CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 History

Treatment ponds have been employed for treatment of wastewater for over 3,000 years. The first recorded construction of a pond system in the U.S. was in San Antonio, Texas, in 1901 (Gloyna, 1971). Today, over 8,000 wastewater treatment ponds, comprising more than 50 percent of the wastewater treatment facilities in the United States, are in place (Bastian, pers. comm., 2010). Ponds are used to treat wastewater generated by small communities in Europe. Larger pond systems are in place in New Zealand, Australia and Africa (Mara, 2003). They are used to treat a variety of wastewaters, from domestic to complex industrial effluent, and they function under a wide range of climatic conditions, from tropical to arctic. Ponds can be used alone or in combination with other wastewater treatment processes. As understanding of pond operating mechanisms has improved, different types of ponds have been developed to meet specific conditions. Ponds generally require less energy than other treatment systems and have lower operation and maintenance costs.

1.1.2 Trends

The basic elements of pond system design have remained unchanged in the 25 years since the publication of the EPA manual (Design Manual: Municipal Wastewater Stabilization Ponds, EPA-625/1-83-015, 1983a). Aspects of the basic pond designs have evolved and several modifications have been developed. These have been in response to increasingly stringent water quality regulatory requirements for point source discharges.

The major procedures, processes and design methods relevant to wastewater treatment ponds that will be discussed in this manual are:

Basic Processes (flow through basins)

- Anaerobic
- Facultative
- Aerobic

In-Pond Design Evolution and Enhancements

- AIWPS® (Oswald)
- Deep Fermentation Pits
- High Performance Shallow Ponds

Oxygen Addition

- LAS International, Ltd.
- PRAXAIR, Inc.

Modifications that Require Energy

- Partial Mix
- Complete Mix

- High-Performance Aerated Ponds (Rich)
- BIOLAC™

Nutrient Removal
- Nitrogen
    - In pond
    - Modified high performance aerated systems for nitrification/denitrification
    - In pond with wetlands and gravel bed filters
- Phosphorus

Effluent TSS (Algae) Removal
- Lemna
- Algae settling basins
- Barley straw

1.1.3 Manual Objective and Scope
This manual provides an overview of wastewater treatment pond systems through the discussion of factors affecting treatment, process design principles and applications, aspects of physical design and construction, effluent total suspended solids (TSS), algae, nutrient removal alternatives, and cost and energy requirements. In this chapter, the biological, physical and chemical processes that occur in wastewater treatment ponds are discussed.

Chapter 2 describes a sequential approach to the development of a wastewater management project. This approach determines feasibility of the process itself and the land area required for treatment, and identifies possible sites. These sites are evaluated based on technical and cost-effective alternatives.

Chapter 3 includes design for the basic types of treatment ponds.

Chapter 4 discusses the physical design and construction criteria that define effective pond performance, regardless of the design equation employed, and must be considered in the facility design process.

Chapter 5 describes the evolution and enhancement of the basic designs within ponds over the last 30 years.

Chapter 6 presents a discussion of the capability of conventional facultative and aerated lagoons to reduce nutrient concentrations, including commercial products for nitrogen (N) and phosphorus (P) removal.

Chapter 7 presents alternatives for control and removal of algae-derived TSS.

Chapter 8 covers cost and energy requirements.

Chapter 9 includes information on the operation, maintenance and troubleshooting of treatment ponds.

Appendix A lists the state criteria for wastewater treatment ponds. A summary of pond design methods is presented in Appendix B. Design models and examples are presented in Appendix C. Case studies are found in Appendix D. Appendix E is a troubleshooting guide; Appendix F contains study guides for operators from the state of Wisconsin; discharge guidance from the state of Minnesota is in Appendix G. Appendix H presents guidance for the use of barley straw to reduce algal TSS from the state of Illinois. Appendix I contains the glossary, and Appendix J contains a conversion table and other general information.

1.2 POND NOMENCLATURE

Ponds are designed to enhance the growth of natural ecosystems that are either anaerobic (providing conditions for bacteria that grow in the absence of oxygen *[O_2]* environments), aerobic (promoting the growth of O_2 producing and/or requiring organisms, such as algae and bacteria), or facultative, which is a combination of the two. Ponds are managed to reduce concentrations of biochemical oxygen demand (BOD), TSS and coliform numbers (fecal or total) to meet water quality requirements. Table 1-1 summarizes information on pond application, loading, and size of wastewater treatment ponds.

Table 1.1. Basic Wastewater Pond Specifications (adapted from Curi and Eckenfelder 1980).

Pond	Application	Typical Loading (BOD_5)*	Typical Detention Time (d)	Typical Depth (m)	Comments
Anaerobic	Industrial wastewater	280-4500 kg / 1000 m^2/d	5-50	2.5-4.5	Subsequent treatment normally required.
Facultative	Raw municipal wastewater. Effluent from primary treatment, trickling filters, aerated ponds, or anaerobic ponds.	22-56 kg/ 1000m^2/d	7-50	0.9-2.4	Most commonly used wastewater treatment pond. May be aerobic through entire depth if lightly loaded.
Aerobic	Generally used to treat effluent from other processes. Produces effluent low in soluble BOD_5 and high in algal solids.	112-225 kg/ 1000 m^2 /d	2-6	0.18-0.3	Maximizes algae production and, if algae are harvested, nutrient removal.

*****BOD_5 = Biochemical Oxygen Demand measured over 5 days

1.2.1 Anaerobic Ponds

Anaerobic ponds receive such a heavy organic loading that there is no aerobic zone. They are usually 2.5 – 4.5 m in depth and have detention times of 5 - 50 days. The predominant biological treatment reactions are bacterial acid formation and methane fermentation.

Anaerobic ponds are usually used for treatment of strong industrial and agricultural (food processing) wastes, as a pretreatment step in municipal systems, or where an industry is a significant contributor to a municipal system. The biochemical reactions in an anaerobic pond produce hydrogen sulfide (H_2S) and other odorous compounds. To reduce odors, the common practice is to recirculate water from a downstream facultative or aerated pond. This provides a thin aerobic layer at the surface of the anaerobic pond, which prevents odors from escaping into the air. A cover may also be used to contain odors. The effluent from anaerobic ponds usually requires further treatment prior to discharge.

1.2.2 Facultative Ponds

The most common type of pond is the facultative pond, which may also be called an oxidation or photosynthetic pond. Facultative ponds are usually 0.9 - 2.4 m deep or deeper, with an aerobic layer overlying an anaerobic layer. Recommended detention times vary from 5 - 50 days in warm climates and 90 - 180 days in colder climates (New England Interstate Water Pollution Control Commission [NEIWPCC], 1998, heretofore referred to as TR-16). Aerobic treatment processes in the upper layer provide odor control, nutrient and BOD removal. Anaerobic fermentation processes, such as sludge digestion, denitrification and some BOD removal, occur in the lower layer. The key to successful operation of this type of pond is O_2 production by photosynthetic algae and/or re-aeration at the surface.

Facultative ponds are used to treat raw municipal wastewater in small communities and for primary or secondary effluent treatment for small or large cities. They are also used in industrial applications, usually in the process line after aerated or anaerobic ponds, to provide additional treatment prior to discharge. Commonly achieved effluent BOD values, as measured in the BOD_5 test, range from 20 - 60 mg/L, and TSS levels may range from 30 - 150 mg/L. The size of the pond needed to treat BOD loadings depends on specific conditions and regulatory requirements.

Facultative ponds overloaded due to unplanned additional sewage volume or higher strength influent from a new industrial connection may be modified by the addition of mechanical aeration. Ponds originally designed for mechanical aeration are generally 2 - 6 m deep with detention times of 3 - 10 days. For colder climates, TR-16 suggests 20 - 40 days. Mechanically aerated ponds require less land area but have greater energy requirements.

1.2.3 Aerobic Ponds

Aerobic ponds, also known as oxidation ponds or high-rate aerobic ponds, maintain dissolved oxygen (DO) throughout their entire depth. They are usually 30 - 45 cm deep, which allows light to penetrate throughout the pond. Mixing is often provided, keeping algae at the surface to maintain maximum rates of photosynthesis and O_2 production and to prevent algae from settling and producing an anaerobic bottom layer. The rate of photosynthetic production of O_2 may be enhanced by surface re-aeration; O_2 and aerobic bacteria biochemically stabilize the waste. Detention time is typically two to six days.

These ponds are appropriate for treatment in warm, sunny climates. They are used where a high degree of BOD_5 removal is desired but land area is limited. The chief advantage of these ponds is that they produce a stable effluent during short detention times with low land and energy requirements. However, their operation is somewhat more complex than that of facultative ponds and, unless the algae are removed, the effluent will contain high TSS. While the shallow depths allow penetration of ultra-violet (UV) light that may reduce pathogens, shorter detention times may work against effective coliform and parasite die-off. Since they are shallow, bottom paving or covering is usually necessary to prevent aquatic plants from colonizing the ponds. The Advanced Integrated Wastewater Pond System® (AIWPS®) uses the high-rate pond to maximize the growth of microalgae using a low-energy paddle-wheel. This use of the high-rate pond will be discussed in Chapter 5.

1.3 ELEMENTS OF POND PROCESSES

1.3.1 The Organisms

Although our understanding of wastewater pond ecology is far from complete, general observations about the interactions of macro- and microorganisms in these biologically driven systems support our ability to design, operate and maintain them.

1.3.1.1 Bacteria

In this section, we discuss other types of bacteria found in the pond; these organisms help to decompose complex, organic constituents in the influent to simple, non-toxic compounds. Certain pathogenic bacteria and other microbial organisms (viruses, protozoa) associated with human waste enter into the system with the influent; the wastewater treatment process is designed so that their numbers will be reduced adequately to meet public health standards. Their fate in wastewater ponds will be discussed in Chapters 5 and 9.

1.3.1.1.1 Aerobic Bacteria

Bacteria found in the aerobic zone of a wastewater pond are primarily the same type as those found in an activated sludge process or in the zoogleal mass of a trickling filter. The most frequently isolated bacteria include *Beggiatoa alba, Sphaerotilus natans, Achromobacter, Alcaligenes, Flavobacterium, Pseudomonas and Zoogoea spp.* (Lynch and Poole, 1979; Pearson, 2005). These organisms decompose the organic materials present in the aerobic zone into oxidized end products.

1.3.1.1.2 Anaerobic Bacteria

Hydrolytic bacteria convert complex organic material into simple alcohols and acids, primarily amino acids, glucose, fatty acid and glycerols (Brockett, 1976; Pearson, 2005; Paterson and Curtis, 2005). Acidogenic bacteria convert the sugars and amino acids into propionic, acetic and butyric acids. Acetogenic bacteria convert these organic acids into acetate, ammonia (NH_3), hydrogen (H), and carbon dioxide (CO_2). Methanogenic bacteria break down these products further to methane (CH_4) and CO_2 (Gallert and Winter, 2005).

1.3.1.1.3 Cyanobacteria

Cyanobacteria, formerly classified as blue-green algae, are autotrophic organisms that are able to synthesize organic compounds using CO_2as the major carbon source. Cyanobacteria produce O_2 as a by-product of photosynthesis, providing an O_2 source for other organisms in the ponds. They are found in very large numbers as blooms when environmental conditions are suitable (Gaudy and Gaudy, 1980). Commonly encountered cyanobacteria include *Oscillatoria, Arthrospira, Spirulina, and Microcystis* (Vasconcelos and Pereira, 2001).

1.3.1.1.4 Purple Sulfur Bacteria

Purple sulfur bacteria (Chromatiaceae) may grow in any aquatic environment to which light of the required wavelength penetrates, provided that CO_2, nitrogen (*N*), and a reduced form of sulfur (*S*) or *H* are available. Purple sulfur bacteria occupy the anaerobic layer below the algae, cyanobacteria, and other aerobic bacteria in a pond. They are commonly found at a specific depth, in a thin layer where light and nutrient conditions are at an optimum (Gaudy and Gaudy, 1980; Pearson, 2005). Their biochemical conversion of odorous sulfide compounds to elemental *S* or sulfate (SO_4) helps to control odor in facultative and anaerobic ponds.

1.3.2 Algae

Algae constitute a group of aquatic organisms that may be unicellular or multicellular, motile or immotile, and, depending on the phylogenetic family, have different combinations of photo-synthetic pigments. As autotrophs, algae need only inorganic nutrients, such as *N*, phosphorus (*P*) and a suite of microelements, to fix $CO_2$and grow in the presence of sunlight. Algae do not fix atmospheric *N*; they require an external source of inorganic *N* in the form of nitrate (NO_3) or NH_3. Some algal species are able to use amino acids and other organic *N* compounds. Oxygen is a by-product of these reactions.

Algae are generally divided into three major groups, based on the color reflected from the cells by the chlorophyll and other pigments involved in photosynthesis. Green and brown algae are common to wastewater ponds; red algae occur infrequently. The algal species that is dominant at any particular time is thought to be primarily a function of temperature, although the effects of predation, nutrient availability, and toxins are also important.

Green algae (Chlorophyta) include unicellular, filamentous, and colonial forms. Some green algal genera commonly found in facultative and aerobic ponds are *Euglena, Phacus, Chlamydomonas, Ankistrodesmus, Chlorella, Micractinium, Scenedesmus, Selenastrum, Dictyosphaerium* and *Volvox*.

Chrysophytes, or brown algae, are unicellular and may be flagellated, and include the diatoms. Certain brown algae are responsible for toxic red blooms. Brown algae found in wastewater ponds include the diatoms *Navicula* and *Cyclotella*.

Red algae (Rhodophyta) include a few unicellular forms, but are primarily filamentous (Gaudy and Gaudy, 1980; Pearson, 2005).

1.3.2.1 Importance of Interactions between Bacteria and Algae

It is generally accepted that the presence of both algae and bacteria is essential for the proper functioning of a treatment pond. Bacteria break down the complex organic waste components found in anaerobic and aerobic pond environments into simple compounds, which are then available for uptake by the algae. Algae, in turn, produce the O_2 necessary for the survival of aerobic bacteria.

In the process of pond reactions of biodegradation and mineralization of waste material by bacteria and the synthesis of new organic compounds in the form of algal cells, a pond effluent might contain a higher than acceptable TSS. Although this form of TSS does not contain the same constituents as the influent TSS, it does contribute to turbidity and needs to be removed before the effluent is discharged. Once concentrated and removed, depending on regulatory requirements, algal TSS may be used as a nutrient for use in agriculture or as a feed supplement (Grölund, 2002).

1.3.3 Invertebrates

Although bacteria and algae are the primary organisms through which waste stabilization is accomplished, predator life forms do play a role in wastewater pond ecology. It has been suggested that the planktonic invertebrate *Cladocera* spp. and the benthic invertebrate family Chironomidae are the most significant fauna in the pond community in terms of stabilizing organic matter. The cladocerans feed on the algae and promote flocculation and settling of particulate matter. This in turn results in better light penetration and algal growth at greater depths. Settled matter is further broken down and stabilized by the benthic feeding Chironomidae. Predators, such as rotifers, often control the population levels of certain of the smaller life forms in the pond, thereby influencing the succession of species throughout the seasons.

Mosquitoes can present a problem in some ponds. Aside from their nuisance characteristics, certain mosquitoes are also vectors for such diseases as encephalitis, malaria, and yellow fever, and constitute a hazard to public health which must be controlled. *Gambusia*, commonly called mosquito fish, have been introduced to eliminate mosquito problems in some ponds in warm climates (Ullrich, 1967; Pipes, 1961; Pearson, 2005), but their introduction has been problematic as they can out-compete native fish that also feed on mosquito larvae. There are also biochemical controls, such as the larvicides *Bacillus thuringiensis* israelensis (Bti), and Abate®, which may be effective if the product is applied directly to the area containing mosquito larvae. The most effective means of control of mosquitoes in ponds is the control of emergent vegetation.

1.3.4 Biochemistry in a Pond

1.3.4.1 Photosynthesis

Photosynthesis is the process whereby organisms use solar energy to fix CO_2 and obtain the reducing power to convert it to organic compounds. In wastewater ponds, the dominant photosynthetic organisms include algae, cyanobacteria, and purple sulfur bacteria (Pipes, 1961; Pearson, 2005).

Photosynthesis may be classified as oxygenic or anoxygenic, depending on the source of reducing power used by a particular organism. In oxygenic photosynthesis, water serves as the source of reducing power, with O_2 as a by-product. The equation representing oxygenic photosynthesis is:

$$H_2O + sunlight \longrightarrow 1/2O_2 + 2H^+ + 2e^- \qquad (1\text{-}1)$$

Oxygenic photosynthetic algae and cyanobacteria convert CO_2 to organic compounds, which serve as the major source of chemical energy for other aerobic organisms. Aerobic bacteria need the O_2 produced to function in their role as primary consumers in degrading complex organic waste material.

Anoxygenic photosynthesis does not produce O_2 and, in fact, occurs in the complete absence of O_2. The bacteria involved in anoxygenic photosynthesis are largely strict anaerobes, unable to function in the presence of O_2. They obtain energy by reducing inorganic compounds. Many photosynthetic bacteria utilize reduced *S* compounds or elemental *S* in anoxygenic photosynthesis according to the following equation:

$$H_2S \longrightarrow S^o + 2H^+ + 2e^- \qquad (1\text{-}2)$$

1.3.4.2 Respiration

Respiration is a physiological process by which organic compounds are oxidized into CO_2 and water. Respiration is also an indicator of cell material synthesis. It is a complex process that consists of many interrelated biochemical reactions (Stanier et al., 1963; Pearson, 2005). Aerobic respiration, common to species of bacteria, algae, protozoa, invertebrates and higher plants and animals, may be represented by the following equation:

$$C_2H_{12}O_6 + 6O_2 + enzymes \rightarrow 6CO_2 + 6H_2O + new\ cells \qquad (1\text{-}3)$$

The bacteria involved in aerobic respiration are primarily responsible for degradation of waste products.

In the presence of light, respiration and photosynthesis can occur simultaneously in algae. However, the respiration rate is low compared to the photosynthesis rate, which results in a net consumption of CO_2 and production of O_2. In the absence of light, on the other hand, algal respiration continues while photosynthesis stops, resulting in a net consumption of O_2 and production of CO_2.

1.3.4.3 Nitrogen Cycle

The *N* cycle occurring in a wastewater treatment pond consists of a number of biochemical reactions mediated by bacteria. A schematic representation of the changes in *N* speciation in wastewater ponds over a year is represented by Figure 1-1. See Chapter 6 for a more detailed discussion of the cycling of *N* species in ponds.

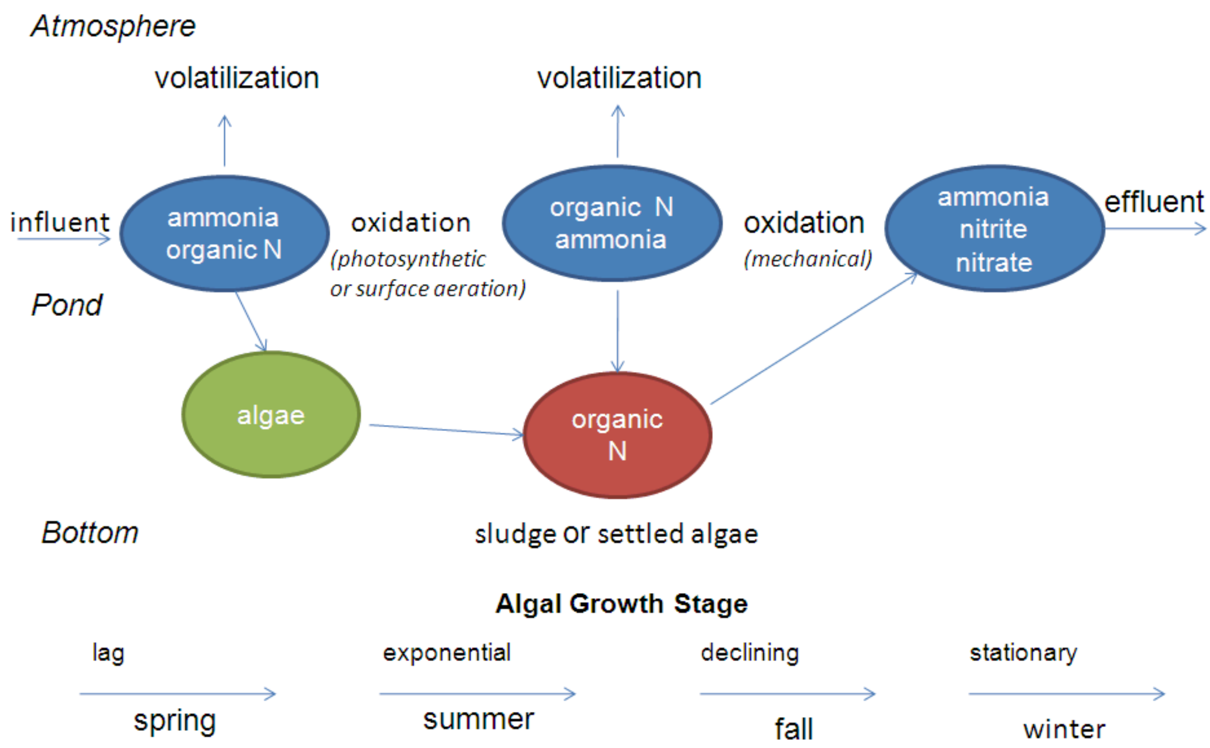

Figure 1-1. The nitrogen cycle in wastewater pond system.

Organic N and NH_3 enter with the influent wastewater. Organic N in fecal matter and other organic materials undergo conversion to NH_3 and ammonium ion NH_4^+ by microbial activity. The NH_3 may volatilize into the atmosphere. The rate of gaseous NH_3 losses to the atmosphere is primarily a function of pH, surface to volume ratio, temperature, and the mixing conditions. An alkaline pH shifts the equilibrium of NH_3 gas and NH_4^+ towards gaseous NH_3 production, while the mixing conditions affect the magnitude of the mass transfer coefficient.

Ammonium is nitrified to nitrite ($NO_2^=$) by the bacterium *Nitrosomonas* and then to NO_3^- by *Nitrobacter*. The overall nitrification reaction is:

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O \qquad (1\text{-}4)$$

The NO_3^- produced in the nitrification process, as well as a portion of the NH_4^+ produced from ammonification, can be assimilated by organisms to produce cell protein and other N-containing compounds. The NO_3^- may also be denitrified to form $NO_2^=$ and then N gas. Several species of bacteria may be involved in the denitrification process, including *Pseudomonas, Micrococcus, Achromobacter,* and *Bacillus.* The overall denitrification reaction is

$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^- \qquad (1\text{-}5)$$

Nitrogen gas may be fixed by certain species of cyanobacteria when *N* is limited. This may occur in *N*-poor industrial ponds, but rarely in municipal or agricultural ponds (U.S. EPA, 1975a, 1993).

Nitrogen removal in facultative wastewater ponds can occur through any of the following processes: (1) gaseous NH_3 stripping to the atmosphere, (2) NH_4^+ assimilation in algal biomass, (3) NO_3^- uptake by floating vascular plants and algae, and (4) biological nitrification-denitrification. The removal of *N* is discussed in detail in Chapter 6. Whether NH_4^+ is assimilated into algal biomass depends on the biological activity in the system and is affected by several factors such as temperature, organic load, detention time, and wastewater characteristics.

1.3.4.4 Dissolved Oxygen (DO)

Oxygen is a partially soluble gas. Its solubility varies in direct proportion to the atmospheric pressure at any given temperature. DO concentrations of approximately 8 mg/L are generally considered to be the maximum available under local ambient conditions. In mechanically aerated ponds, the limited solubility of O_2 determines its absorption rate (Sawyer et al., 1994).

The natural sources of DO in ponds are photosynthetic oxygenation and surface re-aeration. In areas of low wind activity, surface re-aeration may be relatively unimportant, depending on the water depth. Where surface turbulence is created by excessive wind activity, surface re-aeration can be significant. Experiments have shown that DO in wastewater ponds varies almost directly with the level of photosynthetic activity, which is low at night and early morning and rises during daylight hours to a peak in the early afternoon. At increased depth, the effects of photosynthetic oxygenation and surface re-aeration decrease, as the distance from the water-atmosphere interface increases and light penetration decreases. This can result in the establishment of a vertical gradient. The microorganisms in the pond will segregate along the gradient.

1.3.4.5 *p*H and Alkalinity

In wastewater ponds, the *H* ion concentration, expressed as *p*H, is controlled through the carbonate buffering system represented by the following equations:

where:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \quad (1\text{-}6)$$
$$HCO_3^- \leftrightarrow CO_3^{-2} + H^+ \quad (1\text{-}7)$$
$$CO_3^{-2} + H_2O \leftrightarrow HCO_3^- + OH^- \quad (1\text{-}8)$$
$$OH^- + H^+ \leftrightarrow H_2O \quad (1\text{-}9)$$

The equilibrium of this system is affected by the rate of algal photosynthesis. In photosynthetic metabolism, CO_2 is removed from the dissolved phase, forcing the equilibrium of the first expression (1-6) to the left. This tends to decrease the hydrogen ion (H^+) concentration and the bicarbonate (HCO_3^-) alkalinity. The effect of the decrease in HCO_3^- concentration is to force the third equation (1-8) to the left and the fourth (1-9) to the right, both of which decrease total alkalinity. Figure 1-2 shows a typical relationship between *p*H, CO_2, HCO_3^{--}, CO_3^{-2}, and OH^-.

The decreased alkalinity associated with photosynthesis will simultaneously reduce the carbonate hardness present in the waste. Because of the close correlation between *p*H and photosynthetic activity, there is a diurnal fluctuation in *p*H when respiration is the dominant metabolic activity.

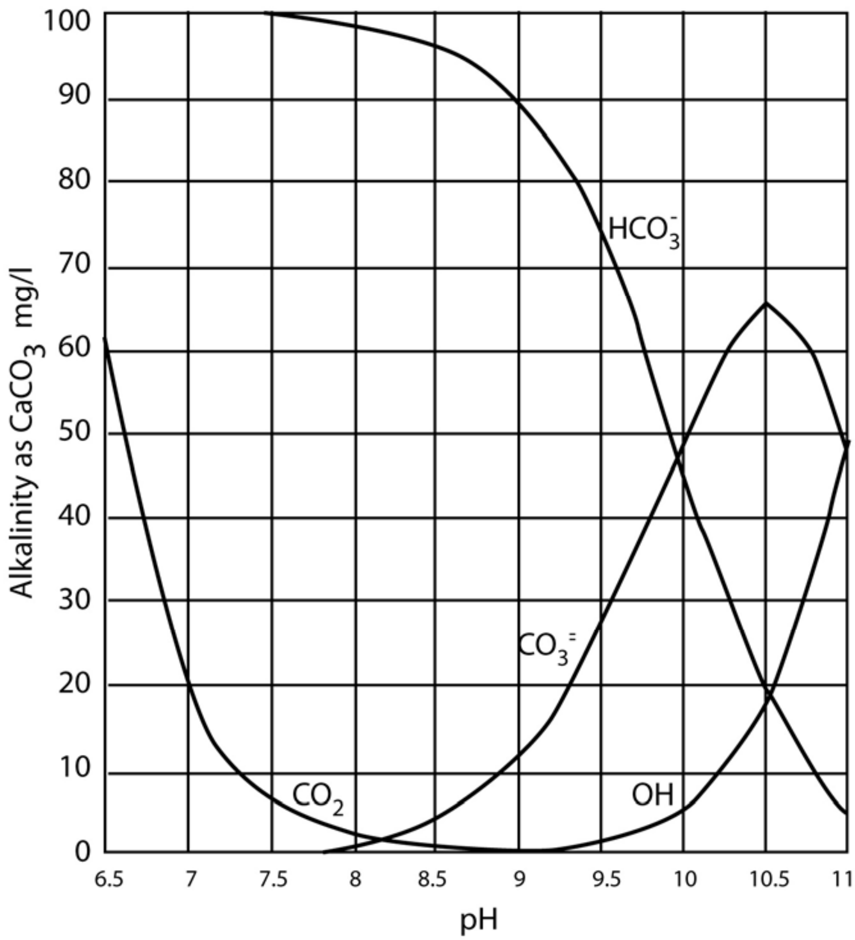

Figure 1-2. Relationship between *p*H and alkalinity (Sawyer et al., 1994).

1.3.5 Physical Factors

1.3.5.1 Light

The intensity and spectral composition of light penetrating a pond surface significantly affect all resident microbial activity. In general, activity increases with increasing light intensity until the photosynthetic system becomes light saturated. The rate at which photosynthesis increases in proportion to an increase in light intensity, as well as the level at which an organism's photosynthetic system becomes light saturated, depends upon the particular biochemistry of the species (Lynch and Poole, 1979; Pearson, 2005). In ponds, photosynthetic O_2 production has been shown to be relatively constant within the range of 5,380 to 53,800 lumens/m^2 light intensity with a reduction occurring at higher and lower intensities (Pipes, 1961; Paterson and Curtis, 2005).

The spectral composition of available light is also crucial in determining photosynthetic activity.

The ability of photosynthetic organisms to utilize available light energy depends primarily upon their ability to absorb the available wavelengths. This absorption ability is determined by the specific photosynthetic pigment of the organism. The main photosynthetic pigments are chlorophylls and phycobilins. Bacterial chlorophyll differs from algal chlorophyll in both chemical structure and absorption capacity. These differences allow the photosynthetic bacteria to live below dense algal layers where they can utilize light not absorbed by the algae (Lynch and Poole, 1979; Pearson, 2005).

The quality and quantity of light penetrating the pond surface to any depth depend on the presence of dissolved and particulate matter as well as the water absorption characteristics. The organisms themselves contribute to water turbidity, further limiting the depth of light penetration. Given the light penetration interferences, photosynthesis is significant only in the upper pond layers. This region of net photosynthetic activity is called the euphotic zone (Lynch and Poole, 1979; Pearson, 2005).

Light intensity from solar radiation varies with the time of day and difference in latitudes. In cold climates, light penetration can be reduced during the winter by ice and snow cover. Supplementing the treatment ponds with mechanical aeration may be necessary in these regions during that time of year.

1.3.5.2 Temperature

Temperature at or near the surface of the aerobic environment of a pond determines the succession of predominant species of algae, bacteria, and other aquatic organisms. Algae can survive at temperatures of 5 - 40°C. Green algae show most efficient growth and activity at temperatures of 30 - 35°C. Aerobic bacteria are viable within a temperature range of 10 - 40°C; 35 - 40°C is optimum for cyanobacteria (Anderson and Zweig, 1962; Gloyna et al., 1976; Paterson and Curtis, 2005; Crites et al., 2006).

As the major source of heat for these systems is solar radiation, a temperature gradient can develop in a pond with depth. This will influence the rate of anaerobic decomposition of solids that have settled at the bottom of the pond. The bacteria responsible for anaerobic degradation are active in temperatures from 15 - 65°C. When they are exposed to lower temperatures, their activity is reduced.

The other major source of heat is the influent water. In sewerage systems with no major inflow or infiltration problems, the influent temperature is higher than that of the pond contents. Cooling influences are exerted by evaporation, contact with cooler groundwater and wind action.

The overall effect of temperature in combination with light intensity is reflected in the fact that nearly all investigators report improved performance during summer and autumn months when both temperature and light are at their maximum. The maximum practical temperature of wastewater ponds is likely less than 30°C, indicating that most ponds operate at less than optimum temperature for anaerobic activity (Oswald, 1968b; Oswald, 1996; Paterson and Curtis, 2005; Crites et al., 2006).

During certain times of the year, cooler, denser water remains at depth, while the warmer water stays at the surface. Water temperature differences may cause ponds to stratify throughout their depth. As the temperature decreases during the fall and the surface water cools, stratification decreases and the deeper water mixes with the cooling surface water. This phenomenon is called *mixis*, or pond overturn. As the density of water decreases and the temperature falls below 4°C, winter stratification can develop. When the ice cover breaks up and the water warms, a spring overturn can also occur.

Pond overturn, which releases odorous compounds into the atmosphere, can generate complaints from property owners living downwind of the pond. The potential for pond overturn during certain times of the year is the reason why regulations may specify that ponds be located downwind, based on prevailing winds during overturn periods, and away from dwellings.

1.3.5.3 Wind

Prevailing and storm-generated winds should be factored into pond design and siting as they influence performance and maintenance in several significant ways:

- Oxygen transfer and dispersal: By producing circulatory flows, winds provide the mixing needed for O_2 transfer and diffusion below the surface of facultative ponds. This mixing action also helps disperse microorganisms and augments the movement of algae, particularly green algae.
- Prevention of short circuiting and reduction of odor events: Care must be taken during design to position the pond inlet/outlet axis perpendicular to the direction of prevailing winds to reduce short circuiting, which is the most common cause of poor performance. Consideration must also be made for the transport and fate of odors generated by treatment by-products in anaerobic and facultative ponds.
- Disturbance of pond integrity: Waves generated by strong prevailing or storm winds are capable of eroding or overtopping embankments. Some protective material should extend one or more feet above and below the water level to stabilize earthen berms.
- A study by Wong and Lloyd (2004) indicates that wind effects can reduce hydraulic retention time.

1.3.6 Pond Nutritional Requirements

In order to function as designed, the wastewater pond must provide sufficient macro- and micronutrients for the microorganisms to grow and populate the system adequately. It should be understood that a treatment pond system should be neither overloaded nor underloaded with wastewater nutrients.

1.3.6.1 Nitrogen

Nitrogen can be a limiting nutrient for primary productivity in a pond. Figure 1-3 represents the various forms that N typically takes over time in these systems. The conversion of organic N to various other N forms results in a total net loss (Assenzo and Reid, 1966; Pano and Middlebrooks, 1982; Middlebrooks et al. 1982; Middlebrooks and Pano, 1983; Craggs, 2005). This N loss may be due to algal uptake or bacterial action. It is likely that both mechanisms contribute to the overall total N reduction. Another factor contributing to the reduction of total N is the removal of gaseous NH_3 under favorable environmental conditions. Regardless of the specific removal mechanism involved, NH_3 removal in facultative wastewater ponds have been observed at levels greater than 90 percent, with the major removal occurring in the primary cell of a multicell pond system (Middlebrooks et al., 1982; Shilton, 2005; Crites et al., 2006).

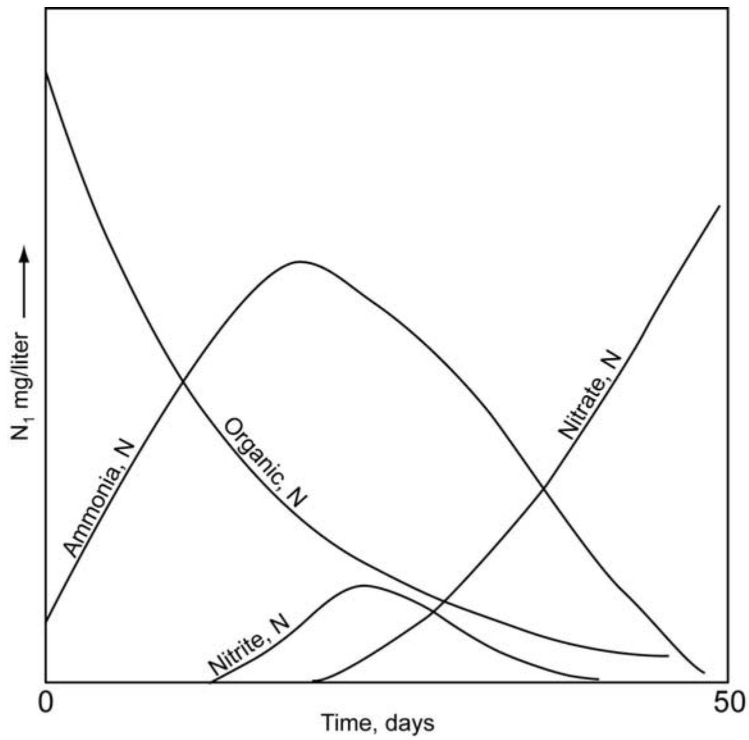

Figure 1-3. Changes occurring in forms of *N* present in a pond environment under aerobic conditions (Sawyer et al., 1994).

1.3.6.2 Phosphorus

Phosphorus (*P*) is most often the growth-limiting nutrient in aquatic environments. Municipal wastewater in the United States is normally enriched in *P* even though restrictions on *P*-containing compounds in laundry detergents in some states have resulted in reduced concentrations since the 1970s. As of 1999, 27 states and the District of Columbia had passed laws prohibiting the manufacture and use of laundry detergents containing *P*. However, phosphate (PO_4^{-3}) content limits in automatic dishwashing detergents and other household cleaning agents containing *P* remain unchanged in most states**.** With a contribution of approximately 15 percent, the concentration of *P* from wastewater treatment plants is still adequate to promote growth in aquatic organisms (Canadian Environmental Protection Act, 2009).

In aquatic environments, *P* occurs in three forms: (1) particulate *P*, (2) soluble organic *P*, and (3) inorganic *P*. Inorganic *P*, primarily in the form of orthophosphate ($OP(OR)_3$), is readily utilized by aquatic organisms. Some organisms may store excess *P* as polyphosphate. At the same time, some PO_4^{-3} is continuously lost to sediments, where it is locked up in insoluble precipitates (Lynch and Poole, 1979; Craggs, 2005; Crites et al., 2006).

Phosphorus removal in ponds occurs via physical mechanisms such as adsorption, coagulation, and precipitation. The uptake of *P* by organisms in metabolic functions as well as for storage can also contribute to its removal. Removal in wastewater ponds has been reported to range from 30 - 95 percent (Assenzo and Reid, 1966; Pearson, 2005; Crites et al., 2006).

Algae discharged in the final effluent may introduce organic *P* to receiving waters. Excessive algal ”afterblooms” observed in waters receiving effluents have, in some cases, been attributed to *N* and *P* compounds remaining in the treated wastewater.

1.3.6.3 Sulfur

Sulfur (*S)* is a required nutrient for microorganisms, and it is usually present in sufficient concentration in natural waters. Because *S* is rarely limiting, its removal from wastewater is usually not considered necessary. Ecologically, *S* compounds such as hydrogen sulfide (H_2S and sulfuric acid (H_2SO_4) are toxic, while the oxidation of certain *S* compounds is an important energy source for some aquatic bacteria (Lynch and Poole, 1979; Pearson, 2005).

1.3.6.4 Carbon

The decomposable organic *C* content of a waste is traditionally measured in terms of its BOD_5, or the amount of O_2 required under standardized conditions for the aerobic biological stabilization of the organic matter over a certain period of time. Since complete treatment by biological oxidation can take several weeks, depending on the organic material and the organisms present, standard practice is to use the BOD_5 as an index of the organic carbon content or organic strength of a waste. The removal of BOD_5 is a primary criterion by which treatment efficiency is evaluated.

BOD_5 reduction in wastewater ponds ranging from 50 - 95 percent has been reported in the literature. Various factors affect the rate of reduction of BOD_5. A very rapid reduction occurs in a wastewater pond during the first five to seven days. Subsequent reductions take place at a sharply reduced rate. BOD_5 removals are generally much lower during winter and early spring than in summer and early fall. Many regulatory agencies recommend that pond operations do not include discharge during cold periods.