Biochemical oxygen demand (BOD): A measure of the amount of oxygen needed by aerobic microorganisms to break down solids and organic matter present in wastewater. Although BOD is not a specific compound, it is defined as a conventional pollutant under the federal Clean Water Act. The BOD_5 test is a five-day laboratory test to determine the amount of oxygen available for biochemical oxidation in a sample.

Precipitate: The conversion of a slightly soluble substance into an insoluble substance that settles out of a solution.

Ruminant: An animal with a multiple stomach (polygastric) system of digestion capable of digesting cellulose. Cow, sheep, and goats are ruminants.

Orthophosphate: Inorganic phosphate.

Phosphorus accumulating organisms (PAOs): Microorganisms with the ability to store and release phosphate in response to environmental conditions; PAOs contain much higher levels of phosphate in their bodies than other bacteria.

into the air if irresponsibly used. Uncontrolled, sixty to seventy percent of nitrogen in raw slurry can be lost through volatilization (Béline et al., 2002).

Manure with high BOD requires a larger amount of oxygen per unit volume, and consequently a more intensive aeration system. High aeration rates may also create foam. Mechanical foam breakers are most often implemented to control foaming. In high BOD situations, the manure also requires more mixing, to ensure the aerobic environment is distributed homogenously.

4.3.2 Additives

Aerobic digestion of livestock manure does not require inoculants or seeding with municipal activated sludge, all the bacteria required for aerobic digestion is available naturally in the manure. There is no advantage to using commercially available inoculants or additives to achieve nitrogen or phosphorus removal (Zhu et al., 2003).

However, other types of additives may provide some benefits. Lime added to fresh swine manure can conserve urea, prevent ammonia production, and improve odor control. Cement kiln dust is high in potassium and calcium and has been added to swine manure to complement the existing nutrient value for fertilizer and to decrease odors. Other additives can alter the pH, cause certain chemicals to **precipitate** out of solution, or reduce foaming. Additives should be used carefully as they can be costly, and some may cause secondary environmental pollution when solids or supernatant is applied to land.

There is also growing research in the area of feed additives which can alter the nutrient content of manure. Phytase is used in the poultry industry to reduce phosphorus levels in chicken litter, but an analogous additive for mammals, especially **ruminants**, has yet to be proven effective.

4.3.3 Nutrient Treatment and Transformation

All microorganisms require nitrogen and phosphorus for growth and reproduction. However, the assimilation of these nutrients into cellular mass accounts for only a small portion of the nutrient removal from manure. Biochemical processes are the primary pathways for nutrient removal, especially for nitrogen.

Nitrogen is transformed during aerobic treatment, but the amount of nitrogen and the form it takes depends on the treatment time, temperature, and amount of dissolved oxygen available to the aerobic microorganisms. During aeration, five to 35 percent of the organic nitrogen in the slurry is converted to ammonia nitrogen (Bicudo, 1999). The ammonia can be further oxidized and converted to nitrate in a process known as nitrification. Nitrate is a common water contaminant so further treatment, such as denitrification, is required to prevent water pollution. See Chapter 6, Nitrification-Denitrification for more information.

Microorganisms in slurry can remove soluble **orthophosphate** from the wastewater and incorporate the phosphorus into their bodies. However, for significant phosphorus reductions, an anoxic period is required to stimulate the **phosphorus accumulating organisms (PAOs).** Additional information on anoxic conditions is available in Chapter 6, Nitrification-Denitrification. When the PAOs die they become part of the solids, the phosphorus also becomes a component of the solids. The phosphorus-rich solids should be further treated or disposed of responsibly to prevent **eutrophication** and other water quality problems.

4.4 Types of Aerobic Digestion Designs

There are two basic types of aerobic treatment designs—fixed film and suspended growth. Both types of treatment are usually followed by solids separation of some sort in order to remove the biomass from the treated wastewater. The HRT and reactor size depend on the desired level of treatment rather than the type of design.

4.4.1 Fixed Film

Fixed film digesters are treatment systems where bacteria grow on a fixed medium—which can be stones, mesh, or any other solid material. The manure is introduced to the reactor, which can be a tank or **lagoon**, and the entire system is aerated. Trickling filters and rotating biological contactors are two types of fixed film aerobic digesters.

a. Trickling Filter

Trickling filters consist of a medium, such as stones, slag, ceramic, or plastic contained in a vented cylindrical vessel. The vents around the outside distribute air across the bottom of the filter and up through the stones. The air moves upward as the liquid waste moves downward, allowing the bacteria growing on the medium to have access to food and oxygen simultaneously. **Figure 4.1** is a diagram of a trickling filter.

The bacterial biomass on the medium grows thicker over time. This growth continues until the bacteria no longer have adequate access to food and oxygen and die. The next wave of manure will shear the dead bacteria from the medium and flush the biomass out of the reactor.

Trickling filters are designed based on the organic loading, the mass of the BOD per unit volume of the filter, and the hydraulic loading, the volume of liquid waste per unit area of the filter.

Eutrophication: A process where a water body becomes nutrient-enriched and eventually unable to sustain plant and animal life.

Lagoon: A shallow pond where sunlight, oxygen, and bacteria degrade and transform compounds in manure.

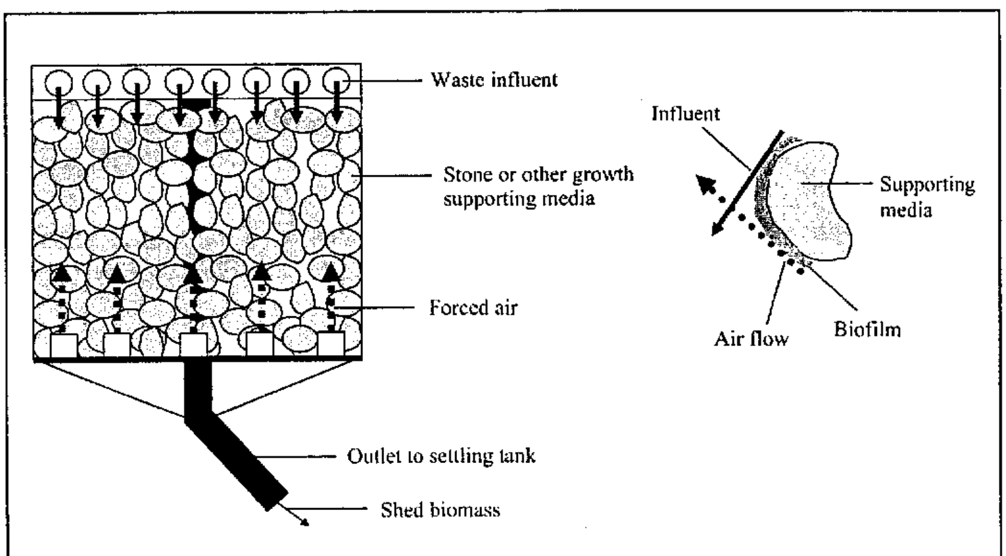

Figure 4.1: Diagram of a trickling filter (adapted from Miner et. al. 2000).

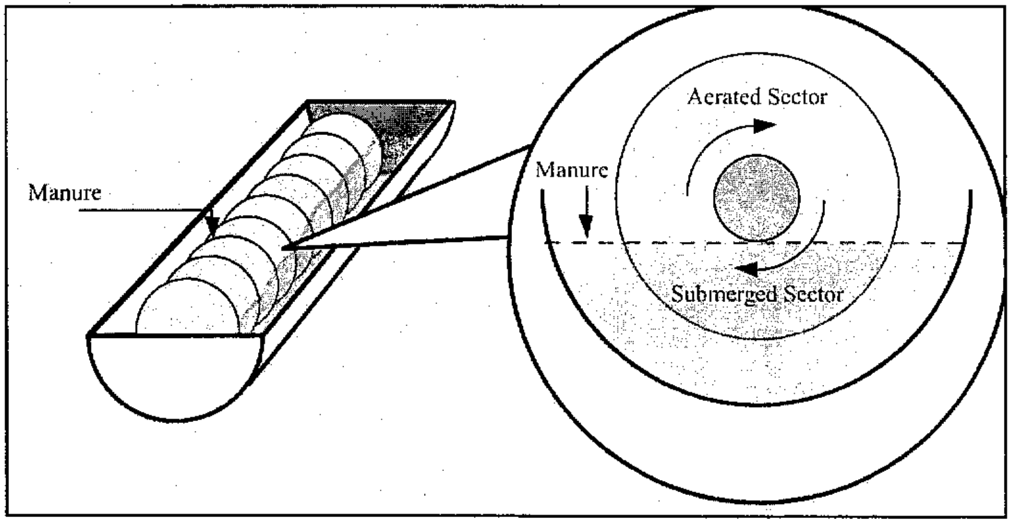

Figure 4.2: Rotating biological contactor (Grady et al., 1998).

Facultative: An environment that contains both oxygenated and oxygen-free regions or microorganisms that can live in both oxygenated and oxygen-free environments. When oxygen is not available, these organisms can switch from respiration to fermentation.

Trickling filters can remove from 75 to 90 percent of the applied organic matter (Miner et al., 2000). Recycling the treated liquid back through the filter a second time may increase the removal rates.

In a packed bed reactor the wastewater moves upward against the medium instead of downward. These reactors may have either continuous wastewater introduction or intermittent wastewater flow; trickling filters are usually designed as intermittent processes.

b. Rotating Biological Contactor

A rotating biological contactor (RBC) is made up of large disks spaced along a horizontal shaft. The disks serve as a medium for the bacteria to grow on. The disks, two to four meters (eight to 12 feet) in diameter revolve at a slow speed. The bacteria growing on the disks are alternately exposed to the air and wastewater as the disks rotate from being immersed in the wastewater and being open to the atmosphere. **Figure 4.2** is a diagram of a RBC.

Rotating biological contactors operate well with livestock waste but can be significantly higher in cost than trickling filters.

4.4.2 Suspended Growth Aerobic Digestion

Suspended growth processes are sometimes referred to as activated sludge systems. In these systems, the bacteria are not attached to anything, but instead are suspended in the wastewater. Aeration in suspended growth processes serves two purposes—to provide oxygen for the aerobic bacteria, and to keep the bacteria suspended and in constant contact with the wastewater. Examples of suspended growth processes are batch reactors, continuous-flow stirred tank reactors, aerobic lagoons, and **facultative** lagoons.

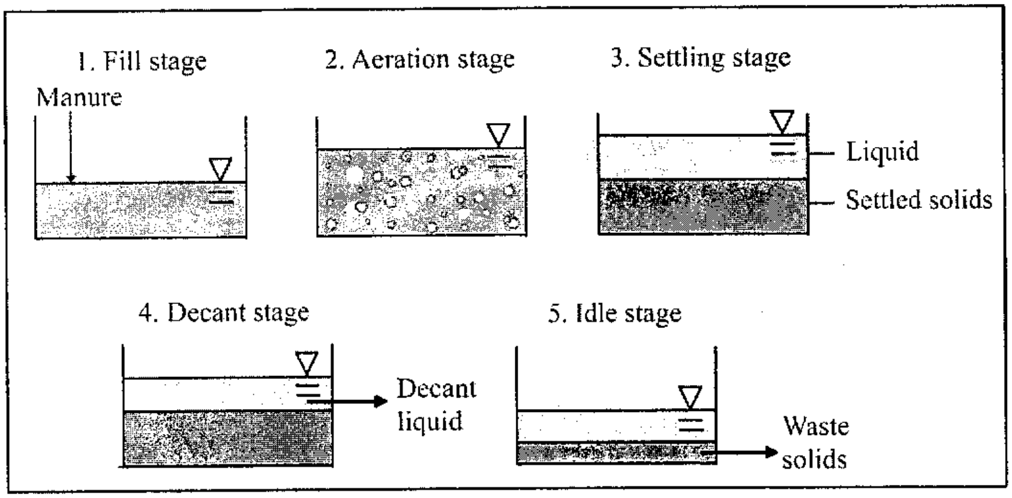

Figure 4.3: Batch reactor (Metcalf and Eddy, 2003).

Decant: To draw off the upper layer of liquid after denser materials have settled to the bottom.

a. Batch Reactor

In a batch reactor the waste enters an empty reactor, is treated, and then discharged from the reactor to storage or further treatment. Even though mixing occurs, complete mixing is not achieved during the incubation period. Aerobic treatment by a batch reactor is a five step process, as illustrated by **figure 4.3**:

1. The reactor is filled with untreated manure,
2. The reactor is aerated,
3. The treated manure is allowed to settle,
4. The supernatant is **decanted** from the reactor, and
5. Solids are removed from the reactor.

A settling basin or other settling system is used to separate the bacterial biomass and digestion byproducts from the supernatant. For further treatment, batch reactors may be placed in series to form a sequencing batch reactor (SBR). Or, like trickling filters, the treated supernatant and solids can be recycled back through the system to increase the removal efficiency.

b. Continuous-Flow Stirred Tank Reactor

In a continuous-flow stirred tank reactor (CfSTR), wastewater is being continually added to and removed from the reactor. Continuous-flow stirred tank reactors are sometimes called complete mix reactors (CMR) because the wastewater is regarded as completely and instantaneously mixed throughout the reactor. **Figure 4.4** is a diagram of a CfSTR.

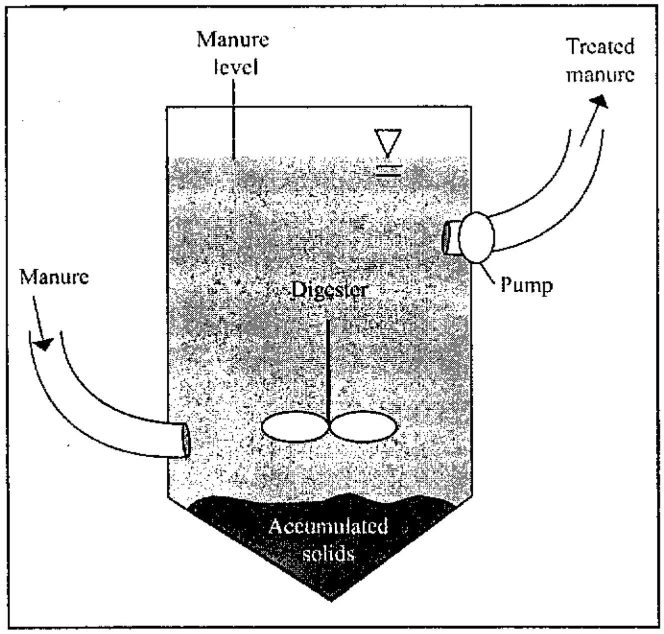

Figure 4.4: Continuous-flow stirred tank reactor (Grady et al., 1998).

The liquid that is removed from the CfSTR is representative of the wastewater remaining in the reactor. This is true both in terms of what chemical compounds are in the discharge and the percent of discharge volume those compounds occupy in relation to the volume they occupy in the reactor.

c. Aerobic Lagoon

An aerobic lagoon is a simple system. A lagoon is excavated and lined with either a compacted clay layer or an impermeable plastic liner to prevent contaminants from migrating to groundwater. The lagoon is filled with manure—either dilute or separated slurry works best. Solids in the manure will increase the amount of oxygen the aerobic bacteria need and the energy required for aeration. **Figure 4.5** is a photograph of an aerobic lagoon. Aerobic lagoons may be continuous or batch-fed.

Aerobic lagoons may be naturally or mechanically aerated. Natural aeration relies on the oxygen that is naturally present in the manure. The depth of naturally aerated lagoons is limited to one to 1.5 meters (three to five feet) to ensure complete aeration (Bicudo, 2001). Mechanical aeration utilizes surface aerators to add air to the manure for bacterial growth. The use of mechanical aerators allows for deeper lagoons. Aerators should be sized to provide enough oxygen to minimize any odor production and to promote adequate aerobic digestion, but not at a rate high enough to throw manure into the air, creating a wind drift problem. Additional oxygen is required if full biological conversion of ammonia to nitrate is a treatment goal, but the additional oxygen should not be supplied at the cost of increasing volatilized ammonia from the lagoon. Aeration requires a large surface area, four to five times what is required for anaerobic digestion.

The HRT for aerobic lagoons is usually around 20 to 30 days (Bicudo, 2001). If odor reduction is the main treatment objective, the HRT can be five or less days (Bicudo, 2001). In a study of farm-scale aerobic lagoons,

Figure 4.5: Aerobic lagoon (M. Grismer, 2004).

odor concentrations were reduced by 50 to 75 percent with HRTs of 1.7 to 6.3 days (Burton et al., 1998). Aerobic lagoons typically operate at ambient temperatures, therefore the HRT may be significantly longer for lagoons located in cold climates.

Aerobic lagoons are typically constructed of earth and have very large surface areas. Embankments should be wide enough to mow and maintain. Trees should not be permitted to grow on the embankment or in the lagoon. The tree roots will penetrate the embankment, jeopardizing the integrity of the embankment, which can lead to a catastrophic spill. Adequate **freeboard** should be maintained in the lagoon and storage areas.

Treated manure must be stored after digestion until it can be treated further or applied to land. A separate storage facility can be used or a lagoon may be partitioned. Partitioning the lagoon provides an area for treatment and also an area for storage of treated manure. Permanent dividers may be installed or temporary baffles can be used to create the partitions.

d. Low-Rate Aeration Processes

Low-rate aerobic processes offer greater operational flexibility with the potential for lower costs. Low-rate and intermittent aeration decreases power needs, and may allow for deeper treatment lagoons and shorter HRTs. Low-rate aeration can still provide odor reductions of 20 to 40 percent (Zhang et al., 2003 and Osada et al., 1991). Low-level aeration can still treat nitrogenous compounds and intermittent aeration may increase phosphorus transformations. Phosphorus accumulating organisms are stimulated by intermittent aeration. The phosphorus in the wastewater is consumed by the phosphorus accumulating organisms and assimilated into their cellular mass. Low-rate aeration cuts biomass production, reducing the frequency of sludge removal.

Facultative lagoons are a type of low-rate aerobic process. Facultative lagoons have both aerobic and anoxic zones. **Figure 4.6** is a photograph of a lagoon where both anoxic and aerobic zones are visible. Up to 75 percent of organic material can be removed using only one-third of the power required for a fully aerobic lagoon (Bicudo, 2001). However, ammonia volatilization often increases with the use of facultative lagoons.

Freeboard: The vertical space between the surface of a water body and the top of the surrounding embankment.

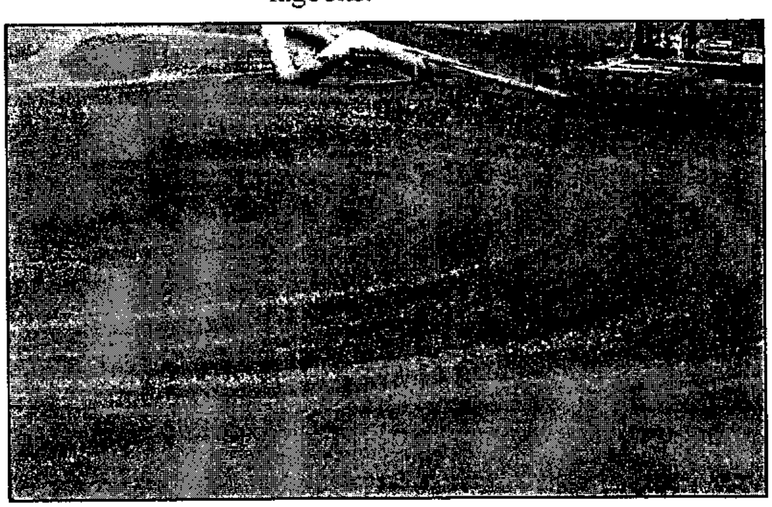

Figure 4.6: Aerobic and anoxic zones (J. Robbins, 2004).

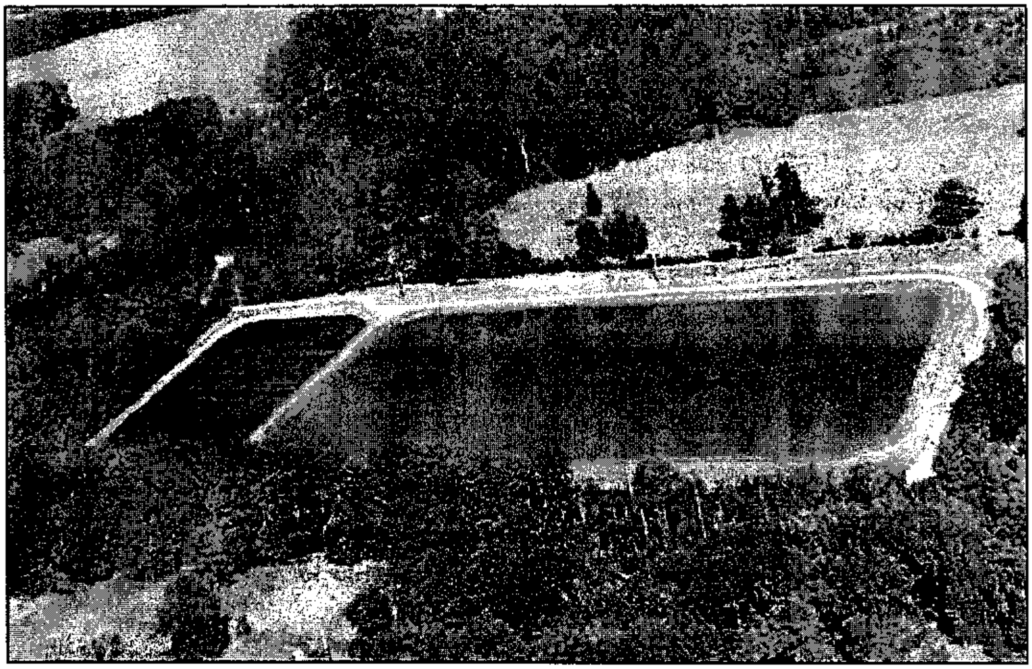

Figure 4.7: Facultative lagoon (Lemna Technologies, Inc. 2004).

Facultative lagoons, especially in the form of oxidation ditches located under barn floors, were once fairly popular in the United States. **Figure 4.7** is a photograph of a facultative lagoon. The energy crisis of the 1980's caused power-driven treatments to fall out of favor (Miner et al., 2000). European farms continue to use facultative lagoons and oxidation ditches because they are well-suited to the smaller land base and strict environmental regulations. These factors make the facultative lagoons and oxidation ditches practical treatment options despite the electricity costs. Oxidation ditches are very similar to batch reactors. They are continually aerated for 20 hours, and then the motors are shut down. During shut down, the biomass settles and the effluent is siphoned off. The treatment reactor can then be refilled with slurry. This process allows both nitrification and denitrification to occur. See Chapter 6 for more information on nitrification-denitrification and oxidation ditches.

e. Combination Processes

There are almost a limitless number of ways that the different aerobic processes can be linked together or with other treatment processes. Intermittent aeration can be performed with or without solids separation, supernatant may or may not be recycled through the system, a mechanically aerated treatment lagoon may be placed in series with a naturally aerated or intermittently aerated lagoon—these are just a few of the many options that are available for aerobic digestion.

4.5 Summary

Aerobic digestion is a treatment process that utilizes oxygen-loving bacteria and other aerobic microorganisms to break down organic matter and nutrients, and to reduce odor and manure gas emissions. Manure must be oxygenated in order for aerobic conditions to prevail and depending on the characteristics of the manure and the design, aeration costs may be high. Aerobic digesters may be fixed-film or suspended growth systems.

Referenced Materials

Barrington, S.F. and A.F. MacKenzie. 1989. The enrichment of swine manures through cement kiln dust incorporation. Biological Wastes. Vol. 29. P. 1-10.

Béline, F., M. Daumer, F. Guiziou, P. Rapion. 2002. Biological treatment of pig slurry in Brittany, France: Efficiency and end-products characteristics. 2002 American Society of Agricultural Engineers (ASAE) Annual International Meeting / International Commission of Agricultural Engineering (CIGR) XVth World Congress. July 28-31 2002. Chicago, Illinois.

Bicudo, J. 1999. Aerobic treatment of animal manures for odor control. Proceedings from Treatment Processes for Reducing Gas and Odor Emissions from Livestock and Poultry Facilities. Shakopee, Minnesota.

Bicudo, J.R. 2001. Managing manure solids. Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. Cornell University, Ithaca, New York.

Burton, C.H., R.W. Sneath, T.H. Misselbrook, B.F. Pain. 1998. The effect of farm scale aerobic treatment of piggery slurry on odor concentration, intensity, and offensiveness. Journal of Agricultural Engineering Resources. Vol. (71). P. 203-211.

Classen, J.J. and S.K. Liehr. 2003a. Battelle's instream water unit at Cox swine farm. Proceedings from 2003 North Carolina Waste Management Workshop. October 16-17 2003. Raleigh, North Carolina.

Classen, J.J. and S.K. Liehr. 2003b. Hoffland Environmental, Inc (HEI). Proceedings from 2003 North Carolina Waste Management Workshop. October 16-17 2003. Raleigh, North Carolina.

Crites, R., G. Tchobanoglous. 1998. Small and Decentralized Wastewater Management Systems. McGraw-Hill. New York, New York.

Danesh, S., D. Small, D. Hodgkinson. 2000. Pilot Plant Demonstration of a Three-Stage Waste Treatment Technology. DGH Engineering, LTD. www.manure.mb.ca/projects/completed/pdf/98-01-31-three-stage-waste-treatment.pdf. Last visited 1 March 2004.

Fenlon, D.R. and P.J. Mills. 1980. Stabilization of pig slurry with lime. Agricultural Wastes. Vol. 2. P. 13-22.

Grady, C. P., G. T. Daigger, H.C. Lim. 1998. Diagram of rotating biological contactor. Biological Wastewater Treatment. Second Edition Revised and Expanded. Marcel Dekker. New York, New York.

Grady, C. P., G. T. Daigger, H.C. Lim. 1998. Diagram of continuous-flow stirred tank reactor. Biological Wastewater Treatment. Second Edition Revised and Expanded. Marcel Dekker. New York, New York.

Grismer, M. 2004. Photograph of aerobic lagoon. University of California at Berkeley. Berkeley, California.

Lemna Technologies, Inc. 2004. Photograph of facultative lagoon. Minneapolis, Minnesota.

Metcalf and Eddy, Inc. 2003. Wastewater Engineering Treatment and Reuse. Fourth Edition. McGraw-Hill. New York, New York.

Metcalf and Eddy, Inc. 2003. Diagram of a batch reactor. Wastewater Engineering Treatment and Reuse. Fourth Edition. McGraw-Hill. New York, New York.

Miner, J.R., F.J. Humenik, M.R. Overcash. 2000. Managing Livestock Wastes to Preserve Environmental Quality. Iowa State University Press. Ames, Iowa.

Miner, J.R., F.J. Humenik, M.R. Overcash. 2000. Diagram of trickling filter. Managing Livestock Wastes to Preserve Environmental Quality. Iowa State University Press. Ames, Iowa.

Osada, T., K. Haga, Y. Harada. 1991. Removal of nitrogen and phosphorus from swine wastewater by the activated sludge units with the intermittent aeration process. Water Research. Vol. 25(11). P. 1377-1388.

Robbins, J. 2004. Photograph of aerobic and anoxic zones. Waterkeeper Alliance. Tarrytown, New York.

Svoboda, I.F. 1995. Aerobic treatment of livestock slurries. STC Technical Note, Environmental Series No. 2. Edinburgh, UK.

Westerman, P.W. and R.H. Zhang. 1997. Aeration of livestock manure slurry and lagoon liquid for odor control: a review. Applied Engineering in Agriculture. American Society of Agricultural Engineers. Vol. 13(2). P. 245-249.

Yanosek, K.A. 2003. Enhanced biological phosphorus removal from dairy manure to meet nitrogen:phosphorus crop nutrient requirements. M.S. Thesis. Virginia Polytechnic Institute and State University. Blacksburg, Virginia.

Zhang, R.H. and P.W. Westerman. 1997. Solids-liquid separation of animal manure for odor control and nutrient management. Transactions of American Society of Agricultural Engineers. Vol. 13(3). P. 385-393.

Zhang, R.H., P. Yang, C.A. Collar, L. Ham. 2003. Treatment of flushed dairy manure by solid-liquid separation and lagoon aeration. Proceedings from Ninth International Symposium of Animal, Agricultural, and Food Processing Wastes. October 11-14, 2003. Raleigh, North Carolina.

Zhu, J., A. Luo, Z. Zhang. 2003. Effect of a microbial additive on the removal of nutrients in swine manure by aeration. Proceedings from the 2003 American Society of Agricultural Engineers Annual International Meeting. July 27-30, 2003. Las Vegas, Nevada.