United States
Environmental Protection
Agency

Wastewater Technology Fact Sheet

Anaerobic Lagoons

DESCRIPTION

An anaerobic lagoon is a deep impoundment, essentially free of dissolved oxygen, that promotes anaerobic conditions. The process typically takes place in deep earthen basins, and such ponds are used as anaerobic pretreatment systems.

Anaerobic lagoons are not aerated, heated, or mixed. The typical depth of an aerated lagoon is greater than eight feet, with greater depths preferred. Such depths minimize the effects of oxygen diffusion from the surface, allowing anaerobic conditions to prevail. In this respect, anaerobic lagoons are different from shallower aerobic or facultative lagoons, making the process analogous to that experienced with a single-stage unheated anaerobic digester, except that anaerobic lagoons are in an an open earthen basin. Moreover, conventional digesters are typically used for sludge stabilization in a treatment process, whereas lagoons typically are used to pretreat raw wastewater. Pretreatment includes separation of settlable solids, digestion of solids, and treatment of the liquid portion.

Anaerobic lagoons are typically used for two major purposes:

1) Pretreatment of high strength industrial wastewaters.

2) Pretreatment of municipal wastewater to allow preliminary sedimentation of suspended solids as a pretreatment process.

Anaerobic lagoons have been especially effective for pretreatment of high strength organic wastewaters. Applications include industrial wastewaters and rural communities that have a significant organic load from industrial sources. Biochemical oxygen demand (BOD) removals up to 60 percent are possible. The effluent cannot be discharged due to the high level of anaerobic byproducts remaining. Anaerobic lagoons are not applicable to many situations because of large land requirements, sensitivity to environmental conditions, and objectionable odors. Furthermore, the anaerobic process may require long retention times, especially in cold climates, as anaerobic bacteria are uneffective below 15° C. As a result, anaerobic lagoons are not widely used for municipal wastewater treatment in northern parts of the United States.

Process

An anaerobic lagoon is a deep earthen basin with sufficient volume to permit sedimentation of settlable solids, to digest retained sludge, and to anaerobically reduce some of the soluble organic substrate. Raw wastewater enters near the bottom of the pond and mixes with the active microbial mass in the sludge blanket. Anaerobic conditions prevail except for a shallow surface layer in which excess undigested grease and scum are concentrated. Sometimes aeration is provided at the surface to control odors. An impervious crust that retains heat and odors will develop if surface aeration is not provided. The discharge is located near the side opposite of the influent. The effluent is not suitable for discharge to receiving waters. Anaerobic lagoons are followed by aerobic or facultative lagoons to provide required treatment.

The anaerobic lagoon is usually preceded by a bar screen and can have a Parshall flume with a flow recorder to determine the inflow to the lagoon. A cover can be provided to trap and collect the methane gas produced in the process for use elsewhere, but this is not a common practice.

Microbiology

Anaerobic microorganisms in the absence of dissolved oxygen convert organic materials into stable products such as carbon dioxide and methane. The degradation process involves two separate but interrelated phases: acid formation and methane production.

During the acid phase, bacteria convert complex organic compounds (carbohydrates, fats, and proteins) to simple organic compounds, mainly short-chain volatile organic acids (acetic, propionic, and lactic acids). The anaerobic bacteria involved in this phase are called "acid formers," and are classified as nonmethanogenic microorganisms. During this phase, little chemical oxygen demand (COD) or biological oxygen demand (BOD) reduction occurs, because the short-chain fatty acids, alcohols, etc., can be used by many microorganisms, and thereby exert an oxygen demand.

The methane-production phase involves an intermediate step. First, bacteria convert the short-chain organic acids to acetate, hydrogen gas, and carbon dioxide. This intermediate process is referred to as acetogenesis. Subsequently, several species of strictly anaerobic bacteria (methanogenic microorganisms) called "methane formers" convert the acetate, hydrogen, and carbon dioxide into methane gas (CH_4) through one of two major pathways. This process is referred to as methanogenesis. During this phase, waste stabilization occurs, represented by the formation of methane gas. The two major pathways of methane formation are:

1) The breakdown of acetic acid to form methane and carbon dioxide:

$$CH_3COOH \quad CH_4 + CO_2$$

2) The reduction of carbon dioxide by hydrogen gas to form methane:

$$CO_2 + 4H_2 \quad CH_4 + 2\ H_20$$

Equilibrium

When the system is working properly, the two phases of degradation occur simultaneously in dynamic equilibrium. That is, the volatile organic acids are converted to methane at the same rate that they are formed from the more complex organic molecules. The growth rate and metabolism of the methanogenic bacteria can be adversely affected by small fluctuations in pH substrate concentrations, and temperature, but the performance of acid-forming bacteria is more tolerant over a wide range of conditions. When the process is stressed by shock loads or temperature fluctuations, methane bacteria activity occurs more slowly than the acid formers and an imbalance occurs. Intermediate volatile organic acids accumulate and the pH drops. As a result, the methanogens are further inhibited and the process eventually fails without corrective action. For this reason, the methane-formation phase is the rate-limiting step and must not be inhibited. For the design of an anaerobic lagoon to work, it must be based on the limiting characteristics of these microorganisms.

Establishing and maintaining equilibrium

The system must operate at conditions favorable for the performance of methanogenic bacteria. Ideally, temperatures should be maintained within the range of 25 to 40 C. Anaerobic activity decreases rapidly at temperatures below 15 C , when water temperature drops below freezing, and biological activity virtually ceases. The pH value should range from 6.6 to 7.6, but should not drop below 6.2 because methane bacteria cannot function below this level. Sudden fluctuations of pH will inhibit lagoon performance. Alkalinity should range from 1,000 to 5,000 mg/L.

Volatile acid concentration is an indicator of process performance because the acids are converted to methane at the same rate that they are formed if equilibrium is maintained. Volatile acid concentrations will be low if the lagoon system is working properly. As a general rule, volatile acid concentrations should be less than 250 mg/L. Inhibition occurs at volatile acid concentrations in excess of 2,000 mg/L. Table 1 presents optimum and extreme operating ranges for methane formation. The rate of methane formation drops dramatically outside these extreme ranges. In addition to adhering to the above guidelines, sufficient nutrients such as nitrogen and phosphorus must be available. Concentrations of inhibitory substances, including ammonia and hydrogen when a high concentration of sulfate ions are present, and

TABLE 1 IDEAL OPERATING RANGES FOR METHANE FERMENTATION

Parameter	Optimum	Extreme
Temp. (C)	30-35	25-40
pH	6.6-7.6	6.2-8.0
Alkalinity (mg/L as $CaCO_3$)	2,000-3,000	1,000-5,000
Volatile acids (mg/L as acetic acid)	50-500	2,000

Source: Andrews and Graef, 1970.

concentrations such as calcium, should be kept to a minimum. Excessive concentrations of these inhibitors produce toxic effects. Depending on its form, ammonia can be toxic to the bacteria as well as affect its concentration. Concentration of free ammonia in excess of 1,540 mg/L will result in severe toxicity, but concentrations of ammonium ion must be greater than 3,000 mg/L to produce the same effect. Maintaining a pH of 7.2 or below will ensure that most ammonia will be in the form of ammonium ion, so higher concentrations can be tolerated with little effect. Table 2 provides guidelines for acceptable ranges of other inhibitory substances.

TABLE 2 CONCENTRATIONS OF INHIBITORY SUBSTANCES

Substance	Moderately Inhibitory (mg/L)	Strongly Inhibitory mg/L)
Sodium	3,500-5,500	8,000
Potassium	2,500-4,500	12,000
Calcium	2,500-4,500	8,000
Magnesium	1,000-1,500	3,000
Sulfides	100-200	>200

Source: WEF and ASCE (1992), reprinted from Parkin, G.F. and Owen, W.F. (1986).

APPLICABILITY

Type of wastewater

Anaerobic lagoons are used for treatment of industrial wastewaters, mixtures of industrial/domestic wastewaters with high organic loading, and as a first stage in municipal lagoons. Typical industries include slaughterhouses, dairies, meat/poultry-processing plants, rendering plants, and vegetable processing facilities.

Typically, anaerobic lagoons are used in series with aerobic or facultative lagoons, enhancing the operation of both types of lagoons as aerobic or facultative lagoons providing further treatment of the effluent. Initial treatment in an anaerobic lagoon often renders the waste more amenable to further treatment and reduces the oxygen demand.

Anaerobic lagoons often are used in small or rural communities where space is plentiful but costs are a concern. Low construction and operating costs make anaerobic lagoons a financially attractive alternative to other treatment systems, although sludge must occasionally be removed.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of anaerobic lagoons are listed below:

Advantages

More effective for rapid stabilization of strong organic wastes, making higher influent organic loading possible.

Produce methane, which can be used to heat buildings, run engines, or generate electricity, but methane collection increases operational problems.

Produce less biomass per unit of organic material processed. Less biomass produced equates to savings in sludge handling and disposal costs.

Do not require additional energy, because they are not aerated, heated, or mixed.

Less expensive to construct and operate.

Ponds can be operated in series.

Disadvantages

Require a relatively large area of land.

Produce undesirable odors unless provisions are made to oxidize the escaping gases. Gas production must be minimized (sulfate concentration must be reduced to less than 100 mg/L) or mechanical aeration at the surface of the pond to oxidize the escaping gases is necessary. Aerators must be located to ensure that anaerobic activity is not inhibited by introducing dissolved oxygen to depths below the top 0.6 to 0.9 m (2 to 3 feet) of the anaerobic lagoon. Another option is to locate the lagoon in a remote area.

Require a relatively long detention time for organic stabilization due to the slow growth rate of the methane formers and sludge digestion.

Wastewater seepage into the groundwater may be a problem. Providing a liner for the lagoon can prevent this problem.

Environmental conditions directly impact operations so any variance limits the ability to control the process, (e.g. lagoons are sensitive to temperature fluctuations).

DESIGN CRITERIA

The design of aerobic lagoons is not well defined and a widely accepted overall design equation does not exist. Numerous methods have been proposed, but the results vary widely. Design is often based on organic loading rates and hydraulic detention times derived from pilot plant studies and observations of existing operating systems. States in which lagoons are commonly used often have regulations governing their design, installation, and management. For example, state regulations may require specific organic loading rates, detention times, embankment slopes (1:3 to 1:4), and maximum allowable seepage (1 to 6 mm/d).

Optimum performance is based on many factors, including temperature and pH. Other important factors to consider include:

Organic loading rate

Typical acceptable loading rates range between 0.04 and 0.30 kg/m^3/d (2.5 to 18.7 lb BOD$_5$/10^3 ft^3/d), varying with water temperature.

Detention time

Typical detention times range from 1 to 50 days, depending on the temperature of the wastewater.

Lagoon dimensions

Because anaerobic lagoons require less surface area than facultative lagoons since the oxygen transfer rate is not a factor, their design should minimize the surface area-to-volume ratio. Typical surface areas range from 0.2 to 0.8 hectares (0.5 to 2 acres). The lagoon should be as deep as practicable, as greater depth provides improved heat retention. A depth of 2.4 to 6.0 m (8 to 20 feet) can be used; however, depths approaching 6.0 m (20 feet) are recommended to reduce the surface area and to conserve heat in the reactor (lagoon). The lagoon should be designed to reduce short circuiting and should incorporate a minimum freeboard of 0.9 m (3 feet).

Construction of lagoon bottom

Groundwater seepage may be a concern. The lagoon should be lined with an impermeable material such as plastic, rubber, clay, or cement.

Control of surface runoff

Lagoons should not receive significant amounts of surface runoff. If necessary, provision should be made to divert surface water around the lagoon. Table 3 summarizes general design criteria for anaerobic lagoons.

PERFORMANCE

System performance depends on loading conditions, temperature conditions, and whether the pH is maintained within the optimum range. Table 4 shows expected removal efficiencies for municipal wastewaters. In cold climates, detention times as great

TABLE 3 DESIGN CRITERIA

Criteria	Range
Optimum water temperature (C):	30 - 35 degrees (Essentially unattainable in municipal systems)
pH	6.6 to 7.6
Organic loading:	0.04-0.30 kg/m^3/d (2.5 - 18.7 lbs/10^3 ft^3/d ((temperature dependent)
Detention Time:	1 to 50 days (temperature dependent)
Surface Area:	0.2 to 0.8 hectares (0.5 to 2 acres)
Depth	2.4 to 6.0 meters (8 to 20 feet) (depths approaching 6.0 meters [20 feet] preferred)

Source: Metcalf & Eddy, Inc., 1991.

as 50 days and volumetric loading rates as low as 0.04 kg BOD_5/m^3/d (2.5 lbs/10^3 ft^3/d) may be required to achieve 50 percent reduction in BOD_5. Table 4 shows the relationship of temperature, detention time, and BOD reduction. Effluent TSS will range between 80 and 160 mg/L.

The effluent is not suitable for direct discharge to receiving waters. Lagoon contents that are black indicate that the lagoon is functioning properly.

OPERATION AND MAINTENANCE

Operation and maintenance requirements of a lagoon are minimal. A daily grab sample of influent and effluent should be taken and analyzed to ensure proper operation. Aside from sampling, analysis, and general upkeep, the system is virtually maintenance-free. Solids accumulate in the lagoon bottom and require removal on an infrequent basis (5-10 years), depending on the amount of inert material in the influent and the temperature. Sludge depth should be determined annually. Table 1 depicts optimum and extreme operating ranges for methane formation. Rates outside of these extreme ranges will decrease the rate of methane formation.

TABLE 4 FIVE-DAY BOD REDUCTION AS A FUNCTION OF DETENTION TIME AND TEMPERATURE

Temperature (deg. C)	Detention time (d)	BOD reduction (%)
10	5	50
10-15	4-5	30-40
15-20	2-3	40-50
20-25	1-2	40-60
25-30	1-2	60-80

Source: World Health Organization, 1987.

COSTS

The primary cost associated with constructing an anaerobic lagoon is the cost of the land, earthwork appurtenances, required service facilities, and the excavation. Costs for forming the embankment, compacting, lining, service road and fencing, and piping and pumps also need to be considered. Operating costs and power requirements are minimal.

REFERENCES

Other Related Fact Sheets

Other EPA Fact Sheets can be found at the following web address:

http://www.epa.gov/owm/mtb/mtbfact.htm

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