Lagoon Systems

Lagoons are often used in manure-handling systems that remove livestock waste from barns in liquid form. The **design of lagoons is unique**: they are the only manure storage systems with a treatment volume intended to reduce solids incorporated into their design and management (VanDevender, 2011). Lagoon systems handle highly diluted manure (96 percent or more water) that can be pumped through irrigation systems (Fulhage and Pfost, 2007). Properly designed and managed anaerobic lagoon treatment systems should have less than 1 percent solids, typically **from 0.1 to 0.5 percent solids** (Lorimor et al., 2004).

Lagoons are commonly used on swine farms because swine waste is easily moved in liquid form. Large amounts of liquids needed to clean housing and milking facilities make lagoons a popular choice on many dairy farms, as well. Lagoons are less popular today in new poultry layer operations, although many older laying hen operations across the Southeast still operate lagoons (Hamilton et al., 2006).

Lagoons are pondlike earthen basins sized to provide biological treatment and long-term storage of animal waste (Figure 1). Livestock **lagoons are small-scale waste treatment plants** containing manure that is usually diluted with water and rainfall (Pfost et al., 2000). Dilution controls ammonia and salt concentrations so that bacteria can function properly (Lorimor et al., 2004). Lagoons are designed to enhance microbial digestion of organic matter and volatilization of nitrogen compounds, thereby reducing the land area requirements for disposal by 50–75 percent.

Anaerobic processes occur in the absence of free oxygen and liquefy or degrade organic wastes with high biochemical oxygen demand. Well-designed and managed lagoons often have a **somewhat musty but not offensive odor**. Offensive odors likely indicate a problem or malfunction in the lagoon system. Properly functioning lagoons may sometimes cause nuisance odors because of their size or location or because of topography, weather conditions, distance from other lagoons, and distance from residences (Pfost et al., 2000).

Lagoon Use in Animal Agriculture

Agricultural lagoon design falls into five categories:

- uncovered anaerobic/facultative lagoons
- covered anaerobic lagoons
- naturally aerated lagoons
- mechanically aerated lagoons
- hybrid anaerobic/aerobic lagoons

We will only discuss **uncovered anaerobic/facultative lagoons as they are the most common** type of treatment lagoon used in animal agriculture. “Treatment” is defined in agricultural operations as any process that alters the volume or character of raw materials to improve handling, reuse, appearance, odor, or safety. Lagoons perform a number of these functions (Hamilton et al., 2006). They separate solids from liquids so that liquid handling pumps and equipment may be used to irrigate effluent. Nutrients and organic matter contained in effluent are made soluble for efficient crop and soil uptake. Effluent is treated to a sufficient quality to be recycled back into the buildings. Lagoons minimize nuisance conditions, atmospheric emissions, and odors. Finally, lagoons reduce pathogens in effluent and sludge.

Figure 1. Anaerobic poultry waste treatment lagoon.

Lagoons serve as storage and treatment components of manure-handling systems that recycle manure nutrients through crop production (Hamilton et al., 2006). Poultry lagoon effluent contains varying amounts of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) that can benefit vegetation (Raabe et al., 1984). Anaerobically treated poultry manure effluent produces approximately the same corn grain yield as urea (Field et al., 1986). However, like land application of solid manure, land application of lagoon effluent, if improperly managed, can contribute to degradation of surface and ground water.

Lagoons are **biological processors, similar to an animal's digestive system**. The lagoon does not function properly unless material is moving through the system (Hamilton et al., 2006). Lagoons provide storage for both liquids (effluent) and solids (sludge). With proper design and management practices, adequate planning, and some irrigation equipment, this storage allows for effluent to be applied at the precise times that plants are actively using nutrients.

Soluble plant nutrients (nitrogen and potassium) are found primarily in lagoon effluent, while less soluble nutrients (phosphorus and calcium) are located in the sludge (Fulhage, 1980). Adequate sludge storage must be provided within the lagoon so that accumulation of sludge does not decrease the liquid volume of the lagoon beyond a minimum value (Hamilton et al., 2006). Differences between nitrogen and potassium solubilities in the lagoon means that the two nutrients are handled differently; **nitrogen on an annual basis when effluent is pumped down and potassium on a much longer basis**, perhaps every 5–20 years when sludge is removed.

Anaerobic Lagoons

Lagoons are generally not used in the northern U.S. because of the cold weather. However, **lagoons are a common occurrence in the South**, particularly with cage layer and swine operations. Uncovered anaerobic lagoons are typically used for livestock waste management. Anaerobic bacteria can decompose more organic matter per unit of lagoon volume than aerobic bacteria and are predominantly used for treatment of concentrated organic wastes (Barker, 1996). The anaerobic process is not dependent on maintaining dissolved oxygen, and, therefore, anaerobic lagoons can be much deeper and require less surface area.

Lagoon **depth is an important factor** in nutrient retention. Deep lagoons (20–25 feet) have average nitrogen levels approximately twice the levels of shallow lagoons (8–12 feet; Lorimor et al., 2004). The difference is thought to be due to different surface area-to-volume ratios that affect ammonia volatilization. Anaerobic decomposition of livestock waste can result in production and emission of odorous gases, primarily hydrogen sulfide, ammonia (NH_3), and intermediate organic acids (Barker, 1996). However, an anaerobic lagoon can be properly sized and managed to operate with minimum objectionable odors. Deep lagoons are **more temperature stable** than shallow lagoons. Shallow lagoons are more subject to **influence from air temperature fluctuations**. A minimum lagoon depth of at least 6 feet is recommended.

Anaerobic lagoons have advantages and disadvantages (Pfost et al., 2000).

Advantages

- Manure can be handled hydraulically with flushing systems, sewer lines, pumps, and irrigation systems.
- High degree of stabilization reduces odors during land application.
- High nitrogen reduction minimizes land area required to make use of the effluent.
- Long-term storage is provided at low cost.
- Construction cost, labor, operating, and energy requirements are low.
- Fly control (if a fibrous mat does not form on the surface).

Disadvantages

- Public perception may be that a lagoon is an "open container of manure."
- Undesirable odors may be produced during seasonal (spring and fall) temperature swings and spring start-up after the winter period of relatively little biological activity.
- Objectionable odors may drift off-site during atmospheric temperature inversions.
- Undesirable odors may be present during application by spray irrigation.
- Fly breeding can occur if a fibrous mat develops on the surface.
- Nutrient availability is limited if manure is used as a fertilizer (due to nitrification of nitrogen in the lagoon and most phosphorus settling to the bottom.
- The cost of removing built-up solids if the lagoon is shut down and solids have been allowed to accumulate for several years without agitation during annual pump-down could be high. In addition, land area required to dispose of accumulated nitrogen and phosphorus may not be available nearby.

There is a danger of effluent leaching into groundwater if the lagoon leaks, so proper lagoon construction is required. Overflow events or embankment failure can result in large volumes of effluent discharge with severe environmental impacts (fish kills, water quality destruction, and soil contamination) and legal consequences (fines, penalties).

Nutrient concentrations in all properly working anaerobic lagoons are low because of the high volume of dilution water, nutrient settling, and ammonia volatilization (Lorimor et al., 2004). During storage and treatment, **nitrogen and phosphorus are reduced in concentration**. The **phosphorus tends to settle to the bottom** and accumulate in the sludge, which is infrequently (if ever) removed. An estimated 80–90 percent of the phosphorus produced by the animals will be retained in the sludge (Bodman, 1996). The **nitrogen is lost from the lagoon surface as ammonia and other nitrogen gas**. Nitrogen loss can range from 30 to 80 percent depending on temperature, storage duration, and pH. As a result, lagoon effluent contains a relatively small amount of nitrogen.

An estimated **95 percent of the potassium** produced by the animals will remain in solution and be removed annually when the effluent is land applied (Bodman, 1996). An anaerobic lagoon in proper balance will have a **pH ranging from 7 to 8** (slightly basic). The pH in new lagoons without adequate dilution water or in overloaded lagoons may be 6.5 or less, which will create odor problems (Barker, 1996). Nitrogen losses will be greater in warm weather.

Management practices and climatic variations have the greatest influence on lagoon effluent nutrient differences. An estimated nutrient concentration of 4-2-3 pounds ($N-P_2O_5-K_2O$) per 1,000 gallons is a good representation of many lagoons (Lorimor et al., 2004). Approximately 80–90 percent of nitrogen in well-seasoned, steady-state anaerobic lagoons is in the ammonia form (Lorimor et al., 2004). Lagoons **work best when they are loaded continuously**. Therefore, the waste management system should load the lagoon at least weekly, and preferably daily (Pfost et al., 2000). Infrequent shock overloading can result in sharp increases in odor and wide fluctuations in nutrient content.

Lagoons should be filled with water to one-third to one-half of the design volume before introducing manure into the lagoon (Pfost et al., 2000). This will minimize start-up odors and ensure sufficient dilution water is available for the establishment of bacterial activity. **Starting a new lagoon in late spring/early summer is best** and will allow establishment of a bacterial population before cold weather and help prevent excessive odors the following spring (Pfost et al., 2000). Generally, the bottom liner of most lagoons is compacted earth. Some type of clay is the preferred material. Materials such as bentonite can be added to improve the acceptability of soil for liner material. If the soil type is inappropriate, then an impervious liner may need to be added (plastic, concrete, etc.).

Microbial Communities in Lagoons

Degradation of animal manure involves a series of complex, interrelated microbial processes (Masse and Droste, 2000). Settleable manure solids fall to the bottom of the lagoon to be broken down into sludge, soluble liquids, and gases. Lagoons contain many microbial communities working together to digest organic matter (Hamilton et al., 2006). The extent to which organic matter is degraded depends on the communities present in the lagoon and characteristics of the effluent to be degraded. Several distinct microbial communities are found in lagoons, including anaerobic and facultative (organisms that can survive with or without oxygen) heterotrophic bacteria, phototrophic organisms, and aerobic bacteria (Hamilton et al., 2006).

During warm weather, some **lagoons may turn various shades of pink or purple**, indicating good lagoon action. The purplish color is caused by sulfur-eating bacteria. Odor is reduced because sulfur bacteria grow near the surface of the lagoon and convert odorous compounds (primarily hydrogen sulfide) into less offensive gases (Worley, 2009). A reddish-brown color is also good, but a more brilliant reddish-pink or dark lavender is better (Bodman, 1996). When this condition exists, odors are at a minimum. The goal should be to have every lagoon turn purple within the first year of operation and to retain the pink or purple color at least 8 months per year (Bodman, 1996). A properly working lagoon will reduce odors and convert much of the organic matter into gases that are given off into the air (Worley, 2009).

Anaerobic lagoons have a stratification (or layering) effect. The symbiotic relationship of various biological processes occurring at different locations in the lagoon lead to manure degradation. The aerobic phototrophic bacteria reside near the surface of the lagoon; at progressively lower levels are the anaerobic phototrophic bacteria, anaerobic heterotrophic bacteria, and sludge, respectively. Symbiosis between communities of acid-forming bacteria and methanogenic bacteria, acid-forming bacteria and phototrophic organisms, sulfate-reducing bacteria and purple sulfur bacteria, algae and aerobic bacteria, plus ammonia-oxidizing bacteria and nitrate-reducing bacteria are important processes in lagoon treatment (Hamilton et al, 2006).

The amount of food available to lagoon microorganisms follows an annual cycle (Hamilton et al., 2006). Biological activity depends on temperature; therefore, organic matter **accumulates in the lagoon during winter** when microbial activity is lower. As temperatures warm in the spring and an excess food supply creates a period of biological hyperactivity, an increase in odors often occurs. Lagoons **do not turn over as is common in lakes**; however, because of wide temperature fluctuations, they do experience prolonged periods in the spring and fall where the various layers may mix and become unstable (Hamilton and Cumba, 2000).

Lagoons are generally formed by excavation and aboveground berms and are designed for a 365-day storage capacity, with all the manure going into the lagoon. The berms divert surface water runoff away from the lagoon. Effluent storage is a balance of what goes into the lagoon minus what goes out. The effluent balance takes place during the “water year.” The water year is different than the calendar year. The water year starts at the point in the year (usually the fall) when area lakes and streams (and manure treatment lagoons) begin to fill with water (Hamilton, 2017). The start of the water year varies from location to location across the country.

Summary

Lagoons are pondlike earthen basins sized to provide biological treatment and long-term storage of animal waste. They are common in the southern U.S., particularly with cage layer and swine operations. Anaerobic/facultative lagoons are the most common type of “treatment” lagoon used in animal agriculture. A variety of microbial communities perform various stages of the treatment process in an anaerobic lagoon. Lagoons are primarily biological treatment systems because the treatment steps all depend on the growth of a host of living organisms within the lagoon. Like other systems, **lagoons have advantages and disadvantages** that must be weighed to determine if a lagoon is the proper waste disposal system.

In addition, **public perception is a major issue for agriculture** today. Proper lagoon management is critical not only from an environmental standpoint but also in how agricultural production systems are viewed by a public that demands more of agriculture than past generations. Every effort should be made to **make a lagoon as pleasing as possible from an aesthetic standpoint**. If the lagoon is in public view, a vegetative buffer of tall grasses and/or trees will help restrict the view. As with other waste management facilities, a well-groomed and well-maintained lagoon is less likely to attract unwanted attention or cause issues than an improperly managed lagoon with an offensive odor or appearance.

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