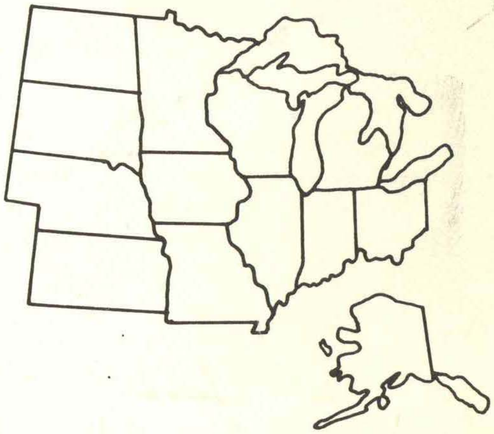
LIVESTOCK WASTE MANAGEMENT WITH POLLUTION CONTROL

NORTH CENTRAL REGIONAL RESEARCH PUBLICATION 222

Agricultural Experiment Stations of Alaska, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin, and the U.S. Department of Agriculture cooperating.



June 1975

FOREWORD

This publication supersedes number 206, prepared in 1970 by this same research group. That bulletin summarized the technology of animal waste management as it had been advanced by the extensive research effort coordinated through project NC-69 (1963-68) and NCR-67 (1968-70). This bulletin expands and updates the technology and practice as it has continued to evolve through the NC-93 research program (1970-1975) and other contemporary public and private research efforts.

Earlier work focused particularly on waste handling, storage, transport and to a lesser degree on processing and disposal. More recent emphasis has shifted to various processes, system integration and runoff-management, with lesser but increasing attention to refeeding, utilization on crop land, other utilization concepts and odor control. The situation now takes on quite new dimensions and presents a need for different orientation of this regional research effort.

These changes result from several forces active during the five year tenure of NC-93: 1. The productive and practical research of this group itself has changed the setting. 2. Regulatory agencies have become active and their actions have defined new problems. 3. Equipment and material industries have become more involved in developmental efforts of equipment, products and systems. 4. The livestock production industry has become active in applying the resulting technology to render their operations environmentally compatible with the public interest and to enhance production efficiency. 5. The energy crisis has become a major factor and relates to animal waste management both as a consumer and potential source of energy.

As is reflected in much of the technical content of this document, the agriculturally important North Central Region represents a wide range of operating parameters for livestock enterprises: from the industrial Great Lakes area to the outdoor-recreation-oriented north to the agriculturally heavy Great Plains; from densely populated northern Illinois to sparsely populated North Dakota; from humid northern Ohio to arid western Kansas; from the temperature range of northern Minnesota to that of southern Missouri. This project has demonstrated the desirability and productivity of regional coordination. At the same time, it has been essential that nearly all states participate to provide the input of specific systems design to provide compatibility with local circumstances. The various research approaches of participating stations appropriately reflect both the commonalties and the uniquenesses.

The material presented here illustrates how this and related research has provided technology and operating systems. It provides system selection, design and operational information as it exists for satisfying field needs resulting from social, regulatory and economic pressures. Many livestock enterprise operators have provided valuable assistance in defining requirements, implementing studies and evaluating results. The industry in general is demonstrating interest in conforming to the broad public interest, which includes not only the environmental quality dimension but also economically produced food supply and energy conservation and/or production.

It is significant that much of the technology reported here has found field application to a substantial degree even as it was in very tentative form. This testifies to the time-critical nature of the problem area. It also suggests the importance of prompt dissemination of this comprehensive state-of-the-art information. But, both the industry and regulatory efforts must accommodate continued refinement and advancement of the technology involved.

This progress itself, coupled with changing circumstances, points up new priorties of related problem areas for concentrated research attention. These areas include (1) management systems (2) atmospheric contaminants (3) by-product utilization and (4) non-point pollution, all related to livestock wastes, Thus, it is clear that however valuable the research reported herein may be, it must not provide satisfaction precluding continuing effort.

R.W. Kleis, Associate Director
Nebraska Agriculural Experiment Station
Administrative Advisor, c-93

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ABSTRACT

The aspects of livestock-waste management described in this report reflect the variations encountered across the 13 states of the North Central Region. The main objective of this report is to present information on waste management that will free a livestock producer from unnecessary labor, yet, at the same time, will allow him to operate within the confines of current environmental legislation. The NC-93 committee recognizes that such an objective alone is inadequate; hence, there are large sections of the report devoted to by-product recovery.

The report starts by summarizing the necessary features of any livestock-waste-management system and presents basic information on manure production and content. The effect of housing on livestock-waste management is discussed in two sections on management of roofed facilities and unroofed facilities. Air pollution by gases and dust is regarded of major importance, and one section is devoted entirely to this topic. Conventional biological waste stabilization receives attention in the two sections on aerobic and anaerobic treatment. The section on utilization attempts to analyze manure-processing technology for harvesting useful by-products. Some of the topics discussed are land application with crop production, hydroponics, composting, production of livestock feed supplements, and pyrolysis. The report ends with two sections on information retrieval and technical terms encountered in livestock-waste management.

Miner, J.R., and R.J. Smith (eds.). 1975. Livestock waste management with pollution control. (North Central Regional Research Publication 222). Midwest Plan Service Handbook MWPS-19.

LIVESTOCK WASTE MANAGEMENT WITH POLLUTION CONTROL

Edited by
J.R. Miner and R.J. Smith

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INTRODUCTION

The increased production of meat, poultry, and dairy products in the United States and the world has been paralleled by an increase in the production of livestock wastes. National consumption of meat per capita shows an upward trend (Kottman and Geyer, 1971). Table 1 shows that increased beef consumption accounts for most of this trend. Milk consumption declined during the same period.

Livestock production has changed rapidly in the past few years. Livestock are being fed in larger, more highly concentrated units than in the past when there were many small feedlots. Instead of having cropland available for the disposal of animal wastes, some large feedlots use most of the land area for livestock and have little available for waste disposal. Thus, a major waste-disposal problem with a sizable pollution potential may exist.

Table 1. Annual per-capita consumption of meat and dairy products in the United States during selected periods from 1947-1971

Product	1947-49 lb	1957-59 lb	1967-69 lb	1971 lb
Beef and veal ------------------	75[α]	89[α]	112[δγ]	116[δ]
Pork ---------------------------	68[α]	63[α]	65[δγ]	73[δ]
Lamb and mutton ----------------	4.8[α]	4.4[α]	3.7[δγ]	3.1[δ]
All dairy products (milk equivalent) ------------	742[β]	679[β]	577[ε]	558[ε]
Fluid milk and cream (fluid milk equivalent) ------	359[β]	337[β]	280[ε]	259[ε]

Sources: [α] U. S. Department of Agriculture, Economic Research Service. 1966. Food consumption, prices and expenditures. p. 59. In: Agricultural Economics Report No. 138.

[β] Ibid. p. 62.

[γ] U. S. Department of Agriculture, Economic Research Service. 1969. Food consumption prices and expenditures: Supplement for 1968. p. 13. In: Supplement to Agricultural Economics Report No. 138.

[δ] U. S. Department of Agriculture, Economic Research Service. 1972. Livestock and meat situation. LMS-188.

[ε] U. S. Department of Agriculture, Economic Research Service. 1973. Dairy situation. DS-345.

State and federal legislation was enacted during the 1960s for the regulation of animal-waste disposal and waste-management practices in animal enterprises. The public became particularly conscious of the problem because of some fish-kills attributed to feedlot runoff, and national concern over the quality and future of our nation's water resources increased. Since then, several federal water-quality acts have been initiated. The Federal Water Quality Act of 1965 requires the states to establish water-quality standards. The Refuse Act of 1899 has been used as an additional means of controlling pollution of watercourses. the Solid Waste Disposal Act of 1965, as amended in 1970, authorizes the development of federal guidelines for solid-waste management, including animal manure. Legislation to abate pollution of water, air, and land continues to be generated.

Many states have passed laws regulating feedyards and other animal enterprises. Most of these states issue permits whenever minimum livestock numbers are reached and whenever compliance with state regulations is achieved. The regulations require control of runoff wastes and management of all animal wastes, as well as general sanitation.

Odors arising from animal wastes have been the object of several court actions between the owners of animal enterprises and individuals or residential areas. Zoning of agricultural land has been used as a means of reducing the number of such conflicts. Zoning can be used to control the location of an animal enterprise with respect to a residential, commercial, or recreational area.

SELECTION OF A WASTE-MANAGEMENT SYSTEM

Effect of Climate

The selection of a waste-management system is highly dependent upon the location of the livestock facility. Ideally, a livestock enterprise should be located in an agricultural area, downwind from nearby residential areas, and on sufficient land to permit adequate treatment and disposal of waste materials. When unroofed facilities are planned, a site should be selected that will allow the diversion of runoff water from areas outside the pens.

Other major factors to be considered in the selection of a waste-management system are: terrain, soil type, climate, type of animal-management system, economics, and local, state, or federal regulations. Some factors require engineering, economic, and legal decisions.

Local site selection: Major points to be considered in local site selection are location with respect to water sources, diversion of precipitation flowing outside the lot, lot topography and drainage, soil type and structure, land area, prevailing wind direction, and location with respect to residential areas.

Climate: Climatic considerations involved in the selection of an animal-housing and waste-management system are temperature, precipitation, evaporation, wind velocity and direction, and solar radiation.

The general type of housing and waste-management systems for a given location can be determined from a map of climatic zones; these zones are based upon temperature and moisture deficit (evaporation minus precipitation) (Figure 1).

The cold, wet zone is characterized as having an average January temperature below 20°F (-7°C) and an excess of precipitation over evaporation. In this zone, consider a housing system that is totally enclosed, environmentally controlled, and has a means of storing the waste throughout the freezing period.

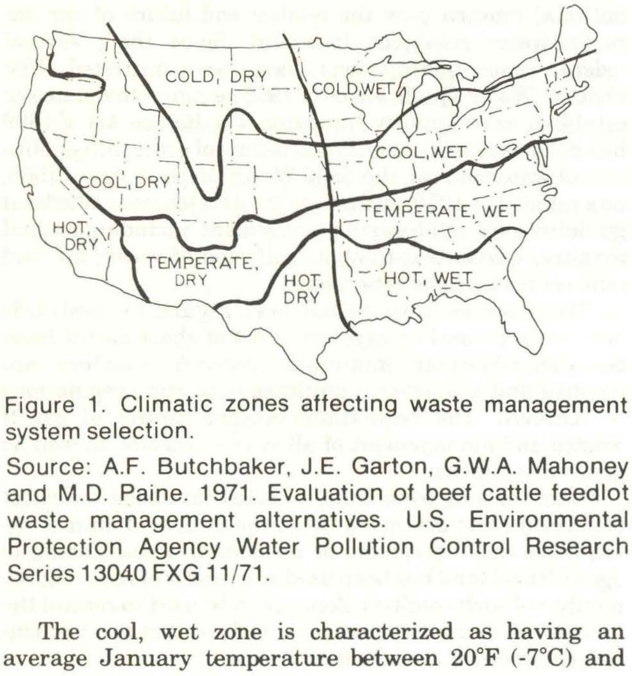


Figure 1. Climatic zones affecting waste management system selection.

Source: A.F. Butchbaker, J.E. Garton, G.W.A. Mahoney and M.D. Paine. 1971. Evaluation of beef cattle feedlot waste management alternatives. U.S. Environmental Protection Agency Water Pollution Control Research Series 13040 FXG 11/71.

The cool, wet zone is characterized as having an average January temperature between 20°F (-7°C) and 32°F (0°C) and having excess precipitation over evaporation. This area is compatible with open-front housing during the winter and less waste storage capacity because of the shorter freezing period.

The temperate, wet zone is between the 32°F (0°C) average January temperature and 80°F (27°C) average July temperature lines. This area has an excess of precipitation over evaporation. Open-front housing and, possibly, even open lots may be considered for this area. The period for storage of waste during the winter months is short. Treatment systems that depend upon moderate ambient temperatures operate well throughout most of the year.

The hot, wet zone is characterized by 80°F (27°C) average July temperatures or above and an excess of precipitation over evaporation. Freezing periods are very short, and waste treatment and disposal operations can operate throughout the year.

In the cold, dry zone, an excess of evaporation over precipitation exists, and average January temperatures are colder than 20°F (-7°C). Totally enclosed confinement buildings or some means of protecting animals from the wind and blizzards during the winter should be considered. Storage of the waste should be reviewed for the same period. Liquids can evaporate easily during the summer and fall; thus evaporation ponds may be used for the ultimate disposal of liquids.

The cool, dry zone is between the 20°F (-7°C) and 32°F (0°C) average January temperature and has more evaporation than precipitation. This zone could be considered for open-front buildings or open lots. The period for storage of the waste would be only a few weeks during the winter, and liquids would be able to evaporate over the year in evaporation ponds.

The temperate, dry zone is characterized by a 32°F (0°C) average January temperature, and 80 (27°C) average July temperaure. evaporation exceeds rainfall. It is in an optimum zone for performance of beef animals in outside lots. The lots would be relatively dry throughout the year. Liquids arising from runoff-carried waste could be easily evaporated in evaporation ponds over the year.

The hot, dry zone and the hot, wet zone are characterized as having above 80°F (27°C) average July temperatures with intense solar radiation. Thus, sunshades for livestock production are required. Waste disposal on a year-around basis and evaporation ponds for disposing of the liquid waste can be used.

Animal-management system: Wide variation exists throughout the United States for systems of livestock production and management. Beef breeding herds and sheep breeding flocks continue to exist largely on pasture and range conditions. Thus, there is a limited waste-disposal problem with no point sources of pollution. Feedlots for cattle are becoming larger, with a high percentage of cattle finished in large commercial lots (5,000- to 100,000-head capacity) before slaughter. The number of small farmer feeders is decreasing. Dairy herds are increasing in size and are being managed under close-confinement conditions as opposed to extensive range or pasture conditions. Thus, both cattle feedlots and dairy operations are beginning to have higher concentrations of animals and, consequently, greater waste-disposal problems. Swine operations are trending toward more confinement-building operations, with fewer pasture or open-feedlot operations. Thus, each species of animal requires a distinct type of housing and management practice and, consequently, distinct waste-control facilities.

The type of ration also affects the amount of waste produced and the pollution potential of that waste. For instance, feeding additional salt results in additional salt being in the waste material and also affects the water consumption and urine volume. Other management practices, such as flushing of floors, also affect the amount of waste that has to be handled, as well as the type of handling and treatment system selected.

Economic factors: The prime considerations in selecting a waste-management system are economic. Some systems that require high initial or fixed costs, in terms of facilities and equipment, may have lower operating or variable costs because of low labor requirements. The variable costs also include added fuel, electrical, and maintenance costs. Some costs may be recovered by marketing of the waste-system by-products, such as soil conditioners and fish.

Another factor that should be considered is equipment or facility obsolescence resulting from either changing legislation and regulations or changing technology. The operator should be cognizant of changing laws and zoning regulations as they affect decisions regarding site selection and types of waste-management systems.

A decision may be necessary in determining whether a useful by-product can be obtained from a waste-management system or whether the treatment system should merely render the waste inoffensive in the least expensive way possible.

Integrating Components into a System

Component compatibility: The producer and the designer of an animal-production facility and its associated waste system should be aware that alternatives exist for the components of a waste-management system. In Figure 2, the overall animal-production and waste-management system is illustrated in a block diagram, beginning with the animal. Each of these blocks can be broken into components, but the components must be compatible from one block to another. For instance, if the animal facility is to handle the waste as a slurry, then the treatment and disposal systems must likewise be able to handle a slurry.

Livestock production facilities: Animal production systems vary from open-range types, with very little designed waste-management, to total-confinement buildings with a high degree of waste treatment. Alternatives for animal production facilities are shown in Figure 3.

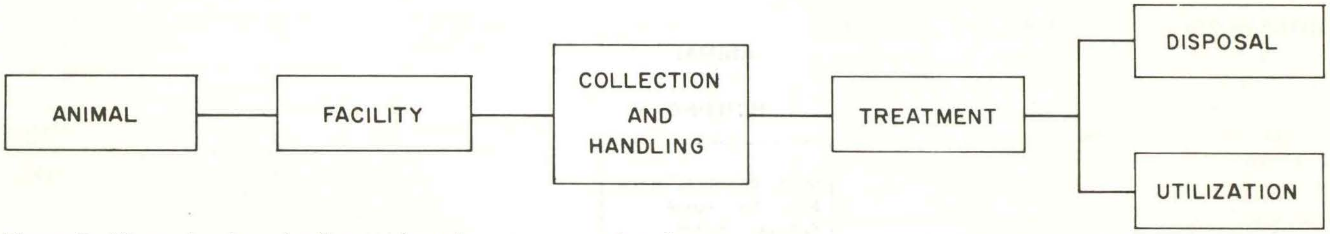


Figure 2. The animal production and waste management system.

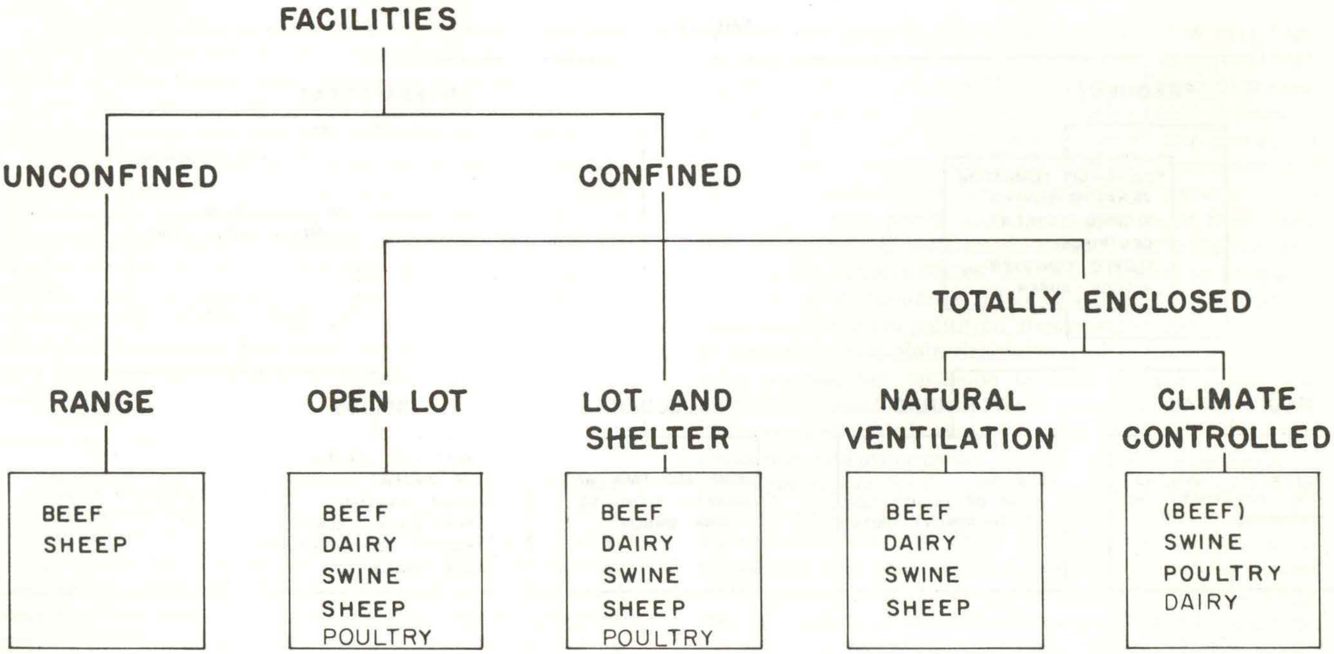


Figure 3. Types of animal production facilities.

Collection and handling: Animal wastes may be collected and handled as either solids or liquids. Some alternatives for collection and handling are illustrated in Figure 4. When the wastes are handled as solids, bedding may also be included for some housing types. Equipment used for handling dirt and other solids generally can be used for handling solid wastes. Liquid wastes are handled either as slurries (primarily the raw waste consisting of feces and urine) or as diluted waste from a flushing system. Generally, specific equipment that can handle a high percentage of solids must be selected for handling slurry wastes. Pumping and liquid-handling equipment that can handle a small percentage of solids can be used for transporting diluted waste from flushing systems.

Runoff-carried wastes from open feedlots generally are controlled by techniques derived from soil erosion-control practices. The runoff wastes carry solids originating both from the animal waste and the soil. Some solids settle out under low-velocity flow conditions. If settling basins are not used, the solids may settle in the holding ponds. Liquid stored in the holding ponds may be pumped by conventional liquid-handling equipment, with possible precautions for preventing equipment corrosion.

In liquid systems, the separation of the solids from the liquid will permit less expensive pumps and equipment to be used for the transport of the liquid. The solids fraction may be composted, field-spread, or used in some other way.

Treatment: Waste-treatment processes are used to modify the physical and chemical characteristics of the waste and to reduce its pollution potential. Treatment alternatives are illustrated in Figure 5.

For liquid-handling systems, biological treatments can be classified as either anaerobic or aerobic. Anaerobic systems contain bacteria that can live in the absence of dissolved or free oxygen, whereas aerobic systems contain bacteria that require dissolved or free oxygen. Most animal-waste lagoons are anaerobic. Naturally aerobic lagoons for animal waste require extremely large surface areas and often a high dilution of the waste. Mechanically aerated lagoons are becoming increasingly popular because fewer odors are produced. Another form of aerobic treatment is an oxidation ditch. This method uses a rotor that mixes atmospheric oxygen into the liquid waste. Anaerobic digesters, patterned after municipal units, may be used for the treatment of animal waste, but are more expensive than other methods. Sale of by-products, such as fertilizer or fuel, may change this position.

Another method being used for the treatment of organic waste is a spray-runoff system, which utilizes a sprinkler-irrigantion system placed on sloping land of low porosity. This system requires the soil surface to be kept moist and aerobic; a suitable cover crop is also an essential part of the system.

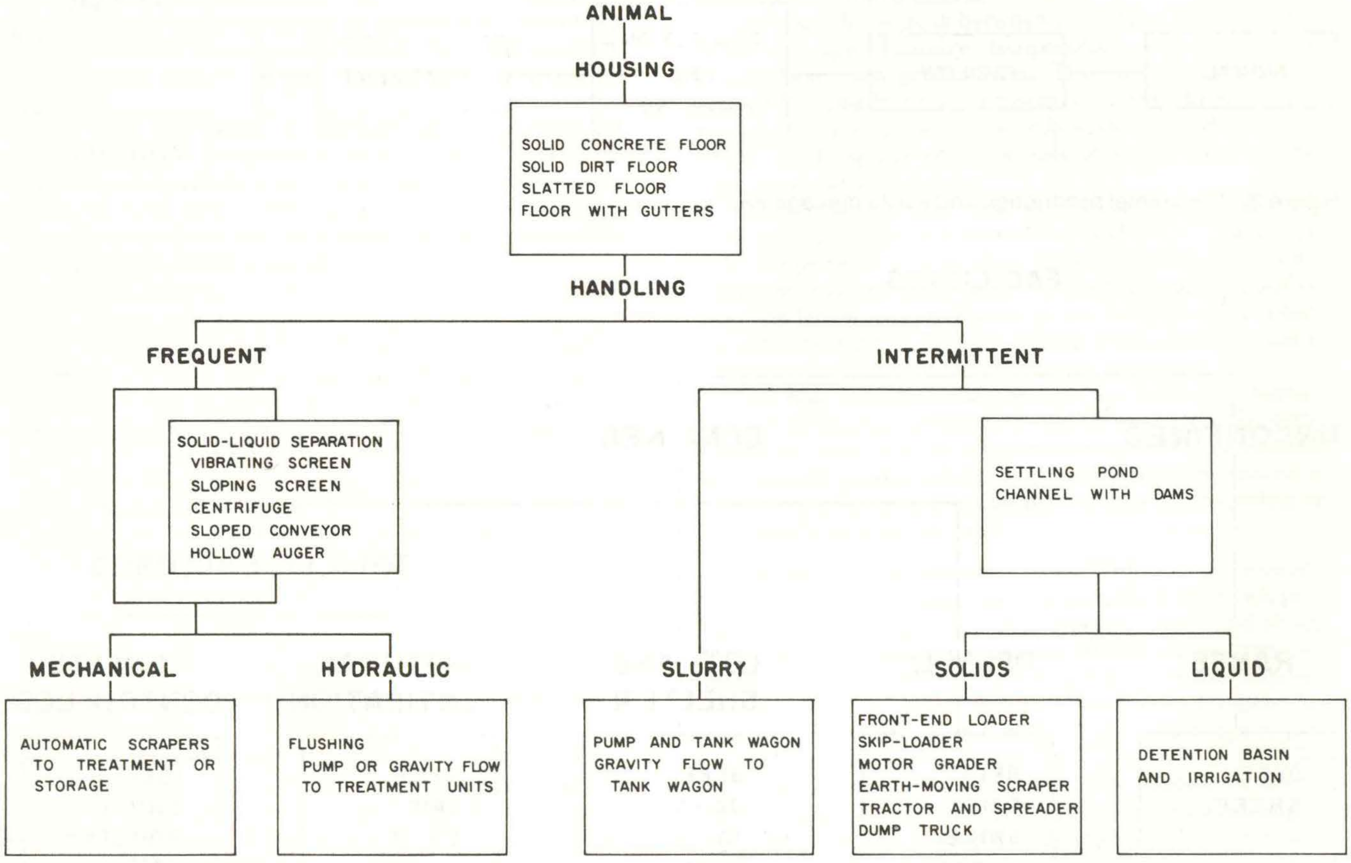


Figure 4. Alternatives for the collection and handling of animal wastes.

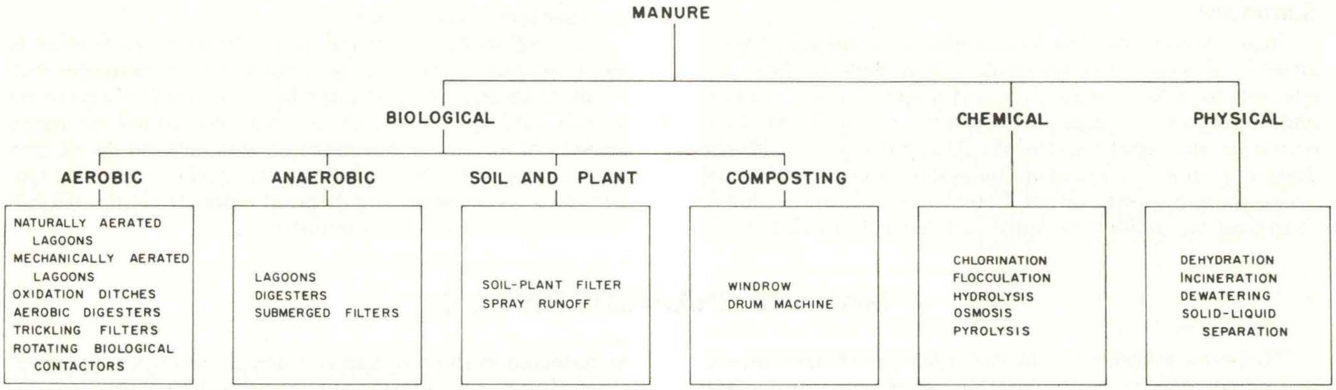


Figure 5. Alternatives for the treatment of animal wastes.

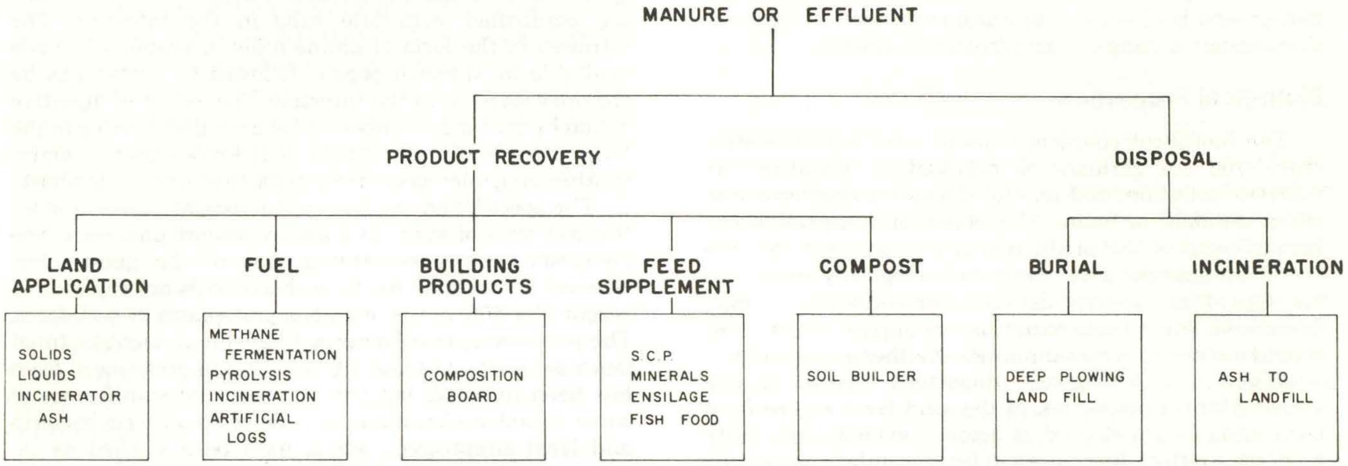


Figure 6. Alternatives for the disposal and utilization of animal wastes.

Composting can be used as a solid-waste treatment method to render the material biologically stable after a period of time under high temperatures with sufficient oxygen and moisture. The compost produced is suitable for land disposal and has little odor or attraction to insects.

Numerous physical and chemical processes have application to specific waste fractions. Poultry wastes have been dried in preparation for by-product recovery, but the gases evolved require treatment to control odors. Liquid wastes containing primarily soluble and colloidal organic matter can be treated by chemical flocculation and chlorination, either separately or simultaneously. Chemical-treatment processes generally are expensive and have not been applied to livestock wastes except for odor control.

Disposal and use: Alternatives for disposal and utilization of animal wastes are illustrated in Figure 6. Currently, most animal waste is applied to agricultural land; liquids usually are irrigated, and solids or slurries applied by a spreader. The term, disposal area, has gained undesirable currency. If long-term pollution of surface or ground water is to be avoided, rates of manure application must match the assimilation capacity of the site; that is, a capacity that minimizes release of pollutants. In some arid areas of the country, this matching may allow very high manure applications for one year, followed by several resting years for assimilation. Humid areas with regular rainfall generally will not be able to follow such a practice because of nutrient infiltration or runoff. The concept of disposal areas is not compatible with the maintenance of soil productivity. Examples of true disposal areas would be the evaporation ponds used to remove water from open beef-feedlot runoff. Such ponds are common in the hot, arid areas of the United States. Another disposal technique is deep burial of the wastes if leachate from the site will not cause groundwater pollution. Incineration offers a method of obtaining complete destruction of organic matter in solid wastes, but emission of odor, certain gases, and particulate matter in the stack gases will need control. The conversion of animal waste into fuel, building materials, and other useful products is being examined.

Experiments have been conducted using processed animal waste as protein and mineral supplements for animal and fish feed. Such products are still being investigated and may require approval from federal and state agencies before they can be adopted generally. Thus, their manufacture should not be attempted until approval by these agencies and until the effects of potentially harmful residuals, such as antibiotics, heavy metals, or viruses, have been adequately evaluated.

Summary

Many factors need to be considered in the selection of an animal-waste management system. Among these are site selection for the facility and disposal area, climate, and livestock-management system, as well as local economic and legal constraints. Alternatives exist for the design of an animal-production system and its associated waste-management system. Potential obsolescence due to changing technology or state and federal regulations is another factor to consider.

The following sections of the publication are devoted to some of the principles of animal-waste management. Many of these principles have been the result of recent research findings. Research is being continued on many aspects of animal-waste management, and no doubt new techniques will be developed to make animal-waste handling, treatment, and disposal more efficient with full consideration of environmental quality.

MANURE CHARACTERISTICS

To devise systems for the management of farm animal wastes, a quantitative understanding of their nature and behavior is necessary. This understanding must include the bacteriological and chemical behavior of manure, as well as the physical properties. An understanding of the biology and biochemistry of waste treatment is important to an understanding of waste-treatment systems.

Biological Properties

The biological characteristics of farm animal wastes considered are germane to degradation (stabilization), nutrient pollution, and animal diseases transmissible to other animals or man. The object of livestock waste management is the production of end products that are free from objectionable odors, are biologically inert, and are free from animal diseases transmissible to man (zoonoses). When these materials are applied to soil, they should not result in contamination of either air or water.

When the biological properties, including the microbiological properties, of the solid fecal wastes from farm animals are studied, it becomes evident that waste properties reflect differences in feed formulations and the differences between the digestive systems of ruminants and nonruminants. These differences affect the proportion of organic matter in animal feces that is easily digestible and the proportion that is slowly degradable.

All farm animals are fed predominantly plant products. Such feeds consist of complex organic compounds; this complexity results in the biological differences in the composition of the liquid and solid wastes among farm animals. This can be best illustrated by comparing the nature of the feed and the digestive system of animals with only one simple stomach, such as swine and poultry, with the feed and digestive system for ruminant animals with a four-compartment stomach, such as cattle, sheep, and goats.

Nonruminant digestion: Swine and poultry, which are nonruminants, require feeds high in readily digestible nutrients including carbon sources for energy, such as starches, sugars, and fats, and nitrogen sources that include the essential amino acids, usually in the form of proteins. Similarly, sulfur and phosphorus sources, vitamins, minerals, purines, pyrimidines, and other growth factors must be supplied in a form usable to the animal. Large amounts of roughage in the ration decrease the proportion of the food available for the animal. Because the animal lacks the enzymes necessary for cellulose breakdown in its digestive system, the cellulosic fibers appear in the feces and nondegradable roughage.

Microorganisms seem to have only a minor role in the digestive system of such animals. Few or no bacteria can be detected in the esophagus, stomach, or upper intestinal tract. Starch degradation starts with salivary amylases, is aided by acid in the stomach, and is completed in the intestine. The resulting blood glucose is used for energy and synthesis. Fats furnish another energy source after they are emulsified with bile salts in the intestine. The nitrogen in the form of amino acids in proteins is made available by stomach pepsin, followed by proteolysis by enzymes secreted in the intestine. The extent of digestive action by the large numbers of bacteria that develop in the large intestine is not known. It is known that vitamin-synthesizing microorganisms in the intestine aid the host.

The species and numbers of microorganisms in the intestinal tract of such animals are almost unknown. The anaerobic, non-spore-forming rods of the genus Bacteroides and related fusiform-shaped rods are reported to account for 50% of the microbial protoplasm in such feces. The presence of true bacteria, filamentous bacteria, fungi (such as yeasts and molds), viruses, and protozoa in feces has been reported, but the numbers and significance of these organisms are not known. Selected coliform bacteria and fecal streptococci, which have been studied as indicators of the presence of feces in the environment, will be discussed separately.

If a monogastric animal, such as a pig, were provided with a balanced, liquid diet with all needed soluble sugars, amino acids, vitamins, growth factors, and minerals, but no fiber or roughage, the excretion of waste nitrogen as urea in urine would be normal. The small bulk of feces, however, would consist entirely of waste body cells, secretions, and intestinal microorganisms. The entire feces would be easily degradable in the absence of insoluble, fibrous organic matter. This illustrates the importance to waste-management design of the fibrous component of feeds for nonruminant animals.

The horse is a nonruminant animal, but commonly has a high percentage of roughage in its diet. The cellulosic material (roughage) is retained in the cecum (part of the large intestines) where it is enzymatically digested or hydrolyzed by indigenous anaerobic bacteria. The soluble compounds formed are used as an energy source.

Ruminant digestion. Cattle, sheep, and goats have four-compartmented stomachs. Ruminants form a symbiotic partnership with a continuous culture of microorganisms that are maintained in the first-stomach compartment, the paunch or rumen; this functions as a large fermentation vessel supplied with large amounts of saliva and an intermittent supply of food. The constant 101°F (38°C) temperature, the anaerobic environment, and continuous food supply result in the growth of enormous numbers of microorganisms, 10 billion per ml of fluid.

The cellulose fibers that are insoluble in water are hydrolyzed by enzymes from certain species of anaerobic bacteria and ciliated protozoa with the formation of soluble carbohydrates. The carbohydrates, in turn, are rapidly converted to volatile organic acids that form a major component of the energy supply of the animal. The anaerobic environment favors the fermentation of sugars to volatile organic acids by non-spore-forming anaerobic rods and cocci. Carbon dioxide gas also is a product of fermentation by bacteria.

Other fermentation products are hydrogen or hydrogen donors; these are used by the methane-forming bacteria, such as **Methanobacterium ruminantium,** to convert carbon dioxide, the most oxidized carbon form, to methane, the most reduced carbon form. The net result is the production of from 1.4 to 2.1 ft^3 (40 to 60 liters) of carbon dioxide and methane gas per day in a rumen of 3.5 ft^3 (100 liters). These metabolic conversions of oxidized to reduced organic compounds also occur among nitrogen compounds with the conversion of nitrates from plants to ammonia, and then to amino acids and protein in the microorganisms.

The conversion of nitrate nitrogen, and especially supplementary urea nitrogen, to ammonia and to the proteins of microorganisms is very important to a ruminant. For example, cattle feeding on alfalfa hay, which has 90% organic matter and 10% digestible protein, make up their deficiency in protein nitrogen by the microbial protoplasm generated in the rumen. This protein, formed from both protein and nonprotein in nitrogen in the feed, becomes available in the third and fourth stomachs where typical mammalian digestion begins. Vitamins and purines, pyrimidines, and even organic phosphorous compounds, such as nucleic acids, are also synthesized by the microorganisms.

The net result of the rumen digestion (a combination of degradative and synthetic action by the microorganisms) is to break down the fibrous celluloses and pentosans so that the amount of insoluble matter in the feed is much reduced in the feces. About one-fourth to one-third of the fecal organic matter is microbial cells.

The urine of mammals contains urea as a waste product. Poultry excrete the waste nitrogen as uric acid in the feces. The action of many bacterial ureases releases ammonia and carbon dioxide from waste urea.

Coliforms as indicators of fecal pollution: Although the microorganisms inhabiting the intestinal tract of farm animals have not been adequately studied, selected types have been chosen as indicators of fecal pollution. These are the fecal coliform bacteria and the fecal streptococci. Although the coliform bacteria occur in large numbers in the feces of all farm animals, the term is nonspecific because the ability to ferment lactose broth to form gas in 48 hr at 95°F (35°C) is shared by about five genera of bacteria. The development of elevated temperature tests for true fecal **Escherichia coli** in E C medium at 113°F (45°C) has been reviewed by Geldreich (1966). The numbers and significance of the fecal streptococci also were discussed as possible indicators of fecal pollution. The numbers of fecal coliform bacteria and fecal streptococci also were reviewed by Geldreich as a possible method of distinguishing farm animal versus human fecal sources of water pollution as indicated by Table 2 of coliform data from Geldreich and fecal streptococcus data from Kenner et al. (1960).

A difference has been noted among the fecal streptococci in the feces of ruminants versus nonruminants. The term "fecal streptococcus" is a general term, which includes all the enterococcus group of streptococci. These are defined in Bergey's Manual (Breed et al., 1957) to include **Streptococcus faecalis, bovis, equinus,** and sometimes two species, **S. salivarius** and **S. mitis,** which originate in animal saliva; all are included in the term fecal streptococcus because they can be isolated from feces of cattle, sheep, and goats. Deibel (1964) reviewed the properties of these streptococci. Starch-degrading bacteria are important in the rumen; the number of starch-hydrolyzing streptococci has been observed to be from 1 to 20 million cells per ml of rumen fluid. The organism identified as **Streptococcus bovis** has been found in the feces of cattle and sheep. The presence of **S. bovis** in the feces of ruminants, but not in feces of other animals or man, may serve as an indicator of the presence of feces of ruminants in water or on land.

Physical and Chemical Properties

Fecal parameters: Feed ration, age of animal, and management practice significantly affect the production rate and characteristics of animal manures. Table 3 gives manure production and characteristics per 1000 units of liveweight (lb or kg). These are average values presented for preliminary design purposes. Where known factors affect production or characteristics, corrected vales should

Table 2. Estimated per-capita contribution of indicator microorganisms from man and selected domesticated animals.

	Fecal parameters[α]		Av. indicator density		Av. contribution per capita day		Ratio
Animal	Av. wt. of feces g/day	Moisture content %	Fecal coliform[α] per gram	Fecal streptococci per gram	Fecal coliform[α]	Fecal streptococci	coliform/ streptococci
Man --------	150	77	1.3×10^{7}	3.0×10^{6}[β]	2.0×10^{9}	4.5×10^{8}[β]	4.3
Duck -------	336	61	3.3×10^{7}	5.4×10^{7}	1.1×10^{10}	1.8×10^{10}	0.6
Sheep ------	1130	74	1.6×10^{7}	3.8×10^{7}[β]	1.8×10^{10}	4.3×10^{10}[β]	0.4
Chicken ----	182	72	1.3×10^{6}	3.4×10^{6}[β]	2.4×10^{8}	6.2×10^{8}[β]	0.4
Cow --------	23600	83	2.3×10^{5}	1.3×10^{6}[β]	5.4×10^{9}	3.1×10^{10}[β]	0.2
Turkey -----	448	62	2.9×10^{5}	2.8×10^{6}	1.3×10^{8}	1.3×10^{9}	0.1
Pig --------	2700	67	3.3×10^{6}	8.4×10^{7}[β]	8.9×10^{9}	2.3×10^{11}[β]	0.4

Sources: [α] E. E. Geldreich. 1966. Sanitary significance of fecal coliforms in the environment. U.S. Department of the Interior, Federal Water Pollution Control Administration, Water Pollution Control Research Series WP-20-3.

[β] B. A. Kenner, H. F. Clark, and P. W. Kabler. 1960. Fecal streptococci. II. Quantification of streptococci in feces. American Journal of Public Health 50:1553-1559.

be used. Trends in livestock production are toward confined feeding operations in which no bedding is used. Therefore, the data presented are for manure without bedding. These data have been gathered from research conducted within the last 10 years.

The raw-manure (RM), feces plus urine, data are presented as daily production in relation to standardized body weight. To obtain volume per day, a density value of 60 lb/ft^3 (960 kg/m^3) may be used, which is an average value for all the animal manures reported. The feces:urine ratio data are presented for use in preparing samples for testing where collection of RM is not practical. When cattle are fed high-roughage rations, larger amounts of RM will be produced.

Rationale for parameter selection: Livestock wastes are sufficiently different from municipal wastes that not all the standard sanitary engineering analytical methods described in Standard Methods (American Public Health Association, 1971) are applicable. A typical example would be the measurement of total solids, the procedure described in Standard Methods is drying at 217°F (103°C). Other methods are the vacuum oven, or distillation of water vapor driven off by heating the sample with toluene. Identical samples do not generally yield identical results from all three methods. The differences may be significant if the sample contains large quantities of volatile materials, such as organic acids, ammonia, or hydrogen sulfide. The manure parameters listed in Table 3 are those obtained by using Standard Methods procedures, unless accompanied by a qualifying statement.

Total solids can be used as a base parameter for calculating other parameters. Total solids are measured by drying a sample to constant weight at 217°F (103°C). Volatile solids are related to the organic-matter fraction of total solids. Volatile solids are measured by burning a sample at 1020°F (550°C); volatile solids loading is a design parameter for anaerobic treatment of manures.

Although volatile solids are related to the organic matter in a waste sample, other measurements are needed to characterize raw wastes and treated effluents. Traditionally, the parameters used have been measures of oxygen demand. There are two oxygen-demand tests in common use: the BOD test measures oxygen depletion as the waste is acted upon by microorganisms, and the COD test oxidizes the waste by using a strong chemical oxidant. Both analyses give useful information, but the results need judicious interpretation. The BOD test over a 5-day period was designed to measure the effect that a treated **liquid** effluent might have on a receiving stream as the waste was assimilated by the organisms in that stream. BOD_5 values also have been used to design municipal activated-sludge plants, and later still, oxidation ditches for livestock wastes. The use of the BOD_5 test on raw manure samples is really an abuse of the original intent of the test because great dilution of the sample is necessary. The BOD_5 values recorded in Table 3 should be regarded only as an indicator of potential biological oxygen demand, because the standard 5-day period is too short a time to assess the oxygen demand of the particulate material in the waste. In contrast, the COD test oxidizes most particulate mater, but it gives no indication of the biological digestibility of the waste.

Data on the major fertilizer elements, N, P, and K, are important with respect to application rates for land disposal of manures. Also, the economic value of the manure as fertilizer is a factor in manure-management systems. Nigroten application on fields usually is considered the limiting factor in determining manure application rates because of the possibility of polluting the groundwater with nitrates. Guidelines on application rates for nitrogen and other elements should be obtained from applicable state pollution-control agencies. Nitrogen losses differ, depending on treatment, handling, and storage methods. Table 4 gives estimated nitrogen losses for different manure-management systems. The phosphorus content and salinity of both treated and untreated waste may be of more concern in some areas of the United States. The section on utilization examines the effects of these components in more detail.

Ration and fecal composition: The influence of ration on manure characteristics has been recognized, but few definitive data have been accumulated. Working with beef cattle, Frecks and Gilbertson (1973) have determined

Table 3. Manure production and characteristics of domesticated livestock per 1000 liveweight units (lb or kg).

Parameter		Dairy cow	Beef feeder	Swine feeder	Sheep feeder	Poultry		Horse
						layer	broiler	
Raw Manure (RM)[a]	Wt./day	82	60	65	40	53	71	45
Feces:urine	Ratio	2.2	2.4	1.2	1.0	--	--	4.0
Total Solids (TS)	Wt./day	10.4	6.9	6.0	10.0	13.4	17.1	9.4
	% RM	12.7	11.6	9.2	25	25.2	25.2	20.9
Volatile Solids (VS)	Wt./day	8.6	5.9	4.8	8.5	9.4	12.0	7.5
	% TS	82.5	85	80	85	70	70	80
BOD_5	Wt./day	1.7	1.6	2.0	0.9	3.5	--	--
	% TS	16.5	23	33	9.0	27	--	--
COD	Wt./day	9.1	6.6	5.7	11.8	12.0	--	--
	% TS	88	95	95	118	90	--	--
Nitrogen	Wt./day	0.41	0.34	0.45	0.45	0.72	1.16	0.27
(Total, as N)	% TS	3.9	4.9	7.5	4.5	5.4	6.8	2.9
Phosphorus	Wt./day	0.073	0.11	0.15	0.066	0.28	0.26	0.046
(as P)	% TS	0.7	1.6	2.5	0.66	2.1	1.5	0.49
Potassium	Wt./day	0.27	0.24	0.30	0.32	0.31	0.36	0.17
(as K)	% TS	2.6	3.6	4.9	3.2	2.3	2.1	1.8

[a] Feces and urine with no bedding

Source: American Society of Agricultural Engineers, data adapted from Structures and Environment Committee 412 report AW-D-1, revised 14 June 1973.

some of these values. In that work, the high-roughage ration was chopped brome hay, protein content 8.26%. The high concentrate was a mixture of predominantly corn (82.5%), corncobs (10%), molasses (5%), and urea (1%). The results of that study are summarized in Table 5.

Table 4. Estimated nitrogen losses from different manure-management systems.

System	Percent N loss
Oxidation ditch, followed by storage lagoon and land application	84
Deep pit storage and land application	66
Anaerobic lagoon and land application	78
Aerobic lagoon and land application	61
Bedded confinement, solid spreading	34
Open lot (with or without shelter), solid spreading, runoff collected and applied to land	57

Source: D. H. Vanderholm. 1973. Area needed for land disposal of beef and swine wastes. Iowa Cooperative Extension Service Pamphlet 552 (Revised).

Table 5. Comparison of beef-cattle manure from animals fed high-concentrate and high-roughage rations, mean values.

Parameter	High concentrate		High roughage	
	Feces	Urine	Feces	Urine
Solids (% Wet Basis)				
Total	27.1	6.1	26.3	6.1
Volatile	25.5	4.8	22.8	4.6
Fixed	1.6	1.4	3.4	1.5
Particle Size				
Percent finer than (by weight):				
2.0 mm	80	--	97	--
0.5 mm	57	--	62	--
0.1 mm	48	--	30	--
Particle density g/cm^3	1.50	--	1.53	--
Bulk density g/cm^3	1.10	--	1.09	--
Chemical oxygen demand mg/l	331,000	34,300	323,000	29,400

Source: G. A. Frecks and C. B. Gilbertson. 1973. The effect of ration on engineering properties of beef cattle manure. ASAE 73-442. American Society of Agricultural Engineers, St. Joseph, Michigan.

MANURE HANDLING, ROOFED FACILITIES

Roofed facilities for livestock housing provide a management system in which manure may be handled with only controlled addition of dilution water. This provides a major difference in livestock waste handling as compared with feedlot production. Feedlot systems must be planned to provide for handling of polluted runoff from rainfall. Milkrooms and parlors are examples of roofed livestock-production facilities in which large quantities of dilute wastes are generated. Water flushing systems are sometimes used in roofed facilities. These systems may generate wastes similar to the runoff from feedlots, but the flow periods and flow-rates are predictable. Systems for collection, treatment, storage, and transport of wastes from roofed facilities may be designed for any one of the categories of liquid, semisolid, or solid waste. Components for systems must be selected to handle the waste in whichever form selected.

Collection

Slatted floors: Hoibo (1960) published the results of structural tests made in Norway on concrete floor slats for cattle. Burgener (1961) adapted these test results to designs suitable for the United States. These floor slats, designed for cattle, were developed as simple beams. Hoibo presented an extensive analysis of the loading assumptions appropriate for the design of the slats. These assumptions suggest individual loads of ¼ the animal weight. The distance between two adjacent loading points (that is, between two hooves) is assumed to be 1 ft (0.3 m), and the distance between adjacent animals is 2 ft (0.6 m). Hoibo concluded that slats having a trapezoidal cross section provided best disposal of droppings, and the slats need not be reinforced for diagonal tension.

Berhe (1967), Pratt and Nelson (1968), and Binek and Pratt (1969) presented analytical procedures for grid work designs for floor systems. It was assumed that, if 4 or 5 slats were integrated into a grid, livestock loads cannot be applied to all the slats at one time. In addition, the cross slats convey load stress from loaded slats to the others in the system. This load transfer makes it possible to design smaller slats in a grid than if individual slats were used. Loading criteria have been rationalized and are presented in Table 6.

Table 6. Loading criteria for slatted floors used for domestic animals.

Animal	Load per unit length[a]		Solid floor and floor support	
	lb/ft	N/m	lb/ft^2	Pa
Beef cattle				
calves to 300 lb (136 kg)	150	2190	50	2390
feeders, breeding stock	250	3650	100	4790
Dairy cattle				
calves to 300 lb (136 kg)	150	2190	50	2390
mature	250	3650	100	4790
mature stall area	250	3650	60	2870
maternity or hospital pen	150	2190	50	2390
Swine				
to 50 lb (23 kg)	50	730	35	1680
200 lb (91 kg)	100	1460	50	2390
400 lb (181 kg)	150	2190	65	3110
500 lb (227 kg)	170	2480	70	3350
Sheep				
feeders	100	1460	40	1920
breeding stock	120	1750	50	2390
Horses	250	3650	100	4790
Turkeys	25	360	30	1440

[a] Check slat strength in shear and bending for a 220 lb (980 N) point load.

Source: Draft recommendations for ASAE Engineering Practice. June 1974. American Society of Agricultural Engineers, St. Joseph, Mich.

Slats for livestock are currently made of concrete, steel, aluminum, plastic, and wood. Hoibo (1960) and Hammer (1960) presented conclusions from Europe on slat design that formed a basis for the development of slatted floor systems in the United States. Wood and concrete slats were compared. Metal slats came into use at a later date. Rough hardwood slats were found suitable for hogs, but deteriorated rapidly. Concrete slats were said to stay drier and cleaner than wood. Jensen (1961) reported on the use of wood and concrete slats for pigs. He also included expanded metal flooring in his tests at the University of Illinois. In 14 tests involving 728 pigs weaned at 2-3 weeks of age, pigs on the expanded metal floor gained 19.5% faster than pigs on the concrete floor. The flooring had no consistent effect on the amount of feed required per pound of gain. Flattened, expanded steel floors had no deleterious effect on the feet and legs of pigs weighing from 33-236 lb (15-107 kg). Both growth rate and feed efficiency were excellent. Rough-cut lumber gave the pig a better footing than did smooth lumber, particularly when the surfaces were wet.

Slotted floors are used both inside buildings and in outside areas. Milne and Redmon (1971) have conducted tests on outdoor slotted floors for beef cattle in cold climates. They reported that outdoor slotted floors worked satisfactorily under winter conditions, if a reasonable management effort was made. For such a system to work, only a minimum amount of chopped bedding could be used. In some instances, manual labor was required to keep slats open during extreme conditions. Outdoor liquid manure systems function satisfactorily in severe winter climates provided that sufficient storage volume is provided for holding a 6 mo accumulation of manure and that the bedding used is of a type that can be readily incorporated into a pumpable slurry.

Steel slats were tested at Iowa State University (American Iron and Steel Institute, 1970). Of the various materials tested, the porcelain on steel and modified type 410 stainless steel exhibited the best performance in this most severe application.

Data from three years of work involving five housing systems for feedlot cattle at Morris, Minn. were reported by R.E. Smith et al. (1972). The systems included: Conventional open shed with an outside concrete lot, manure-pack confinement with manure-scraped alley, cold slotted-floor confinement, heated slotted-floor confinement, and open lot with dirt mound and windbreak fence. The average daily gains for the three years were highest for cattle housed at 17 or 25 ft^2 (1.6 or 2.3 m^2) per head in the warm, slotted-floor unit, followed closely by the cattle housed at 17 ft^2 (1.6 m^2) per head in the manure-scraped unit. A decrease in average daily gain was observed for cattle in the cold, slatted-floor unit as density increased from 25 to 17 to 14 ft^2 (2.3 to 1.6 to 1.3 m^2) per head. Cattle in the open lot had the lowest average daily gain.

E.S. Bell et al. (1967) reported on the effect of floor type on swine performance. The data indicated that the various floors studied (solid concrete, 25% slatted, 50% slatted, and fully slatted) did not affect rate of gain for hogs. Cleanliness of animals and pens was affected by floor type; generally, cleanliness improved with increasing percentages of slatted-floor area.

A study conducted by Hegg and Larson (1971), to determine the quantity and distribution of waste produced by steers fed a high-energy ration and housed in a fully slotted confinement building, showed that 53%-63% of the fecal material was deposited on the half of the slatted floor nearest the feed bunk.

Transport

Mechanical cleaning: Mechanical equipment is frequently required to move solid waste materials from barns. Equipment has been developed to handle these wastes for dairy and poultry housing systems. It also is used to a limited extent in the hog production industry.

Gutter cleaners in dairy barns have been used for many years and represent the first attempts to mechanize manure handling. Richey et al. (1961) reported that mechanical barn cleaners were first introduced in the early 1940s. Types developed included portable, self-propelled, power-driven scoops that fitted into the gutter and were pulled via the scraper, a pullout apron with chain and flights that was drawn out of the building conveying the manure into a spreader, and an endless-chain type of cleaner consisting of rigid bar with hinged paddles. The bar was operated with a reciprocating motion, and the paddles engaged manure in the gutter and conveyed it out of the building.

Witz and Pratt (1971) have used the cable type of scraper for slotted floors in an experimental beef housing unit. Solid-liquid separation is achieved in the building, and the scrapers convey the solids from the building.

Hydraulic cleaning: Moving livestock wastes with water is an old practice, but its automation for confined livestock housing is relatively new. A theoretical analysis of the process was presented by E.E. Jones et al. (1971). After relating manure transport to bed-load transport in rivers, they discuss a channel with a stairstep configuration (Figure 7). Their objective was to improve manure transport at low flows by increasing the liquid velocity. These authors considered the stepped gutter fairly satisfactory, but they did observe that, as the pigs grew heavier, they tended to avoid the gutter because they found it slippery. Hazen (reported by R.J. Smith et al., 1973) also tried a channel cross section, which improved scouring at low flows (Figure 8). This channel section has been installed under slats and has proved satisfactory. The need for improved scouring with the covered gutter had been suggested by R.J. Smith (1971) who had observed that, in spite of hydraulic deficiencies, the action of the pigs' feet in the open gutter was instrumental in keeping the manure moving.

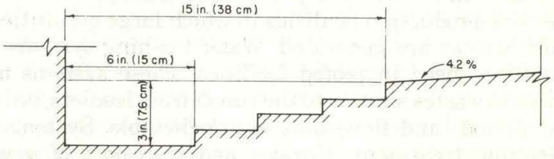


Figure 7. Stairstep section channel for hydraulic manure flushing.

Source: E.E. Jones, Jr., G.B. Willson, and W.F. Schwiesow. 1971. Improving water utilization efficiency in automatic hydraulic waste removal. pp. 154-158. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

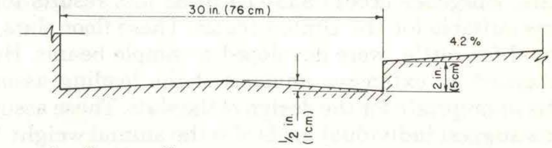


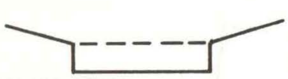
Figure 8. Gutter-floor section for use with hydraulic manure transport when flushing with a dosing syphon.

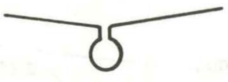
Source: Smith, R.J., T.E. Hazen, and G.B. Parker. 1973. Waste management. 14 pp. In: Proceedings, Pork Producers Day, Iowa State University Cooperative Extension Service AS 391.

Both George (1973) and R.J. Smith et al.(1973) have published design recommendations for swine flushing gutters. These two papers approached the problem by assuming a quasi steady-state flow to allow application of Manning's equation for open-channel flow. George attempted to correlate flushing volume requirements with manure deposition rates, but R.J. Smith et al., working from past experience, limited their discussion to hourly (or more frequent) flushing. Consequently, the final design recommendations differed; George suggested a variable slope and variable width channel, but R.J. Smith et al. specified only one width and slope. George's approach conserves flushing water, but the approach of R.J. Smith et al. is valid for recycling systems where flow quantities do not affect fresh water usage. Both George and R.J. Smith et al. follow the 3 ft/sec (1 m/sec) velocity recommendation of E.E. Jones et al. (1971).

All flushing systems require initial discharge at the head of the channel at such a rate that the steady-state velocity in the channel reaches 3 ft/sec (1 m/sec) or more. Early work by Gribble and Bennett (1965) described the use of an over-center tilting tank and also a falling-dam system of water discharge. Both these methods are described in relation to dairy cows and milking operations. E.E. Jones et al. (1971) and Taiganides and White (1971) used siphon flush tanks for flushing swine wastes. R.J. Smith (1971) used an electrically controlled valve for rapid discharge from an elevated tank, but this device was abandoned as being too mechanically complex. E.C. Miller and Hansen (1973) reported successful manure transport under 8 ft (2.5 m) slatted-floor sections using tilting tanks. They also presented design information. At present, the siphon and the tilting tank seem the two methods of choice. R.J. Smith et al. (1973) presented design recommendations on siphon tanks, and Hazen (1973) and E.C. Miller and Hansen (1973) have recommendations for tilting tanks. Flushing using elevated tanks suffers from the need to maintain the tanks above freezing, which limits application to warm climates or climate controlled housing.

D.L. Jones[1] described a pilot system for flushing between slats in a swine building; extensive data on animal density and flushing frequency were recorded. The winter of 1972-73 was abnormally wet in the Midwest, and the condition of beef animals in open feedlots often was pitiable. As a result of studies by two men involved in commercial cattle feeding (Kissinger and Frankl, reported by Peach, 1973), the latter part of 1973 saw a boom in the construction of two other forms of hydraulically cleaned feeding floor. In the Kissinger form, the solid section of the floor slopes to a 4-ft (1.25-m) channel covered by slats. In the Frankl form, the slats and channel are replaced by a 2-in. (5-cm) slot set above an 8-in. (25-cm) diameter flume.


Kissinger


Frankl

Both systems are intended for use in open-front beef buildings and overcome freezing problems by using direct pump discharge. Melvin et al. (1973) described some installations in Iowa. A lagoon system to provide adequate flushing liquid is a necessary adjunct of both systems.

Hydraulic transport of manure in an open gutter is obviously a potential vehicle for disease transmission. This hazard does not seem as severe in practice as in theory. Although R.J. Smith (1971) showed that the TGE virus could be detected after passage through an anaerobic lagoon, Schmitt et al. (1974) could not show any major effects on pig performance, unless the sole source of water was recycled lagoon water. We may conclude that hydraulic flushing of swine manure, using shallow open channels, is a well-established practice that is unlikely to lead to significant disease hazards. One caveat remains, most research has been conducted using closed herds.

The design of flushing gutters and discharge devices is fairly flexible within two boundaries. The velocity of the water at all points in the gutter should equal or exceed 3 ft/sec (1 m/sec). Channels wider than 30 in. (0.75m) may require division into multiple channels to avoid deposition of fetid manure piles caused by meandering of the flush water. The tipping bucket and the siphon are both satisfactory forms of discharge devices, but the siphon may prove less costly. Flushing may be performed in open channel or under slats; open-channel flushing would seem more economically attractive in growing-finishing houses, but under-slat flushing is probably desirable for farrowing and nursery houses. Flush cleaning of beef confinement buildings would seem to have considerable promise.

Solid-Liquid Separation

Livestock manures vary markedly from species to species, but they have one factor in common, they are usually difficult to pump in the raw state. Some manures, in particular those from ruminants, can be separated into a liquid portion, containing most of the biologically active components with a rapidly exerted oxygen demand, and a coarse particulate solids portion. This latter will drain readily and is relatively inert biologically. If the animals are provided with bedding, this material often complicates pumping, but can be separated quite readily from the manure by screening. Elam (1971) reported that one dairyman used the dried, coarse solids obtained from a vibrating screen as the bedding in a free-stall barn. Biological treatment of wastes provides another incentive for solid-liquid separation; both anaerobic lagoons and mechanically aerated basins function with less trouble if hair, straw, or feathers can be kept out. Production of single-cell protein (SCP) from wastes is a much-discussed concept; this would be much easier to control if the coarse solids were first removed from the waste stream. Finally, the liquid effluents from most treatment systems are returned to the land through irrigation equipment. In many instances, it is desirable to be able to use conventional small-bore nozzles, such as are found on both hand-carry and large, center-pivot systems. Satisfactory operation of such small nozzles demands removal of coarse solids.

There are two fundamental means of solid-liquid separation. The first uses the difference in density between the particulate matter and the liquid (sedimentation and centrifuging), and the second uses the shape and size of the particles to effect separation (screening and filtering).

Characteristics of the separated solid and liquid portions: Gilbertson and Nienaber (1972) examined the physical characteristics of the components of beef feedlot runoff. Size classification was performed by wet sieving (0.0787 to 0.0015 in., 2 to 0.037 mm openings). The volatile fraction of each component was determined; this fraction became smaller as the particle size decreased. Thus, Gilbertson and Nienaber concluded that particles of less than 0.0098 in. (0.25 mm) size are soil particles. Liquid, obtained by filtering the runoff, contained solids that were 67% volatile. Settling tests on the runoff samples were

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[1] D.L. Jones. 1972. Flushing between slats as a method of swine manure disposal. Student paper submitted to the 1972 American Society of Agricultural Engineers National Student Paper Contest.

performed using both Imhoff cones and graduated cylinders. All samples showed a rapid decrease in suspended solids for the first 0.25 hr, but a much slower decline over periods extending to 24 hr. Gilbertson and Nienaber also measured the gross energy of the various fractions by using a bomb calorimeter. Only results for the finest suspended and dissolved/colloidal solids were reported, and these indicated gross energies of 2290 and 2990 Btu/lb (5330 and 6950 J/g).

Ngoddy et al. (1971) examined the characteristics of the various size fractions in fresh beef and swine manures. On a gross superficial basis, they note that the solids retained on the screen are fibrous, about 90% volatile, and would drain and dry to become odorless and inoffensive. Conversely, the liquid remaining after screening was odorous and very susceptible to biological decomposition. This report by Ngoddy et al. contains extensive tables of the properties of the various size classifications. The findings can be summarized for design purposes by noting that the liquid effluent from any screen in the range 60 to 325 mesh (0.0098 to 0.0017 in., 0.25 to 0.044 mm opening) will contain about 60% of the total (or volatile) solids from the influent and about 70% of the COD. Also, some 60% of the nitrogen will appear in the screen effluent. The screened solids contain 75% -85% water, and some of this will drain, so the actual figures to be used in design should reflect the added liquid effluent from this source. The figures in the report suggest that adding the drainage to the screen effluent will increase this by 5%-10%.

Frecks and Gilbertson (1973) examined the characteristics of the manure from beef animals fed two different rations. The high-roughage ration (HRR) consisted of 100% chopped bromegrass hay, and the high-concentrate ration (HCR) consisted of 82% corn with 10% chopped corncobs and a balance of supplementary materials. Frecks and Gilbertson concluded that ration did not affect the total solids content of the feces and urine. Particle size distribution was affected; 20% of the HCR was retained on a 78.7×10^{-3} in. (2 mm) sieve but only 2% of the HRR. Twenty-two percent more HRR feces particles were retained on the smaller sieves (0.0197, 0.0098, and 0.0041 in., 0.5, 0.25, and 0.105 mm) relative to the HCR. The HCR screenings all showed a higher volatile solids fraction than the HRR. These investigators did not record the distribution of solids or other parameters according to screen size.

Gravity settling: Conventional gravity settling consists of detaining a fairly dilute wastewater in a quiescent state so that the particles in the waste can settle to the bottom or float to the top. Witz and Pratt (1971) described a variation on this theme. The wastes from beef cattle on a slatted floor fell through the slats onto a solid floor with a 2% slope. A chain and flight conveyor moved slowly up this slope, and some solid-liquid separation took place as the liquid ran down the slope and the solids were conveyed to the top. The moisture content of the solids was reported to be 80%. The system seemed promising, but needed further refinement.

Verley and Miner (1973) reported on a device using a similar combination of filtration and gravity settling. This device is illustrated in Figure 9. The idea was to provide a series of settling basins with the liquid effluent from one flowing into the next lower one; at the same time, these basins moved up the slope and discharged the dewatered solids at the top. All this was achieved in the spaces formed between the flights of a hollow auger and its cylindrical sheath. Verley and Miner discussed the hydraulic parameters that could be expected to affect the operation of the device, but they concluded that the settling characteristics of manure particles were not well enough defined to warrant an elaborate mathematical model. Because it was difficult to maintain a uniform infeed of manure, most of the tests were performed on beet pulp. Using the device with the dimensions shown in Figure 9, Verley and Miner found that 64% of the suspended solids could be removed from the sugar-beet slurry at a flow rate of 0.5 gpm (0.11 m^3/hr). Increased flowrates deteriorated solids-removal efficiency. A modified design to allow better dewatering of the sludge before discharge also was described.

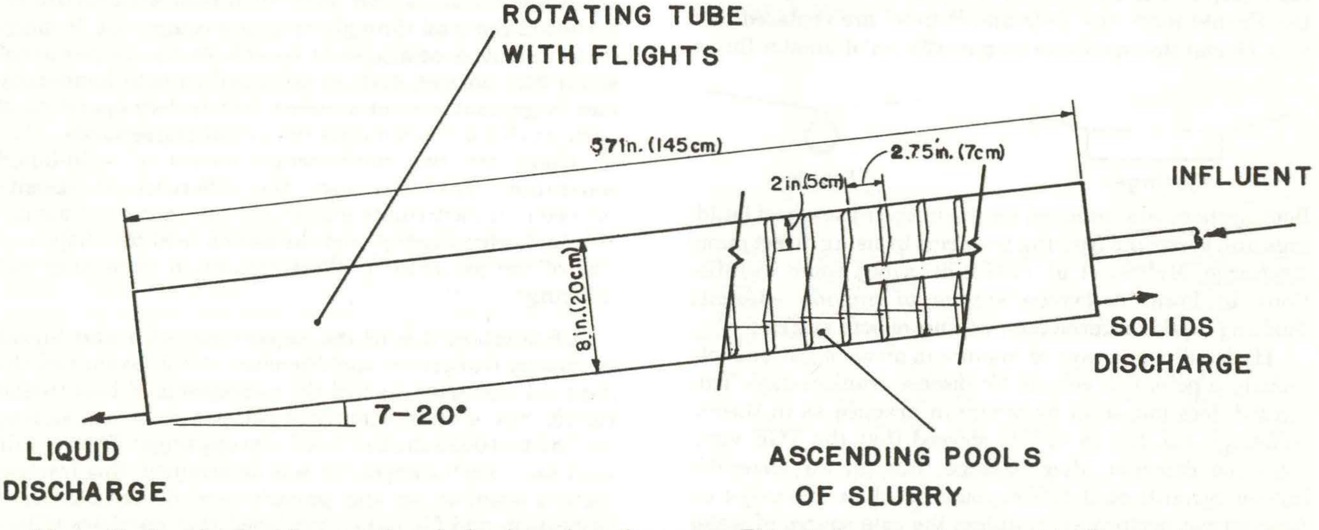


Figure 9. A solid-liquid separation device based on the auger. This device was developed in Oregon for use on dairy manure discharged from facilities using hydraulic flush cleaning.

Source. W.E. Verly and J.R. Miner. 1973. A rotating flighted cylinder to separate manure solids from water. ASAE 73-410. American Society of Agricultural Engineers, St. Joseph, Michigan.

Sobel (1966) reported on the settling characteristics of dairy and poultry manures. He found that the manure would have to be diluted with twice its volume of water before significant settling would occur. All dilutions above 1:2 showed a rapid period of settling, followed by a long period of compaction. The duration of the initial settling period decreased as the dilution ratio was increased.

Moore et al. (1973) extended the work on gravity settling to beef, dairy, horse, poultry, and swine manures. Wastes from each of these species were mixed to give 0.01%, 0.1%, and 1% total solids slurries. The settling studies were performed in a Plexiglas cylinder 5.5 in. (14 cm) inside diameter and 16.5 in. (40.6 cm) high. A sample was taken from the top of each cylinder at 0, 1, 10, 100, and 1000 min. Chemical oxygen demand, total solids, and total volatile solids were measured on all samples. All the manure slurries showed rather similar behavior. The results of the tests using beef slurry are shown in Figure 10. Moore et al. conclude that settling can provide useful removal of TS and COD from a dilute slurry and that the shapes of the settling curves are almost identical for the dilutions tested.

Centrifugal separation: Because the equipment is rather expensive and requires skilled maintenance, centrifugal separation has been little used for livestock manures. Because few agricultural engineers have been exposed to the techniques of continuous-flow centrifugation, a brief review of modern sanitary engineering practice may be useful. Albertson and Guidi (1967) described the three types of solid-bowl centrifuge that have been used in industrial waste treatment. These are presented in Figure 11. They reviewed the history of centrifugal separation in municipal waste treatment, and they indicated that centrifuging was not accepted until the advent of the cylindrical conical machine with a longer bowl and a shallower cone angle than had been used previously (Figure 12). The shallow cone angle allows the more fragile biological flocs to be dewatered on the beach. The performance of a centrifuge is described primarily in terms of gravity minutes. This parameter is the product:

[Pool volume (gal) ÷ Feed flowrate (gal/min)] Av. centrifugal force (G)

As an example, Albertson and Guidi mentioned that a gravity clarifier would have a rating of 120 gravity minutes, but a centrifuge would have ratings in the range 930-4600 gravity minutes. This parameter is not wholly adequate to categorize performance because the rate of transport up the beach and the detention time on the

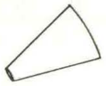
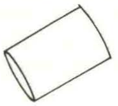
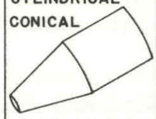
TYPE	DEWATER	CLASSIFY	CLARIFY
CONICAL  L:D < 1·8	GOOD	GOOD	POOR
CYLINDRICAL  L:D = 1·5 – 3·5	POOR	FAIR	V. GOOD
CYLINDRICAL – CONICAL  L:D = 2·5 – 3·5	GOOD	FAIR TO GOOD	GOOD

Figure 11. A comparison of the dewatering, classifying, and clarifying capabilities of three categories of centrifuge.

Source: O.E. Albertson and E.J. Guidi, Jr. 1967. Advances in the centrifugal dewatering of sludges. Water and Sewage Works Reference Number R 133-142.

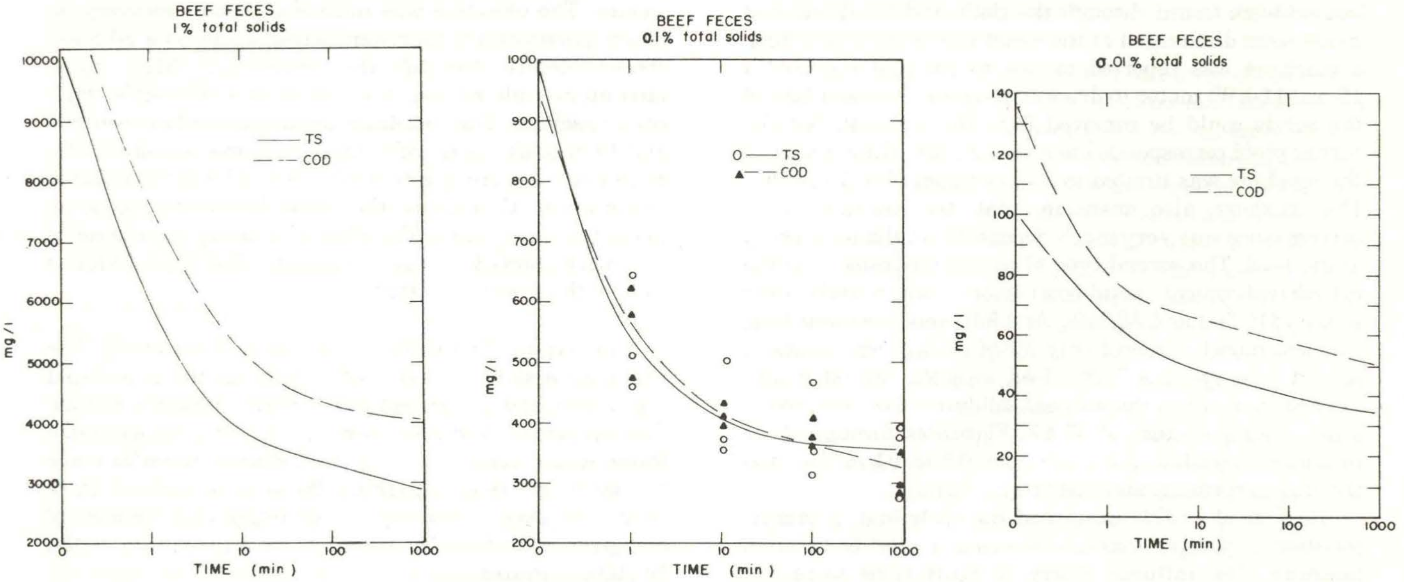


Figure 10. Gravitational settling of beef waste slurries. Total solids and chemical oxygen demand for 1%, 0.1%, and 0.01% total solids slurries.

Source: J.A. Moore, R.O. Hegg, D.C. Scholz, and E. Strauman. 1973. Settling solids in animal waste slurries. ASAE 73-438. American Society of Agricultural Engineers, St. Joseph, Michigan.

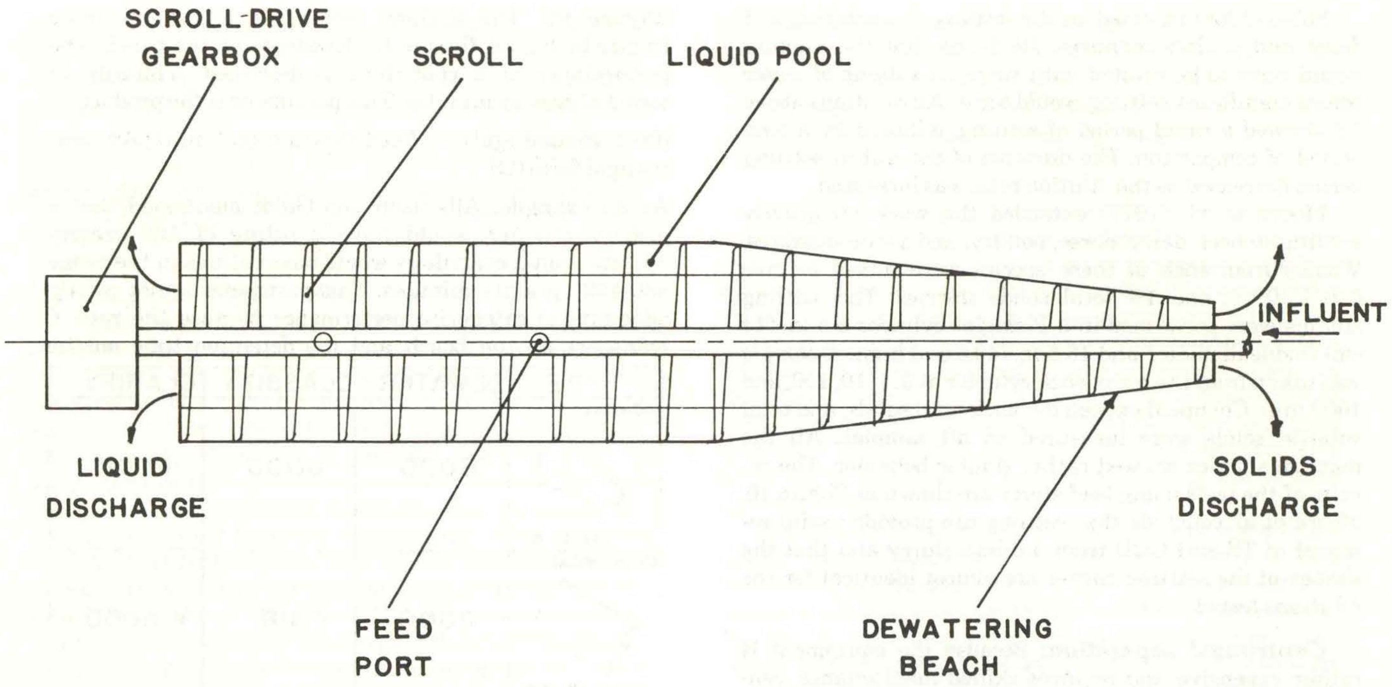


Figure 12. A cylindrical-conical centrifuge for sludge dewatering.

Source: O.E. Albertson and E.J. Guidi, Jr. 1967. Advances in the centrifugal dewatering of sludges. Water and Sewage Works Reference Number R 133-142.

beach also are important. Albertson and Guidi described how the centrifugal dewatering properties of a specific waste slurry may be determined by using a scale-model centrifuge whose operating parameters are fully controlled and instrumented.

Glerum et al. (1971) described the use of two types of centrifuge on pig slurry. The first type was a centrisieve that had a conical drum with a filter cloth liner; the liquids were forced through the cloth, and the dewatered solids were discharged at the wider end of the drum. Such a machine was reported to cost $2,100 and required a 15-hp (11-kW) motor to drive it. Between 30% and 50% of the solids could be removed from the influent, but the higher yield corresponded to a wetter cake. The capacity of the machine was limited to 35 to 44 gpm (8 to 10 m^3/hr). The authors also mention that the uniformity of performance was very much dependent on the uniformity of the feed. The second type of centrifuge tested was the cylindrical-conical, solid-bowl type. Two models were tested ($12,500 and $8,350). At 1.92% solids-content feed, the first model removed only 3% of the influent solids. A second test, using a 7.58% feed with the second model, showed that 14% of the influent solids could be removed at a dry-matter content of 37.4%. Flowrates through these machines were low, 2.7 to 4.9 gpm (0.6 to 1.1 m^3/hr), and the energy consumption was large.

Ross et al. (1971) examined the centrifuging characteristics of poultry manure by using a solid-bowl batch machine. The influent slurry concentrations were 5%, 15%, and 25% solids. At the lowest solids content, all slurries showed the same dewatering characteristics over the range 2,000 to 10,000 G. As the initial solids concentration increased, the amount of water that could be removed decreased, and the effect of centrifugal force became more important. Most of the data presented showed that virtually all separation took place after 4 min. The authors also tried varying the influent temperature in the range 40 to 160°F (4.5 to 71°C); water removal improved as the influent temperatures increased.

Holmes et al. (1971) reported on the centrifugation of the mixed liquor from an oxidation ditch treating swine wastes. The objective was microbial protein recovery, so coarse particles and hair were screened out on a 20-mesh screen before feeding the centrifuge. After some laboratory-scale studies, they obtained a pilot-scale solid-bowl machine. This machine could operate between 500 and 2000 G. Using an influent solids concentration of 12%, Holmes et al. were able to remove 90%-95% of the influent liquid at 500 G or above, the higher figure corresponding to the higher G rating. The effect of G rating on cake solids was more marked because it required 1600 G to produce a cake with 7% solids content.

Screening: There are two methods of screening: The first uses a slow relative motion between the slurry and the screen, and the second uses a rapid vibratory motion. The equipment required is complex and only available through commercial sources; thus, allusion must be made to specific pieces of apparatus. We wish to make it quite clear that such references do not imply endorsement of any particular branded item by the universities in the NC-93 committee.

Ginaven and Wittenmyer[2] described the concept of the "hydrasieve" (Figure 13).

1. Fluid-solids slurry must be metered uniformly in thickness over the full width of the screening media.

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[2] M.E. Ginaven and J.D. Wittenmyer. 1972. The hydrasieve dewatering screen design and applications. Unpublished paper. Presented at the Environmental Protection Agency Technology Transfer Program-Design Seminar, Atlanta, Georgia.

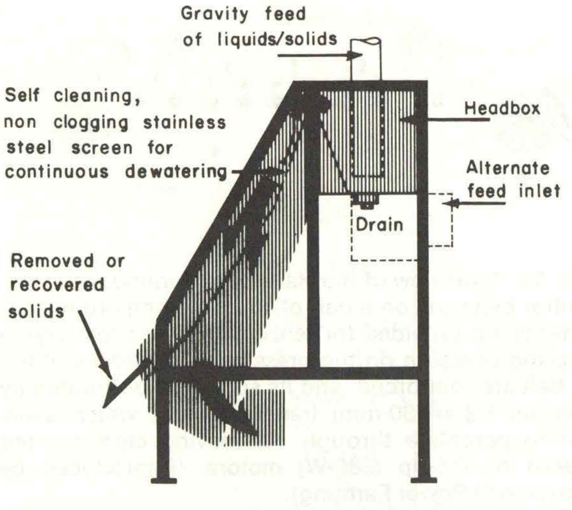

Figure 13a. Side view of a Hydrasieve showing flow paths of the separated liquids and solids.

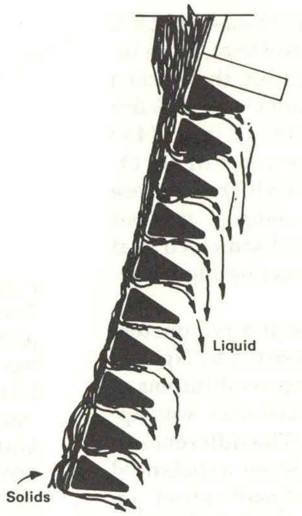

Figure 13b. Magnified view of the wedge-wire screen used on the Hydrasieve to achieve wall attachment of the liquid.

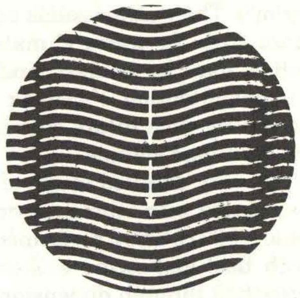

Figure 13c. Magnified frontal view of the Hydrasieve showing the ripple conformation to windrow the solids as they traverse the front of the screen.

Figures 13a, b, and c are reproduced by permission of the Bauer Brothers Co.

2. Trap all heavy foreign materials in the feed system.
3. Accelerate the flow of the fluid from the feeding chamber or a headbox to cause a stratification of the suspended solids and a lengthwise orientation of fibrous material in the flow.
4. Remove as much fluid as is feasible quickly through the use of hydraulic shear and wall attachment to transverse wires, essentially triangular in cross section, and formed in a rigid flat sheet.
5. Cause the dewatered solids to roll at some point on the screen to develop some kinetic forces for maximum fluid removal.
6. Permit the solids to re-mass at the lower end of the screen for a stalling effect to the dewatered material to permit final drainage. Use mechanical device, if necessary, for solids removal.
7. Make the device as simple as possible for low maintenance and trouble-free operation.

They stated that the influent flowrate is 4 to 16 gpm/in. (36 to 143 m^3/hr.m) of screen width.

Graves et al. (1971) described tests with a model hydrasieve with 0.02 in. (0.51 mm) bar spacing. Dilutions of fresh dairy manure, ranging from 2:1 to 50:1, were tried. If the dilution exceeded 6:1, good separation was achieved by the screen, total solids being reduced by about 60% in all instances. The solids content of the particulate material flowing from the bottom of the screen was about 6%. Significant reductions in COD (55%) and organic N (43%) also were noted. Inspection of the results presented by Graves et al. indicates that 10:1 dilution would be a good compromise between water use and screening efficiency. A later paper by Graves and Clayton (1972) gave extensive data on tests using hydrasieves with three different bar spacings, 0.01, 0.03, and 0.06 in. (0.2, 0.86, 1.52 mm). Their conclusions were:

1. Effluent with the lowest total and settleable solids was produced with the smallest bar spacing.
2. Screened solids with the lowest moisture content were produced by the larger bar spacings.
3. In terms of flowrate and blinding, the larger bar spacing achieved higher flow rates with less blinding and channeling of the screen.

In this series of tests, a 10:1 dilution of free-stall manure came through the 0.06-in. (1.52-mm) screen with 41% of the total solids removed and a dry matter of 13% in the screened solids. Graves and Clayton remarked that additional water would drain from the screened solids, but the solids had no offensive odor and did not attract flies.

Taiganides and White (1972) used a full-scale hydrasieve with 0.06-in. (1.52-mm) bar spacing (later replaced by 0.04-in., 1-mm, spacing) to screen the effluent from a swine confinement unit that was hydraulically cleaned. No screening efficiency results were given, although the authors mentioned some problems with slime growths on the screen. These growths were controlled with a chlorine solution. Such growths also have been observed by R.G. Light[3] who was working with a full-size screen installed at a large duck farm. The growths were particularly troublesome in warm weather, but could readily be controlled by regular spraying with a chlorine compound.

Separation of solids from liquids by use of a vibrating screen was described by Fairbank and Bramhall (1968). Their work was related to the wastewater from hydraulically cleaned holding pens for dairies in

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[3] R.G. Light. 1972. Personal communication. Food and Agricultural Engineering Department, University of Massachusetts, Amherst.

California. They recommended using a 20-mesh (32.8 x 10^{-3} in., 0.83 mm) screen, and they suggested that, if the influent slurry contains about 0.4% dry matter, the washed manure solids from the screen will contain about 20% dry matter and will have a bulk density of 27 lb/ft^3 (430 kg/m^3). The washed solids are inoffensive and will not attract flies. In warm climates, such as California, these solids may be heaped, and they will compost without further attention. Fairbank and Bramhall indicated that screening such dilute slurries causes a negligible reduction in liquid volume.

A very detailed study of the engineering parameters associated with vibrating screens was reported by Ngoddy et al. (1971). They performed their studies on dilutions of both beef and swine wastes. Sieve performance was approached through dimensional analysis. The difference in angular position between the top and bottom unbalanced weights was shown to have a significant effect on performance. Various screen sizes were tried, but the 74-mesh screen gave the best separation for both swine and beef manure. Virtually all the test results showed that 55%-60% of the total solids from swine manure (1.2%-5.44% TS slurry) could be removed; the removal for beef manure was somewhat less. This approach to determining the engineering parameters of vibrating screens would seem to have considerable merit, and the very brief review given here does not do justice to the material contained in the study.

Filtration: Screening and filtration may have some features in common. The filter media usually have finer mesh sizes than screens and are often made of organic fibers. The most significant difference is in the method of operation. In screening, the classification is achieved mainly by the screen-mesh size, because the layer of slurry being screened is kept minimal. In filtration, however, the particles in the slurry form the filtering medium, and the filter-cloth mesh only determines the characteristics of the initial filtrate. One factor that should now be quite clear is that slurries containing discrete, fairly rigid particles (e.g., sand) will filter much more easily than materials containing gelatinous substances that can block the passages in the filter cake. The two devices described next are intermediate between filters and screens, but their operation seemed rather more filterlike, hence their inclusion in this section.

The device shown in Figure 14 appeared in Power Farming (1972). The filter belt is a composite of nylon and rubber, both porous and strong enough to be tensioned. Powered rotary brushes and water jets keep the belt clean. The article indicated that the machine is already in use for sewage sludge and costs about $7,200.

Bartlett et al. (1973) described a porous belt machine with metal mesh belting $^{1}/_{16}$-in., 1.59-mm mesh); this passed under press rolls. The machine was tested on bovine manure. The solids discharged from this machine had a moisture content of 75% and were inoffensive. The material was crumbly and easily handled.

Dale (1973) reported on a commercial device developed by Babson Brothers Company. This machine used an inclined screen before a porous belt and a roller squeezer. The manure had to be diluted with an equal volume of water to make the equipment function well. Dale claimed that the solids discharged were 50%-55% dry matter. The liquor from the system contains 3%-4% dry matter.

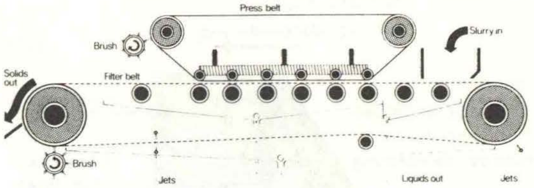

Figure 14. Side view of the Harleyford continuous press. The filter belt runs on a pair of 16-in. (41-cm) drums. Adjustments are provided for tensioning it and for varying the spring pressure on the press belt. The edges of the filter belt are reinforced, and its surface is perforated by numerous 1.2-in (30-mm) transverse slits which allow liquid to percolate through. All moving elements are powered by 0.5-hp (380-W) motors. (Reproduced by permission of Power Farming).
Source: Power Farming. 1971. Slurry squeezer. Power Farming 49(3):31.

The vacuum filter (Figure 15) has intrigued livestock waste-treatment engineers because it has performed well with municipal and industrial wastes. The waste slurry enters the chamber at the bottom of the machine, and a submerged filter cake is formed. As the drum rotates, the valving to the various segments of the drum operates so that the cake is dried by drawing air through it, and in some filters, the cake is lifted by a positive pressure to facilitate removal. The machines are costly to install and require competent management; thus few commercial livestock producers have adopted them.

The vacuum filter's operating cycle can be modelled by using samples of filter media in a Buchner funnel. The dewatering characteristics of poultry manure were examined by Cassell et al. (1966) using such apparatus. Municipal and industrial practice has shown that most sludges are more easily dewatered after pretreatment with a chemical sludge conditioner. Cassell et al. tried ferric chloride and various organic polyelectrolytes; they concluded that a combination of anionic polyelectrolyte, followed by a dose of the cationic type, gave the best results. This combination could yield filter cakes with dry-matter contents in excess of 30%, and the filtrate was described as being a clear yellow liquid. Cassell et al. recommended that vacuum filtration be used with dilute manure sludges; their data indicated that less than 10% solids would be regarded as dilute. The dose of polyelectrolyte required varied between 1.9%-3.6% of the manure total solids.

Backer et al. (1973) used a vacuum filter test kit to simulate vacuum filter operation. This consisted of a rectangular filter leaf with a sample of the filter medium

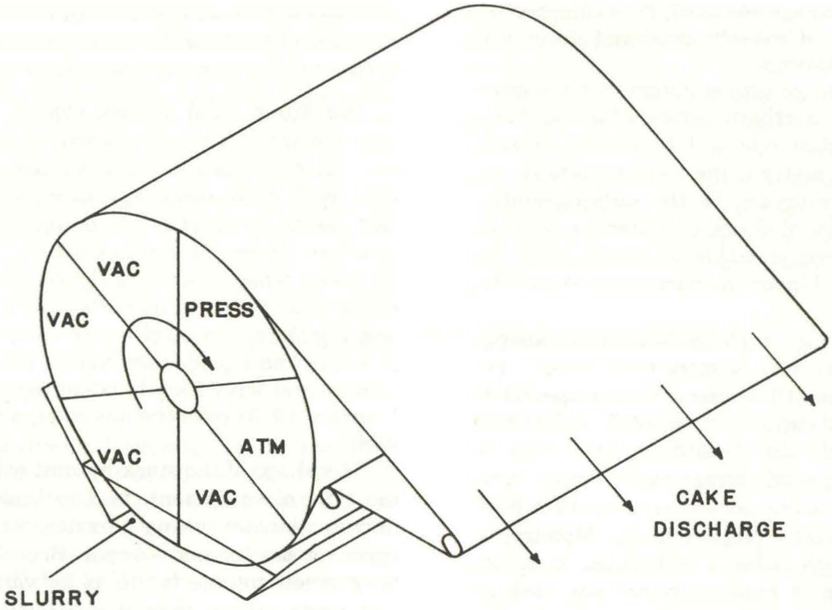

Figure 15. Schematic view of a vacuum filter.

(area 1/6 ft^2, 0.016 m^2). This leaf could be dipped in the manure slurry for known time periods and then held in the air to simulate various operational parameters of the full-scale unit. The beef manures were tested at 87% and 91% moisture content. Backer et al. presented their results in terms of drum rotational speed and percentage submergence. In general, their results show that 25% submergence and drum speeds of 1/9 rpm would yield cakes with 26%-28% solids. They concluded that the performance would only be marginally satisfactory because a moisture content of less than 60% is required for easy stripping of the filter cake. No chemical conditioners were tested.

Conclusions: Solid-liquid separation is most easily achieved by using sedimentation or screening. Poultry manure is not easily dewatered, although the vacuum filter and pretreatment with polyelectrolytes holds some promise. Bovine manure is readily dewatered by screening or by the new designs of mechanically pressed cloth filters. If the objective is to produce inoffensive, fairly dry solids, most devices work better when the manure is diluted with 5 parts of water or more. The vibrating screen and the stationary sloping screen produce similar results. Because the vibrating screen has moving parts, it may require more maintenance than the stationary type; conversely, routine removal of biological growths on the stationary screen cannot be ignored. Many areas in the North Central Region will require that a screening device be housed in a heated building. This cost must be added to the cost of the screening device. Centrifuging and vacuum filtration require apparatus of high initial cost, and their application to livestock wastes seems limited at present. If microbial protein production for refeeding gains momentum, such devices may become necessary. A large operation that intends to use solid-liquid separation should be aware that the screened solids are bulky and will require proper handling facilities. Solids-liquid separation will definitely simplify treatment and land application of liquid effluent. With the limited data available, it seems reasonable to expect that at least 40% of the influent COD will be in the solids from a mechanical screening process. Because this figure is dependent upon screen opening and on influent dilution, it will be good practice to refine the design parameters by pilot tests.

Storages

A major emphasis is being placed on manure-storage systems for a number of reasons: convenience, reduced runoff pollution, and limited availability of land. The type of storage unit selected will depend upon the type of manure handled and type of animal-housing system used. The three types of manure are liquid slurries and semisolid and solid manure. The basic differences are the moisture content and the amount of bedding added. Liquid manure has been sufficiently diluted or biologically degraded to be pumped using centrifugal pumps, while semisolid manure can be pumped with positive displacement pumps if assisted to the suction. Solid manure is of such a consistency that when placed in a stack, it will retain its shape unless subject to precipitation.

Tanks: Liquid manure storage tanks are popular for medium sized livestock operations (medium would comprise 50-250 livestock units of 1000 lb, 454 kg). Most tanks are located under the floor of the livestock building, but they can also be located partly under the floor, or completely away from the barn. Manure is scraped into the tank through openings in the floor, is worked through a slatted floor, or is conveyed to a remote tank by pumping or gravity. Design procedures have been developed for manure tanks (Midwest Plan Service, 1971; American Society of Agricultural Engineers, 1972). J.O. Curtis (1973) discusses the design criteria for such tanks. Storage volume requirements are determined by the formula

$$S = (N \times DP \times D) + \text{dilution water}$$

where S = volume of storage required, N = number of animals, DP = volume of manure produced daily per animal, and D = days of storage.

The recommended storage time will vary, but 180 days is recommended for the northern states. Midwest Plan Service (1973) indicated that 1/5 to 3/5 of the storage volume may be needed for extra water if the manure is to be irrigated. This dilution water can be the milking-center wastewater, or wash-down of floors, or waterer overflow. When full, the manure level should be at least 1 ft (0.3 m) below the top of the tank. Under-the-barn tanks should be ventilated.

In some instances, e.g., high groundwater, above-ground storage structures may be more economically attractive. Pos and Bellman (1973) described the operation for two tanks with a total capacity of 56,500 ft^3 (1600 m^3). Hamilton[4] investigated the feasibility of using a chromized steel, above-ground storage tank. Tanks have commonly been circular, using reinforced concrete or concrete-stave silos with extra reinforcement. Manure is pumped into the tank with either a centrifugal or piston manure pump. Agitation is required before the tank is emptied; this can be achieved by recycling with the unloading pump or by a built-in agitator.

Liquid manure ponds: As herds become larger, the cost of concrete or steel tanks becomes prohibitive. One alternative is the storage pond, which is an engineered, earth basin (Converse et al., 1974). It is constructed 10 to 15 ft deep (3 to 4.5 m), with 2:1 to 3:1 side slopes, and 12 to 15 in. (30 to 40 cm) free board. Fencing is required. Manure flows by gravity into the storage pond or is pumped with a centrifugal or piston manure pump. Provisions, such as a wall part way along one side, a pumping platform, or a ramp, are necessary to provide a support for the mixing pump. The mixing pump must be a high-volume low-pressure pump; approximately 2000 gpm (450 m^3/hr) is a typical capacity for a centrifugal liquid-manure pump. The volume required for the lagoon must include the manure volume plus precipitation. Additional volume requirements may include milking-center wastes. The manure, if dilute enough, can be irrigated from the storage lagoon, but irrigation requires a second pump (high pressure, low volume). If the manure is removed by tank wagon, the second pump is not required. Most of this information is derived from dairy practice; manure ponds are less common for other species.

Semisolid storage: A number of storage designs have been used to handle semisolid manure. Some units have been constructed below ground by using sloping side walls and a ramp so that accumulated manure may be removed with a front-end loader. Ramps should be no steeper than 12:1; less slope is desirable. The floor is at least partly concrete. Some are built with concrete slabs on the sloping sides. Others have been built above ground with walls on all sides; one wall is provided with an opening, and the floor is sloped away from the opening. The manure is scraped in through the opening, or the elevation is such that the manure may be dropped in from a platform. Others are using a piston pump, which pushes the manure to the storage area through a large plastic pipe. Liquid separation from the solids by gravity is difficult because of the lack of bedding, so the storage should be designed to hold the feces, urine, and any direct incident precipitation.

Stacking: Solid manure storage, referred to as stacking, is more common in stanchion dairy facilities than in any other livestock facilities because of the amount of bedding used. When stacking is to be used, both the liquid portion (urine and precipitation) and the solids manure portion have to be taken into account. Three approaches can be taken when designing the components of the system: containment of the solid portion, with the liquids (seepage) seeking their own level in the environment; containment of solids and liquids together; or separation of solids and liquids and with each handled separately. Converse and Cramer (1973) gave the advantages and disadvantages of each.

The shape of the stacking unit will be dependent upon the type of equipment used to load the structures: stationary elevator, swing elevator, thrower, overhead conveyor, or tractor and scraper. Bruns and Crowley (1973) have given volume formulas for various shapes of units. The units ranged from a simple concrete platform to a post-and-plank, bunker-type storage with an overhead conveyor.

The size of the storage unit will be dependent upon the number of days storage desired, number of animals and their size, type of manure (solid or liquid portion or both) and the type and amount of bedding used. Bruns and Crowley gave the following formula for estimating the quantity of manure produced, taking into account the bedding portion.

$$S = (N \times D)(DP + B/2BD)$$

where S = volume of storage required, N = number of animals, DP = volume of manure produced daily per animal, D = days of storage desired, B = mass of bedding used per animal per day, and BD = bedding density. Note that only half the total bedding volume is included because of compression and absorption of liquids.

For a bunker-type storage unit where 6 to 8 lb (kg) of bedding per 1000 lb (kg) liveweight is used and the stack is well drained, a daily volume of 1.6 ft^3 per 1000 lb (0.1 m^3 per 1000 kg) of liveweight is recommended (Cramer et al., 1973; Tenpas et al., 1972).

The seepage from the stack is dependent upon the surface area of the storage unit exposed, the amount of precipitation and evaporation, the amount of bedding used, the surface area of exposed manure in the structure, and the ability of the porous media under the manure to drain moisture from it (Converse and Cramer, 1973).

Because these variables are indeterminate, no formula can be used for calculating the amount of seepage from the storage unit. Seepage losses from a bunker type unit using 6 lb (kg) of bedding per 1000 lb (kg) liveweight were 2.88 gal per day per 1000 lb (0.024 m^3 per 1000 kg) liveweight for an unroofed unit. When the unit was roofed and 8.5 lb (kg) per 1000 lb (kg) liveweight of bedding was used, the seepage loss decreased to 1.32 gal per day per 1000 lb (0.011 m^3 per 1000 kg). These figures are for November through May. During the summer, the amount of seepage was slightly greater for the roofed than for the unroofed

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[4] Harvey Hamilton. 1973. Personal communication. Agricultural Engineering Department, University of Kentucky, Lexington.

because of reduced evaporation and greater precipitation during the year the unit was roofed (Tenpas et al., 1972).

Detention ponds are suitable for storage of the seepage. If constructed in permeable soil they should be lined with a 4 to 6 in. (10 to 15 cm) layer of clay. Design the pond to hold twice the average rainfall accumulation for the storage periods. Construction details for the pond are the same as those for a lagoon with no overflow. The liquid can be irrigated onto cropland and by using a 1-hp (746-W) centrifugal pump, which will handle small amounts of solids, and 1¼ to 1½ in. (3 to 4 cm) flexible plastic pipe with small bore sprinkler heads. In row crops, a perforated plastic pipe laid across the rows may replace the sprinkler heads.

Fly control is necessary if summertime stacking is practiced. Spraying the stack with chemicals is too expensive and impractical. A method of biological control that has been successful is containing chickens on the stack. The chickens will eat the fly larvae (Converse and Cramer, 1973). Gojmerac (1972) reported that fly larvae will not develop in manure that is more than 3 to 4 weeks old.

TRANSPORTING LIVESTOCK WASTES

Pump Selection

Manure characteristics: Pumping may be required for both treated and raw livestock wastes. Treated manure, such as effluent from a lagoon, often contains 1% or less solids. This liquid will be similar to water in viscosity and density. Raw manure has characteristics very different from water (Table 7). The increased viscosity is the dominant factor affecting pumping.

Table 7. Bulk density and viscosity of beef-cattle manure as a function of moisture content.

Material	Temperatures		Moisture content, wet basis	Bulk density		Viscosity	Slump	
	°F	°C	%	lb/ft^3	kg/m^3		in.	cm
Water[α] ------	32	0	--	62.4	1000	1.792	--	--
Water[α] ------	100	37	--	61.9	995	0.679	--	--
Beef animal manure[β]----	--	--	25	26.3	423	--	1.25	3.18
Beef animal manure[β]----	--	--	45	32.6	524	--	1.00	2.54
Beef animal manure[β]----	--	--	65	67.2	1080	--	3.50	8.89
Beef animal manure[β]----	77	25	85	65.7	1060	960	--	--

Sources: [α] L. S. Marks. 1951. Mechanical engineers' handbook. 5th ed. McGraw-Hill Book Company, Inc. New York.

[β] R. L. Houkom, A. F. Butchbaker, and G. H. Brusewitz. 1972. Thermal properties of beef manure. ASAE 72-316. American Society of Agricultural Engineers, St. Joseph, Michigan.

There are two aspects of viscosity needing better characterization. First, some indication of how readily the material will flow into a pump suction and, second, the head loss incurred in forcing the material through a closed pipe. Sobel (1966) tried to classify manures as semisolid, semiliquid, and liquid, but he did not give any numerical indices. Hart et al. (1966) examined various forms of pumps and concluded that positive-displacement pumps usually failed because of suction starvation if the solids content of the waste exceeded 15%; centrifugal pumps failed to draw material that exceeded 7% solids.

The ability to flow into a pump suction is related to the rheological properties of the fluid. Fluids may be characterized into three classes (Figure 16) by the shape of their shear-stress vs. strain-rate curves (McCabe and Smith, 1967). A Bingham plastic has an initial stress to be overcome before any motion can occur. Babbitt and Caldwell (1939, 1940) have indicated that municipal sludges behave as Bingham plastics. The presence of an initial shear stress would not preclude pumping, but would entail designing adequate pump inlet conditions so that gravity would overcome this initial yield stress. Kumar et al. (1970) have used a specially made coaxial cylinder viscometer on various samples of dairy manure, with and without sawdust. Their graphs indicated pseudoplastic behavior and did not show any shear stress at very low strain rates.

Liquid wastes, 4% solids or less: Dilute wastewater, 4% solids or less, is encountered in handling systems where solids are separated from liquids or in which hydraulic transport is used. Feedlot runoff and dairy barn wastewater are examples of dilute wastewater. These wastes can be handled with pumps used for slurries having higher solids contents, but with proper management, other, less specialized pumps will be satisfactory. Large quantities of these wastes are usually encountered in a system. Pipeline transport is most common because it is impractical to transport such wastes by tank wagon.

Most irrigation pumps, such as vertical turbine pumps and centrifugal pumps, will handle dilute livestock waste. These pumps are available in a wide range of capacities and can be selected to operate against high heads if needed. Pumps used for slurries also can be used for liquids. These include open impeller, induced flow cen-

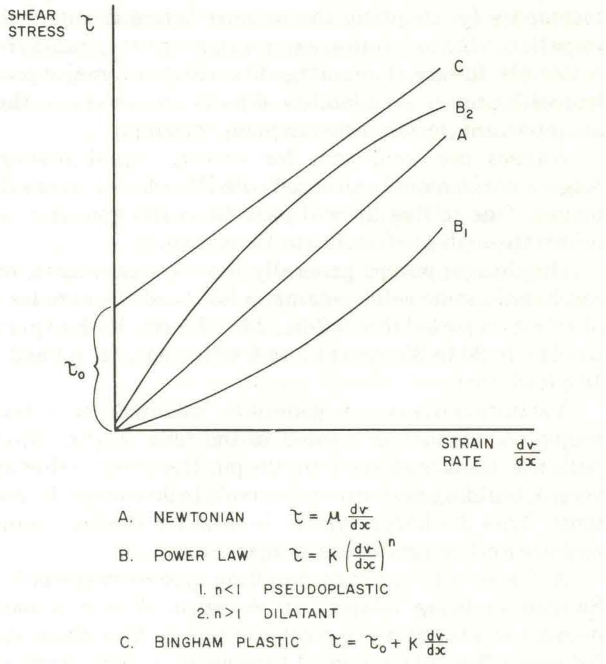

Figure 16. Shear-stress vs. shear-rate relations for three categories of fluids.

trifugal, diaphragm, helical rotor, or piston pumps. They generally are higher in cost and less efficient than centrifugal pumps. Propeller pumps can serve satisfactorily in some furrow-irrigation systems where low-head, high-volume discharges are appropriate.

Slurries, 4%-15% solids: Slurries with high solids contents are frequently pumped from storage containers to tank wagons or to other storages. They also can be moved through properly designed pipelines and sprayed on farmland. Solid-liquid separating occurs in stored slurries of livestock wastes, so slurries must be agitated before they can be pumped. The large quantities of fibrous solids can plug pumps of improper design.

Centrifugal pumps used to fill tank wagons often are used to agitate slurries in storage tanks. Capacities of up to 2500 gpm (570 m^3/hr) are used for this purpose.

Pumps used to move slurries through pipelines will have to operate against high heads if sprinklers are used. Pumps for furrow irrigation or for filling tanks operate against lower heads.

Three types of pumps adapt to pumping heavy slurries against high pressures, such as through a sprinkler system: piston, helical-rotor, and submerged-centrifugal pumps. These pumps are self-priming and, therefore, can be adapted to automation. Although they handle thick slurries, their performance will be improved if water is added.

Pumps suitable for moving heavy slurries against low lifts include submerged centrifugal, auger, and diaphragm. Submerged centrifugal pumps have the impeller below the liquid level. These are high-capacity pumps delivering up to 3000 gpm (680 m^3/hr) and are suitable for agitating storage tanks and for filling tank wagons. Agitation is accomplished through a bypass that recirculates the slurry in the tank. Some have chopper attachments for chopping the manure before it enters the impeller. Since manures contain gritty, abrasive materials, failure of submerged bearings is a major problem with pumps. Availability of parts and service is thus an important consideration in pump selection.

Augers are inefficient for moving liquid manure. Augers are commonly powered with PTO driven hydraulic motors. One to five hp will pass 40 to 180 gpm (9 to 41 m^3/hr) through 4 to 6 in. (10 to 15 cm) augers.

Diaphragm pumps generally have low capacities, but can handle some solids against a low head. Taiganides et al. (1964) reported that a 3-in., 2-hp (7.5-cm, 1.5-kw) pump would lift 20 to 35 gpm (4.5 to 8 m^3hr) against a head of 10.5 ft (3.2 m).

Vacuum pumps are generally mounted on a tank wagon. A vacuum is created in the tank wagon, which pulls the manure slurry from the pit. The pump is then reversed, building pressure in the tank, to discharge the contents. This discharge system is used for field-spreading manure and for agitating storage tanks.

A "mole hill" manure handling system developed in Sweden is being adapted in America. Within a barn, manure is scraped into a receiving hopper; from there, it is fed into a 9-in. (23-cm) steel tube where a piston forces it horizontally through an 8-in. (20-cm) tube to an outside manure pile or lagoon. If it is moved to a manure pile, the conveying pipe is turned upward at the pile, and the manure is forced up to form a "mole hill." Proponents claim that, because the pile is built up from below by newly extruded manure, odor and freezing problems are reduced.

Agitation: Slurries having high solids content must be agitated to put solids in suspension before pumping. Hog manure generally can be agitated with ease, but cattle manure requires larger energy inputs. Some cattle-manure solids settle where they are deposited, such as along feed bunks, while others may float. Floating manure dries and becomes caked. Cattle manure in these forms is difficult to suspend. Sewell (1971) has applied model study to the problem of locating settled solids deposition in tanks used to store dairy manure. The Prandtl mixing length theory was used to determine which variables should be incorporated in the dimensional analysis. Peat moss was used to simulate dairy cow manure. Sewell indicated this distorted model was corrected by using suitable prediction factors. Sewell concluded that the configuration of internal baffles was most important. A 2:1 length-to-width ratio rectangular tank without baffles showed appreciable settled solids after agitation; the installation of side and center baffles eliminated any residual solids.

Agitation devices in use include paddle wheels with vertical shafts, inclined augers, blow-back from vacuum-filled tanks, and submerged centrifugal pump recirculation. All these devices will stir hog wastes, but pump recirculation is the only one that is dependable for cattle manure. Paddle wheels, augers, and blow-back from tankers may be used on small tanks. The auger probably is least effective. If pump recirculation is used, the maximum tank dimension should be 40 ft (12 m). Diaphragm pumps do not have enough capacity to be used for agitation.

Manure in round or square tanks is easier to agitate than that in rectangular tanks. In round tanks, flow should be directed across the tank either from the edge or center. In rectangular tanks, flow should be directed across the tanks rather than along its length.

Gases escaping from agitated manure are potentially harmful to animals and humans. Operate all ventilation fans and provide for maximum air movement when agitating and unloading manure storage tanks under slatted floors.

Pipeline Transport

Long-distance pumping of semisolid manures (4%-15%) is relatively uncommon, the major exception being the land application of liquid dairy manure through a manure gun. Because raw manure usually has been handled by spreaders or tank wagons, the amount of design data relating to pumping livestock-waste slurries through pipes is limited.

If the fluid is Newtonian, the head loss in a circular pipe flowing full will be given by

$$h = (4\,flv^2)/2gd$$

where h is head loss, f is a friction factor, 1 is the length of pipe, v is the mean velocity of flow, g is acceleration of gravity, and d is the pipe diameter. The value of f can be determined from a table of f vs. Reynold's number. Unfortunately this simple approach is valid only if the fluid is Newtonian and the viscosity known. Hart et al. (1966) showed that dairy, swine, and poultry manures could be considered equivalent to water if the solids contents were less than 2.5%, 2.97%, and 5%, respectively. They presented head-loss data for the same manures at 8.54%, 13.45%, and 16.4% solids content. In all instances, head losses for the high-solids wastes were higher than those for water.

Staley et al. (1971) measured head losses when pumping 2%-9% solids dairy manure slurries through 2- and 3-in. (5- and 7.5-cm) aluminum irrigation pipe. Like Hart et al. (1966), they showed that a small quantity of solids (usually less than 2%) can actually reduce the head loss to less than that measured for water at the same flow rate. No reasons were given for this phenomenon, also no attempt was made to derive general equations. Rolfes and Gilbertson[5] have attempted to rationalize laboratory measurements of rheological parameters with pumping trials through 2-, 3-, and 4-in. (5-, 7.5-, and 10-cm) PVC pipe. Beef manure ranging from 2%-13% solids was used. The results were inadequate for a fully satisfactory mathematical model.

Land Application

Irrigation: Fluid wastes containing less than 5% solids can be handled by most irrigation systems. These fluid wastes are typical of feedlot runoff or effluents from a lagoon system or milkhouse. The type of irrigation system selected depends upon topography, soil type, and cropping practice. A properly designed system should enable management of the system without runoff or erosion. Irrigation of animal wastes also will be controlled by nutrient loadings.

In most instances, dilute wastes are most economically applied to cropland by pipeline irrigation. For example 1 ac-in. (1 ha-cm) of runoff is 27,200 gal (103 m^3), which would represent 18 trips with a 1500-gal (5.7-m^3) tank wagon. If an irrigation pump of 40-gpm (9-m^3hr) capacity were used, the runoff could be applied, unattended, in 11.5 hr. Some of the pumping cost can be recovered from the fertilizer value of the nutrients in the wastewater.

Some disadvantages of wastewater irrigation are: a high initial investment is necessary, there will be operating costs for pumping, good management is necessary to avoid runoff or groundwater pollution, low-cost irrigation equipment may have a high labor demand, odor problems may be more widespread, untimely application may reduce crop yields, sprinkler irrigation may lose ammonia by volatilization, tight soils may only accept small quantities of liquid before runoff occurs, and tile drainage may be necessary in humid areas. In spite of all these potential disadvantages, irrigation is the most realistic means of dewatering detention ponds used for runoff from open beef feedlots of appreciable size.

Design of an irrigation system for liquid wastes involves the selection of the distribution system (gated pipe, sprinklers, or others), the sizing of pipes and laterals, and pump selection. The spreading system selected will influence the pump capacity and will contribute to the pressure that the pump must work against, as will friction loss in the pipes. Total head in the system and pump capacity must be calculated to complete the design of the system.

Liquid waste, 4% solids or less; surface spreading: Liquid wastes from pipeline systems can be spread by gravity by use of open ditches, flat irrigation tubing, or gated pipe. Sprinkler systems available include hand move, towline side-roll boom, center pivot self propelled, traveling gun, and solid set.

Four types of surface irrigation are suited to disposal of liquid wastes; border irrigation, furrow irrigation, corrugations, and wild flooding. Waste water can be supplied to the disposal field by gated pipe, lay-flat irrigation tubing, open ditches with siphon tubes, or open ditches with turnout gates. Gated pipe or open ditches with turnout gates are recommended because they are easily cleaned. Because no runoff is desired when disposing of lagoon effluent, additional labor is required for surface irrigation, such as changing gates and checking distance of flow. A more expensive sprinkler system may be chosen to reduce labor.

Gated pipe is 4 to 12 in. (10 to 30 cm) diameter aluminum or plastic pipe, with openings or gates every 30 to 80 in. (76 to 200 cm). This pipe is portable, giving flexibility to the system. The cost of gated pipe is greater than spile or siphon tubes, but less than sprinkler systems. Also, less labor is required, and the desired flow can be more easily managed. Spile tubes are ¾ to 3 in. (2 to 7.5 cm) diameter tubes with stoppers installed in the bank of an open ditch. Canvas, concrete, or metal check dams are used to control the flow. Open ditches with spile tubes require a low investment, but labor and maintenance may be quite high.

Wastewater should not be applied to a wet disposal area. The border, furrow, or corrugation systems should be shut off before wastewater reaches the low end of the field to eliminate runoff. This should be done when the water is ⅔ to ¾ of the way to the end. Catching the runoff from the field in a basin and returning it to the irrigation system is an alternative.

Irrigation with furrows provides relatively uniform distribution of wastewater for row crops. Furrow irrigation generally is not recommended on fields steeper than 1%. Steeper slopes, however, may be irrigated for short distances. Slopes up to 10% can be irrigated with contour furrows where furrow grade is kept less than 1%. Often some land grading is required for good water distribution. A row crop may be planted on ridges. The furrows may be constructed with disk or middlebuster furrow openers. Furrow flow rates should not exceed the furrow carrying capacity nor cause erosion. Use Table 8 as a guide. Furrow irrigation runs should generally not exceed ¼ mile (0.4 km).

Corrugations provide a means of irrigating relatively steep, irregular land by surface irrigation. Best adapted to close-growing crops, the corrugations (V notches) are constructed by pulling a tool bar implement over the ground after the seedbed is worked, but before planting. This practice is especially useful for permanent grass. These V notches usually are spaced closer than furrows and are

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[5] M. Rolfes and C. Gilbertson. 1974. Private communication. USDA-ARS, Agricultural Engineering Department, Universty of Nebraska, Lincoln.

Table 8. Maximum recommended flow rates per gate through gated pipe with 30-40 in. (75-100 cm) spacing.

Flow rate		Land slope
gpm	m^3/sec	%
1	6.3×10^{-5}	5
5	3.2×10^{-4}	2
10	6.3×10^{-4}	1
12	7.6×10^{-4}	0.8
16	1.0×10^{-3}	0.6
25	1.6×10^{-3}	0.4
40	2.5×10^{-3}	0.2

shallower. Guidelines for furrow flow rates generally may be used for corrugations.

Low, parallel soil berms constructed in the direction of the maximum slope of the field are used for border irrigation. The berms or borders are spaced from 30 to 100 ft (9 to 30 m) apart. Pasture and other close-growing crops can be irrigated with a border system. The length of run for border irrigation generally should not exceed ¼ mile (0.4 km) and should be proportionately less for slopes exceeding 1%. Maximum slope should not exceed 4%. Uniform water distribution depends on a sheet of water passing down through the border at a depth of 3 to 5 in. (7.5 to 12.5 cm). Consequently, the fall between berms should not exceed 2 ft (0.6 m). Because of this limitation, border irrigation requires an even, gently sloping field, either naturally or through land grading. Berms may be spaced close together with a border maker, a road maintainer, or a rear blade on a tractor.

Wild flooding generally refers to applying wastewater to land with no control structures other than the distribution pipe or ditch. This method has a low initial cost, adapts to a wide range of irrigation flows, and can be used on close-growing crops, rolling land, and shallow soils. Wild flooding, however, often subdivides the field and has a high labor requirement and uneven water distribution.

Liquid wastes, 4% solids or less; sprinkler application: Rolling and irregular land that would require extensive reshaping for surface irrigation can often be irrigated with sprinkler systems. Although initial and operating costs are generally higher for sprinklers, labor requirements are sometimes reduced, and some systems may be automated. Uniformity of application also is improved. For all sprinkler systems, select sprinklers and spacings that will not cause runoff on the particular soil type in relation to topography, crop, and time of application. Flushing the system with clean water after use is desirable to prolong equipment life and to avoid leaving a coating of solids on the crop.

Hand-carry sprinkler systems, unpopular for crop irrigation because of high labor requirements, have special merit for waste disposal on soil-plant filters because small acreages are involved. Adaptability to diverse topography, relative low initial cost, and availability of used systems are advantages. Large manure guns can be handled in this way.

The towline system can be towed from one set to another by tractor. These systems generally have lower initial and operating costs than traveling sprinkler systems. For corn, travel lanes and turn space are required, amounting to about 10% of the land area. Underground mainline pipe may be used, or the mainline may be laid in a shallow ditch, which enables the operator to cross the mainline pipe. The lateral is disconnected from the mainline for each move. A short flexible hose connects the lateral to the mainline. Towline systems are often designed for laterals spaced 60 ft (18 m) apart, with sprinklers spaced 40 ft (12 m) apart on the lateral. An 80 x 60 ft (24 x 18 m) spacing also is used. The towline has special merit over hand-carry systems for waste disposal because of the relative ease of moving the lateral line with a tractor at little increase in cost.

Side-roll lateral sprinkler systems can be used only with low-growing crops on rectangular fields because the aluminum pipe is the axle for movement of the lateral sideways through the field. Crop clearance is slightly less than ½ the diameter of the wheels used at each lateral joint. A separate air-cooled engine is used to roll the lateral from one setting to the next.

The traveling sprinkler consists of a single large sprinkler mounted on a four-wheel carriage. Power for travel is provided by a small auxiliary engine, a water turbine, or a water cylinder. The auxiliary-engine units generally travel at more uniform speed but have a higher initial cost. These traveling units range in capacity from 50 to 1500 gpm (11 to 340 m^3/hr). A cable, mounted on a winch on the machine, is extended 660 to 1320 ft (200 to 400 m) across the field and anchored at the far end. As the power source drives the cable winch, the unit is pulled across the field, irrigating as it travels. A flexible hose connects the traveling sprinkler to a rigid pipe at the midpoint of its travel path. As the self-propelled unit passes adjacent to the water-supply outlet (usually portable aluminum pipe), the hose forms an elongated "U" behind the unit. As the self-propelled unit proceeds along its travel path, the hose is extended full length in the opposite direction from its original layout. This allows for continuous movement of twice the length of the hose, or 1,320 ft (400 m) for a 660 ft (200 m) hose. These hoses can be purchased in different lengths. A popular size for waste disposal uses only 330 ft (100 m) of flexible hose, and makes a 660 ft (200 m) pass. Four-inch (10-cm) hose generally is used. In some positions, much of the hose is moved. This hose filled with water is a heavy load. Speed of water turbines varies as load varies. Speed of movement can be varied from 0.5 to 8 ft/min (0.15 to 2.4 m/min) supplying from 0.3 to 3.5 in. (0.8 to 9 cm) per application. Travel distances of not more than 1320 ft (400 m) should be selected. The traveling guns are adapted to irregularly shaped fields and rough terrain. They cross a terrace best when moving directly perpendicular to it. When row crops are to be irrigated, most units will require that two or three rows be left out of production (or mowed if rows are not straight) to provide lanes for the traveling unit.

Solid-set sprinkler systems are the most labor-saving and flexible of all systems. They consist of lateral lines and sprinklers covering the entire disposal area. If automation is desired, remote control valves can be programmed from an automatic timer to operate separate laterals or blocks in sequence (Koelliker et al., 1972).

Sprinkler head selection is of major concern for waste-application systems. The uniformity of application may be more important for a waste-disposal system than for clean-water irrigation. If the nutrients in the effluent are limiting the quantity applied, or if a large amount of water is being applied to the area, uniformity may become critical. Under these two conditions, excessive water or nutrients may be applied to areas near the sprinkler, where the application rates are normally higher. The application rate of a system should be less than the intake rate of the soil. This is controlled by the selection of nozzle size, pressure, and spacing. Small nozzles have lower pressure requirements, cover small areas, and have lower application rates. In contrast, large nozzles require high pressure, cover large areas, generally have poorer distribution patterns, and are more affected by wind. For waste disposal, single-nozzle sprinklers probably will be more successful than a sprinkler with two nozzles. The size of particles in the water may limit the minimum nozzle size. Nozzles less than 3/16 in. (4.8 mm) are not generally practical. When larger particles or organic matter are present, nozzles of ¾ in. (19 mm) may be required.

Semisolid wastes, 4%-15% solids; manure guns. Large-bore irrigation nozzles adapt to handling relatively heavy slurries (up to 15% solids) as well as liquid wastes with low solids content. These large sprinklers generally have a capacity of 100 to 400 gpm (23 to 91 m^3/hr) and can cover from 0.5 to 2 ac (0.2 to 0.8 ha) at a setting. The large nozzle can usually pass ¾-in. (19-mm) diameter solids. Some models have rubber nozzles. Pipeline design procedures are similar to those used to design for wastewater having low solids contents except that components selected should handle the large amount of solids. Head losses will be higher (see earlier section on pipeline transport).

Big guns can be adapted to hand-carry, permanent-set, or traveling sprinkler systems. PVC plastic pipe is suitable for pipeline installation. It has been reported that liquid will drain from portable aluminum irrigation pipe if the pump shuts down, leaving a deposit of solids in the pipe. Removing these solids may be a problem. Sufficient water is the key to successful operation of a manure gun sprinkler system. This will probably mean adding some additional water to the pit. Some difficulty has been reported in applying manure to growing crops; the solids coat the leaves, thus reducing photosynthesis. If possible, operate the manure gun sprinkler system on clean water for 10 to 15 min after each set, before moving the sprinkler. This cleans out the pipe, cleans off the pipe near the sprinkler, and washes the solids off the foliage. Another problem encountered without this rinse period is that a large pool of liquid manure comes out and kills the crop when the sprinkler is detached from the pipe. Daily pumping may make it impractical to move the pump to a clean water supply each time. An alternative is to use a smaller centrifugal pump (e.g., 5 hp, 3.7 kW) to pump from a clean water source into the line. At the least, this eliminates the large pool at the end of the line. Another alternative is to run water from the farm water system into the liquid manure tank.

Semisolid wastes, 4%-15% solids; tank wagons: Tank wagons are available for transporting fluid wastes in capacities ranging from about 415 to 3000 gal (1.6 to 11.3 m^3). They are available as pull-type wagons with two or four wheels, or they may be truck-mounted. When four wheels are used, they are mounted in tandem. Tankers are most commonly loaded with high-capacity pumps. Slurries must be agitated in the storages before they can be satisfactorily pumped into tankers. Some sites permit gravity loading of tankers, sometimes several hundred feet from the storage pit and closer to the fields. With this system, it may be possible to load tankers at sites away from the congestion found near barns. Drawing slurries into tank wagons by creating a vacuum in the tank is a third method of filling.

Vacuum-loaded tankers may prove less expensive than equipment needing centrifugal or helical rotor pumps. Vacuum loading also avoids problems of pump-bearing failure and corrosion because of submergence in manure. The large size of suction hose used permits large solids to pass. Rapid unloading and, theoretically, a more uniform application of manure to cropland is possible when tankers are pressurized. The air pump also is used to agitate the contents of some tankers during transport. The air pump plus an appropriate diffuser also can be used to agitate storage pits, although a separate agitator is recommended. The blowback from a tanker is applicable to agitation of small storages containing swine or poultry manure.

Unloading of tank wagons may be accomplished by pumping, by pressurizing the tank, or by gravity. Agitation of the tanker contents during transport to the field will provide a more uniform application of manure solids on the field. In some tankers, the slurry is spread evenly on both sides of the wagon; in others, it is spread on one side. Subsurface injection of odorous manure slurries may be necessary in some situations to prevent offense to neighbors. Tank wagons are available with two chisel-type injector shanks or with moldboard plow attachments. Management and planning are critical if liquid systems are to be operated effectively and conditions avoided that would lead to water and air pollution. The length of the storage period should be selected so that land is available in a condition to receive waste without polluting waters. Odors associated with liquid manure and spreading are highly offensive and may be the cause of nuisance complaints.

Solid manure; spreaders: Manure having a moisture content of 80% or less can be handled as a solid. Characteristics of solid manure vary with the animal, the amount and type of bedding incorporated with the manure, and the amount of liquid waste that is removed by a separation process.

Most spreaders used for transporting solid manure are box type, but one or two manufacturers supply open-tank spreaders. Besides serving as the transport vehicle for the manure, the spreader should provide for a uniform distribution of the manure on the cropland. Many mechanisms are available on spreaders to distribute manure, but the effectiveness of all is dependent on the characteristics of the manure being spread. Under some conditions, the quality of the spreading is satisfactory. In poor operating conditions, the manure will drop in a windrow behind the spreader.

Open tank spreaders generally are built with a shaft mounted near the open top and parallel to the main axis of the tank. Chains on this shaft act as flails when the shaft turns, and the manure is thrown out of the side of the spreader. Box spreaders may be obtained as pull-type machines, or they may be mounted on trucks. Pull-type spreaders range in capacities from 70 to 524 bu (2.5 to 18.5 m^3). The spreading mechanism on spreaders having capacities under 100 bu (3.5 m^3) are available with either ground-driven mechanisms or PTO drives. PTO drives are used on spreaders having capacities over 100 bu (3.9 m^3). Two or four wheels are used, depending on the capacity of the spreader and size of tires used. Truck-mounted, box-type spreaders range in capacity from about 175 to 524 bu (6.2 to 18.5 m^3). Both steel and wood are used to fabricate the spreader boxes, and both are available in water-tight models. Paddles, flails, and augers are among the devices used for the spreader mechanism. It is a common practice to provide for variable speed on the apron. Some spreaders have moving front-end gates.

MANURE MANAGEMENT, UNROOFED FACILITIES

Waste Categories

Waste management for confined livestock-feeding facilities that are not under roof has two principal aspects. Manure accumulation must be controlled to maintain a surface suitable for efficient animal performance, and precipitation that drains from the pens must be controlled so that it does not result in runoff that contributes to water pollution. Thus, two systems, a solid- and a liquid-handling system, must be provided. The overall process may be viewed as shown schematically in Figure 17.

Solid Manure

Effects of location on accumulation: Solid waste accumulation on an outdoor feedlot surface is affected by many factors: animal density, feedlot slope, ration, feedlot surface, cleaning period, and climatic conditions. Results of research to determine manure accumulations on beef cattle feedlots in eastern Nebraska are presented in Table 9. The experimental feedlots had pens 20 ft (6.1 m) wide and 100 ft (30.5 m) long stocked to provide 100 ft^2 (9.3 m^2) per animal and 200 ft^2 (18.6 m^2) per animal. The lots were cleaned twice yearly. The total dry matter (zero moisture) removed from the feedlot surfaces averaged 0.9 and 2.34 ton/ac (2 and 5.25 tonne/ha) of feedlot daily for space allocations of 200 and 100 ft^2/head (9.3 m^2 and 18.6 m^2 per head), respectively. Feedlot slopes of 3%, 6%, and 9% did not have a significant effect on the dry matter removed from the feedlot. Generally, dry matter removed from the high-density lot was significantly greater than from the low-density lot on an area basis (Gilbertson et al., 1971a).

Weather significantly affected the amount of material removed. The June 1969 cleaning period followed muddy conditions during the winter and spring months. Under the wet conditions, soil became mixed with the manure as a result of cattle movements, with the greatest amount of mixing occurring on the 9% slope. Additional fill material was needed for leveling depressions near the feedbunks and waterers after each cleaning period. The moisture content of the material varied with the cleaning period; slope and animal density, however, seemed to have very little effect on the moisture content of the material removed. Material removed from the outdoor feedlot in eastern Nebraska was highly variable in quantity and quality. Uncontrolled weather conditions seemed to influence the variability.

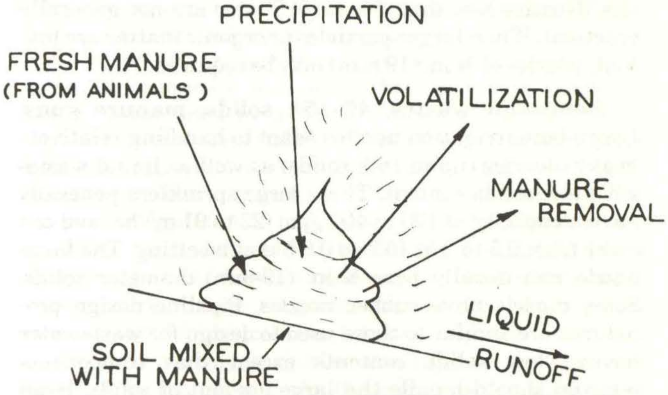

Figure 17.–Schematic representation of a manure-transport, material balance for an unroofed feeding area.

Table 9. Average dry matter estimated in beef cattle excreta and in wastes removed from sloped, outdoor, paved feedlots at two stocking rates in eastern Nebraska per animal-day.

Cleaning date	Animal space ft^2	Animal space m^2	Excreta lb	Excreta kg	Manure removed lb	Manure removed kg	Manure removed %(VS)
Nov. 1968 ---------	100	9.3	4.5	2.0	11.5	5.2	30
---------	200	18.6	5.0	2.3	6.0	2.7	50
June 1969 ---------	100	9.3	4.5	2.0	15	6.8	25
---------	200	18.6	5.0	2.3	22	10	23
Nov. 1969 ---------	100	9.3	4.0	1.8	10	4.5	40
---------	200	18.6	4.5	2.0	9.5	4.3	43
June 1970 ---------	100	9.3	5.0	2.3	9	4.1	50
---------	200	18.6	5.5	2.5	8.5	3.8	35
Nov. 1970 ---------	100	9.3	4.5	2.0	12	5.4	33
---------	200	18.6	5.5	2.5	8.5	3.8	50
Av. ---------------	100	9.3	4.5	2.0	11	5.0	36
---------------	200	18.6	4.5	2.0	8.0	3.6	37

Source: C. B. Gilbertson, T. M. McCalla, J. R. Ellis, and W. R. Woods. 1971. Characteristics of manure accumulations removed from outdoor, unpaved, beef feedlots. pp. 132-134. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

Solid-waste accumulation on a feedlot surface was affected by ration composition (Table 10) in studies near Lubbock, Texas (Wells et al., 1972). An all-concentrate finishing ration (90.8% sorghum grain, 6% cottonseed meal, the rest supplement) resulted in 2.3 lb (1.0 kg) of dry-waste accumulation per head daily. A 12% roughage, finishing ration (consisting of 75% sorghum, 7% cottonseed meal, 6% cottonseed hulls, 6% alfalfa hay, the rest supplement) resulted in 5 lb (2.3 kg) per animal-day. A 10% roughage ration resulted in 4.5 lb (2.0 kg) of dry waste per animal-day. Both covering the feedlot and continuously wetting the open pen surface reduced the dry-waste ac-

Table 10. Solid waste accumulation during feeding periods in west Texas.

	Experiment 1		Experiment 2. 10% roughage		
Item	All concentrate	12% roughage	Covered	Open	Continuously wet
No. of animals ------	23	24	26	27	13
Feed dry matter,					
lb -----------------	60,768	77,110	60,430	64,229	30,723
kg -----------------	27,564	34,977	27,411	29,134	13,936
Waste accumulation:					
Total, lb -----------	19,110	44,930	29,850	33,610	19,950
kg -----------	8,670	20,380	13,540	15,250	9,050
Dry matter, % -------	47.0	46.9	48.2	49.0	44.0
Dry matter, lb ------	8,982	21,072	14,388	16,469	8,778
kg ------	4,074	9,558	6,526	7,470	3,981
Feed waste ratio, DM basis ------------	6.8:1	3.7:1	4.2:1	3.9:1	3.5:1
Animal days ---------	3,950	4,237	3,600	3,672	1,815
Animal space, ft^2 ----	95	88	42	41	84
m^2 ----	8.3	8.2	3.9	3.8	7.8
Live weight, lb -----	745	775	678	679	649
kg -----	338	351	308	308	294
Daily dry matter waste accumulation:					
lb/animal -----------	2.3	5.0	4.0	4.5	4.8
kg/animal -----------	1.0	2.3	1.8	2.0	2.2
lb/1000lb livewt. ---	3.1	6.5	5.9	6.6	7.4
lb/ft^2 --------------	0.024	0.057	0.010	0.10	0.057
kg/m^2 --------------	0.12	0.28	0.49	0.49	0.28

Source: D. F. Wells, G. F. Meenaghan, R. C. Albin, E. A. Coleman, and W. Grub. 1972. Characteristics of waste from Southwest beef cattle feedlots. pp. 385-404. In: Waste management research (Proceedings, Cornell Agricultural Waste Management Conference).

Table 11. Manure removed from south-central Kansas unsurfaced cattle feedlot pens.

	Feeding period	Animal space		Dry solids removed, daily basis	
Cleaning date	days	ft^2	m^2	lb/animal	kg/animal
Aug. 1969 -----------	290[a]	265	25	10.3	4.7
Jan. 1969 -----------	287[a]	245	23	13.2	6.0
Nov. 1969 -----------	153	216	20	7.9	3.6
Jan. 1970 -----------	155	262	25	13.6	6.2
Feb. 1970 -----------	141	250	23	14.3	6.5
Feb. 1970 -----------	163	256	24	11.9	5.4
Mar. 1970 -----------	129	290	26	9.7	4.4
June 1970 -----------	138	292	26	10.7	4.9
July 1970 -----------	149	272	25	3.8	1.7
July 1970 -----------	139	308	29	5.2	2.4
Sep. 1970 -----------	146	224	21	2.6	1.2
Nov. 1970 -----------	146	245	23	8.8	4.0
Dec. 1970 -----------	144	250	23	13.2	6.0
Dec. 1970 -----------	147	295	26	14.9	6.8
May 1971 -----------	159	283	26	17.5	7.9
May 1971 -----------	160	256	24	17.1	7.8

[a] Represents two feeding periods without intermediate cleaning.

Source: H. L. Manges. Unpublished data. Agricultural Engineering Department, Kansas State University, Manhattan.

cumulation. The effects of slope, dirt vs. concrete pen surfaces, open vs. covered pens, and continuously clean vs. continuously wet concrete surfaces indicated no significant differences in animal performance. Results of research conducted at Pratt, Kans.[6] (Table 11), during the same years that research was conducted in eastern Nebraska indicated that the dry manure (zero moisture) ranged from 3.8 lb (1.7 kg) per animal-day for a July cleaning to a high of 14.9 lb (6.75 kg) per animal-day for a December cleaning (Manges et al., 1971). Thus, considerable variation exists in the amount of dry manure removed. A difference exists between the amounts removed during the spring months from a winter-spring feeding period and the amounts of manure removed in the fall, from a summer-fall feeding period. Evidently, more soil is mixed with the manure during the winter-spring months when feedlot surfaces are likely to be wet and sloppy. The soil mixes with the manure because of cattle movement on the lot. Moisture content is variable; therefore, the actual weight of material removed will vary, depending upon moisture conditions. During dry weather, the moisture content may be as low as 30%, whereas during winter or other wet periods, it may be 50% or more.

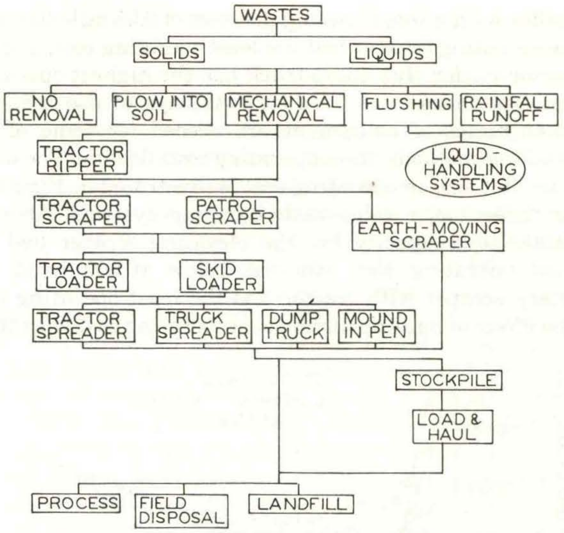

Figure 18. Alternatives for handling solid wastes from open feedlots.

Source: A.F. Butchbaker, J.E. Garton, G.W.A. Mahoney, and M.D. Paine. 1972. Evaluation of beef waste management alternatives. pp. 365-384. In: Waste management research (Proceedings, Cornell Agricultural Waste Management Conference).

Handling: possible alternatives for handling of solid wastes from open feedlots are illustrated in Figure 18.

Scraping: In removing solid waste from a feedlot surface, the first step is scraping material from the surface. Some of the commonly used methods of scraping the feedlot surface are: tractor with front-end loader, commercial loader with bucket, tractor with ripper and mounted blade, patrol scraper, rotary scraper, or large earth-moving scrapers. When any of the first four pieces of equipment is used, the scraped material is windrowed or stockpiled in the center of the pen for subsequent pickup with a commercial loader or front-end loader with tractor. Stockpiling in the center of the pen provides a temporary storage area and, in many instances, a mound on which cattle will be able to rest and keep dry.

Loading and transporting: The next step is loading and transporting the material to a stockpile for field-spreading or for further processing. Common methods are to use a tractor and front-end loader or commercial loader to load the material onto a dump truck, a truck spreader, or a tractor and spreader. Most of the larger feedlots use dump-truck spreaders. Some large feedlots use large earth-moving equipment for pen cleaning. These pieces of equipment are capable of performing several operations, such as scraping, loading, and hauling. Because of the high investment cost, many feedlots contract with roadbuilding contractors or manure-hauling firms for pen cleaning and manure hauling and disposal.

The operating cost of six different methods of handling solid waste from open feedlots was a function of days of use per year and is illustrated in Figure 19. For a 20,000-head

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[6] H.L. Manges. Unpublished data. Agricultural Engineering Department, Kansas State University, Manhattan.

feedlot with a short hauling distance of 0.25 mile (0.4 km), the elevating scraper had the least operating cost, and the tractor loader plus dump truck had the highest operating cost (Butchbaker et al., 1972). As days of use increase, fewer pieces of equipment are needed for some of the handling methods; thus, operating costs decline. The effect of feedlot size on operating cost is illustrated in Figure 20 for three major solid-waste-handling systems. Above a 10,000-head-capacity lot, the elevating scraper had the least operating cost, whereas below 10,000 head, the rotary scraper with tractor had the least operating cost. The effect of hauling distance on operating cost with three common solid-waste-handling systems is shown in Figure 21. Again, the elevating scraper had the lowest cost for 100 days of use per year. As distance increases over 2 mi (3.2 km), however, the commercial loader plus spreader truck may become the least-cost method of hauling the waste for land application.

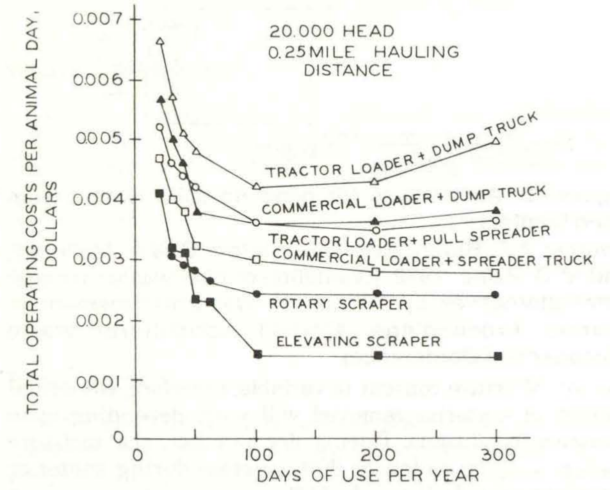

Figure 19. Solid waste handling from open feedlots: total operating cost vs. days of use per year.

Source: A.F. Butchbaker, J.E. Garton, G.W.A. Mahoney, and M.D. Paine. 1972. Evaluation of beef waste management alternatives. pp. 365-384. In: Waste management research (Proceedings, Cornell Agricultural Waste Management Conference).

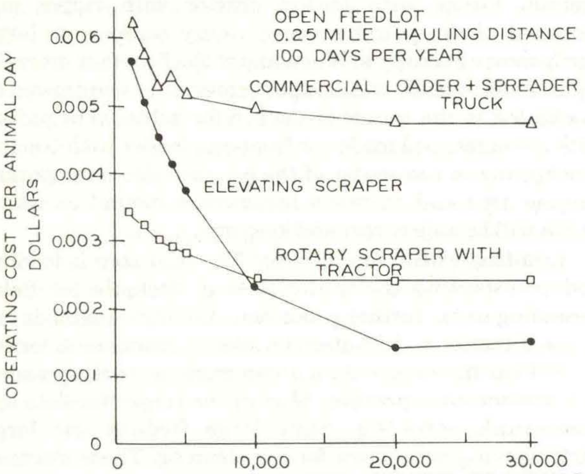

Figure 20. Solid waste handling from open feedlots: operating cost vs. feedlot capacity.

Source: A.F. Butchbaker, J.E. Garton, G.W.A. Mahoney, and M.D. Paine. 1972. Evaluation of beef waste management alternatives. pp. 365-384. In: Waste management research (Proceedings, Cornell Agricultural Waste Management Conference).

Runoff

Fifty-six percent of the cattle on feed and 50% of cattle slaughtered in the United States are in the nine north-central states of Ohio, Indiana, Illinois, Iowa, Missouri, Nebraska, Kansas, South Dakota, and Minnesota. These Corn Belt states provide 82% of the United States and 39% of the world production of corn (Statistical Reporting Service, 1971). Iowa and Nebraska account for half of the beef fed in the Corn Belt.

The 1970 corn acreage of 48.7 million ac (19.7 million ha) in the Corn Belt dwarfs the 50,000 ac (20,000 ha) required for feedlots for the 7.5 million animals on feed in the region. There are nearly 1,000 ac (ha) of corn for each acre (ha) of feedlot. Cattle feedlots are an environmental concern, but are not important to the total hydrology of a region. The hydrology of open feedlots and their environmental impact is on the immediate watershed.

Hydrology and the effect of climate: Dague (1968) has stated that hydrology is important from standpoints of selecting the feedlot site, determining the necessity for installing pollution controls, and designing the controls. The rate of delivery of runoff from a feedlot is a function of the topographic, meteorologic, and hydraulic characteristics of the feedlot area. Rainfall, snow, temperature, and evaporation are factors affecting the microbiological, chemical, and physical factors active on the feedlot surface. All these have interrelated roles on feedlot runoff, its quantity, and composition.

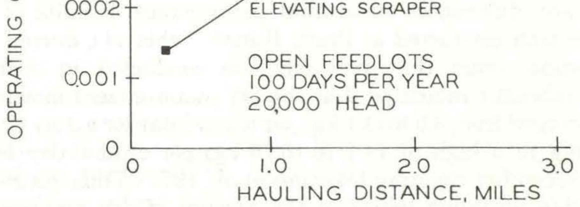

Figure 21. Solid waste handling from open feedlots: operating cost vs. hauling distance.

Source: A.F. Butchbaker, J.E. Garton, G.W.A. Mahoney, and M.D. Paine. 1972. Evaluation of beef waste management alternatives. pp. 364-384. In: Waste management research (Proceedings, Cornell Agricultural Waste Management Conference).

Annual precipitation in the north-central states ranges from 15 to 40 in. (38-100 cm), with a major part occurring during the growing season. Annual rainfall increases from west to east, and snowfall from south to north, across the north-central states. High-intensity summer thunderstorms generally are more severe in the west than in the east. Average annual snowfall ranges from 20 to 30 in. (50 to 75 cm). The average winter precipitation, December through February, ranges from 2 to 8 in. (5 to 20 cm) over most of the area. The average warm-season precipitation, April to September, is about 20 in. (50 cm) from central Nebraska across Ohio. Averages are misleading, however, and cyclic extremes may be the most important consideration. For example, the wettest summers occur in Iowa and eastern Nebraska. Average annual temperatures, including maxima and minima, by months do not vary greatly from east to west across the north-central states. Neither do the average depths of frost penetration, average lengths of frost-free period, or the average numbers of days with snow cover (United States Department of Agriculture, 1941). The really important climatological difference appears in the mean annual evaporation, which ranges from 55 in. (140 cm) in central Kansas to 30 in. (76 cm) in northern Illinois, Indiana, and Ohio (Richey et al., 1961). This range in annual evaporation is directly related to the increased number of cloudy days, greater average annual precipitation, and somewhat higher relative humidities that are expected in the central and eastern Corn Belt. The greater wind movement and lower humidities expected in the west also are factors.

Precipitation is, of course, the most important variable in the hydrology of the feedlot. Runoff and direct evaporation from the feedlot surface are the two major factors in the water balance. Transpiration and interception are not important because vegetation is absent from a continuously stocked feedlot. Infiltration and groundwater storage and return flows are minimal for most established feedlots in continuing use. Infiltration is essentially limited to water stored in the manure and soil-manure mixture on the feedlot surface. Once a manure pack is formed on the surface of a continuously used feedlot, movement of water into the soil profile is insignificant (Mielke et al., 1970, 1974).

Pollutant transport: Runoff provides transport of pollutants from the feedlot and requires facilities both for pollution control and for drainage from animal occupancy areas. The pollutants are chemicals, microorganisms, organic materials, and soil sediments. Proper assessment of the pollution potential is dependent, not only on the area and other physical characteristics of the feedlot, but also on the intensity, duration, and frequency of rainfall (Swanson et al., 1971). Pollutants in feedlot runoff are transported in solution, in suspension, and as bedloads. The soil-erosion process initiated by rainfall is a combination of detachment of solid particles by raindrop impact and transport of solids by overland flow. Water erosion of soil by rainfall on an average annual basis may be quantitatively expressed as a function of land slope, slope length, infiltration rate, and physical properties of the soil. Ayres (1936) stated that the amount, intensity, and duration of rainfall have a profound effect on the amount and rate of the resultant runoff, as does the elapsed time since the preceding rain. An unpaved feedlot is subject to the same erosion-producing rainfall as adjacent cropland. Although surface conditions are much different in the feedlot, the effects of rainfall and runoff for detachment and transport are similar. It is desirable to maximize both runoff and evaporation from a feedlot for feeding efficiency and waste management. Evaporation is influenced by exposure to the sun. Southerly slopes dry more rapidly and have long been recommended for feedlots.

Runoff data obtained from instrumented feedlot sites in Nebraska show that runoff may not be expected from rainfall of 0.5 in. (1.2 cm) or less, unless rainfall has occurred within the previous 3 days (Swanson et al., 1971). These data also show that greater rainfall intensities provide earlier initial runoff, greater runoff rates, and increased total runoff. Water storage in the soil and manure mixture of the feedlot surface can be appreciable. On 2 Sept. 1970, after 2 weeks of dry weather, a prolonged rain totaling 0.88 in. (2.2 cm) caused only 0.04 in. (0.1 cm) of runoff from a feedlot having 6% slope and southerly exposure. On 29 June 1971, after 11 dry days, 0.96 in. (2.4 cm) of rainfall was received without producing runoff.[7] The water absorbed by the surface usually evaporates soon after a rain. Runoff from rains following within a day after other runoff-producing events did not approach rainfall amounts except for relatively high-intensity rains. Analysis was made from 19 individual storms that followed within 72 hr of runoff-producing rains. The regression equation was:

$$\text{Runoff (in.)} = 0.01 + 0.41\ \text{rainfall (in.)}$$
$$\text{Runoff (cm)} = 0.025 + 0.41\ \text{rainfall (cm)}$$

with a correlation coefficient of 0.78, significant at the 1% level of confidence. Once moistened, the feedlot surface absorbs water more rapidly (Swanson et al., 1971).

Runoff sample analyses from 10 storms, selected from April through October 1970, with three or more individual samples per storm showed solids contents ranging from 0.18%-2.18¾%, with an average of 0.75%. Volatile solids ranged from 19.6%-75.0% of the total solids and averaged 36.0%. The COD ranged from 144 to 12,790 mg/l. A 1% solids content in runoff is equivalent to 1.13 ton of solids per ac in. (1 tonne per ha cm) of runoff. Precipitation occurred on 324 days from July 1968 through December 1972 and resulted in 98 runoff events. Regressions of precipitation and runoff for the precipitation events producing runoff are given in Figure 22 for these years. The average of 20 runoff events per year on the feedlot contrasts to an average of 8 per year for 1969 through 1971 on unterraced cropland about 35 mi (56 km) east.[8] At both locations, each runoff event had a value of 0.01 in. (0.025 cm) or more.

Runoff from feedlot snowmelt is different from runoff from rainfall. Sublimation is appreciable on southern exposures. The radiation-absorbing characteristics of snow are very markedly influenced by foreign substances such as dust, bark fragments, twigs, and practically any substance other than snow (Gartska, 1964). Animal action rapidly packs snow on the feedlot, providing an ice-like density. Deposits of fresh manure on the surface of such a snowpack are particularly vulnerable to transport by overland flow produced by the melting snow and ice. The dark color permits rapid absorption of heat from the sun, and on slopes of 3% or more, the mass of manure flows readily over the frozen surface below. Gilbertson et al.,

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[7] N.P. Swanson. Unpublished data. Agricultural Engineering Department, University of Nebraska, Lincoln.

[8] R. Spomer. Unpublished data. USDA-ARS, Location Leader, Watershed Studies. Treynor, Iowa.

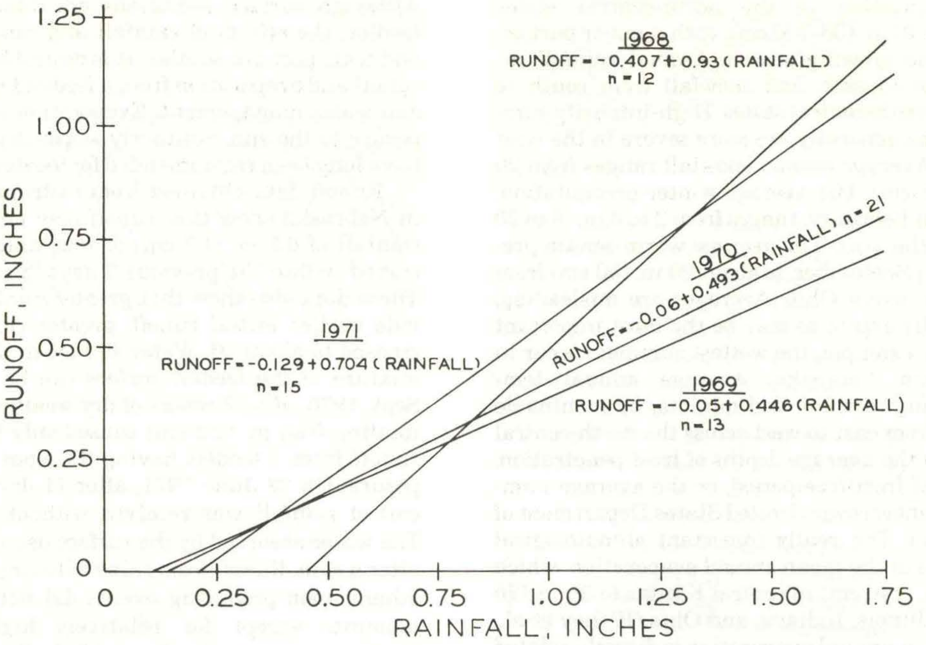

Figure 22. Rainfall-runoff relationships for the years 1968-1971, sloping cattle feedlot, Gretna, Nebr.

Source: N.P. Swanson, L.N. Mielke, J.C. Lorimor, T.M. McCalla, and J.R. Ellis. 1971. Transport of pollutants from sloping cattle feedlots as affected by rainfall intensity, duration and recurrence. pp. 51-55. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

(1970) have reported lava-like snowmelt flows of manure and water on rather densely stocked, sloping lots (100 and 200 ft^2, 9.3 and 18.6 m^2 per animal). In early 1969, similar, but not so heavily solids-laden snowmelt flows were observed by Swanson[9] pm on the 6% slope, southern exposure near Gretna, Nebr. This feedlot was stocked to provide about 500 ft^2 (47 m^2) per head at the time. The suspended solids and bedloads transported by snowmelt are usually much higher than those in rainfall-runoff. Gilbertson et al. (1970) reported early 1969 snowmelt runoff events with total solids content of 1.4%-10.7%. It was estimated that the total solids in the winter runoff ranged from 6.2 to 7.9 ton/ac in. (5.5 to 7 tonne/ha cm) of runoff for lots stocked at 200 ft^2 (18.6 m^2) per animal and from 17.9 to 21.6 ton/ac in. (15.8 to 19.1 tonne/ha cm) lots stocked at 100 ft^2 (9.3 m^2) per animal. The total solids were about 50% volatile solids. The COD content of the winter runoff on these lots ranged from 14,129 to 77,804 mg/l as compared with 1,300 to 8,247 mg/l for rainstorm runoff on the same lots. Slope exposure has much to do with the time and rate of snowmelt. Southern slopes profit more from evaporation, and melting begins quicker. Under eastern Nebraska conditions, snowmelt runoff should not create problems on a feedlot in more than 2 or 3 of 10 years (Swanson[10]). Total winter snowfall averages 25 in. (64 cm), about 2.5 in. (6.4 cm) of water equivalent.

Table 12. Characteristics of beef feedlot runoff at Pratt, Kans.

Parameter	Range	Mean	Standard deviation
From rainfall			
COD , mg/l ----------	1514 -14309	6111	2631
N , mg/l ----------	85 - 962	494	211
P , mg/l ----------	19 - 482	87	89
TS , mg/l ----------	2971 -17669	7528	2622
TS , ton/ac in. ----	0.34- 2.0	0.85	0.3
TS , tonne/ha cm ---	0.3 - 1.8	0.75	0.26
VS , mg/l ----------	1429 -11437	3891	1627
From snowmelt			
COD , mg/l ----------	7299 -35764	13767	8087
N , mg/l ----------	590 - 2337	1033	617
P , mg/l ----------	65 - 459	209	171
TS , mg/l ----------	9282 -36684	19308	11425
TS , ton/ac in. ----	1.05- 4.15	2.18	1.29
TS , tonne/ha cm ---	0.9 - 3.65	1.93	1.14
VS , mg/l ----------	5253 -23551	11620	7924

Source: W. J. Fields. 1971. Hydrologic and water quality characteristics of beef feedlot runoff. M.S. thesis. Kansas State University Library, Manhattan.

Pollutant characteristics: Feedlot runoff is a highly concentrated organic waste. Its quality is quite variable. Table 12 gives characteristics of feedlot runoff from both rainfall and snowmelt, as reported by Fields (1971). The runoff was from two types of pens, a dirt surface with the upper one-fifth concrete and a dirt surface with earthen mounds on two sides, both lot-drainage slopes averaging 1.3%. The concentration of pollutants in runoff from snowmelt was 2 to 3 times that from rainfall.

Wells et al. (1972) reported COD and total N of runoff from dirt-surfaced lots in Texas in the same ranges as those determined by Fields (1971) (Table 12). Concentration of pollutants in runoff from concrete lots was 2 to 4 times that from dirt lots. White and Edwards (1972) found that the COD of runoff from an unpaved feedlot in Ohio varied from 347 to 5649 mg/l, with the lower values in the summer months.

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[9] N.P. Swanson, op. cit.

[10] Ibid.

McCalla et al. (1972) reported lower COD concentrations from rainfall runoff and higher values for snowmelt runoff in Nebraska for dirt-surfaced lots than those given in Table 12. Gilbertson et al. (1971b) found that quality of feedlot runoff depends more on rainfall than on feedlot slope or animal density.

The pollution load of feedlot runoff is too high for direct diversion to streams. Therefore, runoff from precipitation must be collected and stored in reservoirs until it can be treated and released or disposed of so as to prevent pollution of the environment. Treatment of feedlot runoff by conventional biological systems is impractical because of the high concentrations of pollutants and of the erratic frequency and quantity of runoff. Disposal onto land is the only economically feasible method for ultimate disposal of feedlot runoff.

Prediction of runoff rate and quantity: Because runoff is produced by precipitation, design rates are related to intensity and design volumes, to intensity and duration. Maximum intensities usually are experienced for only short times, and data for the 10-yr, 1-hr storm may be appropriately applied. Quantities of precipitation are most generally associated with extended rainfall periods such as the 25-yr, 24-hr storm. Although many states have related feedlot runoff design criteria to the 10-yr, 24-hr storm, these criteria will need reviewing in light of new federal regulations. The U.S. Environmental Protection Agency (1974) stated in February 1974 that:

> 412.13.b) Process waste pollutants in the overflow may be discharged to navigable waters whenever rainfall events, either chronic or catastrophic, cause an overflow of process waste water from a facility designed, constructed and operated to contain all process generated waste waters plus the runoff from a 25 year, 24 hour rainfall event for the location of the point source.

Because dewatering of storage ponds is not always practical immediately after a 24-hr storm, Manges and Koelliker[11] have given consideration to 10-day or "chronic wet periods." Many states have made allowance for such conditions by requiring storage capacity to contain 120-180 days of accumulated runoff. It has been reasoned that the cold season in the major cattle-producing states is unsuitable for land application of liquid from storage ponds, and this season lasts for 120-180 days, depending on location. Precipitation patterns and probability data for specific areas are of particular value for planning runoff-control facilities. The U.S. Environmental Protection Agency has indicated that it intends to accept values for "10 year, 24 hour rainfall event" or similar events obtained from the U.S. Weather Bureau (1963). In many instances it may be permissible to use more comprehensive data derived for a particular region; e.g., Colville and Myers (1965) data for Nebraska.

Runoff control structures include channels for conveying runoff and ponds for storing it. The "rational formula," used by hydrologists, may be used to predict peak runoff rates for designing channels. The rational formula is

$$Q = CIA \text{ (English units)}$$
$$Q = 100\,CIA \text{ (Metric units)}$$

where: Q is the peak runoff (ft^3/sec, m^3/hr); C is a runoff coefficient; I is the rainfall intensity for the design recurrence interval, and for a duration equal to the time of concentration (T_c) of the watershed (in./hr, cm/hr); and A is the area of the watershed (ac, ha). Note that the English-units formula is dimensionally consistent with a dimensionless constant C because 1 ac in./hr = 1.008 ft^3/sec. The use of the rational formula is somewhat questionable because its accuracy depends on a subjective choice of a value for C, but the formula has the merit of simplicity. Further details may be found in any text on hydrology; e.g., Frevert et al. (1955). The time of concentration is a factor used to account for the size and slope of a watershed; it is calculated from:

$$T_c = 0.0078(L/\sqrt{S})^{0.77} \text{ (English units)}$$
$$T_c = 0.0194(L/\sqrt{S})^{0.77} \text{ (Metric units)}$$

where: L is the maximum length of travel (ft, m), and S is the slope (ft/ft, m/m). Once the value of T_c has been calculated for the feedlot in question, the value of I can be obtained; the full procedure is given by Frevert et al. The value of C varies with soil type, land slope, and surface conditions. Fields (1971) found that C = 0.7 was applicable to dirt feedlot surfaces with slopes up to 2%. Fields also concluded that the rational method will not accurately predict peak runoff from individual storms, but it may be used to predict the peak runoff from a feedlot for a hypothetical storm specified by a given recurrence interval; e.g., 25 yr.

Although discharge rates are important for designing channels, the primary concern of most designers will be the detention-pond volume. This volume will have two components: the volume required for storage during periods when dewatering is not possible and the volume required to contain the EPA-specified 25-yr, 24-hr storm. These two volumes are not necessarily additive; 25-yr, 24-hr storms generally take place in the warm part of the year. Koelliker and Manges[12] are currently collecting data for a computer model covering Kansas and similar climates. When this model is sufficiently refined, it should provide rational data for sizing detention ponds in many locations. Until the model is published, designers would be best advised to calculate both the volume required for cold-season storage and the volume required to contain a 25-yr, 24-hr storm. Selection of the larger of the two should be a satisfactory compromise in most instances. The period for cold season storage will vary from less than 90 days in Oklahoma to more than 180 in Minnesota.

Shuyler et al. (1973) have reviewed the literature relating runoff to precipitation and they concluded that a form of SCS equation

$$R = (P - 0.352)^2/(P + 1.41) \text{ (English units)}$$
$$R = (P - 0.895)^2/(P + 3.68) \text{ (Metric units)}$$

is applicable where: R is the runoff measured as equivalent rainfall on the feedlot area (in., cm) and P is the actual rainfall (in., cm). This formula takes into account that 0.25 in. (0.6 cm) of rain will be stored before runoff takes place. Wise and Reddell (1973) used a regression analysis to show that, in Texas

$$R = 0.863P - 0.458$$

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[11] H.L. Manges and J.K. Koelliker. 1973. Performance of feedlot runoff control structures in Kansas. Report submitted by Kansas Agricultural Experiment Station, Manhattan, to the Environmental Protection Agency as comments on "Proposed Effluent Limitation Guidelines, Feedlot Category."

[12] J.K. Koelliker and H.L. Manges. 1974. Unpublished data. Agricultural Engineering Department, Kansas State University, Manhattan.

Data from other states (e.g., Gilbertson et al., 1971c) can be made to fit an equation of the form

$$R = aP - b$$

Because this equation is linear, it could be applied to either the accumulated runoff during the cold season or to the runoff from a 25-yr, 24-hr storm. Until better data are gathered, the values $a = 0.8$ and $b = 0.5$ will give a conservative basis for design.

Neither the SCS equation nor $R = aP - b$ includes slope as a variable. Gilbertson et al. (1971a), however, concluded that neither feedlot slope nor animal density significantly affected runoff quantity.

Suspended solids removal: Runoff contains soil and organic particles, and these should be removed before the liquid enters the storage pond. The inorganic matter merely accumulates and reduces the storage volume available; the organic fraction, however, increases the likelihood of malodors from the storage pond. Gilbertson et al. (1971c) have developed a channel with porous dams; these impede the liquid flow enough that the solids may settle out and dry on the channel floor. The liquid flows on into the storage pond. The dams can be made of rough timber, hardware cloth, or other coarse porous materials. The material chosen should be easy to clean. The slope of the channel should start at 1% but can be increased to about 2% after the first dam. Because the length and width of channel must be related to the area of feedlot drained (4500 ft^3/ac, 310 m^3/ha), this system of solids removal is best suited to the smaller operation. Frequent cleaning of the channel is desirable because this will restrict the thickness of manure solids deposited and will encourage drying.

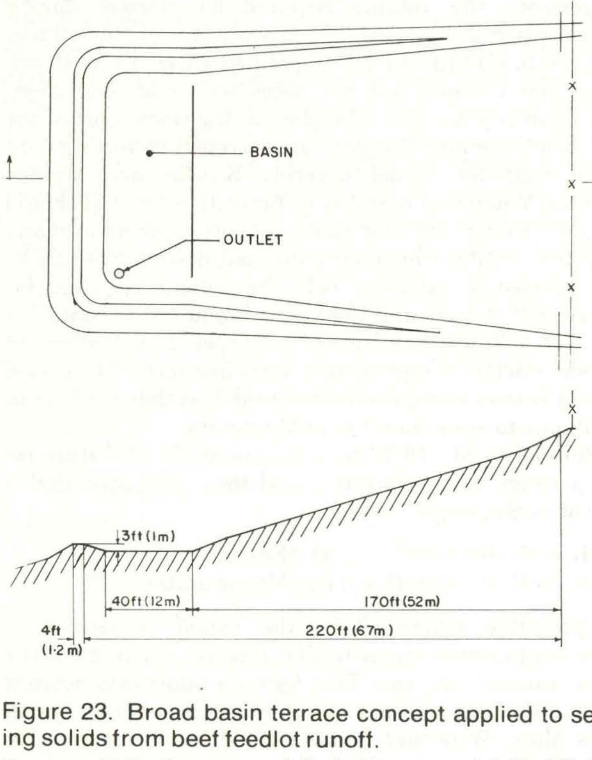

Figure 23. Broad basin terrace concept applied to settling solids from beef feedlot runoff.

Source: N.P. Swanson, J.C. Lorimor, and L.N. Mielke. 1973. Broad basin terraces for sloping cattle feedlots. Transactions of the American Society of Agricultural Engineers 16:746-749.

Larger lots will need to install primary settling ponds or broad basin terraces before the storage ponds. The broad basin terrace (Figure 23) has been described by Swanson et al. (1973). A 3-ft (1-m) berm is constructed at the lower boundary of the feedlot, and the dirt between this berm and the feedlot is graded level. A perforated inlet is placed in this level area. During a runoff-producing event, the basin will detain the runoff just long enough to settle out the solids. The level area allows the dry solids to be removed by a front-end loader. Swanson et al. note that the feedlot slope and the basin are continuous, allowing the cattle free access to the basin. Some operators blank off the lower part of the inlet during the summer, allowing the cattle to take advantage of cooling themselves in the ponded runoff.

Maintenance of the Lot Surface

Experience has shown that animals in muddy lots will have reduced daily gains during cold weather. During warm weather, wet lot surfaces tend to be more odorous, although, in this instance, a balance is required because very dry lots are a source of dust. Sufficient gradient must be maintained to provide for movement of water off the lot surface. All clean runoff from areas above the lot should be diverted around the lot. Drainage channels across the lots should have a minimum slope of about 2%. Gilbertson (1972a) recommended that dirt lots be sloped 3%-10%, the limits being set by poor drainage and excessive erosion, respectively. Texas Tech University (1971) reported that concrete-surfaced lots with slopes of about 15% are self-cleaning if some method for removing the accumulated wastes is provided. Each lot should drain directly into a drainage channel without flowing across adjacent lots. Otherwise, wastes will accumulate at lot fences, and poor drainage will result. In areas where land slopes are less than 2%, additional slope can be provided artificially by earth or manure mounds. When constructed of manure, these mounds should be well packed to provide substantial, dry footing for the animals. As the feedlot location moves eastward or northward into more humid areas, earth mounds are preferable.

Summary

Two waste-handling systems are required for open feedlots, one to handle the solids accumulation on the lot and one to handle the liquid runoff from the lot. Cattle feedlots are an environmental concern, but are not important to the total hydrology of a region because of their small area compared with cropland. Infiltration is essentially limited to water stored in the manure and soil mixture on the lot surface. Once a manure pack is formed on the surface of a continuously used feedlot, infiltration into the soil profile is insignificant. Water storage in the soil-manure mixture can be appreciable. Rainfall amounts approaching 1 in. (2.5 cm) have been absorbed without runoff after dry summer periods. If there has been no rainfall during 3 preceding days, then the next rainfall must usually exceed 0.5 in. (1.2 cm) for runoff to take place. Runoff will start sooner and be greater from a feedlot than from a similar area of adjacent cropland. In eastern Nebraska, this implied a runoff from a feedlot of about 9 in. (23 cm) annually. Moderate increases in rainfall intensity initiate disproportionate solids losses. Snowmelt runoff may contain 10 to 12 times the solids and COD concentration of rainfall runoff from the same lots. High stocking rates contribute greatly to the solids content of snowmelt runoff. Long, steep slopes greatly accelerate the movement of solids by runoff within the feedlot and result in increased costs and management problems. Drainage from the feedlot can best be maximized by increasing slopes (avoiding more than 10% for a dirt lot) and decreasing slope lengths. Overall management of the system is simplified if settleable solids are removed from runoff by settling channels or broad basin terraces. The volume of storage pond required must equal or exceed that required to contain the runoff from a 25-yr, 24-hr storm. It must also store all runoff during the cold season when dewatering is not possible. The volume chosen will be a compromise between these two requirements. Runoff may be taken as approximately 0.8 times precipitation for a dirt lot. Flat locations may be improved by providing earthen or manure mounds in the lot.

ODOR, DUST, AND AEROSOLS

Nature, Detection, and Measurement of Odors

Just as the escape of manure into streams has been judged objectionable, so has the escape of excessive quantities of certain components into the air. Of primary concern relative to livestock production is the escape of toxic or corrosive gases, odors, ammonia, dusts, and possibly aerosols. Odors have received the greatest attention to date.

Thermodynamically there is a difference between a vapor and a gas. If the ambient temperature is below the critical point of a fluid, the fluid may be either a liquid or a vapor, the state will depend upon the partial pressure on the fluid. Physiologically, there is no difference between a gas and a vapor, and the distinction will be ignored in this report.

Manure is biologically active when excreted and continues to undergo microbial degradation so long as suitable environmental conditions are maintained. The environment in which this degradation occurs determines the pathways by which the material decomposes and, hence, the nature and quantity of the individual volatile compounds. The feed ration and type and age of the animal also have an influence on the volatile compounds that appear in the manure. Environmental parameters of particular importance are temperature, moisture content, pH, and oxygen concentration.

Toxic and corrosive gases: The anaerobic decomposition of manure results in the release of measurable quantities of carbon dioxide, methane, ammonia, and hydrogen sulfide. Each of these gases has the potential of being hazardous in connection with livestock production facilities. In combination, these gases have been fatal to both livestock and humans (Muehling, 1970). Fatalities have occured among animals after a ventilation failure in a tight building when a manure storage pit beneath slotted floors was vigorously agitated or when an animal fell into a storage pit. Death to humans has resulted from entering a manure storage pit without first ventilating it properly. The exact cause of death in each of these instances has been difficult to determine. Death may have resulted from oxygen deficiency (by the gases physically displacing the air) or from actual physiological toxicity. Both ammonia and hydrogen sulfide are potentially toxic. Physical characteristics and hazardous concentrations of these gases are summarized in Table 13.

The corrosive nature of livestock-confinement-building environments was documented in a study by the American Iron and Steel Institute (1970). The conclusions recognized the swine building environment as severely corrosive and suggested that porcelain on steel and Modified Type 410 stainless steel were the most suitable of the steels evaluated for pen partitions and slatted floor sections. These components are subject to abrasion from animal activity as well as to the agressive environment. Concrete and aluminum flooring materials also have been widely used for their corrosion resistance.

Instrumental analysis: Odor complaints have been associated with livestock production at an increasing frequency throughout the country. This increase in frequency is attributable to several factors, but in particular: the trend to larger livestock operations, mechanized manure

Table 13. Properties and physiological effects of the major gases produced in the anaerobic decomposition of manure.

Gas	Specific gravity[a]	Odor	Concentration ppm[b]	Exposure period[c]	Class	Physiological effects[d]
Ammonia	0.6	Sharp, pungent	400	--	Irritant	Irritation of throat
			700	--		Irritation of eyes
			1,700	--		Coughing and frothing
			3,000	30 min		Asphyxiating
			5,000	40 min		Could be fatal
Carbon dioxide	1.5	None	20,000	--	Asphyxiant	Safe
			30,000	--		Increased breathing
			40,000	--		Drowsiness, headaches
			60,000	30 min		Heavy, asphyxiating breathing
			300,000	30 min		Could be fatal
Hydrogen sulfide	1.2	Rotten egg smell, nauseating	100	hours	Poison	Irritation of eyes and nose
			200	60 min		Headaches, dizziness
			500	30 min		Nausea, excitement, insomnia
			1,000	--		Unconsciousness, death
Methane	0.5	None	500,000	--	Asphyxiant, flammable	Headaches, nontoxic

[a] The ratio of the weight of pure gas to standard atmospheric air. If number is less than 1, the gas is lighter than air; if greater than 1, it is heavier than air.

[b] In parts of the pure gas per million parts of atmospheric air; to change concentration to percentage volume, divide the listed numbers by 10,000.

[c] The time during which the effects of the noxious gas are felt by an adult human being and an animal (especially pig) of about 150 lb in weight.

[d] Those found to occur in adult humans; similar effects would be felt by animals weighing 150 lb; lighter animals will be affected sooner and at lower levels; heavier animals at larger times and higher concentration.

Source: E. P. Taiganides and R. K. White. 1969. The menace of noxious gases in animal units. Transactions of the American Society of Agricultural Engineers 12:359-362.

handling, and the intermingling of livestock production and nonagricultural land use. The identification of specific gases responsible for livestock and poultry manure odors has proved a difficult and tedious task. Identification of the common and most abundant gases has not satisfactorily explained the observed odors. Research findings indicate that odorous gases are a combination of those end and intermediate products of anaerobic decomposition that have sufficient volatility to escape from the liquid phase.

The primary tool for odorant identification has been gas-liquid chromatography. Thin-layer chromatography and mass spectroscopy have received limited use. The major limitation in specific compound identification has been the low concentrations at which the odorants are present. Many of the compounds have perceptible odors at concentrations of less than 1 ppm and less than the minimum detectable concentration of the most sensitive detectors currently available on gas chromatographs. Where highly sensitive detectors have been used, frequently other compounds, present in many times greater concentrations but of less odor significance, tend to interfere with the analyses. To overcome the problems of detecting these low concentrations, various selective enrichment schemes have been utilized. The use of cold traps in which the odorous gases were passed through a U-tube submerged in a cold liquid, dry ice-acetone, or liquid nitrogen, has been helpful, but suffers from a lack of selectivity. Solid media covered with selective absorbents have been successfully used, as have general absorbents brought into equilibrium with the odorous gas. Selective liquid absorbents e.g., dilute acid for ammonia and amines, mercuric salt solutions for sulfur-containing compounds, propylene glycol for alcohols, and dichloromethane for carbonyls) have been most commonly used and with general success.

An examination of the lists of compounds isolated from the air in contact with anaerobically decomposing manure (Table 14) documents the existence of a large number of compounds of potential importance in odorous air. This large list also contributes to the complexity of odor analysis and further explains the variability in odor characteristics commonly attributed to animal wastes. Changes in feed ration, animal type and age, or manure handling may be expected to alter the quantitative makeup of the volatile by-products of manure decomposition and, thus, the exact nature of the odor produced by a livestock operation.

Use of the nose: Two separate aspects of odor can be identified, strength or intensity and quality. Odor strength or intensity can be evaluated by diluting the odorous material (gas or liquid) with sufficient odor-free air or water so that the human nose cannot distinguish the dilution from the odor-free material. That concentration barely distinguishable from odor-free air is termed the threshold odor. The strength of an odor can be defined in terms of the number of dilutions required to reduce the odor to the threshold concentration. Odor-strength measurements have been used by Sobel (1969, 1971) to compare the effect of various moisture levels and storage periods on the odor strength of poultry manure. Odor strength increased during storage for both diluted and undiluted manure, but to a greater extent for the diluted manure. Barth et al. (1972) correlated the odor intensity index (011) with concentrations of volatile acids, ammonia, and hydrogen sulfide in stored liquid dairy manure.

Field measurement of odor intensity, although subject to considerable variation, is facilitated by the use of a scentometer. The scentometer is essentially a rectangular Plexiglas box (6 in. by 5 in. by 2½ in., 15 cm by 12.5 cm by 6 cm) with two ports through which air passes to activated carbon absorption beds. There are four odorous air inlets ($^{1}/_{16}$, $^{1}/_{8}$, ¼, and ½ in. diameter, 1.6, 3.2, 6.4, 12.6 mm diameter), these are directly connected with a mixing chamber to which are connected the nasal outlets (Figure 24). In use, the scentometer is taken to the point where an

Table 14. Compounds identified in the air exposed to the products of the anaerobic decomposition of livestock and poultry manures.

- Alcohols$^{\alpha\beta}$
  - Methanol$^{\alpha\beta}$
  - Ethanol$^{\alpha\beta}$
  - 2-Propanol$^{\alpha\beta}$
  - Butanol$^{\beta}$
  - Propanol$^{\beta}$
  - iso-Butanol$^{\beta}$
  - iso-Pentanol$^{\beta}$
- Acids$^{\epsilon\zeta\eta}$
  - Acetic$^{\epsilon}$
  - Propionic$^{\epsilon}$
  - Butyric$^{\epsilon\zeta\eta}$
  - iso-Butyric$^{\epsilon}$
  - iso-Valeric$^{\epsilon}$
- Aromatics$^{\eta}$
  - p-Cresol$^{\eta}$
- Nitrogen heterocycles$^{\alpha\epsilon\eta}$
  - Indole$^{\alpha\epsilon}$
  - Skatole$^{\alpha\epsilon}$
  - Pyrazines$^{\eta}$
- Amines$^{\alpha\gamma\delta}$
  - Methylamine$^{\delta}$
  - Ethylamine$^{\gamma\delta}$
  - Trimethylamine$^{\gamma}$
  - Triethylamine$^{\delta}$
- Carbonyls$^{\alpha\beta\eta\theta}$
  - Formaldehyde$^{\beta}$
  - Acetaldehyde$^{\alpha\beta\theta}$
  - Propionaldehyde$^{\alpha\beta\theta}$
  - Butyraldehyde$^{\beta}$
  - Valeraldehyde$^{\beta}$
  - Heptaldehyde$^{\beta}$
  - Octaldehyde$^{\beta}$
  - Decaldehyde$^{\beta}$
  - iso-Butyraldehyde$^{\beta}$
  - Diacetyl (2, 3-Diketo-butane)$^{\eta}$
  - Hexanal$^{\eta}$
  - Acetone$^{\theta}$
  - 3-Pentanone$^{\theta}$
- Mercaptans$^{\gamma\epsilon}$
  - Methylmercaptan$^{\gamma}$
- Sulfides$^{\gamma\epsilon}$
  - Dimethyl sulfide$^{\gamma}$
  - Diethyl sulfide$^{\gamma}$
- Esters$^{\alpha\gamma}$
  - Ethyl formate$^{\alpha}$
  - Methyl acetate$^{\alpha}$
  - Propyl acetate$^{\gamma}$
  - Butyl acetate$^{\gamma}$
  - iso-Propyl acetate$^{\alpha}$
  - iso-Butyl acetate$^{\alpha}$
  - iso-Propyl propropionate$^{\alpha}$
- Fixed gases$^{\iota}$
  - Carbon dioxide$^{\iota}$
  - Methane$^{\iota}$
  - Ammonia$^{\iota}$
  - Hydrogen sulfide$^{\iota}$

Sources: [α] Bethea, R. M., and R. S. Narayan. 1972. Identification of beef cattle feedlot odors. Transactions of the American Society of Agricultural Engineers 15:1135-1137.

[β] Merkel, J. A., T. E. Hazen, and J. R. Miner. 1969. Identification of gases in a confinement building atmosphere. Transactions of the American Society of Agricultural Engineers 12:310-316.

[γ] White, R. K., E. P. Taiganides, and C. D. Cole. 1971. Chromatographic identification of malodors from dairy animal waste. pp. 110-113. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

[δ] Miner, J. R., and T. E. Hazen. 1969. Ammonia and amines: Components of swine-building odor. Transactions of the American Society of Agricultural Engineers 12:772-774.

[ε] Burnett, W. E. 1969. Qualitative determination of the odor quality of chicken manure. In: Odors, gases, and particulate matter from high density poultry management systems as they relate to air pollution. Final Report Cornell University Agricultural Engineering Department Contract C-1101.

[ζ] Deibel, R. H. 1967. Biological aspects of the animal waste disposal problem. pp. 395-399. In: Agriculture and the quality of our environment. N. C. Brady, ed. American Association for the Advancement of Science Publication 85.

[η] Hammond, E. G., G. A. Junk, Paulette Kuczala, and Joan Kozel. 1974. Constituents of swine house odors. pp. 364-372. In: Livestock environment (Proceedings, International Symposium). American Society of Agricultural Engineers SP-0174.

[θ] Hartung, L. D., E. G. Hammond, and J. R. Miner. 1971. Identification of carbonyl compounds in a swine building atmosphere. pp. 105-106. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

[ι] Day, D. L., E. L. Hansen, and S. Anderson. 1965. Gases and odors in confinement swine buildings. Transactions of the American Society of Agricultural Engineers 8:118-121.

odor intensity measurement is desired and placed to the nose of the observer. He plugs the odorous air ports to adjust his sense of smell to odor-free air. He then opens successively larger ports until an odor is first detected through the instrument. In this way, dilutions ranging from 1.5 to 170 can be evaluated. In discussing the scentometer, Huey et al. (1960) stated that their experience had shown that odors above 7 dilutions to threshold or higher would be described as a serious nuisance.

In contrast to odor strength, which can be estimated in a quantitative way, odor quality is more difficult to define. One technique is to compare an odor with a familiar sensation. White et al. (1971) used the following words in describing the various chromatographically separated peaks in stored dairy manure: foul, sweetish, acetate, nutlike, putrid, butterlike, and garlic. An alternative scheme, used by Sobel (1971), was to rank the offensiveness 0 to 10.

Control of Gases

Chemical agents: Three mechanisms exist for chemical control of odor from livestock manures, bacterial inhibition, oxidation, or masking. Day (1966) showed that chlorine or lime inhibit anerobic decomposition and thus alleviate odors. Oxidants investigated have included potassium permanganate (Faith, 1964), hydrogen peroxide (Kibbel et al., 1972, Hollenbach[13], O'Neil[14]), and paraformaldehyde (Seltzer et al., 1969). Several proprietary odor control chemicals are available, which are claimed to control manure odors. A series of these products was evaluated by Burnett and Dondero (1968). They concluded that some of the products were effective in controlling the odors immediately after addition to the waste. They found the masking agents and odor counteractants to be more effective than the deodorants, and the enzymatic digestive deodorants least effective. Repeated application is required for most chemicals unless exorbitantly large initial applications are used. As an example of cost, Burnett and Dondero estimated on the basis of a field trial with poultry manure that one of the better masking agents tested would cost 63 cents per 450 gal (37 cents per 1 m^3).

Management: Although complete odor elimination around a livestock operation is not currently possible, several principles have been proposed to minimize odor complaints (Miner, 1970).

Locate a livestock operation such that close proximity to residential areas is avoided. Although no maximum distances have been established beyond which complaints are not legally valid, it would seem logical to keep away from urban areas and housing developments. Wind directions and topography are of some importance, but in most areas, there is sufficient fluctuation in wind direction to make these factors of little help.

Feeding areas and animal pens should be kept dry. The primary source of odor from a livestock operation is that of anaerobic manure decomposition. If manure-covered surfaces are kept dry, this decomposition can be minimized. This same procedure, not only is helpful as an odor control scheme, but also is beneficial in the control of water pollution due to runoff and as an aid in fly and insect control.

Manure-management systems should be designed to prevent dirty, manure-covered animals. The warm body of an animal, when covered with wet manure, makes an area of accelerated bacterial growth and odor production. Once produced, the odorous by-products of manure decomposition are quickly vaporized into the air by animal heat.

In the selection of manure-treatment processes, low odor-producing units may be selected rather than those known to be more odorous. Aerobic treatment processes are preferred to anaerobic in this respect. Covered or enclosed manure-handling and disposal units, such as covered storage tanks and soil injection minimize the escape of odorous gases.

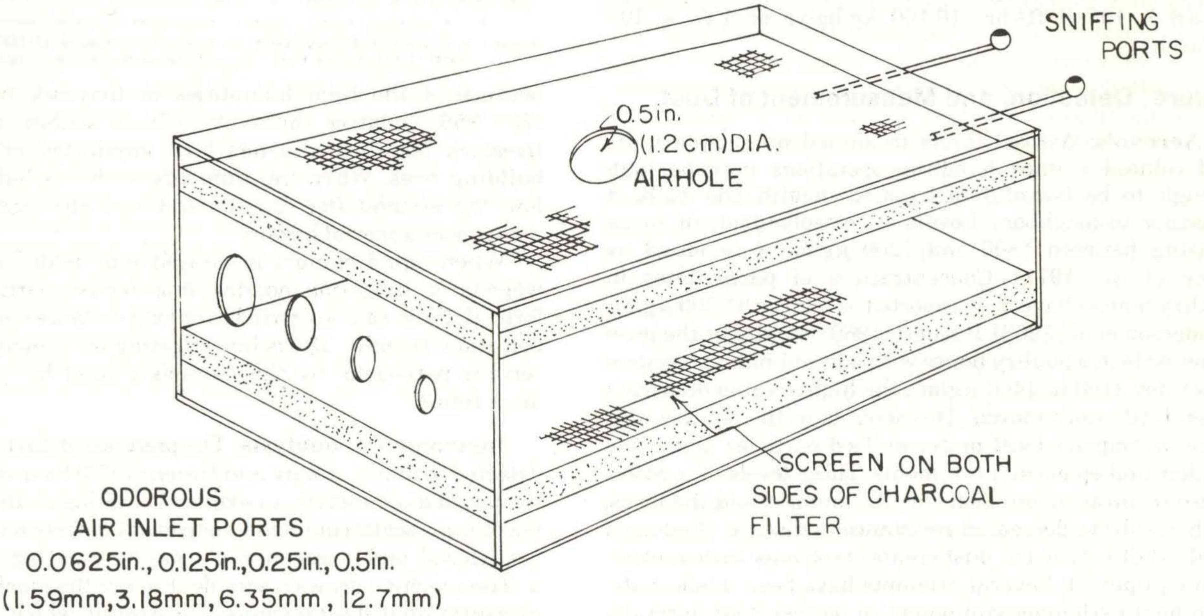

Figure 24. The scentometer: a device for obtaining the threshold dilution of odorous air in the field.

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[13] R.C. Hollenbach. 1971. Personal communication. (Manure odor abatement using hydrogen peroxide. FMC Corporation Report 5638-R). FMC, Princeton, New Jersey.

[14] E.T. O'Neil. 1972. Personal communication. (Manure odor abatement with hydrogen peroxide. FMC Corporation Report 4760-R). FMC, Princeton, New Jersey.

An orderly scheme of runoff collection and manure handling, not only avoids opportunity for water pollution, but also promotes better drainage, thus minimizing areas of odor production. In addition, an orderly appearing operation is effective in suggesting an unoffensive situation.

Dead-animal disposal requires a definite plan to avoid odors, flies, and severe health risks. Prompt handling, with removal from the site within 24 hr is required in most areas.

Volatilization of Ammonia

In spite of its solubility in water, ammonia exhibits a significant vapor pressure in manure and manure slurries. Ammonia may be released into the air from feedlots, storage tanks, treatment units, and other manured surfaces. It may then be transported to nearby lakes or vegetation, thereby potentially contributing to accelerated enrichment. This phenomenon was studied by Hutchinson and Viets (1969) by placing dilute acid absorption traps different distances from cattle feedlots in northeastern Colorado. Their results, summarized in Table 15, show significantly higher rates of ammonia absorption near feedlots as compared with samples collected in other rural areas. The absorption of ammonia by the acidified absorbers was approximately twice that of distilled water. Similar information collected by Luebs et al. (1973) showed high ammonia concentrations in the air near dairies in California. Tables 16 and 17 summarize their data. They found that distilled water absorbed ammonia at a rate 58% as great as the surface traps. Thus, one could anticipate a water surface in that area absorbing up to 200 lb of ammonia per acre (220 kg/ha) annually.

In analyzing the nitrogen balance around a swine-waste lagoon in central Iowa, Koelliker and Miner (1973) calculated that 7,900 lb (3,600 kg) of nitrogen escaped during a 1-yr period by ammonia desorption. That represented an average desorption rate of 14,400 lb/ac-yr or 3.8 x 10^{-5} lb/ft^2-hr (16,100 kg/ha-yr or 1.85 x 10^{-4} kg/m^2-hr).

Table 15. Mean ammonia absorption rates by dilute acid traps during the period 27 July 1968 through 27 Feb. 1969 in northeastern Colorado.

Site description	Mean weekly ammonia nitrogen absorption rate lb/ac	kg/ha
No feedlots within 3 km (1.9 mi)	0.13	0.15
Small feedlots (200 head) at 0.8 km (0.5 mi)	0.3	0.34
0.2 km (0.12 mi) east of 800-head feedlot	0.51	0.57
2 km (1.2 mi) east of 90,000-head feedlot	1.2	1.3
0.4 km (0.25 mi) east of 90,000 head feedlot	2.5	2.8

Source: G. L. Hutchinson and F. G. Viets, Jr. 1969. Nitrogen enrichment of surface water by absorption of ammonia volatilized from cattle feedlots. Science 166:515.

Table 16. Atmospheric concentration of distillable nitrogen (ammonia plus amine) near Chino, Calif.

Location sampled	Date	Distillable nitrogen concentration μg/m^3
Brackett Field 7 mi (11 km) upwind of dairy area	25 Feb. 1971	1
	14 May 1971	2
	5 Nov. 1971	3
Chino airport in dairy area 0.5 mi (0.8 km) from cows	24 Feb. 1971	39
	3 Mar. 1971	37
	5 Mar. 1971	46
	5 Nov. 1971	69

Source: R. E. Luebs, A. E. Laag, and K. R. Davis. 1973. Ammonia and related gases emanating from a large dairy area. California Agriculture 27(2):10-12.

Table 17. Average weekly absorption of distillate (ammonia plus amine) nitrogen by acid surface traps near Chino, Calif., (11 Jan. 1972 to 15 Feb. 1972).

Location	Average weekly absorption rate lb/ac	kg/ha
Dairy area 0.5 mi (0.8 km) from cows	9.40	10.5
Urban area 7 mi (11 km) N.W. of dairy area	0.28	0.31
Poultry and citrus area 21 mi (34 km) E. of dairy area	0.24	0.27
Dryland agricultural area 32 mi (51 km) E. of dairy area	0.18	0.20
National forest 50 mi (80 km) S.E. of dairy area	0.02	0.02

Source: R. E. Luebs, A. E. Laag, and K. R. Davis. 1973. Ammonia related gases emanating from a large dairy area. California Agriculture 27(2):10-12.

Nature, Detection, and Measurement of Dust

Aerosols: Aerosol levels in animal production units and related manure-handling operations may be high enough to be harmful to livestock health and to be a nuisance to neighbors. Levels of aerosols (dust) in swine housing between 1800 and 7200 μg/m^3 were found by Avey et al. (1971). Concentrations of particulates in poultry houses have been reported as high as 41,000 μg/m^3 (Anderson et al., 1966). Burnett (1969) found that the level of aerosols in a poultry house with a liquid-manure system was from 2100 to 4400 μg/m^3, the higher value occurring when birds were moved. The aerosols in the poultry unit were principally fecal material, feed particles, and some feather and epidermal fragments. These levels of aerosols cause respiratory problems for the animals and the birds, with resulting decreased resistance to disease (Anderson et al., 1966). Also, the dust creates problems with ventilation equipment. Several attempts have been made to design heat-exchanger equipment to recover heat normally exhausted from livestock buildings (Arnold, 1972), but most of these have been unsatisfactory owing to the large quantity of dust in the air. The problem is aggravated because of the high humidities in livestock buildings (75%-95% relative humidity). Dust within confined livestock facilities also has been implicated in poultry building fires. When the humidity within a building is low, the accumulated dust on and near electrical equipment poses a special hazard.

When liquid manure is sprayed onto fields from tank wagons or irrigation nozzles, fine aerosol particles are formed; these can be carried over long distances and cause pollution. Diesch[15] also is investigating the propagation of certain pathogens by the aerosols caused by oxidation ditch rotors.

Instrumental analysis: The presence of dust is easily detected visually. Bundy and Hazen (1973) have described the use of a commercial instrument working on the principle of light scattering. This instrument detects and counts particles of, and larger than, the machine setting; e.g., ⩾ 1 μ. The machine draws a sample through the machine and measures an instantaneous particle count, which makes it very suitable for dust-decay studies. The instrument recommended by the Air Pollution Measurements Committee of the Air Pollution Control Association for quantitative

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[15] S.L. Diesch. 1973. Unpublished report to the NC-93 Committee. Department of Veterinary Clinical Sciences, University of Minnesota, St. Paul.

sampling of large volumes of air for suspended particulate matter is the high-volume sampler (Jutze and Foster, 1967). This device consists of a specially housed vacuum pump to which is attached a filter holder or adapter. Air drawn through the filter is measured with a calibrated flow meter. With a known quantity of air passing through the filter, the amount of particulate matter suspended in the air can be determined by weighing the filter paper before and after sampling.

Control of Dust

Techniques for confinement housing: High levels of particulates reported under certain conditions for poultry- and swine-production units indicate the need for equipment and procedures to remove the dust before the air is exhausted into the atmosphere. Willson (1971b) reported that impingement baffles at the ventilation exhaust openings with a water spray can effectively remove dust. Where dust from confined livestock buildings may be expected to cause a nuisance, the use of commercial equipment such as filters, cyclones, and scrubbers, should be considered. Feed- and manure-handling systems can be selected to minimize dust production in the buildings. For example, Bundy and Hazen (1973) indicated that, for swine, the dust level was 50%-75% less on concrete floors with floor feeding than on stainless steel slatted floors with self feeding. These investigators attribute this rather surprising result to the lower activity exhibited by the intermittently fed pigs. The use of under-slat or cage exhaust ventilation also will lower dust levels within the building.

The formation of mist while spraying liquid manure onto land can be prevented by using deflectors on the tank wagon that direct the waste toward the ground. Where irrigation nozzles are to be used, lower pressures and smaller nozzles will lower the stream trajectory and decrease atomization. When windy conditions exist, it may be best to avoid irrigating.

Techniques for open feedlots: Feedlot odors that might otherwise go unnoticed draw complaints because of the attention generated by the visible presence of dust. At more serious levels, the dust and accompanying odor raised by the milling of cattle and carried by the wind to residential areas and across highways cause both a sanitary problem and a traffic hazard. Dust from beef-cattle feedlots has been in part the cause for legal action (Stubblefield, 1966). Research by Wiersma[16] in Arizona indicated that using hygroscopic compounds on the feedlot surface to reduce dust is impractical. Water application is the most satisfactory control, dependent upon cattle density, depth of manure, weather conditions (especially temperature and relative humidity), and frequency of application.

Cattle health, especially in the respiratory system, is impaired by the presence of high levels of airborne particulate matter. Feedlot personnel also are subjected to concentrations of dust, though somewhat less than that which occurs in the immediate confines of the corrals. The problem of feedlot dust is of greatest concern in the desert areas where rainfall and relative humidities are low. The concentrations of dust are heaviest at dusk, when cattle leave the protection of the overhead shade to feed from fenceline mangers, followed by a period of exercise, playful activities, and general milling in the corral. The period often coincides with feed delivery to the manger in trucks, generating still more dust from the dry feeding lanes. The first step in reducing manure dust is the removal of excess manure from the corrals. Minimizing manure accumulation enhances the effectiveness of further control procedures. The only effective means of preventing the transfer of dust particles into the air is one that maintains manure moisture levels sufficiently high to retain all particles within the manure pack. This can be quite effectively accomplished by controlling the cattle numbers in a corral at concentrations such that moisture from urine and feces will keep the manure pack moist. Actual densities required to control dust will depend upon size of animals and weather conditions, but, on the basis of calculation of moisture produced by cattle and manure moisture levels necessary for dust control, a space allocation of about 100 ft^2 per 1000 lb (20 m^2 per 1000 kg) of animal weight should provide reasonably good control. This density for a drylot may be too high for most winter conditions, so adjustments are necessary as the season changes. The need for adjustment often does not coincide with restocking activities and requires additional management considerations. The practice also lacks provision to control moisture levels during periods of midseason rainstorms.

Sprinkling with water is the most effective method for controlling dust. Water can be applied from a mobile tank and large gun sprinkler, with portable lines and small nozzles, or with a permanently installed sprinkler system in the corral area. All are capable of providing good control so long as adequate coverage is achieved and appropriate amounts of water are applied. Good distribution is essential. In corrals with shades, the shaded area is the most heavily occupied and kept moist by the cattle so must receive little or no water. The feed in the mangers also must be kept free from sprinkling water. In the remaining area, sufficient water must be applied to control dust, but, at the same time, avoiding any accumulation of excess water. Excessively wet spots, especially near fences and other locations where cattle traffic is restricted, support anaerobic decomposition, a primary source of feedlot odor. Wet manure also provides a good environment for fly breeding. Manure moisture content below 25% generally is not attractive to flies. The upper limit for breeding common houseflies is 85% (Curley and Fairbank, 1963). This leaves a wide range of moisture levels capable of supporting fly production.

For adequate dust control, the moisture content of the manure pack should be about 25 to 30% (Paine, 1973). This moisture level usually can be maintained by applying about 0.5 gal/yd^2 (2.3 l/m^2) of water of surface area daily (Simpson, 1971). There are two schools of thought among feeders who sprinkle for dust as to the most effective rate and frequency of application (Gray, 1964). Some feeders favor high-capacity sprinklers operating for short periods; others prefer low-capacity systems on a close spacing and operated more nearly continuously. The high-capacity system requires more careful management to prevent accumulations of excess water. Somewhat better dust control is achieved with less frequent, heavier applications than with frequent or continuous light applications (Simpson,

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[16] F. Wiersma. 1973. Unpublished report to the NC-93 Committee. Agricultural Engineering Department, University of Arizona, Tucson.

1971). Although manure odor is closely associated with manure moisture, Simpson observed that fully managed sprinkling in a dry climate could actually aid in reducing odor. The sprinkled water can provide moisture and oxygen for aerobic biodegradation of the manure. A 40% moisture content is required for best aerobic bacteria activity. It is important that careful distribution be provided because this moisture level in stagnant areas will support fly breeding. In deeper, undisturbed manure accumulations, the lower layers of manure also will become anaerobic. Well-agitated manure, either mechanically or by cattle traffic, sprinkled to maintain a 30%-40% moisture level will control dust and minimize odor.

Chemical agents with potential dust palliative capabilities have limited practical use for dust control in feedlots. The various modes of action available are water penetration improvement (calcium sulfate), particle binding (ligno sulfonate), agglomeration (sodium carbonate), and moisturizing by chemicals with an affinity for water (calcium nitrate, glycerol). The first three modes actually are limited to the enhancement of control with sprinkling. The fourth, capturing moisture from the air, is least effective at lower humidities when its action is most needed. All modes are relatively expensive and require reapplication at least as often as manure is removed from the pens. Calcium nitrate will increase the quality of the manure if it is marketed as a fertilizer, and some of the cost may be recovered through this increased quality as a nutrient. Chemicals may be more effective and practical for controlling dust in feed lanes and roadways, a substantial source of dust generation. Road oils or coarse gravels also can be used in these areas.

AEROBIC TREATMENT

The Aerobic Process

The demand for a workable, low-odor-producing method of liquid waste treatment has prompted widespread interest in the aerobic-digestion process. Animal manure is a usable food source for many kinds of microorganisms. Aerobic bacteria require dissolved oxygen (DO) in the water for metabolism. The aerobes use the oxygen as a hydrogen acceptor, whereas anaerobic bacteria use combined oxygen from sulfates, carbon dioxide, or organic compounds as their hydrogen acceptor. Facultative bacteria can use either dissolved oxygen or combined oxygen as their hydrogen acceptor.

In an aerobic process, with an unlimited food supply and a suitable environment, the mass of organisms increases with time at an exponential rate, and bacterial growth is limited only by ability to reproduce. During this time, the rate of oxygen consumption will increase, the food supply will be oxidized, and the mass of cells will increase. As the food supply or oxygen becomes limiting, the rate of cell production slows, with a corresponding decrease in oxygen consumption.

Endogenous metabolism, cell maintenance, exists at all times, but becomes predominant when there is just enough food to keep the microorganisms alive. Under these conditions it is common to find a population of nitrifying bacteria developing, and ammonia is converted to nitrates. In a batch process, the oxygen consumption rate levels off, and mineralization is increased because of the destruction of the volatile solids. The resulting accumulation of solids consists of fixed solids and unbiodegradable volatile solids (Dreier, 1963). Figure 25 schematically diagrams aerobic metabolism in a batch process. In a continuously fed process, all the stages of metabolism exist, and the nature of the process determines which stage predominates. A portion of the solids is relatively inert polysaccharide material, which accumulates at a rate of about 11% of the BOD removed in an activated sludge unit (Stewart, 1964).

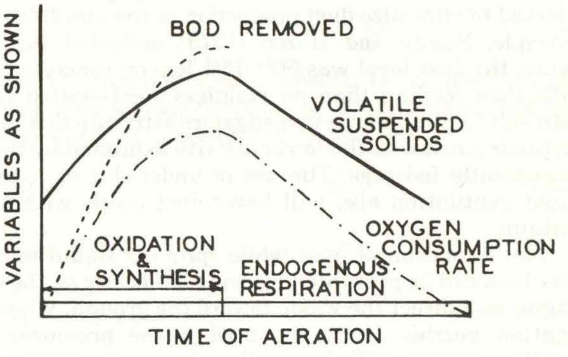

Figure 25. The sequence of aerobic metabolism.

One of the most important parameters in the aerobic-treatment process is the food:microorganism ratio. This ratio, designated by the symbol F/M, is equal to the mass of 5-day BOD applied daily per mass of volatile suspended solids contained in the treatment system (Symons and McKinney, 1958). Municipal oxidation-ditch systems usually have a low F/M ratio (about 0.05:1) compared with those in municipal activated-sludge, sewage-treatment plants (about 0.5:1).

Maintenance of from 1 to 2 mg/l of dissolved oxygen in the waste liquid is sufficient to maintain aerobic conditions. The air, as supplied in aerobic digestion, is used both for agitation and for microorganism growth. Experiments with municipal waste have shown that the air requirements for oxidation generally are met when sufficient air is supplied to keep the solids in suspension. Nitrogen and phosphorus need to be present in the organic matter for bacterial growth. These two nutrients are needed in relatively small amounts and are present in animal waste. The BOD:phosphorus ratio required is about 100.

Development of the Oxidation Ditch

Various schemes, typically used for the treatment of domestic sewage, have been devised to utilize aerobic processes for the storage or treatment of livestock wastes. Among these are the oxidation ditch, aerated lagoon, and naturally aerobic lagoon (oxidation pond). The oxidation ditch was developed during the 1950s at the Research Institute for Public Health Engineering (TNO) in The Netherlands as a low-cost method for treating sewage emanating from small communities and industries (Lakeside Engineering Corporation[17]; Pasveer, 1963). The first full-scalle plant, installed at Voorschoten, The Netherlands, in 1954, is still in operation and has been enlarged to handle increased populations. The oxidation ditch is a modification of the activated-sludge process. The activated-sludge process has the characteristic that, if aeration and mixing are stopped fcr 30-60 min, the bacterial floc and other solids will settle, leaving clarified water on top. In plants treating municipal wastes, this principle is utilized to separate solids from the final effluent. The oxidation ditch has two principal parts, a continuous open-channel ditch shaped like an oval racetrack and an aeration rotor that supplies oxygen and circulates the ditch contents to keep the solids in suspension. A schematic drawing of a municipal oxidation-ditch treatment system is shown in Figure 26.

By using long-term aeration, it is possible to stabilize organic wastes to such an extent that the stabilized solids can be dried without objectionable odors. The raw waste entering the ditch becomes diluted with the large amount of liquid present in the ditch. Two methods of discharging effluent from the oxidation ditch are batch and continuous flow. The liquid level in the batch type of operation is allowed to increase as waste is added to the ditch and is lowered periodically by removing a portion of the mixed liquor. In the continuous-flow method, the liquid level remains constant and is controlled by an overflow device.

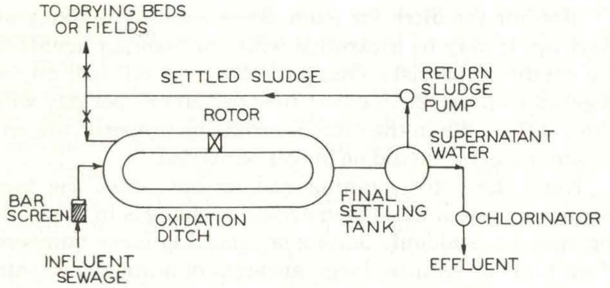

Figure 26. Oxidation ditch plant for treating municipal wastes.

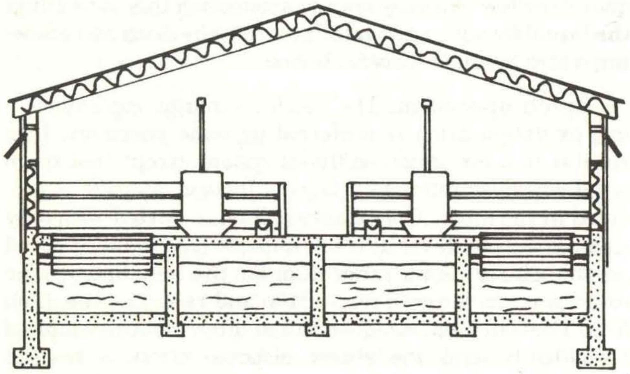

Figure 27. Vertical cross section of a totally slotted-floor, swine-confinement building with an underflow oxidation ditch.

Oxidation Ditches for Animal Wastes

A modification of the oxidation-ditch treatment system is being used by many livestock producers; by 1967, about 400 ditches were in operation across the country, primarily in swine operations (Newtson, 1967). The oxidation ditch offers the following advantages over other possible treatment schemes: (a) Being an aerobic process, it is odorless, with the exception of a slight ammonia or earthy smell. (b) Once the biological process is operating properly, the ditch can absorb brief periods of overload. (c) It requires little attention and maintenance compared with other waste-treatment processes. (d) The process may be combined with the labor-saving, slotted-floor systems, requiring no extra pumping or hydraulic system to move waste from the collection pit to the treatment plant because these are the same pit (Figure 27). Where an under-the-floor storage tank already is planned, the main expenditure required for the channel is to round the corners and connect the ends of the gutter. But additional facilities for effluent storage or removal will be required. The main fixed cost is the rotor itself, approximately $350 per horsepower ($470 per kW). The major operating cost would be the power required to operate the rotors (see Table 18 for operating costs).

Design criteria for oxidation ditches under slotted floors: Livestock waste added to oxidation ditches usually is undiluted and does not contain significant amounts of bedding. Test results from four oxidation ditches for swine and two for beef cattle, along with several laboratory studies, were used as a basis for the design criteria listed in Table 18 (D.D. Jones et al., 1971b). The ditch loading rates in Table 18 were computed on a basis of 30 ft^3 of liquid volume in the ditch per lb of daily BOD$_5$ added (1.5 m^3/kg daily BOD$_5$). With these loading rates, and starting with water in the ditch, operations could continue for an indefinite time if the suspended solids in the ditch were kept at about 25,000 to 30,000 mg/l by periodic or continuous sludge removal. Many livestock producers favor the continuous-flow into a lagoon or holding tank (Figure 28).

Two requirements must be met when selecting a rotor for a specific livestock building: oxygenation capacity equal to twice the daily BOD$_5$ added and a pumping capacity capable of moving the waste at a high enough velocity to keep the solids suspended, a minimum of 1 ft/sec (0.3 m/sec). The rotor manufacturer should be able to supply a pumping value for his rotor. McKinney and Bella (1967) experimentally found a value of 3.4 ft^3/sec-ft (0.31 m^3/sec-m) of rotor (27½-in., 0.7-m diam. cage rotor) at 100 rpm and 6-in. (15-cm) immersion. They also found that, with 1.0 ft (0.3 m) of liquid depth and 1.0 ft/sec (0.3 m/sec) liquid velocity, the channel width can be 1.2 times the rotor width.

To maintain adequate velocity in the ditch, the depth usually is limited to 24 in. (60 cm), and the channel length is limited to about 300 ft (90 m) between rotors. Most rotors, 27.5-in., 0.7-m diameter, can transfer about 1.5 lb oxygen per ft of rotor (2.2 kg/m) hourly in water at standard conditions at 100 rpm and 6-in. (15-cm) immersion (D.D. Jones et al., 1969). Rotor aerators have supplied much more oxygen than this under certain laboratory conditions (Cleasby and Baumann, 1968), but higher

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[17] Lakeside Engineering Corporation. Rotor aeration in the oxidation ditch. Bulletin 141. Chicago, Illinois.

Table 18. Design recommendations for in-the-building oxidation ditches.

Animal	Weight		Daily BOD_5		Daily req. oxygenation capacity		No. of animals per unit length of rotor		Ditch vol.		Daily power reqmt.	Power cost
	lb	kg	lb[a]	kg[a]	lb[b]	kg[b]	per ft[c]	per m^{3}[c]	ft^{3}[d]	m^{3}[d]	kWhr[e]	cents/day[f]
Swine												
Sow with litter ---	375	170.1	0.79	0.36	1.58	0.716	16	52.5	23.7	0.671	0.83	1.66
Growing pig -------	65	29.5	0.14	0.064	0.28	0.127	91	298	4.2	0.119	0.15	0.30
Finishing hog -----	150	68	0.32	0.145	0.62	0.281	41	135	9.6	0.272	0.33	0.66
Dairy cattle												
Cow --------------	1,300	589.7	2.21	1.002	4.42	2.00	6	19.7	66	1.88	2.33	4.66
Beef cattle												
Feeder -----------	900	408.2	1.35	0.612	2.70	1.22	10	32.8	40	1.13	1.42	2.84
Sheep												
Feeder -----------	75	34	0.053	0.023	0.11	0.05	230	755	1.6	0.045	0.06	0.12
Poultry												
Laying hen -------	4.5	2.04	0.0198	0.009	0.0396	0.018	650	2,130	0.6	0.017	0.021	0.042

[a] Use specific production data when known.

[b] Twice the daily BOD_5.

[c] Based on 25.5 lb of O_2 per ft of rotor daily (1.58 kg/m hr).

[d] Based on 30 ft^{3} per lb of daily BOD_5 (1.87 m^{3}/kg).

[e] Based on 1.9 lb of O_2 per kWhr (0.86 kg/kWhr).

[f] Based on electricity at 2 cents per kWhr.

Source: D. D. Jones, A. C. Dale, and D. L. Day. 1971. Aerobic treatment of livestock wastes. Illinois Agricultural Experiment Station Bulletin 737.

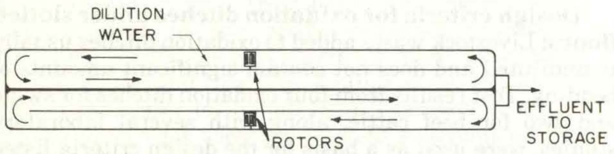

Figure 28. Plan view of a continuous-flow oxidation ditch suitable for use under a totally slotted floor.

capacities generally cannot be expected under field conditions. The performance of a mechanical aerator in wastewater is almost always less than that measured under standard conditions (clean tapwater, 0 mg/l DO, atmospheric pressure 960 mm Hg, 20°C). Some factors that reduce the performance are, lowered levels of saturation DO in the wastewater, temperature of the wastewater not 20°C, atmospheric pressure not 960 mm Hg, and physical characteristics of the wastewater different from clean tapwater. Loehr (1974) has shown how the effects of these variables may be accounted for quantitatively. In practice, it will often be sufficient to select an aerator whose standard daily oxygen transfer rate is equal to twice the daily BOD_5 loading on the ditch. When the power cost is 2 cents/kW hr, the daily operating cost is approximately 2 cents/lb (4.5 cents/kg) of BOD_5 added hourly if the rotor supplies 1.5 lb O_2/hp-hr (0.91 kg O_2/kW-hr) on a motor-input power basis. (Note: Manufacturers' literature for aerators commonly is presented on a net power basis that does not include motor and drive-train inefficiencies. This should be accounted for when comparing equipment.)

Start-up procedure, continuous overflow: When a ditch is to be used in a continuous-flow system with a fairly constant animal loading, the following start-up procedure has been satisfactory.

Fill the ditch with the volume of water required by the ditch loading rate. Do not try to start with anaerobic liquid manure in the ditch.

Adjust the height of the rotor for the desired immersion depth (usually 4-6 in., 10-15 cm). This should not require further adjustment for a continuous-effluent system because the liquid depth will remain constant.

Put animals into the building and start the rotor. It is best to put the animals in gradually if possible so that the full load will not be applied until the bacterial population becomes established.

Monitor the ditch for foam. Some foaming is likely at start-up. It may be controlled with antifoaming agents if the condition persists. One pint of engine oil, fuel oil, or vegetable oil per 2500 gal (1 liter per 20 m^{3}) per day will often suffice. When the ditch is operating properly, the antifoam material should no longer be needed.

Keep the rotor running and do not upset the bio-oxidation system by sudden excessive changes in the loading rate; i.e., suddenly adding or removing large numbers of animals or spilling large amounts of animal feed into the ditch. After a few months of operation, it may be necessary to remove sludge from the system even though the effluent removes solids continuously in the mixed liquor overflow. An easy way to accomplish this is to dilute the liquid by putting a water hose into the ditch and allowing water to run for several hours.

Batch operation: The batch discharge, continuously fed, oxidation ditch is preferred by some operators. It is similar to a continuous-effluent system except that there is no overflow outlet to a lagoon. Instead, storage is provided in the ditch. The oxidation ditch is started with only a shallow water level (it is advisable to have some residual aerobic slurry as an innoculum for the new batch). The rotor must be lowered for startup and raised as the ditch fills. The batch-operated oxidation ditch must be emptied periodically, and the slurry disposed of. It is best to coordinate removal of slurry from the ditch with cropping schedules because the most likely area for disposal is onto cropland where the slurry can be utilized as a fertilizer. In cold climates, the ditch should have a 6 mo storage capacity (allowing for evaporation losses) so that the emptying and hauling can be done in the fall before the ground freezes and in the spring after the ground thaws. If the ditch is subject to extended periods of near-freezing temperatures of the liquid, it may be best to stop the rotor because the bacterial action will be minimal. Odors during a cold period are not usually a problem, and there would be a saving in electrical energy. The accumulated liquid manure should be removed before starting the oxidation ditch again. During summer operation, the higher liquid temperature will cause a high oxygen demand due to the increased biological activity. Slurry may have to be removed every 4 to 8 wk to avoid odor problems from high oxygen demands.

The batch-operated ditch will result in buildups of solids, minerals, salts, etc., because there is a continuous addition of waste with no removal of slurry until the batch is emptied. Also, care must be taken to raise the rotor as the liquid depth increases, or the rotor will become overloaded and can cause motor or drive failures.

Operating problems: All waste-treatment plants require some operator attention. Each system must have regular maintenance to function properly over an extended period. The oxidation ditch, however, is relatively simple and easy to maintain. The most critical period of operation is start-up. If adequate oxygen is not maintained in the ditch, anaerobic bacteria will develop and produce odorous end products. The operator can smell when the ditch is operating properly because aerobic ditch waste is odorless. The anaerobic end products are surface-active so that heavy foaming usually accompanies odor. Although foam can be controlled with antifoaming agents, the anaerobic problem is best controlled by adding more oxygen to the ditch contents. If the mechanical system cannot supply the needed oxygen, it may be done temporarily by adding a chemical such as ammonium nitrate or sodium nitrate (McKinney and Bella, 1967). P.H. Jones and Patni (1972) studied the foaming problems of a ditch handling swine wastes and concluded that foaming was related to insufficient DO in the liquor. These authors stated that no foaming was observed on days when the DO at all points in the ditch exceeded 2.5 mg/l.

Settled solids can be a nuisance to ditch operation. Not only do they reduce the effective ditch volume, but they also will undergo anaerobic decomposition and create odor and foaming problems. Care should be taken in the hydraulic design of the system to prevent solids accumulation in the bottom of the ditch. McKinney and Bella state that, "At no time has foaming ever been noticed except at start-up and with anaerobic conditions." In a system that seemed aerobic, but was foaming significantly, solids were settling out in the corners just before the rotor. These solids underwent anaerobic decomposition and released their surface-active metabolic end products to the water. Adequate oxygen prevented odors, but the material reached the rotor before it could be metabolized, and foaming resulted. Removal of the settled solids eliminated the problem. Foaming, except during the start-up, may be the best indicator of trouble somewhere in the system. Not only is foaming an indication that the ditch is not treating the waste properly, but in extreme instances, the foam may rise up through the slats and the penned animals may be in danger of suffocation.

In a properly operating ditch, the bacteria will convert most of the ammonia to nitrates. But if the oxygen transfer from the rotor is insufficient, ammonia may be liberated into the atmosphere. A slight odor of ammonia will always be present in a building because of urine splashing against the slats, but a strong ammonia odor may be a sign of insufficient oxygen in the ditch.

Oxidation ditches are simple in construction and operation. The major operating problem is failure of rotor bearings. It is essential that the unit be easily removable to replace the bearings. Another problem can be in the drive between the motor and the rotor. Gear reducers can assist in speed reduction, but their cost is high and efficiency low (McKinney and Bella, 1967). Efforts have been made to establish direct drives with belts. These have worked well, but require low-speed motors to gear the speed down to 100 rpm at the motor. The major manufacturers of livestock oxidation-ditch rotors have replaced chain drives with belt drives. Belt drives tend to absorb the shock of blade contact with the water better than do chain drives. It seems that the belts slip slightly with each impact, with a net result of less wear on the equipment. The belts should be kept dry.

If problems from high humidity are anticipated and if climate and ditch construction permit, it may be advisable to place the rotor outside the building. Research to date concerning evaporation in the building is definitely lacking. The effect of a severe winter climate on an exposed rotor, however, will likely outweigh whatever evaporation problems are anticipated.

Effect of cold climate: Ice formation in the ditch has been reported in Minnesota and Illinois in beef operations. In Minnesota, Moore et al. (1969) stated, however, that the oxidation-ditch system can be used to treat beef-cattle waste in climates with extended periods of subfreezing temperatures. Foam production occurred on several occasions in cold weather, but did not force shutting down the rotor. In one trial, during the months November to January, the monthly average liquid temperature was 36.8°F (2.1°C). An ice layer up to 1 in. (2 cm) thick formed over part of the ditch. In one reach of the ditch, the foam froze and provided an insulation blanket. The liquid velocity of 1.2 to 2 ft/sec (0.37 to 0.60 m/sec) minimized the icing problems. In a beef-cattle unit at the University of Illinois, up to 2 in. (5 cm) of ice was observed in the channel opposite the rotor when the air temperature dropped to 5°-10°F (-15 to -12°C) for a week (D.D. Jones et al., 1971a). The velocities in this ditch, although not known exactly, were not as great as in the Minnesota study. The insulation properties of foam that Moore et al. (1969) reported also were observed in two sections of the ditch in the Illinois study.

Biological activity in the ditch is influenced by cold climates. Dale et al. (1969) reported that temperature had a significant effect in their laboratory studies (Table 19). The aerobic decomposition process works much better at 75°F (24°C) than at 39°F (4°C). The values in Table 19 are for 12- to 15-day studies. An oxidation ditch can continue to operate through cold weather. During cold weather, however, bacterial activity and, therefore, oxygen requirements are reduced, and a shutdown period is possible. Exhaust fans drawing air from under the slats should allow the heat produced by the livestock to help prevent the ox-

Table 19. Average reductions of VS, COD, and Kjeldahl nitrogen in 12- to 15-day laboratory aeration studies conducted at two temperatures.

Temperature		Reduction in parameter		
°C	°F	VS %	COD %	Kjeldahl N %
4	39	20.1	24.5	--
24	75	42.3	53.6	43.5

Source: A. C. Dale, J. R. Ogilvie, A. C. Chang, M. P. Douglass, and J. A. Lindley. 1969. Disposal of dairy cattle wastes by aerated lagoons and irrigation. pp. 150-159. In: Animal waste management (Proceedings, Cornell University Conference on Agricultural Waste Management).

idation ditch from freezing. Special precautions must be taken when starting a ditch in cold weather. The temperature of the liquid should be well above freezing. Some type of heater may be needed in the building near the rotor for the first few weeks to encourage rapid growth of a large bacterial population.

Other aeration devices: Aeration devices other than rotors have been used for aerobic treatment of livestock wastes. These have included propeller jets, jet pumps, compressed-air systems, rotating biological contactors (RBC), and tower biological filters. Each of these devices has special characteristics and can be desirable in a particular installation. On the basis of oxygen transfer per unit of power input, however, the rotor seems most efficient (Mitchell and Day, 1973). The RBC and towers using inert biological support media are best suited for dilute wastes. Person and Miner (1972) described the performance of an RBC unit used to treat the effluent from an anaerobic lagoon being fed swine wastes. Performance on the basis of COD or BOD_5 removal seldom exceeded 40% or 50%, respectively, and lower values than these were more common. The performance of the unit improved as the hydraulic retention time was increased. Moore et al. (1974) used an RBC unit to treat beef wastes in a recycling, refeeding system. The system needed skillful management, and the reductions in BOD_5 and COD achieved were generally disappointing. In both instances, the RBC unit was housed in a heated structure, an additional cost. Caution must be exercised when comparing oxygenation efficiency of various devices because some manufacturers rate their equipment on net power rather than gross power, which is of concern to the consumer. Some devices that would seem to have initial promise, such as the RBC, show unsuspected operating problems when used for livestock waste treatment. Pilot-scale operation for at least one year is essential before any new process or device is adopted for treating livestock wastes. Translation of experience from municipal waste treatment is often meaningless.

Minimum Aeration for Odor Control

For optimum aerobic microbial action, a practical minimum dissolved-oxygen concentration of about 1 mg/l must be maintained. Maintaining this level of oxygen, however, is expensive. It would be advantageous if the operating costs could be reduced for the producer who is only seeking odor control.

Converse et al. (1971) conducted a laboratory study to determine whether odors could be kept at an acceptable minimum if liquid swine manure was minimally aerated so that no residual dissolved oxygen was present. Concentrations of NH_3 and H_2S were used to evaluate odor-treatment efficacy. The study showed that liquid hog manure can be aerated without a dissolved oxygen residual and still maintain relatively odorless conditions when compared with septic liquid manure. However, the oxidation-reduction potential (ORP) in the liquid manure must be maintained by aeration in the range from -300 to -340 mV, and the pH in the range from 7.7 to 8.5. The savings in aeration requirements compared with typical aeration amounts were not conclusively evaluated. The reactor, which showed residual DO most consistently, required an air supply of about 500 cm^3/min. This can be compared with 300 cm^3/min for reactors showing no DO, but an acceptable ORP for odor control.

Aerobic Lagoons

The use of aerobic lagoons, either as evaporation ponds or as an intermediate treatment before some other disposal method, has a place in the livestock industry. Aerobic lagoons are classified by the method of aeration, natural or mechanical. Being aerobic, they do not produce highly odorous gases. This is based on the premise that sufficient oxygen will be supplied to the system to insure the maintenance of an aerobic condition.

Naturally aerated lagoons: The naturally aerated lagoon or oxidation pond is a shallow basin 3 to 5 ft (1 to 1.7m) deep. The oxygen demand of the wastewater is satisfied by aerobic bacteria and protozoa, but these organisms do not depend solely upon reaeration at the surface. A major component of the oxygen consumed by the bacteria and protozoa is produced by algae via photosynthesis (Figure 29). During daylight hours, the CO_2 evolved by bacteria and protozoa is used by the algae, and the photosynthesis may be sufficiently vigorous that the oxygen concentration in the water is supersaturated. Figure 30 shows that most ponds are not totally aerobic; there will normally be a bottom layer of anaerobic sludge whose end products will be aerobically metabolized as they diffuse into the upper zones. Barsom (1973) performed an extensive review of the lagooning of municipal waste. Although municipal wastes are relatively high volume and low strength compared with livestock waste effluents, some of Barsom's comments are relevent. Short circuiting was very prominent on municipal ponds, and this can be traced to two causes. Most ponds are nearly square or circular, and Barsom believed this to be a mistake because multiple small ponds, or a baffled large pond, would much

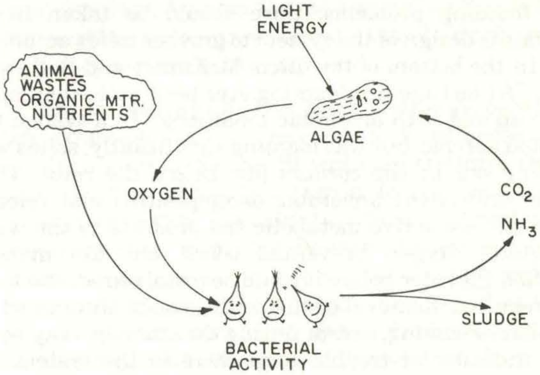

Figure 29. Diagram showing the symbiotic relationship between aerobic bacteria and algae found in naturally aerated waste-treatment ponds.

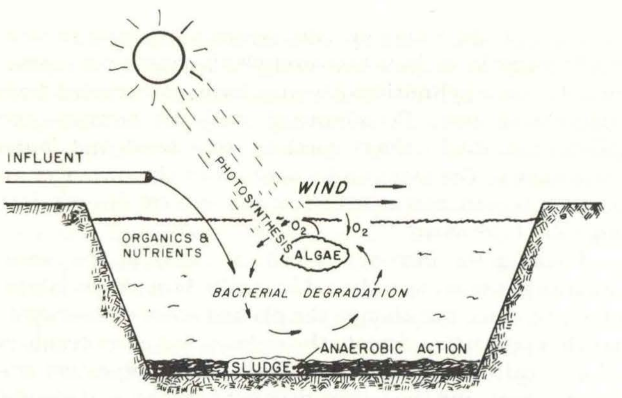

Figure 30. A naturally aerated, waste-treatment pond, showing the zones of algal synthesis, aerobic bacterial action, and anaerobic decomposition in the bottom sludge layer.

reduce the possibility of short circuiting. The other factor is thermal stratification and poor mixing; a thermally stratified pond with a wind directed to the outlet can reduce a designed 30-day detention time to less than 1 hr. Barsom also notes that overloaded ponds can lead to excessive surface algal growth, which, in turn, reduces deep light penetration and, thus, oxygen availability at greater depths. The performance of oxidation ponds with an ice cover also was discussed; effluents high in volatile fatty acids and other anaerobic end products were common. The spring turnover after the ice cover breaks up can lead to an odorous condition because the pond then is susceptible to wind mixing that resuspends the solids deposited during the winter.

Oxidation ponds for livestock wastes will probably find their greatest application when used to treat relatively dilute effluents, such as those from milking parlors or from anaerobic lagoons. It is unlikely that the discharge from an oxidation pond designed for livestock wastes will be acceptable for discharge to a watercourse, unless current federal regulations are changed (U.S. Environmental Protection Agency, 1974). Consequently, the aerobic pond can be justified only under certain special circumstances. Typically, these might be a local limitation on the use of anaerobic lagoons or a desire to provide a better quality water for recycle cleaning of livestock buildings. The odor problem will exist for a short period during the spring in most northern states so that the oxidation pond should not be chosen if no odor is acceptable at any time.

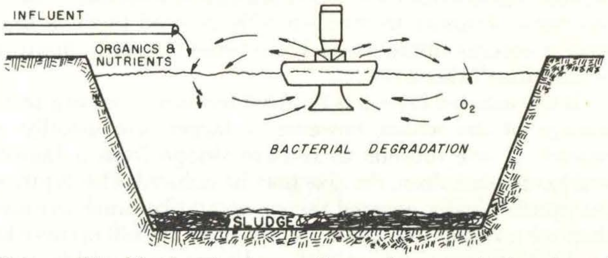

Figure 31. Mechanical aeration of a waste-treatment pond with a floating surface aerator.

The parameter of concern for a livestock-waste pond will be ultimate BOD per unit area and time. A realistic value in the northern states would be 45 lb BOD_L/ac-day (49 kg/ha-day), higher values may be acceptable in southern states where ice cover is not expected. Table 20 gives recommended pond sizes for certain animal species in the Midwest. The table is based on the assumption that urine and feces enter the pond. If solid-liquid separation is practiced, then the area required can be reduced. The reduced area will depend upon the solid-liquid separation process used. Oxidation ponds, particularly those used for raw wastes, may require solids removal after several years.

Table 20. Guidelines for calculating the surface area required for naturally aerated lagoons used for treatment of livestock wastes in the Midwest.

Animal	Surface area[b] per unit animal weight	
	ft^2/lb	m^2/kg
Poultry	3.4	0.72
Swine	1.9	0.40
Dairy cattle	1.6	0.35
Beef cattle	1.5	0.31

[a] Based on a daily BOD_5 loading rate of 45 lb/ac (49 kg/ha) and that the manure enters the pond daily and is well distributed. When these last two criteria cannot be satisfied, the lagoon area should be increased.

[b] To maintain good photosynthetic activity, the pond depth should not exceed 4 ft (1.2 m).

Successful oxidation-pond operation will depend on both good initial design and adequate routine maintenance. Banks should be mowed, and kept free of weeds on the water side; cut vegetation should not be allowed to fall in the pond. A true oxidation pond is not an evaporation basin. Arid areas may require make-up water to control salinity. Mixing will be more effective as the pond depth decreases, the optimum range is probably between 2 and 4 ft (0.6 and 1.2 m). Virtually all livestock waste ponds will seal because of the anaerobic sludge layer that will form; this sealing may be very slow, however, for a lightly loaded pond in a porous soil. Because of the possible danger of groundwater contamination, a porous soil should be sealed with bentonite or clay during construction.

Mechanically aerated lagoons: In mechanically aerated lagoons, oxygen is furnished by some mechanism that "beats" or blows air into the water with a portion of the oxygen being dissolved. The mechanically aerated lagoon, therefore, is not dependent on natural aeration,

Table 21. Suggested water volume of a mechanically aerated lagoon for long-term detention.

Animal	Volume per unit animal weight	
	ft^3/lb	m^3/kg
Poultry	0.75	0.45
Swine	1.00	0.60
Dairy cattle	1.25	0.75
Beef cattle	0.75	0.45

the wind, or algae growth, for the oxygen supply. Thus, the design criteria (surface dimensions and depth) differ greatly from those of the naturally aerobic lagoon. Figure 31 illustrates an aerated lagoon with a floating surface aerator. Satisfactory aerobic treatment of livestock wastes has been obtained in mechanically aerated lagoons that have a volume approximately 50 times the daily manure production (Table 21).

If the aerated lagoon is for final treatment or long-term storage of the waste, however, a larger size usually is needed. If one intends to remove sludge from a lagoon yearly or more often, the size may be reduced. The depth of the mechanically aerated lagoon should be much greater than for an oxidation pond. Depths up to 20 ft (6 m) may be used satisfactorily where soil conditions are suitable, thus reducing the surface area required for any given volume.

For continuous operation, a mechanical aerator that will provide an oxygenation capacity of 1.5 times the total daily BOD_5 loading is the minimum size recommended. If the operation is to be intermittent (off in the extremely cold months, such as December, January, and February), the aerator should have an oxygenation capacity of at least twice the daily BOD loading. For partial odor control, a lesser oxygen supply of one-third to one-half the daily BOD_5 loading may be beneficial. Where this technique is used, it is desirable to restrict the mixing and aeration of the mechanical aerator to the upper third of the lagoon. A low rate of aeration reduces the release of many volatile acids and the accompanying gases. Generally, ammonia production is not stopped, and the odor is still detectable. Although it is not clearly understood, the pH is raised, with the low aeration rate preventing the release of H_2S, but ammonia release will be increased.

There are numerous methods for aerating lagoons. Floating aerators seem satisfactory, but other schemes, such as compressed air entering through diffusers (perforated pipes), also work. Some manufacturers of floating aerators guarantee an oxygenation capacity of about 3.2 lb 0_2/hp-hr (2 kg 0_2/kW-hr) under standard conditions.

General considerations: With an aerated-lagoon system for the treatment of livestock wastes, consideration must be given to the entire system. Some means of routine flushing of the wastes into the lagoon must be provided. In most installations, daily flushing is desirable to prevent odor production from shock loads. Arrangements may be made to use water from the lagoon for channel or floor flushing to reduce the amount of water requiring disposal or when other adequate water supplies are not available.

The actual layout of the lagoon may be varied and depends partly on the available site. A round or oblong shape, depending on the number of aerators to be used, would be the most desirable for good mixing. The lagoon should be located near the livestock area to limit piping costs and plugging problems. Another factor that should be considered in the location of the lagoon is the soil. The lagoon should be located in a tight, preferably clay, soil to prevent leakage and groundwater contamination. If such a soil is not available, arrangements should be made to waterproof the lagoon sidewalls and bottom. Sodium carbonate mixed with clay soil has been found to be a good waterproofing mix, as have bentonite clay and other commercial materials. The use of soil cement or the installation of a plastic lining are also accepted practices in sealing lagoons. Iowa State University[18] also has found it practical to use a cylindrical aeration basin constructed from concrete or steel. Porcelainized steel silo sections and galvanized steel culvert sections were tried and found satisfactory. The steel units were set in the corner of an earthen lagoon, and an overflow weir was cut directly into the side of the basin.

Loading the lagoon is a critical factor in the maintenance of proper operation. Unusually large loads (slugs) of waste materials change the pH and other environmental characteristics, deplete the oxygen, and often result in what is called a "shock load." The biological digestion process is upset, and the lagoon does not function as it should. The most desirable loading system feeds the lagoon (bacteria) with a steady, continuous feed in such quantity as to balance the feed, the microflora, and the oxygenation capacity. Daily loading is satisfactory, but more frequent loading is desirable.

The mechanically aerated lagoon should be aerated continuously since aerobic conditions exist only when oxygen is freely available. When oxygen is not available, the growth and reproduction of aerobic bacteria are inhibited, and anaerobic conditions develop. If this condition persists, the whole system is "upset," and considerable time is required to return to the normal aerobic condition once the aerator is restarted. Part of this problem occurs because storage of dissolved oxygen in the water is limited by its saturation value. The oxygen saturation range is only about 6-9 mg/l of oxygen. After saturation, additional oxygen is not held by the solution, and further aeration is of little use and would add unnecessary expense. The ideal system, then, is one in which the capacity of the aeration device matches the oxygen demand of a uniformly fed waste. The matching should be designed to maintain between 1 and 2 mg/l DO. The aerator should have some reserve capacity to accommodate shock loads, but excessive reserve capacity should be avoided. Because the power demand of a mechanical aerator is more directly related to its hydraulic characteristics than to its instantaneous oxygen transfer rate, an oversize aerator will dissipate unnecessary power just pumping the waste. It will generally prove more economical to employ multiple units rather than one large unit because simultaneous malfunction of all the units is unlikely; also, the number of aerators used can vary with the season of the year. Lest this should seem poor use of equipment, note that 1 hp (0.75 kW) of floating aerator capacity will cost about $750, and running and maintenance will cost about $250 annually. Thus, running and maintenance is an appreciable fraction of the cost.

Cold-weather aeration. The rate of bacterial decomposition is slowed as the temperature decreases. Below 50°F (10°C), bacterial action is greatly reduced, and below 36°F (2°C), there is little activity. On this basis, it seems that little decomposition is accomplished by operating aerators in extremely cold weather. The aerator should be started as soon as the temperature begins to warm in the spring, however, so that aerobic bacterial action can be reestablished. Some objectionable odors can be expected during the start-up period.

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[18] Iowa State University. Designs for the Agricultural Experiment Station Engineering Services. Ames.

A 2-hp (1.59-kW) floating aerator operating in a 6-ft (2-m) deep lagoon at the Purdue University Dairy Farm did not freeze up during the winter of 1967-68, but there was little evidence of bacterial activity during that period. Ice piled up around the aerator, and its efficiency was probably impaired. A similar situation was observed at the University of Illinois during the 1968-69 winter (D.D. Jones et al., 1971b). The type of aeration device chosen for winter operation may be important. G.B. Parker et al. (1973) tested a downdraft, induced-aspiration device. Figure 32 shows this device in use on an outside aeration basin. The basin was fed intermittently with slug loads of swine waste through the winter. Parker et al. reported that the unit was able to operate all winter without any icing in the immediate vicinity of the float; a change in outside air temperature was reflected quite rapidly by a change in liquor temperature; daytime liquor temperatures in excess of 40°F (4°C) were quite common in January, and the reduction in COD of the basin contents usually exceeded 60% during the same month. Incidentally, G.B. Parker et al. indicated that conventional updraft aerators would ice up and require removal during a normal Iowa winter.

Removal of sludge and surplus water: Considerable decomposition of organic solids occurs in aerobic lagoons. Although the rate of decomposition is greatly reduced after some 30 days, decomposition does continue, and it is believed that, in a period of 1½ to 2 yr, the volatile solids may be reduced as much as 60%-70%.

Even with good degradation, however, solids (sludge) will accumulate in the lagoon until removal is necessary; the rate of sludge buildup depends upon the size of the lagoon in relation to the manure added and the breakdown that occurs. The sludge will contain considerable nutrients and may be removed and applied directly on cropland. Late fall seems a good time for removal of sludge from aerobic lagoons. The solids are the most stabilized at that time, and the odors are low if the lagoon has been well aerated during the previous 7 to 8 mo. A vacuum tanker or sewage pump can be used to remove sludge from the bottom of a lagoon. If the sludge has compacted, an auger may be used for stirring and mixing.

When excess water must be removed from a mechanically aerated lagoon, irrigation with the mixed liquor is desirable. Sludge buildup is not a problem because suspended solids are removed by the irrigating unit.

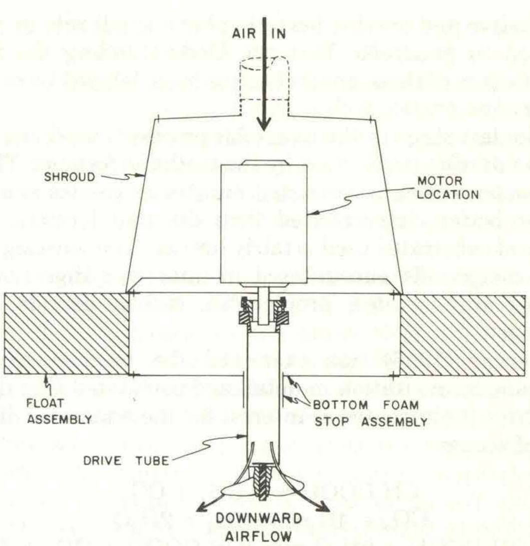

Figure 32. Downdraft, induced-aspiration aerator for use in an outside aeration basin.
Source: G.B. Parker, R.J. Smith, R.S. Blough, and A.R. Mann. 1973. The use of an induced aspiration device for winter operation of unprotected aerated lagoons. ASAE MC-73-303. American Society of Agricultural Engineers, St. Joseph, Michigan.

Harvesting Protein for Refeeding

The aerobic process can result in the production of protein and amino acids that are desirable for refeeding as a protein supplement. The nutritive value of aerobically treated livestock and municipal wastes has been discussed by Day and Harmon (1972). The proteinaceous material is in the very small particles and is essentially single-cell protein resulting from the aerobic biological process. Holmes et al. (1971) have shown that it can be concentrated by centrifuging, but Day and Harmon (1972) have shown that the oxidation ditch mixed liquor can be refed without prior dewatering. Direct refeeding of the ditch liquor to the same animals that provided the waste will much simplify the expenses of transport, storage, further processing, and packaging.

ANAEROBIC TREATMENT

The Anaerobic Process

The objective of waste-stabilization processes is to satisfy the oxygen demand of the waste in a controlled fashion. In the aerobic process, this is performed biologically in the presence of dissolved oxygen, but in the anaerobic process, the waste's oxygen demand is not satisfied oxidatively but converted into a different form, methane gas, CH_4. This methane releases energy when burned, and, because methane is easily stored without putrefaction, anaerobic digestion for methane production is a potentially attractive waste-treatment process. Such intensive anaerobic waste treatment has not been accepted for agricultural wastes, however, because the equipment is quite complex, and skilled management is required.

Chemistry and biology: The composition of animal wastes is variable, but certain classes of compounds predominate, carbohydrates and polysaccharides, proteins, lipids, and inorganic matter. The first stage in the anaerobic process is performed by bacteria classed as acid formers. This group consists of facultative and anaerobic bacteria that split the first three classes of organic compounds into short-chain fatty acids, ammonia, and carbon dioxide. Although various fatty acids may be present, McCarty (1964a) has indicated that acetic acid predominates, followed by propionic acid, with the others being present in much lower concentrations. The acid-forming bacteria are not well characterized and probably vary according to the nature of the waste. Kirsch and Sykes (1971), in an extensive review, concluded that facultative and aerobic bacteria play a small role in comparison to anaerobic bacteria. Understanding the true significance of these anaerobes has been delayed by inadequate enumeration techniques.

The last stage in the anaerobic process is methane and carbon dioxide production by the methane formers. These are bacteria from a restricted number of species and are rather better characterized than the acid formers. The range of substrates used is fairly limited. The most significant compounds encountered in anaerobic digestion of wastes are acetates, propionates, carbon dioxide, and hydrogen.

Barker (1956) has examined the biochemistry of methane fermentation in detail and postulated that there are three main routes of interest for the anaerobic digestion of wastes.

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

$$4CH_3CH_2COOH + 2H_2O \longrightarrow 4CH_3COOH + CO_2 + 3CH_4$$

Jeris and McCarty (1965) have shown that long-chain fatty acids can be fermented via β-oxidation. This entails removal of a two-carbon fragment from the end distant from the carboxyl and the conversion of this to acetate, which is then fermented to CO_2 and CH_4 by methane formers. Since hydrogen is produced during the β-oxidation, this may be combined with CO_2 to form more methane.

When a waste containing a variety of organic compounds is digested anaerobically, the major components of the gas produced are CO_2 and CH_4, and these usually are in the proportions 25%-40% and 75%-60%, respectively. C.D. Parker and Skerry (1968) have measured up to 20% H_2, but this would seem a transient phenomenon associated with inhibition of the methane fermentation.

Buffering: Lawrence and McCarty (1969) indicated that, in digesters operated at 95°F (35°C) or less, the methane formers have much longer generation times than the acid formers. Hence, a slug load of waste, which could be readily converted to fatty acids by the acid formers, might drastically lower the pH. Barker (1956) indicated that most methane bacteria are severely inhibited outside the pH range 6.4 to 7.2; thus, any rapid production of an excess of volatile fatty acids could seriously unbalance digestion. The methane formers would not be capable of reproducing fast enough to metabolize the fatty acids as they were produced. Rapid changes in pH will be moderated if the digestion liquor contains satisfactory buffering capacity. In the pH range in which we are interested, the bicarbonate/carbonic acid system forms a good buffer. The equilibrium equation may be written as

$$[H^+]\,[HCO_3^-]/[H_2CO_3] = K = 4.3 \times 10^{-7}$$

$$= 10^{-6.37} \text{ at } 77°F\ (25°C)$$

which indicates that, if equimolar concentrations of H_2CO_3 and some suitable salt $MHCO_3$ are present, the pH will be 6.37 at 77°F (25°C). Fortunately, most wastes are sufficiently diverse in composition that the cation requirement M^+ is easily provided by Na^+, K^+, Ca^{+2}, Mg^{+2}, or NH_4^+. In wastewater systems, the buffering capacity is related to alkalinity. Standard Methods (American Public Health Association, 1971) now defines alkalinity as the amount of acid required to lower the pH of the solution to 3.7. This quantity of acid is then expressed as if all the alkalinity were in the form of $CaCO_3$. McCarty (1964b) suggested that an alkalinity in the range of 2500-5000 mg/l was desirable for the stable operation of a municipal digester with about 30% CO_2 in the atmosphere above the digesting liquor. A lagoon, which is open to the atmosphere, might be able to sustain a bicarbonate alkalinity of only 250 mg/l at neutral pH because the CO_2 content of the atmosphere over a lagoon is unlikely to exceed 1%. Air of normal composition has a CO_2 fraction of 0.03% (Threlkeld, 1962). McCarty (1964b) also noted that volatile acids will contribute to alkalinity, and this may be verified by observing that Willrich (1966) found that the alkalinity of a swine lagoon varied from 800 to 1600 mg/l, while the volatile acid concentration varied from 100 to 700 mg/l.

Toxicity: Because anaerobic digestion is a microbial process, any substance that inhibits microbial action should be kept out of the digester. The toxic materials of immediate concern are the heavy metals, such as nickel, chromium, and copper. Although they may be toxic in low concentrations, they are not often a problem in digesting livestock wastes because they are present only in small quantities (copper and zinc probably are the most significant), and they usually are rendered insoluble in the presence of sulfides derived from proteolysis. McDermott et al. (1963) found that normal gas production could be maintained in laboratory-scale digesters with up to 10 mg/l copper ion in the primary sludge being fed. Any higher copper concentration inhibited methane production. They also measured 0.7 mg/l soluble copper in normally functioning digesters. Because of this known toxicity of copper, it is unlikely that successful methane production would be possible from swine units that use copper as a chemotherapeutic agent in the ration. But a report by Hobson and Shaw (1975) suggests other factors become inhibitory before copper.

McCarty (1964c) noted that high concentrations of the alkali metals (Mg, Ca, Na, K) also could be toxic to bacteria. Although the effects of the various cations are not clearly defined when they are combined, it would seem that Ca, N, and K are inhibitory in concentrations above 8000 mg/l and that Mg is inhibitory above 3000 mg/l. Although such high concentrations are not common in anaerobic treatment systems for livestock wastes, there is one rather obvious exception. High levels of NaCl are common in beef-cattle rations, and this could lead to an inhibitory effect when using anaerobic lagoons in the more arid parts of the country.

Two nonmetallic substances are of concern. Livestock wastes containing a higher nitrogen: carbon ratio than primary municipal sludge may encounter ammonia toxicity problems. McCarty (1964c) indicated that 1500-3000 mg/l of NH_3-N might show an inhibitory trend and that concentrations above 3000 mg/l were toxic to the methane formers. Schmid and Lipper (1969) verified this during attempts to load laboratory digesters with swine manure at more than 0.2 lb VS/day-ft^3 (3.2 kg VS/day-m^3); measurements of ammonia-N exceeded 2000 mg/l, and the off gases were only 20% or less methane.

McCarty (1964c) also mentioned that soluble sulfides in excess of 200 mg/l as S were toxic. The amount of sulfide that can exist in solution is related to the amount of heavy metals in the waste and also to the pH. It is unlikely that soluble sulfide toxicity will be a problem for livestock wastes as far as bacterial inhibition is concerned, but odor problems from H_2S evolution may arise. This odor problem may be particularly acute in areas where the water is high in sulfate inasmuch as sulfate is rapidly reduced to sulfide in an anaerobic environment.

Temperature: The temperature ranges preferred by various species of bacteria fall into three groups: psychrophilic, 23° - 95°F (-5° - 35°C); mesophilic, 64° - 113°F (18° - 45°C); and thermophilic, 113° - 185°F (45° - 85°C) (Pelczar and Reid, 1965). The methane formers in anaerobic waste digestion exist only in the mesophilic and thermophilic groups. Imhoff and Fair (1940) indicated that the peak activity of the mesophilic bacteria was at 97°F (36°C) and that for the thermophilic bacteria was at 130°F (54°C). Municipal practice has essentially been restricted to the mesophilic range because the improved performance obtained by operating digesters at 130°F (54°C) does not justify the extra heating required to maintain the system at this temperature. Current municipal practice in the United States employs heated, often mixed, digesters held at temperatures very close to the peak for mesophilic methane formers. Consequently, there is little information on anaerobic digestion at low temperatures. When the Imhoff tank, an unheated combined sedimentation-digestion tank, was in use (1906-1940), Imhoff and Fair studied gas production at various temperatures below 97°F (36°C). The results of these tests are shown in Figure 33.

It can be seen that active methane formation is still progressing at 50°F (10°C), but Imhoff and Fair indicated that, if the temperature fell below 40°F (4°C) for an extended period, gas production would cease. Because batch digestion is not representative of modern practice, the data in Figure 33 have limited design use. O'Rourke (1968) has reexamined digestion at low temperatures in relation to kinetic models for waste stabilization. In general, his results confirm those of Imhoff and Fair (1940), except that O'Rourke indicated that, at 59°F (15°C), methane production is drastically reduced and that efficient digestion did not take place, even with a 60-day detention period.

Anaerobic digestion of livestock wastes has been conducted with minimal heat input. It is possible that a low

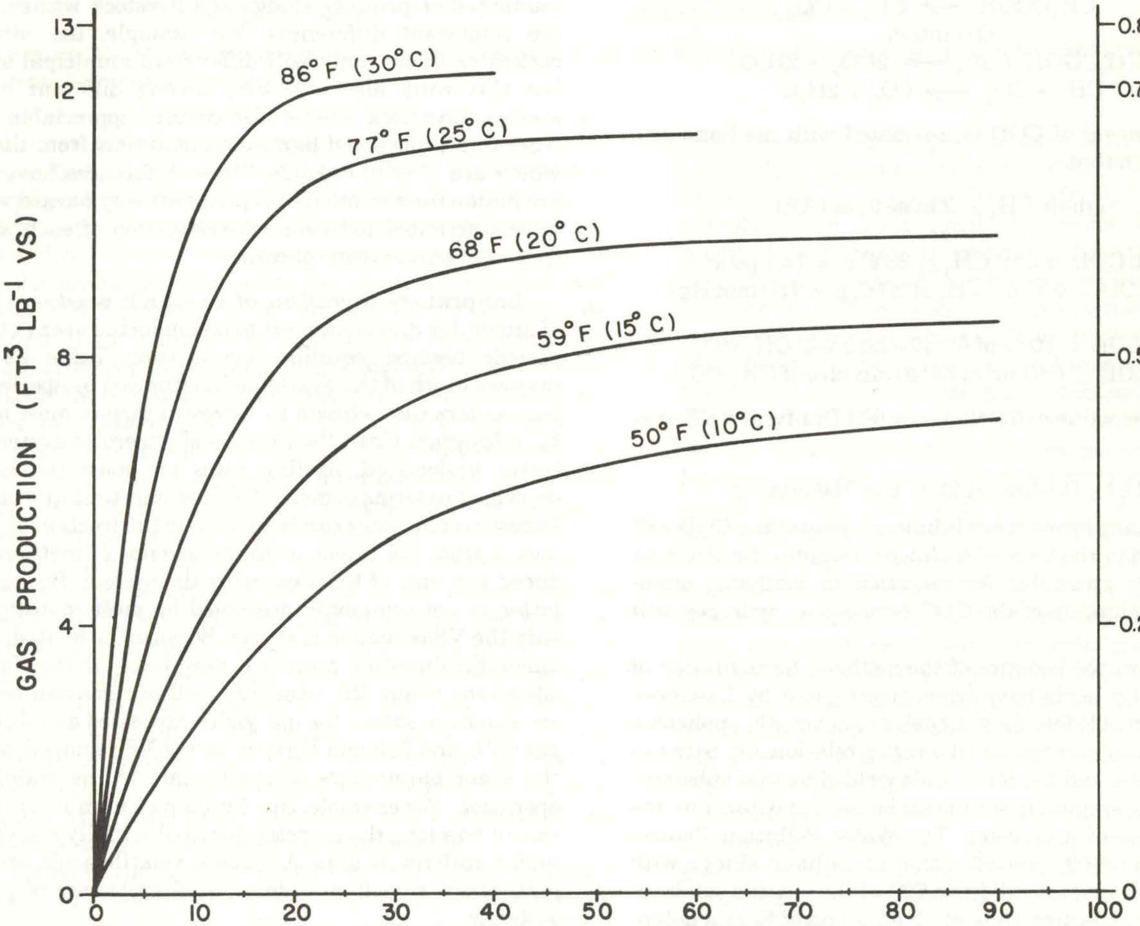

Figure 33. Gas production from batch-fed anaerobic digesters when operated at temperatures from 50° to 86°F (10° to 30°C).

Source: K. Imhoff, and G.M. Fair. 1940. Sewage treatment. John Wiley and Sons, Inc. New York.

limit of 50°F (10°C) might be achieved in relatively simple structures by judicious use of insulation. If active methane fermentation is proceeding, then highly objectionable odors are absent.

Gas production and system performance: The performance of an anaerobic digestion system has been described in terms of various parameters, BOD, COD, and VS. Although the BOD_5 parameter may be useful for easily biodegradable material, its usefulness for raw livestock wastes containing large quantities of cellulosic material, hair, and other poorly aerobically degraded substances is doubtful. Consequently, the more useful parameters for describing the performance of anaerobic systems are COD and VS. In many instances, these two parameters will show a fairly constant ratio. Because any solids measurement implies drying at 217°-221°F (103°-105°C), some volatile oxygen-demanding materials will be lost. Thus, COD may prove the best indicator of treatment efficiency. COD can be measured in a modestly equipped laboratory. The relation between COD removed from the liquid-waste stream and the gas produced is most clearly seen by examination of the digestion of acetic acid.

Anaerobic digestion

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

Oxidation

$$CH_3COOH + 2O_2 \longrightarrow 2CO_2 + 2H_2O$$

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Hence, removal of COD is associated with methane production such that

$$1 \text{ mole } CH_4 \equiv 2 \text{ mole } O_2 \text{ as COD}$$

or

$$1 \text{ lb COD} \equiv 6 \text{ ft}^3\ CH_4 \text{ at } 68°\text{F}, p = 14.7 \text{ psia}$$

$$(1 \text{ kg COD} \equiv 0.37 \text{ m}^3\ CH_4 \text{ at } 20°\text{C}, p = 760 \text{ mm Hg})$$

or

$$1 \text{ lb COD} \equiv 10 \text{ ft}^3 \text{ of } 60/40 \text{ mixture of } CH_4/CO_2$$

$$(1 \text{ kg COD} \equiv 0.62 \text{ m}^3 \text{ of } 60/40 \text{ mixture of } CH_4/CO_2)$$

Calorific value of 60/40 gas = 600 Btu/ft^3 at 68°F, p = 14.7 psia

$$(2.24 \times 10^7 \text{ J/m}^3 \text{ at } 20°\text{C}, p = 760 \text{ mm Hg})$$

If the methane formers are inhibited, some of the COD will be removed in the form of hydrogen. Because the objective is complete anaerobic fermentation to methane, quantitative evaluation of the COD removed as hydrogen will be ignored.

Although the kinetics of the methane fermentation of volatile fatty acids have been investigated by Lawrence and McCarty (1969), their models are not easily applicable to complex substrates. Until a better relationship between the substrate and the fatty acids yielded by that substrate is obtained, empirical data must be used to determine the performance of a digester. The Water Pollution Control Federation (1959) indicated that an influent sludge with 85% volatile matter will have 60% of the volatile solids reduced at a detention time of 15 days and 85% at a detention time of 70 days. Digestion temperatures were from 85°-95°F (29°-35°C). Information on the performance of anaerobic lagoons is not so well summarized.

Carbon dioxide and methane are not the only gases produced during anaerobic digestion. With anaerobic lagoons, ammonia is lost (Koelliker and Miner, 1973). Lagoons generate offensive odors in the spring. The composition of these odors is not well established and is currently being investigated.

Heated Mixed Digestion

Municipal equipment: Most municipal waste-treatment plants use a heated anaerobic digester, which supplies gas to an engine or a boiler. In larger cities, these digesters are often two-stage units in which the first stage is both heated and mixed and the second stage serves to separate the solids, liquids, and gases by natural classification. A schematic of such a two-stage system is shown in Figure 34. The complexity of the system has tended to restrict its use to cities that can afford competent management and maintenance. Also, comprehensive anaerobic digestion equipment is expensive; for example, R. Smith (1968) indicated that a 50,000-ft^3 (1400-m^3) digestion tank would cost $70,000 and that the cost of the sludge heat exchanger would add $7,000 to that figure. R. Smith's data also show, as expected, that there are considerable economies of scale.

Although there are many similarities between municipal or primary sludge and livestock wastes, there are important differences. For example, the nitrogen: carbon ratio, not only will differ from municipal sludge, but this ratio also will vary among different animal species. Livestock wastes also contain appreciable quantities of cellulose and lignaceous materials from the feed, which are slow to degrade. These differences have made prediction from municipal experiences very hazardous and have warranted individual investigation of each animal species of commercial concern.

Laboratory digestion of livestock wastes: Studies of anaerobic digestion need to be conducted over extended periods because equilibration is slow. Table 22 summarizes much of the available information by species. The parameters were chosen to represent factors most needed by a designer. Until the kinetics of anaerobic systems are better understood, loading rates are most consistently described in terms of mass of VS per unit time and volume. Digestion efficiency can be related to the fraction of VS removed from the liquor or to the amount of methane produced per unit of COD entering the system. Because the latter is not commonly presented by most investigators, only the VS reduction is shown. Because the heated, mixed anaerobic digestion process is most likely to find favor in situations where the resulting methane gas can be used, we also have shown the gas yields expressed as volumes of gas (0°C and 760 mm Hg) per unit of VS removed. Most of the other parameters selected relate to the stability of operation. For example, the duration column is an indication of how long the investigator cited actually ran the test under uniform loading. Ammonia, volatile acids, and CH_4 percentage are all considered good indicators of process stability.

All the investigations listed are on the laboratory scale, using digesters ranging from 5 to 200 liter capacity. The major difference between the various investigations was the degree of mixing used. "Natural" indicates that no

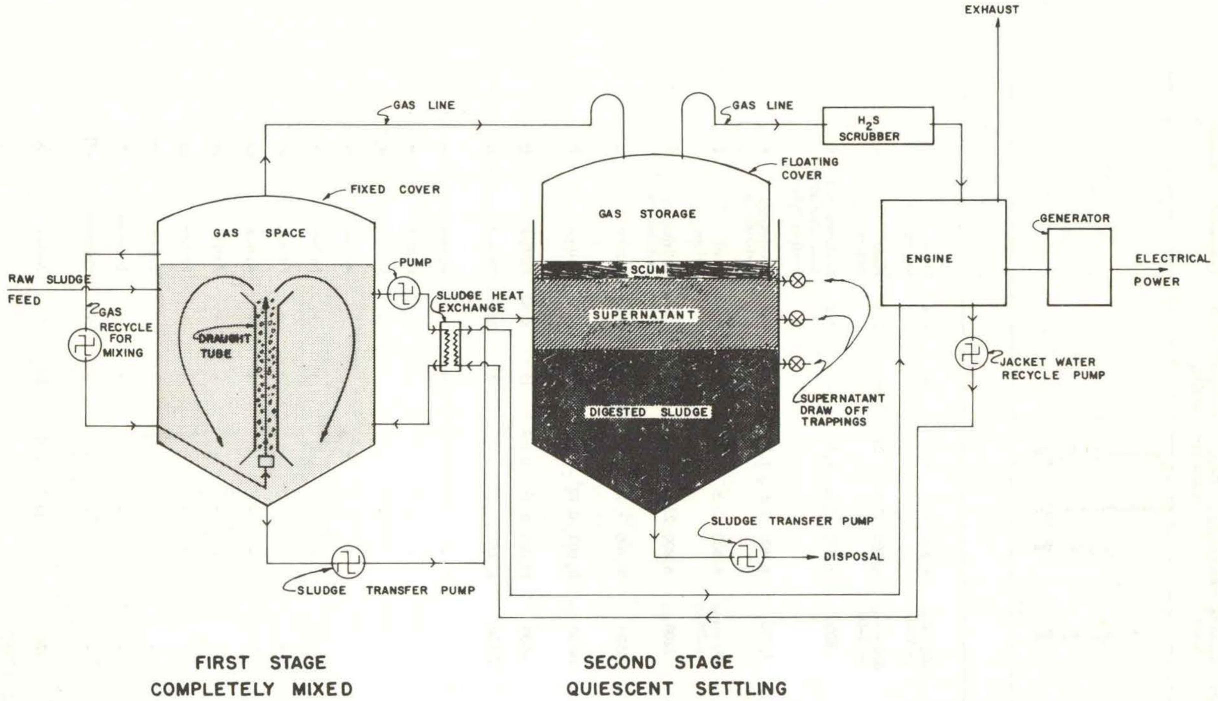

Figure 34. Mixed and heated two-stage anaerobic digester, equipped with appurtenances for methane produced from fermentation of organic slurries.

deliberate stirring was used and that any mixing came about from gas evolution. "Intermittent" indicates that the digesters were manually stirred, usually once or twice each day. The methods of "continuous" mixing were varied, but the end results, continual exposure of substrate to the microbial flora, were the same. All systems used batch loading, mostly once each day. Gas measurements varied from using a constant-volume head space and measuring pressure change (e.g., Taiganides, 1963) to displacement of a confining salt solution under constant pressure (e.g., Meenaghan et al., 1970). There may be some slight differences in the amount of ammonia carried over with the off gases, depending upon the collection method used, but the consensus of the investigators was that very little nitrogen was lost from their systems.

Most investigators were interested in the conventional engineering parameters outlined in the tables; Schmid and Lipper (1969), however, also were concerned with the digestion as a means of improving the flow properties of manure. They indicate that suspended solids were reduced 30%-37% and that the material changed from "consistency similar to a thick milk shake" to being "very liquid, similar to water." They also observed that no settling would occur in the raw manure, but would in the digested liquor. The liquid from a pilot-scale unit was used to flush floors without being judged too objectionable.

Most of the work reviewed was restricted to optimum mesophilic temperatures near 95°F (35°C), but Hart (1963) and Cross and Duran (1970) did examine digestion at 74°F (23°C) and 70°F (21°C), respectively.

Design criteria for anaerobic digesters: We conclude that loading rates and detention times must be chosen critically. Adequate alkalinity, much of it in the form of ammonium compounds, must be available, but the total NH_3-N should not exceed 1500 mg/l and should preferably lie in the range of 1000 to 1400 mg/l. Loading rates and detention times will determine NH_3-N levels. Inasmuch as nitrogen is conserved, if the fraction of total N as NH_3-N in the effluent is known, it is possible to estimate the NH_3-N concentration expected in the digesting liquor from knowledge of the total N in the feed. Detention times seem more critical than loading rates in terms of VS destruction and gas production. The design detention time chosen would seem species-dependent because the amount of CH_4 produced per unit input of VS depends upon the species and increases with increasing detention time. The information cited in Table 22 was used to formulate recommended loading rates and detention times to control excessive volatile acid production, or ammonia toxicity, or both. These data are presented in Table 23. The values are founded on our best current judgment and should be regarded as useful guidelines rather than as absolute values. The uncertainties relate to variations in manure parameters and also to the fraction NH_3-N/Total N expected in the digested effluent; however, the values all fall within limits of actual active digestion tests outlined in Table 22.

Fecal parameters will vary according to ration and management practice. The parameter showing the greatest variation among investigators is the wet weight of the manure. Undoubtedly, many investigators are unavoidably including some wash water and waterer spill. Because dilution will be required for all species except the dairy cow, water use and manure production should be examined by field tests if anaerobic digestion for gas production is planned. The ammonia toxicity problem must be

Table 22. Performance of heated anaerobic digesters used on livestock wastes.

Manure	Loading		Temperature		Duration[a]	Detention[b]	Mixing			VS Reduction	COD Reduction	COD Influent		$(NH_3 + NH_4^+)$-N	Volatile Acids	Alkalinity	Gas Production		Fraction as CH_4	pH	Comments[d]	Source
	lb VS/day ft^3	kg VS/day m^3	°F	°C	Day	Day	Natural	Intermittent	Continuous	%	%	mg O_2/mg VS	mg/l	mg/l	mg/l as HAc	mg/l as $CaCO_3$	ft^3/lb VS removed	m^3/kg VS removed	%			
												Swine growing - finishing										
Urine and feces	0.12	1.9	93	34	40	25			X	54	-	1.32	-	1000 rising to 1800	800 rising to 3200	6,800	16.1	1.01	59	7.4	Final failure	ι
"	0.11	1.8	93	34	35	37			X	52	-	1.32	-	1200 rising to 2000	800 rising to 3400	6,800	17.5	1.09	59	7.4	Final failure	ι
"	0.06	0.96	93	34	30	25			X	41	-	1.32	-	900	800	6,800	22.6	1.41	-	7.2	Exploded, not associated with loading failure	ι
"	0.075	1.2	93	34	110	22			X	47	-	1.32	-	1300	1,500	6,800	19.6	1.23	59	7.4	Satisfactory performance	ι
"	0.12	1.9	93	34	20	40			X	54	-	1.32	-	1400 rising to 1800	800 rising to 2800	6,800	16.8	1.05	59	7.4	Final failure	ι
"	0.025	0.4	93	34	40	48			X	43	-	1.32	-	1200	1200	6,800	23.5	1.47	50	7.4	Satisfactory performance	ι
"	0.2	3.2	95	35	-	20			X	-	-	-	-	1800	16500	10,700	1.0[c]	0.062	30 falling to 15	6.65	Failure	θ
"	0.4	6.4	95	35	-	20			X	-	-	-	-	1800	19000	11,800	0.92[c]	0.057	30 falling to 15	6.75	Failure	θ
"	0.2	3.2	68	20	-	20			X	-	-	-	-	2200	16800	15,000	0.3[c]	0.019	15	6.80	Failure	θ
"	0.4	6.4	68	20	-	20			X	20	-	-	-	2500	17500	15,000	-	-	15	6.90	Failure	θ
Solids from pen floor	0.05	0.8	50	10	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Active	α
"	0.1	1.6	50	10	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Failure	α
"	0.2	3.2	50	10	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Failure	α
"	0.05	0.8	70	21	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Active	α
"	0.1	1.6	70	21	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Failure	α
"	0.2	3.2	70	21	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Failure	α
"	0.05	0.8	90	32	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Active	α
"	0.1	1.6	90	32	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Active	α
"	0.2	3.2	90	32	15	15		X		-	-	-	-	-	-	-	-	-	-	-	Failure	α
Liquor passing through a 60 mesh screen	0.115	1.8	95	35	10	20			X	34	43	-	1,500	-	-	-	-	-	-	-	Unknown	η
	0.16	2.6	95	35	15	10			X	20	38	-	4,200	-	-	-	-	-	-	-	Unknown	η
	0.34	5.4	95	35	10	5			X	40	44	-	5,500	-	-	-	-	-	-	-	Unknown	η
Urine and feces	0.154	2.5	95	35	13	20	X			53.4	-	-	-	-	126	-	16.3	1.02	68	7.4	Active	δ
Blended in blender	0.176	2.8	95	35	13	20	X			61.5	-	-	-	-	514	-	-	-	68	7.47	Active	δ
"	0.194	3.1	95	35	16	20	X			61.5	-	-	-	-	3290	-	9.72	0.61	-	7.4	Failing	δ

Table 22. Performance of heated anaerobic digesters used on livestock wastes (continued).

Manure	Loading		Temperature		Duration[a]	Detention[b]	Mixing			VS Reduction	COD Reduction	COD Influent		$(NH_3 + NH_4^+)$-N	Volatile Acids	Alkalinity	Gas Production		Fraction as CH_4	pH	Comments[d]	Source
	lb VS/day ft^3	kg VS/day m^3	°F	°C	Day	Day	Natural	Intermittent	Continuous	%	%	mg O_2/mg VS	mg/l	mg/l	mg/l as HAc	mg/l as $CaCO_3$	ft^3/lb VS removed	m^3/kg VS removed	%			
Swine growing - finishing (cont.)																						
Manure scraped from solid floor	0.12	1.9	91	32.5	-	10		X		51.6	33.7	-	23,300	450	1090	2,960	7.9	0.49	60.8	6.76	Active	β
	0.12	1.9	90.5	32.5	-	15		X		60.9	54.6	-	35,000	594	200	4,440	11.1	0.69	60.0	7.14	Active	β
"	0.24	3.8	90.5	32.5	-	10		X		44.2	35.5	-	46,000	730	1080	6,330	13.2	0.83	58.0	7.17	Active	β
"	0.24	3.8	90.5	32.5	-	15		X		59.2	41.8	-	70,000	1010	290	7,130	12.2	0.76	59.0	7.27	Active	β
Dairy																						
Urine and feces	0.132	2.1	74	23	37	25.7		X		11.2	-	1.00	-	1040^{e}	1000	8,000	11.0	0.69	52	7.3	Active	γ
"	0.132	2.1	95	35	37	26.3		X		15.4	-	1.00	-	924^{e}	200	7,000	16.2	1.01	64	7.8	Active	γ
"	0.202	3.1	74	23	37	26.3		X		10.4	-	1.00	-	1240^{e}	1000	8,000	16.1	1.01	64	7.5	Active	γ
"	0.215	3.4	95	35	37	25.3		X		16.3	-	1.00	-	1160^{e}	500	9,000	14.3	0.89	58	8.0	Active	γ
"	0.155	2.5	95	35	20	20	X			42.0	-	-	-	-	164	-	6.39	0.4	65	7.1	Active	δ
"	0.176	2.8	95	35	16	16.6	X			48.3	-	-	-	-	162	-	6.15	0.38	65	7.1	Active	δ
"	0.185	3	95	35	18	16.6	X			47.8	-	-	-	-	220	-	4.11	0.26	65	7.0	Active	δ
"	0.216	3.5	95	35	21	16.6	X			53.4	-	-	-	-	176	-	4.97	0.31	65	7.0	Active	δ
Bull manure[i]	0.12	1.9	90.5	32.5	-	10		X		21.8	4.66	-	22,750	120	142	1,800	4.8	0.3	65.8	6.91	Active	β
"	0.12	1.9	90.5	32.5	-	15		X		26.7	11.2	-	34,000	197	152	2,680	5.08	0.32	65	6.98	Active	β
"	0.24	3.8	90.5	32.5	-	10		X		19.4	9.33	-	45,200	206	216	3,320	6.33	0.4	65.2	6.93	Active	β
"	0.24	3.8	90.6	32.5	-	15		X		17.7	13.2	-	68,270	376	177	5,160	8.88	0.56	61.3	7.09	Active	β
Beef																						
Scraped from concrete floor	0.1^{f}	1.6	95	35	-	10			X	55.2	23.8	-	-	-	100	1,500	13.7^{ef}	0.86^{ef}	58	6.7	Active	ε
	0.2^{f}	3.2	95	35	-	10			X	41.9	28.6	-	-	-	100	2,050	17.7	1.11^{ef}	57	6.8	Active	ε
"	0.3^{f}	4.8	95	35	-	10			X	30.7	29.1	-	-	-	175	1,800	28.3	1.77^{ef}	52	6.8	Not totally equilibrated	ε
"	0.4^{f}	6.4	95	35	-	10			X	35.8	33.1	-	-	-	175	1,900	23.6	1.49^{ef}	53	6.7	Not totally equilibrated	ε
Urine and feces[g]	-	-	97	36	55	5^{g}			X	-	40^{g}	-	13,000	-	2990	3,750	4.3^{h}	-	53	6.3	Active	ζ
1st stage effluent	-	-	97	36	55	5^{g}			X	-	40^{g}	-	-	-	1030	4,700	2.82^{h}	-	72	7.1	Active	ζ

Table 22. Performance of heated anaerobic digesters used on livestock wastes (continued).

Manure	Loading		Temperature		Duration[a]	Detention[b]	Mixing			VS Reduction	COD Reduction	COD Influent		$(NH_3 + NH_4^+)$-N	Volatile Acids	Alkalinity	Gas Production		Fraction as CH_4	pH	Comments[d]	Source
	lb VS/day ft^3	kg VS/day m^3	°F	°C	Day	Day	Natural	Intermittent	Continuous	%	%	mg O_2/mg VS	mg/l	mg/l	mg/l as HAc	mg/l as $CaCO_3$	ft^3/lb VS removed	m^3/kg VS removed	%			
										Sheep												
Urine and feces	0.150	2.4	95	35	13	20	X			38.0	-	-	-	-	95	-	9.7	0.61	63.5	7.3	Active	δ
"	0.158	2.5	95	35	13	20	X			36.4	-	-	-	-	105	-	7.28	0.45	63.5	7.2	Active	δ
"	0.176	2.8	95	35	13	20	X			33.2	-	-	-	-	105	-	5.87	0.37	63.5	7.1	Active	δ
										Poultry												
Manure (no bedding)	0.172	2.8	74	23	37	25.2		X		32.4	20.8[e]	1.11	-	2940[e]	5000	13,000	5.1	0.32	23 - 32	7.0	Failure	γ
"	0.173	2.8	95	35	37	26.1		X		44.8	37.4	1.11	-	2490[e]	5000	13,000	9.5	0.59	11 - 48	7.7	Failure	γ
"	0.279	4.5	74	23	37	25.0		X		20.2	2.3	1.11	-	5250[e]	12000	18,000	5.3	0.33	27 - 22	6.9	Failure	γ
"	0.305	4.9	95	35	37	22.5		X		32.2	20.3	1.11	-	4140[e]	12000	22,000	10.7	0.67	36 - 49	7.4	Failure	γ
Fresh manure (no feathers)	0.12	1.9	90.5	32.5	-	10		X		67.2	75.3	-	40,580	1020	350	-	7.28	0.45	58.0	7.2	Active	β
"	0.12	1.9	90.5	32.5	-	15		X		67.8	78.1	-	60,920	1570	175	-	8.56	0.53	57.8	7.35	Active	β
"	0.24	3.8	90.5	32.5	-	10		X		64.2	74.8	-	81,200	1860	-	-	7.64	0.48	52.9	7.42	Doubtful	β
"	0.24	3.8	90.5	32.5	-	15		X		57.0	68.7	-	121,730	3150	-	-	7.9	0.49	52.4	7.52	Doubtful	β

[a] Length of run at steady loading rate.

[b] Detention time calculated from Total volume (or weight) of digester contents/Volume (or weight) added daily

[c] Expressed on the basis of volatile solids added to the digester.

[d] Failure judged with respect to steady-state CH_4 production.

[e] Calculations made by the author, using the original data.

[f] Expressed on the basis of total not volatile solids.

[g] Two-stage digestion, both stages mixed and heated.

[h] Expressed as ft^3/day ft^3 capacity.

[i] Collected weekly from holding tank and screened to remove wood chips.

Sources:

α Cross, O. E., and A. Duran. 1970. Anaerobic decomposition of swine excrement. Transactions of the American Society of Agricultural Engineers. 13:320-322 and 325.

β Gramms, L. C., L. B. Polkowski, and S. A. Witzel. 1971. Anaerobic digestion of farm animal wastes (dairy bull, swine, and poultry). Transactions of the American Society of Agricultural Engineers. 14:7-11 and 13.

γ Hart, S. A. 1963. Digestion tests of livestock wastes. Journal Water Pollution Control Federation. 35:748-757.

δ Jeffrey, E. A., W. C. Blackman, and R. L. Ricketts. 1964. Aerobic and anaerobic digestion characteristics of livestock wastes. University of Missouri Engineering Series Bulletin 57.

θ Schmid, L. A., and R. I. Lipper. 1969. Swine wastes, characterization and anaerobic digestion. pp. 50-57. In: Animal waste management (Proceedings, Cornell Agricultural Waste Management Conference).

ε Loehr, R. C., and R. W. Agnew. 1967. Cattle wastes - pollution and potential treatment. Journal of the Sanitary Engineering Division of the American Society of Civil Engineers. 93(SA4):55-72.

ζ Meenaghan, G. F., D. M. Wells, R. C. Albin, and W. Grub. 1970. Gas production from beef cattle wastes. ASAE 70-907. American Society of Agricultural Engineers, St. Joseph, Michigan.

η Ngoddy, P. O., J. P. Harper, R. K. Collins, G. D. Wells, and F. A. Heidar. 1971. Closed system waste management for livestock. U.S. Environmental Protection Agency Water Pollution Control Research Series 13040 DKP 06/71.

ι Taiganides, E. P. 1963. Characteristics and treatment of waste from a confinement hog production unit. Ph.D. thesis. Iowa State University. 179 pp. (Mic. 63-5200, University Microfilms, Ann Arbor, Michigan).

avoided; yet, excess dilution water will lead to extravagant digester volumes and larger-than-necessary effluent discharges from the system. Anaerobic digestion, however, is only one stage of waste management. The effluent from such systems will most probably be recycled through the land; hence, storage facilities and irrigation or hauling equipment should be planned in addition to the digestion equipment.

Conclusions: Anaerobic digestion of livestock wastes for methane production is technically quite feasible. Most livestock wastes are sufficiently high in organic matter or nitrogen that dilution water must be provided to avoid toxicity. A worked example (Table 24), using fairly conservative assumptions, shows that the power-generation potential of a large confined animal operation may be appreciable. Unfortunately, the technical feasibility of this process is not backed up by economic feasibility; at present, the financial return from either the methane gas or the electrical power is not sufficient to warrant the very high capital investment demanded. Another factor, which is often ignored, is that anaerobic digestion is only a partial waste-stabilization process. Although much longer detention times than 10 to 17 days will increase VS destruction and methane production, the increase in volume of the physical facilities is unlikely to make this economically attractive. Consequently, any realistic anaerobic digester must be followed by further processes of waste stabilization, and these may be expensive, or they may consume power, thus reducing the amount available for sale. One more negative aspect that should not be overlooked is the quality of management and the supporting services required to run an anaerobic digester. Continual monitoring is required to ensure that the biological processes are proceeding as they were designed to; also, a system of such mechanical complexity will require continual maintenance.

Table 23. Tentative guidelines for maximum loading rates of heated mixed anaerobic digesters held at 95°F (35°C) when fed fresh livestock manures. Criteria used in this table are avoidance of ammonia toxicity (total ammonia-N < 1200 mg/l) and avoidance of excess production of volatile fatty acids (lb VS/day ft^3 < 0.37, kg VS/day m^3 < 5.9).

Parameter	Swine growing-finishing	Dairy	Beef	Poultry, layer	Poultry, broiler
Estimated fraction[α] of N as total ammonia-N in digested effluent	0.5	0.2	0.25	0.75	0.75
Dilution as manure/(manure + water)	1:2.9[a]	undiluted	1:1.32[b]	1:8.3[a]	1:10.2[a]
Estimated dilution water required lb H_2O/1000 lb animal	123	0	18.6	387	653
Hydraulic detention time (day)	12.5	17.5	12.5	10	10
Loading rate					
lb VS/day ft^3	0.13	0.37	0.37	0.13	0.1
kg VS/day m^3	2	5.9	5.9	2.1	1.6
Digester volume per animal unit					
ft^3/1000 lb animal	38	23.1	16	72	120
m^3/1000 kg animal	2.38	1.44	1	4.5	7.5
Estimated fraction of VS destroyed at this detention time	0.5	0.48	0.45	0.6	0.6
Ratio COD/VS	1.19	1.06	1.12	1.28	1.28[c]
Estimated total gas production (20 °C) per unit of VS removed					
ft^3/lb VS	11.9	10.6	11.2	12.8	12.8
m^3/kg VS	0.745	0.663	0.7	0.8	0.8
Estimated gas production (20°C) per animal unit if digester is loaded according to this table					
ft^3/day 1000 lb animal	28.6	43.7	29.8	72.3	92.1
m^3/day 1000 kg animal	1.79	2.73	1.86	4.52	5.76

[a] Ammonia toxicity criteria.

[b] Volatile fatty acids criteria, compared with dairy for want of a better criterion.

[c] Taken to be the same as that for layers.

Source: [α] Taken from L. C. Gramms, L. B. Polkowski, and S. A. Witzel. 1971. Anaerobic digestion of farm animal wastes (dairy bull, swine, and poultry). Transactions of the American Society of Agricultural Engineers. 14:7-11 and 13.

Anaerobic Stabilization Ponds

The anaerobic lagoon as a treatment process: At present, there are few livestock producers in a position to take advantage of the methane-production potential of their wastes. Fortunately, there are simpler means of using the waste-stabilizing ability of the anaerobic process. One method, the anaerobic stabilization pond or lagoon, has been in use since the late 1950s. These are ponds, usually unlined, that receive a mixture of waste and dilution water. The biological processes that take place in the pond are much the same as those in a heated mixed digester. The major differences between the systems are that little or no temperature control can be exercised over a pond, mixing usually is a function of gas production, and the partial pressures of the off-gases over the liquid surface are much lower than those over a heated digester. These three differences must be taken into account when considering both the physical and the microbiological features of an anaerobic stabilization pond. This discussion is limited to ponds designed for maximum treatment. This leaves the open-feedlot, runoff detention pond in a different category because its main function is to intercept and store liquid rather than to treat it. The boundary between the two types of pond is diffuse, but the main criterion that makes a pond a treatment unit is that it is fed its waste load in regular quantities at frequent intervals.

Lagoon performance: Documented research on anaerobic lagoons for livestock wastes is limited because of the great difficulties encountered in performing an accurate mass balance on an open pond. Also, field-scale research of a lagoon designed for research is most unusual. Research usually is performed on the lagoon after it has been provided as a working tool for a commercial herd—or for the research herd of a university. As the information in Table 25 shows, most of the more detailed work has been performed on micro-lagoons only a few feet (meters) in diameter (Willrich, 1966; Hart and Turner, 1965).

Modern confined animal production tends to produce uniform quantities of manure each day through the year. This manure is fibrous, high in solids, putrefies readily, has a high oxygen demand, and is rich in nutrients. The treatment system is called upon to accept this manure, convert its putrefiable contents to inoffensive end products, and liquefy its fiber and solids. Ideally, the lagoon should do all this in an odor-free fashion the year around with a minimum of attention from the producer. Production of an effluent suitable for discharge without further treatment, however, is not possible from an anaerobic pond.

Table 24. Worked example of the potential output of a generator fuelled by gas from an anaerobic digester handling the wastes from 10,000 beef animals.

Data

A housed confinement unit has a capacity for 10,000 animals. Manure is delivered to a heated mixed digester on a continuous basis. It is desired to calculate the amount of electrical energy that could be produced if the digester gas is used to run an engine generator, and determine the possibility of maintaining the digester at 95^{o}F (35^{o}C) with engine waste heat.

Average animal weight	800 lb	360 kg
Coldest temperature of the manure-dilution water mixture	50^{o}F	10^{o}C
Coldest temperature around the digester	20^{o}F	-7^{o}C
U value of the digester walls	1.67 Btu/hr ft^2 ^{o}F	9.5 W/m^2 ^{o}C
Brake thermal efficiency of the engine	30%	30%
Fraction of fuel energy transferable to the sludge heat exchanger	50%	50%
Conversion efficiency of the generator	85%	85%
Digester diameter not to exceed	100 ft	30 m
Digester liquid depth not to be less than	25 ft	7.5 m

Calculation of the dilution water required

Daily volume of manure (60/62) x (800/1000) x 10000	7760 ft^3/day	220 m^3/day
Daily volume of dilution water (1.32 - 1) x 7760	2480 ft^3/day	70.3 m^3/day
Daily digester feed volume	10250 ft^3/day	290 m^3/day

Calculation of digester volume and dimensions

For a 12.5 day detention time the volume required is 12.5 x 10250	128000 ft^3	3620 m^3
Check calculation using VS loading rate:		
Daily addition of volatile solids (800/1000) x 5.9 x 10000	47200 lb VS/day	21400 kg VS/day
For a loading rate of 0.37 lb VS/day ft^3 (5.9 kg VS/day m^3) the volume required is (47200/0.37)	128000 ft^3	3620 m^3
Choosing a digester depth of	40 ft	12 m
Diameter necessary	64 ft	19.5 m

Calculation of digester heating requirements

Assuming no heat exchange between influent and effluent		
Heat required to bring the influent temperature to 95^{o}F (35^{o}C) 10250 x 62 x 1 x (95 - 50)	2.86×10^7 Btu/day	3.02×10^{10} J/day
Digester surface area	14400 ft^2	1340 m^2
Heat loss through the digester shell 1.67 x 14400 x (95 - 20) x 24	4.32×10^7 Btu/day	4.56×10^{10} J/day
Daily heat supply to the digester during the coldest weather	7.18×10^7 Btu/day	7.57×10^{10} J/day

Calculation of gas production and engine parameters

Daily gas production at 11.2 ft^3/lb (0.7 m^3/kg) VS destroyed 47200 x (45/100) x 11.2	238000 ft^3/day	6740 m^3/day
Daily heat potential at 600 Btu/ft^3 (2.24×10^7 J/m^3)	1.43×10^8 Btu/day	1.51×10^{11} J/day
Noting that Btu x 2.93×10^{-4} = kW hr		
Electrical power expected (1.43×10^8/24) x (30/100) x (85/100) x 2.93×10^{-4}	445 kW	445 kW
Waste heat available from the engine cooling water 1.43×10^8 x (50/100)	7.15×10^7 Btu/day	7.55×10^{10} J/day

Comments

The amount of electrical power that could be produced is quite appreciable.

The digester could be maintained at 95^{o}F (35^{o}C) using engine waste heat by careful attention to engineering design.

The effluent from the unit would not be completely stable and would need additional processing to avoid air and water pollution.

The digestion step conserves all NPK in the manure, but the conversion of organic N to NH_3-N would lead to rapid N loss by volatilization if the digester effluent were stored in an open lagoon.

Table 25. Performance parameters for anaerobic lagooning of livestock wastes, compiled from the literature (Part 1).

Depth		Plan Shape	Location	Temperature				Scum Layer	Age	Solids Accumulation		Feed	Gas Production	Volatile Acids	Alkalinity		pH		Odor
				Winter		Summer									W	S	W	S	
ft	m			°F	°C	°F	°C		yr	ft	m			mg/l	mg/l	mg/l			
Swine Growing/Finishing																			
5	1.5	Square	Ill.	-	-	-	-	None	-	None		Settled liquor	None	440	-	1360	-	7.6	Mild
7	2.1	Rect.	Ill.	-	-	-	-	None	-	None		Settled liquor	None	440	-	1360	-	7.6	Mild
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Light	1	None		Raw manure	Yes	-	700[b]		6.9[b]		Mild
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Light	1	None		Raw manure	Yes	-	2000[b]		6.7[b]		Slightly manurey
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Light	1	None		Raw manure	Vigorous	-	3000[b]		6.8[b]		Slightly manurey
8.8	2.7	Rect. 2:1	Ia.	36	2	-	-	-	2	1	0.3	Flushed manure	Vigorous	576	988	-	7.8	6.9–7.3	Sweet septic
4	1.2	Rect. 2:1	S. D.	35[d]	1.5[d]	84[d]	29[d]	-	3	31[e]		Flushed manure	Yes	6520	-	5320	-	7.0–7.5	Strong late summer
4	1.2	Rect. 2.5:1	S. D.	-	-	77[d]	25[d]	-	5	21[e]		Flushed manure	Vigorous	393	-	3120	-	7.3–7.6	Slight
3	1	Rect. 4:1	S. D.	44[d]	7[d]	83[d]	28[d]	-	1	40[e]		Flushed manure	Yes	1280	-	1280	-	7.0–7.1	Slight
4	1.2	Square	S. D.	-	-	88[d]	31[d]	-	1	19[e]		Flushed manure	Poor	12175	-	12900	-	6.1–6.6	Variable
8	2.4	Rect. 5.5:1	S. D.	-	-	71[d]	22[d]	-	2	23[e]		Flushed manure	None	10800	-	5690	-	-	Strong
3	1	Rect. 1.5:1	Mi.	-	-	-	-	Light	3	0.63	0.019	Settled liquor	None	-	1800	-	-	-	Mild
8–10	2.7–3	Rect. 2:1	Ia.	34	1	-	-	Light	6	0.83	0.025	Recycle flushing	Vigorous	-	-	-	7.5	7.7	Sweet septic
5	1.5	-	N. C.	-	-	-	-	-	6	None		Flushed manure	None	-	-	-	-	-	-
6	1.8	-	N. C.	-	-	-	-	-	3	None		Flushed manure	None	-	-	-	-	-	-
8	2.4	-	N. C.	-	-	-	-	-	2	None		Flushed manure	None	-	-	-	-	-	-
Dairy																			
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Inoffensive hay, etc.	1	None		Raw manure	Masked by crust	-	1300[b]		7.4[b]		If crust broken
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Inoffensive hay, etc.	1	None		Raw manure	Masked by crust	-	2500[b]		7.0[b]		If crust broken
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Inoffensive hay, etc.	1	None		Raw manure	Masked by crust	-	3500[b]		7.0[b]		If crust broken
-	-	Laboratory	Kan.	-	-	68–73	20–23	-	0.5	None		Floor scrapings	Vigorous	70	-	1600	-	-	Minimal
-	-	Laboratory	Kan.	-	-	68–73	20–23	-	0.5	None		Floor scrapings	Vigorous	200	-	3600	-	-	Minimal
-	-	Laboratory	Kan.	-	-	68–73	20–23	-	0.5	None		Floor scrapings	Vigorous	450	-	4400	-	-	Minimal
-	-	Laboratory	Kan.	-	-	68–73	20–23	-	0.5	None		Floor scrapings	Vigorous	450	-	3800	-	-	Minimal
4	1.2	Square[i]	Kan.	41	5	77	25	-	2	Yes, some removed		Milk center waste	Yes	100–500	2000	15000	4.5[k]	7.0	-
4	1.2	Square	Kan.	41	5	77	25	-	2	Yes, some removed		From first pond	Yes	100–500	-	-	-	-	-
12	3.6	Rect. 7:1	Fl.	-	-	-	-	-	1	None		All wastes and manure	Vigorous	-	-	-	7.2[b]	-	-
14	4.3	Rect. 2:1	Wa.	-	-	-	-	Heavy	-	Heavy		Manure	Masked by crust	-	-	-	-	7.0	-
Poultry																			
3–4	1–1.2	-	S. D.	-	-	80	27	-	1	None		Raw manure	Yes	-	-	-	-	6.8–7.9	Mild
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Algal	2	None		Raw manure	Yes	-	400[b]		7.6[b]		None
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Wet feathers	2	None		Raw manure	Vigorous	-	750–2000[p]		6.8	7.2	Septic and ammonia
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Wet feathers	2	None		Raw manure	Vigorous	-	5500[b]		7.3[b]		Putrid and sulphide
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Wet feathers	2	None		Raw manure	Vigorous	-	4800[b]		7.1[b]		Sharp putrid
7	2.1	4' diam.	Cal.	55–45[a]	13–7[a]	68–77[a]	20–25[a]	Dried feathers	2	None		Raw manure	Vigorous	-	7500[b]		7.3[b]		Very sharp putrid
Beef																			
-	-	Laboratory	Kan.	-	-	68–73	20–23	Yes	-	Yes		Floor scrapings	Yes	120	-	1990	-	6.9	Minimal
-	-	Laboratory	Kan.	-	-	68–73	20–23	Yes	-	Yes		Floor scrapings	Yes	340	-	2400	-	6.9	Minimal
-	-	Laboratory	Kan.	-	-	68–73	20–23	Yes	-	Yes		Floor scrapings	Yes	400	-	1390	-	6.6	Minimal
-	-	Laboratory	Kan.	-	-	68–73	20–23	Yes	-	Yes		Floor scrapings	Yes	180	-	1710	-	6.7	Minimal

Table 25. Performance parameters for anaerobic lagooning of livestock wastes, compiled from the literature (Part II).

Purple Color	Loading Rate (VS) x 10^3		Detention Time	Liquor COD		Reduction COD		Reduction VS		Liquor BOD_5		Liquor Total-N		Liquor NH_3-N		Reduction N		Liquor PO_3^{-3}		Reduction PO_4^{-3}		Source
	lb/day ft^3	kg/day m^3	day	W mg/l	S mg/l	W %	S %	W %	S %	W mg/l	S mg/l	W mg/l	S mg/l	W %	S %	W %	S %	W mg/l	S mg/l	W %	S %	
										Swine Growing/Finishing												
No	0.36	5.8	No overflow	-	1080	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	β
No	0.36	5.8	No overflow	-	1080	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	β
No	4.95	7.82	No overflow	-	-	-	-	-	-	200-1100[c]		-	-	-	-	-	-	-	-	-	-	ζ
No	10.8	173	No overflow	-	-	-	-	-	-	200-3900[c]		-	-	-	-	-	-	-	-	-	-	ζ
No	13.7	219	No overflow	-	-	-	-	-	-	100-3600[c]		-	-	-	-	-	-	-	-	-	-	ζ
Yes	3.5-5	56-80	25-31	1370	-	80	-	84	-	1280	-	580	-	-	-	46	-	-	-	-	-	ο
-	7.5[f]	120[f]	-	-	18600	-	-	-	-	-	14400	-	1450	-	-	-	-	-	-	-	-	γ
-	9.3[f]	149[f]	-	-	3050	-	-	-	-	-	1180	-	564	-	-	-	-	-	-	-	-	γ
-	6.9[f]	110[f]	-	-	4860	-	-	-	-	-	3060	-	1300	-	-	-	-	-	-	-	-	γ
-	10.7[f]	171[f]	-	-	69080	-	-	-	-	-	43700	-	2530	-	-	-	-	-	-	-	-	γ
-	3.2[f]	51.2[f]	-	-	32900	-	-	-	-	-	-	-	3040	-	-	-	-	-	-	-	-	γ
Yes	1.37	21.9	-	-	2190	99[h]	-	80	-	1140	-	410	-	-	-	85	-	173	-	80	-	✓
Yes	3	48	200-250	2000	140	92[h]	95[h]	90	-	1000	-	450	310	70	93	62[h]	74[h]	300	73	-	-	η θ ξ
-	0.6[f]	9.6[f]	208[f]	360[i]		-	-	-	-	390		244		83		-	-	142		-	-	δ
-	0.42[f]	6.7[f]	900[f]	340[i]		-	-	-	-	270		168		71		-	-	112		-	-	δ
-	0.28[f]	4.5[f]	1200[f]	470[i]		-	-	-	-	610		287		83		-	-	116		-	-	δ
										Dairy												
No	4.49	72	No overflow	-	-	-	-	-	-	80-800		-	-	-	-	-	-	-	-	-	-	ζ
No	8.30	133	No overflow	-	-	-	-	-	-	200-1500		-	-	-	-	-	-	-	-	-	-	ζ
No	10.4	166	No overflow	-	-	-	-	-	-	600-3500		-	-	-	-	-	-	-	-	-	-	ζ
No	80	1280	10	-	2800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ι
No	160	2560	10	-	5100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ι
No	240	3840	10	-	8700	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ι
No	320	5120	10	-	6800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ι
-	12.3	197	-	-	-	-	-	-	-	1000	150	-	-	-	-	-	-	-	-	-	-	λ
-	6-3.3[f]	9.6-53	-	-	-	-	-	-	-	1000	100	-	-	-	-	-	-	-	-	-	-	λ
-	7[l]	112[l]	37	-	5200	-	67	-	66	-	77	-	-	-	-	-	-	-	18.6	-	31[h]	μ
-	70[g]	1120[g]	-	-	-	-	-	-	91	-	1370	-	210	-	35	-	0	-	212	-	24[h]	α
										Poultry												
No	4-11	64-176	No overflow	-	1000	-	-	-	-	-	200-500	-	150	-	90	-	-	-	-	-	-	ε
Yes	1.3	21	No overflow	-	-	-	-		41.3[m,n]	18-105[c]		-	-	-	-	74.4[o]		-	-	64.8[o]		ζ
No	3.94	63	No overflow	-	-	-	-		31.9[m,n]	50-280[c]		-	-	-	-	74.4[o]		-	-	63.3[o]		ζ
No	6.16	99	No overflow	-	-	-	-		57.3[m,n]	150-600[c]		-	-	-	-	61.3[o]		-	-	25.0[o]		ζ
No	10.6	170	No overflow	-	-	-	-		64.0[m,n]	150-600[c]		-	-	-	-	79.4[o]		-	-	51.5[o]		ζ
No	16.4	262	No overflow	-	-	-	-		56.4[m,n]	800-3000[c]		-	-	-	-	60.8[o]		-	-	16.4[o]		ζ
										Beef												
-	100[q]	1600[q]	10	-	4660	-	-	-	-	-	-	-	360	-	-	-	-	-	-	-	-	κ
-	200[q]	3200[q]	20	-	7150	-	-	-	-	-	-	-	560	-	-	-	-	-	-	-	-	κ
-	300[q]	4800[q]	10	-	5550	-	-	-	-	-	-	-	500	-	-	-	-	-	-	-	-	κ
-	400[q]	6400[q]	10	-	7380	-	-	-	-	-	-	-	700	-	-	-	-	-	-	-	-	κ

Footnotes, Table 25.

[a] Variation from top to bottom.

[b] Mean over test period.

[c] Range over the year.

[d] Taken from individual data points.

[e] Measured as ft^3/pig.

[f] Estimated by the editors.

[g] Allows for solids accumulation.

[h] Concentration basis.

[i] Total organic carbon.

[j] Two lagoons in sequence.

[k] Caused by excess sludge removal in late November.

[l] Design value.

[m] Modified to account for infiltration.

[n] Overall mass balance after 2 years.

[o] Assumed to be infiltration losses.

[p] Rising trend not correlated with temperature.

[q] Total solids basis.

Sources, Table 25.

[α] Bhagat, S. K., and D. E. Proctor. 1969. Treatment of dairy manure by lagooning. Journal Water Pollution Control Federation. 41:785-795.

[β] Clark, C. E. 1965. Hog waste disposal by lagooning. Journal of the Sanitary Engineering Division of the American Society of Civil Engineers. 91(SA6):27-42.

[γ] Curtis, D. R. 1966. Design criteria for anaerobic lagoons for swine manure disposal. pp. 75-80. In: Management of farm animal wastes (Proceedings, National Symposium). American Society of Agricultural Engineers.

[δ] Department of Biological and Agricultural Enginnering, School of Agriculture and Life Sciences, North Carolina State University at Raleigh. 1971. Role of animal wastes in agricultural land runoff. 114 pp. U. S. Environmental Protection Agency Water Pollution Control Research Series 13020 DGX 08/71.

[ε] Dornbush, J. N., and J. R. Anderson. 1964. Lagooning of livestock wastes in South Dakota. Purdue Engineering Extension Series. 117:317-325.

[ζ] Hart, S. A., and M. E. Turner. 1965. Lagoons for livestock manure. Journal Water Pollution Control Federation. 37:1578-1596.

[η] Koelliker, J. K. 1972. Sprinkler application of anaerobically treated swine wastes as limited by nitrogen concentration. Ph.D. thesis. Iowa State University. 206 pp. (Mic. 72-19,989, University Microfilms, Ann Arbor, Michigan).

[θ] Koelliker, J. K., and J. R. Miner. 1970. Pasture application of aerobic lagoon water: A practical experience. ASAE 70-406. American Society of Agricultural Engineers, St. Joseph, Michigan.

[ι] Loehr, R. C. 1967. Effluent quality from anaerobic lagoons treating feedlot wastes. Journal Water Pollution Control Federation. 39:384-391.

[κ] Loehr, R. C., and R. W. Agnew. 1967. Cattle wastes - pollution and potential treatment. Journal of the Sanitary Engineering Division of the American Society of Civil Engineers. 93(SA4):55-72.

[λ] Loehr, R. C., and J. A. Ruff. 1968. Anaerobic lagoon treatment of milking parlor wastes. Journal Water Pollution Control Federation. 40:83-94.

[μ] Nordstedt, R. A., L. B. Baldwin, and C. C. Hortenstine. 1971. Multistage lagoon systems for treatment of dairy farm waste. pp. 77-80. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers. PROC-271.

[ν] Shindala, A., and J. H. Scarbrough. 1972. Evaluation of anaerobic lagoon treating swine wastes. Transactions of the American Society of Agricultural Engineers. 15:1150-1152.

[ξ] Smith, R. J. 1971. A prototype system to renovate and recycle swine waste hydraulically. Ph.D. thesis. Iowa State University. 188 pp. (Mic. 72-5258, University Microfilms, Ann Arbor, Michigan.)

[ο] Willrich, T. L. 1966. Primary treatment of swine wastes by lagooning. pp. 70-74. In: Management of farm animal wastes (Proceedings, National Symposium). American Society of Agricultural Engineers.

The parameters in Table 25 describe pond performance according to the criteria listed in the preceding paragraph. In addition, the reduction of the nutrients N and P are recorded. The current trend in high-intensity confinement is towards greater animal populations on ever-smaller acreages; if the land is to be used as a final depository for treated manures, this land must not be so overloaded with nutrients, or salts, that soil productivity is adversely affected. The anaerobic lagoon can remove nutrients and thus increase the ratio of Animals Confined:Manure Disposal Acreage. The limit is not yet well defined, so lagoon effluent disposal sites should be monitored with great care over the next decade or more.

Table 25 shows that swine waste lagooning has been examined most actively, followed by dairy, poultry, and beef. Such ranking is the outcome of present production practices. Swine and dairy animals already have their waste treated by lagooning on an extensive commercial scale, but poultrymen have tended to show more interest in "dry" manure handling. The number of beef animals not in open dirt feedlots is rather small, but this may change as the dust and odor generated by these lots becomes of greater concern.

The first conclusion is that a single criterion, mass of VS per day-volume, is not sufficient for all species. Swine lagoons form virtually no crust, but poultry and dairy lagoons may. Hart and Turner (1965) showed that heavily loaded poultry lagoons may have a moist feather crust that is not simply aesthetically unpleasant, but also serves as a breeding place for flies. The crusts on dairy lagoons seem to be a function of flow-through rate as well as of loading rate. Hart and Turner, and Bhagat and Proctor (1969) mention heavy crusting, yet Nordstedt et al. (1971a) do not mention any. Age is another important criterion; acclimated populations of anaerobic microorganisms seem to take 2 or more years to develop. Many investigators indicate that odors generated during the temperature transition from winter dormancy to summer gasification become less rank as the lagoon matures. Shape and depth seem to be a function of flow-through rate. Both D.R. Curtis (1966) and Dornbush and Anderson (1964) noticed solids accumulation and an accompanying stench if the lagoon was either too shallow or too narrow. Nordstedt et al. (1971a), however, did not encounter this difficulty with a high flow-through rate and a deep, long, narrow lagoon. Many observations have been made on lagoons that were only 1 to 2 years old, and there was no overflow, all water loss being due to evaporation and infiltration. This is only transient because bottom sealing will ultimately take place. S. Davis et al. (1973) have examined infiltration rates in some detail, and they conclude that dairy-waste ponds will be self-sealing. Experience at Iowa State University with various ponds 5 years old or more also verifies this for swine wastes.

Purple sulfur-fixing bacteria: Odors from anaerobic waste-treatment ponds vary with the season of the year. This subject of odor and digestion temperature was discussed in an earlier section (The anaerobic process, Temperature), and it was concluded that digestion at temperatures above 50°F (10°C) would not lead to unpleasant odors. An exception is the odor of hydrogen sulfide. Any anaerobic system may evolve H_2S, either from sulfur-containing organic matter in the waste or from sulfate in the conveying water. When waste-stabilization ponds first became popular in the early 1960s, Oswald (1960) mentioned lagoons with prolific growths of **Thiopedia rosea,** a bacterium that can reduce H_2S to elemental sulfur. Lindstrom (1964) has reviewed the ecology of the sulfur-fixing bacteria. There are the family **Thiorhodaceae,** commonly called the purple sulfur bacteria, and the **Chlorobacteriaceae** or green sulfur bacteria. Both families can use reduced sulfur compounds such as sulfides and thiosulfates. Although there is some evidence that these bacteria can use reduced carbon compounds, they are quite capable of growing in a strictly inorganic medium. Lindstrom mentions that the photosynthetic bacteria have a unique niche in bacteriology because they are able to assimilate oxidatively the reduced molecules in a totally anaerobic environment. This ability is solely derived from their photosynthetic mechanism.

The family that seems of primary importance in waste-treatment lagoons are the **Thiorhodaceae** because pink lagoons predominate if sulfur-fixing bacteria are present. Sletten and Singer (1971) reported on the occurrence of purple sulfur in an anaerobic lagoon treating swine wastes at Iowa State University. They believed that they had discovered a new genus of the **Thiorhodaceae** family, **Rhodothece,** which they described as spherical, occurring singly, in pairs or in short chains, and being nonmotile. The pigments were intracellular and consisted mainly of bacterial chlorophylls and xanthophylls, with only trace amounts of carotenes. Holm and Vennes (1970) reported finding **Chromatium vinosum** and **Thiocapsa floridana** in an overloaded municipal lagoon in North Dakota. This lagoon was turned anaerobic by the seasonal loading of a potato-processing plant. Holm and Vennes showed that the population of the purple sulfur bacteria was dependent upon the level of sulfide in the lagoon; when sulfide could no longer be detected, the population of sulfur bacteria began to decline. These authors also examined the ability of these genera of bacteria to assimilate various organic substrates; significant use of volatile fatty acids was noted.

Meredith and Pohland (1970) examined purple sulfur bacteria obtained from poultry-processing plants. They attempted to obtain pure cultures by using serial dilutions and enrichment techniques with a specific inorganic medium containing thiosulfate. Although a completely pure culture was not obtained, the authors believed the predominant genus to be **Chromatium.** The effects of various environmental factors on growth were studied (e.g., pH and temperature), but perhaps the most interesting observation was that the ability of the bacteria to store sulfur intracellularly was inhibited by an iron deficiency. Low iron concentrations (less than 1×10^{-13} mg/l) would result in noticeable H_2S odors.

In summation, we can observe that the genus of Thiorhodaceae expected in a waste-treatment pond cannot be specified. It also seems that growth of these bacteria is most favored around neutral pH and a temperature greater than 68°F (20°C). Where the bacteria do not establish themselves, iron deficiency may be one factor that should be examined.

Nutrient reduction: Lagoons are only part of a waste-management system. There will be a liquid effluent, which will be quite high in N, P, and K, and adequate cropland must be available for applying this material. At present. there is little information concerning the actual amounts of N and P removed by a lagoon. Until better information becomes available, the land application area should be sized on the basis of the total animal population, the crop, and the expected nutrient reduction in the lagoon. Table 26 gives tentative nutrient reduction on passage through a normal, unmixed anaerobic lagoon pumped out in the summer. Because each situation will vary somewhat, a field assessment of nutrient concentration and total discharge is recommended whenever practical.

Table 26. The fraction of the influent nutrient expected in the effluent of an anaerobic stabilization pond pumped out during the warmest months of the year.

Nutrient	Percentage in the effluent
N	25
P	50
K	60

Source: R. J. Smith. Unpublished data. Agricultural Engineering Department, Iowa State University, Ames, Iowa.

A feature related to nutrient removal in anaerobic lagoons is the phenomenon of magnesium ammonium phosphate deposition on most items submerged in anaerobic lagoon liquor. The problem of $Mg(NH_4)PO_4$ deposition has been recognized by sanitary engineers for some years because it can cause plugging in municipal digesters (Rawn et al., 1939). The widespread use of anaerobic lagoon water for flushing manure from livestock buildings has brought the problem to the attention of agricultural engineers. R.J. Smith (1971) reported that $Mg(NH_4)PO_4$ deposits in recycling pumps being used in a swine system in Iowa became so thick that binding occured between the impeller and the pump body. Mayer and Baier[19] have indicated that $Mg(NH_4)PO_4$ deposition has been a problem when pumping liquors from anaerobic dairy-waste ponds in California. Control of $Mg(NH_4)PO_4$ deposition is an important requirement in recirculating manure-transport systems; thus, Booram et al. (1973) have examined the chemical phenomena relating to deposition. Following the procedure of Stumm and Morgan (1970), Booram et al. showed that, with a typical swine lagoon liquor containing Mg = 48 mg/l, NH_3-N = 375 mg/l, and PO_4 = 250 mg/l, precipitation was only marginally likely at a typical lagoon pH of 7.5. They noted, however, that deposition was far more of a problem on metal parts than on plastic, so they hypothesized that crystallization is promoted by interaction with a metal surface. This was not a complete answer because deposits were occasionally found in horizontal runs of plastic pipe. In this instance, the deposition was believed started on grit, which had first settled on the pipe invert. R.J. Smith et al. (1973) have shown that $Mg(NH_4)PO_4$ depositions in plastic plumbing systems can be controlled by periodic flushing with 1:50 acetic acid solution. The use of acetic acid rather than a mineral acid

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[19] J.L. Mayer and D. Baier. 1971. A progress report on manure waste ponding. University of California, Agricultural Extension Service, Stanislaus, San Joaquin, and Merced counties.

is recommended because the acetic acid will be degraded in the lagoon.

Design criteria for anaerobic lagoons: Although evidence presently available does not warrant rigid design criteria, Table 27 can serve as a guide. There are other important factors that must be taken into account when designing lagoons, in addition to those concerned with loading rates. Good mixing improves the operation of an anaerobic lagoon. Gas boils rising from biologically active bottom sludge are the main cause of natural mixing; hence, deep lagoons with simple shore lines are recommended. Depths can be as great as 20 ft (6 m), depending upon local groundwater conditions. In the special case of flow-through ponds for dairies in warm climates, it seems that rectangular ponds with length-to-width ratios of up to 8:1 may be used. Ponds that will have liquid pumped out only in the warm summer months should be basically square or circular, although deviations to rectangles or ovals with length-to-width ratios of 2:1 also will perform satisfactorily. When little fresh water will be available for flushing wastes into the pond, the pond should be constructed before the buildings. Then clean runoff water should be diverted to the pond until it attains the minimum volume indicated in Table 27. Once filled in this fashion, divert all clean runoff water away from the pond.

Few livestock producers can afford to use fresh water for transporting manure to the pond, nor is this desirable because it would generate large volumes of overflow from the treatment system. This leaves two alternatives: flushing manure with recycled lagoon water or using mechanical scrapers. Both these have one feature in common; use over a long period may lead to salt concentration in the lagoon. In most areas of the North Central Region this will not be a problem, but in the more arid areas, such as southern Kansas and Oklahoma, we suggest that a lagoon liquor sample be tested for its inorganic dissolved salt concentration once each year. When this concentration exceeds 5000 mg/l, add fresh water. Often, clean runoff water can be used for this purpose.

Swine and poultry lagoons that have been sized according to Table 27 may be used for 10 yr or longer before sludge must be removed. In general, leave sludge for at least 3 yr before removal and then remove only part of the sludge, or odorous conditions are likely to result. The most favorable time for sludge removal is early fall. Dairy lagoons may require more frequent cleaning, especially if the influent manure is contaminated with inorganic materials.

Because anaerobic stabilization ponds can be quite odorous during the early spring of succeeding years, we suggest that the pond be sited at least 0.5 mi (0.9 km) from any residence. If the terrain makes it possible for odor-laden air to follow a valley to a populous area, then an anaerobic lagoon is not a good choice of treatment system. Spring odor production may sometimes be curtailed if a large pump is available to mix the lagoon contents as soon as the ice cover melts and temperatures rise above 45°F (7°C).

Table 27. Tentative loading rates for unmixed, uncovered, anaerobic stabilization ponds to be constructed in the Midwest.

Animal	Loading rate		Vol/1000 unit mass animal unit	
	lb VS/day ft^3	kg VS/day m^3	ft^3	m^3
Swine	0.005	0.08	960	51.4
Dairy	0.0075	0.12	1150	71.6
Poultry				
Layer	0.004	0.064	2350	147
Broiler	0.004	0.064	3000	187
Beef	0.005	0.08	1180	62.5

Notes:

1. Add 20% to the volumes calculated from the given loading rates for sludge storage.
2. When winter storage is required, add the volume contributed by the animals over this period to the figures derived from the table.
3. When winter storage will be practiced, add sufficient volume to account for direct precipitation into the pond during the storage period.
4. The loading figures may be adjusted upwards 20% for lagoons situated in warm southern areas and downwards 20% for areas with more extreme winters.

Influent sewers to lagoons can be arranged to enter above or below water level. Submerged inlets are recommended only if manure flushing takes place every 1 to 2 hr (or more frequently). In all other cases, there is a danger of settling solids blocking the sewer. It is generally more satisfactory to use sewers above the water level or open gutters if manure transport is irregular. Experience indicates that 6 to 8 in. (15 to 20 cm) diameter plastic pipe is adequate for most installations; avoid using a pipe diameter that gives flow velocities of less than 3 ft/sec (1 m/sec), but also avoid using very extended runs of pipe less than 4-in. (10-cm) in diameter. Excessively large sewer diameters may cause trouble from stranding of solids and ultimate plugging.

Lagoons are usually unlined earthen basins. The side slopes should be between 2:1 and 3:1, depending on accepted local practice. Very permeable soils may need a clay or bentonite sealing layer initially, but ultimately, soils will seal under the action of anaerobically digesting manures (S. Davis et al., 1973).

Conclusions: Anaerobic lagooning of swine wastes is a well-established practice and can be quite acceptable when applied with discretion. Anaerobic lagoons cannot be totally odor-free and may be exceptionally rank for 4-8 wk in early spring. Lagoons should not be considered in the vicinity of urban development nor closer than 0.5 mi (0.8 km) to an individual residence. Lagoons may be abnormally odorous at all times of the year in areas where the water supply is high in sulfates. Hydrogen sulfide odors can be controlled by adding iron salts to precipitate the sulfate ion. The same palliative effect may occur naturally if purple sulfur bacteria become established. Lagoons are more suited to warmer climates, but their use can be acceptable in northern states where the separation between the lagoon and residential areas is greater. Lagooning for species other than swine and poultry is quite feasible, but has not been practiced extensively in the North Central Region. The number of beef lagoons increased dramatically in 1973, but information on the performance of these lagoons is sparse. An anaerobic lagoon is only part of a system in most of the North Central Region because the lagoon will need dewatering annually in most states. Even in states with an excess of evaporation over precipitation, occasional dewatering and dilution will be required to maintain salinity at an acceptable level; this level is not well established, but may be about 5000 mg/l. Deposition of $Mg(NH_4)PO_4$ will occur on most objects bathed by lagoon liquor, deposition is particularly severe on metal surfaces. Nonmetallic plumbing, particularly plastic, is recommended. When deposits do occur they can be dissolved with dilute acetic acid. Anaerobic lagoons will seal virtually any soil in time, and the long-term danger to groundwater is minimal.

Anaerobic Filters

It is well established that, in a process consisting of many sequential steps, the kinetics of the slowest step will tend to dictate the overall kinetics of the whole process. In the two-stage process of methane fermentation of heterogeneous substrates, it is well established that the methane-forming bacteria have lower growth rates than those of the acid formers. Lawrence and McCarty (1969) have shown that, as the detention time in a fully mixed reactor is reduced below some critical value, the organisms are not able to replace themselves as fast as they are washed out of the system. Because the bacteria in anaerobic waste treatment are not easily separated from the mother liquor, the concept of anaerobic activated sludge (Dague et al., 1966) has not gained wide acceptance outside the laboratory. The difficulty, in the main, has been that actively fermenting organisms do not settle by gravity because of the buoying effects of the attached gas bubbles.

Recently, however, various schemes have been developed in which the biological growths are restrained from being washed out with the liquor. A feature all devices have in common is that the liquid has a very tortuous path through some supporting matrix. One of the more successful variations on this theme has been the anaerobic filter. This is simply a normal trickling filter operated so that the liquid entirely occupies all the void space in the media. A comprehensive laboratory study by Young and McCarty (1969) has shown that the anaerobic filter can handle soluble wastes of relatively low COD strengths (e.g., 1500 mg/l) with liquid detention times as low as 4.5 hr. Such a detention time would be unthinkable with a conventional mixed-tank digester.

There is little or no published work on the application of these filters to livestock wastes, but research at Iowa State University (unpublished) indicated that the process can be applied to the liquid portion of the effluent from a hydraulically flushed swine unit. Much more work is required, but initial results seem to indicate that this process may be one method for the farm production of methane, without some of the capital investment and management difficulties alluded to earlier.

Another agricultural use of the anaerobic filter has been for denitrifying irrigation tail waters. The U.S. Environmental Protection Agency Water Quality Office et al. (1971) examined the performance of laboratory and pilot-scale filters at various temperatures. They summarize their results by noting that 80% or more of the influent NO_3-N could be removed with detention times of as little as 1 hr. Methanol was used as a carbon source in all tests. Although short-term denitrification was satisfactory at temperatures exceeding 54°F (12°C), cell growth within the filter caused flow problems; also, discharges of wasted cells would lead to high Kjeldahl-N in the filter effluent. The report indicated that the problem of long-term cell growth needed further investigation.

UTILIZATION

Tradition of Land Application

Land application of manure has been practiced for centuries in the temperate zones. The practice developed partly because there was no other place to put the manure, but man also has long recognized the agronomic benefits accruing from manure. Manure has been shown to improve soil tilth, increase water-holding capacity, lessen wind and water erosion, improve aeration, and promote the growth of beneficial soil organisms.

Confined animal housing is not new; for many generations, the Scandinavians have confined their animals in barns during the long northern winters. In the spring, the mixture of manure and bedding was taken to the fields on wagons. Such a simple approach worked well when the number of animals owned by any one man was small. The current trend is to divorce livestock production from crop production; consequently, we must now address ourselves to the problem, not of soil amelioration, but of soil abuse from manure application. Land will undoubtedly remain the most logical place for ultimate placement of manure, or its derivatives, but there now is very strong commercial incentive from some intensive livestock producers to look at land as a disposal site. Disposal may be a word that should have no place in our vocabulary because it implies an action causing something to disappear without trace. A rudimentary analysis of material and energy balances soon shows that such a concept is impossible. Nitrogen has received the greatest attention at present (e.g., Committee on Nitrate Accumulation, 1972), but the potential of other substances to have detrimental effects cannot be ignored. Two such areas of concern would be phosphate accumulation and salinity.

The objectives of this section on utilization of farm-animal wastes are to show how livestock excreta can be regarded as a raw material for by-product recovery rather than waste that needs "disposal."

Current Land-Application Practices

Retention of nutrients: Where land spreading of manure is practiced in most northern states, there is a danger of water pollution from runoff during spring thawing and, to a lesser extent, from warm-season precipitation (Midgley and Dunklee, 1945). Consequently, it is necessary that winter manure storage be provided as a part of most livestock production systems. The time of storage may vary from about 90 to 180 days according to location. Another beneficial aspect of storage is that it allows application at that time of year when the manure can do most good. Unfortunately, storage of manure is presently accompanied by some loss of nitrogen; Vanderholm (1973) indicated that this may range from 34%-84%, depending upon the system in use. The smaller producer may wish to conserve as much of the excreted N as possible; hence, he may wish to choose a system that conserves N rather than labor. The section of this report on anaerobic treatment indicated that the loss of P and K in an anaerobic lagoon may be 50% and 40%, respectively.

Again, these reductions may be regarded as beneficial if land for application is restricted, but they are disadvantages if maximum P and K recovery is desired. In general, mechanization of manure handling and the associated trend toward liquid systems leads to losses of nutrients. Losses of nitrogen by NH_3 or N_2 gases are, in a sense, not recoverable, but the losses of P and K usually are caused by sedimentation and could be recovered if the expense of doing so was warranted.

Economic value of manure: Numerous authors have reported on the value of farmyard manure for increasing the yields of crops (Wiancko et al., 1935; Salter and Schollenberger, 1939; M.F. Miller, 1947; Turk and Weidemann, 1949; Rose and Kramer, 1957; Benne et al., 1961; Guttay et al., 1956). Some of the larger yield responses obtained for corn in rotation were 3.8, 1.5, 1.3, and 1.3 bu/ac (0.33, 0.13, 0.11, and 0.11 m^3/ha) for corn grain, wheat, barley, and soybeans, respectively, and 145 lb/ac (163 kg/ha) for hay. Most research indicated that, although higher application rates resulted in greater crop yields, lower rates gave greater specific returns per unit of applied manure. Recovery of nutrients from manure by various crops ranged from about 10%-30% for N, 10%-20% for P, and 30%-100% for K (Bartholomew, 1928; Russell and Watson, 1940; Widdowson et al., 1963; Williams et al., 1963). These values are comparable to those reported for crop recovery from applications of commercial fertilizers.

The yield improvement of farmyard manure applied to corn or wheat in a corn-oat-wheat-clover-timothy rotation at Wooster, Ohio, over a period of 33 yr was $3.39/ton ($3.74/tonne) for grain crops at the 8-ton/ac (18-tonne/ha) application rate and $2.86 ($3.15) at the 16-ton/ac (36-tonne/ha) rate (Salter and Schollenberger, 1939). In Minnesota, Rose and Kramer (1957) found that yield increases for first-year corn caused by manure were worth $4.72/ton ($5.20/tonne) at an 8-ton/ac (18-tonne/ha) application rate in a corn-corn-oats-hay rotation. Weidemann and Millar (1951) found that, in Michigan, the increase was worth $4.46/ton ($0.92/tonne) for a 5-ton/ac (11-tonne/ha) application on corn in a corn-barley-wheat rotation and that the worth decreased to $3.82/ton ($4.21/tonne) and $3.02/ton ($3.33/tonne) for 10- and 15-ton/ac (22- and 34-tonne/ha) rates, respectively.

Frequently, the value of farm manure is calculated solely on the basis of the value of its N, P_2O_5, and K_2O contents. At delivered prices of $0.14, 0.13, and 0.06/lb ($0.31, 0.29, and 0.13/kg) for the respective constituents in dry, mixed fertilizers, the value of dairy manure containing 10 lb/ton N, 5 of P_2O_5, and 10 of K_2O (5, 2.5, 10 kg/tonne) would be about $2.65/ton ($2.92/tonne). This figure is appreciably lower than figures cited in relation to yield increments caused by manure application. No doubt, there are other benefits provided by the manure, such as its supply of trace elements. and improvement of soil structure.

The value of manure can be evaluated better by using a scheduling model and a systems approach to the various parameters that affect manure handling. Such models not only consider the market value of the N, P, and K in the manure, but also attempt to assess the value of better labor scheduling that can result from improved manure handling. Storage is becoming an essential part of any waste-handling system because it allows longer-term planning of manure spreading in relation to other determinants, such as labor availability, crop condition, and weather conditions. Decisions can then be made on an optimization basis, rather than just taking care of the tank when it is full. For example, Nordstedt et al. (1971b) showed that increased storage capacity in one system could result in a 15% increase in the value of the manure.

Application rates for optimum crop growth: Manure applications that result in considerable yield increases suggest that soil fertility had not been adequately maintained (Hedlin and Ridley, 1964). Low rates of manure application over a large cropland area often result in greater returns than do heavy applications on a small area. A number of investigators have noted that the lowest losses of N and best crop yields generally occurred for manure kept moist during storage and incorporated into the soil before drying occurred (Russell and Richards, 1917; Turk and Weidemann, 1949). Hensler (1970), in Wisconsin, examined the effect of four manure pretreatments on corn yields. Fresh, fermented (piled), and anaerobic liquid dairy-cow manure all gave similar yield increases, and all treatments were superior to aerobic liquid manure. All treatments were applied to Miami silt loam in the greenhouse (Table 28). Similar trends were noted for steer manure. A 50-ton/ac (67-tonne/ha) rate resulted in 20% greater yields, but 5%-10% lower recovery of N and P compared with the 15-ton/ac (34-tonne/ha) rate. Average recovery of N by the crop ranged from 18.5% for aerobic liquid to 52.5% for anaerobic, liquid dairy-cattle manure. Average recovery of P ranged from 19.5%-29% for the same treatments. Recovery of N and P from steer manure generally was greater than that from dairy-cattle manure. Allowing the manure to dry 1 wk before incorporation usually gave 10% lower yields and 5%-40% lower recovery values for N, P, and K.

Research data from Pennsylvania indicated that crops contribute very significantly to the removal of N applied in wastewater. For example, silage corn removed 3% more N than was applied in wastewater when the nitrogen application rate was approximately 100 lb/ac (110 kg/ha) of N (Kardos, 1968; Parizek et al., 1967).

Table 28. Effect of method of handling of dairy cow and beef manures on average yield and recovery of N, P, and K by one crop of corn grown on a Miami silt loam in pots.

Type of manure[a]	Yield[b]		Recovery by crop[b]		
	lb/pot	g/pot	N %	P %	K %
No manure	0.0242	11.0	--	--	--
Dairy cow					
Fresh	0.043	19.5	44.0	19.5	40.5
Fermented	0.043	19.5	42.0	22.5	49.5
Aerobic liquid	0.0374	17.0	18.5	19.5	38.0
Anaerobic liquid	0.05	22.5	52.5	29.0	48.0
Beef					
Fresh	0.0705	32.0	53.0	23.5	73.5
Fermented	0.0716	32.5	54.5	23.5	74.0
Aerobic liquid	0.0452	20.5	13.0	14.5	34.5
Anaerobic liquid	0.0727	33.0	65.5	27.5	83.0

[a] Manure applied at rate of 15 ton/ac (34 tonne/ha) on fresh-weight basis including 2% oat straw.

[b] Average of three replications and drying treatments; recovery values calculated on fresh-weight basis for manure.

Source: R. F. Hensler. 1970. Cattle manure: I. Effect on crops and soils; II. Retention properties for Cu, Mn, and Zn. Ph. D. Thesis. University of Wisconsin. (Mic. 70-22651, University Microfilms, Ann Arbor, Michigan).

Abnormally high application rates of solid manure: The growth in numbers of cattle managed by an individual producer has necessitated research into the effects of applying manure at rates much greater than standard agronomic practice would suggest. The soil has a remarkable capacity for assimilating animal manures, but this capacity has a limit. Some of the hazards of concern are deterioration of soil structure from high levels of Na and K, toxicity to plants from excess NH_3 and P, osmotic stress on plants from excess salinity, and contamination of groundwater with NO_3-N.

Murphy et al. (1972) and Manges et al. (1972) have described a study conducted at the Pratt Feedlot in Kansas. Application rates ranged from 0 to 320 ton/ac (0 to 720 tonne/ha) on a dry-rate basis (manure analysis shown in Table 29). Irrigated corn silage showed a maximum yield increase at an application rate of about 120 ton/ac (260 tonne/ha). Greater rates of manure application led to high accumulations of soluble salts and NH_3-N in the top 12 in. (30 cm) of soil; these accumulations were considered high enough to be toxic and responsible for poor germination and seedling vigor. Nitrate accumulation down to 6 ft (2 m) depth was indicated, but this could not be positively correlated with the high application rates, although single heavy applications seemed to drive NO_3-N deeper than did repeated lighter applications. Phosphorus accumulation in the top 16 in. (40 cm) of soil was recorded. The accumulation of NO_3-N in the silage was not excessively high (700 ppm) despite the accumulated manure applications. Manges et al. showed that irrigation with clean water before planting would improve seed germination. A linear relation existed between manure loading rate and soil saturation extract conductivity. Conductivities up to 5.3 mmho/cm were measured, which would put these soils into the medium soil-salinity classification (Table 30).

In a Minnesota study (Goodrich et al., 1973), corn wilted on plots receiving 31 ton/ac (70 tonne/ha) of liquid beef manure, dry-matter basis. The plant damage was associated with an increased electrical conductivity of the soil saturation extract. Solid beef manure and liquid hog manure also elevated the electrical conductivity, but the effect was not so pronounced, and no plant damage was noted. McCalla (1974) stated that damage to salt-sensitive crops may occur when the conductivity reaches 2 mmho/cm and that few crops can grow if the conductivity reaches 16 mmho/cm. If, as is usually true, part of the conductivity is caused by Na^+, then soil structure may deteriorate at high conductivities.

Table 29. Average yearly analyses of the manure applied to corn land in Kansas.

Year	N %	K %	Ca ppm	Mg ppm	P ppm	Zn ppm	Fe ppm	Na ppm
1969 ------	1.04	1.09	7757	3934	4166	66	8825	2280
1970 ------	3.12	0.39	5580	4450	7100	--	--	1675
1971 ------	0.89	0.97	9800	4200	5700	56	4810	2490

Source: H. L. Manges, L. S. Murphy, and E. H. Goering. 1972. Disposal of beef feedlot waste onto cropland. ASAE 72-961. American Society of Agricultural Engineers, St. Joseph, Michigan.

Table 30. Salt tolerance of selected crops.

Crop	Electrical conductivity of soil water extract mmho/cm	Salinity level
Bermuda grass ----------------------	13	
Barley ----------------------------	12	
Tall wheatgrass --------------------	11	Very high
Sugar beets ------------------------	10	
	8	- - - - - - - - - - - -
Wheat -----------------------------	7	High
Tall fescue ------------------------	7	
Sorghum ---------------------------	6	- - - - - - - - - - - -
Soybeans --------------------------	5.5	
Corn ------------------------------	5	Medium
	4	- - - - - - - - - - - -
Alfalfa ----------------------------	3	
Potato ----------------------------	3	Low
Orchard grass ----------------------	3	

Source: H. S. Jacobs, and D. A. Whitney. 1968. Determining water quality for irrigation. Kansas Cooperative Extension Service Circular 396.

Heavy applications of manure to certain soils may lead to nitrate contamination of groundwater. Unfortunately, the parameters involved in this phenomenon are numerous, and mathematical models of widespread applicability have not been developed. If manure is applied to a normal fertile soil with a growing crop, the nitrogen in the manure will be acted upon by soil organisms to form ammonia and, later, nitrate (Figure 35). These two forms can be taken up by the growing plant, although there is a preference for nitrate uptake. The ammonium ion is bound by clay minerals in the soil and does not normally leach. The nitrate ion, however, may leach quite readily. Just because nitrate is formed in the upper layers of the soil, it does not necessarily mean that groundwater contamination will follow. If there is a sufficient, readily available carbon source and anaerobic conditions exist, then nitrate will be reduced to N_2 and N_2O gases. These are lost to the atmosphere (Bremner and Shaw, 1958). Heavy manure application undoubtedly leads to significant denitrification, although it has not been possible to perform accurate mass balances in the field. For groundwater contamination to take place, there must be leaching water. In some dry areas, such leaching may be very infrequent; thus, there may be high levels of nitrate in the soil profile, but these will not necessarily be a health hazard because their rate of release may be very slow.

Mathers and Stewart (1971) applied increments from 0 to 240 ton/ac (0 to 538 tonne/ha) of beef feedlot manure (1.32%-1.78% N, wet basis) in Texas (High Plains area). A study of the soil profile showed clearly that all application rates in excess of 10 ton/ac (22 tonne/ha) caused a front of NO_3-N to move down into the soil. The results, however, showed that NO_3-N accumulation was not linearly related to application rates, being relatively less at greater application rates. The NO_3-N concentration in plants **(Sorghum vulgare)** was greater than that recommended for silage. Murphy et al. (1972) presented a graph of NO_3-N vs. depth 2 yr after a one-time application of about 200 ton/ac (450 tonne/ha); this showed a massive increase at the 80-in. (200-cm) depth. The manure application corresponded to 4160 lb/ac (4680 kg/ha) of N. Marriott and Bartlett (1972) applied dairy-cattle manure slurry in 15-ton/ac (33-tonne/ha) increments up to 75 ton/ac (170 tonne/ha). These tests were performed in Pennsylvania. The rainfall during the test year was 35 in. (89 cm), being distributed approximately evenly through the year. Each 15-ton/ac (33-tonne/ha) increment corresponded to 700 lb/ac (780 kg/ha) as N; the forage crops removed only 141 lb/ac (160 kg/ha) of N at the greatest application rate. The

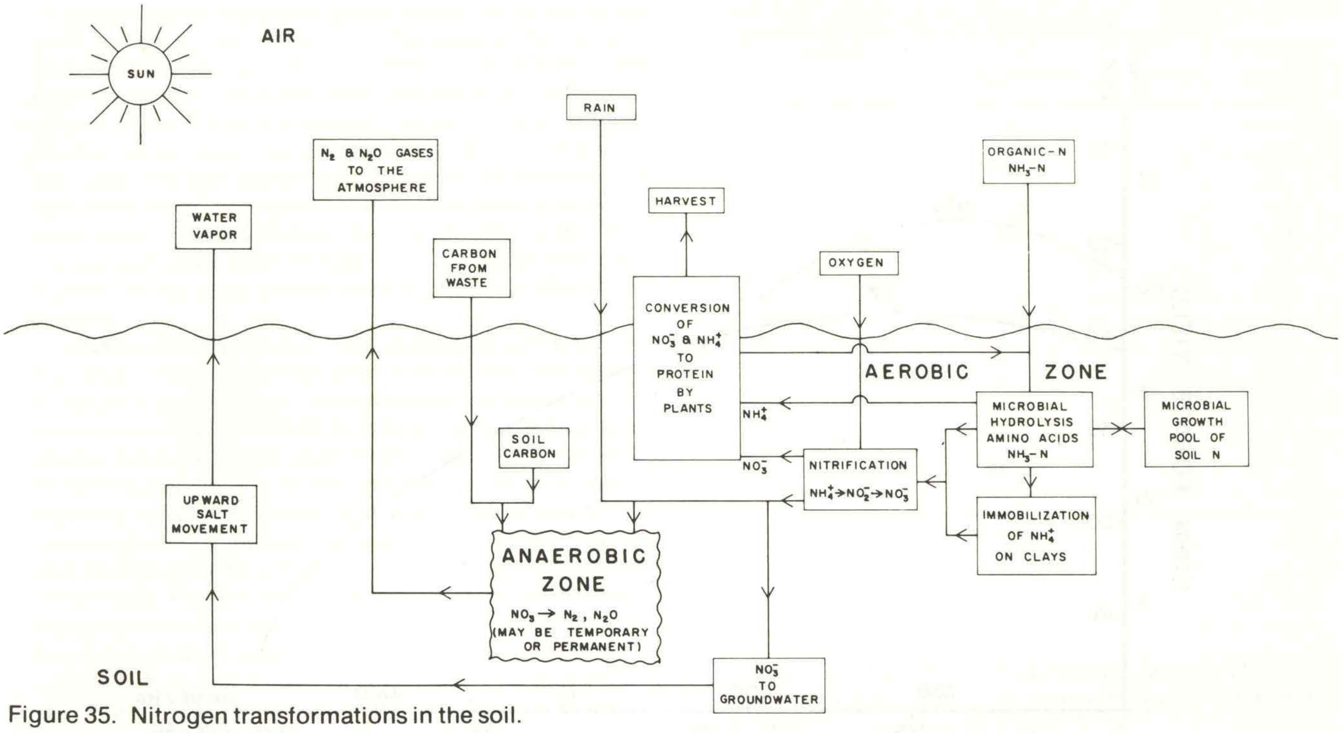

Figure 35. Nitrogen transformations in the soil.

NO_3-N concentration in soil water samples (suction lysimeter) exceeded 67 mg/l at the 4-ft (1.2-m) depth, and Marriott and Bartlett concluded that, in Pennsylvania, annual application rates in excess of 700 lb/ac (780 kg/ha) could lead to unacceptable contamination of the groundwater.

Butler (1973) continued the work of Marriott and Bartlett (1972) by developing a computer model for nitrate movement in the same soils. Laboratory data relating denitrification and nitrification in the particular soils studied were obtained under controlled moisture conditions. When the results of the model were compared with the actual field data to a depth of 33 in. (100 cm), the computer model and field results agreed very closely. The model, however, indicated that the NO_3-N front moved down into the soil more rapidly than field tests verified.

Adriano et al. (1971) conducted soil surveys in the Chino-Corona Basin in California. This is an intensive dairy area where the annual rainfall is about 10 in. (25 cm), most of which falls between December and March. Soil water from pastures used for manure-disposal areas showed average NO_3-N concentrations of 74 mg/l at depths of 10-19 ft (3-6 m). The manure disposal rate on these pastures corresponded to about 10 cows/ac (25 cows/ha) or 1460 lb/ac (1640 kg/ha) of N annually. Such NO_3-N concentrations could be explained by postulating that 50% of the applied N was lost by denitrification. Adriano et al. suggested that, if the NO_3-N in groundwater were to be kept below 10 mg/l, then only the wastes from 3 cows/ac (7.5 cows/ha) or 440 lb/ac (490 kg/ha) as N should be applied annually.

It is questionable whether leaching of NO_3-N is the only criterion that should govern land application; loss of soil fertility may be equally important. Cross et al. (1971) conducted extensive trials with beef manure; application rate, plowing depth, and seeding rates were the variables investigated. The plots were sown with Sudex, a sorghum-sudan cross. The plots were furrow-irrigated with well water. The four manure application rates were 0, 40, 120, and 260 ton/ac (0, 90, 270, and 580 tonne/ha) dry basis. Depth of plowing did not affect soil yields, but manure application rates caused yield differences between no manure, 40 and 120 ton/ac (90 and 270 tonne/ha), and 260 ton/ac (580 tonne/ha). Peak yields were for 40- and 120-ton/ac (90- and 270-tonne/ha) rates; the 260-ton/ac (580-tonne/ha) rateshowed a severe yield depression. Cross et al. also expressed concern that continuing high-rate applications would lead to soil-structure deterioration because of high Na and K levels. After 3 yr of field trials, Manges et al. (1972) showed that the effects of manure applications on corn forage yields are additive (Figure 36). The calculated maximum yields of 23.2 ton/ac (52 tonne/ha) in 1970 and 18.9 ton/ac (42 tonne/ha) in 1971 were obtained from accumulated manure loadings of 102 and 137 ton/ac (230 and 307 tonne/ha), respectively. Forage yields in 1972 showed that a maximum forage yield of 27.2 ton/ac (61 tonne/ha) resulted from an accumulated manure loading of 120 ton/ac (270 tonne/ha). Manges et al. also commented on the adverse effect on the soil structure caused by excessive manure applications.

A somewhat conflicting attitude was taken by Weeks et al. (1972) who applied heavy rates of dairy manure to test plots in Massachusetts. The soil on all test plots was described as a well-drained fine sandy loam. Dairy-cattle manure was applied in increments up to 350 ton/ac (785 tonne/ha), which corresponded to 3850 lb/ac (4320 kg/ha) of N. There seemed to be little difference in corn yields between plots receiving 200 lb/ac (224 kg/ha) and those receiving 1840 lb/ac (2060 kg/ha). The yields from the 3850

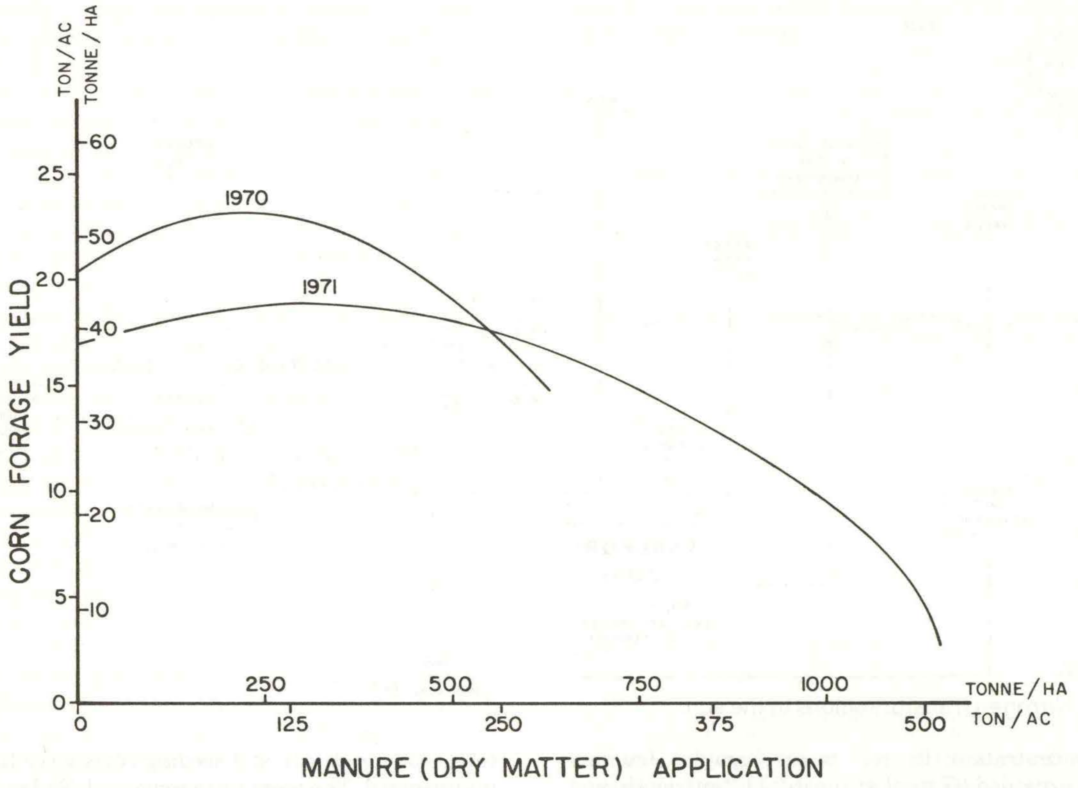

Figure 36. Cumulative effect of heavy manure applications on corn forage yield.
Source: H.L. Manges, L.S. Murphy, and E.H. Goering. 1972. Disposal of beef feedlot wastes onto cropland. ASAE 72-961. American Society of Agricultural Engineers, St. Joseph, Michigan.

lb/ac (4320 kg/ha) plots were not obtained, but a "good crop" was reported. Weeks et al. concluded that, in the sandy loam soils of the Connecticut Valley, large applications of 600 ton/ac (1350 tonne/ha) of dairy-cattle manure would not adversely affect crop yields, although these authors still expressed some reservations concerning nitrate in either crops or groundwater. Reddell et al. (1971) reported on deep plowing (30 in., 76 cm) of beef feedlot manures at very high rates of application in Texas. Quantitative data were not presented, but barley was observably growing well, even on plots that had received 900 ton/ac (2000 tonne/ha) wet basis. At the Pecos location, fall crops of barley, alfalfa, and sugar beets all were doing well. Goodrich et al. (1973) indicated that corn yields in Minnesota were depressed slightly when 30 ton/ac (67 tonne/ha) dry basis of dairy manure was applied, but 10- and 20-ton/ac (22- and 44-tonne/ha) rates did not produce yield differences between these two rates.

Most investigators have reported difficulties in applying manure at very heavy rates. Goodrich et al. (1973) found that, when application rates of liquid beef manure exceeded 100 ton/ac (220 tonne/ha) wet basis, it was impossible to plow, even after a winter had elapsed. Reddell et al. (1971) used deep plowing under Texas conditions. A 30-in. (76-cm) moldboard plow was used, and this was fitted with a blade ahead of the plow to move the manure into the open furrow. This was effective in turning under 300-900 ton/ac (670-2000 tonne/ha) wet basis. An 18-in. (46-cm) moldboard plow was successful only where the application rates were less than 600 ton/ac (1350 tonne/ha) wet. A 27-in. (69-cm) trencher worked well, even with 900 ton/ac (2000 tonne/ha), and heavier rates could have been accommodated. A 50-in. (127-cm) disk plow did not shed soil well, and too much manure remained on the surface. Some costs of deep plowing taken from this study are shown in Table 31. These costs are for plowing only and do not include hauling or spreading the manure.

Table 31. Costs of deep plowing manure for various application rates in western Texas.

Tillage equipment	Contract cost		Unit cost of plowing under manure					
			300 ton/ac (670 tonne/ha)		600 ton/ac (1350 tonne/ha)		900 ton/ac (2000 tonne/ha)	
	$/ac	$/ha	$/ton	$/tonne	$/ton	$/tonne	$/ton	$/tonne
30 in. (76 cm) moldboard --	40	99	0.133	0.147	0.067	0.074	0.045	0.05
18 in. (46 cm) moldboard --	12-15	30-37	0.04-0.05	0.046-0.055	0.02-0.025	0.022-0.028	--	--
27 in. (29 cm) trencher ---	560	138	1.86	2.05	0.93	1.03	0.62	0.58
50 in. (127 cm) disk ------	12.50	31	0.042	0.047	0.021	0.023	--	--

Source: D. L. Reddell, W. H. Johnson, P. J. Lyerly, and P. Hobgood. 1971. Disposal of beef manure by deep plowing. pp. 235-238. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

Application of waste-pond effluents: Many of the problems discussed in the preceding section (Abnormally high application rates of solid manure) also relate to the land application of waste-pond effluents. As with solid wastes, there is a great tendency to apply these liquid effluents on too small an area because this will minimize management and equipment investment. Wastewater differs from "solid" waste in that the solids content is seldom more than 0.5%; therefore, the liquid will move into a porous soil much more rapidly than the liquid from solid wastes would; thus, nitrate leaching is generally of real concern.

McGauhey and Krone (1967) conducted a review of the literature associated with the use of the soil mantle as a treatment system. They concluded that soil maintained in an aerobic condition would be able to remove more organic matter from the liquid applied than would anaerobic soils; moreover, aerobic soil would maintain infiltration ability, whereas anaerobic soils tend to plug. Because denitrification is generally desired, a regime of alternate soaking and drying must be instigated if the best use of the soil is to be made. Parizek et al. (1967) have described extensive renovation studies with sprinkler irrigation of secondarily treated municipal wastewater. With application rates of 1 or 2 in./wk (2.5 or 5 cm/wk), they found that 68%-82% of the NO_3-N was removed by the top 12 in. (30 cm) of woodland soil. Four in./wk (10 cm/wk) also was tried, but removals of N were inferior.

Koelliker et al. (1971) reported on a tiled and instrumented irrigation field receiving effluent from an anaerobic swine lagoon. They concluded that such effluent can be applied to Iowa soils between mid-April and early November. The soils were poorly drained, and 2 in. (50 cm) at a rate of 0.4 in./hr (1 cm/hr) was the maximum single application recommended. Soil filtration removed more than 80% of the COD and often up to 93%; phosphorus removal was 90%-97%, and nitrogen removal 48%-67%. They comment that multiple small applications gave better treatment. Koelliker et al. concluded that application rates up to 600 lb/ac (720 kg/ha) of N annually might be possible on suitable crops because denitrification and crop harvesting would remove most of this N. Booram et al. (1974) examined the effects of effluent from the same swine-treatment lagoon on corn and sorghum. Nitrogen and phosphorus were at increased levels in the leaves of both corn and sorghum harvested from the plots receiving heavy applications of lagoon water. Corn yields were not affected by the lagoon-water application, but the sorghum yields decreased by as much as 53 bu/ac (1.9 m^3/ha). Salinity was not a problem because the conductivity value for the maximum application rate of 1350 lb/ac (1630 kg/ha) was only 0.56 mmho/cm. The average total N and P concentrations in the applied lagoon liquid were 349 and 417 mg/l, and 77 and 63 mg/l for 1971 and 1972, respectively. Tables 32 and 33 give the nutrient analyses for the lagoon and the nutrient levels found in corn leaves, respectively.

Larsen and Axley (1971) reported on irrigating wastes from a poultry processing plant. The irrigation field was a sandy loam sown to tall fescue. Table 34 shows the composition of the wastewater; applications were 34, 44, 108, and 200 in./yr (86, 112, 274, and 508 cm/yr). Table 35

Table 32. Nutrient analysis at Unit K anaerobic lagoon, Swine Nutrition Station, Iowa State University.

Parameter	Date				Average
	8/16/71	10/5/71	6/22/72	8/28/72	
Aluminum	10	1.2	--	--	5.6
Boron	0.43	0.63	1.0	0.55	0.65
Calcium	53	103	59	43	51.3
Chromium	--	--	3.1	--	3.1
Copper	0.16	0.24	1.7	0.04	0.54
Iron	1.8	4.2	4.6	0.81	2.85
Lead	--	--	2.9	0.03	1.47
Magnesium	73	70	52	16.3	52.8
Manganese	0.35	0.37	1.60	0.39	0.68
Molybdenum	0.02	0.02	--	--	0.02
Nickel	--	--	0.80	0.02	0.41
Potassium	303	347	--	256	302
Phosphorus[b]	82	82	69	69	75.5
Zinc	0.22	0.67	0.80	0.10	0.45
pH[b]	7.5	7.5	7.3	7.3	7.4
Kjeldahl-N[b]	371	371	432	432	401
Ammonia-N[b]	296	296	415	415	355
Conductivity[b]	--	--	5010	5010	--

[a] All parameters as mg/ℓ, except pH.

[b] Average values.

Table 33. The effect of anaerobic lagoon effluent on nutrient uptake of corn as measured by concentration of elements in corn leaves (Sept. 1972).

Element	Treatment[b]			
	1	2	3	4
Phosphorus (%)	0.37	0.80**	0.45	0.74**
Potassium (%)	1.28	1.92**	1.45*	1.76**
Magnesium (%)	0.33	0.21**	0.30	0.22**
Sodium (%)	0.07	0.13**	0.09	0.14**
Manganese (ppm)	34	82**	42	78
Iron (ppm)	156	221**	184	250**
Zinc (ppm)	27	50**	34	48**
Aluminum (ppm)	170	261**	184	270**
Barium (ppm)	7.3	11.3*	8.5	10.3*

[a] Expressed as treatment means for leaves opposite and below primary earshoot at physiological maturity of grain (8 September).

[b] Treatments 1, 2, 3, and 4 had, respectively, received 0, 19.8, 4.0, and 20.2 inches of effluent by 8 Sept. 1972.

* Denotes significance at the 0.10 level.
**Denotes significance at the 0.05 level.

Table 34. Chemical composition of sewage from the poultry processing plant.

Compound	Concentration ppm
Organic nitrogen as N	46
Ammonium nitrogen as N	9
Nitrate nitrogen as N	10
Nitrite nitrogen as N	0.9
Organic phosphorus as P	7.4
Inorganic phosphorus as P	7.6
Potassium	15
Calcium	50
Magnesium	25
Sodium	50
Total carbon	1000

[a] The pH of the sewage was 7.1.

Source: V. Larsen and J. H. Axley. 1971. Nitrogen removal from sewage waters by plants and soil. pp. 338-340 and 347. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

Table 35. Nitrogen and chloride content of poultry processing plant sewage as it passed through the soil and the carbon-nitrogen ratio of the soil at various depths of soil as influenced by different sewage application rates.

Sewage application rate		Depth of soil		Effluent content (ppm)					
in./yr	cm/yr	ft	m	Total-N	Organic-N	NO_3-N	NO_2-N	NH_4-N	Cl
		0	0.0	65.9	46.0	10.0	0.9	9.0	64
34	86	1	0.3	32.7	0.5	31.1	0.81	0.3	89
		3	0.9	33.9	0.0	34.2	0.00	0.0	89
		10	3.0	4.8	0.0	4.5	0.10	0.0	31
		20	6.0	5.3	0.0	2.6	1.85	0.0	30
44	112	1	0.3	38.1	10.8	36.1	0.41	0.8	85
		3	0.9	33.0	1.3	31.5	0.14	0.1	85
		10	3.0	14.9	1.4	13.4	0.12	0.0	58
		20	6.0	4.0	0.3	2.7	0.98	0.0	19
108	274	1	0.3	51.7	12.7	36.0	0.89	2.1	64
		3	0.9	47.9	10.0	37.4	0.21	0.3	64
		10	3.0	18.1	0.3	17.6	0.16	0.0	59
		20	6.0	14.1	0.0	15.9	1.04	0.0	57
200	508	1	0.3	61.1	35.5	21.1	0.81	3.7	65
		3	0.9	49.3	23.3	24.0	1.07	0.9	66
		10	3.0	33.8	3.5	30.0	0.15	0.0	64
		30	9.0	12.0	0.8	11.2	0.00	0.0	56

[a] The carbon:nitrogen ratio was determined on the soil.

Source: V. Larsen, and J. H. Axley. 1971. Nitrogen removal from sewage waters by plants and soil. pp. 338-340 and 347. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

shows the fate of the nitrogen in the soil. Larsen and Axley observed that the poultry plant has used a 27-ft (9-m) deep well in the 200-in./yr (508-cm/yr) disposal area as its water supply and that the nitrate level in this water only just exceeds the NO_3-N limits of 10 mg/l set by the U.S. Public Health Service. Satterwhite and Gilbertson (1972) examined the effect of beef feedlot runoff on several species of grasses. The study included both field and greenhouse studies. Control plots were established that received equal quantities of stream water in place of runoff. The 1970 applications were 42, 84, 126, and 168 lb/ac (50.3, 101, 151, and 201 kg/ha) of N. Protein analyses of bromegrass, reed canary grass, and bluegrass all showed increases on the plots irrigated with runoff. The greenhouse studies extended over the years 1969 and 1970. Because the nitrogen content of the 1969 runoff was 4 times that of the 1970 runoff, several of the grass species showed poor survival. Some of the grasses doing well under the high N-concentration runoff were side-oats grama, bromegrass, orchardgrass, switchgrass, reed canary grass, and Indian grass. Satterwhite and Gilbertson conclude that runoff of the 1970 quality (66 mg/l N) applied at 2 in./wk (5 cm/wk) would stimulate good grass growth. Swanson et al. (1974) discussed the application of beef feedlot runoff to perennial grass oversown with clover. The test site was in Nebraska on a silty clay loam. The amounts of runoff applied and the resulting loadings of nutrients, salts, and solids are shown in Tables 36 and 37. Swanson et al. noted that clover dominated the crop after the first harvest, yet the clover had only a low salt tolerance. The effluent applications generally improved forage yield, and chemical analyses of plant tissue did not reveal any undesirable or toxic constituents. Swanson et al. did remark that the quality of runoff pond water varied markedly during the irrigation season. Runoff water monitored shortly after a storm was high in total N, but in 1971, prolonged storage in the pond without further runoff reduced this N to half owing to biological action.

Table 36. Feedlot effluent and water applications to grass and clover plots, silty clay loam soil, Springfield, Nebr., 1970-1972.

Treatment	Year	Number of applications	Total depth applied		Total depth including rainfall[a]	
			in.	cm	in.	cm
2 in. (5.1 cm) of water once each week	1970	10	20	51	31.45	79.9
	1971	18	36	91	40.44	102.7
	1972	17	34	86	43.89	111.5
1 in. (2.5 cm) of effluent once each week	1970	10	10	25	21.45	54.5
	1971	18	18	46	22.44	57
	1972	17	17	43	26.89	68.3
2 in. (5.1 cm) of effluent once each week	1970	10	20	51	31.45	79.7
	1971	18	36	91	40.44	102.7
	1972	17	34	86	43.89	111.5
3 in. (7.6 cm) of effluent once every 2 weeks	1970	5	15	38	26.45	67.2
	1971	9	27	69	31.44	79.9
	1972	9	27	69	36.89	93.7

[a] Rainfall during season of application: 11.45 in. (29.1 cm), 1 July to 30 Sept. 1970; 4.44 in. (11.3 cm), 1 June to 15 Oct. 1971 (16 in., 41 cm, normal); and 9.89 in. (25.1 cm), 1 June to 1 Oct. 1972.

Source: N. P. Swanson, C. L. Linderman, and J. R. Ellis. 1974. Irrigation of perennial forage crops with feedlot runoff. Transactions of the American Society of Agricultural Engineers 17:144-147.

Table 37. Quantities of solids and nutrients applied to grass and clover plots, Springfield, Nebr., 1970-1972.

Parameter	Year	Mass application					
		1 in. (2.5 cm) weekly		2 in. (5.1 cm) weekly		3 in. (7.6 cm) biweekly	
		lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/ha
	1970						
Total solids		15020	16800	30035	33700	23850	26700
Volatile solids		8085	9060	16175	18100	12845	14400
Total nitrogen		805	902	1610	1800	1280	1430
Total phosphorus		40	45	80	90	65	73
Salts		6680	7490	13355	15000	10605	11900
	1971						
Total solids		12240	13700	24480	27400	18360	20600
Volatile solids		5290	5930	10585	11900	7940	8900
Total nitrogen		370	414	740	830	555	622
Total phosphorus		175	196	350	392	265	297
Salts		3600	4040	7200	8070	5400	6050
	1972						
Total solids		8470	9500	16945	19000	13455	15100
Volatile solids		3850	4320	7700	8630	6115	6850
Total nitrogen		215	241	430	482	340	381
Total phosphorus		80	90	160	179	130	146
Salts		3005	3370	6005	6730	4770	5350
	1970-1972						
Total solids		35730	40100	71460	80100	55665	62400
Volatile solids		17225	19300	34460	38600	26900	30200
Total nitrogen		1390	1560	2780	3120	2175	2440
Total phosphorus		295	331	590	661	460	516
Salts		13285	14900	26560	29800	20775	23300

Source: N. P. Swanson, C. L. Linderman, and J. R. Ellis. 1974. Irrigation of perennial forage crops with feedlot runoff. Transactions of the American Society of Agricultural Engineers 17:144-147.

Most of the work described in this section has been based on the assumption that irrigation rates are limited to being less than the system can accept without runoff. Law et al. (1970) have described a system that deliberately promotes runoff. The system consists of rolling land carefully terraced and sown with reed canary grass, tall fescue, and red top. These pastures receive sprinkler-irrigated waste from a soup cannery in Texas. The management of the system is such that a biological mat is formed where the grass emerges from the ground; nutrients and organic matter in the wastewater are removed by this mat, and the renovated liquid evaporates, infiltrates, and continues to flow overland. Law et al. estimated that 18% is lost by evaporation, 21% infiltrates, and 61% appears as runoff. The irrigation is intermittent so that aerobic conditions are achieved at some stage during the cycle. The wastewater was reported as having mean values of 806 mg/l COD and 17 mg/l Kjeldahl N. The reduction in these two parameters (mass removal, applied vs. runoff) was greater than 90% and 85%, respectively. The spray-runoff approach to wastewater renovation has been applied to beef feedlot runoff by Kramer et al. (1974). The two irrigation areas used (Figure 37) allowed the runoff to be processed again after passage through a polishing pond. The irrigation area had a loam topsoil underlain by heavy clay at 1.5-3 ft (0.5-1 m). The slope varied from 1%-3%. The slope lengths varied from 160 to 200 ft (49 to 61 m). The grasses used included tall fescue, reed canary, and tall wheatgrass. The primary area receiving the feedlot runoff was irrigated for 5 hr/day, 6 day/wk. The recirculation area was irrigated for 2 hr every 6 hr. The primary area was dosed at 0.07 in./hr (0.2 cm/hr), and the recirculation area at 0.134 in./hr (0.34 cm/hr). The qualities of the various flows are shown in Tables 38, 39, and 40. Algae grew in the recirculation pond, but passage down the recirculation slope removed some of the algae, judged by diminution of the characteristic algal green color of the liquid. Mass reductions after passage through the whole system were better than 90% for BOD_5, COD, N, and P. Although the recirculation pond water had a mean BOD_5 of 35 mg/l and total suspended solids of 74 mg/l, Kramer et al. expressed doubts that this liquid would be acceptable for discharge. The salinity of the soil water in the irrigation areas was determined, but the levels of salts or alkali were not considered hazardous after 2 yr of operation. Problems with channelling were mentioned. This showed the need for careful grading of any spray-runoff system.

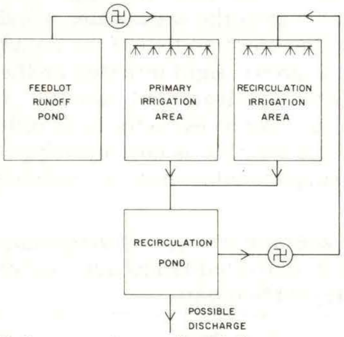

Figure 37. Scheme of overland flow areas used to renovate runoff from the Circle E feedlot, near Wichita, Kans.

Source: J.A. Kramer, D.E. Eisenhauer, and H.L. Manges. 1974. A spray-runoff system with recirculation for treating beef cattle feedlot runoff. ASAE MC-74-301. American Society of Agricultural Engineers, St. Joseph, Michigan.

Barriered-landscape technique: The soil and its microbial population are capable of removing nitrogen by nitrification and denitrification reactions; phosphorus may be removed by adsorption. Unfortunately, a natural field situation is rather uncontrollable with regard to predicting N and P removal. Erickson et al. (1971) have attempted to control N and P removal by tailoring the soil profile for this specific purpose. The result is the Barriered Landscape Water Renovation System (BLWRS). The BLWRS has three layers (Figure 38). The top layer has slag or limestone and a cover crop; this layer is designed to act as a phosphorus trap if the native soil is deficient in clay (e.g., a sandy soil). The second layer is normal, active topsoil that serves to degrade organic matter and promote nitrification. Finally, there is a lower layer that can be kept flooded and anaerobic. The BLWRS is isolated from the soil under it by placement of an impermeable membrane. Water that has percolated through the system can be either collected by perimeter drains or allowed to seep horizontally into undisturbed soil. The lower anaerobic layer is fitted with a perforated pipe that allows a carbon source to be added. Erickson et al. (1971) used molasses as a carbon source; Koelliker and Miner (1970) have shown that raw swine wastes also can be used to promote de-

Table 38. Quality of wastewater applied to the primary irrigation area at the Circle E feedlot, Kansas.

Parameter	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation
				mg/l		
BOD_5 ---------------	13	122	156	140	148	14
COD ---------------	16	872	1567	1257	1220	212
Ammonia-N ----------	17	61	140	106	110	22.0
Kjeldahl-N ---------	16	105	300	166	150	53
Total-P -----------	12	9.8	22	16	15	5.5
Total suspended solids ------------	12	280	565	432	482	142
pH[a] ---------------	17	7.5	8.1	7.9	8.0	0.2
Conductivity[b] ------	17	4300	5100	4650	4700	245

[a] Expressed in pH units.

[b] Expressed in mmho/cm.

Source: J. A. Kramer, D. E. Eisenhauer, R. I. Lipper, and H. L. Manges. 1974. A spray-runoff system with recirculation for treating beef cattle feedlot runoff. ASAE MC-74-301. American Society of Agricultural Engineers, St. Joseph, Michigan.

Table 39. Quality of runoff from the recirculation irrigation area at the Circle E feedlot, Kansas.

Parameter	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Difference in means[a]	Difference in means[b]
				mg/l			%	%
BOD_5 ---------------	8	16	17	17	17	0.5	-54	-88
COD ---------------	12	410	750	635	659	91	- 4	-50
Ammonia-N ----------	11	1.4	4.3	2.6	2.6	1.0	-54	-98
Kjeldahl-N ---------	12	19	35	25	26	4	-24	-85
Total-P -----------	8	5.5	7.8	6.5	6.2	1	- 5	-59
Total suspended solids[c] ------------	--	--	--	18	--	--	-76	-96
pH[d] ---------------	12	8.0	8.8	8.5	8.6	0.2	+ 2	+ 8
Conductivity[e] ------	12	3300	5200	4483	4650	570	+ 5	- 4

[a] Difference in means of water applied to and field effluent from recirculation irrigation area.

[b] Difference in means of water applied to primary irrigation area and field effluent from recirculation irrigation area.

[c] Only one representative composite sample was analyzed.

[d] Expressed as pH units.

[e] Expressed as mmho/cm.

Source: J. A. Kramer, D. E. Eisenhauer, R. I. Lipper, and H. L. Manges. 1974. A spray-runoff system with recirculation for treating beef cattle feedlot runoff. ASAE MC-74-301. American Society of Agricultural Engineers, St. Joseph, Michigan.

Table 40. Quality of runoff from the primary irrigation area at the Circle E feedlot, Kansas.

Parameter	Number of Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Difference in means of applied and effluent water
		mg/l					%
BOD_5	11	43	92	64	60	18	-54
COD	14	675	1239	966	1012	191	-23
Ammonia-N	15	5.5	28.0	12.9	10.0	8.0	-88
Kjeldahl-N	15	31	94	53	50	16	-68
Total-P	11	6.5	19	10	8.8	4.6	-35
Total suspended solids	10	170	280	236	280	57	-45
pH[a]	15	7.8	8.9	8.2	8.2	0.4	+ 4
Conductivity[b]	15	4100	5200	4917	4800	584	+ 6

[a] Expressed in pH units.

[b] Expressed in mmho/cm.

Source: J. A. Kramer, D. E. Eisenhauer, R. I. Lipper, and H. L. Manges. 1974. A spray-runoff system with recirculation for treating beef cattle feedlot runoff. ASAE MC-74-301. American Society of Agricultural Engineers, St. Joseph, Michigan.

nitrification without adding excessive amounts of COD or reduced N to the effluent. Their work used a liquid system in a digester only and was not extended to denitrification in the soil. After the encouraging performance of the prototype BLWRS, Erickson et al. (1972) built four more systems. These systems were used in pairs to allow a resting period and restoration of infiltration rate by aerobic activity. The results obtained by using these units on swine and dairy waste are shown in Table 41. Erickson et al. (1972) have indicated that there are problems during the winter. An attempt to maintain above-freezing temperatures by using electrical heating tapes was not successful.

Hydroponic Culture

Hydroponics is a method of growing plants without soil. Nutrients are carried to the plants in a liquid medium. Plant roots are suspended in the medium. Because nutrients are removed from the liquid, hydroponic systems may be used to upgrade wastewater from livestock-waste systems. The nutrients removed from the waste are in the crops, which may then be harvested and recycled through the livestock. One method of using hydroponic culture for treating livestock wastes is to construct a series of long, narrow beds for growing the plants. An inert supporting material is placed in the bed to provide mechanical support for the plant roots. Screens suspended on the liquid surface may also serve as support, but it is difficult to maintain the proper relationship between the screen and the liquid level. A granular anchoring medium, typically gravel, is the most common supporting system. The effluent to be treated is introduced at one end of the long, narrow beds. As the liquid moves through the beds, nutrients are removed from the water, and some water is lost to the atmosphere through evapotranspiration. The mass flow of nutrients leaving the hydroponic beds will be less than that entering. The amount of nutrients removed from the wastewater will depend upon several factors: the retention time of the liquid in the beds, the type of plants grown, light intensity on the plants, and the atmospheric environment around the plants. Hydroponic culture can be exploited to its fullest extent in mild climates; cold weather is not conducive to good plant growth, and supplemental heat is unlikely to prove economical.

Table 41. The average analysis of waste applied and effluent from the barriered-landscape, water-renovation system (BLWRS) in Michigan.

Parameter	Swine		Dairy	
	Waste mg/l	Effluent mg/l	Waste mg/l	Effluent mg/l
Org N + NH_3 -N	650	2	300	3
NO_3 -N	10	6	10	10
PO_4 -N	20	0.02	40	0.02
BOD	1100	5	1200	5
COD	2000	40	3000	70

Source: A. E. Erickson, J. M. Tiedje, B. G. Ellis, and C. M. Hansen. 1972. Initial observations of several medium sized barriered landscape water renovation systems for animal wastes. pp. 405-410. In: Waste management research (Proceedings, Cornell Agricultural Waste Management Conference).

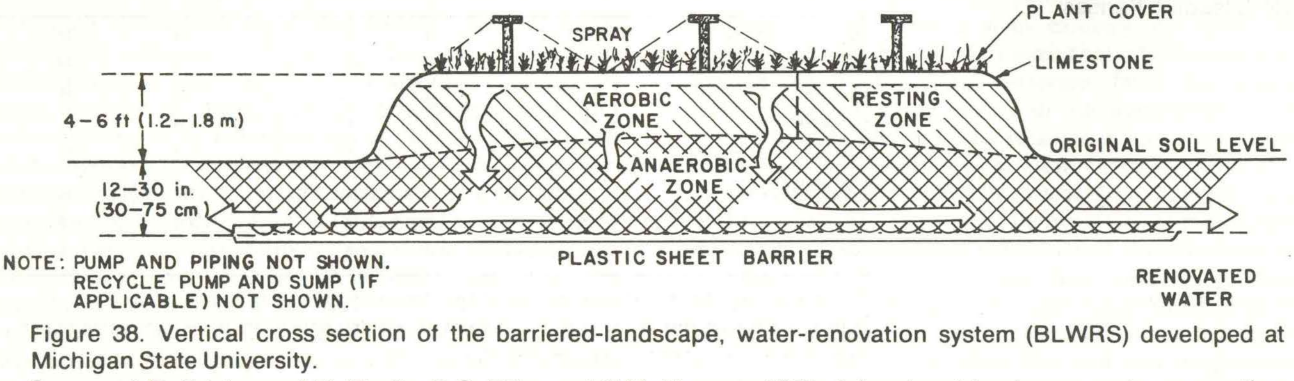

Figure 38. Vertical cross section of the barriered-landscape, water-renovation system (BLWRS) developed at Michigan State University.

Source: A.E. Erickson, J.M. Tiedje, B.G. Ellis, and C.M. Hansen. 1971. A barriered landscape water renovation system for removing phosphate and nitrogen from liquid feedlot waste. pp. 232-234. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

A cooperative study between the U.S. Department of Agriculture and the University of Maryland examined the suitability of various grasses for hydroponic culture in dairy-waste lagoon effluent (Eby, 1966). Orchard grass and timothy did not show good growth because their root systems do not develop properly in a liquid environment. Tall fescue, rye, brome, and reed canary grasses removed about 75% of the N and 64% of the P. The yields that may be expected from hydroponically grown grasses are shown in Table 42. Assuming that the grasses had established a mature root system, the yields shown for the period 25 Jan. to 28 Feb. would have corresponded to a wastewater flow of 45,500 gal/ac (425 m^3/ha) of bed area daily; 356 lb/ac (420 kg/ha) of nutrients would have been extracted by the harvested portion of the fescue, and 115 lb/ac (139 kg/ha) by the roots. Eby considers that a bed depth of 1.5 ft (0.45 m) is a good compromise. With this depth, a pea gravel with a porosity of 43%, and a 5-day detention time (based on total volume divided by the influent flowrate), then a bed area of 2.4 ac (260 ha) would be required for an influent flowrate of 100,000 gal (100,000 m^3) daily. Eby indicated that the total evaporation losses are about 0.017 ft^3/ft^2 (0.0052 m^3/m^2) of bed surface area daily; hence, the effluent expected from a system based on the preceding parameters would be 87,000 gal (87,000 m^3) daily.

Table 42. Grass yields calculated from hydroponically grown cuttings.

Grass	Period	Yield			
		Green cut		Hay	
		ton/ac	tonne/ha	ton/ac	tonne/ha
Brome	29 Sept. 1965- 25 Jan. 1966	6.3	14	--	--
Reed canary		4.8	11	--	--
Tall fescue		8.5	19	--	--
Rye		3.5	7.9	--	--
Brome	25 Jan. 1966- 28 Feb. 1966	4.46	10	1.31	2.94
Reed canary		5	11.2	1.29	2.89
Tall fescue		8.41	18.9	1.53	3.43
Rye		5.34	12	0.925	2.07
Brome	28 Feb. 1966- 31 Mar. 1966	3.65	8.18	1.02	2.29
Reed canary		5	11.2	1.47	3.3
Tall fescue		7.84	17.6	1.76	3.95
Rye		6.56	14.7	1.26	2.82

Source: J. J. Eby. 1966. Evaluating adaptability of pasture grasses to hydroponic culture and their ability to act as chemical filters. pp. 117-120. In: Management of farm animal wastes (Proceedings, National Symposium). American Society of Agricultural Engineers SP-0366.

Table 43. Nitrogen balance on four water-hyacinth pools for the treatment of anaerobic lagoon effluent, Ames, Iowa, 1 June 1970 to 10 Oct. 1970.

Parameter	Nitrogen		
	Concentration	Total	
	mg/l	lb	kg
Input			
Average lagoon supernatant concentration			
Kjeldahl nitrogen[a]	300		
Ammonia nitrogen	286		
Nitrate plus nitrite nitrogen	0		
Quantity pumped into pool 1			
Kjeldahl nitrogen[a]		25.44	11.55
Ammonia nitrogen		24.32	11.06
Output			
Average effluent concentration from pool 4			
Kjeldahl nitrogen[a]	34		
Ammonia nitrogen	29		
Nitrate plus nitrite nitrogen	10		
Quantity discharged from pool 4			
Kjeldahl nitrogen[a]		1.27	0.577
Ammonia nitrogen		1.07	0.486
Nitrate plus nitrite nitrogen		0.39	0.177
Inventory			
Quantity remaining in system, 10 Oct. 1970			
Kjeldahl nitrogen[a]		2.53	1.15
Ammonia nitrogen		2.10	0.953
Nitrate plus nitrite nitrogen		0.43	0.195

[a] Kjeldahl nitrogen analyses include both organic nitrogen and ammonia.

Source: J. R. Miner, J. W. Wooten, and J. D. Dodd. 1971. Water hyacinths to further treat anaerobic lagoon effluent. pp. 170-173. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

Miner et al. (1971) used water hyacinths (**Eichornia crassipies**) in a treatment system to remove nutrients from an anaerobic lagoon treating swine wastes. There were four pools in series, but vigorous plant growth took place only in the last two in the series. Plants harvested from these two ponds yielded 84 ton/ac (190 tonne/ha). The average dry-matter content was 5.9%. When the area of all four pools was counted, the N removal by the plants was 250 lb/ac (302 kg/ha) on an annual basis. The system effluent contained only 7% of the influent N, and the plants contained 7% of the influent N. Loss to the atmosphere and storage in the ponds accounted for the rest. The nitrogen balance for the system is given in Table 43. Miner et al. also note that only 12% of the influent COD was discharged. Some use of the plants for livestock feed has been made, but the results were insufficient to determine the economic aspects of this system of wastewater renovation.

Hydroponic recovery of nutrients may deserve more attention than it has had in the past. Conceptually, it offers two major advantages to the livestock producer. First, it can recover inorganic nitrogen as protein, and second, it can renovate a lagoon effluent and render it aesthetically more suitable for reuse for such purposes as stock watering. Large-scale adoption of hydroponic growth of commercially important plants has not been practiced because mechanical harvesting and handling of the crop are not highly developed. A fruitful research effort might be hydroponic growth followed by ensiling.

Composting

Test results with various livestock manures: Composting is a process in which the volatile solids in garbage, fecal solids, or virtually any other natural organic waste are digested by aerobic microorganisms. The process differs from conventional aerobic waste treatment because it takes place at a much larger ratio of solids:water. This low water content allows the development of a loose matrix of material, which can be aerated with less mixing than would be required in a liquid system; consequently, biological activity in a viable compost has sufficient heat energy to drive the temperature into the thermophilic zone (ca. 160°F, 70°C) without external heat supplies. Maintenance of aerobic, thermophilic conditions is inhibitory to most pathogenic organisms. Because the process is aerobic, it is free of offensive odors, and it also has been found that fly breeding does not occur (Howes, 1966). Composting reduces the weight and volume of the original waste and produces an inoffensive, stable material. This can be used as a soil amendment to improve structure, but the material is too bulky to be classed as a true fertilizer.

Toth and Gold (1971) have reviewed composting, and they indicated that most wastes will compost if the amount of N exceeded 2.5% of the waste dry weight. This percentage varied according to the organisms involved. Livestock wastes have adequate N and may be used to fortify a compost that is very high in carbon. Potassium and phosphorus also are required by microorganisms and may require supplementation in certain circumstances. Toth and Gold indicated that an unturned pile of compost would be stabilized in 8 to 12 wk and that 40%-60% of the organic matter would be lost. The final composted material would be dark brown to black and would have a moisture content between 10% and 20%.

Howes (1966) has used a commercially produced inoculum containing 46 strains of microorganisms, peat moss, and minerals. This material could be blended with chicken litter. After the initial thermophilic stage had elapsed, the chickens could be put on the litter, and the natural action of the birds would sustain continued composting of the droppings. Some management was required to mix caked areas near waterers and to add wood shavings to provide cellulose for bacterial action and to promote a better litter structure. R.G. Bell (1970) reported on a laboratory study using a mixture of 2 parts by weight of fresh poultry manure to 1 part dry, ground corncobs. The corncobs were necessary to lower the moisture content. The mixture was composted in a cylinder through which controlled airflows were passed. Bell determined the temperature at various points in the direction of the airflow and showed that too little air left an anaerobic zone at exit, whereas too much air removed metabolic heat so fast that thermophilic temperatures were not attained. R.G. Bell and Pos (1971) continued this work on composting poultry manure by constructing a pilot-scale, drum composter. This unit could be stirred during the composting cycle and could be fed and discharged to simulate a continuous flow process. After they tried the same mixture of corncobs and manure, the corncobs were replaced by wood shavings because the resulting mixture more truly represented a typical litter composition. Composting, as signified by temperature, was readily achieved by the drum composter, but several mechanical weaknesses were evident from the failure of the drive train several times. R.G. Bell and Pos concluded that compaction of the material within the cylinder was the cause. They also mention that thermal insulation of the cylinder would be necessary to maintain optimum composting temperatures under winter conditions. Although the compost discharged from the drum was inoffensive, except for a strong ammonia smell, it did heat up on standing, further indicating lack of complete stabilization. Pos et al. (1971) used the data from these pilot studies to construct a field-scale unit for poultry manure. This unit was a channel of square cross section (6 ft x 6 ft, 2 m x 2 m), 30 ft (10 m) long with concrete sides and bottom. Blower aeration was provided through slots in the floor. Mixing and transport were performed by an inclined chain and slat conveyor mounted on a carriage running on the top of the walls. The mixing conveyor was passed through the system once daily. The working volume of the composter was about 630 ft^3 (18 m^3), and the daily feed and discharge was 120 ft^3 (3.4 m^3). Temperature profiles showed that the material was well stabilized at discharge. Some tests with the blowers off showed clearly that the aerating action of the chain and slat conveyor-mixer was inadequate for maintenance of aerobic conditions. Not only was composting impaired, but the mechanical handling of the manure became more difficult because of increased stickiness. Pos et al. performed the tests in the winter, and their remarks about supplementary aeration refer only to cold-weather operation.

Galler and Davey (1971) have examined the effect of pH and carbon:nitrogen (C:N) ratios on composting mixtures of poultry manure and sawdust. It seemed that thermophilic activity could be correlated with a rise in pH to around 8.5. Lower initial pH corresponded to longer delays before thermophilic action occured. The range of carbon:nitrogen:phosphorus (C:N:P) ratios regarded as optimum for composting was 30:1:0.2 to 50:1:0.2. In practice, the mixtures tested ranged from 21:1:0.19 to 43:1:0.15. Batch results showed that the lower C:N ratios had a higher oxygen usage, and this extended over a longer time. Galler and Davey observed that the amount of VS reduction paralleled the manure fraction in the waste, so they concluded that little sawdust degradation was taking place during the batch tests. Measurement of the holocellulose fraction confirmed this. If the compost discharged from the batch tests was piled, further fungal decomposition did take place, and holocellulose was reduced about 45% in 12 wk. Nitrogen conservation in the compost seemed more correlated with adequate aeration than with C:N ratio; adequate aeration improved nitrogen retention in the compost. Trials using the compost as a soil conditioner showed improved plant performance when compost was added to a soil low in nutrients.

Wells et al. (1969) have tried composting solid, beef-feedlot wastes in Texas. Both manually turned open piles and a drum composter were used. Manures derived from cotton seed hulls, all-concentrate, and sorghum-silage rations were all composted with equal success. The moisture content of the compost in the piles was held as near to 50% as possible. Fly larvae were noted in the piles at first, but were not sustained as the piles were turned. By the end of 6 wk, all three manures had composted to stable dark brown or black material similar to potting soil. The results from the drum digester were not as satisfactory. First, Wells et al. found that the relative humidity of the air being blown through the compost was so low that the resulting evaporative cooling inhibited microbial action; passing the air through water at 120°F (50°C) overcame this difficulty. The next setback occurred when the composting material exceeded 50% (wet basis) because balls would form as the drum rotated, and the center of these balls remained anaerobic. Modification to a stationary drum design avoided the balling condition; mixing was by intermittent rotation twice each day. The temperatures in both the piled and drum compost rose to 160°-175°F (70°-80°C) in the first day or two, but fell gradually to about 120°F (50°C) after 10 days. Wells et al. concluded that a stable compost that would not support bacteria of putrefaction, coliform organisms, or fly larvae could be obtained in 10 days.

Dairy manure from stanchion barns is an attractive material for composting because the addition of the bedding brings the waste to a favorable moisture content. Using both unheated (pilot-scale) and heated (bench-scale) composting units, Willson (1971a) was able to obtain a stable compost in 19-56 days. The heated units were smaller and the air distribution was better than in the unheated units, so stabilization was more nearly complete after 22 days. Oxygen use was at a maximum 2-3 days after a batch was started; consumption ranged from 0.31 to 1.12 ft^3/min ton (0.0097 to 0.035 m^3/min tonne) of compost. Moisture content was quite critical. Between 40 and 55% gave the best results. Partly anaerobic conditions and undesirable odors occured if the moisture content exceeded 55%; above 75%, thermophilic temperatures were not achieved. The dry-matter content of the manure was re-

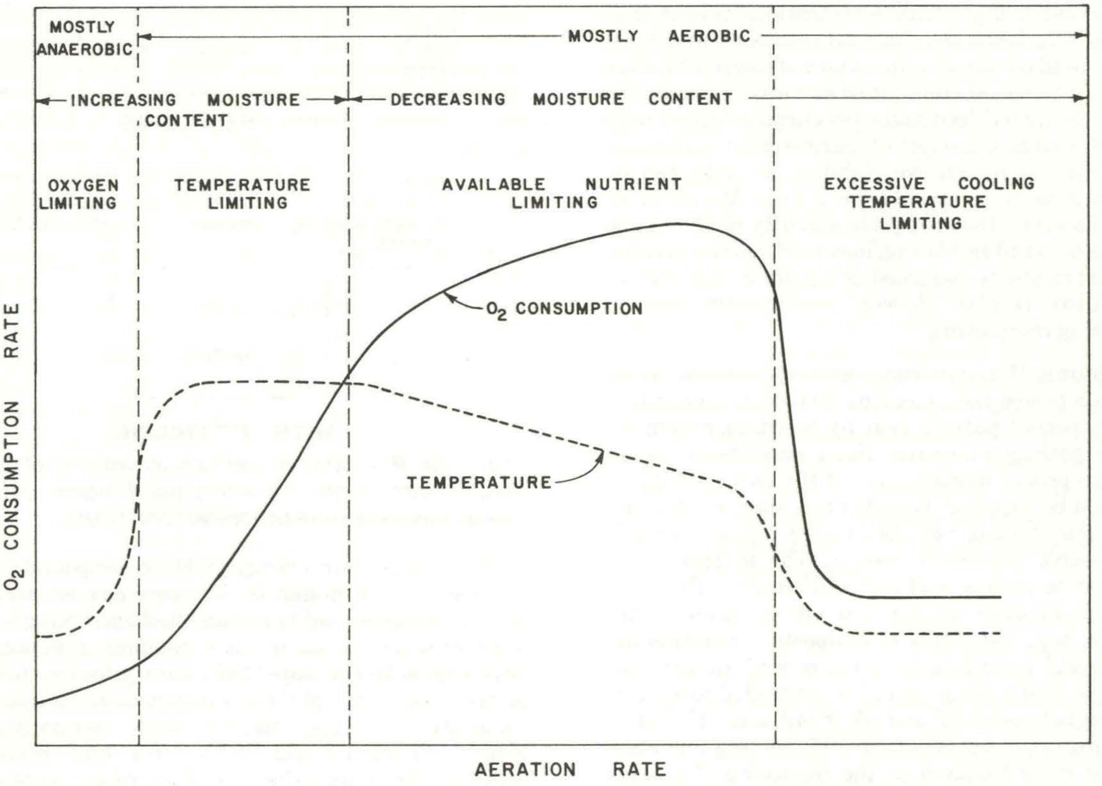

Figure 39. Generalized curves of oxygen-consumption rate and temperature as functions of aeration rate for composting animal manures.

Source: G.B. Willson, and J.W. Hummel. 1972. Aeration rates for rapid composting of dairy manure. pp. 145-158. In: Waste management researčh (Proceedings, Cornell Agricultural Waste Management Conference).

duced by about 60%, and the volume by 10%-45%. Willson noted the same trends in pH described by Galler and Davey (1971); working compost achieved a pH of 9.5. Willson and Hummel (1972) continued the work on composting dairy manure by refining the analytical measurements. Data were presented to show that NO_3-N increased as composting continued, but there did not seem to be a clear correlation between nitrate formation and ammonia decrease. Combining all the bench-scale results produced generalized curves of oxygen-consumption rate and temperature as functions of aeration rate (Figure 39). These curves led Willson and Hummel to suggest some management practices:

> Ideally, the aeration rate would be varied during the process in the following sequence: 1. During the warmup stage of the process, aeration would be applied at increasing rates in the low part of the temperature-limiting range. 2. When thermophilic temperature is reached, the aeration rate would be increased to the top of the temperature-limiting range. If some drying is desirable, a higher aeration rate would be selected. 3. As the level of activity decreases, the rate of aeration would be reduced to prevent cooling. This operating procedure will keep temperatures up until any desired degree of decomposition is reached.

Willson and Hummel also describe a pilot scale channel composter with chain and slat mixer-conveyor, rather similar to that described by Pos et al. (1971). One pass through the channel (15 days detention) did not suffice to stabilize the manure adequately, but the addition of dry compost or other bulky filler to the fresh manure improved performance markedly. The mechanical aspects of the channel composter have received further attention (Hummel et al., 1974). Power requirements were very much higher for the wet, raw feed than for the finished, granular compost. The work also showed some mechanical deficiencies needing attention.

Windrow composting of swine wastes has been investigated by Martin et al. (1972). No forced aeration was used because they considered that the capital investment in separate machinery for mixing and for aeration would not be commercially realistic. The windrows were 10 ft wide by 3 ft high (3 m x 1 m) and were turned by a commercially available composting machine. One research objective was to determine an optimum frequency of turning. Seven trials were run with turning frequencies varying from 1/wk to 4/day. More regular turning increased the rate of temperature rise in the windrow. Odor was quite noticeable until the windrows heated up. The moisture content in all windrows varied between 40% and 50%. Measurements of oxygen content of the gases within the windrow showed that aerobic conditions were not being maintained between turning intervals, even at the highest turning frequency. Further evidence of poor aeration was provided by the lack of nitrate formation in the pile.

Martin et al. verified previous investigators' results that active composting takes place at a pH between 8 and 9. All windrows showed a reduction in volume of about 50% after 15 to 18 wk. The use of compost or straw to improve the structure of the initial feed had a beneficial effect on both odor prevention and the onset of thermophilic conditions. The time required to achieve stability, as indicated by absence of self-heating, varied from 1-7 mo. Martin et al. mentioned, however, that complete stability might not be necessary before land spreading, inasmuch as odor production potential might be regarded as a more critical factor. The analytical results showed considerable loss of nitrogen during composting.

Conclusions: Manures from domestic livestock can be stabilized in a period not exceeding 20 days to a condition that will not permit putrefaction, fly breeding, rodent infestation, or pathogen survival. Such stabilization is dependent upon proper management of the composting process. Air must be supplied at such a rate that aerobic conditions are maintained, yet not at such a rate that will lead to excessive convective cooling. The structure of a compost must be porous, and this will require dilution of raw livestock waste with straw, wood shavings, or dry compost. The best indicators of composting progress are temperature and oxygen level in the core of the compost. Aeration rates and mixing should be controlled to achieve temperatures between 120° and 160°F (49° and 71°C) at an oxygen saturation of not less than 10%. Mixing and aeration must be more frequent at the beginning of a batch process. Continuous-flow composting would be a desirable goal because of ease of controlling environmental conditions, but this is not yet feasible with machines that are economically acceptable to livestock producers. The ability to retain nitrogen in low-C:N-ratio composts is not well established, although there seems to be some evidence that adequate aeration can retain some nitrogen through nitrification. High-rate composting (10 to 20 days) will stabilize the readily degraded, organic fraction of manure, but extended storage (2 to 6 mo) is required to degrade cellulose or to reduce moisture content to 10%-20%. Although composting is a process requiring less energy input than aerobic liquid-waste treatment, the energy required must be taken into account. The partition of energy requirements into mixing and aeration categories is not well determined. Most composting research has been reported from areas experiencing relatively mild winters; achieving thermophilic temperatures during the prolonged periods of subzero temperatures often encountered in the North Central Region may require protective structures.

Refeeding Livestock Excreta

Biological aspects: Livestock excreta contain many of the same classes of chemical compounds found in feeds. If economical methods of processing the excreta were found, it might be possible to recover more nutrients from the original feed and, as a consequence, to produce less waste (Figure 40). The process of returning manures to the land and the part conversion of nutrients to harvestable plants is well established. Although this process is viable, it does not lead to the degree of energy, protein, and mineral recovery that should be possible. Processes are required that will allow more rapid excreta recycling than is possible with the soil-plant cycle.

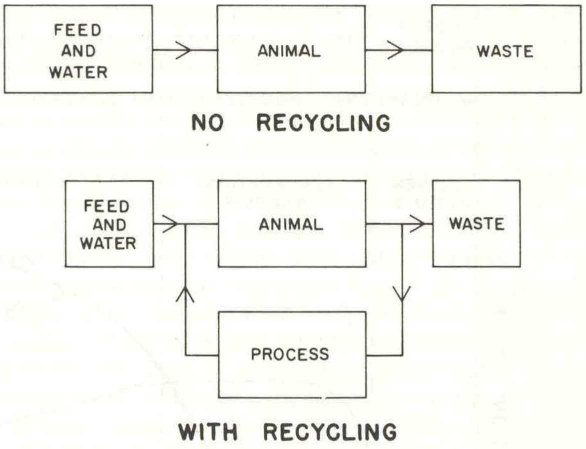

Figure 40. Potential reductions in volume of feed and manure that might be achieved if some part of an animal's excreta were processed and refed.

Excreta contain energy-yielding compounds, nitrogen compounds, and minerals. All these can be manipulated into forms more readily metabolized upon reingestion. But there also are less-desirable substances in manure whose effects must be evaluated before any refeeding process can be accepted. Some of these substances are drugs, metallic chemotherapeutic agents, hormones, and pathogenic organisms. Fontenot and Webb (1974) have reviewed the possible effects that these residues might have on ruminants. Instances of copper toxicity in ewes fed broiler litter were mentioned, the high copper level in the litter resulted from feeding copper sulfate. Copper toxicity is a particularly severe problem with sheep; Fontenot and Webb indicated that their studies with cows fed poultry litter containing high levels of copper showed no adverse effects. Trials using poultry litter containing residues of the drugs penicillin, chlortetracycline, and amprolium showed that none of these was consistently increased in ruminant tissues if a 5-day withdrawal period was imposed before slaughter.

The problem of pathogen survival in processed poultry manure has been examined by Messer et al. (1971). **Salmonella pullorum, S. typhimurium, Arizona sp.,** and **E. coli** were spray-inoculated into poultry litter, and this litter was then subjected to treatment by ethylene oxide and to moist heat in an autoclave. Although none of the bacterial species employed in the tests was resistant to moist heat treatment, the survival of **S. typhimurium** exceeded that of **E. coli,** suggesting that **E. coli** should not be used as an indicator organism. Ethylene oxide reduced bacterial populations, but did not eliminate them. Tests of the passage of certain chemicals also accompanied the bacteriological tests. Arsenic was present in most litters, but the highest levels detected were traced to the use of an arsenical pesticide used in the house. Furazolidone and nitrofurazone also were detected in most litters.

In comparison with other livestock manures, poultry manure is high in N (Table 3). Because some of this N is in a nonprotein form (uric acid), feeding poultry waste to ruminants is being studied. Poultry may be fed a variety of substances designed to enhance growth. Calvert (1973) has described a variety of these substances and has examined the effect of residues in excreta when the excreta were fed to sheep and cows. Calvert concentrated his attention on arsenical compounds because these are very widely used in poultry feeds. Manure, from caged broilers being fed a diet containing 3-nitro-4-hydroxyphenylarsonic acid at 0.005%, was fed to sheep at 0, 7, or 14% (dry basis) of the ration. The arsenic content of the manure was 42 mg/kg (dry basis). About 87% of the arsenic ingested by the sheep was excreted, leaving only 2.4 mg retained in a 30-kg animal. Because this quantity was too little to be of concern, an orchardgrass ration was supplemented with four incremental levels of arsanilic acid. The sheep were slaughtered after a 28-day feeding trial and after various withdrawal periods after the trial. Liver, kidneys, and blood showed increases in arsenic content during the feeding period, but the levels dropped rapidly during withdrawal. Calvert concluded that the sheep showed no signs of arsenic toxicity. Only at the highest level of arsenic fed (273.3 mg/kg of diet) would there have been high enough residuals to be considered a potential consumer hazard after the withdrawal period. Preliminary trials with Holstein cows also were conducted, but again, a withdrawal period served to reduce arsenic in the milk to low levels.

Harmon (1974) has described another toxicity problem resulting from faulty waste processing. An oxidation ditch was being used to stabilize swine manure, and the resulting single-cell protein was refed to swine. High levels of nitrates built up in one ditch (5000 mg/l), and these caused severe death losses when the liquor was used in a feeding trial.

Nutritional aspects: The nutritional value of livestock manures is a very complex topic that cannot be handled in depth in this publication. The engineering aspects of waste processing for refeeding, however, cannot be divorced from the metabolic aspects, so a brief review will be attempted.

The type of animal to be fed is most important. Ruminant animals have the ability to convert most cellulosic compounds and nonprotein nitrogen to microbial cell mass. This microbial cell mass can be used in the lower digestive tract as energy and a source of protein. The ruminant also can use the volatile fatty acids resulting from carbohydrate fermentation. The monogastric animal, however, does not have such abilities. Energy must be provided in a form that can be used by the digestive enzyme system, and this system can only use certain limited sugars, starches, and fats effectively. Amino acid requirements must be supplied by protein (or, in some instances by individual amino acids) because nonprotein nitrogen sources such as ammonia, urea, or uric acid cannot be used. Excreta from ruminants and monogastrics will consist of undigested food, spent gut mucosal material, minerals and inorganic nitrogen, intestinal microflora, and other minor components such as vitamins and hormones. L.W. Smith (1971) indicated that recycling ruminant feces through the ruminant again could lead to anywhere from 5%-70% of the cellulose being further digested. Previously, L.W. Smith et al. (1969) had shown that fiber digestibility was much enhanced if the feces were first treated with NaOH or Na_2O_2.

Fontenot and Webb (1974) conducted an extensive literature review on feeding poultry manure. They concluded that poultry wastes, particularly poultry litter, may be a source of energy as well as nitrogen when fed to ruminants. The review also cites instances of poultry manure being included as 30% of a grain ration for dairy cows, with no effect on milk production or taste. Blair and Knight (1973a, 1973b) also have published a comprehensive review of the value of dried manure as a feed supplement. Again they concentrate most on the use of poultry manure. They indicated that most published results show that monogastric animals make relatively poor use of poultry manure compared with ruminants. This review contains two very detailed tables of the composition of various livestock manures.

At present, the Food and Drug Administration (FDA) does not accept processed manures as feed supplements. Evidence of the safe use of processed manures, particularly heat-dried poultry manure, however, is continually accumulating, and FDA acceptance is likely in the future. If and when the FDA does accept processed manure as a feed supplement, we should expect quite restrictive regulations to accompany the acceptance. But it is unlikely that these regulations will overly simplify the waste-disposal aspect because the aspects of nutrition and animal health will be of paramount importance.

Processing for enhancing the feed value of wastes: Although processing methods cannot be isolated from the specific type of waste being processed, some general comments may be useful. The two major concerns are protection of animal health through control of pathogens and enhancement of excreted nutrients so that they can be metabolized by the animal being fed. Chicken manure is relatively low in moisture content compared with other livestock manures, and this factor has led to heat drying as the preferred processing method. The resulting product seems to be free of pathogens, fairly stable during storage, and concentrated enough to be blended with other dry feed ingredients. The main disadvantages of drying are the amount of thermal energy required and the equipment investment.

Swine and beef manures are fairly high in water; it is not practical to separate urine and feces as they are voided. Consequently, there has been less interest in drying and more in the biological conversion of nonprotein nitrogen into microbial protein. This has been done by using aerobic processes, such as the oxidation ditch, and anaerobic processes, such as digestion and ensiling. These processes will be described in more detail in later sections (e.g., Processing swine waste). In all instances, the metabolic value of the nitrogen is increased, but there still are unanswered questions relating to pathogen survival. A major disadvantage of most biological systems is the need for processing and refeeding to take place within a rather short time, the exception to this being ensiling, which yields a stable end product that can be stored.

Solid-liquid separation has been tried because the fractions derived may prove easier to process individually. The liquids may be processed to form microbial protein, and the solids can be ensiled or treated chemically. The coarse solids derived from livestock manures seem biologically rather stable. Some work has been done to modify chemical structure by using chemicals such as NaOH, but these techniques have not been developed on a large scale.

The economics of waste processing for refeeding are in their infancy. There are tradeoffs between the cost of the feed supplement produced and the credit obtained from diverting some of the manure from the waste treatment system.

Table 44. Amino acid content of oxidation ditch mixed liquor (ODML) (summary of 13 weekly samples) and fresh swine feces.

Amino acid	Swine[α] ODML % of dm	Fresh swine[β] feces % of dm	Amino acid	Swine[α] ODML % of dm	Fresh swine[β] feces % of dm
Alanine ---------	2.83	--	Lysine ---------	1.42	0.60
Arginine --------	1.28	0.44	Methionine -----	0.77	--
Aspartic --------	3.73	--	Serine ---------	2.55	--
Glutamic --------	5.06	--	Phenylalanine --	1.48	0.81
Glycine ---------	2.29	--	Proline --------	1.29	--
Histidine -------	0.47	0.14	Threonine ------	1.96	0.53
Isoleucine ------	1.49	0.52	Tyrosine -------	1.17	--
Leucine ---------	2.79	0.92	Valine ---------	2.06	0.58

Sources: [α]B. G. Harmon, D. L. Day, A. H. Jensen, and D. H. Baker. 1972. Nutritive value of aerobically sustained swine effluent. Journal of Animal Science. 34:403-407.

[β]W. B. Anthony. 1966. Utilization of animal waste as feed for ruminants. pp. 109-112. In: Management of farm animal wastes (Proceedings, National Symposium). American Society of Agricultural Engineers. SP-0366.

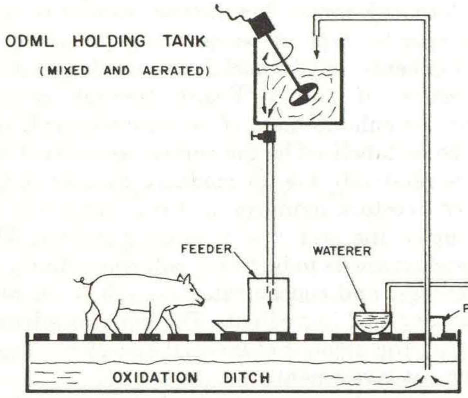

Figure 41. Oxidation ditch mixed liquor (ODML) is pumped from the oxidation ditch into a holding tank where it is kept mixed and aerated between feedings to prevent the possiblility of feeding any unprocessed waste. The ODML is fed by adding it to a regular ration in the ratio of 2 parts ODML to 1 part dry diet.

Source: D.L. Day, and B.G. Harmon. 1974. A recycled feed source from aerobically processed swine wastes. Transactions of the American Society of Agricultural Engineers, 17:82-84, 87.

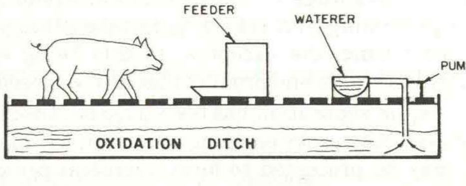

Figure 42. Oxidation ditch mixed liquor (ODML) is pumped from the oxidation ditch directly into a watering trough. No other water is provided.

Source: D.L. Day, and B.G. Harmon. 1974. A recycled feed source from aerobically processed swine wastes. Transactions of the American Society of Agricultural Engineers, 17:82-84, 87.

Processing swine waste: Refeeding swine wastes has not received very much attention. Early work by Diggs et al. (1965) incorporated dried swine feces at 15% and 30% of a finishing pig diet. The lower fraction sustained performance comparable to the control diet, but the higher fraction caused a decrease in feed efficiency. Orr et al. (1971) conducted trials with dried swine feces in place of soybean meal (20% of the total diet). Although the ration was well accepted by the animal, gain and feed efficiency were both depressed. No off flavors were detectable in the meat taken from the pigs.

The oxidation ditch has been used to process swine wastes at the University of Illinois. The results of several years of work have recently been summarized by Harmon (1974). This report noted that there is a linear increase in amino acid concentration as particle size decreases, which supports the hypothesis that aerobic treatment converts some fecal material into single-cell protein. The data inTable 44 show an appreciable change in amino acid composition after aerobic treatment. After early attempts to harvest the solids from the oxidation ditch, it was decided to incorporate the oxidation ditch mixed liquor (ODML) directly into the feed (Figure 41). Harmon noted that both gain and efficiency values were significantly greater for pigs receiving ODML, but he also noted that nutrient intake cannot be greatly changed because ODML is 97% water. Pigs slaughtered after this trial showed no evidence of liver or lymphatic alteration. In a further modification, the ODML was pumped into troughs that could overflow back into the ditch (Figure 42). The liquid in these troughs was the only source of drinking water available to the pigs. As in the previous trial, when suboptimal levels of protein were fed in the dry diet, the gain and feed efficiency for pigs with the ODML drinking supply were significantly greater than pigs receiving normal water (Harmon, 1974).

Some health problems have occurred during the trials. High levels of NO_3-N (5000 mg/l) appeared in ditch liquor following a period of excessive aeration due to low manure loadings. Several deaths resulted. In another trial, the ditch became contaminated with ascarid eggs, and these were recycled through the pigs drinking ODML. Harmon suggested that both problems were minor and could have been overcome by suitable management practices. Although performance was not significantly enhanced, the trials using ODML as a sole drinking supply controlled the water content in the ditch to such an extent that no discharge from the building was necessary during the trial. Water was added to maintain a constant volume in the ditch.

Orr et al. (1973) reported no improvement in gain or feed efficiency when feeding half as much aerated liquid waste (ODL) as Harmon (1974) used. A corn and limited soybean ration was mixed with ODL in the ratio 1:1 by weight, but these investigators claimed that no improvement in performance could be detected; moreover, diets containing ODL resulted in lower apparent digestibility coefficients for dry matter, protein, and energy. Miller et al. (1974) reported levels of 0.06%-0.1% ammonia in the ODL.

Processing beef waste: At one time in the Midwest, it was a common sight to see swine rooting in the manure

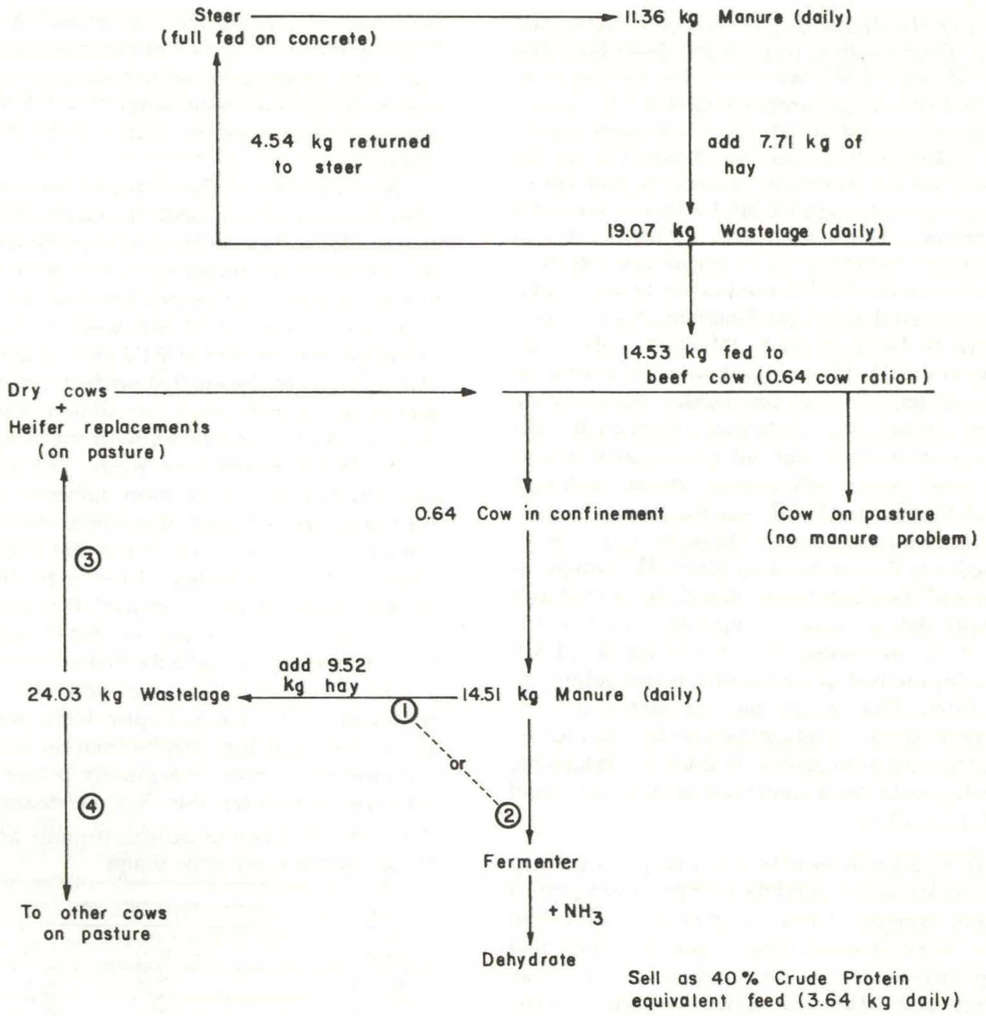

Figure 43. Flow sheet for recycling manure from cattle in confinement.

Source: W.B. Anthony. 1971. Cattle manure as a feed for cattle. pp. 293-296. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

dropped by cattle on feed. These animals made up the pork credit from beef feeding. The nutritive characteristics of cattle manure have been discussed by Anthony (1966); he cited two references indicating that both B-vitamins and essential amino acids are found in cattle manure. Anthony (1966) then described several feeding trials using whole and fractionated beef manure as supplements for beef cattle. The first trials blended the coarse, washed solids from beef manure with a high-concentrate ration based on corn (concentrate 60 parts, manure 40 parts). The ration was well accepted by the animals, and performance was only marginally worse than that of the animals on the control diet. Further trials using whole manure blended with concentrate decreased performance. Ensiling whole manure and coastal bermuda grass hay (57 parts manure and 43 parts hay), however, produced a good-quality silage. This material was used as the sole ration for a group of mature ewes; a control group was given coastal bermuda hay. Animals fed the silage remained in better physical condition, and on a dry-matter basis, consumed only 0.65 times as much hay as did the control group. Anthony (1966) concluded that raw manure should be processed before refeeding; his results indicated that washing to produce coarse solids, cooking the whole manure, or ensiling the whole manure would enhance the nutritive properties. Anthony (1968) formalized his manure processing ideas in a patent in which he specified the various fractions that could be separated from animal manures and used for feed supplements. This patent also mentioned drying certain of the fractions before refeeding. Anthony (1971) then refined his wastelage refeeding concepts. He now has a flow chart (Figure 43) that shows how the manure production and feed requirements of a total cow and slaughter steer operation can be integrated.

Disease transmission is always a threat when refeeding is used. It is not possible to conduct a broad spectrum of tests to detect all known pathogens, but Ciordia and Anthony (1969) did investigate the passage of nematodes through the manure-hay ensiling process. No larvae were recovered after 4 wk of ensiling manure that had a known population of nematode eggs.

Vetter et al. (1972, 1973) used ODML from a beef oxidation ditch as a feed supplement for the animals contributing to the ditch. The ODML was pumped into a mixer wagon and blended with a concentrate ration just before feeding. Four feeding trials were described. The solids content of the ODML was 5% (oven-dry basis at 185°F, 85°C), and the crude protein was 40% (dry basis). The ODML was introduced into the ration in steps until it constituted 37% of the total ration (wet basis). The results of the four trials are not internally consistent, and Vetter et al. concluded that, although ODML had no detrimental effect on performance, neither did it have obvious beneficial effects. Christensen (1973) performed extensive laboratory studies on the ODML used in the trials by Vetter et al. He concluded that 28% of the crude protein was in the form of NH_3-N. Because the ODML had a pH of approximately 8, some NH_3-N would be lost by volatilization when the mixed feed lay in the bunks. Formulating isonitrogeneous rations was made more difficult by this loss. ODML was fed to rats, but did not support normal growth when used as the sole protein source, although judged superior to gelatin. ODML was thought to be deficient in lysine, methionine, and tryptophan. Christensen also commented that the composition of ODML changed as the temperature of the ditch changed, and this variability led to a nitrogen-deficient diet being formulated in one trial. Vetter et al. concluded that refeeding of ODML might be a useful method of controlling water volume in an oxidation ditch. The results they developed did not show any major nutritional advantages to be obtained by using an oxidation ditch to process manure for refeeding, although ODML could be a contribution to protein and mineral supplementation.

Processing poultry waste: In many respects, poultry waste is the most attractive candidate for processing into a feed supplement because it has a higher N:C ratio than other manures. There are two types of poultry waste, and the processing required for each will differ. The birds may have free range over litter; the manure blends into the absorbent litter, controlling moisture and encouraging aerobic decomposition. Waste from such systems will be called poultry litter. Litter systems are most commonly used for broilers. Layers are kept in cages and the manure is collected without any diluent. This waste will be called poultry manure.

Fontenot et al. (1966) substituted 25% and 40% of a high-concentrate ration for beef cattle with poultry litter. One litter had used peanut hulls and the other, wood shavings. The two litters contained 32% and 30.6% crude protein on a dry basis, of which 45.4% and 44.38% were true protein, respectively. No significant differences among the litter ration and the control were found at the 25% substitution. The 40% substitution trial used litters derived from peanut hulls, corncobs, grass hay, and soybean hulls. Differences in daily gain were observed between control, corncobs, and grass hay vs. peanut hulls and soybean hulls. Although less control ration was required per unit of gain, the difference was not significant. Fontenot et al. also indicate that taste panels could detect no differences among meat samples taken from the experimental animals.

Because some of the nitrogen in fresh poultry manure is in the form of uric acid, the quality of feed supplement that could be derived from manure would be improved by conversion of the nonprotein N to protein N. Creger et al. (1973) have shown that ensiling poultry litter at 35%-38% moisture content for 42 days would yield a product with a crude protein content of 21% and no detectable uric acid. The analysis of the ensiled product, as shown in Table 45, seems to indicate that the amino acid composition is changed a little compared with the composition given in Table 46 for dehydrated waste. The silage was fed **ad libitum** to calves. A protein, mineral, and vitamin mixture was poured over the silage daily. Drug residues, known to have been present in the original poultry feed, were not found in muscle, liver, or fat tissue from the experimental animals. No control diet was used to compare rate of gain or feed conversion, but Creger et al. mentioned that the calves gained 2.54 lb/day (1.15 kg/day) and consumed 12 lb (5.6 kg) of silage and 8 lb (3.6 kg) of the protein mix daily. Organoleptic tests, with a 50-member panel, did show that steaks from the animals fed poultry manure silage were marginally poorer than those from animals on a control diet, but the steaks from all animals

Table 45. Analysis of various organic and inorganic constituents of broiler-litter silage.

Organic and inorganic constituents[a]			
Crude protein, %	21.13	Ca, %	1.57
Fat, %	3.48	Mg, %	0.29
Crude fiber, %	59.26	K, %	1.50
Amprolium, ppm	ND[b]	Na, %	0.73
Ethopabate, ppm	ND	Zn, %	0.02
Zinc bacitracin, ppm	1.53	Cu, %	0.02
3-nitro-4-hydroxyphenyl-arsonic acid, ppm	68.5[c]	Fe, %	0.07
Urea N, %	ND	P, %	0.38
Uric acid, %	ND		
Creatinine, %	ND		

Amino acid composition[a]	% of sample		% of sample
Alanine	4.55	Lysine	1.16
Aspartic	2.61	Methionine	1.21
Arginine	0.47	Serine	0.97
Glutamic	3.93	Phenylalanine	0.78
Glycine	1.67	Proline	0.83
Histidine	0.23	Threonine	1.03
Isoleucine	1.43	Tyrosine	0.06
Leucine	2.07	Valine	1.34

[a] All values expressed on a dry-weight basis.

[b] ND=none detected.

[c] Determined by conversion of total arsenic found to 3-nitro-4-hydroxyphenylarsonic acid.

Source: C. R. Creger, F. A. Gardner, and F. M. Farr. 1973. Broiler litter silage for fattening beef animals. Feedstuffs 45(3):25.

Table 46. Mean amino acid composition of dehydrated poultry waste.

Amino acid	Crude protein g/100g	True protein g/100g	Amino acid	Crude protein g/100g	True protein g/100g
Alanine	4.38	9.73	Lysine	2.01	4.45
Aspartic acid	4.38	9.73	Methionine	0.37	0.82
Arginine	1.93	4.27	Serine	2.13	4.73
Cystine	4.51	10.00	Phenylalanine	1.84	4.09
Glutamic acid	6.35	14.09	Proline	2.21	4.91
Glycine	3.40	7.54	Threonine	2.05	4.54
Histidine	0.82	1.82	Tyrosine	1.07	2.36
Isoleucine	2.05	4.54	Valine	2.58	5.73
Leucine	3.32	7.36			

Source: C. C. Sheppard. 1970. Poultry pollution: Problems and solutions. Michigan State University Farm Science Report 117.

were acceptable. Microbiological examination of the silage showed no detectable salmonella, staphylococcus, or coliform organisms.

A novel approach to waste processing has been described by Calvert et al. (1971). Fly larvae were grown on poultry manure at a seeding rate of 1360 eggs/lb (3000 eggs/kg) of manure; after 5 days, the larvae were forced to migrate from the manure by spreading the manure in thin layers on a wire mesh. Strong lighting on the top of the manure layer caused the larvae to move down through the mesh; once free of the manure the larvae pupated in a 1-2 day. The larvae were dried and ground to form the feed ingredient. Because the total protein of the pupa meal was 63.1%, this material was diluted with ground cellulose until it approximated soybean meal at 50%. This diluted meal was fed to young chicks in a ration compounded to contain 23% protein. Chicks on the pupa meal showed improved weight gains over the birds on a soybean control, but feed conversion differences were not consistent. A further test allowed the pupae to hatch into adult flies, and the flies were also ground and fed to young chicks. Again, the performance of the chicks matched that of chicks on a soybean control diet. Calvert et al. concluded that a feed supplement derived from either pupae or adult flies could replace soybean meal in chick starter rations.

Most attempts to recycle poultry manure have used dehydration. Britain has been using dried poultry manure as an accepted feed ingredient for some years, although this practice is not sanctioned in the United States. Blair and Knight (1973a, 1973b), reviewing British experience, indicated that the largest market was for fattening sheep and beef cattle. If barley and dried poultry manure are mixed, the optimum ration should contain about half of each component. Ration compounding was a matter of economics contrasted to protein deficiency or bulk limitation if excessive dried poultry manure was used. Although ruminants may be the best class of animal for using poultry wastes, manure processing would be more attractive to many poultry producers if their own stock could use the recycled product. Quisenberry and Bradley (1969) described experiments in which both poultry litter and poultry waste were fed at 10% and 20% of the diet of laying hens. The diets were adjusted so that they were isocaloric and isonitrogenous. The performance in all trials was essentially the same, and taste panels could not consistently determine any off flavor in eggs taken from hens being fed manure in the diet. An economic analysis showed that the poultry waste fed at 10% gave the best cost advantage. At that time, the manure would have had a feed replacement value of $72.90/ton ($80.40/tonne).

Poultry manure drying and refeeding the product to the birds has been actively pursued by research workers at Michigan State University (Sheppard, 1970, 1971; Flegal and Zindel, 1971; Surbrook et al. 1971; Flegal et al. 1972). A concern of all investigators working with waste processing for refeeding purposes is public acceptance of a seemingly distasteful process. In an attempt to overcome the connotations of "manure," the workers at MSU have coined the words "poultry anaphage" to describe dried poultry waste (DPW) used as a feed supplement. Zindel[20] has defined poultry anaphage as a poultry by-product, which has been processed under high temperatures to markedly reduce the bacterial burden while yielding a product that contains 10% or less moisture.

The DPW used in the MSU trials had been processed in an OPPCO[21] drier whose internal workings are shown in Figure 44. Surbrook et al. (1971) have described the operation of this dryer in detail; they indicated that temperature control was very important because there seemed to be an inverse relationship between the crude protein content of the product and the drying temperature. The product from the dryer had particles ranging from 0.02 to 0.2 in. (0.5 to 2.5 mm) and a bulk density of 12 to 20 lb/ft^3 (190-320 kg/m^3). The results indicated that 9.45 gal of fuel oil were required to remove 1000 lb of water (0.079 m^3/1000 kg). Some results obtained from using the dryer on other livestock manures are displayed in Tables 47 and 48. Zindel has calculated the numbers of animals that could be served by the small OPPCO dryer used in the MSU studies (Table 49). Some indication of the NPK content of dried livestock manure is presented in Table 50. Zindel has also collected information on commercial dryers (Table 51, 52, and 53). Dryers are complex pieces of equipment, and large-scale studies of manure dehydration will require commercial equipment; a list of some sources of such equipment is given in Table 54.

Although the properties of DPW may be expected to vary according to methods of collection, diet, and drying technique, the information in Tables 46, 55, 56, and 57 may be used as a design guide. Table 58 is included to contrast the amino acid composition of poultry to bovine wastes.

Flegal et al. (1972) examined the effect on crude protein content of DPW caused by delaying the collection of

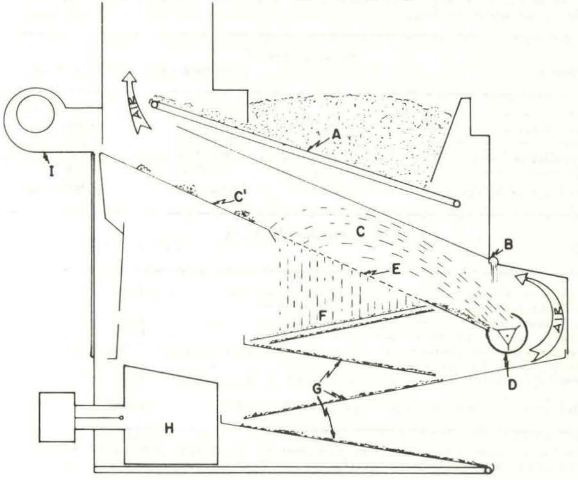

Figure 44. Vertical cross section of the manure drier used at Michigan State University. The inclined surfaces (C′ E, F, G) are rigidly connected and shake horizontally to cause material flow. Legend: (A) manure feed mechanism, (B) dried feedback mechanism, (C,C′) initial drying area, (D) hammermill, (E) screening plate, (F) intermediate drying area, (G) final drying area, (H) firebox, and (I) fan.

Source: T.C. Surbrook, C.C. Sheppard, J.S. Boyd, H.C. Zindel, and C.J. Flegal. 1971. Drying poultry waste. pp. 192-194. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). Society of Agricultural Engineers PROC-271.

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[20] H.C. Zindel. 1973. Personal communication. Poultry Science Department, Michigan State University. East Lansing.

[21] Mention of commercial products by name does not constitute endorsement by the NC-93 committee.

Table 47. Performance data from a dryer processing different kinds of animal excreta at Michigan State University.

Excreta	Fresh excreta production rate lb/hr	kg/hr	Moisture initial %	final %	Fuel consumption gal/hr	l/hr	Electrical consumption kW	Efficiency %
Poultry	340	155	76.3	11.1	2.4	9.1	4.2	71.8
Bovine (2% straw)	243	110	82.4	12.0	2.6	9.9	4.2	51.6
Swine	225	100	72.2	12.5	2.4	9.1	4.2	44.1

Source: C. C. Sheppard. 1970. Poultry pollution: Problems and solutions. Michigan State University Farm Science Report 117.

Table 48. Bulk density of dried animal excreta.

Animal	lb/ft^{3}	kg/m^{3}
Dairy and beef cattle	12	192
Poultry	17	273
Swine	20	320
Undried animal excreta	64	1000

Source: T. C. Surbrook, C. C. Sheppard, J. S. Boyd, H. C. Zindel, and C. J. Flegal. 1971. Drying poultry waste. pp. 192-194. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

Table 49. Projected number of animals that can be served with the excreta dryer operating 40 hours per week.

Animal	Initial moisture %	Weight of animal lb	kg	Final moisture %	Animals served by dryer
Hens	76.3	4.5	2	11.1	7800
Dairy and beef	82.4	1400	635	12.0	15
		1000	454		22
		750	340		29
Swine	72.2	175	80	12.5	102
		100	45		184

Source: H. C. Zindel. 1973. Personal communication. Michigan State University. East Lansing.

Table 51. Installation and operating costs of an OP-PCO dryer (model 1000) installed in Pennsylvania.

Conditions of Operation

Costs are based on a 70% moisture content input and dry material output of 12-14% moisture content. Rated capacity is a moisture removal rate of 2000 lb (900 kg) of water per hour.

Parameter	Operating costs Dollars based on dry product	
Fuel	16.20/ton	17.86/tonne
Electricity	1.80/ton	1.98/tonne
Labor	10.00/ton	11.02/tonne
Depreciation	2.64/ton	2.91/tonne
Maintenance	2.00/ton	2.20/tonne
Total operating costs	32.64/ton	35.97/tonne

Item	Estimated capital costs Cost in dollars
Dryer with afterburner	69,000
Live bottom wet manure pit 10.5 ton (11.6 tonne) capacity	8,000
Installation of machine and pit	4,500
Concrete work for the base	1,500
Storage hopper for the dry product	4,500
Elevator conveyor	4,000
Total	91,500

[a] Mention of commercial products by name does not constitute endorsement by the NC-93 Committee.

Source: E. Mathewson. 1973. OPPCO Corporation, Grandhaven, Michigan.

Table 53. Characteristics of a Mawo dehydrator.

Size	Capacity	Oil consumption lb/hr	kg/hr	Electricity kW	Dry product lb/hr	kg/hr
1	25	55	25	12	290	130
2	50	110	50	18	530	240
3	150	330	150	28	1210	550

[a] Mention of commercial products by name does not constitute endorsement by the NC-93 Committee.

Source: Joe Ruet. 1973. Department of Agriculture and Marketing. New Minas, Nova Scotia.

Table 50. Nutrient levels in dried excreta, based on an oven-dry basis.

Animal	N %	P %	K %
Dairy cattle	2.6	1.2	0.8
Swine	3.6	2.3	1.4
Poultry (hens)	3.6	2.4	1.9

Source: T. C. Surbrook, C. C. Sheppard, J. S. Boyd, H. C. Zindel, and C. J. Flegal. 1971. Drying poultry waste. pp. 192-194. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

Table 52. Test data from a Heil dehydrator installed at West, Texas.

Conditions of Operation

The incoming poultry waste with a moisture content of 76% was blended with a portion of the dried product to give a feed to the drier with 48% moisture content.

Parameter	Data Units		
Input of composite feed (48% mc)	9928 lb/hr		4500 kg/hr
Output (10% mc)	5765 lb/hr		2610 kg/hr
Net output to storage (10% mc)	1515 lb/hr		690 kg/hr
Water evaporated	4155 lb/hr		1890 kg/hr

Parameter	Operating costs Units		
Natural gas used assuming 1000 Btu/ft^{3} (3.72×10^{7} J/m^{3}) and 1500 Btu/lb (3.49×10^{6} J/kg) of water removed	6233 ft^{3}/hr		176 m^{3}/hr
Cost if \$0.50/1000 ft^{3} (\$17.7/1000 m^{3}) for gas		\$3.12/hr	
Cost per unit of 10% mc product	\$4.12/ton		\$4.54/tonne
Electrical requirements	90 hp		67 kW
Cost if \$0.03/kWhr		\$2.01/hr	
Cost per unit of 10% mc product	\$2.65/ton		\$2.92/tonne
Labor requirements		\$2.50/hr	
Cost per unit of 10% mc product	\$3.30/ton		\$3.64/tonne
Depreciation and write off	\$5.00/ton		\$5.51/tonne
Maintenance	\$1.50/ton		\$1.65/tonne
Conveying excreta to the dryer	\$3.35/ton		\$3.69/tonne
Total operating costs per unit of 10% mc product	\$19.92/ton		\$21.95/tonne

Item	Capital costs Cost in dollars
Dryer	45,928
Mixer, bins, conveyors and screen	32,600
Installation	10,000
Total	88,528

[a] Mention of commercial products by name does not constitute endorsement by the NC-93 Committee.

Source: G. Eddy. 1973. Diamond International Corporation, Farmington, Mich.

Table 54. List of manure dehydrator manufacturers.

Name	Manufactured by	Sold and serviced by
Aero Glide Dehydrator	Aero Glide Corp. North Carolina	6300 Hillsboro Road Box 1839 Raleigh, N. C. 27602
Arnold Dryer	The Heil Company Wisconsin	The Heil Company 3000 W. Montana St. Milwaukee, Wis. 53201
Atlas PM Plants	Atlas Baltorpvej 154 DK-2750 Copenhagen, Denmark	Big Dutchman, Inc. Zeeland, Mich. 49464
Colman Rotary Manure Dryer	Colman House Sudbury, England	Big Dutchman, Inc. Zeeland, Mich. 49464
Fairfield Digester	Fairfield Engineering Co.	Fairfield Engr. Co. Marion, Ohio 43302
Hamada Drying Plants for Poultry Excreta		12898 Lake Shore Drive Grand Haven, Mich. 49417
Haro Manure Dryer (4 sizes)	Ross Davies Engr. Co., Ltd. England	Ross Davies Engr. Co., Ltd. 4 Willow Lane Mitcham, Surrey, England
Mawo (3 sizes)	Mawo Switzerland	Mawo Switzerland
OPPCO (3 sizes)	OPPCO Grand Haven, Mich.	Welded Products Inc. Technology, Inc., Subs. 335 N. Griffin St. Grand Haven, Mich. 49417
Wolverine Dryer	Wolverine Sales Co. Grand Haven, Mich.	Wolverine Sales Co. 12898 Lake Shore Drive Grand Haven, Mich. 49417

[a] Mention of brand names does not constitute endorsement by the NC-93 Committee.

Source: H. C. Zindel. 1973. Poultry Science Department, Michigan State University. East Lansing.

Table 55. Average nutritional analyses of dried poultry waste.

Parameter	Percent
Crude protein	33.44
True protein	10.25
Ash	25.98
Crude fiber	9.54
Ether extract	2.64
Water	5.79
Nitrogen free extract	22.61

Source: H. C. Zindel. 1973. Unpublished data. Poultry Science Department, Michigan State University. East Lansing.

Table 56. Chemical analyses of poultry manure (as excreted) expressed as expected ranges.

Parameter	Percent
Water	72.01 - 74.01
Nitrogen	1.00 - 1.50
Phosphorus	0.68 - 0.71
Potassium	0.70 - 0.74
Calcium	2.79 - 3.01
Magnesium	0.26 - 0.29
Copper	0.00009 - 0.00011
Iron	0.22 - 0.25
Manganese	0.008
Sodium	0.24
Zinc	0.13 - 0.16
pH	7.17 - 7.33

Source: H. C. Zindel. 1973. Unpublished data. Poultry Science Department, Michigan State University. East Lansing.

Table 57. Average fertilizer value of dried poultry waste.

Nutrient	Percent
Total nitrogen as N	5.24
Total phosphorus as P	3.28
Total potassium as K_2O	2.54

Source: H. C. Zindel. 1973. Unpublished data. Poultry Science Department, Michigan State University. East Lansing.

Table 58. Amino acid content of dried poultry and cattle waste.

Amino acid	Poultry[α] % of dm	Cattle[β] % of dm	Amino acid	Poultry[α] % of dm	Cattle[β] % of dm
Alanine	--	0.65	Lysine	0.36	0.47
Arginine	0.36	0.18	Methionine	0.11	0.09
Cystine	0.02	--	Serine	--	0.24
Glutamic	--	0.62	Phenylalanine	0.34	0
Glycine	2.34	0.44	Proline	--	0.29
Histidine	0.21	0.12	Threonine	--	0.29
Isoleucine	0.36	0.21	Tyrosine	0.28	0.03
Leucine	0.56	0.62	Valine	0.48	0.38

Sources: [α] B. Hodgetts. 1971. The effects of including dried poultry waste in the feed of laying hens. pp. 311-313. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

[β] W. B. Anthony. 1971. Cattle manure as feed. pp. 293-296. In: Livestock waste management and pollution abatement (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-271.

poultry manure. The crude protein content dropped from 30% to 20% in about 50 days, but little change was noted during the first 28 days. The same report also described continuous recycling of DPW through the birds providing the waste. The DPW constituted either 12.5% or 25% of the diet; 31 cycles were completed. Even after this extensive recycling, the proximate analysis of the DPW from the birds in the trial was similar to DPW from birds on a normal diet. The 12.5% substitution seemed to give best results, although the advantages in feed consumption and egg production were small. Nesheim (1972) also used DPW in the diets of laying hens. The waste made up 22.5% of the ration in two diets; the other two diets were compounded with wheat bran and soybean meal or with soybean meal alone. The rations varied from 1110 kcal/lb (2400 kcal/kg) to 1300 kcal/lb (2900 kcal/kg) metabolizable energy. Although the poultry-waste rations were poor sources of energy, Nesheim suggested that this material could have a value of $26.00/ton ($29.00/tonne) when regarded as a source of phosphorus. The amino acid content also was beneficial. A disadvantage of feeding the dried waste was the increased manure production. The control hens defecated 28.4% of the feed on a dry-matter basis, but hens in the two waste feeding trials defecated 37.7% and 42%, respectively.

Fuel costs for dehydration are high. Gerrish et al. (1973) have described a system in which the manure was automatically conveyed from the cages to the dryer. The exhaust air from the dryer and the exhaust ventilation air from the house were directed over the manure to predry it before it reached the dryer (Figure 45). The system had not been operated sufficiently to obtain any quantitative data by the time the paper was written, but superficial observations indicated that the performance was encouraging.

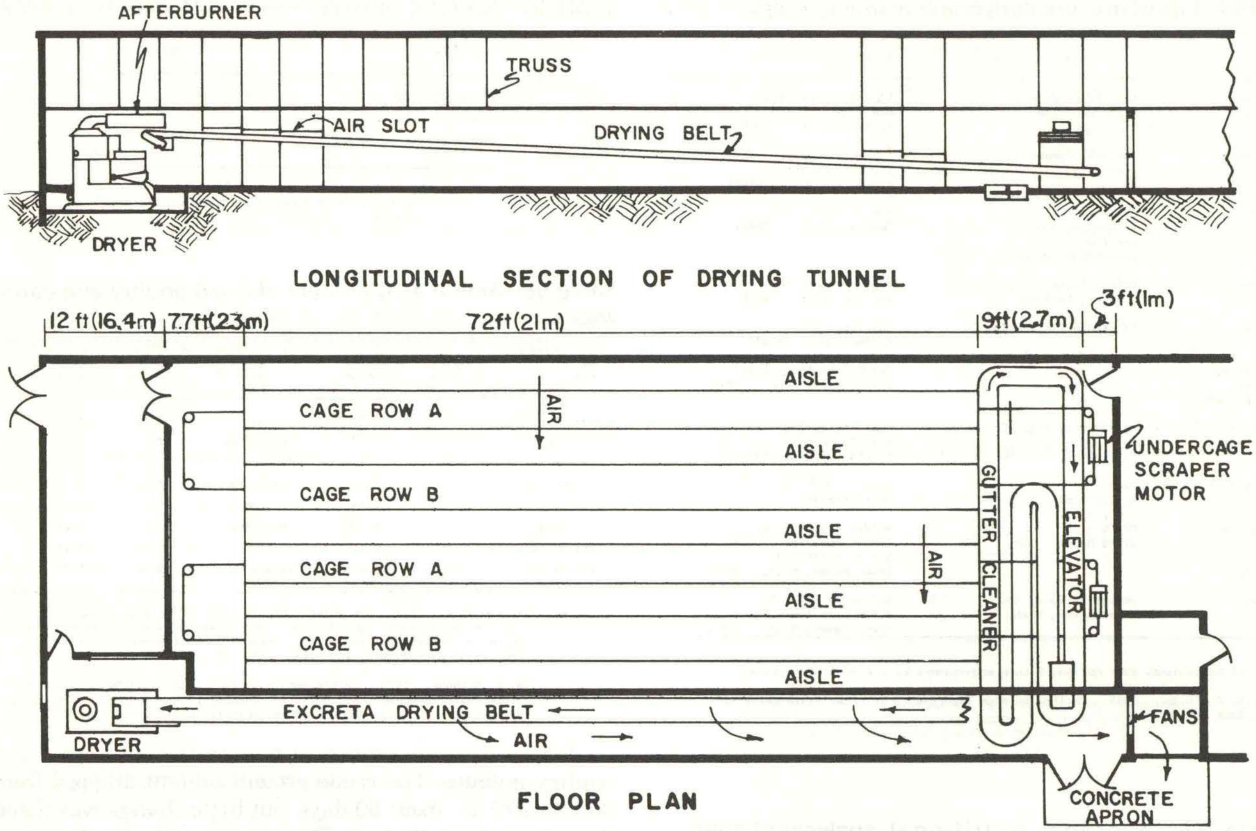

Figure 45. Integrated poultry-manure drying and transport system developed by Michigan State University.

Source: J.B. Gerrish, J.E. Dixon, M.L. Esmay, G.H. Quebe, C.J. Flegal, C.C. Sheppard, and H.C. Zindel. 1973. Engineering aspects of handling and dehydrating poultry excreta: A progress report. ASAE 73-4560. American Society of Agricultural Engineers, St. Joseph, Michigan.

Conclusions: If legal sanction of the practice of manure refeeding is given, we can expect stringent specifications controlling the amounts of injurious chemicals or pathogenic bacteria that will be tolerated in the processed product. At the time of writing, only two processes seem to provide adequate control. When the process of ensiling under anaerobic conditions has been applied to beef and poultry manures, the resulting product is palatable to ruminants and seems free of pathogenic organisms. The ensiling process also converts a significant fraction of the nonprotein nitrogen into microbial nitrogen. The major drawback of ensiling is that the product can most usefully be fed to ruminants; this will not be an obstacle for reusing beef manure, but may limit the usefulness of the process when applied to poultry manure unless mixed livestock operations with integrated manure handling among species are established.

Drying poultry waste also provides a product largely free of pathogenic organisms. The stability in storage of DPW at 15% moisture content or less is good, and the material may readily be blended with other feed ingredients in a dry form. Although DPW can be incorporated in poultry rations, it is not yet proved that this practice will markedly reduce the total amount of manure leaving the system. The greatest value of DPW seems to be the inorganic components it contains. Compounding ruminant feeds with DPW is practiced in Britain, and the material has a commercial value that adequately covers the costs of drying and transport.

Refeeding ODML from either beef or swine oxidation ditches may have very real merit with respect to mineral uptake by the animal and water control in the ditch, but the protein and energy contributions of ODML are not so well established. Further work with solid-liquid separation and microbial harvesting is required before ODML can really be regarded as a viable feed supplement.

Physical and Chemical Processing

Incineration: Incineration is a process in which the volume and weight of organic matter is reduced by burning. The combustible fractions of the waste are burned, and the mineral matter is left as an ash. Materials having a low moisture content will support combustion, but materials having a high moisture content will require a supplemental fuel supply. Livestock wastes presently are being incinerated on a very limited scale. It is possible to incinerate with production of a minimum amount of odor that might offend people. The process is used where human population is dense. It is also being practiced where land is not available for the spreading of waste material.

Some laboratory-scale studies of the incineration of livestock manures have been performed by E.G. Davis et al. (1972). As much as 90% weight reduction and volume reductions of 85% were reported. Both fluidized bed and rotary kilns were used in the tests. Whereas wet manure could be fed to the rotary kiln, only dry manure could be handled by the fluidized bed. Heats of combustion of oven-dried manures ranged from 2520 Btu/lb (5.85 MJ/kg) to 7810 Btu/lb (18.2 MJ/kg). The lowest value was attributed to contamination by sand. Wet manure incinerated in the rotary kiln at 1000-1380°F (650°-750°C) required natural gas at 2.5 ft^3/lb (0.16 m^3/kg) wet feed to sustain combustion. The ash remaining after combustion was pelleted and tested chemically for its fertilizer properties; 80%-85% of the K was soluble in water after 2 hr, and a citrate test showed that 90% of the P was available. The P and K in the ash varied according to the source of the manure. The ranges were 13%-16% as P_2O_5 and 8-14% as K_2O. The authors noted that the nitrogen in the manures was discharged as NH_3 in the flue gas, although this gas could be processed to recover the NH_3.

Incinerating equipment is designed for either batch-loading or continuous-flow operations. Batch loading requires a large amount of labor. It is also inefficient because the incinerator cools each time it is charged. Continuous-feed types of incinerating equipment are more expensive.

Air pollution can be generated by incineration equipment. Smoke from the incinerator can carry odors from the burning organic matter. After-burners are used on some incinerators to remove the odor from the smoke before it is discharged into the air. Other incinerators incorporate water-spray systems, mechanical fly-ash collectors, or electrostatic precipitators to control air pollution.

The cost of incinerating animal wastes is not well documented. Until further research is done, persons wishing to consider incineration should be advised to contact engineering firms who specialize in this line of work.

Pyrolysis: Organic material may be pyrolyzed by holding it at 480°-1830°F (250°-1000°C) in an oxygen-deficient atmosphere. The products are gases, oils, and ash. The gases given off include hydrogen, water, methane, carbon monoxide, and ethylene (Shuster, 1970). Shuster's work showed that pyrolysis in a low-oxygen atmosphere tended to produce more hydrocarbons. The yield of low-boiling tarry compounds became less as the reaction temperature was increased. The substrates used in this work were paper, dried sewage sludge, and dried leaves. Because the study was concerned with identifying the compounds yielded by the reaction, few data were presented relating to quantitative yields or energy yields. White and Taiganides (1971) pyrolyzed various livestock manures and newspaper. They classified the gaseous products as CO_2, CO, H_2, illuminants, combustibles, O_2, and N_2. The pyrolysis was at atmospheric pressure, and about 1 g (dry basis) of material was used for each test. Dairy feces produced the most gas per unit of dry solids, followed by chicken, beef, and swine feces. Some 50%-60% of the product gas was combustible. The heating values of the gases produced ranged from 1400 Btu/lb (3.3 MJ/kg) of dry swine feces to 1900 Btu/lb (4.4 MJ/kg) of dry feces. The heat value of the carbon char remaining after pyrolysis was 1700 Btu/lb (4 MJ/kg) of dry swine feces, but 3500 Btu/lb (8.1 MJ/kg) for dairy. White and Taiganides also discussed the energy required to dry fresh feces compared with the energy available from the pyrolyzed products. It was noted that pyrolysis of swine feces would not be self-sustaining.

Organic wastes also may be converted to low-sulphur oils by exposing them to CO, and Na_2CO_3 as a catalyst, at high pressures and temperatures. Appell et al. (1971) were able to obtain 40% yields of oil from newsprint by holding it at 1840 lb/in.^{2} (12.7 MPa) at 480°F (250°C) for 1 hr. One of the attractions of this oil production process is that some water is beneficial, playing a definite part in the reactions. For example, beef manure containing 45.5% water was processed at 710°F (380°C) to yield 47% of its dry weight as oil. No catalyst was needed because the calcium, potassium, and sodium salts present in manure performed that function. A pilot plant using sucrose as a substrate had been run on a continuous basis yielding 33% of the sucrose dry weight as oil. This oil had a heating value of 15,200 Btu/lb (35.3 MJ/kg); the chemistry of the oil was quite complex.

Although pyrolysis and oil production are scientifically possible, the equipment for such processes has not been developed for processing livestock manures. The degree of management is likely to be very great, and this will tend to limit adoption of the processes to very large operations. As with anaerobic digestion for methane production, pyrolysis and oil production will be best suited to livestock operations using climate-controlled housing because manure collection and transport already will be part of the system.

ADDITIONAL INFORMATION

Numerous conferences devoted entirely or in part to the presentation of research information on livestock waste management have been conducted. Transactions from these conferences provide a valuable source of information for the person interested in pursuing livestock waste management in greater detail. An incomplete list of proceedings of these conferences and their publishing organizations is provided below.

1. Proceedings, National Symposium on Poultry Industry Waste Management. Poultry Science Association. Lincoln, Nebraska (1966).
2. Proceedings, Second National Symposium on Poultry Industry Waste Management. Poultry Science Association. Lincoln, Nebraska (1964).
3. Management of farm animal wastes. Proceedings, National Symposium on Animal Waste Management. American Society of Agricultural Engineers. St. Joseph, Michigan. SP-0366 (1966).
4. Proceedings, Farm Animal Waste and By-Product Management Conference. University of Wisconsin Extension Service. Madison, Wisconsin (1969).
5. Animal waste management. Proceedings, Cornell University Conference on Agricultural Waste Management. Ithaca, New York (1969).
6. Agricultural practices and water quality. Proceedings, Conference, The Role of Agriculture in Clean Water. Iowa State University Press. Ames, Iowa (1970).
7. Farm wastes. Proceedings, Symposium on Farm Wastes. The Institute of Water Pollution Control. University of Newcastle upon Tyne. United Kingdom (1970).
8. Relationship of agriculture to soil and water pollution. Proceedings, Cornell University Conference on Agricultural Waste Management. Ithaca, New York (1970).
9. Proceedings, Agricultural Wastes in an Urban Environment. New Jersey Animal Waste Task Force (1970).
10. Agricultural wastes: Principles and guidelines for practical solutions. Proceedings, Cornell University Conference on Agricultural Waste Management. Ithaca, New York (1971).
11. Animal waste management. Proceedings, National Symposium on Animal Waste Management. Council of State Governments. Washington, D.C. (1971).
12. Livestock waste management and pollution abatement. Proceedings, International Symposium on Livestock Wastes. American Society of Agricultural Engineers. St. Joseph, Michigan. PROC-271 (1971).
13. Waste management research. Proceedings, Cornell University Conference on Agricultural Waste Management. Ithaca, New York (1972).
14. Proceedings, Livestock Waste Management Conference. University of Illinois. Champaign, Illinois (1973).
15. Proceedings, Midwest Livestock Waste Management Conference. Iowa State University. Ames, Iowa (1973).
16. Processing and management of agricultural wastes. Proceedings, Cornell University Conference on Agricultural Waste Management. Ithaca, New York (1974).

A Bibliography of Livestock Waste Management was published by the Midwest Plan Service, Iowa State University, Ames, as MWPS-17 in the summer of 1972. An Annotated Bibliography of Farm Animal Wastes by J.B. McQuitty and E.M. Barber was published by the Water Pollution Control Directorate, Environmental Protection Service, Department of the Environment, Ottawa K1A OH3, Ontario, Canada in December, 1972, as Report Number EPS 3-WP-72-1. G.A. Whetstone, H.W. Parker, and D.M. Wells have also published an annotated bibliography, Study of Current and Proposed Practices in Animal Waste Management. This is available from the U.S. Government Printing Office, Washington, D.C., as EPA-430/9-74-003. Another useful source of abstracts, although not specifically devoted to agricultural wastes, is Selected Water Resources Abstracts. This biweekly publication is available from the National Technical Information Service, Springfield, Virginia.

Research papers related to livestock waste management are routinely published in several scientific journals. A listing of those most regularly publishing papers in this area are:

Agricultural Engineering
Agronomy Journal
American Society of Civil Engineers. Journal of the Sanitary Engineering Division
Applied Microbiology
Journal of Agricultural Science
Journal of Animal Science
Journal of Dairy Science
Journal of Soil and Water Conservation
Journal of Water Pollution Control Federation
Poultry Science
Soil Science
Transactions of the American Society of Agricultural Engineers
Water Research
Water Resources Research

GLOSSARY

Activated sludge process: A biological wastewater-treatment process in which a mixture of wastewater and aerobic microorganisms is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation and wasted or returned to the process as needed.

Adsorption: (1) The adherence of dissolved, colloidal, or finely divided solids to the surfaces of solid bodies with which they are brought into contact. (2) Action causing a change in concentration of gas or solute at the interface of a two-phase system.

Aerobic bacteria: Bacteria that require free elemental oxygen for growth. Oxygen in chemical combination will not support aerobic organisms.

Aerobic decomposition: Reduction of the net energy level of organic matter by aerobic microorganisms.

Aerobic lagoon: See **Lagoon.**

Aeration: (1) The bringing about of intimate contact between air and a liquid by one or more of the following methods: (a) spraying the liquid in the air, (b) bubbling air through the liquid, (c) agitating the liquid to promote surface absorption of air. (2) The supplying of air to confined spaces under nappes, downstream from gates in conduits, etc., to relieve low pressures and to replenish air entrained and removed from such confined spaces by flowing water. (3) Relief of the effects of cavitation by admitting air to the section affected.

Definitions included in this section were taken from ASAE Recommendation: ASAE R292.1. Uniform Terminology for Rural Waste Management. pp. 464-66. In: Agricultural engineer's yearbook. American Society of Agricultural Engineers. St. Joseph, Michigan. 1973.

Aeration tank: A tank in which sludge, wastewater, or other liquid is aerated.

Aerosol: A system of colloidal particles dispersed in a gas, smoke, or fog.

Agitation: The turbulent remixing of liquid and settled solids.

Agricultural wastes: Most such wastes are associated with the production of food and fiber on farms, ranges, and forests. These wastes normally include animal manure, crop residues, and dead animals. Agricultural chemicals, fertilizers and pesticides, which find their way into the soil and subsequently into the surface and subsurface water, also are classified as agricultural wastes.

Algae: Primitive plants, one or many-celled, usually aquatic and capable of synthesizing their foodstuffs by photosynthesis.

Alkalinity: The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally, borates, silicates, and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate.

Anaerobic bacteria: Bacteria not requiring the presence of free or dissolved oxygen for metabolism. Strict anaerobes are hindered or completely blocked by the presence of dissolved oxygen and sometimes by the presence of highly oxidized substances, such as nitrates, nitrites, and perhaps, sulfates. Facultative anaerobes can be active in the presence of dissolved oxygen, but do not require it.

Anaerobic decomposition: Reduction of the net energy level and change in chemical composition of organic matter caused by microorganisms in an anaerobic environment.

Bacteria: A group of universally distributed, rigid, essentially unicellular microscopic organisms lacking chlorophyll. Bacteria usually appear as spheroid, rod-like or curved entities, but occasionally appear as sheets, chains, or branched filaments. Bacteria usually are regarded as plants.

Biochemical oxygen demand (BOD): The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. A standard test used in assessing wastewater strength.

Biodegradation (biodegradability): The destruction or mineralization of either natural or synthetic organic materials by the microorganisms populating soils, natural bodies of water, or wastewater-treatment systems.

Biological oxidation: The process whereby living organisms in the presence of oxygen convert the organic matter contained in wastewater into a more stable or a mineral form.

Biological stabilization: Reduction in the net energy level of organic matter as a result of the metabolic activity of organisms.

Biological wastewater treatment: Forms of wastewater treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Intermittent sand filters, contact beds, trickling filters, and activated sludge processes are examples.

Carbon-nitrogen ratio (C:N): The weight ratio of carbon to nitrogen in a waste material.

Chemical oxidation: Oxidation of organic substances without benefit of living organisms. Examples are by thermal combustion or by oxidizing agents such as chlorine.

Chemical oxidation demand (COD): A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specified test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. Also known as OC and DOC, oxygen consumed and dichromate oxygen consumed, respectively.

Chlorination: The application of chlorine to water, sewage, or industrial wastes, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results.

Coagulation: In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

Coliform-group bacteria: A group of bacteria predominantly inhabiting the intestines of man or animals, but also occasionally found elsewhere. It includes all aerobic and facultative anaerobic, Gram-negative, nonspore-forming bacilli that ferment lactose with production of gas. Also included are all bacteria that produce a dark, purplish-green colony with metallic sheen by the membrane-filter technique used for coliform identification. The two groups are not always identical, but they are generally of equal sanitary significance.

Colloidal matter: Finely divided solids that will not settle but may be removed by coagulation or biochemical action or membrane filtration.

Composting: Present-day composting is the aerobic, thermophilic decomposition of organic wastes to a relatively stable humus. The resulting humus may contain up to 25 % dead or living organisms and is subject to further, slower decay, but should be sufficiently stable not to reheat or cause odor or fly problems. In composting, mixing and aeration are provided to maintain aerobic conditions and permit adequate heat development. The decomposition is done by aerobic organisms, primarily bacteria, actinomycetes, and fungi.

Dehydration: The chemical or physical process whereby water in chemical or physical combination with other matter is removed.

Denitrification: The reduction of nitrates, with nitrogen gas evolved as an end product.

Detention pond: An earthen basin constructed to store runoff water until such time as the fluids may be recycled onto land.

Deoxygenation: The depletion of the dissolved oxygen in a liquid under natural conditions associated with the biochemical oxidation of organic matter present.

Digestion: Although aerobic digestion is being used, the term digestion commonly refers to the anaerobic breakdown of organic matter in water solution or suspension into simpler or more biologically stable compounds, or both. Organic matter may be decomposed to soluble organic acids or alcohols and subsequently converted to such gases as methane and carbon dioxide. Complete destruction of organic solid materials by bacterial action alone is never accomplished.

Disinfection: The art of killing the larger portion of microorganisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

Dissolved oxygen (DO): The oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percentage of saturation.

Effluent: (1) A liquid that flows out of a containing space. (2) Wastewater or other liquid, partly or completely treated, or in its natural state, flowing out of a reservoir, basin, treatment plant, or part thereof.

Electrophoresis: The movement of suspended particles through a fluid under the action of an electromotive force applied to electrodes in contact with the suspension.

Escherichia coli (E. coli): One of the species of bacteria in the coliform group. Its presence is considered indicative of fresh fecal contamination.

Evaporation rate: The quantity of water, expressed in terms of depth of liquid water, evaporated from a given water surface per unit of time. It is usually expressed in inches (centimeters) depth per day, month, or year.

Food to microorganisms ratio (F:M): The ratio of organic food, BOD, to microorganisms.

Facultative bacteria: Bacteria that can adapt themselves to growth in the presence, as well as in the absence, of oxygen.

Facultative decomposition: Reduction of the net energy level of organic matter by facultative microorganisms.

Fertilizer value: The potential worth of the plant nutrients contained in the wastes and that could become available to plants when applied onto the soil. A momentary value assigned to a quantity of organic wastes represents the cost of obtaining the same plant nutrients in their commercial form and in the amounts found in the waste. The worth of the waste as a fertilizer can be estimated only for given soil conditions and other pertinent factors such as land availability, time, and handling.

Filtration: The process of passing a liquid through a filtering medium (which may consist of granular material, such as sand, magnetite, or diatomaceous earth, finely woven cloth, unglazed porcelain, or specially prepared paper) for the removal of suspended or colloidal matter.

Flocculation: In water and wastewater treatment, the agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means. In biological wastewater treatment where coagulation is not used, agglomeration may be accomplished biologically.

Gasification: The transformation of soluble and suspended organic materials into gas during waste decomposition.

Holding unit: A storage unit in which accumulations of manure are collected before subsequent handling or treatment, or both, and ultimate disposal. Water may be added in the pit to promote liquefaction.

Humus: The dark or black carboniferous residue in the soil resulting from the decomposition of vegetable tissues of plants originally growing therein. Residues similar in appearance and behavior are found in composted manure and well-digested sludges.

Hydraulic collection and transport system: The collection and transportation or movement of waste material through the use of water.

Incineration: The rapid oxidation of volatile solids within a specially designed combustion chamber.

Incubation: Maintenance of viable organisms in or on a nutrient substrate at constant temperature for growth and reproduction.

Infiltration: The process whereby water enters the soil through the immediate surface.

Infiltration rate: (1) The rate at which water enters the soil or other porous material under a given condition. (2) The rate at which infiltration takes place, expressed as depth of water per unit time, usually in inches (centimeters) per hour.

Influent: Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant, or any unit thereof.

Inoculum: Living organisms, or an amount of material containing living organisms (such as bacteria or other microorganisms), added to initiate or accelerate a biological process (e.g., biological seeding).

Lagoon: An all-inclusive term commonly given to a water impoundment in which organic wastes are stored or stabilized, or both. Lagoons may be described by the predominant biological characteristics (aerobic, anaerobic, or facultative), by location (indoor, outdoor), by position in a series (first stage, second stage, etc.), and by the organic material accepted (sewage, sludge, manure, or other).

Leaching: (1) The removal of soluble constituents from soils or other material by water. (2) The removal of salts and alkali from soils by abundant irrigation combined with drainage. (3) The disposal of a liquid through a nonwatertight artificial structure, conduit, or porous material by downward or lateral drainage, or both, into the surrounding permeable soil.

Liquefaction: (1) Act or process of liquefying or of rendering or becoming liquid; reduction to a liquid state. (2) Act or process of converting a solid or a gas to a liquid state by changes in temperature or pressure. (3) The changing of the organic matter in wastewater from a solid to a soluble state.

Liquid manure: A suspension of livestock manure in water, in which the concentration of manure solids is low enough so that the flow characteristics of the mixture are more like those of Newtonian fluids than of plastic fluids.

Litter: (1) Vegetative material, such as leaves, twigs, and stems of plants, lying on the surface of the ground in an undecomposed or slightly decomposed state. (2) The bedding material used for poultry.

Manure: The fecal and urinary defecations of livestock and poultry. Manure may often contain some spilled feed, bedding, or litter.

Manure flume: Any restricted passageway, open along its full length to the atmosphere, through which liquid moves by gravity.

Manure stack: A place with an impervious floor and side walls to contain manure and bedding until it may be recycled.

Manure tank: A storage unit in which accumulations of manure are collected before subsequent handling or treatment, or both, and ultimate disposal. Water may be added in the tank to promote liquefaction.

Milkhouse wastes: The wastewater containing milk residues, detergents, and manure generated in a milkhouse.

Mixed liquor: A mixture of activated sludge and organic matter undergoing activated-sludge treatment in the aeration tank.

Odor threshold: The point at which, after successive dilutions with odorless water, the odor of the water sample can just be detected. The threshold odor is expressed quantitatively by the number of times the sample is diluted with odorless water.

Organic matter: Chemical substances of animal or vegetable origin, or more correctly, of basically carbon structures, comprising compounds consisting of hydrocarbons and their derivatives.

Oxidation ditch: A modified form of the activated-sludge process. An aeration rotor supplies oxygen and circulates the liquid in an oval, racetrack-shaped, open-channel ditch.

Oxidation pond: A basin used for retention of wastewater before final disposal, in which biological oxidation of organic material is effected by natural or artificially accelerated transfer of oxygen to the water from air.

pH: The negative of the logarithm of the hydrogen-ion concentration. The concentration is the weight of hydrogen-ions, in grams, per liter of solution. Neutral water, for example, has a pH value of 7 and a hydrogen-ion concentration of 10^{-7}.

Percolation: The flow or trickling of a liquid downward through a contact filtering medium. The liquid may or may not fill the pores of the medium.

Percolation rate: The rate of movement of water under hydrostatic pressure through the interstices of the rock or soil, except movement through large openings such as caves.

Permeability: The property of a material that permits appreciable movement of water through it when saturated and actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.

Pollution: The presence in a body of water (or soil or air) of material in such quantities that it impairs the water's usefulness or renders it offensive to the senses of sight, taste, or smell. Contamination may accompany pollution. In general, a public health hazard is created, but in some instances, only economy or aesthetics are involved, as when waste salt brines contaminate surface waters or when foul odors pollute the air.

Population equivalent (PE): A means of expressing the strength of organic material in wastewater. Domestic wastewater consumes, on an average, 0.17 lb (0.08 kg) of oxygen per capita per day, as measured by the standard BOD test. This figure has been used to measure the strength of organic industrial waste in terms of an equivalent number of persons. For example, if an industry discharges 1,000 lb (454 kg) of BOD per day, its waste is equivalent to the domestic wastewater from 6,000 persons (1,000/0.17 = 6,000). Caution must be exercised when using population equivalents because of the difficulty in comparing agricultural wastes directly with municipal wastes.

Putrefaction: Biological decomposition of organic matter with the production of ill-smelling products associated with anaerobic conditions.

Rural wastes: Wastes produced in rural areas. Most such wastes are associated with the production of food and fiber on farms, ranges, and forests. These wastes normally include animal manure, crop residues, and dead animals. Residual fertilizers, pesticides, inorganic salts, and eroded soils may also be classified as rural wastes when they are in nonurban areas. Domestic solid refuse, human sewage, and industrial wastes generated and handled in the rural environment are considered rural wastes.

Sediment: (1) Any material that is carried in suspension by water and will ultimately settle to the bottom after the water loses velocity. (2) Fine water-borne matter deposited or accumulated in beds.

Sedimentaion tank: A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation basin, settling basin, settling tank.

Seepage: (1) Percolation of water through the lithosphere. Definitive meaning usually is described by an adjective such as influent, effluent (see infiltration). (2) The slow movement of water through small cracks, pores, and interstices, of a material into or out of a body of surface or subsurface water. (3) The loss of water by infiltration from a canal, reservoir, manure tank, or manure stack. It generally is expressed as flow volume per unit time.

Septic tank: A settling tank in which settled solid matter is in immediate contact with the wastewater flowing through the tank and the organic solids are decomposed by anaerobic bacterial action.

Settleable solids: (1) That matter in wastewater that will not stay in suspension during a preselected settling period, such as 1 hr, but either settles to the bottom or floats to the top. (2) In the Imhoff cone test, the volume of matter that settles to the bottom of the cone in 1 hr.

Settling tank: See **Sedimentation tank.**

Sewage: The spent water of a community. Term now being replaced in technical usage by preferable term wastewater.

Silt: (1) Soil particles that constitute the physical fraction of a soil between 0.005 mm and 0.05 mm in diameter. (2) Fine particles of soil carried in suspension by flowing water. (3) Deposits of water-borne material in a reservoir, on a delta, or on overflowed lands.

Slotted floors: The floor surface of a building, which has open splits, spaces, or grooves to allow material to drop below the floor surface.

Sludge: (1) The accumulated solids separated from liquids, such as water or wastewater, during processing, or deposits on bottoms of streams or other bodies of water. (2) The precipitate resulting from chemical treatment, coagulation, or sedimentation of water or wastewater.

Sludge volume index (SVI): The ratio of the volume of milliliters of sludge settled from a 1,000-ml sample in 30 min to the concentration of mixed liquor in milligrams per liter multiplied by 1,000.

Solids content: The residue remaining when the water is evaporated away from a sample of water, sewage, other liquids, or semisolid masses of material and the residue is then dried at a specified temperature, usually 103°C (217°F).

Stabilization pond: A type of oxidation pond in which biological oxidation of organic matter is effected by natural or artificially accelerated transfer of oxygen to the water from air.

Sterilization: The destruction of all living organisms, ordinarily through the agency of heat or of some chemical.

Supernatant: The liquid standing above a sediment or precipitate.

Suspended solids: (1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and that are largely removable by laboratory filtering. (2) The quantity of material removed from wastewater in a laboratory test, as prescribed in Standard Methods for the Examination of Water and Wastewater and referred to as nonfilterable residue.

Total solids: The sum of dissolved and undissolved constituents in water or wastewater, usually stated in milligrams per liter.

Trickling filter: A filter consisting of an artificial bed of coarse material, such as broken stone, clinkers, slate, slats, brush, or plastic materials, over which wastewater is distributed or applied in drips, films, or spray from troughs, drippers, moving distributors, or fixed nozzles, and through which it trickles to the underdrains, giving opportunity for the formation of zoogleal slimes that clarify and oxidize the wastewater.

Volatile acids: Fatty acids, containing six or less carbon atoms, that are soluble in water and that can be steam-distilled at atmospheric pressure. Volatile acids are commonly reported as acetic acid equivalent.

Volatile solids: The quantity of solids in water, wastewater, or other liquids lost in ignition of the dry solids at 600°C (1110°F).

Volatile suspended solids (VSS): That portion of the suspended solids residue driven off as volatile (combustible) gases at a specified temperature and time, usually 600°C (1110°F) for at least 1 hr.

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