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Introduction

Lagoons are one of the oldest wastewater treatment systems. They consist of inground, earthen basins where wastewater is received, held for a period of time, treated, and then discharged (Fig. 1.1). Depending on the composition, strength, and volume of wastewater to be treated and discharge requirements, a predetermined "hold" or retention time for the wastewater is used. Although lagoons are simple in design, there are many complex biological, chemical, and physical processes that occur in lagoons. There are several different terms for lagoons. Many of these terms are used interchangeably. These terms include pond, oxidation pond, polishing pond, sewage pond, stabilization pond, maturation pond, and cell. Some terms refer to the role of the lagoon in a wastewater treatment process (Table 1.1).

Lagoons or natural impoundments were used in the United States in the 1920s to capture liquid wastes. With increasing knowledge of the wastewater treatment ability of lagoons, they were and are used to treat agricultural, domestic, industrial, and municipal wastes and wastewaters.

Lagoons became popular in the 1950s. Today, numerous lagoons and lagoon systems are used, especially in rural areas for the treatment of domestic and municipal wastewaters. Although performance varies from good to bad, lagoons that are properly designed, constructed, and operated can produce effluent that meets secondary treatment standards.

Lagoons are one of the most popular, simplest, and least expensive technologies for treating wastewater. Lagoons do require relatively large amounts of land. For each million gallons per day (MGD) of wastewater, approximately 30 acres of lagoon are required for 50 pounds biochemical oxygen demand (BOD) per acre per day. Some "once-through" lagoons are as large as 40 MGD.

The Biology and Troubleshooting of Facultative Lagoons, First Edition. Michael H. Gerardi.

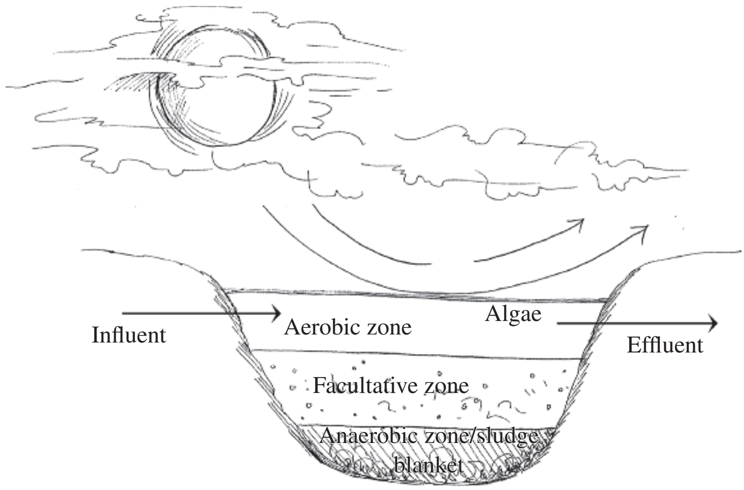

Figure 1.1 Facultative lagoon. A facultative lagoon has three active microbial zones where wastewater is treated. The zones consist of aerobic, facultative, and anaerobic habitats.

TABLE 1.1 Terminology for lagoons or ponds

Term	Description
Maturation	Improves effluent from activated sludge process or trickling filter to tertiary quality, principally to reduce the number of pathogens and nutrients
Oxidation	Wastewater is purified by sedimentation and aerobic and anaerobic treatment
Polishing	Increases the environmental quality of effluent from previous treatment
Primary	Receives raw (unsettled) wastewater and has a sludge layer that is responsible for methane production
Secondary	Receives settled wastewater or effluent from an anaerobic lagoon
Stabilization	An anaerobic, facultative, or maturation lagoon

TABLE 1.2 Advantages of lagoons as compared with more advanced wastewater treatment processes

Can handle intermittent use and shock loads better than other processes
Inexpensive to construct
Relatively small quantity of equipment is needed
Reduced maintenance costs
Relatively simple to operate
Effective in removing pathogens
Effluent often suitable for irrigation due to high nutrient content
Fewer solid-handling problems

Lagoons use natural and energy-efficient processes to provide low-cost wastewater treatment, and they offer an alternative to more advanced wastewater treatment processes. Although lagoons offer many advantages such as reduced maintenance cost when compared with other wastewater treatment systems (Table 1.2), they also have disadvantages such as the requirement for large amounts of land (Table 1.3).

Lagoons are designed to satisfy a specific site and need. The design is based on several factors including type of soil, amount of land area required, climate, quantity and composition of the wastewater to be treated, and discharge requirements. However, lagoon effluent may require additional treatment or polishing to remove pathogens or nutrients.

TABLE 1.3 **Disadvantages of lagoons as compared with more advanced wastewater treatment processes**

Less efficient in cold climates than other processes
Require large amounts of land
Effluent quality varies with seasonal changes in wastewater temperature
Effluent from facultative lagoons contains algae and may require additional treatment to meet discharge requirements
Seasonal turnover and release of benthic organisms
System upsets usually result in odor production
If not properly maintained, lagoons can provide a breeding area for midges, mosquitoes, and other insects

Most lagoons are found in small rural communities. Here, lagoons often cost less to construct, operate, and maintain than other wastewater treatment systems. Although lagoons require more land than other wastewater treatment systems, land is usually more available and affordable in rural areas. Because lagoons treat a large variety of wastes, they must be properly constructed to prevent soil and groundwater contamination.

Wastewater lagoons must be sealed or lined to prevent seepage at the bottom and sidewall of the lagoon to prevent subsurface and groundwater contamination. There are several types of liners that are used: (i) clay, cement, and asphalt; (ii) synthetic and rubber; and (iii) natural. Most liners typically perform well for 15 years. However, premature failure can occur and is usually due to (i) cleaning or dredging operations, (ii) membrane puncture, (iii) scour of cover material, (iv) substandard liner material, and (v) weed growth. The most commonly used liners for industrial wastewater lagoons include (i) chlorosulfonated polyethylene or Hypalon®, (ii) polypropylene (rPP), (iii) polyvinyl chloride, (iv) reinforced liner—low density, and (v) XR-5®/XR3®. These liners are tolerant of ice buildup and exposure to harsh and prolonged sunlight.

Clay liners shrink and swell according to wastewater temperature and wet-and-dry conditions. However, compacted clay liners are susceptible to erosion and vegetative growth in the dike. These conditions damage the integrity and strength of the liner and dike.

Installation of clay requires proper moisture content and compaction. Cement and asphalt liners can crack under temperature change and wet-and-dry conditions. Synthetic liners are commonly used and usually consist of some type of plastic. They require careful installation by an experienced contractor. If the liner is properly installed and is not punctured, seepage does not occur. Synthetic liners are inert and therefore, they are often used in lagoons that contain toxic wastes.

The clogging of soil pores forms natural liners. This occurs due to (i) settled solids, (ii) microbial growth, and (iii) chemical clogging of the soil due to ionic charges. However, natural liners tend to be unreliable because these natural modes for forming a natural liner or sealant are dependent on changing characteristics of the wastewater.

Large and diverse populations of archaea, algae (Fig. 1.2), bacteria, and protozoa (Fig. 1.3) are found in lagoons. Changes in numbers and dominant groups or species of organisms depend on biotic (biological) and abiotic (chemical and physical) factors (Tables 1.4 and 1.5). The most important abiotic factors are (i) composition and strength of the influent, (ii) dissolved oxygen, (iii) pH, (iv) temperature, and (v) sunlight.

The organisms found in facultative lagoons are more diverse than those found in many other biological, wastewater treatment processes including aerated and anaerobic lagoons. The

(a)

(b)

(c)

(d)

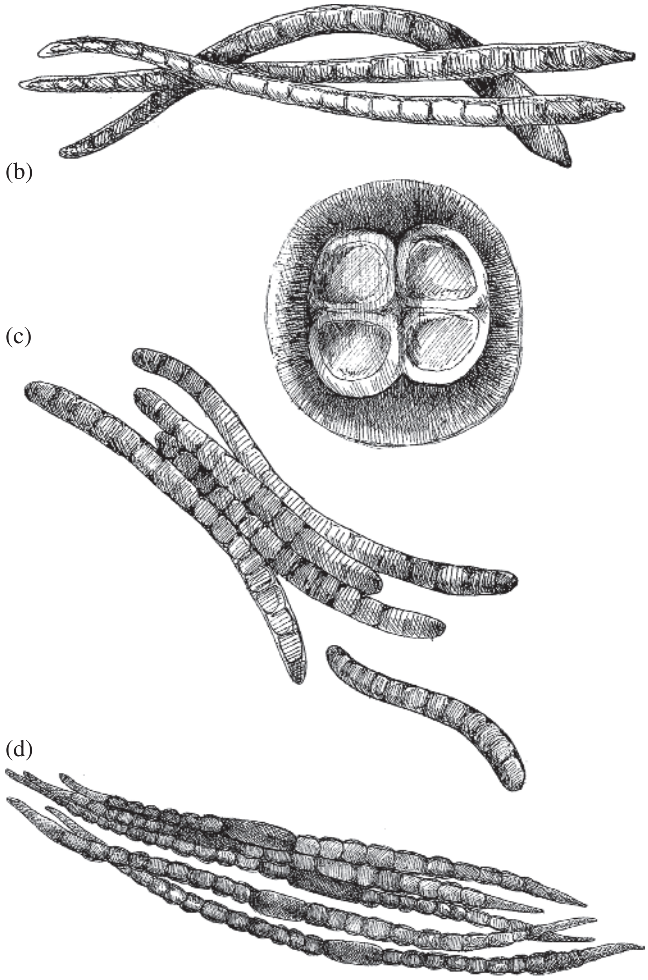

Figure 1.2 *Commonly occurring algae in facultative lagoons. Commonly occurring blue-green algae or cyanobacteria in facultative lagoons include (a)* Phormidium*, (b)* Aphanotheca*, (c)* Planktothrix*, and (d)* Aphanizomenon*.*

greater diversity of life is due to the highly complex growth conditions in lagoons where algae, archaea, bacteria, crustaceans, and rotifers are present in large numbers and perform significant roles. Lagoons rely primarily on bacteria to degrade organic (carbonaceous biochemical oxygen demand, cBOD) and nitrogenous (nitrogenous biochemical oxygen demand) wastes. The biological degradation of wastes is similar to the natural purification of wastes in streams, natural ponds, and lakes. These organisms are components of a food web (Fig. 1.4) where carbon and energy are transferred from one organism to another. The interactions between these organisms are complex, and they contribute to changes in wastewater chemistry.

There are three basic types of lagoons according to microbial activity that are used to degrade organic and nitrogenous wastes. The types of lagoons are aerobic (aerated), facultative, and anaerobic. The biological differences between the lagoons consist of the

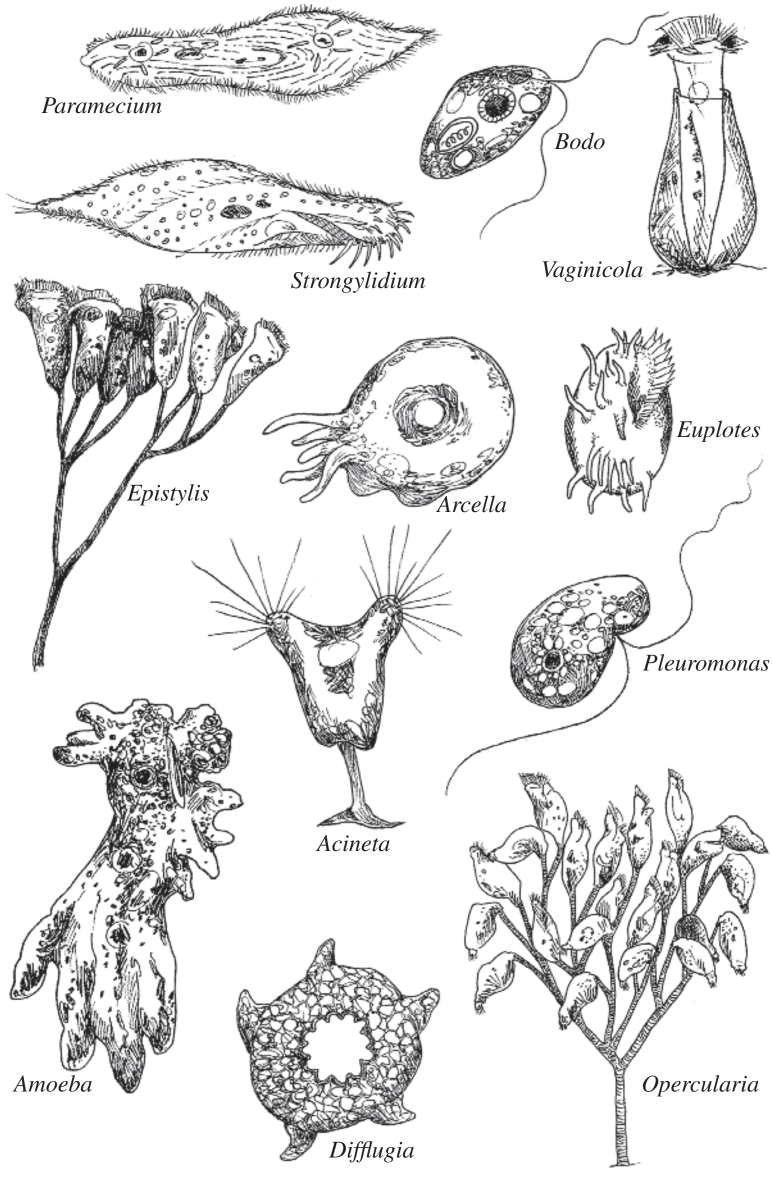

Figure 1.3 *Commonly occurring protozoa in facultative lagoons. Commonly occurring protozoa in facultative lagoons include the amoebae* Arcella, Amoeba, *and* Difflugia; *the flagellates* Bodo *and* Pleuromonas; *the free-swimming ciliates* Paramecium *and* Strongylidium; *the crawling ciliates* Euplotes, *the stalk ciliates* Epistylis *and* Opercularia; *and the suctorian* Acineta*.*

following: (i) the dominant microbes present in the lagoon (Table 1.6), (ii) the dominant biological reactions that occur in the lagoon, and (iii) the depth of the lagoon.

Lagoons can be used alone or in combination with other wastewater treatment processes. Lagoon systems can consist of a single lagoon or multiple lagoons and may include wastewater recirculation. Multiple lagoons can be configured in series or parallel mode of operation (Fig. 1.5).

TABLE 1.4 Biotic factors affecting changes in numbers and dominant groups of organisms in facultative lagoons

Algal growth
Available niches
Burrowing animals
Carbon dioxide production
Cell lysis
Denitrification
Dominant microbes
Food webs
Methane production
Mixed acid production
Mutualistic relationships
Nitrification
Oxygen production
Photosynthesis
Plant growth (aquatic and terrestrial)
Population densities
Predator–prey relationships
Production of toxic products including ammonia and hydrogen sulfide
Sulfur oxidation
Sulfur reduction
Syntrophic relationship

TABLE 1.5 Abiotic factors affecting changes in numbers and dominant groups of organisms in facultative lagoons

Alkalinity
Evaporation
Flow (quantity and pattern)
Ice cover
Loadings (cBOD and nBOD)
Nutrients (major and minor)
pH
Precipitation
Surface area for the adsorption of fungi and nitrifying bacteria
Temperature
Retention time
Sunlight
Total dissolved solids (TDS)
Toxic elements and compounds
Volume of sludge blanket
Water currents
Wind

cBOD, carbonaceous biochemical oxygen demand; nBOD, nitrogenous biochemical oxygen demand.

AEROBIC LAGOON

An aerobic (aerated) lagoon contains dissolved oxygen from surface to bottom and has an average detention time of 3–10 days. The lagoon usually is 6–20 ft deep. Oxygen is supplied through diffused or mechanical aeration. A significant advantage of an aerated lagoon is the small land requirement.

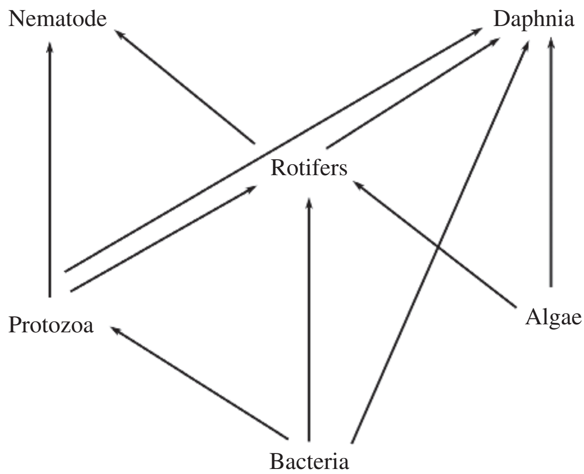

Figure 1.4 *Food web in a facultative lagoon. Significant organisms in a facultative lagoon that perform direct or indirect roles in the stabilization of wastes are connected by a food web where each organism is a predator and/or prey of another organism.*

TABLE 1.6 **Dominant microbes in basic types of lagoons**

Lagoon	Dominate microbes
Aerobic	Facultative anaerobic bacteria
Anaerobic	Facultative anaerobic bacteria
	Methanogens
Facultative	Algae
	Facultative anaerobic bacteria
	Methanogens
	Photosynthetic bacteria

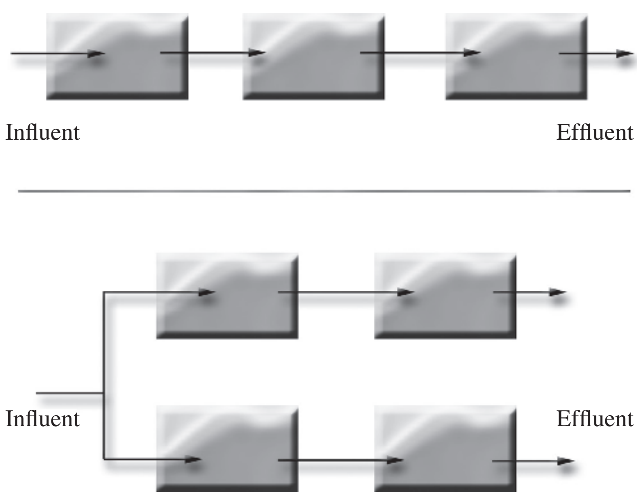

Figure 1.5 *Series and parallel modes of operation of multiple lagoons. In series mode of operation, two or more lagoons are operated in "train-like" fashion where the influent enters only one lagoon and discharges to the next lagoon. In parallel mode of operation, influent enters at least two lagoons.*

ANAEROBIC LAGOON

An anaerobic lagoon receives a heavy organic loading (175–200 pounds BOD per day) and has an average detention time of 20–50 days. The lagoon is usually 10–14 ft deep. The lagoon typically is used to store and/or treat agricultural wastes and industrial wastewaters and for the pretreatment of high strength wastewater with enough fats, oils, or grease to form a scum layer. An anaerobic lagoon is not used for domestic wastewater alone unless a cover or seal is provided and is not used where influent fluctuates greatly.

There are three basic microbial groups that degrade organic wastes in anaerobic lagoons. These groups are (i) hydrolytic archaea and bacteria, (ii) fermentative or acid-forming bacteria, and (iii) methane-forming archaea or methanogens. The dominant biochemical reactions are (i) the solubilization of colloids and particulate materials, (ii) the production of volatile fatty acids, and (iii) the production of methane (CH_4). The pH of an anaerobic lagoon usually is less than 6.5 due to the production of fatty acids.

FACULTATIVE LAGOON

The facultative lagoon is the most commonly used lagoon, especially by small communities and individual households. It is approximately 4–8 ft deep and has an aerobic zone on the surface and an underlying anaerobic zone that usually contains a sludge blanket.

Dissolved oxygen for the aerobic zone is produced mostly by photosynthetic algae, and the facultative zone is produced by the consumption of dissolved oxygen by aerobic and facultative anaerobic bacteria as they degrade cBOD. The settling of volatile solids and living and dead biota produce the anaerobic sludge blanket. In the facultative zone, bacteria degrade the settled solids. Facultative organisms are responsible for most of the treatment that occurs in the lagoon. The degradation of organic wastes produces carbon dioxide, most of which is used by algae.

Although algae produced the necessary dissolved oxygen for facultative lagoons, dissolved oxygen is found only in the top few inches of wastewater. Algae are critical to the successful degradation of the organic load, but they usually are the most serious problem associated with facultative lagoons. Therefore, it is necessary to control algal growth in order to maintain efficient treatment and acceptable effluent quality.

Odors from a facultative lagoon usually are not objectionable. As odorous compounds such as hydrogen sulfide (H_2S) and volatile compounds are produced in the anaerobic zone, they rise to the surface and pass through the dissolved oxygen in the aerobic zone. Here, bacteria oxidize hydrogen sulfide and the volatile compounds before they can escape to the atmosphere. Hydrogen sulfide is also chemically oxidized.

Operational problems associated with facultative lagoons are listed in Table 1.7. Perhaps, the most frequently occurring problems are as follows: (i) the overgrowth of algae and sulfur bacteria, (ii) the discharge of high effluent BOD and total suspended solids (TSS), (iii) the presence of low dissolved oxygen or absence of dissolved oxygen, (iv) short-circuiting or short hydraulic retention time, (v) sludge and solids accumulation, and (vi) incomplete or partial nitrification.

Today, numerous regulatory agencies are requiring wastewater treatment processes to remove nitrogen and phosphorus in relatively large quantities to satisfy ever-increasing, more stringent discharge limits. Although a lagoon serves as a nutrient “sink” that contains excess or high concentrations of nitrogen and phosphorus in the sludge blanket, lagoons

TABLE 1.7 Operational problems associated with facultative lagoons

Algal and sulfur bacterial overgrowth
High effluent BOD
High effluent TSS
High pH
Low pH
Odors
Overloading and low dissolved oxygen
Poor total nitrogen removal
Short-circuiting
Ice cover in cold climates

BOD, biochemical oxygen demand; TSS, total suspended solids.

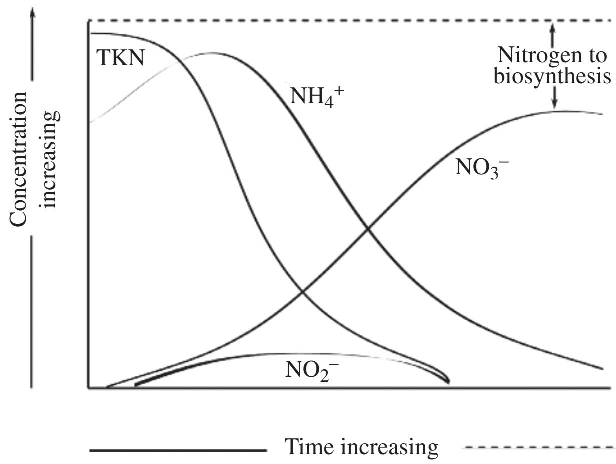

Figure 1.6 *Transformation of nitrogen in a facultative lagoon. Nitrogen enters a facultative lagoon as ammonium (NH_4^+) and organic nitrogen. Ammonium and organic nitrogen together make up the total Kjeldahl nitrogen (TKN). As nitrogen travels across the lagoon, organic nitrogen undergoes ammonification and ammonium is released to the lagoon from the amine groups ($-NH^2$). This results in a temporary increase in ammonium. As ammonium travels across the lagoon, some ammonium is removed from the bulk solution by bacterial cells and assimilated into new cells. Some ammonium is converted to ammonia (NH_3) at high pH values and stripped to the atmosphere. If operational conditions are favorable for nitrifying bacteria, nitrification occurs. Nitrification results in the oxidation of ammonium to nitrite (NO_2^-) and then nitrate (NO_3^-).*

can be operated and retrofitted to satisfy these discharge requirements. Nitrogen can undergo a number of biochemical and physical processes that include ammonification, nitrification, denitrification, assimilation, and settling of particulate organic nitrogen (Fig. 1.6). Nitrification also can be enhanced during cold weather months with the use of fixed-film media. Phosphorus as reactive phosphorus or orthophosphate ($H_2PO_4^-/HPO_4^{2-}/PO_4^{3-}$) is assimilated in large quantities in algae and can be chemically precipitated from the wastewater either in the lagoon or in the treatment tank downstream of the lagoon.