ENVIRONMENTAL ISSUES IN LIVESTOCK PRODUCTION HOME STUDY COURSE

Livestock
Industry
Facilities &
Environment

The *Environmental Issues in Livestock Production* home study series was developed for livestock producers, educators, students, and others seeking to better understand potential air and water quality impacts of animal agriculture, and to learn more about management practices that can minimize these impacts.

Modules in this series include:

- *Open Feedlot Runoff;*
- *Odor Assessment and Control;*
- *Manure Application;*
- *Livestock Environmental Regulations; and*
- *Manure Treatment*

For information concerning home study course completion certificates, and supplemental teaching materials (Power Point presentations) for use in the classroom, contact Agricultural & Biosystems Engineering Extension, 207 Davidson Hall, Iowa State University, Ames, IA 50011-3080 (phone 515-294-6360), email tglanvil@iastate.edu, or visit our World Wide Web site at http://www.ae.iastate.edu.

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Ames, Iowa

Manure Treatment

Home Study Lesson 5

This lesson discusses manure treatment methods to reduce odors, and/or nutrients associated with the manure. This module was developed by Jeffery Lorimor, Extension Ag Engineer and Assistant Professor, Agricultural and Biosystems Engineering, Iowa State University, Ames, IA.

Objectives:

Upon successful completion of this unit you will:

- Know the different manure treatment technologies available and the processes by which each method works.
- Have a better understanding of the feasibility of using the various treatment systems.

Introduction

The best use of livestock manure is land application for nutrient recycling to crops. A well-managed system represents sustainable utilization, and results in minimum environmental degradation of soils and water. However, not every producer can use such a system. There are many reasons why other treatment strategies may be desirable. Lack of adequate land for optimum nutrient use, odor control, energy harvesting; lack of physical space for proper lagoon sizing, and alternative products development (composting solids for instance) are examples of reasons for treating manure. For these and other reasons, simple land application is not always the most desirable alternative, so other treatment processes are sometimes needed.

This lesson describes six alternative treatment systems. The advantages and disadvantages of each are discussed, as well as some of the theory and mechanisms that make the treatment systems work. The treatment technologies discussed in this home study include:

- Anaerobic digestion
- Aerobic treatment
- Partial aerobic treatment
- Liquid-solids separation
- Constructed wetlands
- Pit additives

Technologies

Anaerobic digestion

Anaerobic digestion is a system that has been around since time began. In an uncontrolled situation, it is simply organic decomposition that occurs naturally. It smells, but it works. The challenge is to contain the materials and control the system, to minimize odors and maximize solids decomposition. For animal manure, two different types of anaerobic digestion is practiced. Anaerobic lagoons are large, highly diluted, open bodies of water. They are the most common type of manure treatment, and result in low nutrient concentrations and high volumes of liquid to handle. For information on anaerobic lagoons see the LIFE series publication, *Design and Management of Anaerobic Lagoons in Iowa for Animal Manure Storage and Treatment,* Iowa State University Extension publication Pm-1590.

This lesson will discuss closed, heated and completely mixed anaerobic digestors from which methane can be harvested. They are typically made of concrete or steel, and are often constructed at least partially underground. Underground construction allows them to be fed by gravity, and helps retain heat during Iowa's cold seasons. Insulation is often included as part of the construction to minimize heat loss during cold Iowa winters.

Anaerobic digestion is a two stage process, carried out by two different types of microorganisms. In the first stage, a group of microbes referred to as "acid formers" break down the volatile portion of the manure solids (volatile solids) into volatile fatty acids (VFAs). These microbes have the ability to multiply quickly, and can quickly produce large quantities of acids if given a large supply of food all at once. VFAs are a primary source of offensive odors. The second group of microorganisms are the "methane formers." This group utilizes the VFAs' produced by the first group as a food source, and reduces them further to gases such as methane, carbon dioxide, hydrogen sulfide and others. Acid formers multiply and react much more quickly than the methane formers.

For anaerobic digestion to work properly, the environment within the digestor must be maintained so the two groups of microbes remain in balance. The methane formers are more sensitive than the acid formers. Temperature fluctuations, too low of pH, too high of concentrations of some nutrients (especially ammonia) can all inhibit the methane formers. If, for example, a large food supply is suddenly introduced, acid formers might overwhelm the methane formers, cause a buildup of VFAs, reduce the pH, and the digestor might fail. The keys to proper anaerobic digestion are constant temperature, a constant food supply at the proper nutrient/solids concentration. Digestors should be maintained at a constant temperature of approximately 95 degrees Fahrenheit. Maintain pH levels between 6.6 and 7.6; and solids between 4 and 5 percent. To achieve efficient digestion, digestors should be completely mixed so the microbes have access to all the incoming food supply. The mixing can be done mechanically or hydraulically.

Digestion takes time. Digestors should be designed to hold the manure solids for approximately 15 to 20 days. A properly operating digestor will produce about 30 cubic feet of biogas for each 1,000 pounds of animal bodyweight per day. The gas will be about 60 percent methane and 40 percent carbon dioxide, with a heating value of 500 to 600 BTUs per cubic foot. With the proper equipment (scrubber to remove H_2S, valves, compressor and safety equipment) it can be captured and burned for energy, or used to run an internal combustion engine. In Iowa, much of the energy from the methane may be needed to maintain the digestor's temperature in the winter. Some systems utilize the methane to run engines to drive electric generators. The excess heat from the engine is then circulated through a heat exchanger to heat the digestor. Table 1 gives approximate energy production by species.

Table 1. Typical biogas production from heated, completely mixed digestors

Animal	Biogas production ft^3/day-1,000 lbs wgt	Methane percent	Heat value BTU/day
Dairy	39	54	20,700
Beef	22	53	11,700
Swine	28	58	16,400
Layers	37	60	22,700
Broilers	51	60	30,400

Anaerobic digestion controls odor by containing the manure in the closed digestor. The volatile compounds are broken down and stabilized in the digestor prior to exiting to a storage pond. When the generated gas is burned off, it is oxidized and gaseous odors are eliminated in the process. Gas scrubbers are sometimes used to remove hydrogen sulfide from the biogas before it's burned in an internal combustion engine to prevent sulfuric acid from forming when the engine is stopped. Scrubbers can be eliminated if the engine is run continuously.

Figure 1. Exterior of anaerobic digestor near Mt. Pleasant, Iowa. The digestor itself is beneath the control structures in photo. The pipe on the left is used to burn off methane.

If we can control odors and harvest some energy; then why doesn't every producer use an anaerobic digestor? There are some disadvantages to consider. First, little if any manure volume reduction is achieved. The manure liquid must still be land applied. It is typically held in a pit or lagoon until time for pumpout. If dilution water is added to achieve proper operation, you may even have more liquid to handle than if you didn't use a digestor. All the plant nutrients are still in the liquid (you have removed only carbon, hydrogen and oxygen) as it leaves the digestor, so land requirements have not been reduced. Typically a pit or lagoon is used to hold the liquid until land application can be done once or twice a year.
Most systems are complex and have significant maintenance requirements.

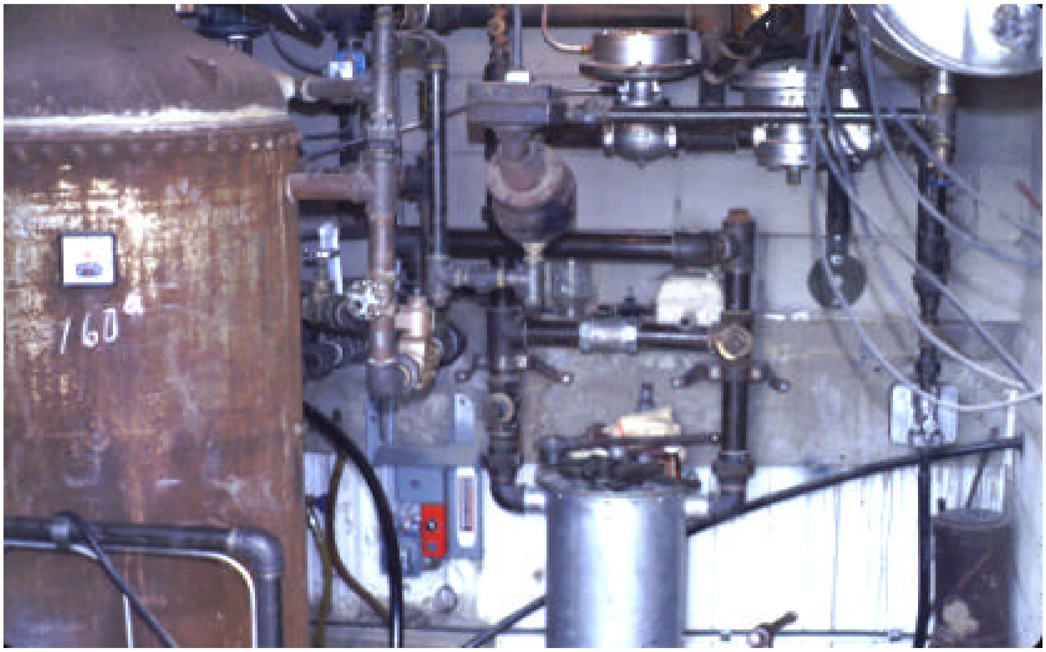

Figure 2. Inside the anaerobic digestor control room near Mt. Pleasant. Piping and plumbing are complex.

Methane is dangerous; it is explosive at concentrations of 5 to 15 percent, so safety must be designed into the system. Hydrogen sulfide, which is also produced in digestors, is very corrosive, and is hard on equipment.

Finally, digestor cost is generally high, starting with a large concrete or steel tank that will provide adequate detention time for the manure. Anaerobic digestors can be purchased as "turn-key" units. Cost estimates, in 1996 dollars, are $450 to $550 per dairy cow, and approximately $350 per sow for a farrow-to-finish swine operation. Digestor equipment includes the tank, a mixing device, heat exchanger, burner, flow control devices, engine and generator if producing electricity. A holding pond to collect the digestor effluent between hauling periods, as well as pipes, pumps and valves to control the flow of both the liquids and gases are also needed.

There is interest in using covered anaerobic lagoons to capture methane. Some systems in the U.S. have done so. They are typically located in southern states at large production facilities (1000 head dairies, 5000 head swine operations). A recent project by the Department of Energy looked at the economics of such systems. They found typical payback periods of about 6 years if all sources of income were utilized including sale of solids removed, elctricity generated, and heat recovered. Electricity generation alone was uneconomical. In Iowa, temperature becomes a factor. Methane generation from lagoons goes from approximately 0.25 cubic meters per square meter per day at 68^{o}F to essentially zero at about 40^{o}F. The period of time methane would be generated from Iowa lagoons would be short.

Aerobic treatment
Aerobic treatment requires oxygen. The microorganisms for aerobic treatment will die if oxygen is not available. Aerobic treatment controls odors and reduces nutrients in the liquid. Aerobic lagoons are the most common form of aerobic treatment for agriculture, some industries, and many small towns. . . large shallow lagoons that are lightly loaded. They are designed so that natural oxygen transfer to the lagoon liquid meets or exceeds the oxygen demands of the microbes. Biological Oxygen Demand (BOD) is a commonly used measure of the amount of oxygen needed by the microbes. Swine produce about 3.1 pounds of BOD per day per 1,000 pounds of bodyweight. Dairy and beef produce about 1.6 pounds/1,000 pounds/day.

Aerobic lagoons are used by small towns across Iowa. They must provide oxygen at a rate at least equal to the BOD, or they will become anaerobic. Municipal aerobic lagoons are designed for a maximum depth of 6 feet, and a loading rate of 25 pounds of BOD per acre of lagoon surface. For a 1,000 head swine finishing building, a lagoon based on this design criterion would be:

1,000 head x 150 lbs bw/hd x 3.1 lbs BOD/1,000 lbs bw	=	465 lbs BOD/day
465 lbs BOD/ 25 lbs BOD/acre	=	18.6 acre lagoon

Gases generated by aerobic treatment are odor free, such as carbon dioxide, nitrogen gas, and water vapor. A significant reduction in crop nutrients occurs in aerobic lagoons as phosphorus settles, and nitrogen is volatilized to the atmosphere. Generally 80 percent reductions in phosphorus and nitrogen occur.

Mechanical aeration can be used to minimize lagoon size. See Figure 3. Mechanical aerators either whip, bubble or pump air into the liquid, or pump the liquid into the air like a lawn sprinkler. The main disadvantage of mechanical aeration is the operating costs. Mechanical aerators are generally rated by pounds of air transferred to the liquid per kilowatt-hour, or per horsepower-hour . . . typically about 3 pounds per kWh. We know the BOD requirement, so we can estimate aeration operating costs. For our 1,000 head finisher listed above, mechanical aeration operating costs would be:

2 x (465 lbs BOD/day) / 3.0 lb BOD per kWh	=	310 kWh/day
at $.06/kWh the daily operating cost would be 0.06 x 310	=	$18.60/day
For one turn of pigs (assume 120 days) cost would be	=	$2232.00 ($2.32/head)

Freezing can be a problem with mechanical aerators during the winter as liquid is continuously pumped. Frozen foam or freezing droplets can soon render a unit useless.

Figure 3. Mechanical aerator in round concrete tank. Air is sucked down vertical pipe into manure liquid.

Aerobic treatment does not reduce the manure liquid volume. While it does control odors, and reduce nutrient concentrations in the liquid, the full volume of liquid must still be stored and land applied. Storage lagoons are typically used behind mechanical aeration systems to hold the liquid until pumpout and land application. Phosphorus will settle out in the bottom of the lagoon if not removed via settling tanks between the aeration and storage systems, and will eventually have to be land applied.

Partial aerobic treatment

Research is being conducted into maintaining aerobic conditions in just the surface layer of pits and lagoons. The object of surface aeration is strictly to control odors during storage. As anaerobic gases are generated from within the pit, and rise to the surface, they must bubble up through the aerobic layer at the surface. Laboratory research has shown that surface aeration does help reduce volatile acids and odors in the surface layer while the manure is in storage. It will likely not reduce odors when the manure is land applied, since the bulk of the volume is still anaerobic. More research is needed to determine how much oxygen to provide for partial aeration, and the best ways of providing it in various types of pits and lagoons.

Liquid-solids separation

Solids separation is one potential technique for minimizing the size of the lagoon. It's also thought to be desirable by producers wanting to use the solids for bedding, for refeeding, or for composting for use as soil amendments. Solids separation has been used for years to reduce the pollutant load from open feedlots going into receiving water bodies. By removing solids, lagoons or digestors for confinement systems can be reduced in size due to lowered volatile solids concentrations. Iowa Department of Natural Resources (IDNR) standards allow a 50 percent reduction in anaerobic lagoon size following solids removal. If an aeration system is used, it could also be designed smaller. Typically, solids separation works well for dairy and beef manure, and not so well for swine.

Settling basins are the standard method for solids removal from open lots. Mechanical separation is sometimes used in conjunction with confinement systems. Mechanical separation equipment includes stationary and rotating screens, vibrating screens, filtration, screw presses, roller presses, and centrifuges. Research has shown solids removal rates of 45 to 70 percent for bovine slurry, and 14 to 45 percent for swine. Stationary screens are the most popular, but least effective of the mechanical systems. Screens provide removal rates of 45 to 65 percent for bovine solids, but only 14 to 20 percent for swine solids. Settling tanks are also used. Like mechanical systems, they are more effective for bovine solids than for swine. Settling tanks must be pumped out frequently to remain effective.

Settling can be enhanced through the addition of chemicals to cause coagulation (smaller particles forming large clumps). Researchers at Iowa State University and elsewhere have achieved nearly 90 percent swine solids removal using polyelectrolyte coagulation agents in the laboratory. The effect of the polyelectrolytes on the environment, and the economics of the chemical additions must be evaluated before the system can be judged.

Another factor to consider prior to investing in solids settling systems is what to do with the solids once they are removed. One option may be composting to convert the solids to other uses. Bedding and soil conditioners for horticultural use are most often mentioned. Research is underway at ISU on composting of swine solids for horticultural use.

Figure 3. Rotary screen solids separator processing dairy manure

Constructed wetlands
Much interest has been expressed in using wetlands for treatment of animal manure. Research has shown that wetlands can result in dramatic reductions of nutrients and microorganisms in the water. Over 90 percent reductions have been recorded for nitrogen, phosphorus, BOD, and fecal coliform. In addition, wetlands benefit waterfowl and other wildlife. Due to regulatory constraints, only constructed wetlands can be used to treat manure. Natural wetlands cannot be used for manure treatment.

Direct treatment of animal manures is not feasible without either initial treatment, or additions of large volumes of dilution water. Like anaerobic digestors, the organisms in wetlands can't tolerate high concentrations of nutrients, especially ammonia-nitrogen. However, while an anaerobic digestor can tolerate 1,000 to 1,500 ppm of ammonia-N, a wetland can only tolerate about 100 ppm. Research has shown that the maximum loading rate for wetlands is 3 pounds of nitrogen per acre per day. Using our 1,000 head finisher again, a wetland to treat the waste directly would need to be:

1,000 head x .07 lb N produced/day	=	70 lbs N per day
70 lb N per day/ 3 lb per acre per day	=	23 acres required

To reduce the influent ammonia concentration to 100 ppm from (an assumed) 2,000 would require 20 gallons of fresh water for each gallon of manure. Clearly wetlands are difficult to adapt for direct treatment of confinement manure; some type of pretreatment must be employed. One option might be solids removal, then lagoon storage and treatment. Another potential treatment is soil filtration. Early work showed that large reductions in nutrient concentrations could be achieved by land application and tileline collections of the infiltrated lagoon liquid. Treating the tileline flow with a wetland may be a feasible alternative in some instances.

Pit Additives
There are a number of pit additives on the market. They generally have one of two objectives; to reduce solids, and/or to reduce odors. They work in one of several modes of action.

- Masking agents
- pH adjustments
- Bacteria and enzymes
- Disinfectants

Masking agents act as perfumes to cover disagreeable odors. They do work. If they do not mask the odor adequately, you can increase the additive concentration until they do. Unfortunately, research and experience have shown that after a short time, the masking agent becomes disagreeable, and in effect becomes an odor itself, so little has been gained by its use.

Adjustments to pH levels have been shown to have an effect. Recent research at ISU has shown a reduction in odor through the addition of alkaline by-products. By raising the pH, ammonia becomes more volatile while acidic components become less volatile. In both laboratory and field trials, odor was significantly reduced from swine pits through its use.

Performance of bacteria and enzymes are less predictable. They will result in a change in odor and possibly a volatile solids reduction. The question is whether the new odor is better or worse . . . or just different. One thing to keep in mind with these additives is that it may take some time for populations to build up enough to be effective. You may see little result the first week or two.

Disinfectants inhibit biological activity that may result in an odor reduction. The disinfection will also decrease (or stop) solids decomposition, which may be undesirable. Disinfection dosages may have to be increased as the microbes acclimate to the disinfectant.

One theme common to all of these products is cost. While some of them offer odor or solids decomposition advantages, they must be evaluated with respect to cost. In general they will have little, if any, effect on manure volume or nutrient concentration. Evaluate them carefully with respect to the cost of the material and equipment required for proper application as well as product effectiveness.

Engineers in the Ag and Biosystems Engineering Department at ISU are testing pit additives for their effects on odors. At this writing, 15 have been tested. Five have resulted in odor reductions of up to 85 percent, and varying solids reductions. Because the list of products tested is changing rapidly, a list is not provided here. For specific information, contact ISU Extension Ag Engineering Extension at 515/294-6360, or if you're on the World Wide Web, check our home page at www.ae.iastate.edu and look under agricultural waste management. Other factors that must be considered before selecting any additives are management methods necessary to make the products perform properly, and any special equipment necessary.

Odors from pits and lagoons are only one component of livestock odors. Odors also emanate from the buildings as both gases and particulates. Dust and gases are removed by fans and put into the atmosphere. Work is progressing on biofilters to reduce airborne odors from buildings, which must be controlled as well as pit gases, to eliminate odors.

Conclusion

We have briefly looked at six different treatment strategies. In general, the objective of most of them is either solid-liquid separations, solids decomposition, or odor reduction. The result is typically little, if any, overall volume reduction. Most of the treatments do control odor, but do not reduce the total manure volume. You should not plan on a treatment system reducing the volume of manure, although it may reduce the amount of land you need to apply the manure. The question of cost for any of the systems is a real issue, and must be evaluated on an individual case basis.

Test Questions
Lesson 5, Manure Treatment

1. Lagoons often smell worse in the spring because the acid formers get ahead of the methane formers and produce these obnoxious chemicals. They are ____.

2. How many cubic feet of biogas per day should we expect from a high temperature, completely mixed anaerobic digestor per 1000 poundsof hog bodyweight (about 2.5 sows)?

3. That volume of biogas would have a heating value of _______________ BTU's. There are approximately 300 BTU's in a kilowatt hour. Assuming 100% efficiencies how many kilowatt hours would be produced each day from the biogas? ____________________kwh. And at 6 cents per kwh, how many dollars per head of gas was generated? __________________

4. A 1000 finisher required a 19 acre lagoon if designed like municipal aerobic lagoons. Is this a feasible alternative for livestock?

5. Will mechanical aeration eliminate pit odors?

6. Screens are much more effective at removing solids from dairy manure or swine manure?

7. What forms of pretreatment might be used ahead of a constructed wetland?

8. If a pit additive could achieve an 80% reduction in odor from the pit, would the overall odor reduction from the facility be 80%?

10. What would you, as a producer, be willing to spend per head marketed for effective odor control?

Answers to Lesson 5, Manure Treatment

1. Lagoons often smell worse in the spring because the acid formers get ahead of the methane formers and produce these obnoxious chemicals. They are VFAs - volatile fatty acids.

2. How many cubic feet of biogas per day should be expect from a high temperature, completely mixed anaerobic digestor per 1000 pounds of hog bodyweight (about 2.5 sows)? Approximately 28 cubic feet per day.

3. That volume of biogas would have a heating value of ______________ BTUs. There are 3413 BTUs in a kilowatt hour. Assuming 100% efficiencies how many kilowatt hours would be produced each day from the biogas? _________________ kwh. And a 6 cents per kwh, how many dollars per head of gas was generated? __________________

The heating value would be approximately 16,400 BTU/day which would equate to 16,400/3413 = 4.8 kwh per day at $0.06 per kwh = 0.06 x 4.8 = $0.29 per day. Since this was for 2.5 sows: 0.29/2.5 = $0.12 per sow per day.

4. A 1000 finisher required a 19 acre lagoon if designed like municipal aerobic lagoons. Is this a feasible alternative for livestock? No

5. Will mechanical aeration eliminate pit odors? Yes, odors are eliminated by adequate mechanical aeration systems.

6. Screens are much more effective at removing solids from dairy manure or swine manure?

Dairy. Mechanical solids removal from swine manure is not efficient (14-20% removed). From dairy, removal efficiencies can be up to 65%.

7. What forms of pretreatment might be used ahead of constructed wetland? Solid removal and/or lagooning.

8. If a pit additive could achieve an 80% reduction in odor from the pit, would the overall odor reduction from the facility be 80%? No. Odors emanate from not only the pit, but also the floors, the animals, feed mill, etc.

9. What would you, as a producer, be willing to spend per head marketed for effective odor control?

Your own answer goes here. Typical costs of odor control technologies are from $0.20 - $1.50 per head of swine marketed.

Home Study Module Evaluation

Environmental Issues in Livestock Production - Manure Treatment

Thank you for participating in the Iowa State University *Environmental Issues in Livestock Production* home study series. Please take a few minutes to give us your suggestions for improving these materials, and to guide our development of new home study materials. If you wish to obtain a certificate of completion for this module, mark the certificate request line at the bottom of this form, fill in your name and address, and attach your answers to the homework problems for this module. (Note: your answer sheet will NOT be returned)

Describe your objective(s) for completing this module:

___Personal interest in environmental issues ___Background for other class work
___To evaluate and/or modify your livestock enterprise ___Background for your profession
___Other (please specify)____
____

Do you feel that you met your objectives? ___Yes ___No

The content of this module was:
___too easy ___somewhat easy ___about right ___somewhat difficult ___too difficult

It took me about ______ hours to complete this module.

What did you learn from this module that was of greatest value to you?

Your suggestions for improving this module.

Please suggest other subject(s) you would like to have home study materials on.

___I would like a certificate of completion from Iowa State University for the *Manure Treatment* module. **My answers sheet for the homework problems in this module are enclosed as proof of completion**, and my name and mailing address are as follows:

Your name: ________________ Address:____

Return this form to: Livestock & Environment Home Study Project, Department of Agricultural & Biosystems Engineering, 207 Davidson Hall, Iowa State University, Ames, Iowa 50011-3080, OR FAX to L&E Home Study Project at 515-294-9973, OR email your responses to tglanvil@iastate.edu.