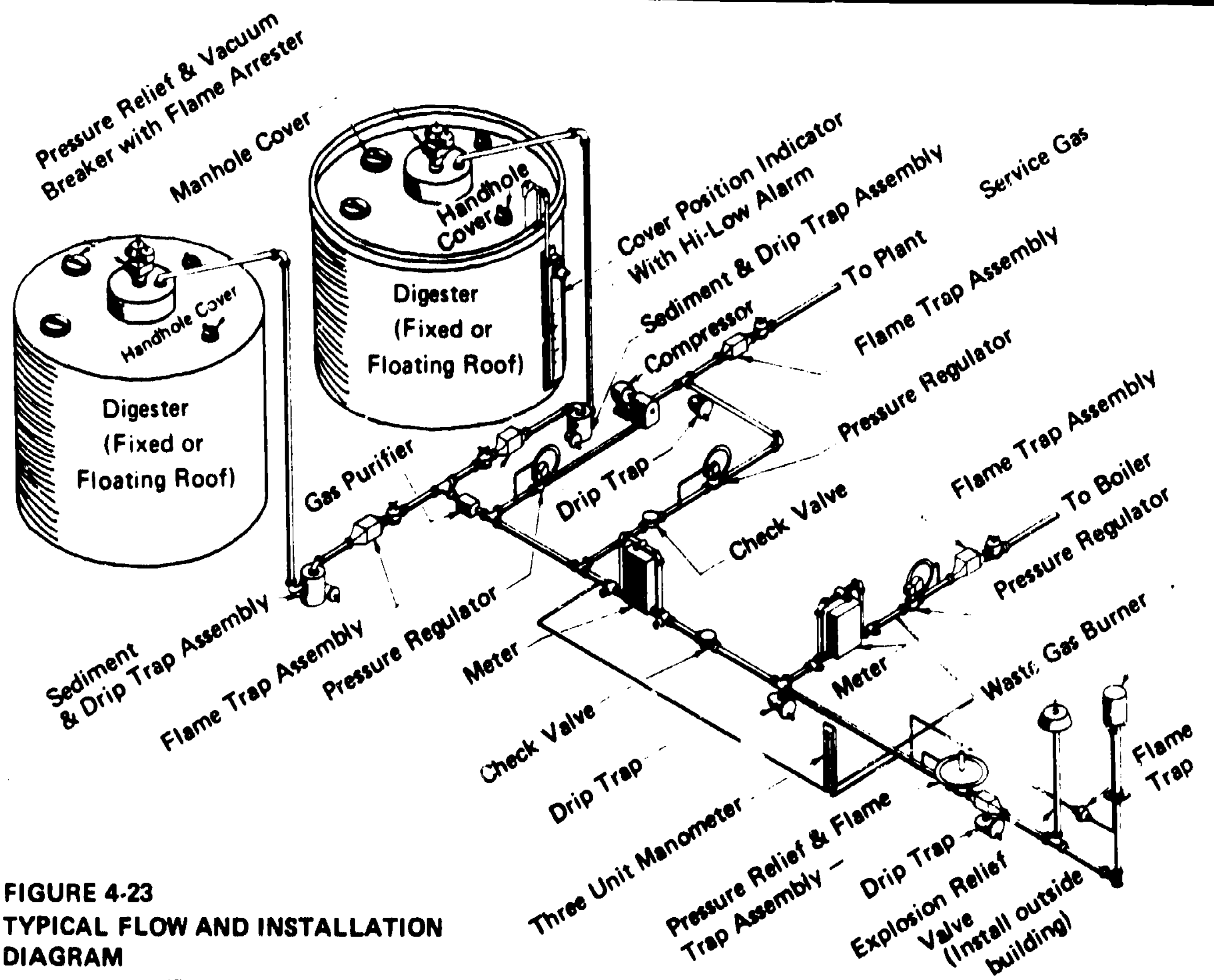


FIGURE 4-23
TYPICAL FLOW AND INSTALLATION DIAGRAM

3. **Sediment and Drip Trap Assembly.** Water that condenses in gas lines is normally taken out at the low points in drip traps. This water should be removed daily or more frequently when condensation rates are high. Gas seals sometimes leak due to drying out of the material; therefore, these should be checked monthly and the entire unit disassembled and inspected annually.

4. **Flame Trap Assembly.** Flame traps are installed in lines to prevent flames traveling up the gas line and reaching the digester. The trap consists of a metal grid which allows the gas to cool down below the combustion point as it passes through the metal grid. If a high amount of impurities is in the gas, the metal grid may become fouled and prevent gas passing through. These units should be disassembled annually and washed out in a safe solvent. Refer to the manufacturer's instructions for specific details.

5. **Pressure Regulator.** When gas is used, a lower pressure than the system operating pressure may be needed. Regulators are installed to maintain a constant pressure at the point of use. The pressure regulator can be adjusted to values less than system pressures; however, adjustments should be made following the manufacturer's instructions.

6. **Gas Meter.** Several types of gas meters are in use in treatment plants. These can be a useful tool or an exasperating headache depending on where they are installed and the difficulties in keeping them operating. Several of these are discussed below:

a. **Bellows Type Meter.** The bellows meter is most similar to the device that the old fashioned blacksmith used to provide air for his fire.

b. **Shunt-Flow Meter**. This meter, which has a propeller in it, allows a certain amount of gas to bypass the main section of the meter while a measured amount passes through the meter.

c. **Positive Displacement Type Meter.** This meter operates like a gear motor or in reverse of a lobe type blower. Internal moving parts turn in direct ratio to the amount of gas passing through them. Some operators maintain a spare unit for emergencies.

7. **Check Valve.** When dual gas systems are used (such as a dual fuel engine), check valves are installed to prevent flow of the higher pressure gas back to the digester. These are built to allow flow in one direction only and should be inspected and cleaned annually to assure that all moving parts are free of corrosion and debris.

8. **Manometers.** Gas pressure is measured by a glass column, which contains a special oil or water. These columns are called manometers. The measured pressure is read in inches of water column.

Several sources of information are available for discussions on gas systems. The reader is referred to the ***Operation of Wastewater Treatment Plants—A Field Study***, Chapter 8, pages 8-17 to 8-40, for more detailed discussion and pictures of the devices described above.

INTRODUCTION

The first thought that comes to most operator's minds when the subject of control is mentioned is laboratory testing. However, there are a variety of "tools" that should not be overlooked in addition to what the lab results can provide. These include:

1. Eyes (to judge sludge thickness, supernatant quality, desirable color of digested sludge, etc.).

2. Ears (changes in thickness of raw sludge can be detected by listening to a piston pump "hammer" when sludge gets too thin).

3. Nose (some industrial wastes, such as phenolic, that can cause digester problems can be "smelled" in time to prepare for handling them).

4. Hands (feeling texture of sludge can tip the experienced operator to sand, grease or uncomminuted components).

Nonstandard tests are also used. These are described on page 2-29.

A common question that the operator may ask is: "What is normal for my digester?" This has to be considered for the individual plant. Some insight may be gained by answering the following questions

1. Is the digester operation taking more hours than it should? (See the section on Manpower Requirements, Part III.)

2. Is the digester causing problems in other parts of the plant?
   a. Supernatant in the primary clarifier?
   b. Supernatant in the aerators?
   c. Foaming over the digester walls?
   d. Excess BOD, SS or turbidity in the effluent?

3. Is the digester causing problems off-site?
   a. Odors from the digester?
   b. Odors from the sludge beds?

4. Is the system costing too much money to maintain?
   a. Some estimate the average annual maintenance cost at 4% of capital cost.
   b. Others use 2% of capital cost for the first 10 years of use and 5% after this time, as an estimate.
   c. EPA cost estimates show that digester operation costs are about 10% of the annual plant operation and maintenance costs and drying bed operation runs about 5% of plant costs.

5. Is the system being upset by industrial wastes?

6. Are operating procedures letting the digester become upset?

Some of these problems can be resolved by looking at the way certain operations are done and revising them to prevent possible problems and improve digestion results.

A number of operation procedures are reviewed in the following pages. An operation check list is included at the close of the section.

HOW TO SET UP A FEED SCHEDULE

First, the difference between feeding and loading should be explained. Feeding concerns only the raw sludge system while loading considers both the feed and the volume and contents of the digester.

Keeping excess water at a minimum and feeding at regular intervals are important features of a feeding schedule.

Control of Excess Water

Controlling the solids concentration going to the digester may be done in several ways as described in Operation Guide 1.

Total solids is the normal method for describing solids concentration. This test is described on page 4-20 and Appendix E-9.

Three other methods can be substituted for the total solids test by correlating them with the total solids test results. These are: lab centrifuge readings, motor amperage and the Imhoff cone test. An example of how this is done is given below using the lab centrifuge to estimate solids.

Example: Take six samples ranging from thin to thick sludge, approximately (1% to 8% total solids) run both tests on each concentration and plot results. Run centrifuge at maximum speed for 15 minutes. Be sure test is run at same speed for same time period each time.

1. Record total solids and value of the other indicator at 5 or 6 points between 1% and 8% total solids.
2. Plot on a graph, drawing a line connecting the points as shown on Figure 2-2.
3. Determine the lowest desired solids feed level and set up system to stop pumping when below that percent solids.

Feed Schedule Interval

Although the frequency of pumping may vary from once a day to continuous, operators should review this schedule to see if it can be improved. The best feed schedule is continuous at a low rate. The next best is frequent pumping for short periods and once a day is the worst. Several methods are discussed in Operation Guide 1.

A caution about pumping to the digester: ***do not allow the pump to be left on accidentally.*** Hydraulic washout is one of the major causes of digester upset and all too often it is traced back to an operator who left a raw sludge pump control in the "on" or "hand" position overnight.

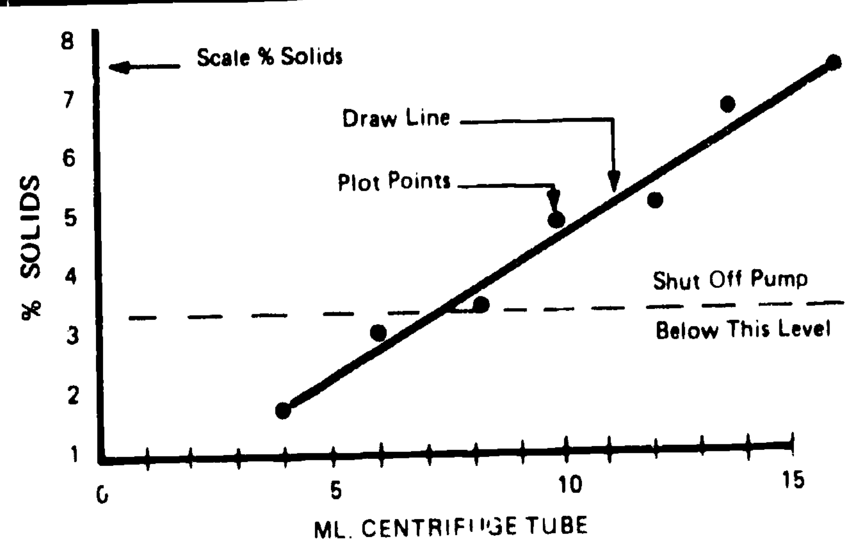


FIGURE 2-2
CORRELATION GRAPH

OPERATION GUIDE 1 DIGESTER FEEDING

DESIRED GOAL	PLANT EQUIPMENT/ CONDITIONS	METHOD
A. Don't pump excess water to the digester.	1. Sludge drawn to pit or vault before pumping to the digester.	1a. Watch sludge while being drawn. Shut off when too thin. b. Sample and compare different sludge concentrations by running lab centrifuge tests or use Imhoff cone for quick estimate.
	2. Sludge drawn directly from clarifier hopper or gravity thickener with positive displacement pump.	2a. Check pump discharge gauge, higher pressure generally indicates thicker sludge. b. Compare sound of pump with sludge thickness. Excessive hammering of piston pump indicates thin sludge. c. Coordinate total solids with pump amperage. Tie ammeter to pump controls to shut it off if sludge is too thin. See page 3-34, Gadgets. d. Install solids concentration meter that reads percent solids and use signal from meter coordinated with time clock to control feed solids concentration.
B. Pump at regular intervals to prevent adding food too fast for bacterial action and prevent temperature change.	1. Single stage digesters.	1a. Pump at least several times per day by hand and stop when solids drop too low. b. Install time clock control if none provided and set schedule for 10 a.m.—midnight. Let settle overnight with no mixing and draw supernatant in early morning.
	2. Two stage digesters.	2a. Spread pumping over 24 hours *unless freezing weather makes this unsafe when plant is not manned*. Control pumping so that excessive water is not pumped during low flow periods. See Methods 2c and 2d in A above.
C. Review pumping schedules and respond to changing conditions.	1. Winter vs. summer.	1a. Cold weather operation causes problems with sludge bridging over in rectangular clarifiers. Closer control must be exercised to avoid reducing digester temperatures. b. Increase pumping time during storms because of increase in solids. Decrease afterwards because solids accumulate in sewer lines and do not reach the plant.
	2. Industrial wastes.	2a. Most vegetable processing wastes increase the volume of sludge and decrease solids content. Adjust pumping rates to match changing conditions.

HOW TO CONTROL LOADING

In order to calculate loading, the operator must have a record of the pounds of volatile solids per day being fed to the digester and must also know the volume of usable capacity in tank. This calculation is given in Part IV, The Basics, on page 4-20.

As noted in the introduction to this section, two of the three major causes of digester upset are hydraulic and organic overload. In the first case excessive amounts of water flush out the methane formers, leaving the tougher acid formers to increase and cause volatile acids to use up the buffering capacity.

In the case of organic overload, either the amount of volatile solids increases due to an excess of food or the digester capacity is reduced by scum and grit accumulations, making the effective volume too small for the amount of food being handled.

One approach to making a loading survey is presented below.

Organic Loading Survey

To get a representative idea of an average loading, take a series of grab samples on the raw sludge feed three or four times throughout the day and on several days of the week.

Use the procedure given on page 2-21 and the calculations presented on page 4-21 and calculate the actual available volume of digester space and the volatile solids expressed in pounds per day. Do the calculations and compare the figures with those listed on page 2-4. If the numbers are significantly more than those listed in the manual as being average or normal, it's time to remove the grit and sand from the bottom of the digester and restore the original available volume.

Some general guidelines that apply to loading control are noted here and should be included when the procedures for digester loading control are written for individual plants.

General Loading Guidelines

Operators generally have no control over the characteristics or the total pounds of solids to be fed to the digester. They do, however, have control over the concentration and frequency of feeding. These are two very important controls, and they are also the ones which cause the greatest number of sludge-handling problems.

The operator must maintain the best possible balance between the incoming raw sludge and the sludge already in the digester. This is best done by:

1. Establishing a feed schedule which is frequent and in small amounts. A time clock control on the pump will allow this. However, the schedule should be set so that excess water is not pumped at night.

2. Feeding the highest solids concentration possible. Typical total solids ranges for various sludges are:

primary raw sludge	5-8%
waste-activated	1½-2%
trickling filter humus	1-3%
mixed primary/waste activated	3-5%

3. Obtaining good mixing throughout the tank. A general rule of thumb is to recycle a quantity equal to the volume of the tank once a day. If the primary digester has a volume of 250,000 gallons (950000 l) the mixer should be capable of moving at least 175 gpm (11 l/sec.).

4. Not overfeeding. One rule of thumb says that the volatile solids in the total daily feed should not exceed 5% of the volatile solids already in the digester.

5. Controlling digested sludge withdrawal to keep buffering capacity high.

6. Maintaining an efficient grit removal system.

Methods for Determining Digester Capacity

1. Measure the amount of grit and inorganic material in the bottom of the digester by probing with a long stick or piece of pipe and estimate the total cubic feet occupied by this material. Another method of finding the top of the grit layer is to take temperature readings at lower digester depths. The grit layer will be several degrees cooler.

2. If scum blankets have formed at the surface of the tank, they should be measured. One method of measuring this is to use a stick with a hinged flap of metal. When the stick is passed down through the scum layer and then lifted up, the flap will open up underneath the scum blanket. This device is discussed more fully on page 3-31.

OPERATION GUIDE 2 DIGESTER LOADING

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Prevent hydraulic overload.	1. Single stage digester, manual sludge pumping. 2. All types digesters, automatic pumping.	1a. Pump thickest sludge possible, taking care not to leave pump on accidently. 2a. Control pump schedule so that pumping rate equals sludge accumulation rate. b. Impress personnel with the importance of not over-pumping or leaving pump on accidently.
B. Prevent organic overload.	1. Single stage digesters.	1a. Spread feeding over maximum portion of the day. b. Clean digester on regular schedule (every 2-3 years). See Part III on Digester Cleaning. c. Control industrial loading by ordinance adoption and enforcement. d. Monitor volatile solids loading and VA/Alk ratio and be prepared to take corrective action if necessary to restore buffering. e. Graph digester lab test data and watch for trends.
	2. Multiple tanks.	2a. Consider the information in B–1a-1e above. b. Spread loading between several tanks if one tends toward upset. c. Recycle from the bottom of a secondary digester or another well buffered primary digester at a rate of 50% of raw feed per day. d. Adjust temperature–find most efficient level for particular waste. e. Increase mixing to maximum capacity.

HOW TO CONTROL DIGESTER TEMPERATURE

Specific temperature control methods will depend on equipment used for heating the digester. Because it is important to hold constant temperatures, the operator should be sure of the following:

1. The temperature should be measured at a point that represents the active part of the digester.

2. The heating system should control the temperature evenly so that it is not causing digester upset.

3. If cold weather makes temperature control erratic (changes of more than 2°F per day), lower the operating temperature to a level that can be kept more constant.

Some operation suggestions are given on Operation Guide 3 and problems with temperature control are discussed in Troubleshooting Guides 5 and 6. Heating equipment operation is discussed in Equipment Operation Guides 5 and 6.

HOW TO CONTROL MIXING

The goals of mixing control are to bring bacteria in contact with the food as it is added and to keep scum and grit formations at a minimum. Internal, external and recirculation methods are discussed in Part IV, The Basics Troubleshooting Guides 7, 8 and 9 give more information on the subject.

OPERATION GUIDE 3 DIGESTER TEMPERATURE CONTROL

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Get accurate readings.	1. No temperature gauges or installed thermometer.	1a. Allow recirculation pump to run for at least 10 minutes, pulling from "active zone." Pull sample and let bucket come to sludge temperature, dump first sample, draw another and measure temperature using lab thermometer. b. Lower sampler into digester, pick samples at various levels according to procedure in 1a and measure with lab thermometer. (See page 3-29, Gadgets.)
	2. Installed measuring device giving questionable readings	2a. Use either method 1a or 1b above to check temperature device, taking sample as close as possible to where the device measures temperature. b. If device is in a recirculation pump line, be sure pump is operating and pulling representative sample.
B. Change operating temperature up or down by at least 5 deg. F. (2.8 deg. C.).	1. Changing weather condition or waste characteristics.	1a. Adjust heat controls such that temperature does not change more than 1 deg. F. (0.5 deg. C.) per day.
C. Desire to try thermophylic range.	1. Heating equipment capable of maintaining 130 deg. F. (54 deg. C.), multiple tanks available.	1a. Consult references in Appendix B. b. Use only one tank at a time. c. Change temperature at a rate of 1 deg. F. (0.5 deg. C.) per day or 3 deg. F. (1.7 deg. C.) in two days at maximum. d. Be prepared for a month period of transition. e. Control using VA/Alk ratio and hold below 0.1.

The mixing schedule will vary depending on the type of equipment and tank configuration. The important things to consider are:

1. Does the mixing system do a good job of bringing food in contact with the bacteria?

2. Are scum blankets and grit accumulations reducing the volume of the tank enough to cause organic overload?

3. Is the mixing (particularly gas-type) causing supernatant quality to upset the plant?

Scum Blanket Control

Adequate mixing normally prevents scum from forming a blanket. However, many digesters were installed with no mixers or inadequate mixing devices. Under these conditions, the scum blanket is a major problem.

Keeping the scum blanket moist will normally prevent the problem. This allows gas to pass through and assist in preventing the blanket from becoming too thick. A maximum depth should be less than 24 inches.

Scum blankets in digesters usually have a rolling movement if mechanical or natural digester gas mixing is adequate. This movement can be observed through the the thief hole. If movement is slight or not present, the operator should check mixer operation or probe the scum blanket for thickness.

Several suggestions on mixing control are given in Operation Guide 4.

OPERATION GUIDE 4 HOW TO CONTROL MIXING

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Keep scum and grit accumulation at a minimum and provide good contact between food and bacteria.	1. Single stage digester.	1a. Run mixing equipment following each sludge addition but shut off when it affects supernatant quality. Time clock control on both sludge pump and mixer helps accomplish this. b. If mixer fails, check possibility of using raw sludge pump to provide some mixing when not pumping raw sludge. c. Draw level down to minimum and recirculate and mix simultaneously for 24-48 hours every six months if buildups are a problem.
	2. Two stage digesters.	2a. Run mixer continuously in primary digester unless secondary supernatant quality goes above 5,000 mg/l total solids. If above 5,000 mg/l, decrease mixing time by manual or time clock control. Measure scum and grit accumulation to find optimum mixing time.
B. Break up scum blanket	1. Mixing equipment not operable, several digesters available.	1a. Adjust number of tanks to allow loading ratio of 0.3-0.4 lb. VS/cu.ft./day (4.8-6.4 kg/m^3/day). Gas generation in the tank will cause natural mixing. *Caution:* The loading rate must be held in this range continuously and the VA/Alk ratio monitored to keep the tank in control. b. Introduce compressed digester gas into the bottom sludge draw-off line and allow bubbles to provide limited mixing.

HOW TO CONTROL SUPERNATANT QUALITY AND EFFECTS

One of the traps that some operators fall into is believing that all process problems in other parts of the plant are caused by outside sources, when many times the trouble is from digester supernatant returning to the headworks or other points in the plant. Each plant will have its own limits. However, problems begin to develop in most plants if the supernatant total solids exceed 0.5 to 0.75% (5000 to 7500 mg/l).

General Guidelines for Supernatant Control

When drawing off supernatant in unmixed digesters, the operator should select a drawoff point which will give the best supernatant. In single tanks with internal mixers, the operator should stop mixing for periods of 6-12 hours or plan for intermittent mixing to allow settling before selecting and drawing off supernatant. This will also require programming sludge feed and sludge withdrawal.

Effects of Tank Types on Supernatant Quality. Where two tank systems are operating, the active sludge mixture is transferred from the primary digester to the secondary where the sludge is detained without mixing. The supernatant qualities obtained from the secondary digester will depend on the detention time and the type of sludge feed.

Single stage tanks with moderate loading will generally produce good supernatant if the operator can find the right layer. Part of the key to success is having several drawoff points and selecting the best one. Several patented supernatant selectors are installed in digesters but even the best ones are subject to plugging with hair, rags and other stringy debris. The superior "selector" is the vigilant operator who is willing to experiment until he finds the optimum pattern for mixing, resting and drawing the sought after "clear" supernatant.

The type of plant also affects supernatant quality as shown by Table II-1 below.

Table II-1
TABLE OF EXPECTED RANGES OF SUPERNATANT QUALITY FOR DIFFERENT TYPE PLANTS

	Primary Plants (mg/l)	Trickling Filters* (mg/l)	Activated Sludge Plants* (mg/l)
Suspended solids	200-1,000	500- 5,000	5,000-15,000
BOD_5	500-3,000	500- 5,000	1,000-10,000
COD	1,000-5,000	2,000-10,000	3,000-30,000
Ammonia as NH_3	300- 400	400- 600	500- 1,000
Total phosphorus as P	50- 200	100- 300	300- 1,000

* *Includes primary sludge.*

Some of the best results are obtained by drawing the supernatant into an open lagoon or drying bed and skimming the layer that forms with wide circular decant pans. Greater efficiency results when the surface area to depth ratio is large. If land is available and problems exist, this solution should be considered.

High rate gas mixing tends to homogenize the sludge and contribute to poor quality supernatant. One operator had success in improving supernatant quality by adding about 3 mg/l of water soluble anionic polymer to the gravity thickener and reducing the total operating hours of the gas mixer. This reduced the detention time in the digester because thicker sludge was pumped and the reduced mixing time produced lower solids in the supernatant. The product was Zimmite ZT-650.

Other considerations are summarized in Operation Guide 5. Also see Troubleshooting Guide 2.

OPERATION GUIDE 5 SUPERNATANT CONTROL

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Liquid quality that will not affect the rest of the plant.	1. Single tank fixed cover.	1a. Feed digester at as slow a rate as possible, do all mixing after supernatant has quit displacing and allow tank to set without mixing 8-12 hours before feeding again. b. Make up jars containing samples of supernatant stabilized with formaldehyde, which can be used as a standard by operators showing what is and is not acceptable quality.
	2. Single digester, floating cover, single draw-off.	2a. Adjust tank level until best quality liquid is found and operate within these limits. b. Install swivel joint and 4-6 foot length of pipe to draw-off line to allow selection over widar range. See page 3-35, Gadgets.
B. Prevent problems of overload to gravity thickener.	1. Poor quality supernatant due to overloaded digester.	1a. Add polymer to sludge going to thickener to increase solids, decrease quantity of supernatant and increase digester detention time.
C. Prevent high demand supernatant going to aerators. Sidestream treatment.	1. Poor quality due to overloaded digester.	1a. If extra aerator is available, preaerate before discharging to aerator. b. Aerobically digest supernatant to reduce demand. Air demand will be high for first few days but will taper off to 20-25 cfm/cu.ft. (20-25 m^3/min./m^3) tank capacity.
D. Eliminate all recycle to process.	1. Poor quality supernatant due to overload or poor separation in digester.	1a. Discharge to available drying bed or lagoon and spray irrigate decantate. b. Haul or process digested sludge at a rate that will prevent supernatant return. c. Sell to firms or individuals requiring liquids for composting processes.

HOW TO CONTROL SLUDGE WITHDRAWAL

When sludge is drawn out of the digester, either to beds or other sludge handling facilities, there are several important considerations.

1. In small plants, particularly with single-stage digesters, at least 12 hours should lapse between pumping raw sludge and sludge withdrawal. Additionally, the contents should be well mixed to prevent pulling out raw sludge that could create odors as well as contain pathogens.

2. Care must be taken to prevent pulling air into fixed cover digesters when sludge is withdrawn. Sludge from multiple tank systems can be drawn at a rate that will allow gas from another tank to be pulled back into the emptying tank. Single tank operators should pull sludge out slowly enough that air is not pulled in or kept at a minimum. Explosive conditions exist when the methane concentration is below 20% on a volume basis.

HOW TO USE LAB TESTS AND OTHER INFORMATION FOR PROCESS CONTROL

Just as the driver of a car does several things at once to keep control of the car, the operator looks at several indicators to keep the digester from "upsetting." And, like the driver who uses the steering action to keep the car on the road, the operator can use lab tests, such as the volatile acids and alkalinity, for process control. Other tests are also needed to give the full picture and these will be discussed in the following pages.

Methods for running lab tests are found in Appendix E, and a discussion of what the various parameters show is covered in Part IV, The Basics, starting on page 4-11.

Important Indicators

There are certain indicators which measure the progress of sludge digestion and warn about impending upset. No one variable can be used alone to predict problems; several must be considered together. Control indicators in order of importance are:

1. Volatile acids to alkalinity ratio.
2. Gas production rates, both CH_4 and CO_2.
3. pH.
4. Volatile solids reduction (digester efficiency).

None of the above used singly can indicate the condition of the digestion process. For example, volatile acid readings may increase, but which does it indicate:

1. A decrease in percent methane (a rise in percent CO_2)?
2. A decrease in alkalinity?
3. No change in percent methane production?
4. A decrease in pH?
5. A problem or no problem?

Large increases in volatile acids may take place before pH is changed if the digester is heavily buffered (has high alkalinity). Changes in volatile acids mean more when considered with alkalinity.

Obviously, the operator needs more information before responding to the indicator.

The operator is cautioned against looking at an absolute number. The rate of change is much more significant. In summary, then, trends of these indicators are the most useful to predict the progress of digestion and as signals of process upset. A discussion of trends is in Part IV, The Basics, page 4-16, and Appendix, G-2.

Importance of Samples in Process Control

Sampling is the first step in waste analysis. It is absolutely necessary to take good samples to get reliable usable tests. Good samples are obtained by following a few simple rules:

1. The sample must be representative. For example, when drawing samples from an on-off pumping operation, allow pump to run for several minutes to clear the line; then make a composite sample during the time the pump is running. This is done by drawing three samples, at the beginning, at mid-point and at the end of pumping period. Equal volumes of sample should be mixed together.
2. Always run pH and temperature tests immediately (5-10 minutes) to avoid deterioration. If samples are allowed to set too long, CO_2 will be released, causing the pH to rise. Always use the same length of time from collection to determination for each test run. It is important to standardize when taking temperatures. Don't use a warm bucket or thermometer one day and a cold one the next day.

3. Always refrigerate the sample if tests are not run immediately. When storing a raw sludge sample in a refrigerator, it's a good idea to use a plastic wrap over the top of the jar with a rubber band on it to hold it in place. This will allow any gases that might collect in the sample to expand without bursting the jar.

4. The container should be cleaned thoroughly before and after use.

Sample Points for Control Information

There is no specific set or list of tests than can fit all digester systems due to the variability and complexity of systems. However, in general, the following points are usually sampled for digester monitoring and control.

1. Raw sludge
2. Digester sludge (active zone)
3. Digested sludge
4. Supernatant
5. Digester gas

Raw Sludge. Tests performed on samples of raw sludge tell an operator what type of food is being fed to a digester. The operator is actually feeding a tank full of hungry organisms their daily rations, much as a zookeeper would distribute food to cages full of animals. By knowing the condition (pH and temperature) and the content (total and volatile solids), the operator can predict to some degree how the digester will react.

This sample is normally taken at the raw sludge pump or from a well-mixed portion of a sludge pit or vault.

Digester Sludge. The second major sample should be taken from a point in the digester that represents the well-mixed active portion of the primary digester. This determines what is happening inside the tank. This sample gives the operator information on the alkalinity and volatile acids as well as on the solids that will be used in other calculations (described on page 4-20)

Samples may be taken from sample lines, from overflow boxes where sludge passes from a primary to a secondary digester or from a recirculation pump or line where a corporation-cock is installed.

Digested Sludge. The contents of the bottom sludge in the digester is another important point which gives the operator information on how the process is proceeding. This sample may represent what is being transferred from the bottom of a primary digester to a secondary digester, or it may represent the bottom sludge being withdrawn for disposal.

Quantities of sludge transferred from one digester to another or from a digester to a drying bed can usually be determined by:

1. Calculating the volume added to a drying bed, sludge truck or dewatering unit and recording it as gallons per day or gallons per month.

2. Calculating the diameter of a circular digester, the number of gallons per inch or per foot which measure the change in liquid depth, and calculating and recording the volume.

Supernatant. Grab samples of supernatant, if they are fairly uniform and continuous, will give a good idea of what is happening. However, some method must be used to decide when to begin and stop transferring supernatant back to the process. Many times this is done by visual observation. Some operators use an Imhoff cone with a cutoff point of 50 milliliters per liter after 30 minutes of settling to tell them when to stop the flow of supernatant and let the digester rest.

Carbon Dioxide. This is a most easily measured component of the digester gas. Because the sum of the CO_2 and CH_4 is approximately 100%, the amount of CH_4 can be roughly estimated by measuring the CO_2. Well operating tanks range between 25-35% CO_2. The percent of CO_2 can be an early indicator of approaching problems if the trend is upward.

The percent CO_2 will increase shortly after feeding, if sludge is fed two or three times per day. Information should be obtained during different times of the day to find normal values for the plant.

Several CO_2 analyzers are on the market, such as those manufactured by Hays or Orsat. The CO_2 content of the gas coupled with the quantity of gas produced shows the immediate response to how the food is being utilized. If the CO_2 content stays consistently high, it can be a trend toward excess acid production and trouble.

Samples may be taken several places. If gas is piped into the lab and used for Bunsen burners, this can be a very adequate sampling point. It is important to purge the line before collecting a sample. This is done by lighting the burner and letting it burn for a minute or so, turning it off to collect the sample. If samples cannot be run in the lab, the sampling device can be located at a sample point on the digester gas line.

Suggested Tests and Frequency. The following table lists the possible tests and suggested frequencies for a plant with approximately 1 to 2 mgd and two or more digesters.

This table is a suggestion only and would have to be adapted to the type of sludge being received at a plant, the severity of overloading and a number of other factors, but gives some idea of how often information could and should be obtained. Two columns are shown, the first showing the optimum, the second showing the minimum test frequencies.

TABLE II-2
SUGGESTED SAMPLE TESTS AND FREQUENCY
1-2 MGD PLANT, TWO DIGESTERS

	TEMP.		TS		VS		CO_2	pH		ALK		VA		QUANTITY	
Raw Sludge	D	(D)	D	(4/W)	D	(4/W)		D	(W)					D	(D)
Recirculation Sludge	D	(D)	D	(4/W)	D	(4/W)		D	(D)	D	(W)	D	(W)		
Bottom Primary	D	(W)	W	(M)	W	(M)		D	(W)	2W	(W)	2W	(W)	D[a]	(D[a])
Bottom Secondary	M/2	(M)	W	(M)	W	(M)		W	(M)					D[b]	(D[b])
Supernatant	W	(M)	W	(W)	W	(W)		D	(W)					D	(D)
Gas							D							W	(Y/4)
Scum			Y/4	(Y/2)	Y/4	(Y/2)								M	(Y/4)
Grit			Y/4	(Y/2)	Y/4	(Y/2)								M	(Y/4)
Depth Series	Y/4	(Y/2)	Y/4	(Y/2)	Y/4	(Y/2)		Y/4	(Y/2)	Y/4	(Y/2)	Y/4	(Y/2)		

( ) - Minimum frequency
C = Continuous
D = Daily
W = Weekly
M = Monthly

Y = Yearly
M/2 = Twice a month
Y/2 = Twice a year
4/W = Four times a week
a = Amount transferred to secondary, if applicable
b = Or as often as drawn to disposal point

Non-Standard Tests

There are some non-standard tests which are not given in the books which will provide additional useful information.

Visual Gas Test. A yellow flame with blue at the base is normal at the waste gas burner. When too much blue is present and the flame will not stay lit, this may indicate too much CO_2. An orange flame with smoke may be present when the digester has a high sulfur contact.

Test for Grit. Estimates on the amount of grit in the sludge may be obtained by allowing tap water to run into an open beaker of sludge at a slow rate to wash most of the light solids out, leaving the grit in the bottom of the beaker. If the amount of water run into the beaker is the same each time, then the operator can get some visual feeling for the amount of grit in raw sludge, the sludge being drawn out, and the amount in the recirculated sludge. It is difficult to assign numbers to these amounts, but visually the operator can tell if the amount is increasing or decreasing. Using this information along with actual sounding of the digester can give him a feel for the probable grit buildup in the digester.

Sniff Test. Another bit of information can be gained by the non-standard "sniff" test. Simply smelling the sludge samples can tell the operator whether it's septic, sour, well-digested or, in the case of raw sludge samples, whether there are chemicals such as oils, solvents, or other types of materials that might be harmful to the digester. Experience is the best teacher for drawing conclusions from this type of a test, but it should not be ignored by the operator. Examples of digester supernatant sniff indicators are rotten egg odors which may indicate organic overload and a rancid butter smell which may be present when heavy metals toxicity exists.

Digester Profiles

In addition to the above tests, samples should be taken inside the digester. This can be done by lowering sample collectors into the tank at least twice yearly. One procedure is to set aside half a day, or a day if necessary, to take samples at five-foot intervals from top to bottom of all digesters and set up total solids, volatile solids, pH, temperature, and alkalinity on the entire series. By plotting the results after they are obtained, it is possible to have a pretty good idea of how much grit is on the tank bottom, whether there are pockets of undigested material, or whether the temperature is not uniform all the way through. These samples can be taken, using a homemade sampling device, one of which is described on page 3-29. The important thing is to collect a sample that represents the particular level that the sample is taken from.

It is also a good idea to take samples from several different locations and depths. Samples can be taken from prepared sampling holes known as "thief holes." If the tank has a floating cover, it is possible to lower a sampling device alongside the floating cover into the tank. It will probably be necessary to break away the scum layer and although this is not the best location, it will give some information if no other sampling points are available. As a last resort a manhole cover can be taken off; however, safety precautions should be strictly observed. A floating cover should be down on the corbels before the manhole cover is removed.

At the same time the digester profile is being done, both the amount of scum and the amount of grit should be recorded. In order to find the amount of grit that has accumulated, several points in the digester should be sounded using a long stick or a piece of pipe to determine where the top of the grit layer is. Then force the stick down through it until the floor is reached and record the difference in the two measurements. If the plans on the digester are available, the grit layer can be estimated by using the top of the wall as a reference point and measuring down to the top of the grit layer, noting the difference between these measurements.

OPERATIONS CHECK LIST

The following list is prepared to help you make up your own check list and may include items not within your process. Use only those which apply to your plant.

	Suggested Frequency
A. Feed Sludge	
1. Record volume pumped for a 24-hour period.	Daily
2. Run total solids test and compare with amount pumped in to be sure too much water is not being fed.	Weekly (1-3 times)
3. Check pump operation for packing gland leaks, proper adjustment of cooling water, unusual noises, undue bearing heat, and suction and discharge pressures.	Daily
4. Monitor pump time clock operation for proper control and check running time with sludge consistency.	Daily
B. Recirculated Sludge	
1. Record temperature of recirculated sludge.	Daily
2. Collect sample of recirculated sludge and run tests.	Weekly (1-3 times)
3. Check boiler temperatures, burner flame, and exhaust fan for proper operation.	Daily
4. Check hot water circulating temperatures.	Daily
5. Check and record heat exchanger inlet and outlet temperatures.	Daily
6. Check for leaks in sludge lines.	Weekly
7. Check pump operation – packing gland leaks, proper adjustment of cooling water, unusual noises, undue bearing temperatures and suction and discharge pressures.	Daily
C. Digesters	
1. Gas manometers for proper digester gas pressure.	Daily
2. Drain condensate traps – more often if needed.	4/daily
3. Drain sediment traps.	Daily
4. Waste gas burner for proper flame.	Daily
5. Record gas pressures.	Daily
6. Record floating cover position, check cover guides and check for gas leaks.	Daily
7. Record digester and natural gas meter readings.	Daily
8. Check and record fuel oil.	Daily
9. On gas mixers check flow of gas to each feed point.	Daily
10. Check internal moving mixers for proper operation.	Daily
11. Pressure relief and vacuum breaker valves – Verify operation with manometer and check for leaking gas.	Daily/Weekly
12. Check supernatant tubes for proper operation, collect sample, and hose down supernatant box.	Daily
13. Check level and condition of water seal on digester cover.	Daily
14. Check flow meters for correct flows, leaks and vibration.	Daily
15. Check feed sludge density meter for correct density, leaks and vibration.	Daily
16. Check scum blanket through sight glass.	Daily
17. Check gas storage tank for gas leaks and odor. Record readings on pressure gauges and drain condensate traps.	Daily

	Suggested Frequency
18. Check all gas line piping for leaks. Test with soapy solution if a leak is suspected.	Weekly
19. Check gas pressure regulators and verify with manometer reading.	Monthly
20. Check flame trap arrestors by noting the pressure drop across unit or that equipment downstream is working.	Monthly
21. Check scum blanket for dryness and depth.	Monthly
22. Clean and fill manometers.	6 Months
23. Remove, clean and check all safety devices for proper operation.	6 Months
24. Flush and refill digester dome seals.	6 Months
25. Sound digester by sampling from bottom up at 5-foot intervals.	6 Months
26. Remove digester from service and clean and repair unit.	3-8 Years
D. Sludge Withdrawal	
1. Check volatile content of bottom sludge, if below 50% and nuisance odors not present it should be ready to remove.	Weekly
2. Frequency of removal will vary with method of dewatering and/or disposal. Some plants that haul wet sludge to land sites or dewater on filters pull out daily. Plants that have drying beds in wet climates may draw out only in summer and fall months.	Variable
3. Collect several samples and composite for calculation of digester efficiency.	When drawing
E. Compressors	
1. Check for proper operation of unit by looking at the oil level, drive belts and discharge pressure.	Daily
F. Piston Type Sludge Pumps	
1. Check for proper operation of pump and motor by looking at the automatic oiler. Make sure that the eccentric is dripping at a regular rate, packing is adjusted properly, drive belt tension is OK. Note the vacuum and discharge pressures and record revolution counter reading and reset.	4 Hours
2. Collect sample of sludge when operating.	Daily
G. Fire Fighting Equipment	
1. Be sure all units are in place and that unit is still within its inspection date.	Monthly
H. First Aid Kit	
1. Be sure they are in place and that all items match the inventory sheet.	Monthly

PREVENTIVE MAINTENANCE CHECK LIST*

1. Exercise the Variable Speed Drive (Raw Sludge Pump)	Weekly
2. Exercise the Variable Speed Drive (Digested Sludge Pump)	Weekly
3. Inspect Pump (Centrifugal, Hot Water Recirculation)	Weekly
4. Inspect Floating Cover for evenness and gas leaks	Weekly
5. Inspect First Aid Kit	Weekly
6. Inspect Pump (Centrifugal, Sludge Recirculation)	Weekly
7. Inspect and clean Motor (Raw Sludge Pump Drive)	Monthly
8. Inspect and lubricate Raw Sludge Pump (Piston Type, Belt Driven)	Monthly
9. Inspect Piping and Exercise Valves	Monthly
10. Inspect and clean Motor (Sludge Recirculation Pump)	Monthly
11. Inspect and clean Motor (Gas Recirculation Compressor)	Monthly
12. Inspect and clean Motor (Digested Sludge Pump Drive)	Monthly
13. Inspect and clean Motor (Gas Storage Compressor)	Monthly
14. Verify accuracy of Raw Sludge Flow Meter (Magnetic)	Monthly
15. Inspect and lubricate Digested Sludge Pump	Monthly
16. Check accuracy of Raw Sludge Density Meter (Nuclear)	Monthly
17. Lubricate Coupling (Hot Water Recirculation)	Quarterly
18. Lubricate Coupling (Sludge Recirculation)	Quarterly
19. Lubricate Coupling (Gas Recirculation)	Quarterly
20. Clean and fill Gas Manometers	Semi-annually
21. Inspect Compressor (Gas Recirculation)	Semi-annually
22. Disassemble and clean Gas Water Traps (Condensate)	Semi-annually
23. Disassemble and clean Flame Arrestors (Gas Piping)	Semi-annually
24. Check for support and leaks on Digester Internal Piping (Gas Mixing)	Semi-annually
25. Inspect and clean Gas Storage Compressor	Semi-annually
26. Clean Heat Exchanger	Semi-annually
27. Disassemble and clean Gas Pressure & Vacuum Relief Valves (Digester Cover)	Semi-annually
28. Check Fire Fighting Equipment	Semi-annually

* **Review the equipment manufacturers' recommended preventive maintenance procedures and schedules. They should be followed. Also refer to your plant's O & M manual for more detail on preventive maintenance for the plant.**

CHEMICALS USED IN DIGESTER CONTROL

Chemical usage in the digester falls into two categories: pH adjustment and metal toxicity control. This section covers pH adjustment. The subject of toxicity is discussed in a separate section on toxic material in Part III, page 3-21.

CONTROL OF pH

Several chemicals are available which can be used as caustic agents in digesters to raise or control pH. Each has advantages and disadvantages. The choice of which one to use largely depends upon availability, cost, storage and handling preference. In all cases of caustic addition, care must be taken to provide mixing. Mixing is essential to be sure that the caustic solution will be distributed throughout the tank contents and prevent localizing the caustic. This section discusses the use of various chemicals in digester operations.

Lime

Lime is one of the most common caustic agents due to its availability, relatively low cost and ease of handling. Lime is usually used in starting a digester because it speeds up gas production and lowers volatile acids concentration. One limitation to the use of lime is its inability to maintain the pH at higher levels than about 6.8. When lime is added to a digester it combines with CO_2, removing CO_2 from the liquid. This combining reaction forms calcium bicarbonate when the digester is below 6.7 or 6.8 and the **bicarbonate alkalinity** is between 500 and 1,000 mg/l (NOTE This is not total alkalinity). Calcium bicarbonate becomes a buffering agent, neutralizing the acids in the digester and allowing the digester to return to normal.

Too much lime causes insoluble calcium carbonate to form. Like grit, calcium carbonate settles out, takes up space, and may be very difficult to remove. A further disadvantage is that it may create a vacuum in the digester because CO_2 is removed, causing a decrease in gas pressure inside the digester. This occurs when excess lime is added.

If the operator were to continue adding lime after the digester pH has reached between 6.5 and 6.8 and the CO_2 were to continue dropping, a dangerous situation might result. The CO_2 content might drop until it reached about 10% and the pH would start to increase to about 8.0.

As the CO_2 percentage drops, the pressure lowers and a vacuum results. With biological activity continuing, the percent of CO_2 increases, rising again to the 10% level, at which point the pH drops to below 7.0. Additions of lime beyond that necessary to neutralize the acids or indicated by pH are wasteful. They may result in lowered gas pressure, a vacuum inside the tank, and a collapsed cover.

However, it is reported by Perry L. McCarty that some excess calcium carbonate has some benefits: it prevents calcium toxicity and when the pH drops to about 6.5, the insoluble calcium dissolves forming additional bicarbonate alkalinity.

Lime is available in two forms:

1. As unslaked lime, or calcium oxide (CaO),

often called quicklime. It is hygroscopic, which means that it takes up water or moisture quite readily. The major disadvantage is that quicklime must be "slaked" (water must be added in a controlled way) before it can be used. This requires special equipment.

CAUTION: **Always add quicklime to the water to prevent an explosion which may splatter the operator with lime and cause skin burns. Quicklime must be stored in a dry place.**

2. Hydrated lime (calcium hydroxide $Ca(OH)_2$) is the preferred form since it is already slaked and ready to use.

Lime is always mixed with water to form a slurry using about 100 pounds (45.4 kg) of lime to 50 gallons (189 l) of water before being fed to the digester. Most operators add the lime slurry into a sludge or scum pit at the side of the primary clarifier and pump it along with the sludge.

Lime Dosages. Two quick methods can be used as rough approximations for the amount of lime additions.

1. Apply a dosage of 1 pound of lime for every 10,000 gallons (37850 l) in the digester. This is risky. Too much or too little may be added. A better way is given below.
2. The empirical method
   PROCEDURE:
   a. Obtain a sample of representative sludge (about 5 gallons) from the digester and record the exact amount.
   b. Carefully, add calculated amounts of lime to sample until pH reaches about 6.7 or 6.8, then stop. Record total amount of lime used.
   c. Calculate the amount of lime needed to treat the digester using the results of the above step. The following example shows the calculation

   Assume 0.1 pounds of lime was required to treat the 5-gallon sample. If the digester volume is 100,000 gallons (378500 l) then,

   $$\frac{100{,}000 \text{ gallons}}{5 \text{ gallons}}$$

   = 20,000 times the sample volume and 20,000 times as much lime would be needed to treat the digester. Therefore 0.1 times 20,000 equals 2,000 pounds (907 kg) of lime required. To get a better estimate, the experiment could be done three times and the results averaged.

Another method is to add enough lime to neutralize the volatile acids. Use the following procedure to find pounds of lime needed:

Calculate the amount of volatile acids in pounds. Volatile acids in mg/l times 8.34 times volume of digester in million gallons equals pounds of lime needed.

For example: Assume volatile acids to be 1,800 mg/l and digester volume to be 150,000 gallons (0.15 million gallons), then, 1,800 times 8.34 times 0.15 million gallons equals 2,252 pounds.

NOTE: The amount of alkalinity already in the digester in this case would be in excess and is considered a cushion.

The following procedures are recommended for lime addition:

1. Begin adding lime if the pH drops below 6.6.
2. Check the vacuum relief device on the digester to be sure it is working (the addition of lime can cause a vacuum inside the tank). Stop lime addition if vacuum relief begins operating and wait 24 hours before starting lime again.

3. Add the lime slurry only while mixing and/or recirculating the digester and continue for at least an hour or more after the last addition. Check the pit frequently.

4. Stop adding lime when pH reaches 6.8.

Anhydrous Ammonia

Anhydrous ammonia is a gas and is available in pressurized cylinders. It may be used for pH adjustment under controlled conditions. However, lime, or other caustics, are recommended for the smaller plants for safety reasons.

Several precautions are noted below for those using anhydrous ammonia:

1. There is the possibility of ammonia toxicity if the neutral pH is overshot. The toxic level depends on other buffering agents in the digester but the concentration should not exceed 1,400 mg/l as N in any case.

2. The gas cylinders should be handled using all the precautions normally employed with gases under pressure; i.e., do not drop or strike with sharp objects, keep away from excessive heat and use approved regulating valves.

Several feeding procedures are noted below:

1. Make up tight ammonia connections from cylinder to aluminum pipe. Insert the pipe through a thief hole in the top of the digester. The pipe should go to a depth of 10-15 feet (2.5-3.2 m) in the digester. A 1/8" reducing elbow can be attached to the lower end of the pipe so that the pipe can be rotated in a full circle to distribute the gas addition.

2. Make up a connection to a recirculation line which allows gas feed into the sludge while it is being recirculated. The connection may be made using a corporation-cock and necessary fittings to mate with the feed system. Precautions to be observed include:
   a. Use materials in connection [illegible] feed piping that are not affected by ammonia. DO NOT use copper or brass fittings.
   b. Feed ammonia only when sludge is circulating and downstream valves are open.

The digester pH should be carefully watched when using ammonia. The greatest danger lies in ammonium toxicity (see Toxic Materials, Part III, page 3-21).

The following example shows how to find the pounds of ammonia needed:

1. Determine desired amount of excess alkalinity. Suggested amount equals 500 mg/l.

2. Determine alkalinity needed to neutralize volatile acids. When alkalinity is expressed as mg/l $CaCO_3$, the amount needed to neutralize volatile acids is:

$$ALK = 0.833 \times VA$$

Example: If the alkalinity equals 2,000 and VA equals 3,000, then the amount of additional buffering alkalinity needed would be:

$$2{,}000 - 0.833(3{,}000) = -500 \text{ mg/l}$$

(NOTE: the minus sign shows that this amount is **needed** in addition to excess.)

3. Determine amount of ammonia needed by the following formula:

   lbs. of 100% NH_3
   = 2.78 x vol. of dig. in gal.
   x needed alkalinity in mg/l $CaCO_3$
   (excess + buffering) ÷ 1,000,000.

   a. Assume:

Digester volume	250,000 gal.
Alkalinity	2,000 mg/l
Volatile acids	3,000 mg/l
Excess alkalinity desired	500 mg/l

b. Find amount of alkalinity needed to neutralize the VA. (See Step 2 above.)

c. Find total alkalinity needed.

$500 + 500 = 1{,}000$ mg/l as $CaCO_3$

4. Find amount of ammonia needed:

lbs. of 100% NH_3

= 2.78 times dig. vol. in gal.

times mg/l alk. needed per 1,000,000 gal.

= 2.78 times 250,000 times 1,000 per 1,000,000 gal.

= 2.78 times .25 times 1,000

= 695 lbs. (315 kg)

5. Commercial anhydrous ammonia is about 80% ammonia. Correct for this amount by:

$$\frac{100\%}{80\%} \times 695 = 869 \text{ lbs (537 kg) 80\% ammonia}$$

6. Find feed rate:

The feed rate should be about 0.85 lb./1,000 gal. (0.102 kg/1000 l) digester volume per hr. at a pressure of 50 psi (345 KN/m^2).

Feed rate

$$= 0.85 \text{ lb.} \times \frac{250{,}000}{1{,}000} \text{ per hour}$$

= 212 lbs./hr. (96 kg/hr.)

Other Chemicals Used for pH Adjustment

A table entitled "Chemicals Used in Control of Digesters," Table II-4 on page 2-38, lists other chemicals used for pH control in addition to chemicals used for other purposes.

In order to use the pH control chemicals, it is helpful to know how to figure the amount needed based on the alkalinity expressed as $CaCO_3$.

Two factors must be considered, the **equivalent weight** of the chemical and the percent available. The following example shows how to make the calculation using the information given:

Digester volume	250,000 gal.
Volatile acids (VA)	3,000 mg/l
Chemical bicarbonate of soda	
Equiv. wt. from Table	84
% available from supplier	68%
$CaCO_3$ equiv. wt.	100
Alkalinity needed/lb. VA	0.833

1. Find pounds of volatile acids in the digester:

3,000 x 8.34 x 0.25 = 6,255 lb. (2838 kg) VA

2. Find pounds of $CaCO_3$ needed:

6,255 x 0.833 = 5,210 lbs (2364 kg) $CaCO_3$

3. Find pounds 100% bicarbonate ($NaHCO_3$) needed

5,120 lbs. $CaCO_3$

$$\text{times } \frac{\text{equiv. wt. } NaHCO_3}{\text{equiv. wt. } CaCO_3}$$

equals lbs. 100% $NaHCO_3$

$$5{,}120 \text{ times } \frac{84}{100}$$

equals 4,376 lbs. (1985 kg) 100% $NaHCO_3$

4. The amount available is 68% not 100%, therefore:

$$4{,}376 \text{ times } \frac{100\%}{\text{available }\%} = 4{,}376 \times \frac{100}{68}$$

= 6,435 lbs. (6920 kg) of 68% $NaHCO_3$

As a practical matter, the total amount needed would not be added at one time but rather spread out over three to four days in equal increments. Volatile acids, alkalinity and pH should be monitored in the active zone of the digester and records kept on the progress toward recovery.

Another way to estimate chemical dosage is given in conjunction with Table II-3 where the percent concentration of acid in the digester is used to find the appropriate amount of neutralizing chemical.

Using the same information as in the previous example and assuming liquid caustic soda (NaOH) is to be used, the steps would be as follows:

1. The pounds of acid were:

3,000 x 8.34 x 0.25 = 6,255 lbs. (2838 kg) VA

2. Pounds per 100 gallons of digester volume:

$$\frac{\text{lb. VA}}{\text{vol. dig./100}} = \frac{\text{6,255 lb. VA}}{\text{250,000/100 gal.}}$$

$$= \frac{\text{2.5 lb.}}{\text{100 gal.}} \left(\frac{\text{0.3 kg}}{\text{100 l}}\right)$$

3. Read across from the column "pounds of acid per 100 gal." that reads 2.5 to the column "NaOH liquid caustic soda" which reads 3.32 lbs.

4. Find total number of pounds needed:

$$\frac{\text{3.32 lbs. NaOH}}{\text{100 gal.}} \times \text{dig. cap. in gal.}$$

$$\frac{3.32}{100} \times 250{,}000 = 8{,}300 \text{ lbs. (3766 kg)}$$

NaOH

Approximate amounts of other chemicals can be determined by the same method using the information in Table II-3.

Note:
1 kg = 2.205 lb.
1 l = 0.264 gal.

TABLE II-3
QUANTITIES OF VARIOUS ALKALIES REQUIRED TO NEUTRALIZE VOLATILE ACIDS

Actual lbs. of Acid per 100 gals.	NH_3 Anydrous Ammonia lbs.	NH_4OH Aqua Ammonia gals.	Na_2CO_3 Anhydrous Soda Ash lbs.	NaOH Liquid Caustic Soda, lbs.	NaOH Flake Caustic Soda, lbs.
.834	.236	.197	.736	1.11	.555
1.67	.472	.216	1.47	2.22	1.11
2.50	.708	.322	2.21	3.32	1.66
3.34	.944	.429	2.94	4.44	2.22
4.17	1.18	.536	3.68	5.54	2.77
5.00	1.42	.645	4.43	6.68	3.34
5.84	1.65	.750	5.14	7.76	3.88
6.67	1.89	.859	5.89	8.88	4.44
7.51	2.12	.963	6 61	9.96	4.98
8.34	2.36	1.07	7.36	11.10	5.55
16.71	4.73	2.15	14.74	22.24	11.12
25.10	7.11	3.23	22.16	33.42	16.71
33.51	9.49	4.31	29.58	44.60	22.30
41.96	11 88	5.40	36.84	55.84	27.92
50.42	14.27	6.49	44.48	67.06	33.53
84.5	23.92	10.87	74.56	112.42	56.21
171.3	48.5	22.05	151.17	227.96	113.98

Table II-4 CHEMICALS USED TO CONTROL DIGESTION

CHEMICAL NAME		COMMERCIAL NAME	USE/APPLICATION	STORAGE AND HANDLING
Calcium Oxide	Formula CaO Equiv. wt. 56	Unslaked Lime Quick Lime	To raise pH. Must be slaked before using to form a slurry. Do not apply water to quick lime – it explodes.	Comes in 50-pound bags as a powder. Splashing lime will cause skin burns. Wear rubber gloves. Dusty, slakes on standing in air.
Calcium Hydroxide	Formula $Ca(OH)_2$ Equiv. wt. 74	Slaked Lime High Calcium Lime Hydrated Lime	To raise digester pH.	Dusty, keeps better in storage than quick lime. Splashing slurry may cause skin irritation, wear gloves.
Anhydrous Ammonia	Formula NH_3 Equiv. wt. 17	Anhydrous Ammonia or agricultural fertilizer	To raise digester pH. Needs close control to avoid excessive pH and ammonia toxicity. Ammonia is toxic at concentrations of 1500-1600 mg/l as N.	Comes in cylinders or tanks as a gas. Do not store near chlorine. Keep temperatures below 70°F. (21°C.) Store in a well-ventilated room. Have masks available. Wear rubber gloves. An irritating alkali, it can cause severe skin burns on contact. Ammonia is corrosive to copper. Do not neutralize with acid. Use water.
Ammonium Hydroxide	Formula NH_4OH Equiv. wt. 35	Liquid Ammonia used as an agriculture fertilizer	To raise digester pH	Is available in liquid form from farm supply firms.
Sodium Carbonate	Formula Na_2CO_3 Equiv. wt. 106	Soda Ash	pH control. Combines with CO_2 to form calcium bicarbonate. No ecological problems.	Comes in 50-pound bags as a powder. It is highly soluble in water. As a caustic, it will cause skin burns. Its chief problem is as an eye irritant. Use rubber gloves and mask or goggles.
Sodium Bicarbonate	Formula $NaHCO_3$ Equiv. wt. 84	Bicarbonate of Soda	pH control.	Comes in 50-pound bags as powder. Requires same precautions as soda ash.

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Sodium Hydroxide	Formula NaOH Equiv. wt. 40	Lye Caustic Soda	pH control. Combines with water and CO_2 to form sodium bicarbonate. Obtain special handling and use instructions from supplier before using.	Shipped in steel drums or in bags. Available in flake or crystals or as a liquid. Normally purchased in flake or crystals due to special handling problems. Use rubber gloves, cotton clothing and goggles or face shields. Neutralize with water only.
Ferrous Sulfate	Formula $FeSO_4$	Ferrous Sulfate.	To precipitate heavy metals. Contact supplier for dosages and application.	Obtain handling and safety instructions from supplier.
Ferric Sulfate	Formula $Fe_2(SO_4)_3$	Ferrisul-Monsanto Corp. Ferriclear-Stauffer Chemical Co.	To precipitate heavy metals. Contact supplier for dosages and application.	Obtain handling and safety instructions. from supplier.
Hydrogen Peroxide	Formula H_2O_2	Hydrogen Peroxide	For odor control in sludge handling facilities (beds, etc.) when emptying sour digesters Add at rate of 1.5 lb. H_2O_2 per lb. sulfide. (1.5 kg/kg)	Shipped in 50-gallon (189 l) drums as a liquid. Use a 30 or 35% solution to avoid severe burns. Wear rubber gloves and face shield. Neutralize with water. See supplier instructions before using.

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Troubleshooting begins by knowing the system. The operator needs to know:

1. What each part of the system is supposed to do.

2. How each process or piece of equipment operates normally.

3. How to recognize abnormal conditions.

4. What alternatives are available when trouble develops.

Briefly, to recognize when something is bad you must know how it works when no trouble exists.

The purpose of this section is to present a ready and quick operator's reference to process problems and their solutions. They have been drawn from operator's experience in dealing with these problems and from the many authors who have contributed their knowledge.

The Trouble Guides are arranged in columns as explained below:

INDICATORS. The information in this column shows what has been indicated or observed by the operator.

PROBABLE CAUSE. This shows the most likely cause of the indicated upset.

CHECK OR MONITOR. The operator should perform the listed monitoring until the process has recovered. Usually no single indicator tells the whole story.

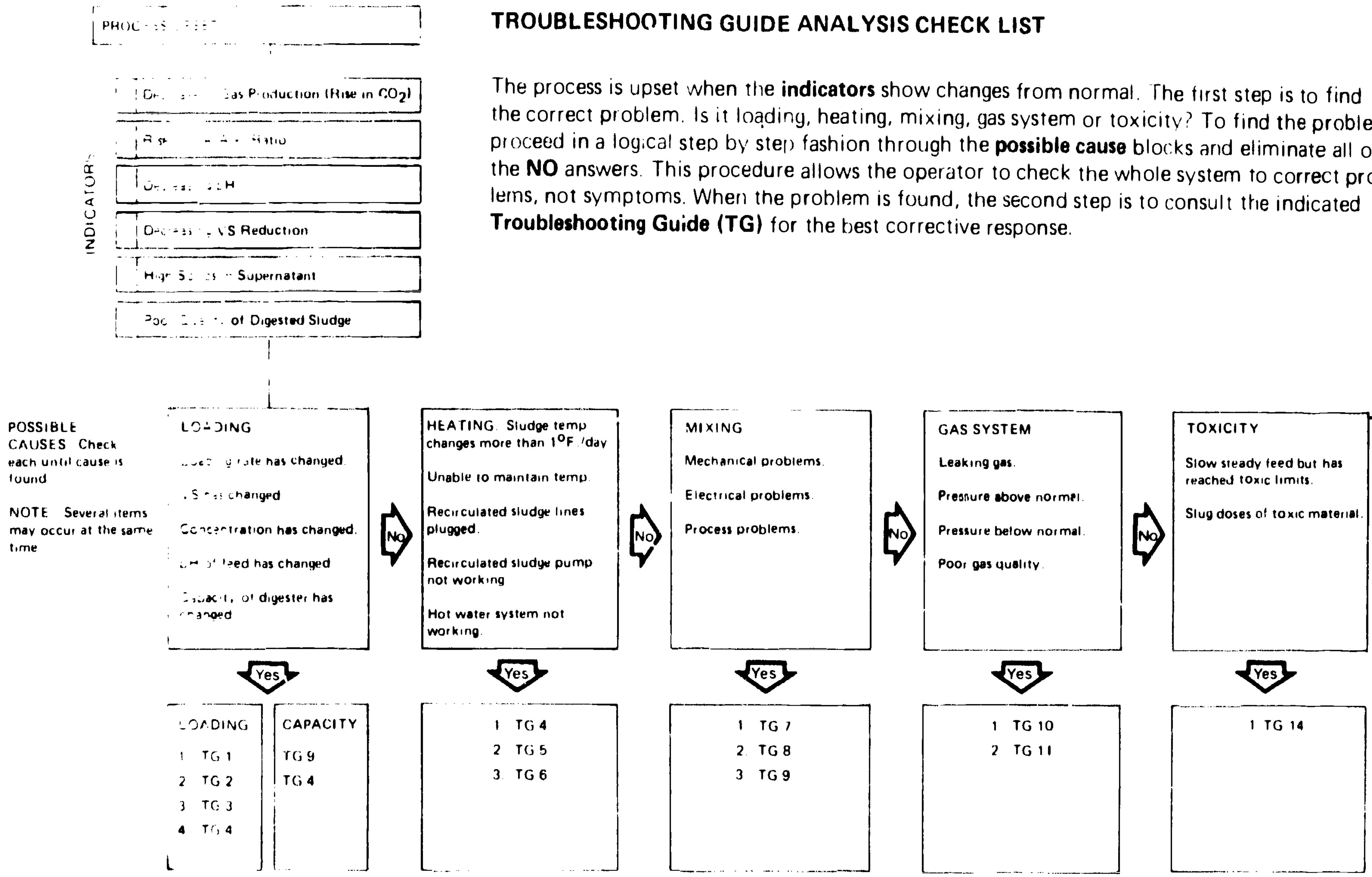
SOLUTIONS. The operator should perform any of the suggested solutions available to him as indicated.

REFERENCES. This column could be entitled "Help!" The numbers appearing in this column show where in the manual the operator can find additional information.

Reading across the page, follow the numbers. As an example, the number one in the **Solutions** column refers to the number one in the **Indicator** column.

TROUBLESHOOTING GUIDE ANALYSIS CHECK LIST

The process is upset when the **indicators** show changes from normal. The first step is to find the correct problem. Is it loading, heating, mixing, gas system or toxicity? To find the problem, proceed in a logical step by step fashion through the **possible cause** blocks and eliminate all of the **NO** answers. This procedure allows the operator to check the whole system to correct problems, not symptoms. When the problem is found, the second step is to consult the indicated **Troubleshooting Guide (TG)** for the best corrective response.



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TROUBLESHOOTING GUIDE 1 LOADING

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. A rise in the volatile acid/alkalinity (VA/Alk.) ratio due to hydraulic overload.	1. Overfeeding caused by storm infiltration, accidental overpumping, withdrawing too much sludge.	1. Monitor the following twice daily until problem is corrected: . Volatile acids . Alkalinity . Temperature	1. If ratio increases to 0.3: a. Add seed sludge from secondary digester (or) b. Decrease sludge withdrawal rate to keep seed sludge in digester (and/or) c. Extend mixing time. d. Check sludge temperatures closely and control heating if needed.	2-27, 2-22 4-23 2-10 3-14 3-33 3-42 4-11 4-18
2. A rise in volatile acid/alkalinity ratio due to organic overload.	2. Discharge of industrial waste or increase in septic tank sludge to the plant.	2. Monitor sludge pumping volume, amount of volatile solids in feed sludge.	2. If ratio increases to 0.3: a. Add secondary seed sludge (if available). b. Increase mixing time. c. Decrease bottom sludge withdrawal. d. Check temperature and hold heating at rate to maintain even temperature.	
3. If VA/Alk. ratio rises to 0.5, the concentration of CO_2 in the gas starts to increase.	3. See 1 and 2.	3a. Waste gas burner. b. Gas analyzer.	3. Continue 1b, 1c and 1d as above and starting adding lime or other caustic solution using the volatile acids to calculate the amount.	2-23
4. If ratio rises to 0.8, the pH will start to drop and CO_2 will have increased to the point (42-45%) that no burnable gas is obtained.	4. See 1 and 2.	4a. Monitor as indicated above. b. Hydrogen sulfide (rotten egg) odor. c. Rancid butter odor.	4a. Add lime or other caustic solution. b. Decrease loading to less than 0.01 lb. vol. solids/cu.ft./day until ratio drops to 0.5 or below.	2-23 2-33 3-21 3-34 TG14
5. Meter temporarily out or never installed.			5. Install some type of measuring indicator and attach a cord to the floating cover so that the end can indicate the distance the dome travels when pumping in and not removing supernatant. Calculate the amount pumped in a 24-hour period by this method. Volume computed by the inch or by the foot.	

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TROUBLESHOOTING GUIDE 2 SUPERNATANT

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Foam observed in supernatant from single stage or primary tank.	1a. Scum blanket breaking up. b. Excessive gas recirculation. Loading at approximately 0.4 lb. vol.solids/cu.ft./day will produce natural mixing.	1a. Check condition of scum blanket. b. Volatile solids loading ratio.	1a. Normal condition but should stop withdrawing supernatant if possible. b. This condition may indicate an organic overload in digester, making it necessary to slow down feeding.	2-16 4-8
2. Lumps and particles of scum in supernatant from single stage or primary tank.	2a. Scum blanket breaking up caused by excessive mixing or excessive gas production. b. Scum blanket too thick.	2a. Visual observation through window in digester cover. (Unusual increase in gas production also an indicator.) b. Depth of scum by measuring through thief hole or in gap beside floating cover.	2a. Decrease mixing time. Readjust sludge feed. Add more seed sludge. Add lime or other caustic. b. See TG 9, "Scum Blanket."	
3. Supernatant is a gray or brown color from single stage or primary tank.	3a. Inadequate stratification, raw sludge laying in pockets in the tank. b. Digestion time is too short. Sludge concentration is too low or: digester capacity is reduced due to grit and scum layers. c. Digester ecological balance is upset. d. Overloading digester. See TG 1, "Loading."	3a. Check mixing—may be undermixed. Take samples at various depths to detect pockets of undigested sludge. Check temperature gradient in the digester. b. Probe digester to determine grit deposits. c. CO_2 content, compare gas production to amount of volatile solids being fed. Gas production should average 7-12 cu.ft./day/lb.volatile solids destroyed.	3a. Increase mixing or increase frequency of feeding or increase recirculation. b. Readjust feed concentration. Increase mixing or clean out digester. c. Reduce feed rate by diverting to another digester or by some other means increase detention time. d. See alternatives in sections on digester feeding.	2-19

(Continued Next Page)

TROUBLESHOOTING GUIDE 2 SUPERNATANT (Cont.)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
4. Supernatant has a sour odor from either primary or secondary digester.	4a. The pH of digester is too low. b. Overloaded digester ("rotten egg odor"). c. Toxic load (rancid butter odor).	4a. pH of supernatant should be 6.8. b. See TG 1, "Loading." c. See TG 14, "Toxicity."	4a. Add lime or other caustic. b. See TG 1, "Loading." c. See TG 14, "Toxicity."	TG 1 TG 14
5. The SS solids in supernatant returning to process is too high, causing plant upsets.	5a. Excessive mixing and not enough settling time. b. Supernatant draw-off point not at same level as supernatant layer. c. Raw sludge feed point too close to supernatant draw-off line. d. Not withdrawing enough digested sludge.	5a. Put 10-20 liters in glass carboy and observe separation pattern. b. Locate stratum of supernatant by sampling at different depths. c. Determine volatile solids content. Should be close to value found in well mixed sludge and much lower than raw sludge. d. Compare feed and withdrawal rates—check volatile solids to see if sludge is well-digested.	5a. Allow longer periods for settling before withdrawing supernatant. b. Adjust tank operating level or draw-off pipe to get into stratum c. Schedule pipe revision for soonest possible time when digester can be dewatered. d. Increase digested sludge withdrawal rates. CAUTION: Withdrawal should not exceed 5% of digester volume per day. e. No solution, due to poor settling sludge such as primary-activated sludge mixture.	

TROUBLESHOOTING GUIDE 3 DIGESTED SLUDGE

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Gray or brown color from bottom of primary or secondary tank.	1a. Improper digestion. b. Short-circuiting, insufficient mixing.	1a. Layers of unmixed sludge in tank bottom. b. Raw sludge feed point too close to drawoff.	1a. See TG 7 and 8, "Sludge Mixing." b. Change feed point either by external valve or pipe arrangement or revise internally when tank is empty.	TG 7 TG 8
2. Sour odor.	2a. pH of digester is too low. b. Second stage of digestion is retarded. c. Overloaded digester.	2a. Check pH at different levels. b. Check CO_2 content of gas. c. Check ratio of volatile solids added to primary digester.	2a. Add lime. b. Let digester rest. c. See TG 1.	TG 1
3. Bottom sludge too watery or disposal point too thin.	3a. Short-circuiting. b. Excessive mixing.	3a. Draw-off line open to Supernatant Zone. b. Take sample and check how it concentrates in setting vessel.	3a. Change to bottom draw-off line. b. Shut off mixing for 24-48 hrs. before drawing sludge.	
4. Digester full of well-digested sludge and supernatant SS are high.	4a. Not withdrawing enough digested sludge.	4a. Check process indicators. All should be near normal values. Check withdrawal records and compare to feed records.	4a. Increase digested sludge withdrawal to dewatering or disposal. Withdrawal should not exceed 5% of digester volume per day.	4-8 4-18
5. Complete lack of biological activity.	5a. Highly toxic waste such as metals or bacteriocide.	5a. Gas production (or lack of). b. Analyze sample by spectrophotometer or chemical means. (May need commercial lab.)	5a. Empty contents. Be sure to get necessary approvals as required.	

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TROUBLESHOOTING GUIDE 4 SLUDGE PUMPING AND PIPELINES

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Sludge concentration below normal in raw sludge sample.	1. Sludge bridging or coning, allowing excess water to be pumped.	1a. Total solids or visual sample. b. Pump discharge pressure lower than normal due to less resistance in line. c. Rising solids in the clarifier.	1. Use water or air to break up raw sludge by attaching a 15′ length of pipe to an air hose or to a non-potable water source, then direct the stream into the built-up sludge. Adjust raw sludge pump cycle. If the cause is coning in a digester, several options are available. See item 2 below.	2-7
2. Sludge concentration below normal in sludge from bottom of digester.	2. Sludge coning, allowing lighter solids to be pulled into pump suction.	2. Total solids test or visual observation.	2a. "Bump" the pump 2 or 3 times by starting and stopping. b. Use whatever means available to pump digester contents back through the withdrawal line. c. If available, attach a water hose to the pump suction line and force water through it. (Water source must be nonpotable.) *CAUTION: Run this for no more than 2 or 3 min. to avoid diluting the digester.*	
3. Pump suction and discharge pressures erratic. Pump makes unusual sounds.	3a. Sand, grease or debris plugging suction line. b. Grease from scum pit plugging line.	3a. Pump suction and discharge pressure. b. Pump suction and discharge pressure	3a. Backflush the line with heated digester sludge. b. Use mechanical cleaner. c. Apply water pressure. *CAUTION: Do not exceed working line pressure.* d. Add approx. 3 lb./100 gal. water of trisodium phosphate (TSP) or commercial degreasers. (Most convenient method is to fill scum pit to a volume equal to the line, add TSP or other chemical, then admit to the line and let stand for an hour.)	

TROUBLESHOOTING GUIDE 5 SLUDGE TEMPERATURE CONTROL USING INTERNAL COILS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Low water feed rate to heat exchanger.	1a. Air lock in line. b. Valve partially closed.	1. Inlet and outlet meter readings lower than normal but equal.	1a. Bleed air relief valve. b. Upstream valve may be partially closed.	2-13 4-14
2. Normal feed rate into the heat exchanger but low feed rate out of it.	2a. Faulty meter. b. Leak in heat transfer pipes.	2. Higher inlet meter reading than outlet reading on the water system.	2a. Check by interchanging inlet and outlet meters. b. May require emptying digester to fix.	
3. Boiler burner not firing on digester gas.	3a. Low gas pressure. b. Unburnable gas.	3a. Check for leak in system. b. Check for process problems.	3a. Locate and repair. b. Follow solutions listed in TG 1, "Loading."	
4. Low heat loss between inlet and outlet water.	4. Check for coating on tubes.	4. Temperature gauges on inlet and outlet lines read about the same.	4. Remove coating on the outside of the water tubes which will require draining tank if tubes are internal.	
5. Too high temperature.	5. Solids caked on the outside of the heat exchanger tubing.	5. Temperature records.	5a. Remove coating, may require draining tank. b. Control water temperature to 130 deg. F. maximum.	
6. Coating on inside of heat exchanger piping.	6. Too high temperature.	6. Temperature records.	6a. May be controlled by adding chemicals to boiler make-up water. b. May have to be removed by rodding out lines.	

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TROUBLESHOOTING GUIDE 6 SLUDGE TEMPERATURE CONTROL USING EXTERNAL HEAT EXCHANGERS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Low rate of sludge fed through the exchanger.	1a. High temperature override shuts pump down to prevent caking of sludge on the exchanger. b. Check high temperature circuit tied in with hot water heater to assure that it is cutting off at the correct temperature.	1. Low pressure and higher water temperatures.	1a. Open closed valve on pump. b. Check and remove obstruction in the sludge pump. c. Check for and remove obstruction in heat exchanger (spiral type exchangers can be dewatered and opened fairly easily).	2-13 3-14 4-11
2. Recirculation pump not running; power circuits O.K.	2. Temperature override in circuit to prevent pumping too hot water through tubes.	2. Visual check, no pressure on sludge line.	2a. Allow system to cool off. b. Check temperature control circuits.	
3. Sludge temperature is falling and cannot be maintained at normal level.	3a. Sludge is plugging heat exchanger. b. Sludge recirculation line is partially or completely plugged. c. Inadequate mixing.	3a. Check inlet and outlet pressure or exchanger. b. Check pump inlet and outlet pressure. c. Check temperature profile in digester.	3a. Open heat exchanger and clean. b. See TG 4, "Line Plugging." c. Increase mixing time.	
4. Sludge temperature is rising.	4. Temperature controller is not working properly.	4. Check water temperature and controller setting.	4. If over 120 deg. F., reduce temperature. Repair or replace controller.	
5. Temperature readings not accurate.	5. Probes have electrical short or separation internally.	5. Compare with thermometer known to be accurate.	5. Leave probe connected to read-out device, immerse in bucket of water at approximate digester temperature with thermometer in it. Compare readings. (Replace probe if bad, if O.K., see problems above for checking heating system.)	
6. Unable to maintain temperature.	6. Hydraulic overloading.	6. Incoming sludge concentration.	6. See TG 1	

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TROUBLESHOOTING GUIDE 7 SLUDGE MIXING—GAS MIXERS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Compressor running hot and/or noisy.	1a. Low oil level. b. High ambient temperature.	1. Visual or audible observation; or by feeling of the unit.	1a. Check oil level in the compressor. b. Check for excessive ambient temperature, provide cover and/or ventilation if necessary. c. Check compressor for excessive wear.	2-12 4-14 2-21
2. Gas feed lines plugging.	2a. Lack of flow through gas line. b. Debris in gas lines.	2. Identify low temperature of gas feed pipes or low pressure in the manometer.	2a. Flush out with water. b. Clean feed lines and/or valves. c. Give thorough service when tank is drained for inspection.	
3. Mixers not operable.	3. Mechanical or electrical problem.	3. Rate of volatile loading to digester.	3. Natural gas evolution will cause mixing if loading is held at 0.3-0.5 lb. volatile solids per cu.ft. per day. *Closer monitoring will be necessary to prevent process upset (See TG 1, "Loading").*	

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TROUBLESHOOTING GUIDE 8 SLUDGE MIXING—MECHANICAL MIXERS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Corrosion of exposed parts by weather and/or corrosive sewage gas.	1. Lack of paint or other protection	1. Note presence of rust, corrosion, or bare exposed metal.	1a. Construction of protective structure. b. Preparation and painting of surfaces.	2-12 4-14 2-21
2. Gear reducer wear.	2a. Lack of proper lubrication. b. Poor alignment of equipment.	2. Excessive motor amperage, excessive noise and vibration, evidence of shaft wear.	2a. Verify correct type and amount of lubrication from manufacturer's literature. b. Correct imbalances caused by accumulation of material on the internal moving parts.	See item 5 below.
3. Shaft seal leaking.	3. Packing dried out or worn.	3. Evidence of gas leakage when checked by soap solution or evident odor of gas.	3a. Follow manufacturer's instructions for repacking. b. Replace packing any time the tank is empty if it is not possible when unit is operating.	
4. Wear on internal parts.	4. Grit or misalignment.	4. Visual observation when tank is empty, compare with manufacturer's drawings for original size. Motor amperage will also go down as moving parts are worn away and get smaller.	4. Replace or rebuild—experience will determine the frequency of this operation.	
5. Imbalance of internal parts because of accumulation of debris on the moving parts (large-diameter impellers or turbines would be affected most).	5. Poor comminution and/or screening.	5. Vibration, heating of motor, excessive amperage, noise.	5a. Reverse direction of mixer if it has this feature. b. Stop and start alternately. c. Open inspection hole and visually inspect. d. Draw down tank and clean moving parts.	
6. Power source interruption.	6. High ambient temperature.	6. Excessive amperage, corroded power connections, overheating causing circuits to kick out.	6. Protect motor by covering with ventilator housing.	

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TROUBLESHOOTING GUIDE 9 SCUM BLANKET

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Rolling movement is slight or absent.	1a. Mixer is off. b. Inadequate mixing time. c. Scum blanket is too thick.	1a. Mixer switch or timer. c. Measure blanket thickness.	1a. May be normal if mixers are set on a timer. If not and mixers should be operating, check for malfunction. b. Consider increasing the mixing time. c. See items 4 and 5.	2-12, 2-21 3-39 4-8
2. Dry and cracked scum blanket (Open digesters.)	2. Lack of recirculation, combination of grease and hair.	2. Visually measure scum depth.	2. Recycle thin sludge with portable pump (with explosive-proof motor).	
3. Scum blanket is too high.	3. Supernatant overflow line is plugged.	3a. Check gas pressure, it may be above normal or relief valve may be venting to atmosphere. b. See 1a above.	3a. Lower contents through bottom drawoff then rod supernatant line to clear plugging. b. Increase mixing time or break-up blanket by some other physical means.	See item 4 below.
4. Scum blanket is too thick.	4. Lack of mixing, high grease content.	4. Probe blanket for thickness through thief hole or in gap beside floating cover.	4a. Break up blanket by using mixers. b. Use sludge recirculation pumps and discharge above the blanket. c. Use Sanfax or Digest-aide to soften blanket. d. Break up blanket physically with pole. e. Tank modification.	
5. Draft tube mixers not moving surface adequately.	5. Scum blanket too high and allowing thin sludge to travel under it.	5. Rolling movement on sludge surface.	5a. Lower sludge level to 3-4" above top of tube allowing thick material to be pulled into tube—continue for 24-48 hours. b. Reverse direction (if possible).	

TROUBLESHOOTING GUIDE 10 DIGESTER GAS SYSTEM

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Gas is leaking through pressure relief valve (PRV) on roof.	1. Valve not seating properly or is stuck open.	1. Check the manometer to see if digester gas pressure is normal.	1. Remove PRV cover and move weight holder until it seats properly. Install new ring if needed. Rotate a few times for good seating.	
2. Manometer shows digester gas pressure is above normal.	2a. Obstruction or water in main burner gas line. b. Digester PRV is stuck shut. c. Waste gas burner line pressure control valve is closed.	2a. If all use points are operating and normal, then check for a waste gas line restriction or a plugged or stuck safety device. b. Gas is not escaping as it should. c. Gas meters show excess gas is being produced, but not going to waste gas burner.	2a. Purge with air, drain condensate traps, check for low spots. *CAUTION: Care must be taken not to force air into digester.* b. Remove PRV cover and manually open valve, clean valve seat. c. See 1a and also relevel floating cover if gas escapes around dome due to tilting.	
3. Manometer shows digester gas pressure below normal.	3a. Too fast withdrawal causing a vacuum inside digester. b. Adding too much lime.	3a. Check vacuum breaker to be sure it is operating properly. b. Sudden increase in CO_2 in digester gas.	3a. Stop supernatant discharge and close off all gas outlets from digester until pressure returns to normal. b. Stop addition of lime and increase mixing.	
4. Frozen PRV valve.	4. Winter conditions.	4. Remove valve cover and inspect PRV.	4. Possible remedies are: a. Mixture of salt and grease applied to seat ring. b. Place vented barrel over valve with an explosionproof light bulb inside.	3-35 4-16
5. Pressure regulating valve not opening as pressure increases.	5a. flexible diaphram. b. Ruptured diaphram.	5. Isolate valve and open cover.	5a. If no leaks are found (using soap solution) diaphram may be lubricated and softened using neats-foot oil. b. Ruptured diaphram would require replacement.	4-16
6. Yellow gas flame from waste gas burner.	6. Poor quality gas with a high CO_2 content.	6. Check CO_2, content it will be higher than normal.	6. Check concentration of sludge feed—may be too dilute. If so, increase sludge concentration.	

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(Continued Next Page)

TROUBLESHOOTING GUIDE 10 DIGESTER GAS SYSTEM (Cont.)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
7. Gas flame lower than usual.	7a. High gas usage in plant. b. Gas leak from digester piping or safety devices. c. Low gas production due to process problems.	7a. Check gas production rate against gas usage. b. Check gas collection and distribution system, starting at digester main collection point. c. See TG 1, "Loading."	7a. This may be normal. b. Check for escaping gas, when found, isolate and repair. c. See TG 1, "Loading."	
8. Waste gas burner not lit.	8a. Pilot flame not burning. b. Obstruction or water in pilot gas line. c. Obstruction or water in main waste gas line. d. Pressure control valve closed.	8a. Pilot line pressure at waste gas burner. b. See 8a. c. Waste gas pressure control valve. d. See 8c.	8a. Relight if there is pressure. b. Purge with air and check for low spots in line if there is no pressure. c. Drain condensate traps, check for low spots, purge with air pressure. *(Care must be taken not to force air into digester.)* d. Open valve & verify that setting will allow valve to open when pressure is about ¼" water column above all other use point pressures.	
9. Gas meter failure (propeller or lobe type).	9a. Debris in line. b. Mechanical failure.	9a. Condition of gas line. b. Fouled or worn parts.	9a. Flush with water, isolating digester and working from digester toward points of usage. b. Wash with kerosene or replace worn parts.	
10. Gas meter failure (bellows type).	10a. Inflexible diaphram. b. Ruptured diaphram.	10. Isolate valve and open cover.	10a. If no leaks are found (using soap solution) diaphram may be lubricated and softened using neats-foot oil. b. Ruptured diaphram. c. Metal guides may need to be replaced if corroded.	
11. Manometer leaking or not reading accurately	11a. Leak in gas line to manometer. b. Line plugged.	11a. Inspect for leaks. b. Disconnect and note flow, check for gas flow.	11a. Tighten fittings or replace corroded or damaged line. b. Rod out or use water pressure to clean. *(NOTE: Replace with proper liquid, some use special oil, mercury or water.)*	

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TROUBLESHOOTING GUIDE 11 DIGESTER COVERS–FIXED

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Gas pressure higher than normal during freezing weather.	1a. Supernatant line plugged.	1a. Supernatant overflow lines.	1a. Check every two hours during freezing conditions, inject steam, protect line from weather by covering and insulating overflow box.	2-11 3-35
	b. Pressure relief valve stuck or closed.	b. Weights on pressure relief valve.	b. If freezing is a problem, apply light grease layer impregnated with rock salt.	
2. Gas pressure lower than normal.	2a. Pressure relief valve or other pressure control devices stuck open.	2a. Pressure relief valve and devices.	2a. Manually operate vacuum relief and remove corrosion if present and interfering with operation.	
	b. Gas line or hose leaking.	b. Gas line and/or hose.	b. Repair as needed.	
3. Leaks around metal covers.	3. Anchor bolts pulled loose and/or sealing material moved or cracking.	3. Concrete broken around anchors, tie downs bent, sealing materials displaced.	3. Repair concrete with fast sealing concrete repair material. New tie downs may have to be welded onto old ones and re-drilled. *Tanks should be drained and well ventilated for this procedure.* New sealant material should be applied to leaking area using thiakol or other material with durable plasticity.	Fig. 3-15
4. Suspected gas leaking through concrete cover.	4. Freezing and thawing causing widening of construction cracks.	4. Apply soap solutions to suspected area and check for bubbles.	4. If this is a serious problem, drain tank, clean cracks and repair with thiakol or concrete sealers. *Tanks should be drained and well ventilated for this procedure.*	3-15

"Note Items 1 and 2 of "Covers–Fixed" and No. 2 "Covers–Floating" also apply to "Covers–Gas Holder Type."

TROUBLESHOOTING GUIDE 12 DIGESTER COVERS–FLOATING

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Cover tilting, little or no scum around the edges.	1a. Weight distributed unevenly.	1a. Location of weights.	1a. If moveable ballast or weights are provided, move them around until the cover is level. If no weights are provided, use a minimal number of sand bags to cause cover to level up. (Note: pressure relief valves may need to be reset if significant amounts of weight are added.)	2-11
	b. Water from condensation or rain water collecting on top of metal cover in one location.	b. Check around the edges of the metal cover. (Some covers with insulating wooden roofs have inspection holes for this purpose.)	b. Use siphon or other means to remove the water. Repair roof if leaks in the roof are contributing to the water problem.	
2. Cover tilting, heavy thick scum accumulating around edges.	2a. In one area, causing excess drag.	2a. Probe with a stick or some other method to determine the condition of the scum.	2a. Use chemicals or degreasing agents such as Digest-aide or Sanfax to soften the scum, then hose down with water. Continue on regular basis every two to three months or more frequently if needed.	
	b. Guides or rollers out of adjustment.	b. Distance between guides or rollers and the wall.	b. Soften up the scum (as in 2a) and readjust rollers for guides so that skirt doesn't rub on the walls.	
	c. Rollers or guides broken.	c. Determine the normal position if the suspected broken part is covered by sludge. Verify correct location using manufacturer's information and/or prints if necessary.	c. Drain tank if necessary taking care as cover lowers to corbels not to allow it to bind or come down unevenly. It may be necessary to use a crane or jacks in order to prevent structural damage with this case.	3-15
3. Freezing problems in PRV.	4. See TG 11, item 1.	4. See TG 11, item 1.	4. See TG 11, item 1.	3-35

"Note Items 1 and 2 of "Covers–Fixed" and No. 2 "Covers–Floating" also apply to "Covers–Gas Holder Type."

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TROUBLESHOOTING GUIDE 13 DIGESTER COVERS—GAS HOLDER TYPE

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Cover guides and/or rollers causing cover to bind.	1. Scum accumulation restricting travel.	1. Check scum accumulation and verify the amounts.	1. See TG 12, "Covers Floating," item 1.	4-15
2. Cover binding even though rollers and guides are free.	2. Internal guide or guy wires are binding or damaged (some covers are built like umbrellas with guides attached to the center column).	2. Lower down to corbels. Open hatch and using breathing apparatus and explosionproof light, if possible, inspect from the top. If cover will not go all the way down, it may be necessary to secure in one position with a crane or by other means to prevent skirt damage to sidewalls.	2. Drain and repair, holding the cover in a fixed position if necessary.	3-15
3. Cover tilting, heavy thick scum accumulating around edges.	3a. In one area causing excess drag. b. Guides or rollers out of adjustment.	3a. Probe with a stick or some other method to determine the condition of the scum. b. Distance between guides or rollers and the wall.	3a. Use chemicals or degreasing agents such as Digest-aide or Sanfax to soften the scum, then hose down with water. Continue on regular basis every two to three months or more frequently if needed. b. Soften up the scum (as in 3a) readjust rollers for guides so that skirt doesn't rub on walls.	
4. Gas pressure higher than normal during freezing weather.	4a. Supernatant line plugged. b. Pressure relief stuck or closed.	4a. Supernatant overflow lines. b. Weights on pressure relief valve.	4a. Check every two hours during freezing conditions and inject steam. Protect line from weather by covering and insulating overflow box. b. If freezing is a problem, apply light grease layer impregnated with rock salt.	
5. Gas pressure lower than normal.	5a. Pressure relief valve or other pressure control devices stuck open. b. Gas line or hose leaking.	5a. Pressure relief valve and devices. b. Gas line and/or hose.	5a. Manually operate vacuum relief and remove corrosion if present and interfering with operation. b. Repair as needed.	

"Note Items 1 and 2 of "Covers—Fixed" and No. 2 "Covers Floating" also apply to "Covers—Gas Holder Type."

TROUBLESHOOTING GUIDE 14 TOXICITY

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1 Heavy metals a. VA/Alk increases b. pH drops c. Gas production decreases d. Odor of Butyric Acid (rancid butter).	1. Industrial discharges.	1a. Use a silver/silver sulfide electrode to measure pS (Values greater than 14.0 indicate inhibitory concentrations.) b. Use atomic absorption to identify specific metals.	1. Use any or combination of the following: a. Solids recycle. b. Liquid dilution. c. Decrease feed concentration. d. Precipitate heavy metals with a sulfur compound. Be sure pH in digester is greater than 7.0.	3-23
2. Sulfides	2a. Discharge from metallurgical industries. b. Anaerobic activity in sewers or clarifiers.	2a. Industrial wastes at source. b. Flat sewers or inadequate sludge pumping.	2a. Dilution. b. Use iron salts to precipitate sulfides. c. Containment and slow feeding. d. Institute source control program for industrial wastes.	3-23
3. Ammonia Toxicity	3a. Industrial discharges. b. Organic overload. c. Over-correcting a pH problem.	3a. Wastes from industries handling nitrogenous products. b. Pounds volatile solids/day in feed.	3a. Dilution and solids recycle. b. Decrease feed if possible.	3-23
4. Alkali and Alkaline earth salts: Sodium Potassium Calcium Magnesium	4a. Industrial wastes. b. Over-correcting a pH problem.	4a. Wastes from industries handling industrial chemicals, fertilizer, etc. b. Alkalinity and specific constituent amounts.	4a. Use an antagonistic compound. b. Recycle from bottom of secondary to primary digester at 50% of feed rate.	3-22

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ANAEROBIC DIGESTION

References

"Operations Manual; Anaerobic Sludge Digestion," EPA, 430/9-76-001, Cincinnati, OH, 1976.

"Manual of Practice #11 Operation of Wastewater Treatment Plants," WPCF, Lancaster Press, Lancaster, PA, 1976.

"Operation of Wastewater Treatment Plants," Kenneth D. Kerri, Sacramento State College, Sacramento, CA, 1980.

"Sludge Treatment & Disposal; Anaerobic Digestion I & II" Course 166, U.S. EPA, Cincinnati, OH, and Linn-Benton Community College, Albany, OR, 1980.

ANAEROBIC DIGESTION

Worksheet 1 - Process Theory

1. List four purposes of anaerobic digestion of sewage sludge.

   a.

   b.

   c.

   d.

2. Raw sludge from a primary clarifier contains _____ to ______% volatile matter.

3. List one advantage and one disadvantage which anaerobic digestion has over aerobic digestion.

   a. Advantage

   b. Disadvantage

4. The anaerobic sludge digestion process is a ________ stage process.

5. Volatile solids in raw sludge are attacked by ________________________ organisms to form ________________________ acids.

6. __________ formers then feed off of the __________ acids to form ____________________, ____________________, ____________________ and alkalinity.

7. Which of the two types of major bacteria involved in the anaerobic digestion process is a strict anaerobe?

8. Stabilizing waste by digestion should reduce the volatile content by _____ to ______%.

9. The gas produced by a digester is mainly ______% __________ and ________% ________________.

10. ______ to ______ ft^3 of gas will be produced for each lb of volatile solids digested.

11. One ft^3 of digester gas will produce ______ to _______ BTU of heat.

12. Name three uses of digester gas:

    a.

    b.

    c.

13. Methane can explode when the ratio of air to methane is between ________ and __________.

14. Why is digester gas corrosive?

15. What causes the scum layer in a digester?

16. Water (supernatant) in a digest may come from:

    a.

    b.

17. Digester supernatant can have a BOD of ________ to _________ mg/L and a SS of _______ to ________ mg/L.

18. What are the characteristics of good quality digester sludge?

Worksheet 2 - Types and Components

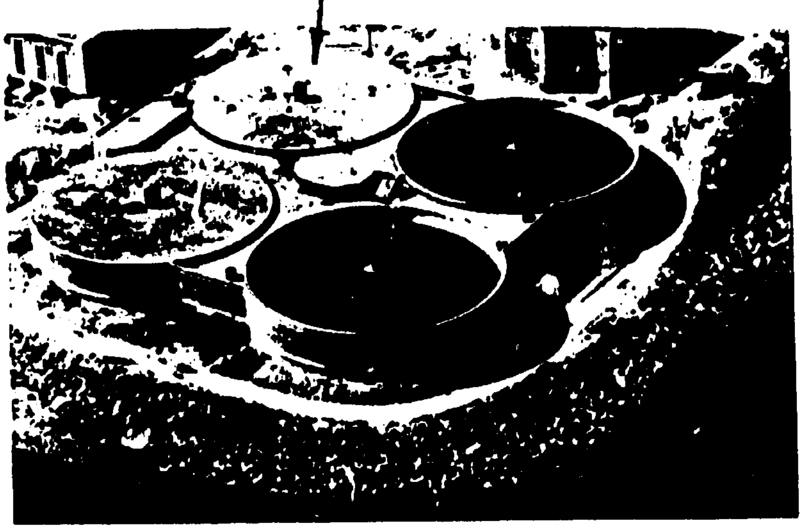
1. Identify the following digesters by cover type (fixed, floating or gas holding).

   a. ____________________

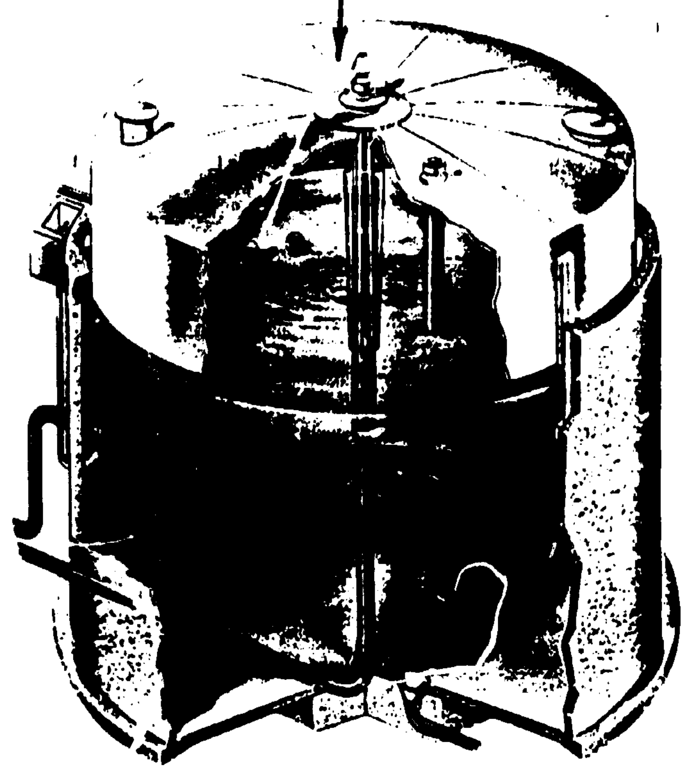
   b. ____________________

   c. ____________________

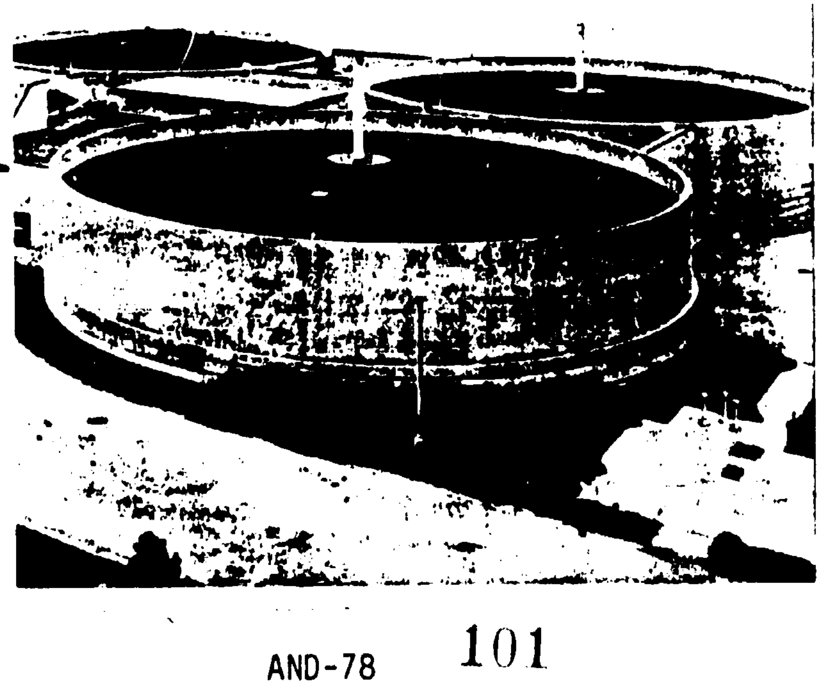
A.



B.



C.



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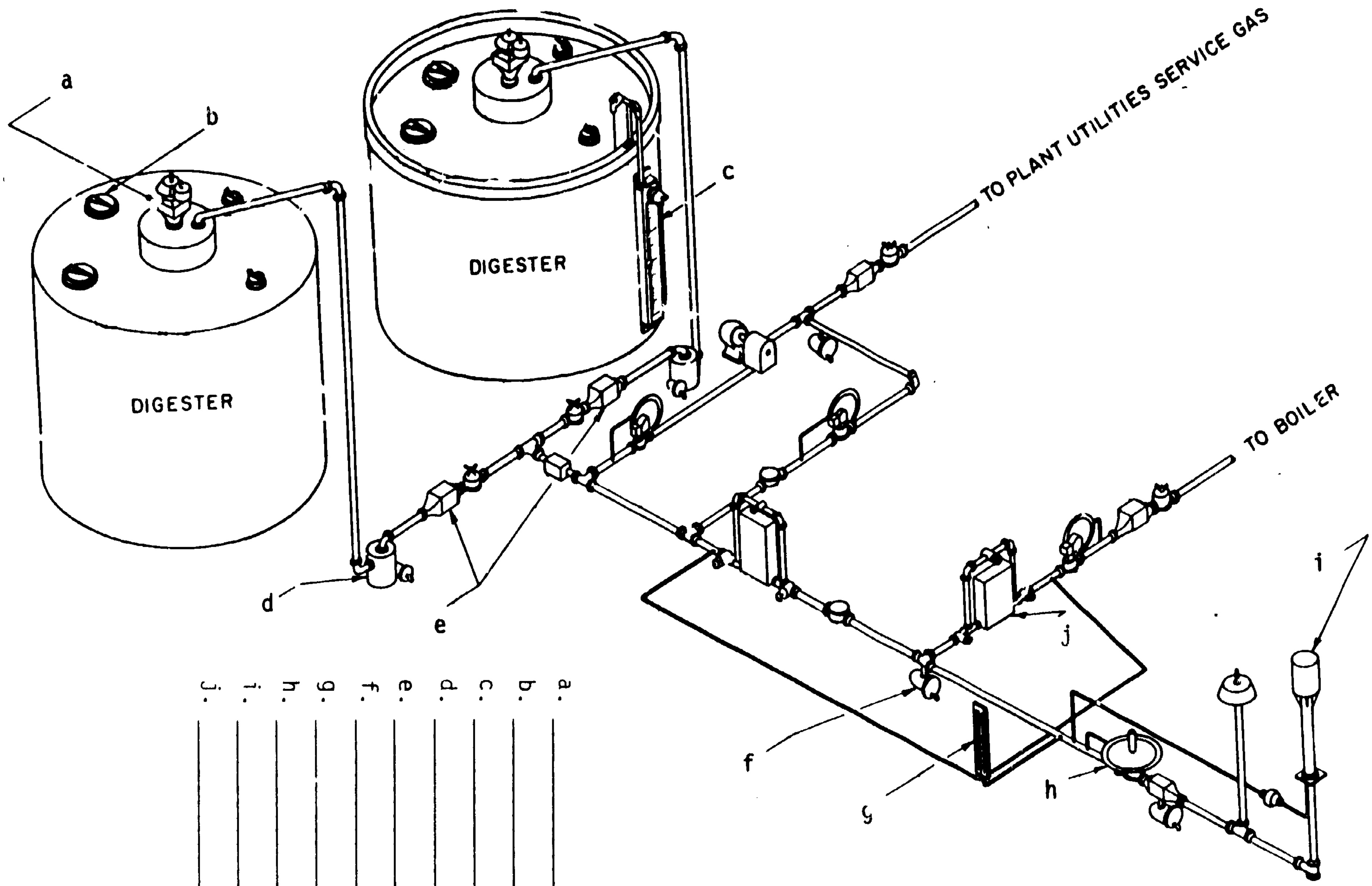
2. Identify the components of the digester gas system indicated.

TYPICAL FLOW AND INSTALLATION DIAGRAM
MULTIPLE DIGESTER GAS SYSTEM



a. ____________________

b. ____________________

c. ____________________

d. ____________________

e. ____________________

f. ____________________

g. ____________________

h. ____________________

i. ____________________

j. ____________________

3. The roof of a fixed roof digester may be made of ______________ or ______________.

4. Internal pressure of a fixed roof digester should not exceed _______ inches of water.

5. Digester heat exchangers may be either ______________ or ______________.

6. Digester sludge may be mixed with digester ________, mechanical _________ or with ______________.

7. Internal pressure on a floating roof digester should be between _______ and ________ inches of H_2O.

8. Name the three temperature zones used to classify digesters.

   a. ________________

   b. ________________

   c. ________________

9. Why is it necessary to have commercial natural gas on hand?

10. Name two types of sludge pumps.

ANAEROBIC DIGESTION

Worksheet 3 - Operational Control

1. Name 6 factors which affect digester operation.

   a. ____________________
   b. ____________________
   c. ____________________
   d. ____________________
   e. ____________________
   f. ____________________

2. There should be ______ times for seed sludge (bacteria) than food by weight of volatile matter.

3. List 3 characteristics of good quality feed sludge.

   a.
   b.
   c.

4. Give the normal operating ranges for each of the following:

   VA/Alk ratio ____________________

   V.S./ft^3 loading ____________________

   temperature ____________________

   pH ____________________

   feed sludge conc. ____________________

5. How does hydraulic loading affect detention time?

6. How is the optimum operating temperature determined?

7. Digester temperature should be changed no more than ____ ^{o}F/day.

8. Volatile acid concentrations in the digester can fall in the range of ______ to _______ mg/L.

9. Alkalinity in the digester can fall in the range of ______ to ________ mg/L.

10. How is detention time controlled?

11. If digester supernatant BOD and SS concentration exceeds ________ mg/L, the biological system of the plant may become overloaded.

12. List the 5 sample points of a typical digester.

    a. ________________________
    b. ________________________
    c. ________________________
    d. ________________________
    e. ________________________

13. For the following tests indicate the samples upon which they should be run:

    pH and temperature -

    Flow -

    Solids (Total, Volatile & % Moisture) -

    CO_2 -

    BOD & SS -

    Volatile Acids & Alkalinity -

Worksheet 4 - Calculations

Consider the following data for an anaerobic digester.

	Raw	Digested	Supernatant
Quantity	12,000 gal/day		12,000 gal/day
Total Solids, mg/L	40,000 mg/L (4%)	60,000 mg/L	4,000 mg/L
Volatile Solids (% of T.S.)	70%	45%	60%
Digester Volume	250,000 gal (33,400 ft^3)		
Digesting Sludge	2% (20,000 mg/L)		

1. Calculate pounds T.S. in digester.

2. Calculate pounds T.S. in raw feed sludge.

3. Calculate pounds T.S. in supernatant

4. Calculate Hydraulic Detention Time.

5. Calculate pounds Volatile Solids fed.

6. Calculate volatile solids loading in lbs/day/ft^3.

7. Calculate volatile solids loading in lbs V.S./day per lb V.S. in digester.

8. Calculate Volatile Solids Reduction.

9. Calculate pounds of volatile solids digested.

10. A digester has a volume of 250,000 gal. Lab tests show that 0.075 lbs of lime is necessary to bring the pH of a 5 gal sample up to 6.8. How many lbs of lime are necessary to adjust the pH of the entire digester?

11. If a digester of Vol. 250,000 gal has 2000 mg/L of Volatile Acids, how many lbs of lime will be needed to neutralize the V.A.'s?

12. If a digester of Vol. 250,000 gal, the alkalinity is 2000 mg/L and the volatile acids is 3500 mg/L, how many lbs of 80% anhydrous ammonia are needed to neutralize the V.A.'s? (Assume an excess of 500 mg/L alkalinity needed.)