Calculations:
Evaluation of Treatment
Technologies
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Dairy Cow Nitrogen to Groundwater, King's County Draft Dairy Element

244,715 Projected Increase in Dairy Cows
1.4 Animal Units/Cow
0.45 lbs N/day/AU, Lactating Dairy Cows, from Animal Waste Management Field Handbook, NRCS
154170.5 lbs N/day Additional Nitrogen produced by new Dairy Cows

Assume that these cows are in freestall dairies with 100% of waste manure routed to anaerobic Digestion lagoons, and that these lagoons are lined to the NRCS standard of 1x10^(-5) cm/s permeability.

Freestall Dairies:
Water use/cow: 150 gal/day
= 20.05079535 cu.ft/day/cow
Milk Production: 18000 lb/year/cow
49.31506849 lb/day/cow
5.91227608 gal/day/cow
Remainder is waste: 144.0877239 gal/day/cow
= 19.26048976 cu.ft/day/cow
Freestall Dairy N/day: 154170.45 lbs N/day
Subtract N emmitted as atmospheric (per Draft Plan estimate)
5840 tons/year ammonia (middle value from estimate in Table 4.2-5a)
4812.16 tons/year ammonia as N
1761 tons/year NOx
397.986 tons/year NOx as N
5210.146 tons/year atmospheric N
28548.74521 lbs N/day
125621.7048 lbs N/day remaining in liquid
Freestall Dairy liquid wastewater:
4713330.752 cu.ft/day
294111839 lbs/day
Concentration of N: 0.000427122
= 427.1222309 mg/l
Average depth of anaerobic dairy lagoon:
15 feet
Total surface area of anaerobic dairy lagoons at freestall operations:
314222.0502 square feet
NRCS Permitted infiltration rate:
0.00001 cm/s
3.28084E-07 ft/sec.
0.028346457 ft/day
8907.081737 cubic feet/day
Infiltration of N from Freestall Dairies at NRCS permitted infiltration rate:
237.3953476 lb/day N
43.32465094 tons/year N

1,000 or more dairy cows increased from 564 to 878 (U.S.D.A., 1992a, 1997), while the total number of dairies decreased from 155,389 to 116,874.

An increasing percentage of milk is produced in dairies classified as "Concentrated Animal Feed Operations," or CAFOs. A CAFO has 1,000 or more animal units, or is specially designated with 300 to 700 animal units. An animal unit is the equivalent of a 1,000-lb animal. Dairies with more than 700 head of mature dairy cows, whether milked or dry, are classified as CAFOs by the U.S. Environmental Protection Agency (EPA) (EPA, 2000).

Along with the transition from family-operated dairies to CAFOs have been several costs. When dairy cows are kept in close proximity to one another, a greater concentration of potential pollutants is generated than was previously the case with small family-operated dairies. These potential pollutants include emitted gases, such as ammonia, hydrogen sulfide (rotten egg gas), nitrous oxides, methane, and other odoriferous reactive organic gases. Many of these gases are toxic as well as odoriferous. There is increasing evidence that methane and other carbon compounds released into the atmosphere at rates above pre-20th century levels contribute to global warming (Wilkie, 1999, EPA, 1993).

Air Emissions From CAFO Dairies

Recent environmental analyses of very large dairies show tremendous potential to emit a wide range of air pollutants. The Kings County *Draft Dairy Element of the Kings County General Plan Draft Program Environmental Impact Report* (EIR), lists ammonia, hydrogen sulfide, reactive organic gases and methane as gases produced emitted from dairy lagoons (Kings County, 2000). Estimated loadings for these same air pollutants were listed in the EIR of a very large proposed dairy in Kern County, California (Kern County, 1999). Air emissions are also one of the primary concerns driving the EPA to advocate use of covered anaerobic digesters (Moser et al, 1998). The following table shows estimated air emissions from dairy sources (Kings County, 2000).

Estimated Annual Dairy Air Emissions, Tons

2,000-Milk Cow Dairy

Sources	**Methane** (CH_4)	**Hydrogen Sulfide** (H_2S)	**Ammonia** (NH_3)	**Reactive Organic Gases**	**Particulate** (PM10)
Fugitive dust from cattle movement in unpaved corrals	NA	NA	NA	NA	54
Manure decomposition	256	--	156	29	NA
Cattle Digestion	372	--	--	--	NA
Total	628	Insignificant	156	29	54

Air emissions from manure decomposition and cattle movement are influenced by the selection of either freestall or corrals to manage dairy cattle, which is discussed further later in this report.

Air emission odors are quantifiable using an odor threshold test as defined in *Standard*

Methods for the Examination of Water and Wastewater. This test could be used to limit the emission of otherwise difficult-to-quantify reactive organic gases (APHA/AWWA/WEF, 1998).

Seepage to Groundwater from CAFO Dairies

Potential pollutants may reach surface or groundwater, including nitrogen compounds, potassium, phosphorus, other nutrients and salts, traces of dairy antibiotics and hormones, minerals and cleansing compounds, and other organic pollutants. High volume releases of dairy waste include high fecal coliform counts and high biochemical oxygen demands that drastically impair water quality. Even small volume releases of insufficiently treated dairy waste to surface water will, over time, increase nutrient loads to those surface water bodies. High nutrient loads in surface waters are well linked to algae blooms, low dissolved oxygen, toxic releases from algae die-off, fish kills and impaired recreational value (Welch, 1990).

Numerous studies have shown that dairy waste may severely impact groundwater. In 1992, a groundwater study was conducted at the Hornby Dairy lagoon near Sunnyside Washington. This study showed that in silty soils, chloride concentrations in all wells downgradient of the main lagoon increased after the second and third quarters of monitoring (between four and ten months after the main lagoon received wastewater), probably due to leakage from the lagoon (Erickson, 1992). Chloride, being highly soluble, is a useful marker for groundwater from different sources.

A study conducted in Orange County, California of the Chino Basin groundwater reservoir showed conclusively that dairies in the basin were contributing most of the salt contaminating groundwater in the three areas of the Chino Basin (CRWQCB, 1990). The concentration of total dissolved solids (salts) in the groundwater of Chino Basin III (where most of the basin's dairies are located) increased from a range of 300 to 500 mg/L in 1950, to 709 mg/L in 1986. In the period from 1991 and 1995, Chino Basin III salt concentrations were 772 mg/L (Wildermuth Environmental, 1999). Compared to other salt load contributors, lands receiving dairy manure contribute significantly more salt per acre. Lands receiving dairy manure include most of the remaining agricultural lands in the basin. In 1997, the theoretical dairy manure disposal area in the Chino Basin was 20,950 acres. Based on the number of milking and non-milking dairy cows, the manure application rate was 23 tons per acre per year, compared to the recommended 3 tons per acre per year to limit salt reaching groundwater (Wildermuth Environmental, 1999; CRWQCB, 1990).

In a recent analysis of a proposed large-scale dairy, Norman, Oklahoma engineer Kathy J. Martin, P.E., calculated the impact to groundwater from seepage from the lagoon system of a large proposed dairy. Assuming that the lagoons held average dairy lagoon concentrations of ammonia and total organic (kjehldahl) nitrogen, and seeped toward groundwater at the California regulatory limit of 1 x 10^{-5} cm/sec, they would contribute 83 tons per year total nitrogen to groundwater (Martin, 2000).

In south-central Idaho, the Idaho Department of Agriculture has been investigating high nitrate concentrations in rural wells located in close proximity to large-scale dairies. To date studies have shown conclusively that agricultural practices are negatively impacting groundwater quality, including elevated nitrates (ISDA, 2000). Large dairies comprise a great deal of the agricultural activity in the impacted areas.

A study comparing the effectiveness of different lagoon lining material in New Mexico showed that even dairies using synthetic liners but with corral-style arrangements for cows contributed to groundwater contamination. Using data collected over a six-year period from monitoring wells around seven lagoons at seven different dairies with 1,000 or more cows, the study showed that even with a synthetic membrane lagoon liner, some contaminants were found at levels significantly above water quality standards. Total kjeldahl nitrogen (TKN), a measure of the amount of organic nitrogen, was relatively constant in the groundwater regardless of herd size and liner material. However, the study showed that use of synthetic liners, even with corral-style herd management, tended to very significantly reduce nitrate and ammonia concentrations in monitored groundwater. The authors' conclusions were that mean contaminant concentrations exceeded groundwater quality standards for nitrate, ammonia, chloride and total dissolved solids at all dairies. The authors also concluded that clay liners are the least effective and synthetic membrane liners are the most effective for reducing groundwater contamination (Arnold and Meister, 1999).

A dairy with 1,000 mature dairy cows produces approximately 2,100 pounds of biochemical oxygen demand (BOD) per day (USDA, 1992b). In contrast, a city of 10,000 people produces about 2,000 pounds of BOD per day (Linsley and Franzini, 1979). Also by comparison, in 1996 out of 16,024 publicly-owned treatment works in operation, serving populations as small as 200 people, all but 176 either did not discharge or had secondary treatment or better (U.S. EPA, 1999).

Dairies are not required to limit discharges to groundwater in any state in the United States to the degree that municipal waste water discharges to groundwater are limited, yet dairy wastewater loads are demonstrably higher per CAFO facility than they are for municipalities with up to 10,000 people. In the state of Washington, with the fourth-largest number of CAFO dairies in the United States (U.S. Census Bureau, 2000), until recently there was no enforced standard for seepage rates from dairy waste lagoons. The current standard in Washington is now based on the Natural Resources Conservation Service (NRCS) recommendation of 1 x 10^{-6}cm/sec. Municipal wastewater lagoons, by contrast, are required by the Washington State Department of Ecology to install synthetic liners (Ecology, 1998). As with air emissions, the style of dairy management greatly affects the potential for impacts to groundwater quality. This subject is discussed further in the following sections.

Dairy Animal Housing and Waste Collection

Many new CAFO dairies are constructed as freestall dairies, either open-air or enclosed. A main advantage of this dairy construction style is ease of herd management and waste management. This arrangement is advantageous to dairy production in allowing for efficient feeding, medication and herding to the milking parlor. A freestall system housed in a barn (enclosed freestall) has the additional advantage of separating precipitation and runoff from the waste volume to be treated. If a scrape system is employed to move manure to a treatment system, then little or no additional water is needed in the treatment process.

Some new dairies under construction have corrals or pens configured between alleys. Such dairies generally have either high liquid waste collection routed to unlined waste storage lagoons that are likely to deteriorate groundwater quality and air quality, or inadequate waste management that will likely impact groundwater and air to an even greater degree than unlined waste storage lagoons. Where corral-style dairies are constructed with lined or monitored waste storage lagoons, the additional construction may result in prohibitively high capital and maintenance costs.

The designs for housing and waste collection on a dairy are logically linked. Along with the movement toward ever larger dairy facilities, dairy cow barn design has evolved toward freestall dairies. To optimize space as well as assist in protecting the health of the animals, freestall dairies are constructed to provide access for each cow to both the feed stalls arranged facing a feed alley, and a walkway behind each stall. The walkway is used by the cows to go toward the milking parlor and by the dairy to manage the herd effectively, rotating dry cows out and newly lactating cows in.

The freestall arrangement is also conducive to waste collection. When a set of cows is in the milking parlor, it is relatively easy for that portion of the freestall area to be scraped or flushed of accumulated manure. Since cows are commonly milked two to three times per day, manure removal can be quite frequent, keeping the freestall clean and relatively odor free.

Scrape waste collection is usually accomplished with small motorized dozers or other non-automatic means. Automatic scraper systems have been determined by some dairies to be too costly for the benefit provided. For very large dairies, with greater than 2,000 milk cows, it might be cost-effective to implement an automated mechanized scraper system to save on labor costs, although the construction of such a system that would be safe for workers and cows would be quite capital intensive.

Open-air freestall dairies tend to use flush systems for waste removal. These systems can be automatic; however, the additional water used for the flush must be treated along with the rest of the waste stream, which may make construction of the treatment system more expensive and possibly uneconomical for the dairy as a whole (U.S.D.A. 1992b).

Dairy Waste Treatment Approaches

There are currently several categories of treatment technologies applied to treat liquid and solid dairy waste at CAFOs. In the four states with the most dairies larger than 500 cows, most dairy waste solids are composted or treated anaerobically[3]. Liquid dairy waste is generally treated in deep lagoons that are functionally anaerobic, though they are usually managed as a storage facility rather than as a treatment facility (EPA, 1997). These anaerobic systems are generally not constructed with controls or monitoring for air emission or groundwater seepage.

Dairy waste treatments in use include: aerobic liquid waste stabilization; facultative lagoons[4]; anaerobic treatment with and without supplemental aerobic treatment; and well-mixed, uncovered anaerobic liquid waste treatment systems (EPA, 2001). Anaerobic treatment systems include plug-flow[5] and mixed systems, as well as essentially unmanaged functionally anaerobic deep lagoons. In addition, there are other technologies currently being evaluated for dairy waste treatment, but that have not been applied to operating dairies.

For systems with low solids concentrations, aerobic treatment alone has been attempted. Even for relatively low solids concentration, high power inputs or large areas are required to achieve adequate treatment for water quality and air emission control. For high solids dairy waste, aerobic treatment is impractical (Roos, 2001). For systems that are operated as freestall dairies, low-liquid anaerobic systems appear to be the most cost-effective and environmentally protective systems currently available.

Dairy Waste Treatment Methods Comparison

	Relative Cost	Air Emission Risk	Groundwater Seepage Risk	Surface Water Risk
High-solids plug flow anaerobic digesters	Moderate with cogeneration	Very low	Very low	Very low
Lined[a], low-solids anaerobic lagoons, well mixed, uncovered	Moderate to high cost	Moderate- primarily methane (CH_4)	Very low	Moderate – may overflow with high precip.
Lined[a], low solids anaerobic lagoons, unmixed	Moderate	Moderate to High – CH_4, ROG[b], H_2S[c], NH_3[d]	Very low	Moderate – may overflow with high precip.
Lined[a], subsurface aerated lagoons, uncovered	High cost installation and operation	Moderate – ROG	Very low	Moderate – may overflow with high precip.
Unlined, unmixed anaerobic lagoons	Low initial cost, potentially high environmental cost	Moderate to High – CH_4, ROG, H_2S, NH_3	Moderate to High – seepage rate depends on soil type	Moderate – may overflow with high precip.

Notes: (a) Lined = synthetic membrane liner, HDPE or equivalent in performance

(b) ROG = reactive organic gases

(c) H_2S = hydrogen sulfide gas

(d) NH_3 = ammonia

In cold and/or temperate climates with relatively high density development and associated high land costs, a plug-flow anaerobic digester coupled with an enclosed freestall dairy appears to offer significant benefits in low operation costs, energy efficiency and cogeneration[6], and a relatively small land use requirement. Recent experience with such digesters indicates that their operation has low maintenance requirements with the added benefits of gas collection, excellent odor control, and marketable, easily handled digested solids suitable for use as a fertilizer (Moser, et al, 1998). In dairies with the low-liquid type of waste solids handling, milking parlor wastewater is most effectively handled with either a recirculating treatment/flush system or stored in a well-mixed[7], anoxic[8], lined basin prior to being carefully land-applied to forage crops.

Milking parlors are operated with relatively dilute wastewater compared to pen area waste. Some milk parlor waste water is recycled, such as cooling water recycled as wash water, then wash water used to provide enough liquid for the plug flow digester to function. If not recycled or added to a plug-flow manure treatment system, parlor wastewater is best treated in a lined, well-mixed anaerobic lagoon or treatment tank.

Parlor wastewater anaerobic treatment lagoons are either covered or uncovered, depending upon proximity to residential areas, prevailing winds, and pollution control requirements. If the anaerobic lagoon is well-mixed, it is more likely to maintain the correct ratio between those bacteria that produce acid and the bacteria that convert the acid to methane. Otherwise, the result is poor digestion, excessive odors, and poor solids characteristics (Wilkie, 1999).

High volume, liquid lagoon-based dairy waste treatment systems are often thought to be cost-effective in certain arid portions of the rural west. In arid climates with annual evaporation rates significantly higher than annual precipitation, a lagoon will evaporate a significant percentage of stored wastewater, making liquid collection and waste storage attractive. However, proper control of air emissions and groundwater quality are imperative and quite expensive with high-volume, liquid lagoon treatment. To protect groundwater, the lagoon should be synthetic-membrane lined and monitored. Air quality can be protected by keeping the lagoon well-mixed and/or covering it with a membrane cover. In many instances, we can predict that the added cost of proper environmental controls will negate cost advantages of this type of treatment. The discussion below describes some of the most recent work on aerated and anaerobic treatment systems.

Aerobic Systems. Conventional surface aerators, while relatively inexpensive to purchase, in general have the disadvantage of a relatively shallow influence on the dissolved oxygen concentration in wastewaters, with DO concentrations reducing in proportion to the cube of the depth below the aerator. Conventional surface aerators also tend to create misting and aerosols that discharge volatile organic compounds, which are often odoriferous as well as environmentally damaging. Conventional surface aeration requires a great deal of power to operate. Therefore, for a look at aeration technology, other aeration techniques were examined for this report. Other aeration techniques include high-output subsurface aeration and subsurface membrane aerators. These techniques tend to have a lower ratio of power required to average DO concentration than surface aerators, and result in more thoroughly aerated treatment volumes.

Subsurface aeration appears to be gaining users in the municipal wastewater treatment industry. However, very few animal residuals generators use aeration of any kind, due to the high cost of power for the aerators. Several food processing industry wastewater generators use subsurface jet aerators. Fine-bubble membrane diffusion is used in high-solids municipal wastewater treatment. If aeration were to be used, these two means of delivering oxygen to the subsurface are the most efficient that are currently available, particularly for relatively high solids such as in dairy waste lagoons (usually total solids are 1,000 mg/L or above). Even with fine-bubble membrane diffusers and jet aeration, there is a very large power requirement compared to mixed anaerobic digestion or plug-flow anaerobic digestion. The operating expense of aeration is not warranted since aeration is best suited to reducing wastewater biological activity, which is not necessary in animal residuals systems that rely on land application.

Anaerobic Systems. For anaerobic digestion to work most efficiently with biosolids such as dairy cow manure, the temperature of the digester is maintained in a narrow range just below 100°F. In some relatively warm climates, maintaining a temperature range just below 100°F is feasible with heat from the biological activity of the digester, particularly if the digester is well insulated (in the ground) with a protected surface area (such as a cover). In climates with wide temperature ranges, where the frost depth may reach several feet below ground during the winter and ambient temperatures may exceed 100°F in the summer, anaerobic digestion without supplemental heat may not be feasible. Experience with unheated and uncovered plug-flow anaerobic digestion systems indicates that the digestion process is quite slow in colder climates, resulting in significant solids buildup while still producing unacceptably high concentrations of ammonia and hydrogen sulfide.

According to Water Supply and Pollution Control, Third Edition by Clark, Viessman and Hammer and published by Harper and Row in 1977, "Problems in operating anaerobic treatment systems result when an inbalance (sic) occurs in the population dynamics. For example, if a sudden excess of organic matter is fed to a digester, acid formers (bacteria) very rapidly process this food, developing excess organic acids. The methane formers (other bacteria), whose population had been limited by a previous lower organic acid (food) supply, are unable to metabolize the organic acids fast enough to prevent a drop in pH. When the pH drops, the methane bacteria are affected first, further reducing their capacity to break down the acids. Under severe or prolonged overloading, the contents of the digester "pickle" in excess acids, and all bacterial activity is inhibited. In addition to organic overloading, the digestion process can be upset by a sudden increase in temperature, a significant shift in the type of substrate (bacterial food material in the wastewater), or additions of toxic or inhibiting substances from industrial wastes." (Clark, et al, 1977)

Inherent in the operation of a plug-flow anaerobic digester system is the cost of maintaining a constant temperature range for the anaerobic cell. In addition, gas and odor control require gas enclosure, recovery, storage, and fate (flaring or power generation). Since anaerobic digestion removes nitrogen from the system by off-gassing nitrogen in the form of ammonia, some of the potential nutrient value of nitrogen for field application is gone. However, this may be desirable in many operations where waste generation nitrogen exceeds the crop requirement of the on-site acreage. The concentrations of phosphorus and potassium are relatively unaffected by treatment in a plug-flow anaerobic digester.

Specific Installations

Aerobic

A high-output subsurface aeration system[9] was examined, but determined to be inappropriate for use on most dairies, since there are more economical treatments available for the waste load and waste characteristics of a 2,000-milk cow dairy. A significantly larger dairy might warrant installation of a high-output subsurface aeration system if cost factors indicated that it was the most efficient treatment system to use. No dairies were located that use high-output subsurface aeration. High-output subsurface aeration systems are in use by the food processing industry, which generally has wastewater with high chemical oxygen demand and high solids loading (Waterlink, 2000).

John Reed and Art Riddick of Reed Engineering in Virginia have designed numerous high-output aeration installations, including many for food processing wastewater treatment plants. Mr. Riddick states that the influent BOD load is about 1,000 mg/l and the influent organic nitrogen load is about 300 mg/l, both similar to dairy wastewater from diluted, open-air freestall dairies. Mr. Riddick also reported that odor is well controlled, and the aerators have been uniformly mechanically reliable and easy to maintain, since all moving parts are located in a dry environment outside of the treatment basin (Riddick, 2000).

Aerobic Systems in the San Joaquin Valley are described in the Kings County Draft Dairy Element of the Kings County General Plan. One dairy facility in Kings County and one dairy facility in Kern County operate aerobic treatment systems. The aerobic treatment system in Kings County was developed as a six-month pilot study conducted at the Longfellow Dairy in Hanford; the study was conducted by Rain for Rent, Mazzei Injector Corporation, University of California at Davis, and the University of California Cooperative Extension Service. The treatment system was designed to handle approximately 5,000 gallons per day of flushed manure. The system consisted of a solids separator, two treatment tanks equipped with aerators (two-stage treatment), and an effluent storage basin. Flushed manure was effectively treated to eliminate the potential generation of ammonia gas by implementing a two-stage process, where the organic loading was reduced in the first stage and the conversion of nitrogen to nitrate was accomplished by nitrification in the second stage. However, although treatment would reduce the total suspended solids of the manure, periodic cleaning of the system would be needed to remove eventual solids accumulation in the tanks (Meyer, et al, 2000, Kings County, 2000).

In the first months of 2001, the cost of electric power has increased significantly in California and appears likely to increase across the nation. Based on a calculation of power consumption for the system, at 10 cents per kilowatt-hour, the electricity cost for aerobic treatment would add 12 cents to the cost of each gallon of milk.

Anaerobic

Covered Anaerobic Lagoon - Dr. Doug Williams of Cal Poly State University in San Luis Obispo, California reports that odor difficulties at the university's dairy were primarily associated with the unmixed storage lagoon that accepts stormwater and the effluent from the covered anaerobic wastewater treatment cell. That lagoon is scheduled to have a mixing and/or aeration system installed in the near future. The anaerobic cell is a 4-million gallon, 250-foot square, 15-foot deep (average depth) basin that is completely covered by an air-tight flexible membrane. Ammonia, methane and hydrogen sulfide are collected inside the membrane and routed to a micro-turbine for power generation used to operate the dairy's milking parlor. Dr. Williams acknowledged that the treatment system was large for the 200 cows currently at the dairy. He said that the dairy system capacity was designed for 500 cows (Personal communication, Williams, 2000).

The influent concentration of the Cal Poly dairy milking parlor wastewater is 4,000 to 5,000 mg/l Chemical Oxygen Demand (COD), and the effluent COD concentration is about 1,000 mg/l. The operating temperature of the cell is between 60° and 74°F, which is considerably below the conventional recommended range. Nevertheless, Dr. Williams reported that the anaerobic bacteria at the Cal Poly facility have adapted to the lower temperature and are keeping up with the influent loading quite well. Since Cal Poly's facility routes stormwater to the storage lagoon below the anaerobic treatment basin, the liquid level in the anaerobic basin is kept at a constant level. Constant temperature, controlled anaerobic conditions, and a constant water level are factors that greatly facilitate maintaining a viable anaerobic bacteria colony. Liquid effluent from the storage lagoon is land-applied for nutrient supplement (Williams, 2000).

Plug-Flow Uncovered Anaerobic Lagoon - Gail Clowers of WSU's Puyallup facility reported that from 1985 until 1997, his facility operated an anaerobic lagoon. During that period lagoons that were not receiving effective treatment filled with solids, even with the temperate climate of Puyallup, Washington. Mr. Clowers reported that he had to spend over $20,000 to dredge the anaerobic lagoons at the dairy to make enough volume available for the required liquid storage for the facility (Clowers, 2000)

The Puyallup facility's anaerobic lagoon was not insulated, nor was there any attempt to recover emitted gases. The sole purpose of the lagoon was to enhance manure handling, which was not effective. It is likely that the lagoon became too acidic, which resulted in odor complaints and poor flow characteristics.

Well-Mixed Anaerobic Lagoons. There are several dairies now utilizing well-mixed anaerobic wastewater lagoons. Researchers contacted at WSU have indicated that they are planning to implement extensive analysis, in conjunction with the University of Idaho, of the ammonia gas production of an existing and also possibly a newly-constructed dairy lagoon system using low-speed surface mixers. As part of that research effort, data will be collected on the lagoon's hydraulics, oxygen, BOD, nitrogen compounds and solids concentration both with and without using low-speed surface mixers (Yonge, 2000).

Plug-Flow Covered/Insulated Anaerobic Digester, Minnesota - The Haubenschild Dairy located near Princeton, Minnesota, is a 450-cow dairy that has a covered freestall barn system. The stalls are cleaned with manure scrapers that deposit the manure in a viscous slurry that is routed to a mixer and then to a heated, insulated, covered anaerobic plug-flow digester. Processed manure from the digester is marketed as a soil amendment. Liquid effluent from the milking parlor washwater is routed to the mixer to provide sufficient dilution for the manure slurry (Nelson & Lamb, 2000). Since the waste stream is entirely contained within impermeable barriers such as the concrete freestall floors and the concrete digester, this dairy does not adversely impact groundwater quality.

Plug-Flow Covered/Insulated Anaerobic Digester, California – The Langerwerf Dairy, located near Durham, California, has been operating a plug-flow anaerobic digester since 1981. In 1998, the digester was refurbished. The key to the successful operation of this digester system is the original digester design and construction, as well as the dairy's attention to maintenance. By the time of refurbishment in 1998, the mechanical systems, predictably, were in the greatest need of replacement. In addition, the digester cover had developed pin-hole leaks, primarily from ultra-violet light degradation of the Hypalon membrane material. One of the findings during clean-out of the digester was the lack of struvite, magnesium ammonium phosphate, a common compound formed during treatment of organic wastes (Moser & Langerwerf, 2000). Struvite buildup physically inhibits the flow in waste treatment systems. The lack of struvite is testimony to the long-term efficient operation of the plug-flow digester at the Langerwerf Dairy. As with the Haubenschild Dairy, the Langerwerf Dairy's use of impermeable surfaces for manure management is protective of groundwater quality.

Mixed, Covered Anaerobic Digester - In the Environmental Impact Report for the Borba Dairy, a 28,000 head facility proposed for location near Bakersfield, California, Mr. John D. Fleming, PhD, of Mead & Hunt West, Inc. suggests that of anaerobic treatment system technologies, a lagoon-based covered anaerobic system is most appropriate for a dairy, based on land availability and relatively low capital cost compared to the required investment for a fixed growth or combination anaerobic digestion system. Mr. Fleming posits that maintaining a temperature in the range of 85 to 95°F would work, as defined in the Standard Handbook of Environmental Engineering by Robert A. Corbett, published by McGraw Hill. Among the features for such a system would be a sealed cover designed to meet seismic 4+ requirements, with methane filtration, moisture separation, and cleaned gas storage. For the proposed Borba Dairy, Mr. Fleming stated that such a system would cost about $8 million, including engineering and installation. This cost would include about 32 days of storage out of the required 120 days, so an extra 88 days of storage capacity and solids removal capabilities would also be required (Kern County Planning, 1999).

A spreadsheet model of the manure cycle for the proposed Borba Dairy was generated. This model indicated that the least cost alternative with sufficient environmental controls on air and water emissions for the proposed 28,000 milk cow facility would be a series of covered plug-flow anaerobic digesters receiving waste from scraped freestalls. Liquid wastes from the milking parlor would be treated most cost-effectively with recycling of cooling water, followed by discharge to a synthetically-lined, mixed anaerobic lagoon for wastewater generated in excess of the makeup water needed for the plug flow digesters.

Glossary

1. A corral-style dairy houses milk cows in large open pens, with access alleys surrounding the pens.
2. A freestall dairy houses milk cows in stalls arranged on either side of an access alley that the dairy worker uses to provide feed to the animals. Behind the stalls, which are open at the back, are runways that allow the cows to move freely between stalls.

3. An anaerobic process is one that takes place in the absence of atmospheric air, particularly oxygen. Anaerobic organisms (mostly bacteria) are the agents of biologic anaerobic processes.

4. A facultative organism can grow and multiply in the presence or absence of oxygen.

5. Plug-flow anaerobic digester is a fully enclosed treatment container through which waste moves as a plug, unmixed within the container. Waste treatment depends on providing the optimum environment for anaerobic bacteria already present in the waste. In the course of the waste's transit through the container, the bacteria within it convert some of the organic material to acid, which is then converted by other anaerobic bacteria to methane and other biologically-derived gases.

6. Cogeneration is power generation from a facility that has a primary purpose other than power generation.

7. Well-mixed, with regard to waste treatment, means that the material within the treatment container is assumed to be mixed enough to have the same composition throughout the container.

8. Anoxic means, literally, "without oxygen". Anoxic reactors utterly lack dissolved oxygen and use the oxygen in nitrate molecules to oxidize waste. This differs from the anaerobic reactor, where nitrogenous wastes are converted from ammonia to nitrate molecules (Biotech Life Science Dictionary Online, 2001).

9. High-output subsurface aeration systems have high volume blowers pushing air through ducts and discharging the air through nozzles. The nozzles are placed at or near the bottom of the waste treatment container, which is generally 12 to 20 feet deep.

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