Chapter 1
Management and Treatment of Livestock Wastes

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Nomenclature

AU	Number of 1000 lb animal units per animal type
BOD_5	Five-day biochemical oxygen demand
BUW	Bedding unit weight, lb/ft^3
Ca^{+2}	Calcium cation
C	Targeted rate concentration
C*	Background rate concentration
Co	Initial concentration of conditions

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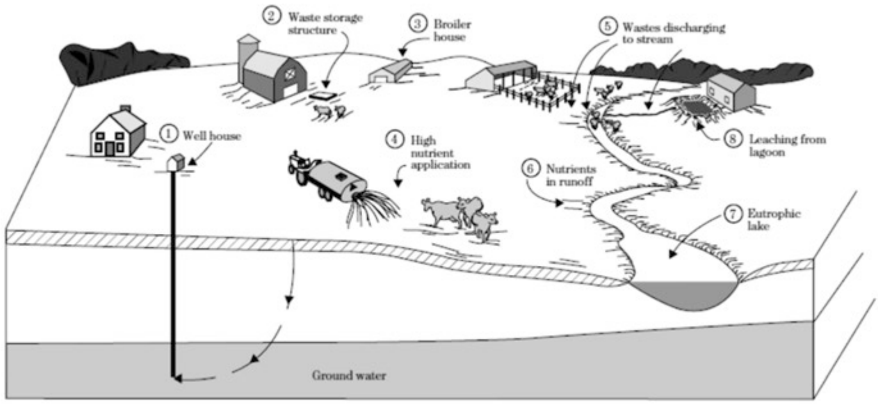
COD	Chemical oxygen demand
CH_3COOH	Acetic acid
CO	Carbon monoxide
CO_2	Carbon dioxide
D	Number of days in storage period
DS	Dissolved solids
DVM	Daily volume of manure production for animal type, ft^3/AU/day
FR	Volumetric void ratio
FS	Fixed solids
H_2	Diatomic hydrogen
HLR	Hydraulic loading rate
k	First-order rate constant (cm/day)
Mg^{+2}	Magnesium cation
$MMCTCO_{2e}$	Million metric tons of CO_2 equivalent
N_2	Diatomic nitrogen
NH_3-N	Ammonia-nitrogen
NH_4-N	Ammonium-nitrogen
NO	Nitrous oxide
OLR	Organic loading rate
PO_4^{-3}	Phosphate ion
q	Hydraulic loading rate (cm/day)
SS	Suspended solids
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
TS	Total solids
TBV	Total bedding volume stored, ft^3
TVM	Total volume of stored manure, ft^3
TWW	Total wastewater stored, ft^3
TVS	Total volatile solids
VMD	Volume of manure production for animal type for storage period, ft^3
WB	Weight of bedding used for animal type, lb/AU/day
WV	Volume of waste stored, ft^3

1.1 Introduction

In recent years, livestock waste management has been a rapidly changing technology. It is subject to government regulation and sensitive to population growth patterns, community attitudes, and land-use changes. It is influenced by variables such as soil type, topography, climate, crops, and livestock production practices. The evolution of larger and more concentrated livestock operations has accentuated the problems of waste management. Better management methods are necessary not only to hold down labor requirements and expense but also to minimize detrimental effects on the environment. Where animals are allowed to roam freely on pastures, such as is still done in many areas of the state, the manure from the livestock is deposited directly on the land and recycled with a minimum hazard to the environment. Even pasture production of livestock, however, requires management to prevent overgrazing, overcrowding, loss of vegetative cover, and the development of potential nonpoint sources of pollution. The facilities that cause the greatest environmental threat, however, are those in which the livestock are confined permanently or frequently on a regular basis. Figure 1.1 provides the consequences of infiltrated livestock waste.

In general, the regulations do not stipulate how waste must be handled but rather delineate the unsatisfactory practices and acceptable methods for correcting unsatisfactory situations. The decision-making process, when a farmer has to deal with correcting a problem situation, is essentially left to the farmer as to the selection of the system or combination of systems to correct the problems.

The frequent use of the term "waste" in this chapter is not intended to imply that we are dealing with a material of no value. The intent is to convey the understanding that the material consists of more than just the feces and urine excreted by the animals, for example, hair, soil, spilled feed, and other materials. In actuality, there is much that can be recovered and reused from this material for supplying plant



1. Contaminated well: Well water contaminated by bacteria and nitrates because of leaching through soil. (See item 4.)
2. Waste storage structure: Poisonous and explosive gases in structure.
3. Animals in poorly ventilated building: Ammonia and other gases create respiratory and eye problems in animals and corrosion of metals in building.
4. Waste applied at high rates: Nitrate toxicity and other N-related diseases in cattle grazing cool-season grasses; leaching of NO_3 and microorganisms through soil, fractured rock, and sinkholes.
5. Discharging lagoon, runoff from open feedlot, and cattle in creek: (a) Organic matter creates low dissolved oxygen levels in stream; (b) Ammonia concentration reaches toxic limits for fish; and (c) Stream is enriched with nutrients, creating eutrophic conditions in downstream lake.
6. Runoff from fields where livestock waste is spread and no conservation practices on land: P and NH_4 attached to eroded soil particles and soluble nutrients reach stream, creating eutrophic conditions in downstream lake.
7. Eutrophic conditions: Excess algae and aquatic weeds created by contributions from items 5 and 6; nitrite poisoning (brown-blood disease) in fish because of high N levels in bottom muds when spring overturn occurs.
8. Leaching of nutrients and bacteria from poorly sealed lagoon: May contaminate ground water or enter stream as interflow.

Fig. 1.1 Consequences of infiltrated livestock waste [1] fertilizers, livestock feed additives, and conversion to energy. Practical management practices to realize these and other benefits are encouraged whenever possible.

The manual has components grouped together by function, and systems are composed of components with different functions. For this reason, some skipping around in the manual will be necessary when using it for planning purposes. The important thing is to insure that the components selected for the system are compatible and adequate for their purpose as well as to insure that the entire system accomplishes its management objective. English units of measurement are used in examples, although metric units are included in many tables.

Another point to consider in consistent planning is whether the failure of one component will result in the failure of the entire system or if adequate flexibility is provided to permit continued operation without disastrous effects when unforeseen events happen. Often simple emergency or contingency measures can be planned into a system at various points, thereby preventing difficult situations later.

Data presented on waste production and characteristics are values generated from different parts of the United States, making it nearly impossible to define consistent values. Where specific values for an individual system can be obtained, these should be used in preference to the manual values. The values found in this chapter are deemed to provide perspective on what occurs in livestock operations across the country.

Selecting a system and the individual components involved is a process that includes engineering, economics, regulatory considerations, personal preferences, and other factors. There is no single system which is best. Each component, facility, or process has advantages and disadvantages. Each of these factors mentioned in the previous sentence needs to be given consideration in order to develop the most suitable waste management system for a given situation.

The information provided in this chapter is intended to create a frame for planning and sizing waste management system components. If systems require further explanation, the reader should consult the resources for further direction on determining what constituents are necessary to create a more adequate design. It may also be necessary to obtain professional design assistance.

1.1.1 Federal Regulations

Federal regulations have been mandated by the US Environmental Protection Agency (USEPA) since its establishment in 1970. For the purpose of livestock waste treatment, legislation is applicable for both air and water. Air pollution research began in 1955 prior to the formation of the USEPA when the Air Pollution Act was passed to support funding and research. In 1970, the Clean Air Act required air quality standards for existing facilities and the refusal of building new infrastructure if not compliance with current legislation [2]. In addition, legislation has the USEPA control air emissions from mobile and stationary sources and establishes the National Ambient Air Quality Standards (NAAQs). NAAQs regulate hazardous air pollutants for the purpose of protecting the public health and environment and are incorporated with State Implementation Plans [3].

Nevertheless, agriculture persists with odor problems, and further mandates were added later through the Clean Air Act Amendments of 1990. In the amendments, the legislation headed by the USEPA and Secrecies of Agriculture and Energy required reduction emissions that produce acid rain and for the protection of ozone, ammonia volatilization from animal and other agricultural operations for water and soil acidification, and methane emissions from rice and livestock production for ozone depletion [2]. Figure 1.2 provides the various methods in which air pollution can be caused by the livestock industry.

Water legislation began as early as 1886 with the River and Harbors Act of 1886 and 1889. Following the induction of the USEPA, the passing of the Federal Pollution Control Act of 1972 placed federal government responsible for creating and enforcing standards for water pollution control and maintaining the integrity of the water supplies, where a goal of having 0% discharge by 1985 was set. However, the biggest impact to water treatment in livestock wastes was the Clean Water Act of 1977. The Clean Water Act of 1977 introduces stringent legislation on feedlots and also required National Pollution Discharge Elimination System (NPDES) permits [2].

The National Pollution Discharge Elimination System (NDPES) regulates the quantity of waste entering navigable waters and also point sources [5]. In regard to

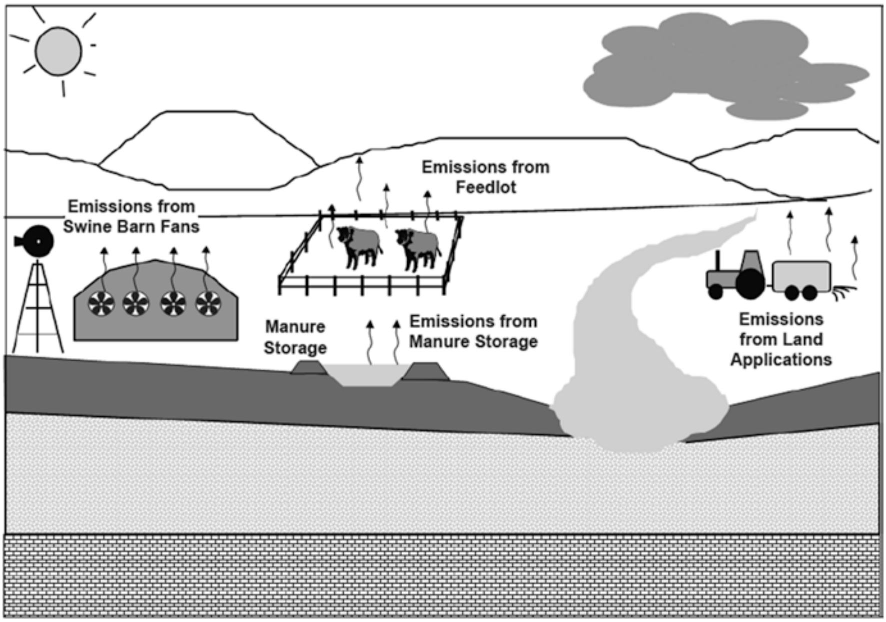


Fig. 1.2 Pathways for manure contaminants in the air [4]

livestock wastes, the NPDES require permits when discharging in the following conditions [2]:

1. Feeding operations consisting of 1000 animals confined for a time greater than 45 days per year and pollution less than 25 year, 24 storm events
2. Feeding operations with 300 animals discharge through a manmade device into navigable waters either from a feed lot of a manmade device
3. Hatcheries and fish farm cold-water ponds that have a total of 20,000 lbs animal production with 5000 lbs of food discharging 30 days per year, or warm-water ponds discharging 30 days per year

There have been several revisions made to NPDES permit involving concentrated animal feeding operations (CAFOs) or feedlots. The 2003 revision makes permits necessary for both open lots and CAFOs, refines the definition of CAFO requirements, and incorporates a nutrition management plan that considers faculty and land application issues where the lack of compliance can require CAFOs to point source. Proposed revisions have been suggested in 2008 and 2011 from outcomes of lawsuits submitted by both the industry and environmental interest groups. For example, in 2011, a proposal was made where it would have been required for a CAFO or its affiliated state to release information. The proposal was not mandated as the USEPA decided to make additional measures to ascertain existing techniques to collect necessary information [6, 7].

1.1.2 State Regulations

Regulations imposed by the state will vary. There are many resources available to the user to determine which regulations are appropriate for a given state. An investigation of specific state investigation will be up to the user. A list of each state's environmental agency with associated links is in Table 1.1.

1.2 Wastewater Characteristics

1.2.1 General Characteristics of Wastewater

1.2.1.1 Terminology

Prior to evaluating the properties of wastewater, it is important to understand the general terminology related to quantifying the characteristics of wastewater. Overall, wastes can be evaluated based on their physical and chemical properties. Tables 1.2 and 1.3 summarize the physical and chemical properties along with characteristics from excreted beef. The most important physical properties within waste include the weight, volume, and moisture content. These properties quantify the amount of

Table 1.1 List of state environmental agencies with associated links

State	State agency	Website
Alabama	Alabama Department of Environmental Management	http://www.adem.state.al.us/default.cnt
Alaska	Alaska Department of Environmental Conservation	http://dec.alaska.gov/
Arizona	Arizona Department of Environmental Quality	http://www.azdeq.gov/
Arkansas	Arkansas Department of Environmental Quality	http://www.adeq.state.ar.us/
California	California Environmental Protection Agency	http://www.calepa.ca.gov/
Colorado	Colorado Department of Public Health and Environment	https://www.colorado.gov/cdphe/
Connecticut	Connecticut Department of Energy and Environmental Protection	http://www.ct.gov/deep/site/default.asp
Delaware	Delaware Department of Natural Resources and Environmental Control	http://www.dnrec.delaware.gov/Pages/Portal.aspx
Florida	Florida Department of Environmental Protection	http://www.dep.state.fl.us/
Georgia	Georgia Environmental Protection Division	http://epd.georgia.gov/
Hawaii	Hawaii Office of Environmental Quality Control	http://health.hawaii.gov/oeqc/
Idaho	Idaho Department of Environmental Quality	http://www.deq.idaho.gov/
Illinois	Illinois Environmental Protection Agency	http://www.epa.illinois.gov/index
Indiana	Indiana Department of Environmental Management	https://secure.in.gov/idem/index.htm
Iowa	Iowa Department of Natural Resources	http://www.iowadnr.gov/Environment.aspx
Kansas	Kansas Department of Health and Environment: Division of Environment	http://www.kdheks.gov/environment/
Kentucky	Kentucky Department for Environmental Protection	http://dep.ky.gov/Pages/default.aspx
Louisiana	Louisiana Department of Environmental Quality	http://www.deq.louisiana.gov/portal/
Maine	Maine Department of Environmental Protection	http://www.maine.gov/dep/
Maryland	Maryland Department of the Environment	http://www.mde.state.md.us/Pages/Home.aspx
Massachusetts	Massachusetts Department of Environmental Protection	http://www.mass.gov/eea/agencies/massdep/
Michigan	Michigan Department of Environmental Quality	http://www.michigan.gov/deq
Montana	Montana Department of Environmental Quality	http://www.deq.mt.gov/default.mcpx

(continued)

Table 1.1 (continued)

State	State agency	Website
Minnesota	Minnesota Pollution Control Agency	http://www.pca.state.mn.us/
Mississippi	Mississippi Department of Environmental Quality	http://www.deq.state.ms.us/
Missouri	Missouri Department of Environmental Quality	http://dnr.mo.gov/env/index.html
Nebraska	Nebraska Department of Environmental Quality	http://www.deq.state.ne.us/
Nevada	Nevada Division of Environmental Protection	http://ndep.nv.gov/
New Hampshire	New Hampshire Department of Environmental Services	http://des.nh.gov/index.htm
New Mexico	New Mexico Environmental Department	http://www.nmenv.state.nm.us/
New York	New York Department of Environmental Conservation	http://www.dec.ny.gov/
North Carolina	North Carolina Department of Environment and Natural Resources	http://www.ncdenr.gov/web/guest
Noth Dakota	North Dakota Environmental Health	http://www.ndhealth.gov/EHS/
Ohio	Ohio Environmental Protection Agency	http://www.epa.state.oh.us/
Oklahoma	Oklahoma Department of Environmental Quality	http://www.deq.state.ok.us/
Oregon	Oregon Department of Environmental Quality	http://www.oregon.gov/deq/pages/index.aspx
Pennsylvania	Pennsylvania Department of Environmental Protection	http://www.depweb.state.pa.us/portal/server.pt/community/dep_home/5968
Rhode Island	Rhose Island Department of Environmental Management	http://www.dem.ri.gov/
South Carolina	South Carolina Department of Health and Environmental Control	http://www.scdhec.gov/HomeAndEnvironment/
South Dakota	South Dakota Department of Environment and Natural Resources	http://denr.sd.gov/
Tennessee	Tennessee Department of Environment and Conservation	http://www.state.tn.us/environment/
Texas	Texas Commission of Environmental Quality	http://www.tceq.state.tx.us/
Utah	Utah Department of Environmental Quality	http://deq.utah.gov/
Vermont	Vermont Department of Environmental Conservation	http://www.anr.state.vt.us/dec/dec.htm
Virginia	Virginia Department of Environmental Quality	http://deq.state.va.us/

Washington	Washington Department of Ecology	http://www.ecy.wa.gov/
West Virginia	West Virginia Department of Environmental Protection	http://www.dep.wv.gov/Pages/default.aspx
Wisconsin	Wisconsin Department of Natural Resources	http://dnr.wi.gov/
Wyoming	Wyoming Department of Environmental Quality	http://deq.wyoming.gov/

Table 1.2 Physical and chemical properties of waste [2]

Physical properties	
Moisture content	Component of a waste that can be removed by evaporation and drying
Total solids	Component of a waste that is left after evaporation
Volatile solids	Component of a waste that has been removed when a waste sample is placed in a muffle furnace at 1112 °F
Fixed solids	Component of a waste that remains after a waste sample is heated in a muffle furnace at 1111 °F
Suspended solids	Component of a waste removed by means of filtration
Chemical properties	
Five-day biological oxygen demand (BOD5)	Water quality index that measures the amount of oxygen needed for microorganisms to degrade material
Chemical oxygen demand (COD)	Water quality index that determines the amount of oxygen consumed by organic material

Table 1.3 Excreted beef waste characteristics [8]

Components	Units	Beef cow in confinement	Growing calf confined (450–750 lb)
Weight	lb/da-a	125	50
Volume	ft^3/d-a	2.0	0.8
Moisture	%wet basis	88	88
TS	lb/d-a	15	6.0
VS	lb/d-a	13	5.0
BOD	lb/d-a	3.0	1.1
N	lb/d-a	0.42	0.29
P	lb/d-a	0.097	0.055
K	lb/d-a	0.30	0.19

waste that must be handled and subsequently treated. Secondary physical properties evaluate categories that are found within a given waste. These secondary properties include total solids (TS), volatile solids (VS), fixed solids (FS), dissolved solids (DS), and suspended solids (SS) [2].

On the other hand, chemical properties are represented as nutrients or wastewater quality indices. Nitrogen (N), phosphorus (P), and potassium are the elements mainly considered as nutrients. These nutrients are further subdivided into subsequent forms that can be beneficial or detrimental to the handling of livestock. Figures 1.3 and 1.4 summarize nitrogen and phosphorus processes that occur within livestock waste. Five-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) are two of the many wastewater quality indices. These indices are evaluated within a laboratory and are important in determining the nature of the wastewater present. BOD_5 relates the amount of oxygen required to degrade waste

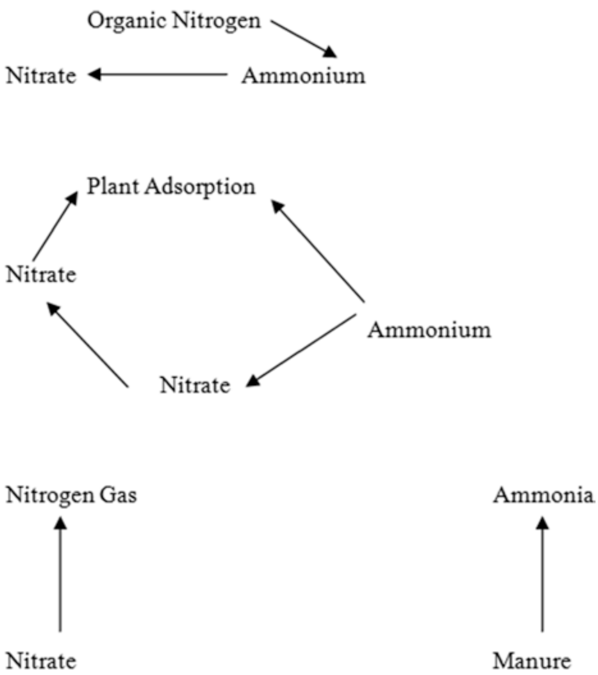


Fig. 1.3 Nitrogen processes involved in manure management (from top to bottom: mineralization, nitrification, denitrification (bottom left), volatilization (bottom right)). (Adapted from [4])

by microorganisms in 5 days at 20 °C, while COD involves the consumption of oxygen by organic and inorganic constituents [2].

1.2.1.2 Wastewater Characteristics

It can be said that the type of manure in wastewater produced varies not only on characteristics but also on the time of year. Based on the data collected between summer and winter for cattle manure and bedding, Loehr (1974) found that the ranges for parameters are different between summer and winter. For example, percent total solids (%TS) in winter have an average of 2.8% versus 2.3% in summer. In regard to biochemical and chemical oxygen demands (BOD_5 and COD), winter indicates higher values of BOD at 13,800 mg/L versus only 10,300 mg/L in summer. Nutrient presence is higher at 2350 mg/L as N for total nitrogen in summer, as compared with 1800 mg/L ion summer, and total phosphorus is 280 mg/L in winter, while only 190 mg/L in summer. These results can be reflected based on conditions such as precipitation and temperature [9].

In addition, having considered swine lagoon analysis in Missouri, liquid wastes are significantly higher in total solids, total nitrogen and ammonia, salts, and minerals as compared to sludge. In particular, liquid wastes contained 3091 mg/L, as

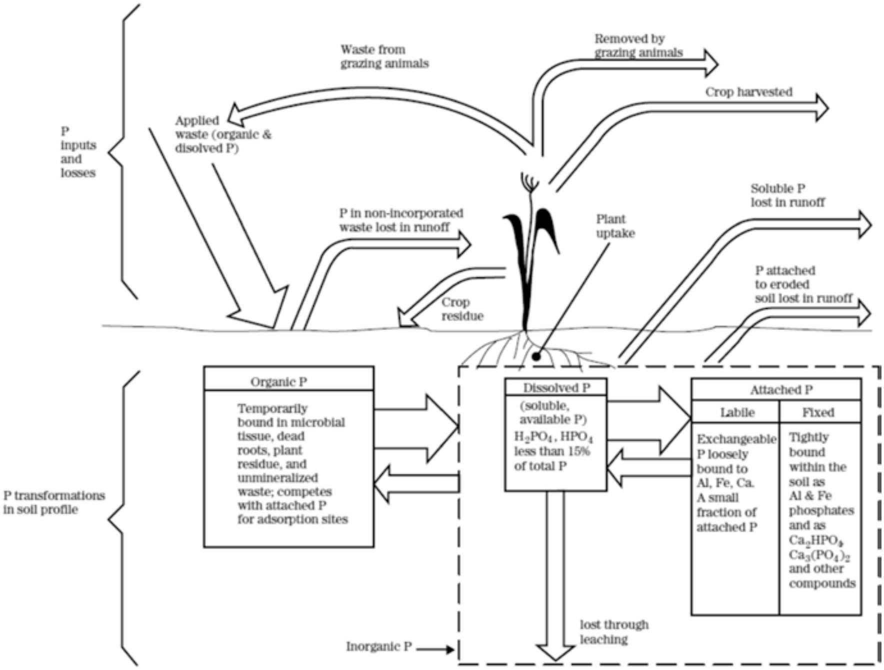


Fig. 1.4 Phosphorus cycle in relation to waste application and transformation of phosphorus in the soil profile [1]

compared to only 203.843 mg/L in solids. This trend is also noticed in terms of salts (Na 470 mg/L, Ca 257 mg/L, and Mg 64 mg/L versus 4.627 mg/L, 6.176 mg/L, and 1.514 mg/L in liquid, respectively) [10].

Also, the waste characteristics of different industries vary. The supernatant for different animal wastes sampled from a lagoon and municipal waste treatment was compared. Poultry lagoons contained the highest concentration of wastes. The mean COD for poultry was 3700 mg/L, compared with 2050 mg/L and 1672 for the swine and dairy lagoons, respectively. This trend can be highly seen in BOD_5, TS, total volatile solids (TVS), suspended solids (SS), and ammonia nitrogen (NH_3-N), where the poultry lagoon contained the highest amounts of all three. Nevertheless, untreated municipal wastewater has significantly lower values for every category; in some cases such as COD values, the lowest animal waste value (1672 mg/L for dairy lagoons) was four times the COD than in municipal waste and almost ten times less than the highest (poultry) [11]. Tables 1.4 and 1.5 present characteristics of manure based on various livestock types. Table 1.6 presents wastewater characteristics of swine waste.

On the other hand, while waste constituents were higher in the animal waste, the untreated municipal wastewater contained higher amounts of trace metals, specifically cadmium, chromium, copper, and lead. In fact, examining copper, the range for copper was between 190 and 440 mg/L for poultry lagoons; however, in untreated

Table 1.4 Total manure, nitrogen, phosphorus, and potassium excreted by different livestock species [12]

Livestock type	Fresh manure (gal/day)	N (lb/day)	P_2O_5 (lb/day)	P (lb/day)	K_2O (lb/day)	K (lb/day)
Beef cattle (1000 lb body weight)	7.5	0.34	0.25	0.11	0.29	0.24
Dairy cow (1000 lb body weight)	11	0.41	0.17	0.074	0.32	0.27
Swine (100 lb body weight)	1	0.045	0.034	0.015	0.036	0.030
Poultry (4 lb body weight)	0.028	0.0029	0.0026	0.0011	0.0015	0.0012

Note: Livestock type is based on 1000 lb body weight

Table 1.5 Manure characteristics per animal [13]

Animal type	Average weight (lb)	Total manure production (ft^3/day)	Total solids production (lb/day)	Volatile solids production (lb/day)
Swine				
Nursery pig	35	0.04	0.39	0.30
Growing pig	65	0.07	0.72	0.55
Finishing pig	150	0.16	1.65	1.28
Gestation sow	275	0.15	0.82	0.66
Sow and litter	375	0.36	2.05	1.64
Boar	350	0.19	1.04	0.84
Cattle				
Dairy	1000	1.39	12.00	10.00
Beef	1000	0.95	8.50	7.20
Poultry				
Layers	4	0.0035	0.064	0.048
Broilers	2	0.0022	0.044	0.034

municipal wastewater, it was found that the range of copper was between 20 and 3360 mg/L, almost four times as much for the averages of these ranges. With the exception of arsenic and cadmium, poultry lagoons consistently had higher amounts of trace elements [11].

Table 1.6 Swine waste characteristics [2]

Component	Units	Grower 40–220 lb	Replacement gilt	Sow		Boar	Nursing/ nursery pig 0–40 lb
				Gestation	Lactation		
Weight	lb/d/1000#	63.40	32.80	27.20	60.00	20.50	106.00
Volume	ft^3/d/1000#	1.00	0.53	0.44	0.96	0.33	1.70
Moisture	%	90.00	90.00	90.80	90. 00	90.70	90.00
TS	% w.b.	10.00	10.00	9.20	10. 00	9.30	10.00
	lb/d/1000#	6.34	3.28	2.50	6.00	1.90	10.60
VS	"	5.40	2.92	2.13	5.40	1.70	8.80
FS	"	0.94	0.36	0.37	0.60	0.30	1.80
COD	"	6.06	3.12	2.37	5.73	1.37	9.80
BOD_5	"	2.08	1.08	0.83	2.00	0.65	3.40
N	"	0.42	0.24	0.19	0.47	0.15	0.60
P	"	0.16	0.08	0.06	0.15	0.05	0.25
K	"	0.22	0.13	0.12	0.30	0.10	0.35
TDS		1.29					
C:N ratio		7	7	6	6	6	8

Average daily production for weight range noted. Increase solids and nutrients by 4% for each 1% feed waste more than 5%

1.2.2 Milk House Wastewater Characteristics

Milk house wastewater is generated from various sources within the dairy industry. These sources include but are not limited to [14]:

1. Wash water from cleaning bulk tanks
2. Cleaning of milk pipelines
3. Cleaning of milking units
4. Cleaning equipment
5. Cleaning of milk house floor
6. Remnant within the milk pipelines, receiver, and bulk tanks
7. Chemicals
8. Water softener recharge
9. Manure
10. Bedding
11. Floor dirt and grit
12. Washing the udders of the cows

Typical milk house and diary wastewater characteristics are listed in Tables 1.7 and 1.8.

The Wisconsin National Resource Conservation Service (NRCS) describes three constituents within milk house wastewater—solids, phosphorus, and ammonia nitrogen and chlorides. Solids contain manure, primarily made of lignin and cellulose. These are a major producer of milk house wastewater. Solids usually have a

Table 1.7 Characteristics of milk house wastewater [14]

Parameter	Final effluent tank (mg/L)	Design (mg/L)
BOD_5	500–2600	1200
Total Solids (TS)	200–1000	450
Fats, Oils, Grease	90–500	225
	30–100	65
Total Phosphorus	21–100	55
pH	6.2–8.0	7.5
Temperature	53–70 °C	–

Table 1.8 Dairy waste characterization; milking center [15, 16]

Component	Units	Milk house only	Milk house and parlor	Milk house, parlor, and holding area	Milk house, parlor, and holding area
Volume	ft^3/day/1000 head	0.22	0.60	1.40	1.60
Water volume	gal/ day/1400 lb cow	2.3	6.3	14.7	16.8
Moisture	%	99.72	99.40	99.70	98.50
COD	lb/1000 gal	25.30	41.70	–	–
BOD_5	lb/1000 gal	–	8.37	–	–
N	lb/1000 gal				
P	lb/1000 gal	0.58	0.83	0.23	0.83
K	lb/1000 gal	1.50	2.50	0.57	3.33

concentration range between 1600 and 7000 mg/L. Depending on the source, some solids can be comprised of high-concentration BOD. For example, it has been determined that raw waste milk can have a BOD concentration of 100,000 mg/L [15].

The presence of phosphorus has been attributed to daily cleaning operations such as pipeline washing or the presence of cleaning chemicals such as detergents and acid rinses, many of which can have 3.1–10.6% phosphorus by weight. Phosphorus in milking house centers is usually soluble and can cause eutrophication [15].

Ammonia is found in manure, urine, and decomposed milk. The discharge of milk house wastewater with substantial concentrations of ammonia can be toxic to fish. On the other hand, chlorides are also found in urine, milking system cleaners and sanitation, and water softening generation. The presence of chlorides can have an impact on the salinity of the wastewater being treated [15].

The daily operations within a milk house require daily cleaning of equipment and pipelines. The University of Minnesota Extension describes a four-stage cleaning process. Cleaning begins with rinsing the transfer lines to remove any raw milk that may remain. Next, organic material is removed by a detergent with an active chlorine concentration of 100 mg/L. This detergent raises the pH above 11. Then, an acid rise is completed to reduce inorganic material. The pH is lowered to around 3.5 to prevent bacteria formation and neutralize any detergent residue that may remain. Finally, chlorine with a concentration of 200 mg/L is added to kill microorganisms in the line. The process of cleaning equipment and pipelines accounts for an additional source of wastewater that needs to be treated prior to any discharge [14].

1.2.2.1 Treatment of Milk House Wastewater

There are several treatment methods for milk house wastewater. Table 1.9 lists several treatment methods that are being used in the state of Minnesota. For example, a viable option of treating milk house wastewater is through a two-stage septic system. It is important to note that wastewater entering into the tank does not include waste milk from cows. Waste milk will be disposed with manure. Treatment by the septic system is contingent on the strength of the wastewater, leaving the parlor and also time spent in the septic tanks [17, 18].

Wastewater is pretreated using two septic tanks consisting of inlet and outlet baffles. The tanks remove settable solids, fats, and grease and inhibit contamination throughout the remaining sections of the treatment plant. In the state of Minnesota, tank sizing is based on either a hydraulic retention time of 3 days or a volume of 1000 gallons, whichever is greater. In addition, Minnesota requires 4 ft of soil cover. Prior to exiting the septic tank, the wastewater passes through an effluent filter. The effluent filter prevents suspended solids from leaving the septic tank [17, 18].

Next, wastewater moves through a bark bed. The bark bed combines soil with bark and shredded wood. The depth of the bark bed is between 18 and 24 inches. The purpose of the mixture is to prevent the soil in colder climates and allows for more oxygen transfer, which in turn increases the rate of degradation at the soil-effluent interface. The sizing and application within the bark bed is determined by the soil type. Typical bark beds consist of a depth of 2 ft of soil to the bedrock or groundwater. Sizing of the bed is computed by taking the loading rate of the soil (contingent on soil type) and dividing it by the total wastewater volume. The loading rate is read from a table based on soil type. Presented values consider a BOD_5 concentration of 750 mg/L, flow rate of 5 gallons per day, and a BOD_5 loading rate of 0.0062 lbs/gallon. Bark beds can also be sized using hydraulic loading as well [19].

Another treatment method that can be employed is the use of constructed wetlands. Because constructed wetlands are not unique to milk house waste treatment, they will be discussed in Sect. 1.3.

Nevertheless, literature has discussed the efficiency of constructed wetlands for treating dairy wastewater. A three-celled surface wetland was used to treat dairy wastewater. The study compared the performance of the summer and winter seasons. The results found that total suspended solids (TSS), total phosphorus (TP), and total Kjeldahl nitrogen (TKN) were reduced in the summer as compared to the

Table 1.9 Treatment methods for milk house wastewater treatment [17, 18]

Treatment method	Description	Requirements
Chemical batch reactor	Coagulation and flocculation	Effluent BOD ≤205 mg/L Discharge into infiltration/filtration system
Bark bed	Soil infiltration with 18–24 inches of barkwood Pressure distribution system disperses effluent	Requirement of soil texture to a minimum of 3 ft bedrock. Treatment consists of three processes: 1. Primary treatment is completed by two septic tanks. Tanks are designated based on an HRT of 3 days or the volume whichever is greater 2. Infiltration area 3. Distribution system: The system consists of a pump, transferring pipe. Effluent traveling to the pipe must have a minimum velocity of 2 ft/s. The transferring pipe must have a diameter of 2 inches with a drainage slope of 1%. Distribution is done through gravel bed or a chamber system
Aeration and media filtration	Aerobic treatment or recirculating media filter	Treatment will consist of three processes: 1. Primary treatment will use two septic tanks. Design requirements similar to bark bed primary treatment 2. Aerobic treatment follows primary treatment where the goal must be less than 200 mg/L effluent BOD 3. Following aerobic treatment the discharge will enter an infiltration/filtration system
Irrigation	Treatment consists of water filled within the tank that will be dispersed onto crops	1. A proper site for irrigation consists of a location where 20% of materials from 2 ft below the buffer zone pass through a #200 sieve 2. The irrigation area must have a minimum 3% slope, where the down gradient should be 50 ft away karst, surface water, or any private wells 3. Treatment consists of using a septic tank. Design requirements are similar to bark bed primary treatment 4. Wastewater moves to a 3-day holding dosing tank with piping for distribution and pumping
Vegetated treatment dosing system	Wastewater from a septic tank is distributed onto vegetation by a sloping elevated pipe where the upslope side of the pipe is enclosed	1. Both siting and primary treatment use similar design criteria as previously mentioned 2. Treated waste from a septic system will travel through a distribution system to a dosing tank by a perforated pipe with perforations between 1/2 and 1 inch diameter. The pipe is elevated 1–1.5 ft above the ground 3. Determination of vegetated area is based on either a flow depth no greater than 0.5 ft using a treatment time of 15 min and a Manning constant of 0.24, or the smallest area that can handle a design loading rate no greater than 0.9 inches/week

winter. In addition, BOD_5 removal was lower than 30 mg/L during the summer months as compared to the winter months. Finally, fecal coliform removal was approximately 31% [20].

To avoid eutrophication in a local surface water body, a three-celled parallel free water surface wetland was used to treat dairy wastewater. The treatment process began with the concrete settling pad for the purpose of eliminating solids prior to entry into the wetland. Following treatment into the constructed wetland, a three-sump pump transfers the wastewater into a holding pond. The authors concluded that BOD_5, conductivity, total dissolved solids (TDS), TSS, TKN, TP, phosphate, ammonia, nitrate, nitrite, and fecal coliform bacteria were generally reduced by the wetland. In addition, all parameters with the exception of nitrate and nitrate were diminished from the settling pad to the holding pond. Fecal coliform was reduced provided that cows were kept from grazing in the constructed wetlands [21].

1.2.2.2 Conservation

Along with dairy wastewater treatment, water conservation is another important facet to properly handle wastewater. Water conservation is important because it provides the dairy plant owners an opportunity to reduce the cost for treatment. In general, wastewaters with high BOD_5 concentration discharged into a municipal wastewater treatment system incur high costs. It can also become expensive for onsite treatment as well; therefore, water conservation efforts provide owners an opportunity to save funds. In addition, methods have a positive impact on areas where water resources are currently being depleted and can also reduce the potential of stringent legislation. In the dairy industry, water reuse can reduce freshwater demand to 1 gal of water/1 gal of milk produced if proper management of goals is provided and maintenance is regularly scheduled [22].

1.3 Waste Treatment

1.3.1 Anaerobic Digestion

Anaerobic digestion is the fermentation of organic waste by hydrolytic microorganisms into fatty acid chains, carbon dioxide (CO_2), and hydrogen (H_2). Short fatty acids are then converted into acetic acid (CH_3COOH), H_2, CO_2, and microorganisms. Acetic acid forms biogas, a combination of methane (CH_4), CO_2, and trace elements by means of methanogenic bacteria. Occasionally, biogas can form hydrogen sulfide by sulfate-reducing bacteria. In general, CH_4 in biogas produces between 55 and 80%, while approximately 65% is found in animal manure [23].

The processes in anaerobic digestion are driven by temperature, moisture, and solid content. There are three major temperature ranges defined—psychrophilic

(<20 °C), mesophilic (35–40 °C), and thermophilic (51–57 °C). Ideally an anaerobic digester should operate at temperatures greater than 35 °C. A moisture content of 60–99% is ideal, while solid content in the digester should be less than 15% [24].

Recently, there has been a big interest in anaerobic digestion for the purpose of energy conversion [25]. Since 1996, the Environmental Protection Agency has partnered with the US Department of Agriculture, the National Resource Conservation Service (NCRS), and the US Department of Energy to develop a program known as AgStar, an opportunity for monetary support in projects related to anaerobic digestive systems. In 1998, the program began by promoting seven farm digesters across the country [26].

There have been reports of profit being made on the energy that has been captured through the use of livestock manure. These values have greatly depended upon the monetary cost of electricity. For example, if one were to sell electricity in Wisconsin and California, a 1000-head dairy farm with manure production would be worth about $56,000 and $77,500, respectively [25]. Statistically speaking, it was found that in 2009, approximately 151 biogas systems that have been installed within the state of Wisconsin produced about 11.6 megawatts of electricity, enough for use by 10,000 homes. Within January 2007 and June 2008 alone, 150,000 kilowatt hours (kWh) of electricity were produced by farms that had 2000-head of animals and 440,000 kWh of electricity for those between 2000 and 4500 [27]. Figure 1.5 indicates the net value of dollars based on the digester per number of head of cattle. Figure 1.6 indicates the number of dairies operating at a given carbon price per operation size.

There are a plethora of reasons why AgStar has become a popular consideration for the development of biogas. Consider that the state of Wisconsin has spent between $16 and 18 billion each year for coal energy imports whereas about $853 million for transportation [27]. If the state of Wisconsin, rich in manure and crop remains and waste components from the dairy processing, fats, and greases can transport this material into fuels, it would create an infrastructure that would be safer and easier to be controlled as compared to the current energy options on the market today and additional revenue for farmers [27].

A recent 2013 study conducted by the US Environmental Protection Agency (USEPA) evaluating the AgStar program found that anaerobic digesters reduce greenhouse gases by 1.73 million metric tons of CO_2 equivalent ($MMCTCO_{2e}$). This is because methane is captured and burned before entering into the atmosphere. On the other hand, anaerobic digesters produced 840 million kWh in 2013. These benefits were contingent on the type of anaerobic digester applied. For example, the most commonly used digesters in the United States were complete mixed and mixed plug flow [28]. Biogas production is also dependent upon the type of livestock. Table 1.10 provides information concerning the daily production of biogas per animal type.

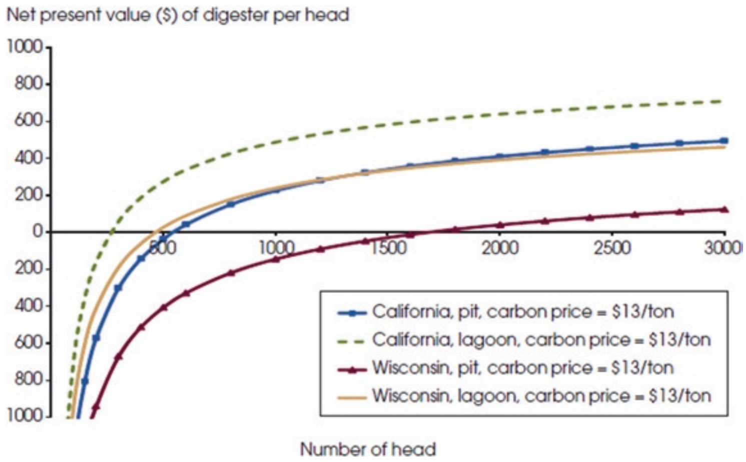


Fig. 1.5 Net value in dollars of digesters per head vs. number of head [25]

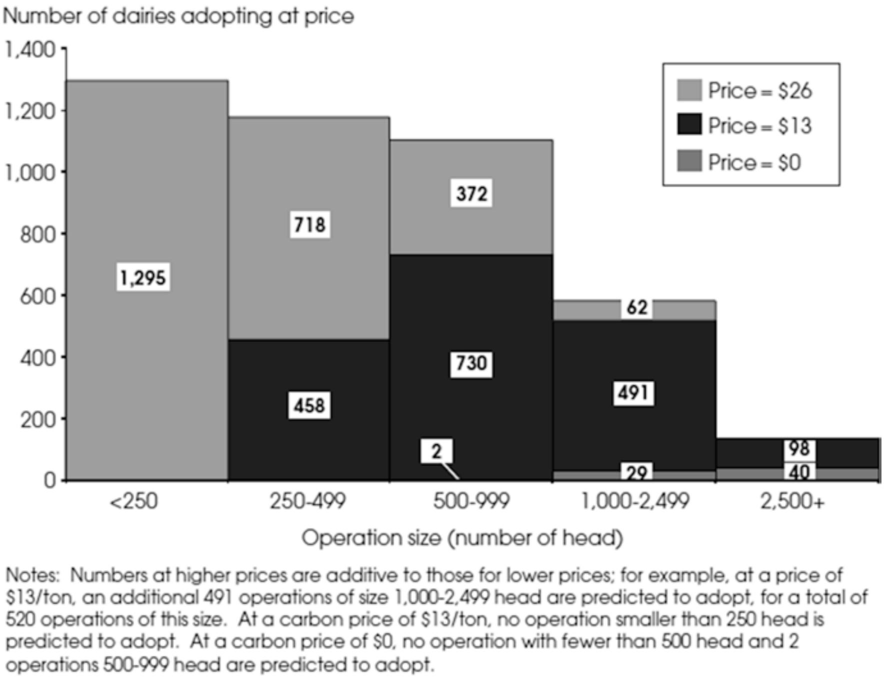


Fig. 1.6 Number of dairies operating at a given carbon price vs. operation size [25]

Table 1.10 Biogas production by animal [23]

Animal type	Average weight (kg)	Biogas/animal/d (m^3)
Dairy	625	1.3
Beef	447	0.32
Swine	70	0.14
Poultry	1.2	0.0092

Table 1.11 Characteristics of various anaerobic digester types [23]

Anaerobic digestion system	OLR COD/m^3/kg	HRT (d)
Covered anaerobic lagoon	0.05–0.2	60–360
Plug flow digester	1–6	18–20
Mixed	1–10	5–20

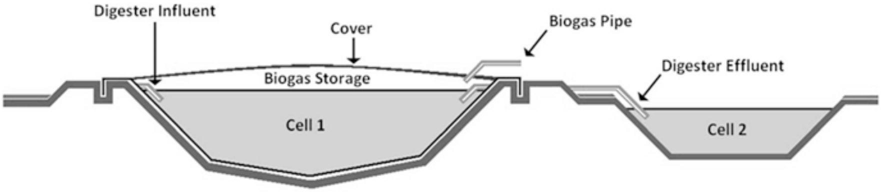


Fig. 1.7 Covered lagoon digester [29]

1.3.1.1 Types of Anaerobic Digesters

There are six types of anaerobic digesters—covered anaerobic lagoons, plug flow, continually stirred tank reactor, fixed film, induced blanket reactor, and anaerobic sequencing batch reactors. Table 1.11 reports the characteristics of three of the six anaerobic digesters (covered anaerobic lagoons, plug flow digester, and mixed). The selection of the appropriate anaerobic digester is determined by appropriate parameters such as the geographic location. Covered anaerobic lagoons form biogas from manure stored in structures and are low cost, simplistic in design, and manageable. There are two types of covers—full and partial. Production of biogas by a covered anaerobic lagoon depends on the temperature. Therefore, covered lagoons are more appropriate in areas of warmer climate. Biogas production in a covered lagoon is collected in pipes at the top of the digester and then transported by using a low vacuum. From there, the remaining biogas is then flared. Additional characteristics of a covered anaerobic lagoon include high total solid (TS) concentration, organic loading rate (OLR) of 0.2–0.5 kg chemical oxygen demand (COD)/m^3 day, and a

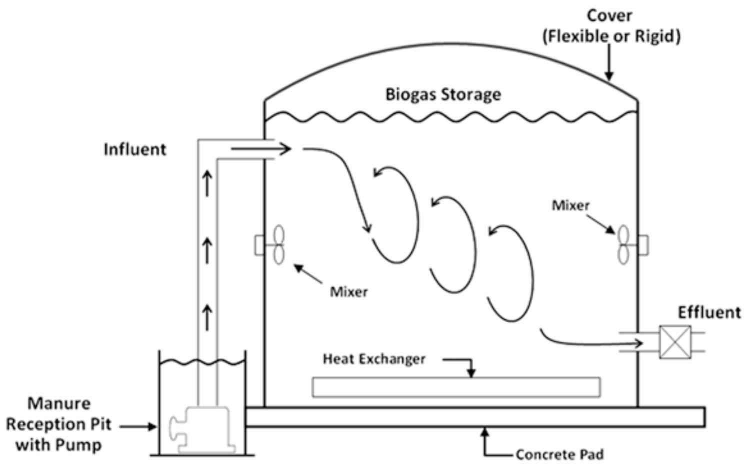


Fig. 1.8 Complete mix digester [29]

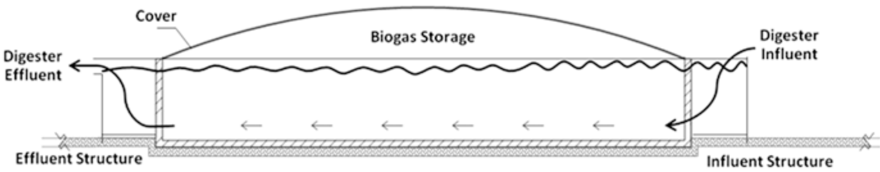


Fig. 1.9 Plug flow digester [29]

hydraulic retention time (HRT) of 60–360 days [23]. Figures 1.7 and 1.8 are diagrams of a covered lagoon digester and a completely mixed digester.

On the other hand, manure in a plug flow digester enters undigested and leaves digested. A typical plug flow digester includes concrete and geosynthetic material for gas collection. Manure enters into the digester and is limited to 11–14% total solid concentration, 1–6 kg COD/m^3 day OLR, and an HRT between 20 and 30 days. In a continually stirred tank reactor, manure enters into a tank and is mixed to maintain a consistent concentration throughout the reactor. Unlike a plug flow digester which is limited to 6 kg COD/m^3 OLR, the maximum allowable organic loading rate for total solids entering into a continually stirred tank reactor is 10 kg COD/m^3 day. In addition, the hydraulic retention time is shorter than a plug flow reactor ranging between 5 and 20 days [23]. Figure 1.9 is a diagram of a plug flow digester.

A fixed film digester is an attached growth reactor with fixed film media. When waste enters into the fixed film digester, anaerobic biomass attaches to the fixed film media. Typical fixed film digesters have a low HRT between 0.5 and 4 days. Influent manure in a fixed film digester has an OLR between 5 and 10 kg COD/m^3 day with a solid concentration less than 1% [23].

Finally, an induced blanket reactor forms a sludge blanket by digesting the waste. Manure moves upward from the bottom of the reactor to the top. Inside the blanket, manure moves upward contacting with anaerobic biomass to become digested. At the top of the tank, the biogas is created while the sludge blanket moves back to the bottom of the reactor. There are two types of blanket reactors—upflow anaerobic sludge blanket (UASB) digester and induced blanket reactor (IBR). UASB involves low concentration of solids, while IBR usually handles high solid concentrations [30].

The cost of an anaerobic digester application has been contingent on the type. In the design and construction of a system, the price involves the initial cost of the system and its operation and maintenance (O & M). The US Department of Agriculture (USDA) reported values on 38 different digesters. The overall cost of an anaerobic digester has been estimated to be between $114,000 and 326,000. Operation and maintenance (O & M) was found to be contingent on the type of waste. The O & M for swine waste was 2.3% of the initial cost for the system, while dairy was 7% [23].

Within the last 5 years, other anaerobic digestion processes have been tested. A specific type of anaerobic digestion design is known as a temperature-phased anaerobic digestion reactor. Temperature-phased anaerobic digestion (TPAD) is a system that completes treatment in two stages at two temperatures—during the first stage, the digester operates at a temperature at the highest thermophilic temperatures, approximately 55 °C while the second stage at the lower ended mesophilic conditions or approximately 35 °C. When using a TPAD for livestock waste, the advantages are significant as the digester is capable of increasing a higher probability of bioconversion and methane production, with lower hydraulic retention times (HRT) and also size reduction [31]. Harikishan and Sung (2003) used a TPAD process to treat livestock wastewater for the purpose of analyzing dairy cattle manure. Having organic loadings of 1.87–5.82 g VS/L/day, 36–41% of volatile solids were removed, converting 0.52–0.62 L methane/g VS. In addition, fecal coliform and *Salmonella* counts meet USEPA Class A standards [31].

Other authors have researched and found results under different conditions. King et al. (2011) used a 3-year pilot in-storage psychrophilic anaerobic digester (ISPAD) to consider swine manure and if it is able to handle psychrophilic conditions and be able to complete anaerobic digestion and successfully produce methane. Results based on the microbial community analysis were able to produce methane, provided that volatile solids (VS) had a rate of 44.6 dm^3/kg day at 35°, 9.8 dm^3/kg day at 18°, and 8.5 dm^3/kg day at 8° and an organic matter content of 24% [32]. Rao et al. (2010) used a self-mixed anaerobic digester (SMAD) combined with a multistage high-rate biomethanation process where the authors were capable of reducing volatile solids (VS) by 58% and producing a methane yield of 0.16 m^3/kg, with a loading rate of 3.5 kg VS/m^3 day and a hydraulic retention time (HRT) of 13 days. The authors considered using the opportunity to reduce the loading rate and the hydraulic retention time and percent treatment [33].

1.3.2 Constructed Wetlands

1.3.2.1 Description

The purpose of a constructed wetland is to provide a low-maintenance treatment system that creates a quality effluent for areas that have a high volume of wastewater. Constructed wetlands house wastewater within wide channels. These channels also support plant life that grows by using the nutrients from the wastewater. There are four major processes employed in constructed wetlands—sedimentation, filtration, plant uptake (oxygen is provided at the plant root for waste decomposition), and biological decomposition (plants provide adequate binding sites for microorganisms) [15].

The basic idea of a wetland is to maintain moist conditions for pollutants to be trapped and broken down by the plant that are contained within them. In addition, constructed wetlands take advantage of combining anaerobic and aerobic conditions that persist through the wetland. The majority of constructed wetland design consists of using either subsurface flow or surface flow. Surface flow wetlands consist of having a “free water zone” about 30 cm deep on top of a soil layer where the majority of plant growth would occur. The advantage of designing a wetland by this manner is that it would place microbial growth in the best advantage to occur in the areas where the water and its contaminants would be. Subsurface flow wetlands, also known as “root zone method,” remove the “free water zone” for the purpose of allowing direct contact between plant material and contaminants present [34]. There are several design parameters that are necessary for treatment—hydraulic loading rate, length-to-width ratio, bottom slope, water depth, and vegetation [35].

The water depth of a constructed wetland is usually between 20 and 40 cm deep. The advantage of using surface constructed wetlands is the biological and physical methods that are employed within the system. Microbial activity (biological) degrades much of the organic materials, while colloids are either settled within the wetland or can become filtered out (physical). Nitrogen is capable of being removed by means of nitrification (the formation of nitrate from ammonium nitrogen) and denitrification (the formation of atmospheric nitrogen from nitrates) [2], while ammonia is volatilized by the use of algal photosynthesis. If any phosphorus is removed, it is by means of wetland plants eventually by either absorption or precipitation [36].

1.3.2.2 Constructed Wetland Types

Literature recognizes three major types of constructed wetlands—free water surface (FWS), vegetated submerged or subsurface system, and floating aquatic plant (FAP) systems [38]. Figures 1.10, 1.11, and 1.12 are drawings of each type of constructed wetland.

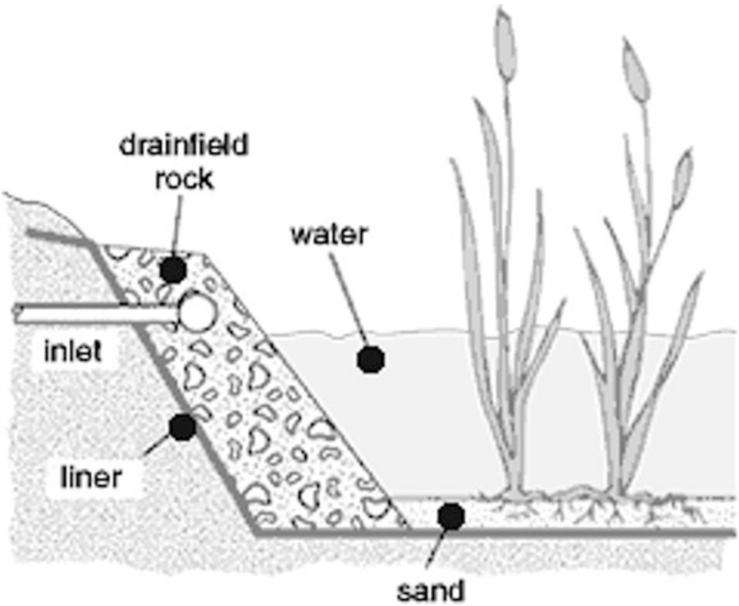


Fig. 1.10 Free water surface (FWS) constructed wetland [37]

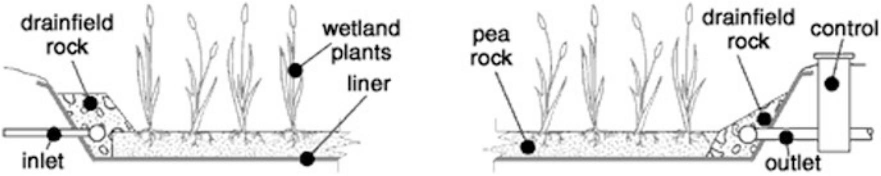


Fig. 1.11 Subsurface constructed wetland [37]

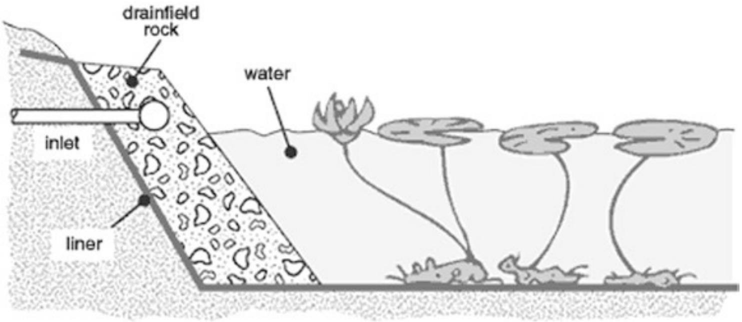


Fig. 1.12 Floating aquatic plant (FAP) constructed wetland [37]

In a free water surface system, the wastewater depth is usually shallow, anywhere between 6 and 18 inches with a flat-bottom slope. Because of their shallow depths, FWS wetlands usually degrade wastewater under aerobic conditions. When wastewater enters an FWS, it moves above the sediment, having direct contact with the plants at the surface. However, the efficiency of FWS treatment is contingent upon the presence of microorganism located throughout the surface. Nevertheless, microorganisms attach themselves to plant stems and/or litter below the water surface, or at the soil/plant-root matrix, creating the proper environment for wastewater treatment. Prior to entry of an FWS, a pretreatment system to remove settling and floating solids is recommended or ammonia [38]. FWS-constructed wetlands have been proven to reduce BOD_5 and TSS to 30 mg/L, ammonia, and ammonium-nitrogen to 10 mg/L [39]. In addition, to the effluent quality, FWS wetlands are very common in livestock operations because they are inexpensive and can be in operation year round [38].

Under the National Resource Conservation Service guidelines, an FWS is to be designed based on a 25-year storm event depending on the state. Sometimes a detention pond downstream may be necessary to meet this requirement. The sizing of an FWS is done by using one of the two methods—presumptive method or the field test method. The presumptive method assumes a BOD_5 concentration, while the field test method is based on an actual daily measurement of BOD_5 from the given livestock operation [39]. The presumptive method approximates a pollutant entering into a wetland by reviewing the BOD_5 or nitrogen concentration and then applies the value to an areal loading rate (typically 65 lb BOD_5/acre/day). The presumptive method has been well-known since the Tennessee Valley Authority (TVA) introduced it in 1989 [38].

The field test method requires a collection of samples and analysis based on BOD_5 and total nitrogen (TN). Some of the important factors examined include average daily flow, temperature, and decay rate constant. The data collection from the field test is used to determine the size of the wetland. The purpose of the field test method is to ensure that the design of the wetland does not exceed discharge limits [38].

On the other hand, in vegetated submerged systems, wastewater flows within the sediment bed, having more contact with the plant roots. The sediment bed is usually made of rock, gravel, and soils. Vegetation is usually planted at the top of the wetland [38]. Because wastewater flows at lower depths, wastewater is usually degraded at anaerobic conditions. The slope of this wetland ranges between 2 and 6%. Sizing of submerged systems is contingent on flow rate and influent and desired outflow BOD_5 [39]. Vegetated submerged systems are not as prolific as surface flow wetlands. This is because the sediment beds can easily accumulate solids. Also, the beds can be very expensive to construct. Nevertheless, vegetated submerged systems can be used to treat wastewater with low flows and solids [38].

Finally, floating aquatic plant systems comprise of one or more ponds. The ponds are designed for plants to grow and float at the top of the ponds. Each pond is designed for a depth between 3 and 5 ft for the purpose of avoiding non-desired plant species to grow and become prominent within the system and gives the plant access to nutrients within the wastewater. There are several factors for appropriately harvesting. These include the number, size, and arrangement of ponds and the technique for harvesting. There are two major plant species in FAP systems—water hyacinths and duckweed [38].

1.3.2.3 Constructed Wetland Design

Constructed wetland design usually consists of first-order models under plug flow conditions, alternating between looking for values of BOD, TSS, ammonium, and fecal coliforms [34]:

$$\ln\left[\left(C-C^{*}\right)\div\left(C_{o}-C^{*}\right)\right]=-\frac{k}{q} \tag{1.1}$$

where

C_0 = initial concentration of conditions
C = targeted rate concentration
C^* = background rate concentration
k = first-order rate constant (cm/d)
q = hydraulic loading rate (cm/d)

An alternative method to designing a constructed wetland would be the use of regression equations for one had the desire to consider looking at multiple components at one time.

Stone et al. (2004) used constructed wetlands, particularly marsh-pond-marsh wetland system at North Carolina A & T University. Six wetland systems with the dimensions of 11 × 40 m treated nitrogen by removing % concentration of ammonia nitrogen of 30% but only removing 8% phosphorus treatment. First-order kinetics were 3.7–4.5 m/day for total N and 4.2–4.5 m/day for P, much lower than the typical model rate constant [40].

In addition, the Environmental Protection Agency has tracked several constructed wetlands that have been used for the purpose of waste treatment. Seven locations to treat three different waste types—swine, dairy, and poultry—were constructed. For swine wastewater, a project in Duplin County, North Carolina, was undertaken for the purpose of removing Total Kjeldahl Nitrogen (TKN), as it was observed that a major factor affecting treatment was loading rates of TKN (3 kg/ha/d TKN) and was able to remove between 91 and 96% TKN, while 10 kg/ha/day only removed approximately 73%. A wetland in Essex, Ontario, reduced TSS (97%), BOD_5 (97%), and 99% fecal coliforms, and 95% *E. coli* from dairy farm milk house wastewater. Auburn University used a constructed wetland for poultry lagoon that considered a series of five wetlands at 3.1 cm/day, a loading rate of 145 kg/ha-day for chemical oxygen demand (COD), and 30 kg/ha-day total TKN at a maximum of 49.8% BOD_6, 60.7% COD, and 36.8% PO_4 [41].

1.3.3 Lagoons

A lagoon is an earthen basin that treats wastewater and stores both liquids and solids [2]. Lagoons can store wastewater, manure, or rainfall runoff [42]. Lagoons are capable of reducing BOD and chemical oxygen demand (COD), nitrogen, and odors [2]. Lagoons can take a round, square, or rectangular shape with a typical length-to-width ratio of 3:1 [43]. In addition, lagoons can be situated as a single or multiple-stage lagoon system. A single lagoon is divided into three major volumes—sludge storage, treatment, and effluent storage. Above the effluent storage is a freeboard for the purpose of protecting the lagoon from storm situations [44]. Figure 1.13 provides a cross-sectional area of a lagoon.

In the sludge storage, sludge settles at the bottom of the lagoon and is digested at the top of the layer. Over time, sludge will accumulate within this layer until it becomes equal to the liquid present. The treatment volume is located above sludge storage consisting of manure at the bottom. Biological degradation converts sludge into organic acids and other compounds. The products of organic acids include methane and carbon dioxide, hydrogen sulfide, ammonia, and volatile organics. Treated wastewater not leaving the lagoon is stored in the effluent storage section. Effluent is stored for the purpose of watering crops [44].

Lagoons are designed based on a 25-year, 24-h storm event. This value is contingent on the location of the lagoon as the 25-year, 24-h storm event varies across the country. The design loading into the lagoon is determined by the number, size, and the species of animal, along with the geographical location of the lagoon. Prior to

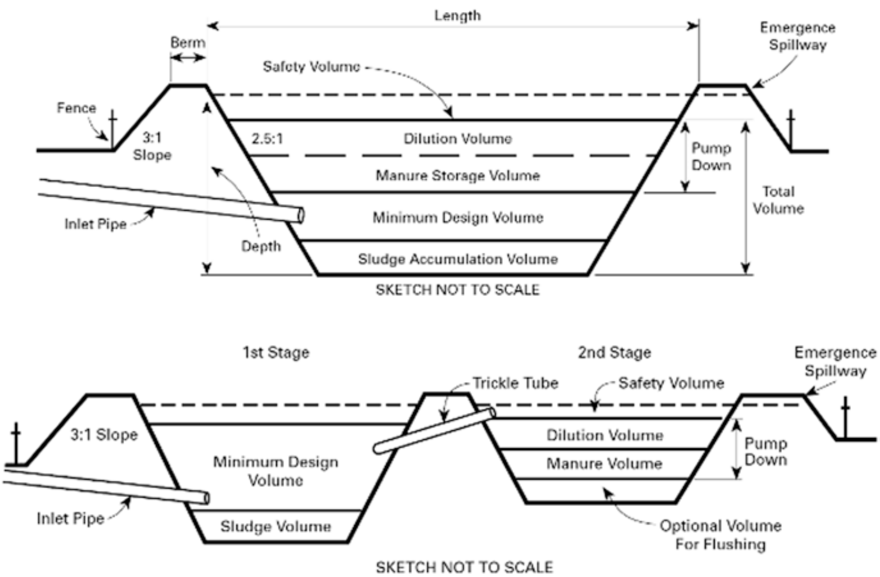


Fig. 1.13 Cross-sectional area of lagoons [13]

land application, dewatering the lagoon is very important. Frequency of dewatering is contingent on the salt concentration and the soil type [45].

The sizing of a lagoon is based on the volume, depth, and pH. The volume of a lagoon is contingent on the loading rate of volatile solids per 1000 cubic foot. This is a function of temperature. The depth of a lagoon is predicated on the precipitation and evaporation rates where the lagoon is located. A typical minimum depth is 6 ft but can be 10 ft for colder climates. However, these values are general and are contingent on the type of lagoon constructed. The optimum pH should be maintained at 6.5 to avoid inhibiting methane bacteria. Anytime the pH is below 6.5, lagoons will experience a high organic loading [2].

Before construction of a lagoon, it is imperative that a soil and groundwater study is done. This is to ensure that sensitive areas are protected from any discharged from the lagoon. These areas would be any region that leads to surface runoff. Avoid areas that are geologically unstable [42]. Pretreatment of wastewater may be beneficial to reduce odor if the BOD_5 loading rate is 50 lb BOD_5/AC/day and the depth of the pond is between 6 and 20 ft [43]. In addition, lagoons should be in close proximity if manure is scraped into the lagoon or below the manure source [42].

Lagoon maintenance is important for controlling odors. Lagoons should be analyzed for the presence of algal blooms. Algal blooms occur in basins that have high loading of nutrients (nitrogen and phosphorus). If a lagoon is void of algal blooms, ensure that aerobic lagoons do not become anaerobic. Anaerobic conditions can produce products that can cause odors. The operator should also check and if necessary provide adequate dilution of waste prior to entry into the lagoon and avoid overloading [46]. This can be accomplished by using a combination of runoff and wash water [45]. If odors still persist, lime addition to the lagoon can reduce the presence of odors [46].

Lagoon operators should also evaluate the species of algae and check for the presence of weeds and grasses and protect them from erosion and unauthorized access. A healthy lagoon should have green algae. Blue-green and filamentous algae can clump within a lagoon blocking the sun. Gray, black, or purple algae are very unhealthy for a lagoon. The presence of weeds can cause a lagoon to short circuit, thereby affecting the flow of wastewater within the unit. Grass covers on the slopes and level surfaces of the lagoon can be beneficial but should be mowed and properly fertilized and should be checked for food, trash, or scum on or near the premise. These items should be discarded. Trees or any bushes should not be present near the berm of a lagoon and should be removed [46]. This will also protect the embankments [44]. In the event of erosion, operators should determine the source and make necessary adjustments to the lagoon if necessary. Unauthorized activity can be avoided by placing fences and warning signs adjacent to the lagoon [46].

Finally, operators should also monitor the sludge storage and sludge depth. Remove excess sludge that has accumulated within the lagoon [44].

1.3.3.1 Anaerobic Lagoons

Anaerobic lagoons are the most common lagoon used for treatment of livestock wastewater. One of the biggest reasons is because anaerobic bacteria have a higher rate of organic decomposition as compared with aerobic bacteria [42]. This is because anaerobic bacteria operate in environments without molecular oxygen a condition that does not require constant maintenance. Generally, anaerobic lagoons are usually very deep. Ranges for depth can vary on the region [46]. For example, the University of Missouri Extension and the State of Mississippi state that lagoons can have depths between 8 and 20 ft [42, 43]. Based on treatment desired, lagoons can be designed to be completed as single stage with no secondary treatment, or in multiple stages where further treatment is completed by additional lagoons [45]. Figure 1.14 is a diagram of a two-stage anaerobic lagoon system.

Anaerobic lagoon can be circular, square, or rectangular. A length-to-width ratio of 3:1 for rectangular anaerobic is desired, with earthen dike and banks slopes between 2:1 and 3:1 [42, 43, 45]. Anaerobic lagoons should have a 1 foot spillway below the top of the berm where inlets should be located on the longest side of the lagoon [42].

During the wastewater treatment process, anaerobic lagoons separate into top and bottom layers. At the top of the lagoon, less dense materials such as oils float to the top of the lagoon, while sludge settles the bottom. The presence of oils and other materials prevents oxygen entry, maintaining anaerobic conditions within the system [46].

Anaerobic lagoons are sized based on the volatile solid (VS) loading rate. These values can be expressed in 1000 ft^3/day or lb VS/1000 ft^3-day. These numbers are affected by the climate. For example, in South Carolina, the volatile solids' loading rate is 5 lb VS/1000 ft^3-day, while Iowa has a VS loading rate of 3.5 lb VS/1000^3-day [48].

Nevertheless, anaerobic lagoons are problematic because of odors. These odors are a product of hydrogen sulfide, ammonia, organic acids [49], and methane. Odors can also be caused by winter to fall and summer to fall turnover within the lagoon or during land application [42]. There are many solutions that can resolve persisting odor problems in a pond. Anaerobic lagoons can be covered to prevent the release of methane gas exiting the system. Anaerobic lagoons can also have induced aerobic

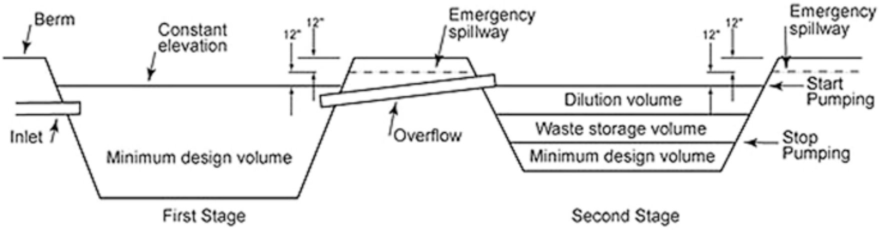


Fig. 1.14 Two-stage anaerobic lagoons for livestock manure treatment [50]

Fig. 1.15 Floating aerator [50]

layers at the top of the lagoon. This can be done by including a floating cover or aerating the top of the lagoon at very low rates [44]. Figure 1.15 is a floating aerator.

1.3.3.2 Aerobic Lagoons

Aerobic lagoons degrade organic matter by the application of dissolved oxygen throughout the lagoon. Because dissolved oxygen persists throughout the lagoon, odors are not present within the system. In order to maintain aerobic conditions, aerobic ponds are shallow but require a large land requirement. These ponds are more commonly found in warm and sunny climates. There two subcategories of aerobic lagoons—naturally and mechanically aerated [46]. Figure 1.16 is a diagram of an aerobic lagoon.

Naturally aerobic, oxidation ponds reduce organic materials within wastewater by using either oxygen from the atmosphere or algae by means of photosynthesis [46]. Wind on the pond surface also mixes with the water within the oxidation pond [44]. These ponds are very shallow with a minimum depth between 1 and 5 ft with a maximum of 5 and 6 ft [46]. The main design parameter is the organic loading rate, which is typically 50 lbs BOD_5/acre of surface area [49]. Nevertheless, naturally aerobic lagoons are not often used for the treatment of livestock wastewater.

Mechanically aerated lagoons mix oxygen throughout the lagoon by mechanical means. The need for supplying energy can make these lagoons expensive. In many cases, solar or wind power supply the power to operate aeration equipment. Also the lagoons can be designed to have anaerobic segments to reduce energy requirement [46]. Compared with naturally aerobic, mechanically aerated lagoons do not have a large area requirement but usually have a depth of 10 ft However, in addition to

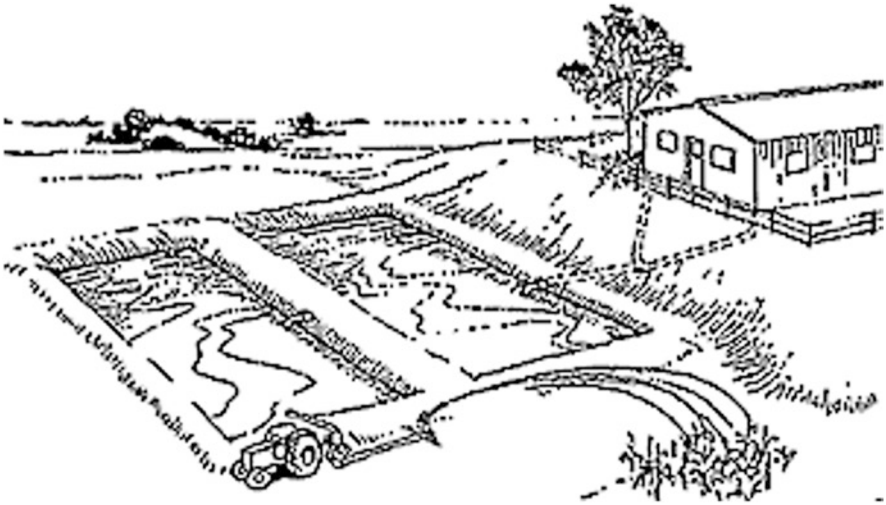


Fig. 1.16 Two-cell aerobic lagoon to treat swine waste [51]

being more expensive, mechanically aerated lagoons tend to generate more sludge, have a high tendency for foaming, and may require additional treatment such as a septic tank to collect and remove solids [49].

1.3.3.3 Facultative Lagoons

Facultative lagoons are basins that operate in both aerobic and anaerobic conditions. These lagoons can be arranged as a two-staged pond system where each pond has a depth of 4 ft or as a single-pond system with a depth of 6 ft [43]. Facultative lagoons usually have three layers. At the top is an aerobic layer. This layer receives sunlight and wind, promoting the process of photosynthesis, and provides oxygen. The middle layer is a facultative layer. In this layer of the lagoon, anaerobic and aerobic conditions exist. The extent as to which condition is prominent is contingent on the geographical location of the lagoon [46]. Bacteria that can thrive in anaerobic or aerobic conditions (facultative bacteria) are commonly found in this layer. The bottom layer is anaerobic. This layer contains an accumulation of sludge from lagoon activities [46]. Because of the layering of the lagoon, odors can be minimized [52].

1.3.4 Thermal and Biological Chemical Treatment for Biogas Producton

1.3.4.1 Description

Recent developments have occurred where there has been a call for the conversion of livestock wastes that can be used for energy, specifically biofuels. To summarize, biochemical processes are transforming organic materials to fuels by means of various processes such as anaerobic and photosynthesis. Following a biochemical process, the remaining solid and slurry within the reactor becomes viable as a reusable resource such as fertilizer [53].

Thermochemical processes convert organic matter into gas, fuels, or other carbon residuals by the use of high temperatures to physically convert the bonds of organic matter. Some of the major chemical conversion procedures include combustion, pyrolysis, gasification, and liquefaction [53].

1.3.4.2 Pyrolysis

Pyrolysis ultimately transfers a given biomass into either char or a volatile gas that can form bio-oil or combustible pyrolytic oils. Slow pyrolysis methods have been used to form char, an entity that has the benefit of producing energy for coal combustion plants, or as an addendum to soil. Some authors have found that chars from various pyrolytic processes are capable of having better absorption than those made from granular activation carbon [53].

There are two major types of pyrolysis—fast and slow/moderate. Fast pyrolysis is a pyrolytic process that consists of using high heat rate and residence time. The resultant products include low molecular weight or an insoluble organic compound such as tar. Reactor examples include bubble fluidized bed, circulating fluidized bed, and vacuum reactor. The requirements within fast pyrolysis includes a particle size less than 1 mm. Slow/moderate pyrolysis is the antithesis of fast as it requires a long vapor residence time and low heat rate. The resultant products are charcoal, depending on the concentration of lignin and hemicelluloses. Examples include rotary kiln and moving bed reactor [54].

Pyrolysis applications have been experimented with various manure types. It has been determined that the effectiveness of char production was based upon manure type and the conditions, as it was observed that organic materials differ between two different waste types [55].

1.3.4.3 Direct Liquefaction

Direct liquefaction is another thermochemical process that converts organic material, specifically lignin components, into various organic oils. Ideal conditions for liquefaction would be having very high pressures (5–20 MPa) and low temperatures (250–350 °C). Following the process, the remainders of direct liquefaction are nonreactive and stable, which are then converted into oil-based compounds with high molecular weights [53].

The process of liquefaction begins when the bonds of organic material are broken into simpler compounds, resulting into the forms of chars, instead of the process of oils. To prevent the formation of chars, solvents are typically added to slow down higher-order solid-state reactions, reducing condensation and the subsequent char formation. Examples of the solvents that are used include dioxane, MDSO, DMF, acetone, and methyl alcohol [54].

1.3.4.4 Gasification

Gasification operates at high temperatures and atmospheric pressure within the range of 800–1300 °C for the purpose of producing chars and a low energy fuel. The gasification process has three components—first, pyrolysis, or the conversion of organic materials into both tars and hydrogen-based combustible fuels. Second, exothermic reactions with the presence of oxygen can occur to remove the bonds within the organic material at high temperatures. Third, methanation or the formation of methane from hydrogen and carbon monoxide proceeds where the conditions consist of lower temperatures [53].

A fixed bed 10 kW power, counter-current atmospheric pressure gasifier was capable of achieving a gas product made from either high ash feedlot manure (HFB) or poultry litter biomass (HLB) that consisted of the following product: H_2, $5.8 \pm 1.7\%$; CO, $27.6 \pm 3.6\%$; CH_4, $1.0 \pm 0.5\%$; CO_2, $6.7 \pm 4.3\%$; and N_2, $59.0 \pm 7.1\%$. Ideal processes included air-blown gasification for the purpose of having a higher energy fuel [56]. If application of a catalyst such as nickel or aluminum would better assist in the formation of gas production by preventing tar cracking, it would be preferable [57].

Priyadarsana et al. (2005) completed gasification studies for the production of both cattle manure and chicken litter biomass under batch mode where it was determined that the molar composition of gas was 27–30% CO, 7–10% H_2, 1–3% CH_4, 2–6% CO_2, and 51–63% N_2 based on the use of air mass flow rate of 1.48 and 1.97 kg/g, where particle sizes are 9.4 and 5.15 mm, respectively [58].

1.3.5 *Composting*

There are many reasons to compost. Composting is done to reduce organic material, degrade dead livestock, and reduce disease transmission at a low cost. There are several factors that affect the quality of composting—carbon-to-nitrogen ratio, moisture content, temperature, and the type of composting materials [59]. A proper carbon-to-nitrogen ratio reduces the odors while the temperature affects the microbial degradation [60]. The temperature affects degradation processes. During the winter season, degradation can be reduced in some places by 20% [61]. Composting materials include sawdust, wood chips, and litter. Composting consist of microorganisms (bacteria and fungi) degrading organic materials within the compost pile to simple products [59].

The general composting values are shown in Table 1.12 below. These values are based on manure composting. Composting consist of primary and secondary processes. In primary composting, the temperature is raised and the organic material is degraded. As composting progresses, degradation begins to slow and the temperature is reduced. Eventually, degradation ends and the material is left idle [60] in a process known as curing. Curing maintains the conditions within the pile. It also allows items such as bones to be degraded [61].

There are two types of composting facilities—bins and piles or windrows. These are contingent on the type of livestock industry. Bins are used in poultry and swine. Beef and dairy cattle use piles or windrows [59]. Windrows or piles place materials into rows at triangular cross-sections. They are usually combined with bulking agents [62]. Aeration occurs by turning the piles by using frontend loader or compost turners [63]. Piles constructed in arid regions will need to receive outside moisture. This can be done by using a high-pressure nozzle from holding ponds or lagoon wastewater. On the other hand, piles in areas with precipitation may need to be covered to prevent odor production [63]. Bins can be designed to have dimensions of 6 ft by 8 ft with a wall height between 5 and 6 ft Bins can be made of 2 × 6 or 2 × 8 lumber or using plywood with a 2 × 6 to provide support behind the plywood [64]. The foundation of bins can be made up of pallets, gravel, concrete, and bare soil [65].

There are two entities that can be composted—manure and dead livestock. Dead animal composting is an option to remove livestock carcasses without having

Table 1.12 Factors that affect composting [59]

Factor	Value
C:N ratio	**25–40:1 (optimum: 30:1)**
Moisture	40–65% (**optimum:** 50%)
Temperature	43–66 (**optimum:** 54–60 C), >71 not ideal
Site selection	1–5% (2–3% account for runoff and erosion)

detrimental effects on the environment [59]. Dead animal composting maintains aerobic conditions, provided gases and liquids are taken away from the system [60]. Livestock operators should consider state requirements to decide what the state requirement of handling dead animals is. For example in the state of Kansas, composting facilities of dead livestock require a roof and floor to sustain moisture and avoid groundwater contamination with a fence surrounding the facility [59]. The process of composting is contingent on the size of the carcass materials [60].

A dead animal composting pile begins with a layer of sawdust 1–2 ft in depth. The dead livestock are then spread evenly across the sawdust layer [60]. Animals are laid on the side in an attempt to maximize the space for livestock [61]. Another layer of sawdust 2 ft in depth covers the dead animals. This second layer of sawdust maintains heat, prevents odors from escaping, and collects liquids and air to encourage microbial activity within the pile [60]. The amount of sawdust needed is contingent on the type of livestock to be composted. A rule of thumb for sawdust application is that in every 1000 lb of carcass, apply 7.4 yd^3 of sawdust in the dimensions of 9 ft × 10 ft [61]. When livestock need to be added to the composting pile, the top sawdust layer is removed, exposing the dead animal layer. At this point, the new animals are added and then covered up with a new sawdust layer. To maintain the quality of the pile, it advised that the pile is turned every 90 days. Once composting is complete, the products can be applied to the land or reused in other capacities [60]. This will usually happen anywhere between 4 and 12 months of composting time [61].

While composting dead livestock is advantageous, there are several concerns involved. These can include leachate of fluids from the carcasses entering into the surface and groundwater and disease-spreading pathogens [65]. Therefore, it is necessary to consider the best place to site the place for composting dead livestock. Changes can include placing the facilities away from the water table, away from low permeable soils, and downwind from neighbors. Facilities should also be constructed away from livestock to suppress disease potential. Livestock operators should also have an emergency plan in case of outbreak [61]. For additional protection, the livestock operator can create a barrier wall to prevent access to the composting pile. The barrier can be 4 ft high using four steel t-posts with concrete floors, wooden walls, and a metal roof [65].

1.3.6 Vermicomposting

An alternative method of treating wastes that has been used related to composting is as vermicomposting. Vermicomposting is a method where earthworms digest a small portion of organic matter where the majority becomes waste in a form known as worm casts. The processes involved in earthworm digestion are typically physical or mechanical, grinding and mixing, and biological or microbial decomposition in nature. In vermicomposting, waste is added to the system. It must be added into the system in thin layers for the purpose of increasing degradation. There is great competition between earthworms and microorganisms for the carbon sources. Application of waste can change—it will either increase or decrease productivity [66].

Vermicomposting treatment technology has been used extensively in animal excretion, sewage, and agroindustrial wastes but not animal manures. Therefore, Loh et al. (2004) treated cattle and goat manures using the earthworm, *Eisenia foetida*. The experiments found that total C, P, and K were high in goat manure worm casts as compared to cattle, whereas cattle worm casts were richer in N content. In addition, cattle manure had a higher biomass and reproductive performance as well along with a higher cocoon production per worm [66]. Other studies have been compiled on cow, buffalo, horse, donkey, goat, and animal [67], dairy [68], and pig [69, 70] to name a few. Within continuous feeding reactors, two different types of pig slurry were compared with 500 earthworms (*Eisenia foetida*); microbial biomass was specifically measured with 3 kg of pig slurry; loss of C was not related to pig slurry rate; rate of manure-earthworm relationships was investigated [71].

1.3.7 Summary

There are many treatment methods that can be considered for the handling of wastes that persist within the livestock industry. An operator must consider what is available in regard to space and the desired treatment needed in order to make an appropriate decision on selecting the proper treatment method.

1.4 Land Application of Livestock Wastes

1.4.1 Description

Land application is a waste management technique that involves recovery of nutrients from manure by plants for the purpose of producing a crop [2]. The classification of manure depends on the percent of dry matter present and the type of livestock waste industry. Manure can be in liquid (less than 5% dry matter), semiliquid (5–10% dry matter), or solid (greater than 15% dry matter) form. Generally, beef and poultry industry handles solid manure, while dairy and swine manure is usually in liquid form [72].

Regardless of the industry, the nutrient content is the primary focus for application. Nutrient content within the manure is affected by the type of animal species, the process for handling of manure, livestock housing, bedding system, diet, temperature, and the nutrients present. The primary nutrients of concern are nitrogen, phosphorus, and potassium. The nitrogen presence affects the type of plants and quality of the produce. There are two important forms of nitrogen that must be considered—organic nitrogen and ammonium nitrogen. When organic nitrogen enters into soils, it is mineralized into inorganic nitrogen. Mineralization is contingent on the temperature and time of year. Warm and moist soils are better for the degradation of organic nitrogen as compared with cool and dry soils. Ammonium-nitrogen is converted to organic nitrogen by plants in a process known as nitrification. Moreover, 25–50% of organic nitrogen is converted to ammonium-nitrogen. However, improper application of manure can lead to volatilization or the conversion of ammonium-nitrogen to ammonia-nitrogen. This becomes problematic because ammonia-nitrogen dissipates into the atmosphere. On the other hand, potassium and phosphorus must be converted to inorganic forms in order for it to be of use by plants [73]. Manure can also be problematic because it can produce various gases. These gases can have grave effects depending on the concentration. Table 1.13 summarizes the major gases found in manure. Previous treatment methods can affect land application. Table 1.14 discusses the various treatment processes and their effects on land application. Therefore, the type of handling equipment, time, and rate of application should be considered if an operator is to consider land application.

1.4.2 Manure Handling Equipment

The equipment necessary for handling manure depends on the type of manure. Each operator must make a decision of handling manure that best distributes the nutrients to the crops being planted. Depending on the type of manure handled, there are unique pieces of equipment that are used in order to safely move the manure onto the field.

1.4.2.1 Solid Manure

Solid manure is incorporated at the surface by using spreaders that are trucked-mounted or trailer-towed. Regardless of the type of spreader, manure can be spread at the side or the rear. Nevertheless, rear manure spreaders are more likely used today [72]. For example, livestock operators in the state of Missouri primarily use

Table 1.13 Manure gases [74]

Gas	Effects (percent indicates percent or concentration in ppm)
Ammonia (NH_3)	Eye irritation (<1%) Coughing, irritation of throat, eyes, lungs (3–5%)
Carbon dioxide (CO_2)	Difficulty breathing, drowsiness, headaches (3–6%) Death (>30%)
Methane (CH_4)	Asphyxiation (5–15%)
Hydrogen sulfide (H_2S)	Dizziness irritation, headache (50 ppm) Death

Table 1.14 Various wastewater and biosolid treatment processes and methods and their effects on land application processes [75]

Process/ Method	Process definition	Effects on biosolids	Effect on land application process
Wastewater treatment process			
Thickening	Low force separation of water and solids by gravity, flotation, or centrifugation	Increases solid content by removing water	Lowers transportation costs
Stabilization method			
Digestion (anaerobic and/ or aerobic)	Biological stabilization through conversion of organic matter to carbon dioxide, water, and methane	Reduces biological oxygen demand, pathogen density, and attractiveness of the material to vectors (disease-spreading organisms)	Reduces the quality of biosolids
Alkaline stabilization	Stabilization through the addition of alkaline materials (e.g. lime, kiln dust)	Raises pH. Temporarily decreases biological activity. Reduces pathogen density and attractiveness of the material to vectors	High pH immobilizes metals as long as pH levels are maintained
Heat drying	Drying of biosolids by increasing temperature of solids during wastewater treatment	Destroys pathogens, eliminates most of water	Greatly reduces sludge volume
Chemical and physical processes that enhance the handling of stabilized biosolids			
Conditioning	Processes that cause biosolids to coagulate to aid in the separation of water	Improves sludge dewatering characteristics. May increase dry solids mass and improve stabilization	The ease of spreading may be reduced by treating biosolids with polymers
Dewatering	High force separation of water and solids. Methods include vacuum filters, centrifuges, filter and belt presses, etc.	Increases solids concentration to 15–45%. Lowers nitrogen (N) and potassium (K) concentrations. Improves ease of handling	Reduces land requirements and lowers transportation costs
Advanced stabilization method			
Composting	Aerobic, thermophilic, biological stabilization in a windrow, aerated static pile, or vessel	Lowers biological activity, destroys most pathogens, and degrades sludge to humus-like material	Excellent soil conditioning properties. Contains less plant available N than other biosolids

rear-end box-type spreaders with beaters. These spreaders can consist of a conveyor with chains to move manure from the front of the spreader to the beaters or a front endgate that moves the manure to the beaters [76]. Once it is moved to the rear, the beaters scatter the manure onto the ground [72].

Rear-end box-type spreaders can have single, horizontal, or double vertical beaters. However, each beater type is limited in its ability to properly distribute nutrients. Single beaters cannot spread manure homogenously onto the land. Horizontal beaters only spread manure in areas of close proximity to the trailer. Double vertical beaters spread manure very wide and thin. Overall, rear-end box-type spreaders have a problem with spreading manure homogenously onto the land. They are also very heavy and have the potential to compact soils if land application is done in the fall and spring. Similar to box-type spreaders, truck-mounted spreaders apply manure using double beaters in various horizontal or vertical configurations. Regardless of application, solid manure handling should be applied within 24 h. This is to ensure the minimization of nutrient loss, the presence of odors, nutrient runoff, and compaction [72].

Since the application of solid manure can generate odors, there are methods that can be done to suppress odors in manure land application. These include placing a cover over solid manure not being applied, using chemical treatment such as alum (also advantageous for preventing ammonia volatilization), and considering the wind direction when applying onto the surface. There are also mechanisms that can be employed that can better spread the manure upon entry on the field. These include a tandem disk or a field cultivator. Solid manure can also be pretreated by drying or composting [77].

1.4.2.2 Semisolid Manure

Semisolid manure is handled by using spreaders with an endgate. The configuration can range from side discharge or a V-shaped hopper. Each of these can be handled by power takeoff (PTO) or ground wheel tractor spreaders or a truck-mounted spreader. The process of application consists of moving the manure by augers to be flung at the point of emission on the spreader. Manure is flung either by using a rotating or flail-type expeller. A rotating expeller directly flings manure, while in a flail-type expeller, manure travels from a hopper onto a rotating shaft with chain-suspended hammers. Once the manure is on the hammers, it is tossed onto land [76].

1.4.2.3 Liquid Manure

Liquid manure can be applied at or below the surface. Surface application of liquid manure is completed by fixed sprinklers, hand-carried sprinkler, traveling guns, or central pivot irrigators [76]. Factors that control application by irrigation equipment are nozzle size and pressure. These affect the size of the drops applied to the surface. Larger-sized drops are greatly preferred to control the loss of nitrogen and decrease odors [77]. A recommended size is greater than 150 μm. Other ways include adding dilution water or drop nozzles [78]. Surface application of manure is preferred in areas where odors and nutrient loss are minimal [76]. Figures 1.17 and 1.18 provide diagrams of irrigation systems.

Subsurface application injects liquid manure below the surface where it is then applied below the soil surface by a self-propelled application. Manure can also be

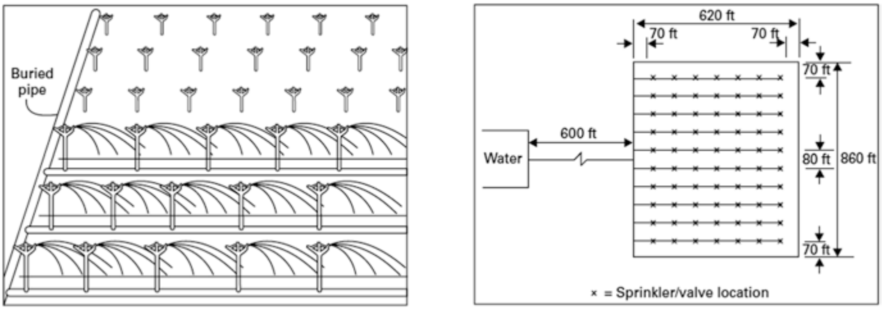


Fig. 1.17 Irrigation system to apply liquid manure [76]

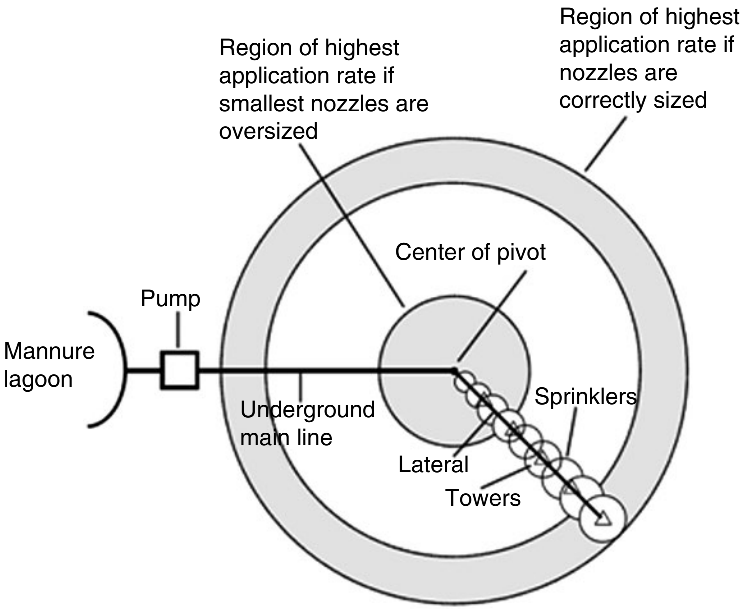


Fig. 1.18 Center pivot irrigation system [79]

transferred by a drag hose or a tractor-drawn applicator. The method chosen is determined by the size of the operation. Usually larger operations opt to use a drag hose or a tractor-drawn applicator. When liquid waste is applied below the surface, injectors have chisels that break up material or sweeps that uniformly apply the liquid manure below the root surface to avoid leaching [76]. Chisel-type knives also prohibit odors and volatilization, while sweep-knife injection reduces volatilization, denitrification, and material degradation [73].

Subsurface is preferred to surface application for several reasons. First, subsurface reduces the potential of ammonia-nitrogen emissions [76], greenhouse gases, and odors [72]. For example, research has shown odors to be reduced by 90% when incorporating a subsurface method [78]. Second, subsurface application reduces runoff potential, availing more nitrogen to plants. Third, subsurface injection spreads the manure so it does not have an impact on the surface of the soil. Despite its many advantages, subsurface application is energy intensive; requires more maintenance, time, and management; has higher equipment costs; and is incapable of being used on rocky soils. Therefore, assessment should be made to determine whether or not subsurface injection is a more viable option than any surface application method [80].

1.4.3 Time of Application

The time when manure is applied determines nutrient availability to plants. Spring is the best season for manure application because nutrients are broken down into the soils during the growing season. Organics are quickly broken down in the soils, increasing nitrogen availability. Summer applications are appropriate if growing hay, pasture, and warm-season grasses and if application is completed by travel guns or the central pivot system. Applying manure during the fall is only appropriate if temperature stays below 50 °F [80]. This is because manure is immobilized and remains in the soil [73, 80], leading to more time for degradation. But when the temperature is above 50°, nitrification, leaching, and denitrification occur [73]. Winter application of manure is never recommended as manure hardly enters the soil and has a higher potential for runoff [80] into surface waters. If manure application is a necessity in the winter, apply at low concentrations or during periods of snow melt [73].

1.4.4 Rate of Application

The amount of nitrogen, type of manure, how manure is applied and used, and additional economic or environmental are the factors that determine how frequently manure will be applied to a given crop. The University of Minnesota Extension provides four steps to determine the process by properly determining the rate of application [73]:

1. Determine the nutrient needs of the crop.
2. Analyze the nutrient content within the manure.
3. Uncover the nutrient available to the crop.
4. Compute the rate of application.

1.4.5 Summary

In summary, the purpose of land application attempts to resolve the issue of losing nutrients that are vital to the growth of crops. Manure should be applied uniformly to land to avoid the volatilization of nitrogen into the atmosphere. It should also maintain the potassium (K) and phosphorus (P) on the field. The time of application should be considered in order to have nutrients maintained within the soils and avoid any subsequent losses that occur during improper times of application [81]. Manure application should be done to avoid the presence of odors [76] and other potential issues. The rate of application depends on the crop's needs.

1.5 Storage of Livestock Wastes

1.5.1 Description

Most often, the treatment of livestock waste is done for the purpose of recycling products back within the system. This can include land application for growing plants. However, there may be times when the conditions are not conducive for reusing treated wastes. Therefore, livestock wastes must be stored until the appropriate conditions take place. There are several factors that should be considered when deciding whether or not to store manure: first, if the soil is saturated, wet, frozen, or snow covered or if the soil will compact under the weight of manure handling equipment; second, if the temperature and/or humidity create a proper environment for the generation of odors; third, if a livestock operation may not have the proper equipment or personnel available to apply manure at the present moment; fourth, if the cropping schedule may require temporary storage; and finally, if there is a higher volume of manure and wastewater than what can be handled [82]. There are several methods for storing wastes. These methods are employed usually based on the time of storage and type of waste treated—i.e., solid, semisolid, and liquid wastes.

1.5.2 Storage Time

Livestock wastes can be stored either on a short-term or long-term basis. When wastes are stored for 60–90 days or up to 180 days, it is termed as short-term storage. Short-term storage is a viable option when poor weather conditions persist, or when setup is not appropriate to properly handle manure. Short-term storage is also used in mild climates or when growing crops [83]. However, it is very seldom for operators to store liquid manure on a short-term basis. Dairy wastes are the most appropriate to be stored short term.

There are many methods for storing manure on a short-term basis. These can include stacking within a field, covered with a plastic sheet, or storage in a detention pond. Manure can also be scraped into open lots in mounds or inside pole sheds. Regardless of the method, the operator should choose to avoid any contamination of water supplies or exposure to bacteria from the manure [84].

Long-term storage can last for approximately 180 days. Facilities are available to hold solid, semisolid, or liquid wastes. For example, walls and slabs can stack solid manure, while semisolid pumps or scrapers help transport waste into areas designated for storage. Liquid waste is usually transported by pumps or pipes [84]. Sometimes manure can be held for longer than 180 days. For example, waste is stored for 6 months for the purpose of application on annual row or small grain crops. In the center and upper Midwest, storage can happen for a full year if fall applications are unsuccessful because of wet conditions [82].

1.5.3 Facilities to Store Livestock Waste

There are many facilities that can be used to store manure. However, the practicality of each facility depends if the operator is storing solid, semisolid, or liquid manure. Table 1.15 provides an estimated cost for manure storage facilities.

1.5.3.1 Solid Manure Storage

The objective in storing solid manure is to reduce the volume, odor, and potential for runoff. Solid manure is stored based on climate and industry. Because the evaporation rate is greater than precipitation, arid regions can store solid manure in a different fashion as compared to regions that retain precipitation. Arid regions simply store manure in stacks or piles. In the beef and dairy industry, manure is composted using windrows or piles, while in the poultry industry, the manure is contained inside stack houses. On the other hand, non-arid regions require the solid

Table 1.15 Estimated costs for manure storage facilities. Numbers based on 500,000 gallon capacity [85]

Storage type	Cost ($/1000 gallon)
Naturally lined earthen basin	25–36
Clay-lined earth basin using clay onsite	50–70
Clay-lined earth basin using clay from off-farm borrow site (depending on hauling distance)	80–100
Earthen basin with plastic liner	100–140
Earthen basin with concrete	120–280
Aboveground pre-cast concrete tank	200–250
Aboveground concrete tank poured in place	230–270

manure to be walled with a concrete bottom and covered with a roof. If solid manure is not housed in this manner, it could also be composted [83]. However, there are alternatives for non-arid region storage of solid manure. Purdue University Extension states that if manure is dried and bedding is added to form a solid, it can be stored on concrete pads. Concrete pad storage of manure reduces the potential of groundwater leaching and runoff provided the operator constructs a roof [86].

1.5.3.2 Semisolid Manure Storage

Pits are a main way to store semisolid manure. Pits in general are a viable option for waste storage because they can reduce waste volume and reduce the production of odors provided they are properly maintained. Pits can be fabricated from concrete or a coated metal or can be completely made of earth. Manure is transferred into them by means of slated floors. Fabricated pits can be constructed for a location completely above, partially above, or below the surface of the ground. The process of transferring semisolid manure is by scraping or flushing the manure from its source. Equipment used for transferring can include collection sump pumps or by gravity, depending where the pit is located. Semisolid manure should be agitated before transfer to ensure all suspended solids are relocated into the pit [83].

Pits made from earthen structures are capable of housing large quantities of semisolid wastes. Therefore, operators will need to ensure ample space is available if a pit from earth is to be used [83]. The incorporation of manure at the bottom of the pit protects the pit from leaching nutrients. This is especially advantageous for very clayey soils. Pits are also lined to protect leaching from the walls. The change in fluid levels can alter the stability of the pit, leading to the formation of cracks [86]. In addition, earthen structures require vegetative cover. Maintenance is then necessary for its upkeep. As with fabricated pits, manure entering into an earth-structured pit also requires agitation. Transporting semisolid wastes into the pit is easily done with the use of a built-in access ramp. This can make hauling and transporting waste very time-consuming. Nevertheless, earthen pits can be a culprit for odor production so proper maintenance is necessary. Despite the time-consuming hauling and the high potential for odors, earthen pits are less expensive as compared to fabricated pits [83].

1.5.3.3 Liquid Manure Storage

Facilities that can store liquid manure can include lagoons, runoff holding ponds, and storage tanks. Table 1.16 provides a detailed description of the solid content within liquid manure systems. Lagoons are a beneficial option for storing liquid manure because they can house liquid manure for 6–24 months [86], can be cost-effective per animal, and reduce odors [83]. Lagoons provide a mechanism for liquid waste to be treated prior to land application [86]. Lagoons require a higher volume than treatment of semisolid manure and must consider the temperature,

Table 1.16 Solid content for liquid manure systems [76]

System	Solid content
Manure pit	
Swine	4–8%
Cattle	10–15%
Holding pond	
Pit overflow	1–3%
Feedlot runoff	<1%
Dairy bard wastewater	<1%
Lagoon, single or first stage	
Swine	½–1%
Cattle	1–2%
Lagoon, second stage	<1/2%

climate, and volume of wastewater to be housed. Biological activities in the lagoon are maintained by replenishing the lagoon with dilution water and prevent salt buildup. This should be monitored during high rates of evaporation [86]. Lagoons should also be monitored to avoid a buildup of settled solids [87]. More information on lagoons can be found in Sect. 1.2.

Runoff holding ponds are typically used for storage during rainfall events. This means that any liquid manure housed must be pumped out following the event [83]. Holding ponds are designed to be smaller than lagoons. This reduces the rate of degradation within the pond. Erosion and overflow is controlled by installing a 12-inch spillway. To maintain liquids within the holding ponds, a settling basin is set up to collect 60–75% of the solid manure. This allows waste removal to be completed by irrigation systems [86].

Storage tanks for liquid waste can be made from glass, concrete, or earth. Similar to pits, storage tanks can be placed above, partially above, or underground. A storage tank is divided into five major sections—residual volume, manure storage, wash water, rainfall and evaporation, and safety volume depth. The residual volume comprises of 6–12 inches from the bottom of the tank. Above the residual volume houses the manure. The manure is pumped into this section of the tank and can be stored for 3–6 months. The wash water stores wash or freshwater. If the tank is open, the net rainfall and evaporation section collects any rainfall that may occur. Finally, the safety volume depth provides adequate space to handle a 25-year, 24-h storm event. Depending on the type of material, storage tanks will have a different depth [88].

1.5.4 Storage Area Design

The storage of manure has been published by the US Department of Agriculture (USDA) and follows the following calculation based on storage volume [2]:

$$VMD = AU \times DVM \times D \tag{1.2}$$

where.

VMD = volume of manure production for animal type for storage period, ft^3
AU = number of 1000 lb animal units per animal type
DVM = daily volume of manure production for animal type, ft^3/AU/day
D = number of days in storage period

The second equation calculates the bedding storing volume:

$$BV = (FR \times WB \times AU \times D)/BUW \tag{1.3}$$

wheres

FR = volumetric void ratio (values range from 0.3 to 0.5)
WB = weight of bedding used for animal type, lb/AU/day
BUW = bedding unit weight, lb/ft^3
Sometimes this equation is multiplied by 0.5 as a volumetric void ratio.

Sizing for a liquid and slurry waste storage can be calculated from the following equation:

$$WV = TVM + TWM + TBV \tag{1.4}$$

where

WV = volume of waste stored, ft^3
TVM = total volume of stored manure, ft^3
TWW = total wastewater stored, ft^3
TBV = total bedding volume stored, ft^3

1.5.5 Summary

The type of manure affects the manure facility chosen. Within the types of manure, there are various facilities that can house manure. Each facility should be analyzed carefully before installation. This ensures that the proper facility is constructed based on the needs of the operation.

1.6 Feedlot Runoff Control Systems

1.6.1 Description

Section 1.1 of this chapter indicates that feedlots are required to have NPDES permits as defined in the Clean Water Act of 1977 [89]. This limits the amount of discharge that can occur at a particular location. A major source of discharge from feedlots is runoff. There are several different systems that properly contain runoff. Many of systems have been discussed in prior sections, and therefore information concerning the significance for runoff control will only be presented. Runoff control protects a feedlot from the presence of weeds, odors, and insects. The collected water provides an alternative source for fertilizers and irrigation water [90].

1.6.2 Runoff Control Systems

1.6.2.1 Descrtiption

The processes of a runoff control systems are multifaceted. A runoff control system captures and reroutes rain or snowmelt. It can also provide a method to treat runoff before it is to be discharged. There are two major subsets of runoff control systems—full containment and discharge runoff control systems. Full containment systems (also known as clean water diversion systems) include the use of terraces, channels, and roof gutters [89].

1.6.2.2 Clean Water Diversion

The purpose of diversion is to control runoff entry into holding ponds and settling basins [94]. In addition, precipitation is prevented from invading manure storage systems, preventing the potential for creating polluted runoff [90].

1.6.2.3 Discharge Runoff Control

Discharge runoff control systems include settling basins and runoff holding ponds. Settling basins are a runoff control system that separate liquid from solids. The separation of liquids from solids allows liquids to be further treated by methods such as storage ponds. Solids settle to the bottom while the liquids remain at the top. There are several processes that will cause solids to separate from liquids. These include risers, slotted board, or porous dams. Settling basins consist of channels or boxes made of concrete or earth. Cleaning the basin is necessary to allow for solid placement. The cleaning of the basin should be done if 50% of the basin is filled with solids. Solids are taken from the basin and led away from the feedlot. If cleaning is not permissible, an alternative method is to increase the size of the basin by 25–50%. Scrapers, high-pressure water systems, and metal screens prevent the system from being clogged. Figure 1.19 is a diagram of a solid-liquid separator [90]. Figure 1.20 depicts a system to handle runoff. Figure 1.21 provides a diagram of a settling basin.

Runoff holding ponds receive and store liquid runoff from settling basins. This process can happen 15–30 min before entry into a settling basin [92]. In general, they are smaller than holding ponds. This means that when wastewater is collected, it will only remain in the ponds for a short period of time. They must be dewatered by using equipment such as a sprinkling systems or perforated pipes. However, if holding ponds are constructed in arid regions, dewatering is not necessary as evaporation will be sufficient. Water removed from the holding pond can be applied onto crops [90]. Figure 1.22 is a diagram of a holding pond.

In general, holding ponds are designed based on a 25-year, 24-h storm [90].The volume chosen for the pond is also contingent upon the time of storage permitted [92].

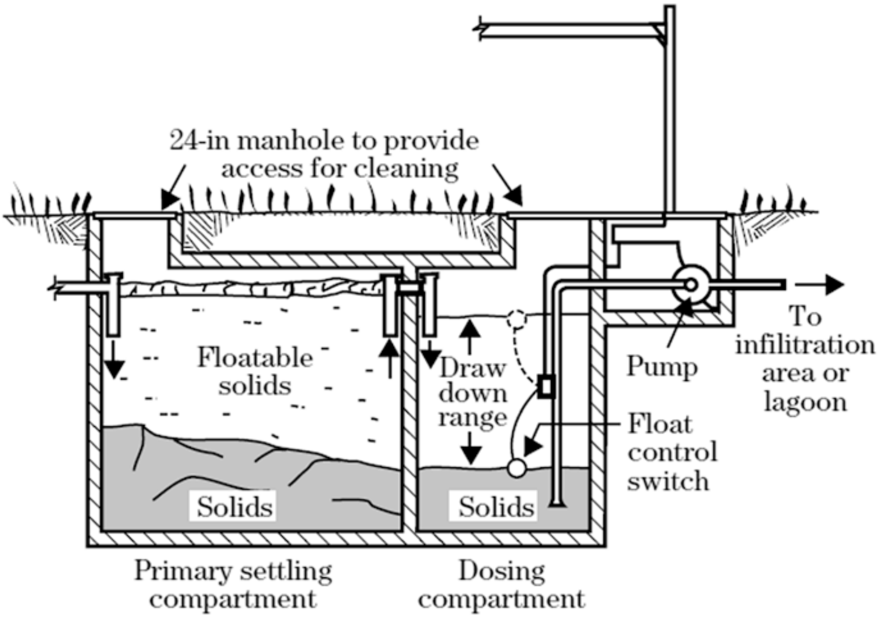


Fig. 1.19 Solid-liquid separator [8]

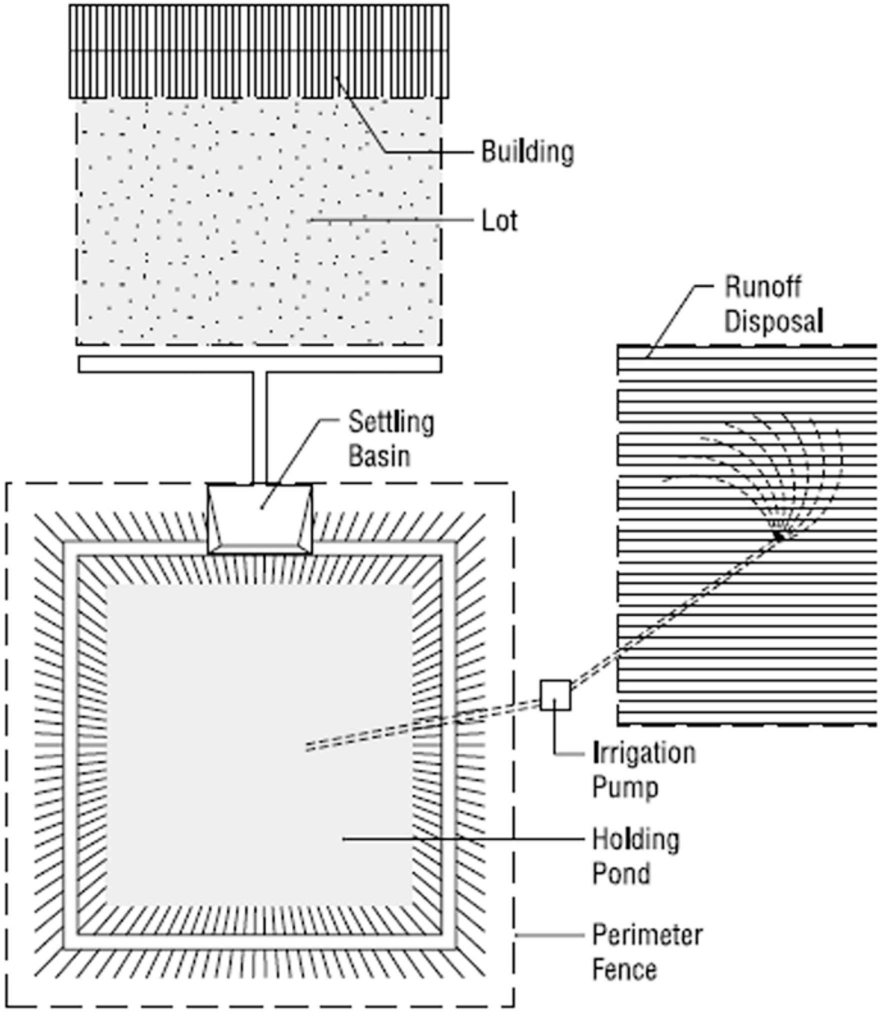


Fig. 1.20 Lot runoff handling system for milking wastewater [91]

1.6.2.4 Vegetative Filter Strips

Another method to control feedlot runoff includes vegetative filter strips. Vegetative filter strips (VFS) are a feedlot runoff control system consisting of vegetation. This vegetation is grown in close proximity to the feedlot, reducing constituents such as sediments, nutrients, and pesticides [93] and COD [94]. In a VFS system, vegetation uptakes pollutants from runoff prohibiting transport beyond the feedlot. The removal of these particulates from the runoff results in clean water [95]. Associated processes include settling, filtration, dilution, pollution absorption, and infiltration [96]. VFS systems are capable of removing 60–70% suspended solids, 70–80% nitrogen

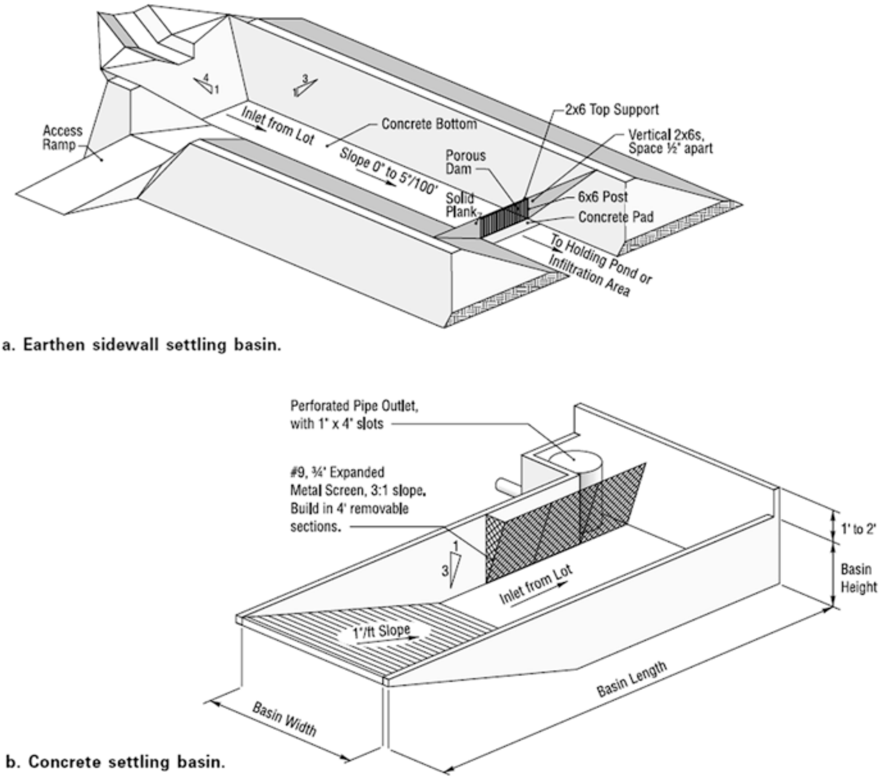


Fig. 1.21 Settling basins for manure management [91]. (**a**) Earthen sidewall setting basin. (**b**) Concrete setting basin

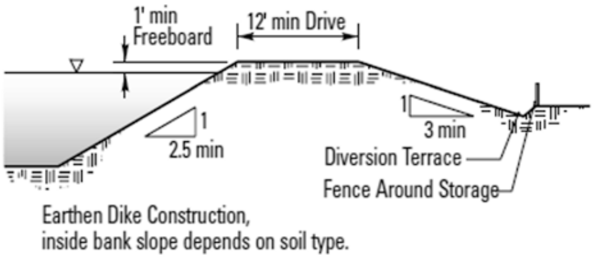


Fig. 1.22 Holding pond for storing milk house wastewater [91]

[94], 7–100% phosphorus, and 64–87% pathogen removal [97]. VFS systems create a mechanism that can reduce non-point pollution runoff. Several factors affect the efficiency of a VFS system. These include the type of pollutant, soil type, vegetation, state of flow, and current plant status [93].

The nature of the pollutant is important in determining its ability to be treated by vegetative filter strips. Vegetative filter strips are capable of reducing particulate-bound pollutants in comparison with soluble particulates. Various processes incorporated within VFS are able to be removed by the system as compared with soluble particulates, which can only be removed by sedimentation. The type of soil is important because of the various processes that occur within soil. Sandy-loam soils with a depth between 3 and 13 ft or clay soil (26–145 ft) are ideal for VFS. Vegetation should be dense and rough and must be able to reduce the surface velocity so that collected solids are kept within the system. Flow entering into the VFS system should be overland sheet flow as compared to concentrated flow. Overland sheet flow prevents sediments from leaving the VFS system, lowering the velocity of the wastewater within the system [93]. Sheet flow is also uniform throughout the system and is shallow [97]. Channelized or channel flow differs from overland flow because runoff flows through a narrow channel such as a gated terrace or a waterway. This presents a problem because water flows a velocity that is higher than one in channelized flow. Channelized flow also requires more land because the strip will need to be longer to accommodate the channel [96]. Loading into the VFS system is also inconsistent. As a result, channelized flow includes a reduction in treatment and an increase in erosion [97].

There are two types of VFS systems—vegetated infiltration basin (VIB) and vegetative treatment area (VTA). A VTA system plants vegetation downslope from crops or livestock housing. On the other hand, VIB is similar to a VTA with the exception of a berm for runoff collection. Included within the treatment system is the presence of aerobic bacteria to treat nitrogen by means of nitrification. When wastewater enters into the VIB system, nutrients are absorbed into the soil and are used by plants. Runoff is collected through tiles in the system where it is transferred to other wastewater treatment systems [97].

A VFS system is most effective if it has a depth less than 1.5 ft. In this scenario, uptake of pollutants by plants is more feasible. Pollutant removal efficiency is also affected by the length of the VFS—the longer the VFS, the more efficient the treatment [93]. A recommended length for a VFS system is 100 ft or 1 ft/animal unit, whichever value is greater. However, the ground slope will affect the length of the system chosen. A 0–2% slope can have a minimum length of 100 ft, while a 6% slope a minimum of 300 ft [94]. Other recommendations for design include 200 ft length for a 1-year, 2-h storm, 300 ft for a 0.5% slope to 860 ft for a 4% slope. VFS treatment system should include a pretreatment step to settle solids from the runoff [97].

There are many types of vegetation that can be used with a VFS system. The University of Kentucky Extension states the type of vegetation planted within the system is contingent on the season. Five plants are suggested—tall fescue, orchardgrass, timothy, Bermuda grass, and gamagrass. Tall fescue is an option because it is capable of using nutrients when planted. However, it cannot be used for grazing. Orchardgrass not only removes nutrients but is capable of being used for grazing, albeit only up to 4 inches, unlike tall fescue. Timothy grass is a viable option for horses and cattle to graze provided grazing is limited to 4 inches. Bermuda grass is a quality choice because it is capable of reducing nutrients and also drought resistant. Bermuda grass can grow up to 8 inches, while grazing is limited to 3–4 inches. Planting gamagrass will absorb nutrients deep from within the treatment system [95].

1.6.3 Summary

In summary, this section presents several feedlot runoff control systems that are available to divert runoff coming from a feedlot. Feedlot operators must consider the characteristics of each control system and consult the state legislation in order to understand what are the design requirements and limitations to use the treatment method chosen by the feedlot.

1.7 Odors and Gases

1.7.1 Odors: Origin and Nature

Dispersed odors in the air travel and can cause great discomfort for those that live in close proximity to livestock operations. There are three major causes for odor compounds in livestock operations—"the livestock themselves, animal housing facilities, feedlots, and feed storage facilities; manure storage structures; and application of livestock manure to agricultural land" [98]. Particular examples include anaerobic degradation of organics in manure, feed, and silage. Odors caused by anaerobic digestion increase in intensity when temperatures are warm. Also if manure becomes wet, it can also be a major cause for odors [99]. In feedlot operations, incomplete fermentation of nutrients by bacteria in manure produces odors [100].

Odors can spread in the air as a gas. Dust particles can also be agents to carry odors. When particles that cause odors come into contact with dust particles, they are absorbed and carried along. The effectiveness of odors spreading is contingent on the weather. Very humid days maintain the odors in the area, while dry and windy days will disperse them [99]. Rainfall can also increase the emission of odors. If rainwater remains on the ground surface, anaerobic conditions can occur on the manure [100].

1.7.2 Sources of Odors

The major sources of odors are gases, anaerobic decomposition of manure, and other various compounds. The compounds that can provide the biggest issue include volatile fatty acids, mercaptans, esters, carbonyls, aldehydes, alcohols, ammonia, and amines [101]. A major proponent of odors is the formation of volatile fatty acids.

The reason why volatile fatty acids cause so many odors is because of the volatile organic compounds that are present within the manure. Volatile fatty acid presence within manure varies between animal types. For example, the majority of compounds found in pig manure include acetic, propionic, n-butyric, iso-butyric, n-valeric, iso-valeric, n-caproic, and iso-caproic acids. These organic compounds vary with the amount of carbon atoms present within the system, where butyric, valeric, and caproic being the highest amount of odor. Other potential dangers for volatile fatty acids increase toxic pathogens within soil base [102].

One can state that the majority of VFAs have carbon numbers between 2 and 9. In addition, the presence of *Eubacteria*, *Peptostreptococcus*, *Bacteroides*, *Streptococcus*, *Escherichia*, *Megasphaera*, *Propionibacterium*, *Lactobacilli*, and *Clostridium* are also noted for contributing to the major problems associated with volatile fatty acids [103]. Volatile fatty acids are generated during the process of fermentation, when carbohydrates are broken down from sugars into pyruvate, which is then fermented into volatile fatty acids in anaerobic conditions. Therefore, the lack of aerobic conditions such as incomplete microbial decomposition or other anaerobic treatment methods are the major cause of this potential issue [98].

Aromatic compounds are a major concern within animal manure due to the presence of indole, skatole, p-cresol, phenols, and 4-ethylphenol. Under anaerobic conditions, bacteria such as *Bifidobacterium*, *Clostridium*, *Escherichia*, *Eubacteria*, and *Propionibacterium* use aromatic amino acids such as tyrosine, phenylalanine, and tryptophan [98].

Sulfate-reducing bacteria typically cause the presence of hydrogen sulfide due to the reduction of amino acids cysteine and methionine. Sulfur-reducing bacteria typically use sulfate as a terminal electron acceptor transforming sulfate compounds into hydrogen sulfate. The most common bacteria heavily involved in this process are *Desulfovibrio desulfuricans*, *Veillonella*, *Megasphaera*, and the enterobacteria [98].

Ammonia emissions causing odor are commonly attributed to ammonia volatilization. The reason behind such a problem can be traced back to the animal species, diet, and age. For example, urea, the nitrogen compound within urine, typically forms ammonium and bicarbonate ions by means of urease enzymes. Nitrogen found in feces is broken down by bacteria, where it transfers from proteins to amino acids and eventually into ammonium. The time in which this occurs depends on the temperature, concentration, and pH [104].

One of the more common entities that is emitted through livestock waste is the presence of hydrogen sulfide. Hydrogen sulfate odor emissions commonly occur from the anaerobic decomposition of sulfur [105]. One of the most common methods of forming hydrogen sulfate is due to the efforts of sulfate-reducing bacteria [106].

1.7.3 Odor Prevention

There are various methods to prevent the spreading of odors. These can include animal nutrition management, manure treatment and handling, waste treatment methods, and better livestock operation management. Tables 1.17 and 1.18 provide various methods to mitigate odors.

1.7.3.1 Animal Nutrition Management

One of the best ways to reduce odors is to alter animal nutrition. If livestock feed contains more crude protein concentration or blood meal, it will lead to the production of odors. Studies have shown that feeding livestock crystalline amino acids or peppermint as compared to a diet heavy with crude protein can reduce odorous manure. Barley-based diets can also reduce odors by 25% as compared with a diet dominated by sorghum [50, 107]. Fecal starches, proteins, and lipids should be eliminated as much as possible. This will prevent incomplete fermentation, which is the main cause of odors [100].

In addition to changing the diet of the animals, the operator should consider a change in feeding schedule. An appropriate feeding schedule could be feeding the animals at sunrise, noon, and sunset. This can not only eliminate the presence of odors but also control the emission of dust in the atmosphere from cattle that move

Table 1.17 Odor emission strategies for livestock housing [50]

Method	Description
Filtration and biofiltration	1. Filtration traps 45% 5–10 μm particles; 40–70% particles greater than 10 μm
Biofilters	1. Biofilters trap and biologically degrade particles; remove odorous emissions 2. Biofilters can remove 90% odors, including 90% hydrogen sulfide and 74% ammonia
Impermeable barriers	1. Dust particles retain odors preventing movement 2. Impermeable barriers such as windbreak walls or dams are very effective
Oil sprinkling	1. Application of vegetable oil can control dust movement 2. Study applying oil reduced hydrogen sulfide concentrations by 40–60%
Landscaping	1. Application of trees and shrubs 2. Landscaping reduces particulate movement and inserts dilute the concentration of emissions

Table 1.18 Examples of odor emission strategies for manure storage [50]

Method	Description
Solid separation	1. Removal of large materials, typically the size of a screen opening 2. Removal of large material reduces the loading rates, thereby producing less odors during decomposition of remaining material 3. Solid separation uses processes such as sedimentation, screening, filtration, or centrifugation
Anaerobic digestion	1. Under anaerobic conditions, odors are biologically reduced from manure 2. Anaerobic digestion encapsulates manure maintaining odors
Additives	3. Application of additional enzymes or chemicals to dilute manure under anaerobic conditions
Impermeable cover	1. Coverage of a manure storage area will control odors from gases 2. Impermeable covers can control wind and radiation
Permeable covers	1. Coverage of a manure storage area to control the contact between manure and radiation and wind velocity 2. Emission rates are reduced 3. Permeable covers create an aerobic zone, encouraging aerobic microorganism growth
Aeration	1. Application of oxygen by mechanical means to maintain aerobic conditions 2. Aeration can cause an increase in ammonia emissions
Composting	1. Composting provides an aerobic environment reducing the creation of odors 2. A more viable option for those that handle solid manure because of high maintenance required to maintain suitable decomposition conditions

their hooves on the ground. As a reminder, dust can be used as an agent to transfer odors [100].

1.7.3.2 Manure Treatment and Handling

Another method for reducing odors is to consider the treatment and handling of manure. First, operators can incorporate additives to manure. Additives can be chemical or biological. Additives can be applied to overpower the presence of an odor, reduce the ability for odors to be smelt, absorb constituents in manure that cause odors, or slow microbial degradation to reduce odors [101]. Choices for additives are based on the product and the rate and frequency of application [50]. Manure can also be chemically treated. The University of Arkansas Extension recommends several options for chemical treatment. These include sodium bisulfate (PLT), ferric sulfate granular (Ferric-3), alum, and zeolite [107].

Next, solid separation can be used to better hand manure. Solid separation processes include sedimentation, screening, filtration, and centrifugation. This process attempts to remove constituents that cannot pass through a specified screen size. The removal of these materials decreases biological degradation and thereby reduces odors [50]. Solid separation also reduces odors by reducing the organic loading. Usually solids are separated before entering a treatment basin such as a lagoon. Some of the materials removed include cattle waste fiber and grit. There are several machines employed for solid separation. These include vibrating screens, sloping stationary screens, or pressure-rolling mechanical separator. Solid separation can occur within a gravity settling basin, earthen settling basin, rectangular metallic, or a concrete settling tank [49].

Finally, operators can make strategic choices in how they apply manure to land for the sole purpose of preventing the spread of odors. Spreading manure can be done in the morning or when the sun is present and on days when the direction of the wind is away from the neighbors [101]. Manure can also be applied during the early evening for better wind dispersion [50]. It is best for the livestock operators to choose the weekdays as opposed to weekends when neighbors will most likely not be at home [107]. When manure is applied, it should be applied quickly, in large quantities, and based solely on the needs of the crop [50]. Operations should employ a liquid waste management schedule [107].

If liquid manure is applied by irrigation equipment, operators can make choices on nozzle size of the sprayers. An alternative would be using a low-rise, low-pressure, trickling system. Application of liquid manure should be done in close range to avoid the spread of odors [50]. Instead of the land application of manure by irrigation, operators can also make the decision to inject manure directly into soils as compared to choosing surface application [107].

When solid manure is not directly applied, operators can select to cover the manure before use. There are two types of covers—impermeable and permeable. Impermeable covers prevent manure storage facilities from the emission of odors into the atmosphere. The covers can also reduce the effects of wind and radiation. Impermeable covers can reduce odors by 90%. Cover efficiency is contingent on the presence of wind and snow [50].

On the other hand, permeable covers (biocovers) are used to cover places for anaerobic digesters or manure storage facilities [50, 107]. Biocovers can consist of straw, cornstalks, peat moss, foam geotextile fabric, or Leka rock [50]. Biocovers can also include use closed-cell polyurethane foam with or without zeolite. Biocovers remove radiation from the surface of the manure storage facility and also reduce the impact of the wind blowing [107]. Biocovers contain an aerobic zone where aerobic microorganisms thrive on the presence of chemical constituents within the manure. These microorganisms reduced the odors. The reduction of odors is contingent upon the material used. Covers that are primarily made of straw reduce odors by 50%, while 85% of odors are reduced when the cover consists of a floating mat or corrugated materials [50].

As an alternative to biocovers, manure storage facilities can be aerated to supply molecular oxygen. This will assist in reducing odors. Nevertheless, aeration can be dangerous because nitrogen is volatilized into the atmosphere as ammonia. Therefore, great care should be taken to prevent this from occurring [50].

1.7.3.3 Waste Treatment Methods

There are many waste treatment methods that can reduce the potential of creating odors. First, operators can install filters to separate odor-causing particles within the air. There are two potential filters available—mechanical and biofilters. Mechanical filtration devices are capable of removing odors from particles. There are indications that 45% of odors are caused by particles with a size between 5 and 10 μm, while 80% are caused by particles greater than 10 μm. Mechanical filtration has been proven to reduce odors between 40 and 70% [50].

Biofilters capture particles where aerobic bacteria degrade them to create products that do not cause odors [50]. Biofilters are supplied air by natural ventilation. The presence of air and adequate environmental conditions allows for the bacteria to grow within the system [99]. Bacteria grow on media consisting of wood chips or compost [107]. For these reasons, biofilters are inexpensive as compared to mechanical filtration. Efficiency of a biofilter is contingent on oxygen concentration, temperature, residence time, and moisture content [50]. The design of biofilters is contingent on the volume of air needed to be treated [107]. Biofilters have been successful in removing 40% of hydrogen sulfide [50]. It has also been reported that biofilters remove 90% of odors [107]. Biofilters are also capable of filtering odor-causing liquids from manure storage [99].

By means of Rockwool packing material, Yasuda et al. (2010) was able to produce 8.2–12.2 mg N/100 g sample of nitrification and 1.42–4.69 mg N/100 g of denitrification [108]. Ro et al. (2008) found that a polyvinyl alcohol (PVA)-powered activated carbon biofilter removed 80% ammonia-nitrogen with hydrogen sulfide removal at 97% [109]. Kastner et al. (2004) found that ammonia-nitrogen concentration ranging between 25 and 95% was removed in waste from swine production, where the major factors that depended on the treatment efficiency were residence inlet time and ammonia concentration [110].

Second, anaerobic digestion is a feasible treatment method to reduce odors. The biological degradation of constituents under anaerobic conditions can reduce the odors significantly in organic material. The products from anaerobic digestion can be safely placed in a liquid storage facility [99]. A study using anaerobic digestion for degradation of dairy waste reported a 50% reduction in odors provided the waste remained in the digester for 20 days. While anaerobic digestion is an expensive method, it can be viable for some operators [50]. Anaerobic digestion can profitable as it produces biogas [99]. More information about anaerobic digestion is presented in Sect. 1.2 of this chapter.

Various enzymes such as peroxidase, specifically horseradish peroxidase (HRP) and trosinate [111], are used to control odors. Horseradish peroxidase (HRP) has become a new method in research for deodorization because of the quantity of peroxidase within the plant, which is capable of transforming aromatic compounds into free radicals or quinones, which ultimately form non-odor compounds [112].

Govere et al. (2007) experimented with pilot-scale reactors with volumes between 20 and 120 L using minced horseradish comparing effectiveness between the addition of either calcium peroxide or hydrogen peroxide to deodorize swine wastewater. From the results, it was determined that the addition of horseradish was capable of completely removing odors [112].

The management of lagoons serves as a way of reducing odors. A healthy lagoon will degrade organic materials into constituents that do not produce odors. Odors can be reduced in a lagoon if manure contains a dilution of 1–2%. Lagoons should also be refrained from having a high solid concentration. When high solids are present, a lagoon is overloaded. Overloaded lagoons change the conditions from aerobic to anaerobic, thereby creating odors [47, 99].

1.7.3.4 Livestock Operations Management

Livestock operators can mitigate the spread of odors by providing better management of the buildings and facilities. This can include disposing unused or even moldy feed, fix leaks and if necessary replace or repair pipes, and designate a location to dispose dead animals. Another alternative is to increase ventilation within these areas. Ventilation can be supplied by mechanical or natural means. Mechanical methods of ventilation include fans and fresh air inlets. If cost is a barrier, an alternative is to use natural methods. Openings, change in roof slope, and rearranging the orientation of the building are ways that a livestock operator can generate natural ventilation within a building or facility. Despite the fact that it saves energy, natural ventilation may be inhibited by environmental circumstances, so the operator should make a wise decision on which method should be chosen [101].

In addition to ventilation, livestock operators can introduce landscape onto the premises to contain odors. Landscaping provides an opportunity to prevent the constituents that cause odors from further leaving the operation. These constituents are either dispersed or diluted. Landscaping also gives an aesthetic appeal to the area. Trees and shrubs are the two most common entities planted [50].

The design and maintenance of feedlot pens should be reviewed to better prevent odor mitigation. Feedlot pens should maintain a dry surface to prevent the formation of anaerobic conditions on the surface. This means that each pen should be designed to have proper drainage. Having pens maintain a slope between 4 and 6% will provide adequate drainage and prevent pens from accumulating standing water. Also, pen scraping should occur once every 3–4 months [100].

1.7.3.5 Summary

With many people leaving municipalities and inner-ring suburbs for rural and farmland communities, the discussion on odor mitigation will continue to increase. Therefore, it is important for livestock operators to develop good relationships with the residents living in close proximity to livestock operation facilities. Regardless of the method(s) chosen, the ultimate goal should be to provide neighbors the ability to feel as liberated as possible from the presence of odors.

1.7.4 Greenhouse Gas Emissions

Recent developments have discussed the relationship between greenhouse gas emissions and livestock. This chapter will discuss some of the current issues related to the relationship between greenhouse gas and livestock waste. The purpose of discussion is not to take sides but rather present what is currently found in literature.

Greenhouse gases consist of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon dioxide is considered a primary greenhouse gas because in general only 9% of greenhouse gas emissions are caused by CH_4 and N_2O [113]. However, in the livestock sector, CH_4 production is 21 times the carbon dioxide, while N_2O 310 times the CO_2 emissions. This is because animals produce methane during the process of enteric fermentation, while nitrous oxides are formed during the degradation of manure when nitrification and denitrification occurs. In general, greenhouse gases maintain the temperature of the Earth to 15 °C. The current debate with greenhouse gases involves global warming and climate change. This debate has been whether or not greenhouse gases cause a change in climate [114]. It was reported that from 2001 to 2010, greenhouse gas emissions from crop and livestock operations increased by 14% [113]. In 2012, it was estimated that the agriculture industry released 526 million metric tons of carbon dioxide equivalent (MMT of CO_{2e}) plus 62 MMT of CO_{2e} related to operating electric products [114].

According to the USEPA, greenhouse gases have caused 9% of the total greenhouse gas emissions in the United States, while the United Nations (UN) have stated 18% of global emissions have been caused by greenhouse gases. There are many sources of greenhouse gases reported. The United Nations mentions that greenhouse gas emissions are caused by livestock feeding, manure management, livestock processing, and transportation of livestock products. On the contrary, the USEPA states that greenhouse gases have affected crop and livestock production. Other sources have stated that deforestation (34%) and ruminant digestion (25%) are additional factors that must be considered [114].

According to the University of Missouri Extension's paper titled "Agriculture and Greenhouse Gas emissions," there are four major areas that have been major contributors to greenhouse gases in the agriculture sector—crop and soil management, livestock manure management, enteric fermentation, and agricultural carbon sequestration. These values are contingent on the US production of greenhouse gases in 2012, data produced by the USEPA [114].

1. **Crop and soil management.** Agricultural crop and soil management produced 307 MMT of CO_{2e} or 48% of the total greenhouse gas emissions within the agricultural sector. Ninety-eight percent of all emissions from greenhouse gas were because of N_2O. This has been attributed to the fact that cropland has produced

more N_2O than lands that are grasslands. In addition, fertilization, manure application, crop residue collection, nitrogen-fixed crops and forage, and soils with organic materials are major practices that lead to N_2O emissions. N_2O emissions occur in the Corn Belt, cropped land in California and the Mississippi Valley, rice production, and burnt fields.

2. **Livestock manure management.** Manure management accounted for 71 MMT of CO_{2e} in greenhouse gas emissions. Most of the greenhouse gases produced in livestock manure are CH_4. The major causes of greenhouse gases include anaerobic decomposition of liquids and slurry. N_2O in manure management is caused by manure, urine, and aerobic and anaerobic degradation. The dairy cattle industry produced 47% of CO_2 emissions, while the beef cattle industry was responsible for 71% of CH_4.
3. **Enteric fermentation.** As previously stated, enteric fermentation causes the majority of CH_4 emissions. Enteric fermentation produced a greenhouse gas total of 141 MMT of CO_{2e}. Varying factors determine the production of enteric fermentation. These include the number of livestock and the type of feed.
4. **Agricultural Carbon Sequestration.** Land use and forestry was responsible for 979 MMT of CO_{2e} or 15% of overall greenhouse gas emissions. A relationship between land use and carbon sequestration was made. This relationship analyzed the carbon sequestration of land in 2012 and its state 20 years before. Land that remained grassland was capable of sequestering carbon where loses only occurred because of drought. This has also been the case when land was converted into grasslands. On the contrary, land that remained cropland or converted into cropland carbon was not sequestered. However, land that remained cropland was able to sequester carbon provided the organic content remained between 1 and 6%.

A more recent study was completed by Caro et al. to assess the global greenhouse gas emissions between 1961 and 2010. Analysis compared the livestock greenhouse gas emissions between developing and developed countries. The results from the study concluded that global greenhouse gas emissions increased by 51%, where the primary source of greenhouse gas emissions was caused by enteric fermentation. In general, the generation of greenhouse gases decreased overall. However, there was a difference in the trends for developing and developed countries. Greenhouse gas emissions in developed countries increased in the 1970s and then gradually decreased by 23%. On the contrary, greenhouse gas emissions increased in developing countries by 117%. The authors attributed increase to changes in economic and ideological changes. The signature year for these changes occurred in 1989. These countries transitioned from being focusing heavy on importing to exporting. With regard to the various livestock industries, the beef cattle industry was accountable for 54% of greenhouse gases, while only 17% was due to the dairy industry [113].

The development of numbers has created an interesting stir within the scientific community. Various authors have published papers that attempt to support the values generated by entities recognizing global climate change (e.g. USEPA, UN, and the International Panel on Climate Change (IPCC)). However, authors such as

Herrero et al. request for a reduction in ambiguity and more consistency in methodologies used to quantify greenhouse gas emissions within livestock. The areas of concern includes the exclusion of CO_2 production by livestock, quantifying emissions due to land use and land change, global warming potential of methane, and the overall allocation of processes to livestock. With a more accurate picture, the authors state that the discussion of greenhouse gas emissions in livestock can improve [115]. Regardless of an individual's stance on greenhouse gas emissions and global warning, the discussion of the livestock industry's role in greenhouse gas emission will continue.

1.8 Pathogens in Livestock Industries

Pathogens are an issue within the livestock industry. The impact from pathogenic outbreak cause a loss in productivity for the livestock operation by becoming detrimental to the animals, the business, and employees. Pathogens can also be harmful to the public and the environment. Survival of pathogens is predicated on the temperatures, the pH, the amount of microbial activity, the routes of transfer, and the applicable host. The routes of transfer for pathogens include fecal-to-oral, foodborne, aerosol, or human-to-animal contact. The applicable hosts can range from humans, farm animals, and other carriers such as flies. There are four major categories of pathogens—viruses, bacteria, mycotic agents, and parasites [62].

For example, contact with viruses for a period of time can lead to illness or death and can limit the product from livestock. Viruses are classified as enveloped and non-enveloped viruses. Enveloped viruses persist within animal manure and can stay for a long period of time without treatment and storage, while non-enveloped viruses are incapable of being destroyed with any treatment method. On the other hand, mycotic agents are not a major concern within the livestock industry and are usually dangerous in soils or self-contained with the body of an animal or human [62]. Examples of each pathogen category are listed in Table 1.19.

Livestock operators can know the quantity of pathogens within its waste by using organisms known as fecal indicator organisms. Fecal indicator organisms are surrogate organisms used in the laboratory as a method for quantifying pathogenic presence. Typically, *E. coli* has been used as a fecal indicator organism, but recent studies have used other organisms such as coliphages and *C. perfringens* spores. An adequate choice for a fecal indicator organism must fulfill a series of criteria. Fecal indicator organisms must:

1. Exist in the same conditions as pathogen.
2. Have a life span similar to pathogens.
3. Withstand disinfectants and unfavorable conditions.
4. Be easily detectable.
5. Be distributed randomly.
6. Portray similar risks in humans as pathogens.

Table 1.19 Examples of each type of pathogen [122]

Pathogen	Example
Viruses	Animal enteroviruses, rotaviruses, hepatitis E
Bacteria	*Aeromonas hydrophila* *Aerobacter* *Bacillus anthracis* *Chlamydia* *E. coli* *Salmonella*
Mycotic agent	*Histoplasmosis capsulatum* *Pneumocystis carinii*
Parasites	Protozoa *Ascaris and Ascariasis* *Cryptosporidium parvum* *Giardia* *Toxoplasmosis*

Table 1.20 Pathogen treatment methods [122]

Pathogen	Method
Dry techniques	Composting
Physical treatment	Sand filtration or dry beds Sedimentation and screening
Biological treatment	Lagoon Anaerobic digestion Sequencing batch reactor Constructed wetlands Overland flow
Disinfection	Chlorine Ozone Chlorine dioxide Lime stabilization Pasteurization

As an alternative, testing for microorganisms can include culture-specific microorganisms, antibiotic resistance patterns, molecular fingerprinting, genotype, and chemical indicators [62].

There are various treatment methods that can be used to reduce the pathogens within livestock waste. The treatment of livestock waste can use dry techniques, physical treatment, biological treatment, and chemical treatment. Examples of treatment techniques found within each category are shown in Table 1.20. Many of these methods have been discussed in grave detail in the previous sections [62].

The presence of pathogens can have a major impact on livestock operations. While this section is not extensive, it does attempt to provide a summary of major pathogen categories, their associated impacts, and the potential treatment methods.

1.9 Livestock Waste Management Computer Software

Within the recent century transition, there has been the presence of computer modeling tools that are capable of being used to predict livestock wastes. For example, the Animal Waste Management Software Tool (AWM) is a computer program designed to determine parameters such as waste storage facilities, waste treatment lagoons, and utilization [2]. Other options include the collaboration between the University of South Carolina's Earth Science and Resource Institute and the Natural Resources Conservation Service (NCRS) in South Carolina to develop a suite of products that include the geospatial tools [ArcGIS] and a nutrient management planning software AFOPro© [116].

Ideas on the use of software for livestock waste management have not been limited to just the United States. A program known as Integrated Swine Manure Management (ISMM) is an integrated decision support system (DSSs) used by Canadian province decision-makers to control manure, considering various criteria such as environmental, agronomic, social and health, greenhouse gas emission, and economic factors [117]. The introduction of computer software for livestock management can be very significant for those that are planning to provide a consistent method of managing livestock. Nevertheless, it is still important to remember that computer software is a "tool" but does not replace proper education and understanding of what is needed for proper livestock waste within the given area.

1.10 Recent Advances in Livestock Waste Treatment and Management

1.10.1 Latest Technology Development, Market-Driven Strategies, and US Policy Changes

In the United States, the major hurdles to reducing the impact of livestock waste pollution on the nation's watersheds are outdated American wastewater treatment policies. Under the prevailing US legislation, the 1972 Clean Water Act (CWA), the majority of wastewater treatment efforts have targeted "point sources of water pollution" with a measurable wastewater discharge. The CWA defines point sources as discharge pipes from industrial plants, utilities, or municipal sewage treatment facilities. Many new environmental process technologies, such as improved chemical coagulation/precipitation, clarification (dissolved air flotation and improved settlers), filtration, membrane bioreactor, advanced oxidation processes, etc., have been developed for water pollution control [118–130], but have not been seriously considered for agricultural waste treatment.

Agricultural wastes, such as livestock manure, farm's storm runoff water, etc., are considered the non-point sources of water pollution, and are not subject to CWA regulations. In the nearly one half of a century since the passage of the CWA, the

American agricultural industry has grown considerably. More than 70% of today's livestock production takes place not on small-scale family farms but on large-scale Concentrated Animal Feeding Operations (CAFO) facilities. However, CAFOs still use small-farm strategies for disposing of animal waste, and about half the crops in the United States are fertilized this way. An ineffective waste strategy, coupled with little meaningful regulation, poses a major hurdle for the rehabilitation of US watersheds. The agricultural water pollution problem must be dealt with its original source. It is the opinion of Director Craig Scott of Bion Environmental Technologies that spending billions of dollars to upgrade downstream wastewater treatment plants and to construct large-scale stormwater projects that recollect and treat the nutrients after they have been released to contaminate the environment is not an acceptable solution from either a cost or a common sense perspective [127–130]. The new market-driven strategies are treating the CAFO wastes with the best available technologies (BAT) and still considering both technical and economical feasibilities.

There are clear signs that the US Federal Government will provide funding for nutrient control and climate control strategies and private sector solutions. In December 2018, the USEPA and the US Department of Agriculture (USDA) notified state and tribal regulators that they are committed to working with all stakeholders to adopt market-based approaches in the fight to clean up America's watersheds and prevent livestock waste from further contributing to the crisis. The agencies said this commitment could include technical and financial support for water quality credit trading programs and public-private partnerships [127–130].

In January 2019, former US President Donald Trump signed bipartisan legislation for federal funding to combat toxic algae blooms in the country's water resources. In February 2019, the USEPA issued a memorandum updating its water quality trading policy and supporting market-based approaches to reduce nutrient pollution in the nation's waterways. The announcement stated "USEPA efforts seek to modernize the agency's water quality trading policies to leverage emerging technologies and facilitate broader adoption of market-based programs."

There is further proof that under the leadership of US President Joseph R. Biden, the US federal policymakers are serious about building the nation's infrastructure (including water and waste treatment). Controlling global warming, climate change, and greenhouse gases are all on the horizon.

1.10.2 Livestock Water Recycling (LWR) System

Livestock Water Recycling (LWR) is one of the world's leading providers of manure treatment technology aiming at reducing greenhouse gas emissions, concentrating and segregating nutrients for strategic fertilizer application, and recycling clean, reusable water.

The LWR system is a proven and fully operating technology that reduces the overall volume of manure, concentrates nutrients, and delivers a renewable, high-quality water source. According to the manufacturer, the company's vision has always been to help livestock farmers increase farm efficiencies while becoming even more environmentally sustainable, and its LWR system provides a minimum of 20–30% return on investment [118].

The LWR company is focused on developing scalable solutions that can be applied quickly and commercialized for maximum return on investment.

LWR system is a patented process technology that uses both mechanical and chemical treatments to remove manure contaminants and segregate valuable fertilizer nutrients at large livestock operations. Figures 1.23 and 1.24 show the LWR system's process flow diagram and process equipment, respectively [118]. As the livestock manure effluent flows through the LWR process, solids are sequentially removed by chemical precipitation, clarification, conventional filtration, and membrane filtration. The result is valuable segregated fertilizer nutrients and clean water that can be reused around the barns.

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The detailed process, descriptions, principles, design criteria, operational procedures, terminologies, etc. of each unit process (chemical precipitation, clarification, conventional filtration, membrane filtration, etc.) can be found in the literature [119–126]. Either sedimentation or flotation can be used for clarification [119, 122].

The nutrient and water recovery capacity of the LWR system is so far the highest on the market. LWR system extracts up to 75% of the water from livestock manure while concentrating dry solids (8%) and segregating nutrients for recycling (17%). By concentrating and segregating, the farm plant managers are given more control over their nutrient application, which minimizes their farm's field work. The result is clean, potable water, dry solids that are rich in both phosphorus and organic nitrogen and a concentrated stable ammonium and potassium liquid. At present, LWR system has the highest nutrient and water recovery capacity on the market, lowest

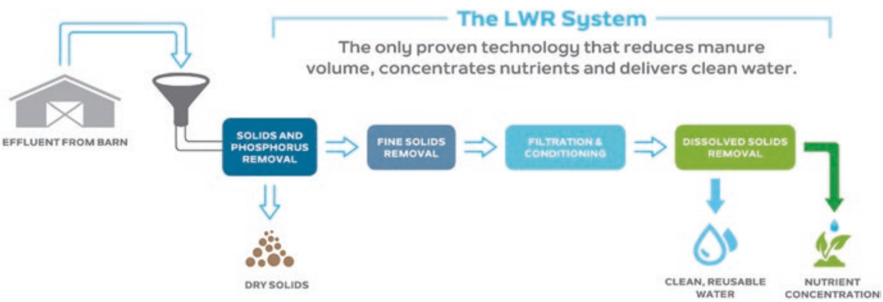

Fig. 1.23 Flow diagram of a Livestock Water Recycling (LWR) system [118]

Fig. 1.24 Process equipment of a Livestock Water Recycling (LWR) system [118]

electrical consumption on the market, and highest number of installations in the water and nutrient recovery market, which are all incredible.

1.10.3 BET Advanced Technologies To Benefit From Policy Changes

There are a few commercial-ready technologies available today that can address the problem of excess nutrient runoff from large-scale agricultural operations. Section 1.10.2 has introduced the Livestock Water Recycling (LWR) system, which is now commercially available for livestock waste treatment.

Another advanced technology in the sector is Bion Environmental Technologies' comprehensive environmental management system, which is also designed for the largest CAFO livestock facilities and focused on maximizing resource recovery.

Bion Environmental Technologies' patented 2G (second-generation) technology has been commercially proven to substantially reduce pathogens from livestock waste while eliminating up to 90% of greenhouse gases and ammonia emissions and 95% of nitrogen and phosphorus. The waste management system harnesses the power of naturally occurring bacteria to convert nitrogen and phosphorus into solid forms that are removable by other processes [127–130]. Figure 1.25 shows the flow diagram of Bion Environmental Technologies' comprehensive environmental management system.

Livestock waste treatment technology not only provides clean water solutions but also creates new sources of revenue, including the production of value-added products such as fertilizers. Bion's patented 3G technology recovers stable concentrated ammonium bicarbonate, a quick-release nitrogen fertilizer, from livestock waste without the use of chemicals. This product is well suited for a wide range of applications in the organic markets. According to Markets and Markets researchers, the market for global organic fertilizers is expected to grow from US$6.3 billion in 2017 to US$11.15 billion by 2022.

In 2019, Bion plans to apply to the USDA's Organic Materials Review Institute for use of its ammonium bicarbonate product in organic food production. The company has already applied for a Patent Cooperation Treaty for international recognition of its ammonium bicarbonate production process.

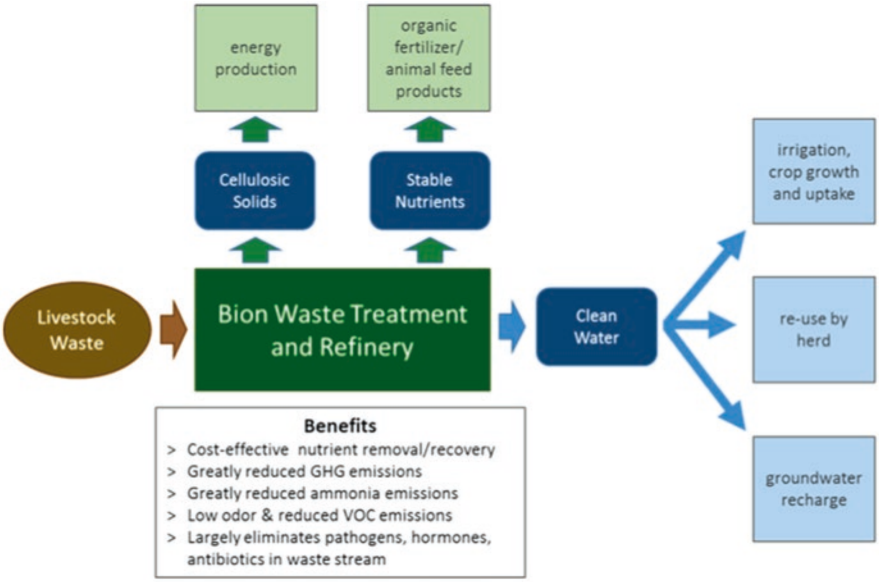

Fig. 1.25 Flow diagram of Bion's livestock waste treatment technology

1.11 Conclusion

This chapter provides a plethora of information concerning livestock waste management from treatment, handling, and storage. While this not an all-encompassing manual for all given conditions, it can be used as a catalyst for research and exploration in how to properly maintain and manage livestock waste for a given industry. The readers are referred to the literature [131–135] for additional technical information on treating the livestock's biosolids, concentrated liquid waste stream, or diluted liquid waste stream.

Glossary of Livestock Waste Management

Anaerobic digestion is the fermentation of organic waste by hydrolytic microorganisms into fatty acid chains, carbon dioxide (CO_2), and hydrogen (H_2). Short fatty acids are then converted into acetic acid (CH_3COOH), H_2, CO_2, and microorganisms.

Biogas is a product from anaerobic digestion containing gases such as methane (CH_4), CO_2, and trace elements. Biogas can be used as a source of energy.

Chemical oxygen demand (COD) is a wastewater quality index that determines the amount of oxygen consumed by wastes.

Concentration animal feeding operations (CAFO) raises livestock within a restricted space. It is also known as feedlot.

Constructed wetland is a treatment method that uses plants (most commonly water hyacinth and duckweed) to degrade organic material.

Denitrification converts nitrate into atmospheric nitrogen using microorganisms known as dentrifiers.

Eutrophication is the condition of a water body (particularly a lake) where molecular oxygen levels have been depleted. Eutrophication most commonly occurs when nutrient levels are high within the water body, forming the presence of algal blooms. When eutrophication occurs, all organisms rely on molecular oxygen to survive.

Five-day biochemical oxygen demand (BOD_5) is a wastewater quality index that determines the amount of oxygen required for microorganisms to degrade a given substance within a 5-day period.

Lagoon is a basin that treats wastewater and stores waste. There are three major types of lagoons—anaerobic, aerobic, and facultative.

Liquid manure contains dry matter less than 5%.

Mesophilic is a state in an anaerobic digester or composting when the temperature remains between 35 and 40 °C.

National Pollution Discharge Elimination System (NDPES) regulates the quantity of waste entering navigable waters and point sources. It was first introduced by the USEPA in the Clean Water Act of 1977. Livestock waste operations are required to have NPDES permits to discharge. State legislation defines the operations that require NPDES permit.

Nitrification is the process of converting ammonium nitrogen (NH_4^+) into nitrate (NO_3^{2-}) with an intermediate step of producing nitrite (NO_2^-). Nitrification is converted by nitrogen-fixing bacteria (nitrifiers).

Psychrophilic is a state in an anaerobic digester or composting when the temperature remains below 20 °C.

Semisolid manure contains 5–10% dry matter.

Solid manure contains dry matter greater than 15%.

Thermophilic is a state in an anaerobic digester or composting when the temperature remains between 51 and 57 °C.

Volatilization is a phase change process that converts constituents into gaseous form. The most common volatilization experienced is ammonia volatilization or the conversion of ammonium-nitrogen to ammonia-nitrogen. This is problematic for livestock operations because plants' nitrogen is lost for plant uptake.

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