Manure Technologies for Today and Tomorrow

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Large dairy herds are continually faced with decisions related to manure management. What is the best method to collect, store, treat, and utilize manure nutrients? Is there any management tool that works universally throughout the United States? Are there any technologies required by law? If I change my herd size, housing type or bedding, will that effect my manure management system?

All dairy producers know there are a few universally accepted truths about manure. Dairy cattle fed for optimum or maximum production will yield plenty of manure daily, and this material must be handled regularly. The increased attention to large animal operations has triggered yet another opportunity for entrepreneurs to market products and goods to dairy producers. **There were NO Federally required treatment technologies adopted during the revision of the Federal Clean Water Act (Dec 16, 2002). There are no Federally required treatment technologies associated with obtaining cost share funds for dairy operations.** For individuals seeking financial assistance through Environmental Quality Incentive Program (EQIP) funds available through the Natural Resources Conservation Service (NRCS) individuals may need to complete a Comprehensive Nutrient Management Plan (CNMP). A well written CNMP will address manure management and land application of manure nutrients at appropriate rates.

Establish a Job Description

Manure treatment technologies utilized on a dairy should be assigned duties and responsibilities. Additionally, it is critical to have a method in place to do performance evaluations on these technologies. What are the expectations? What are the consequences of using the technology? Are there additional ramifications that must be addressed? Each of the major categories of treatment technologies will be reviewed to describe the associated advantages and detriments.

If you are considering the installation of a technology to assist in reducing the footprint of the facility on the environment it will be useful to determine if the technology can potentially address the issues of concern. The usual concerns related to water quality are total solids, phosphorus, and nitrogen. Odor is the usual nuisance issue related to air quality. There are specific compounds that may be of concern depending on the state (ammonia, hydrogen sulfide, reactive organic gases).

Anaerobic digestion

The key objective of anaerobic digestion is to collect and degrade organic material (solids) in an anaerobic environment, capture the methane gas and convert it to electricity. The chemical composition of methane is CH_4. The other major gas that is yielded during anaerobic digestion is carbon dioxide (CO_2). Anaerobic digestion in a controlled environment can be beneficial to reduce odor. Gases are formed within a structure (not released to the atmosphere) and at a pH near 7. At pH 7 methane production should be near optimum and there should be minimal formation of malodorous compounds. Gases formed are burned in the combustion process. Anaerobic digestion is not beneficial for a treatment technology if you need to reduce total nitrogen (N) or phosphorus (P) at a facility.

Anaerobic digestion systems can be designed to use slurry material or a covered dairy retention pond. The type of system depends on the method of manure collection (scraping versus flushing). The size of the system is based on the volume of material collected daily multiplied by the number of days material should be retained for digestion. For liquid systems this size can be considerably large. The volumes of water used to flush freestall lanes increases with decreasing slope of the lanes (less than 2%). It should be noted that the retention pond used as an anaerobic digestion cell is not considered part of the liquid storage capacity. This pond will be managed at capacity and after it is filled, the daily inflow will equal the daily outflow.

Environmental benefits of anaerobic digestion: For manures that are initially left on feed alleys and pushed into corrals there is potentially a net emission of methane if the manure is collected and digested anaerobically. These materials will usually be collected in a semi-solid form and be fed into a sequencing batch reactor or plug flow digester. In the original form materials are maintained in an aerobic environment (presence of oxygen). Since the removal of methane from digested manure is not complete there will be some residual methane in the digester effluent. Once exposed to the atmosphere (post digestion) there is probably off-gasing of methane to the atmosphere. Manures that are normally collected into an anaerobic retention pond should yield fewer emissions to the atmosphere if the retention pond is covered and methane is collected and either flared or converted to electricity.

Typically, anaerobic digestion is used to reduce odor while providing income through electrical generation and use or sale. Anaerobic digestion to yield methane is most productive at pH near 7. The United States Environmental Protection Agency (US EPA) AgStar program has promoted anaerobic digestion on animal facilities for many years. To date 31 digester systems are in operation at commercial livestock farms. Of these, 15 are at swine farms, 14 are at dairy farms, and 2 are at caged layer farms. For a listing of details associated with these facilities go to http://www.epa.gov/agstar/operation/bystate.htm

If you are considering installation of anaerobic digestion treatment technology on your dairy do your homework first. Identify appropriate vendors and determine if your facility is able to accommodate this type of technology. The US EPA maintains a website for location of vendors, equipment, etc. http://www.epa.gov/agstar/tech/index.htm. Another great source of information is On-Farm Biogas Production- NRAES-20. It can be ordered from the Northeast Regional Agricultural Engineering Service, 154 Riley-Robb Hall, Cornell University, Ithaca, NY 14853.

Legget et al. prepared an extension publication on anaerobic digestion. They identified the following questions to ask prior to considering anaerobic digestion: Is manure currently handled as a liquid? Are little amounts of bedding or frozen manure handled? Is the manure in the handling system free from high levels of copper sulfate and antibiotics? Is odor control a major concern? Is there space on the farm to expand the manure handling system with the possibility for gravity flow from a barn to an anaerobic digester or from a digester to a manure storage structure? Does someone on the farm have the interest, time, and technical skills to learn about the anaerobic digestion process, make repairs, and perform general maintenance on equipment? Are resources available to finance an anaerobic digestion system? Can you adhere to the recommended safety practices?

Important questions to address related to anaerobic digestion.

Parameter	Anaerobic digestion technology
Odor control	Do you currently have an odor problem? If not, there is little opportunity for benefit. If you currently have an odor problem identify how you will monitor changes in odor after installation and operation begins.
Energy use/production	Will you flare the methane or convert it to electricity?
Nutrient content	Similar to that of original material
Fertilizer value	Conversion of some organic N to ammonium N (plant available form)
Nutrient stability	More stable after digestion
Total solids	Reduces organic material to some extent

Initial costs may be costly depending on the volume of material and method of digestion. Estimated costs associated with anaerobic digestion installation for liquid collection systems can vary significantly. Through a program in California applicants have estimated cost of technology installation ranging from $350,000 to over $3,000,000. The huge variation is due to method of digestion and herd size (ranging from 200 to over 3,500 cows). Applications related to building and covering liquid manure storage ponds were from herds ranging in size from 525 to over 5,000 milking and dry cows. General summary statistics are provided. Some facilities use such incredibly high volumes of recycled wash water to flush lanes that the retention pond size needed to hold sufficient number of days of material (retention time) is BIG! NOTE: If you think you will ever consider anaerobic digestion and methane recovery from a liquid manure system SLOPE the freestalls.

Estimated costs (2001-2002) associated with installation of covered lagoons with the intent of capturing methane and generating electricity.

Parameter	Low	High	Average
Head (Milking and dry cows)	525	>5,000	2,400
Influent (gal/day/milking and dry cows)	87	510	315
Estimated capital cost (investment/milking and dry cows)	$ 232	$ 711	$ 420
Estimated annual maintenance expenses	$ 2,400	$ 87,600	$ 15,800

- As with any technology, there will be a learning curve for facility managers and operators. A maintenance schedule will be necessary and at least two people at the facility will need to know the intricate details associated with proper digester and engine function. Since a greater amount of nitrogen will now be in the ammonium form, nutrient managers will need to consider the potential to loss more ammonia during land application. It is also important to establish appropriate Occupational Safety and Health Association (OSHA) hazard protocols and training for employees.

Chemical or biological additives

There is an abundant supply of products available on the market with claims to reduce or eliminate solids and/or odors from manure storage structures. Products may be added to feed, animal facilities, or manure storage facilities. Products can be classified by mode of action. Before agreeing to buy a product you might want to consider the answers to a few questions. What is the mode of action? What kind of conditions are necessary for the product to work effectively? How reliable is the product? Are there undesirable outcomes from using the product?

Typically, there are five categories of products (Ritter, 1989): 1) Masking agents have strong odor characteristics of their own. This is designed to cover up the undesirable odor from the manure. 2) Counteractants consist of a mixture of aromatic oils that have a neutralizing effect on the offending odor. 3) Digestive deodorants contain a mixture of enzymes and/or bacteria that eliminate the undesirable odor through biological degradative processes. 4) Adsorbents are products with large surface areas used to adsorb targeted odors before volatilization. 5) Chemical deodorants act as oxidizing agents or germicides to alter or eliminate microbial activity responsible for odor production or chemically oxidize compounds that are components of the offending odor. This classification system was proposed as the mechanisms by which commercial additives would alter odor. All but the first class requires that the offending odorants/compounds be known. This is not always the case, particularly with odor. However, if ammonia is the target, a better assessment of the effectiveness of a specific product may be made, provided sufficient information on product content is supplied. In most situations, this is not the case.

One of the challenges in evaluating the effectiveness of these products is that there are few independent research trials available to glean results and information. What can products potentially do? Potentially, they can reduce odor. Potentially, they can make odor worse. Potentially they can reduce solids. Potentially they can do nothing to the solids. Most independent studies associated with evaluation of commercial products have focused on products associated with treating odors from swine manure. Studies done in laboratory settings use odor panels or analysis of gaseous compounds. Many of these studies were funded by the National Pork Board and were conducted by scientists at North Carolina State University, Purdue University or Iowa State University. Go to the National Pork Board (http://www.porkscience.org) if you are interested in detailed information on these testing procedures.

There have been a few studies related to dairy manure. One such study was conducted in Washington State in 1992 (Bierlink et al., 1993). They evaluated eleven commercially available treatments with claims to control odor. Products consisted of plant extracts, plant growth regulators, microbes with nutrients and/or enzymes and lime and zeolites. Twenty six, 5 gallon buckets were filled with 4 gallons of the manure and treated according to manufacturers recommendations. Buckets were agitated biweekly and 100 ml samples were removed for sniff analysis. None of the treatments significantly improved the olfactory rating (probability $< .10$). One treatment had a tendency for slight improvement while another treatment made the olfactory rating significantly worse (probability $<.10$). All of the companies representing these products could honestly advertise that their product was University tested. As an informed reader you would quickly differentiate that having an unbiased test does not equate to proven product claims. This test was done on slurry manure. One may or may not anticipate different results if the products were added to commercial retention ponds.

When additives, enzymes, and chemicals do work in liquid manure systems they typically fit into either the third or fifth category. Either they serve to degrade the undesirable volatile acids or serve to alter or eliminate microbial activity responsible for odor production. One of the greatest challenges with additives is trying to determine if the product will work under the conditions at a specific dairy.

Theoretically, the products have the potential to work. However, they do not all work. Some only work during part of the year.

Before trying a product identify a method and process to evaluate the effectiveness of the product. Keep in mind that the use of the product will be confounded in time. You will need to determine conditions and normal activities and odors before and after the product is introduced. It is important to select a time period when climate is going to be relatively consistent for the comparison period.

Important questions to address related to chemical and biological additives.

Parameter	Chemical and biological additives
Odor control	Is there a beneficial result from use of the product?
Reliability	Does the product work consistently during different weather conditions and through changes in animal diet and housing?
Nutrient content	Does the product promote ammonia volatilization (undesirable from an air quality point of view)?
Total solids	Is the concentration of total solids reduced? If so, what air emissions occur?

Aeration

The objective of aeration is to add oxygen into a manure storage system to effectively change the microbial population from those that thrive without oxygen to those that use oxygen. Changing the microbial population to aerobic microbes changes the end products of digestion. The end products of anaerobic microbes are methane and volatile organic acids. The end products of aerobic digestion are carbon dioxide and water.

Normal liquid manure collection systems contain manure (feces and urine) and potentially bedding. Contribution of bedding to the liquid waste stream must be calculated when considering aeration. Separation of solids from the liquid waste stream is helpful prior to aeration. This reduces the volume of solids that are available for digestion. However, a competent solids separation system does not guarantee effective aeration.

The use of aeration as a treatment technology in municipal waste treatment plants is designed to match the horsepower to the daily volatile solids loading rate. For many of the aeration technologies generally used on dairy retention ponds the number of units is based on the number of cows. Some companies suggest one unit for each 100 or 125 cows. This may or may not consider the volatile solids loading rate.

One of the key indicators of the effectiveness of aeration is to measure the dissolved oxygen concentration. It is generally accepted that the oxidation-reduction potential (ORP) value is an indirect measure of dissolved oxygen at concentrations that cannot be measured directly with oxygen probes (Kjaergaard, 1977). At relatively low or not measurable oxygen concentrations it is necessary to monitor ORP. Charpentier et al., 1987, provided a table to describe the relationship between ORP, treatment conditions, and carbon, nitrogen, and phosphorus removal. They listed ORP values of –500 mV with fermentative pathway to yield methane and enhanced reduction to yield ammonium. At this

ORP, phosphorus is released into the interstitial liquid. For ORP values of –300 mV the only change was the fate of carbon from methane to volatile acids (these may have offensive odor). For both of these categories there is an absence of dissolved oxygen and there is clear anaerobic zone fermentation. At ORP of 0 mV, nitrate can be measured even through there is no dissolved oxygen. Anaerobic respiration occurs and an oxidative pathway yields carbon dioxide and water. Denitrification of nitrate to dinitrogen gas can occur. Phosphorus is trapped in the sludge. Sludge would need to be removed to yield any benefit to phosphorus concentrations. At positive ORP (+100 mV) dissolved oxygen is present, and aerobic respiration occurs. Carbon end products are similar to 0 mV. There is sufficient amount of oxygen for nitrification to occur (ammonium converted to nitrate). Phosphorus uptake can occur as phosphorus is trapped in the sludge. The sludge would need to be removed to get any type of phosphorus credits.

If you select this technology, be sure to evaluate effectiveness in your operation. Work with a private laboratory to compare ORP values before installation of the technology and after. Work with someone from your local land grant university to establish a reasonable protocol for ORP evaluation. It is important to sample enough locations and under different circumstances (before technology, after infusion of irrigation water, etc.).

In the summer of 2002 we had the opportunity to evaluate ORP concentration on dairy ponds in California. Consistently, we found considerable variation over the surface of a pond. For many of the ponds, the least negative value was the inlet water entering the pond. This water usually was recycled water from the same pond or from another pond. Ponds were sampled at multiple locations and depths. Three of the five dairies did not use aeration devices on their retention ponds. The average ORP and standard deviations for the primary pond at these facilities was –339 ± 159, -230 ± 132, -215 ± 78. Two of the dairies had multiple aerators on the primary ponds. The average and standard deviations for these ponds was -387 ± 26 , -238 ± 98.

Important questions to address related to aeration technology.

Parameter	Aeration Technology
Dissolved Oxygen (DO) Concentration or Oxidation Reduction Potential (ORP)	What are the DO and ORP concentrations in your current system (measure at many locations) ? How will you test the technology? Will you be able to detect measurable concentrations of oxygen? Will you be able to detect changes in ORP?
Energy use	How will you document energy use?
Nutrient content	How will you sample to determine if there is a change in nutrient content of the retention pond water?
Fertilizer value	The nutrient sampling protocol should be developed to determine if there are changes in organic N.
Total solids	Sufficient number of samples need to be obtained to determine if total solids are changed as a result of the technology (many locations and depths).

- As with any technology, there will be a learning curve for facility managers and operators. A maintenance schedule will be necessary and at least two people at the facility will need to know the intricate details associated with proper aerator maintenance. Any individual going in a boat to provide maintenance to the aerator should wear a life preserver. Lifelines should be connected to the individual and the boat and the opposite end of the lifelines should be in the skilled hands of someone directly at the shore of the pond. Swimming in manure ponds is NOT a pleasant activity and can be dangerous. Because retention ponds classify as confined spaces, there are worker safety rules from the Occupational Safety and Health Association.

Solid liquid separation

Probably the largest number of questions dairy producers ask relates to defining the best method to remove solids from a liquid waste stream. Dairies that change housing from corrals to freestalls must consider the consequences of this decision on the liquid storage pond. There are at least four standard methods used to separate solids from a liquid stream: 1) single screen separation; 2) double screen separation; 3) settling basins; and 4) weeping wall separation.

Traditional inclined screens have a straight slope or are slightly concave. The screen openings are usually 1.5 mm (1500 microns) or roughly 60/1000 of an inch. Various screens were evaluated on commercial dairies in California between 1995 and 1997. The work evaluated the effectiveness of the screens at removing total solids and also looked at the nutrient content of the screen influent, effluent and removed solids. In all of these systems recycled liquid manure from the retention pond was used to flush lanes. Therefore, the total solids concentration of the influent started with solids and nutrients before coming in contact with manure in the freestalls. The simple efficiency of total solids removal was either less than 5% (water went from flush lanes into the retention pond and then was pumped over the separator from the pond) or between 9 and 15% (flush water came from lanes, into a sump, and then was pumped over the screen). Removal of water soluble or small particulate form nutrients (ammonium, phosphorus, potassium, calcium, magnesium, and sodium) was a function of the high water content of the removed solids (83 to 85% moisture).

A few years ago there was a trend for dairy producers to install a double screen system where the second screen was much smaller 30 or 20 thousandths (roughly 760 or 510 microns). The initial advertisements indicated that the total solids removal was anywhere from 86 to 95%. One set of tables provided by the scientists conducting the research indicated that there was a 60.2% and a 94.4% reduction of solids retained on their sieves from samples taken at the dairy. These data are on a percent of solids retained and did not include the percent of total solids in the samples or the number of samples processed. Their small screen size was 0.25 mm. Clearly, the advertisements were a bit misleading as they were reporting solids removed when compared to large particles and not on a total solids basis.

A California dairy with the double screen system was evaluated in August and again in October, 2001. Recycled manure water was used to flush the freestall lanes. The two screens were initially sampled at 10 to 15 second increments (influent and effluent). Based on the data, the sampling protocol was extended for the second screen to 30 second intervals as there was little variation in the influent or effluent concentrations. Efficiency of total solids separation was determined as the difference in the concentration of total solids in the influent water entering the first screen and the concentration of total solids in the effluent of the water exiting the second screen. At this dairy, there was a temporary storage basin between the screens so some settling of heavier materials did occur. The combined system efficiency was 34.5 and 35.2%. Samples were taken to evaluate the total solids concentration in the flush water as it entered the flush lanes. An adjusted efficiency was calculated by subtracting the concentration of the original flush total solids from the values obtained at the sampling sites. The adjusted values for total solids removal OVER ESTIMATED the solids removal with a value of 50.4% of total solids removed. The magnitude of the over estimation is unknown. In subtracting out the flush water concentration we are not accounting for that percent of total solids in the manure in the lanes. The actual total solids removal during the sampling trips was between the measured value of 34.5 and the adjusted value of 50.4%. We did not obtain data on bedding use.

Traditional settling basins have appeared in pairs at dairies. One is filled. Then it is dewatered while the second one is filled. An evaluation of basins on two separate dairies was conducted in 1997 and again in 1998. The smaller of the two dairies had 250 milking cows. The larger facility had 700 milking cows. Influent samples were taken at 15 second increments as water fell into the basins. Samples were analyzed for total solids and non-settleable solids. They fill and dewater cycle was one month filling and one month dewatering at both facilities. Daily samples were taken once per week for an eight week period. Efficiency of total solids removal was very variable. For the small dairy, the first summer weekly data were 46.6, 43.7, 9.2 and 17.4%. During the second summer the weekly sampling data were 25.7, 45.6, 22.3, 53.2, and 17.1%. The data for the larger dairy the first summer were 75.3, 75.2, 54.3 and 46.3%. Between the first and second summer an additional freestall was installed for cattle already housed at the dairy and two additional basins were installed. Weekly total solids removal was 27.7, 27.9, < 5, 27.3 during one cycle and 40.7, 40.8, 9.9, and 17.2% during the second cycle.

Settling basins did remove more total solids than did mechanical separators. Performance was inconsistent and could potentially be improved by reducing the number of days each basin was filled (reducing cycle duration to 3 weeks instead of 4) and by changing the inlet to be lengthwise opposite the outlet. In both instances the inlet and outlet were on the same surface. Basins performed differently at the same dairy at different times. Animal use of the freestalls and bedding amount were probably contributors to these differences. Percent of TS removed was 63.4, 59.6, 63.1 and 49.3 % for each of the trips. The higher values obtained during the March trips corresponded to observations made at the dairy that the structure filled faster (roughly eight weeks) in March than in July (roughly 12 weeks).

Through all of these sampling occasions nutrient analyses of some influent and effluent samples have been run. Although there was some benefit in the removal of organic N, other nutrients were not removed in large enough quantities to conclude that the separation devices would be useful in reducing ammonium, phosphorus or potassium in the liquid waste streams. Keep in mind that at all of these dairies, animals were fed commodity feeds, mixed rations, and some supplemented with long hay.

Important questions to address related to solid liquid separation technology.

Parameter	Solid liquid separation technology
Total solids	What percent of the total solids in the liquid stream can be removed? How will you determine if this is achieved?
Energy use	How will you document energy use? What additional resources (labor, equipment) are necessary to manage solids?
Labor use	How much labor will you need for maintenance (daily, weekly, monthly)?
Nutrient content	How will you sample solids to achieve credits for nutrient removal if this is necessary?

Liquid retention pond	Will you overload the retention pond and prevent it from biological activity if the separation technology is not functioning properly?
Bedding	How much bedding do you use? Can you at least recover the equivalent weight of the bedding with the technology?

- As with any technology, there will be a learning curve for facility managers and operators. A maintenance schedule will be necessary and at least two people at the facility will need to know the intricate details associated with proper solid liquid separation technology maintenance. Maintenance individuals need to understand operational aspects of the technology that may put them at risk during routine activities. Appropriate precautions need to be posted and employee training should occur.

Summary

It is anticipated that with the new Federal CAFO rule there will be even more people targeting their wares to dairy operators. There are a variety of technologies and products available to dairy operators to assist in manure management. Be advised that these merely ASSIST in manure management. The key to the actual management IS the manager. Identify where you can get reliable information. Be sure you ask to see research results from an independent party before investing in products. Check the results to be sure they back the claims. Ask others who are using the technology what they like and don't like. See if there are commonalities between your facility and theirs. The appropriate technology for you may not be the same thing for your neighbor. Identify what you want the product/technology to accomplish BEFORE you write a check.

For Future Reading

Bierlink, H. B., W.J. Mathews, D.C. Grusenmeyer. 1993. Fertilizer and olfactory management of dairy manure nutrients. J. Dairy Sci. 76 (suppl 1):258.

Charpentier, J., M. Florentz, and G. David. 1987. Oxidation-reduction potential (ORP) regulation: a way to optimize pollution removal and energy savings in the low load activated sludge process. Wat. Sci. Tech. 19: 645-655.

Kjaergaard, L. 1977. The redox potential: Its use and control in biotechnology. In: *Advances in biochemical engineering*. Springer-Verlag, Berlin, pp. 131-150.

Leggett, J., R.E. Graves, and L.E. Lanyon. Anaerobic Digestion: Biogas Production and Odor Reduction from Manure. G-77.PA.

On-Farm Composting Handbook. 1992. NRAES-54. Northeast Northeast Regional Agricultural Engineering Service, 154 Riley-Robb Hall, Cornell University, Ithaca, NY 14853. http://www.nraes.org

On-Farm Biogas Production- NRAES-20. Northeast Regional Agricultural Engineering Service, 154 Riley-Robb Hall, Cornell University, Ithaca, NY 14853. http://www.nraes.org

Ritter, W.F. 1989. Odor Control of Livestock Wastes: State-of-the-Art in North America. J. Agric. Eng. Res. 42:51-62

US EPA. Guide to technology providers (this is for anaerobic digesters). http://www.epa.gov/agstar/tech/index.htm

US EPA. Guide to operational systems. http://www.epa.gov/agstar/operation/bystate.htm

Western United Resource Development, Inc. California Dairy Production Power Program. Money for Methane. http://www.wurdco.com/