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**United States Department of Agriculture**
Natural Resources Conservation Service

**Part 651
Agricultural Waste Management
Field Handbook**

# Chapter 12    Waste Management Equipment

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# Acknowledgments

# Chapter 12     Waste Management Equipment

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# Chapter 12      Waste Management Equipment

## 651.1200    Introduction and scope

While this chapter is entitled "Waste *Management* Equipment," the objective of the chapter is primarily to explain the equipment used with the agricultural waste handling, treatment, and utilization aspects of management. Machine, implement, device, tool, item, and component are often used instead of the word *equipment*. In this chapter, equipment refers to a specialty item specifically designed to push, lift, convey, agitate, or otherwise handle or process agricultural wastes. In keeping with the six functions of an agricultural waste management system (AWMS) introduced in chapter 2 of this handbook, the equipment will be categorized by the function it primarily addresses. With the exception of roof gutters and downspouts, structural measures, such as flush gutters, tanks, stack pads, waste storage ponds, or waste treatment lagoons, will not be included in this chapter.

Detailed considerations for planning an AWMS are in chapter 2 of the this handbook. The major equipment used in a waste management system is listed in figure 12–1.

## 651.1201    Selecting waste handling equipment

Wastes and equipment relationships are characterized in chapters 4, 9, 10, and 11 of this handbook. The flowcharts in figures 12–2 to 12–5 can be used in equipment selection and handling system planning. The collection flowchart (fig. 12–3) requires that the decisionmaker know if storage is needed. This depends on climate conditions, environmental regulations, and land application space. However, local, State, and Federal regulations and requirements increasingly dictate the use of a storage facility. The storage selection flowchart (fig 12–4) is based on the initial assumption that an earthen waste storage pond is practical. The validity of that assumption is determined by available space and site conditions.

In any individual situation, major considerations of equipment selection and use must meet local conditions. These considerations include climate, management, waste characteristics, available equipment sales and service, and the experience and desires of the decisionmaker. Small to medium family operations, for example, tend to use more daily labor and invest in equipment that can be multipurpose (e.g., tractor loader, elevator-conveyor, box spreader). Large operations require more, but less versatile equipment (e.g., separator, high-capacity pump, long pipeline) for separate AWMS function needs. They typically assign tasks to hired laborers to accomplish in a specified time (e.g., scraping, agitation, hauling).

Safety must be considered in addition to the cost, correct type, size, and practicality of the selected equipment. In an AWMS, relatively complex, pressurized equipment is often used by one person alone. It may be used in a noisy, remote location that is in semidarkness and a long way from help or medical service. Suppliers, owners, and others involved must correctly instruct family and hired help about safe operation of the equipment, hazards involved, and emergency procedures. Also, uninterrupted electric power is essential for operating some equipment (e.g., compost aerator, flushing pump, biogas production), so a system failure alarm and emergency power system may need to be a part of the AWMS.

**Figure 12–1**    Major equipment used in an AWMS

Agricultural Waste Management System

- - - - - - - - - - - - - - - Functions - - - - - - - - - - - - - - -

| Production | Collection | Transfer | Storage | Treatment | Utilization |

**Production**
- Roof gutters and downspouts
- Culvert
- Pipe

**Collection**
- Hand tools
- Scrapers
- Loaders
- Gutter and alley scrapers
- Conveyors and stackers
- Flush gutters and alleys
- Air pressure and vacuum pumps
- Piston-plunger pumps

**Transfer**
- Augers and conveyors
- Pumps
- Picket dams

**Storage**
- Access ramps
- Access ladders
- Depth markers
- Warnings signs
- Valves
- Fences
- Covers
- See detection devices
- Liners

**Treatment**
- Cutters, shredders, crushers, and grinders
- Agitators, stirrers, and mixers
- Aerators
- Separators
- Dehydrators, incinerators, and renderers

**Utilization**
- Box spreaders
- V-box bottom spreader
- Vacuum load tanker spreader
- Pipe and pipelines
- Gated pipe
- Handmove sprinkler
- Towline sprinkler
- Side-roll sprinkler
- Big gun sprinkler
- Traveling gun sprinkler
- Soil injector spreaders
- Biogas production equipment

**Figure 12–2**　Waste management typical component alternatives matrix

(a) Solid



Legend

Waste consistency
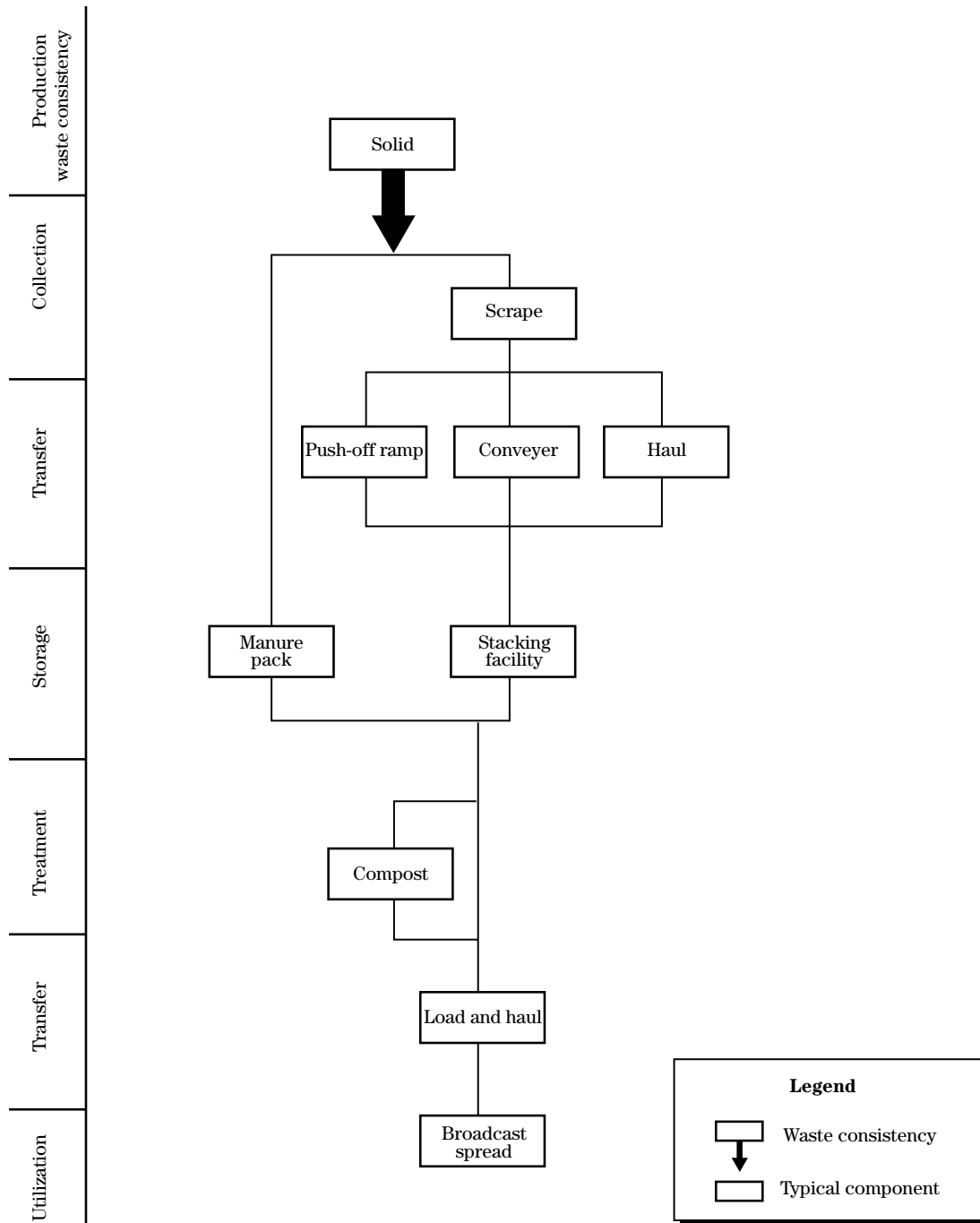
Typical component

**Figure 12–2**     Waste management typical component alternatives—Continued

(b) Semisolid/slurry
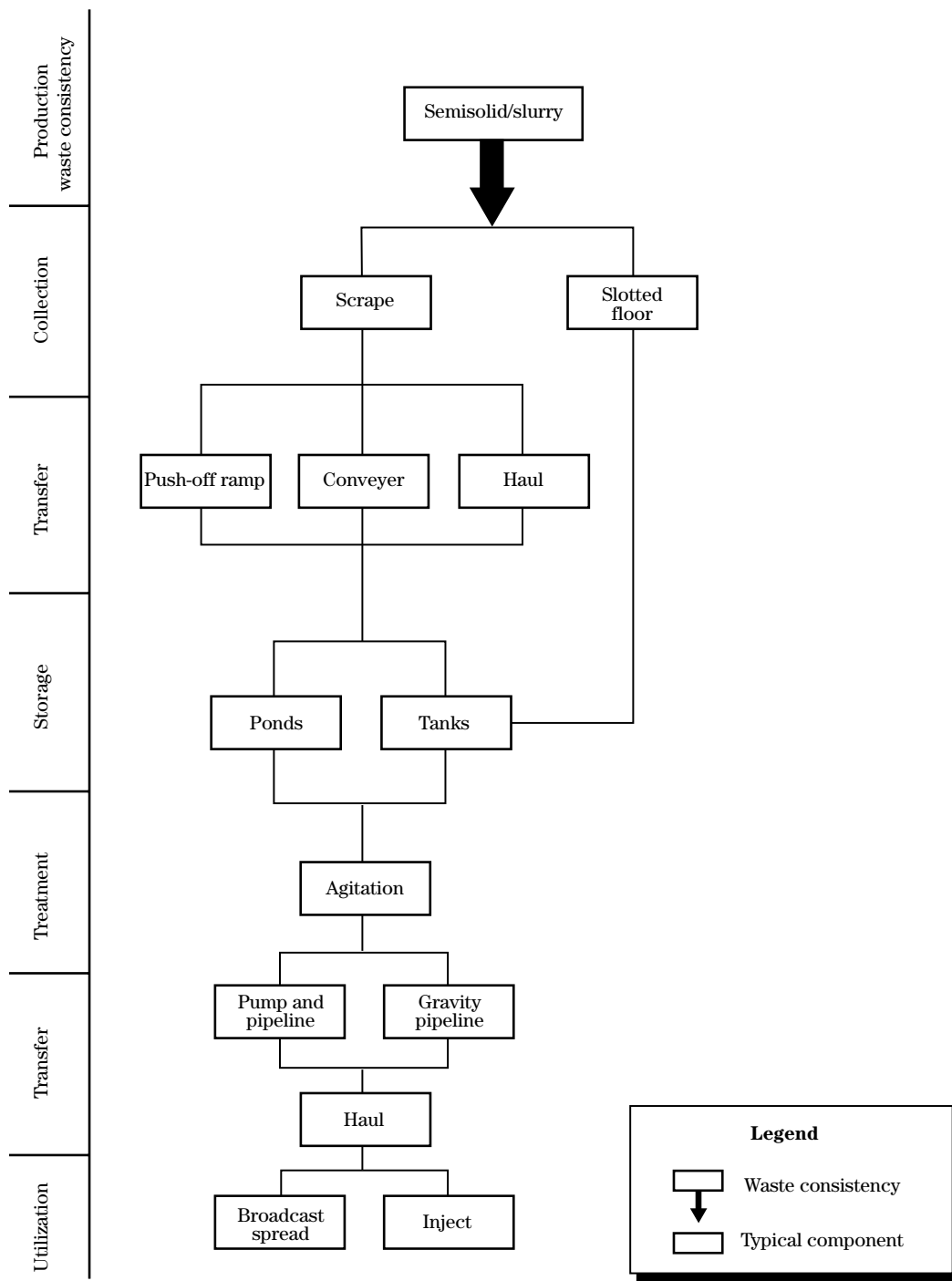
**Figure 12–2**    Waste management typical component alternatives—Continued

(c) Liquid
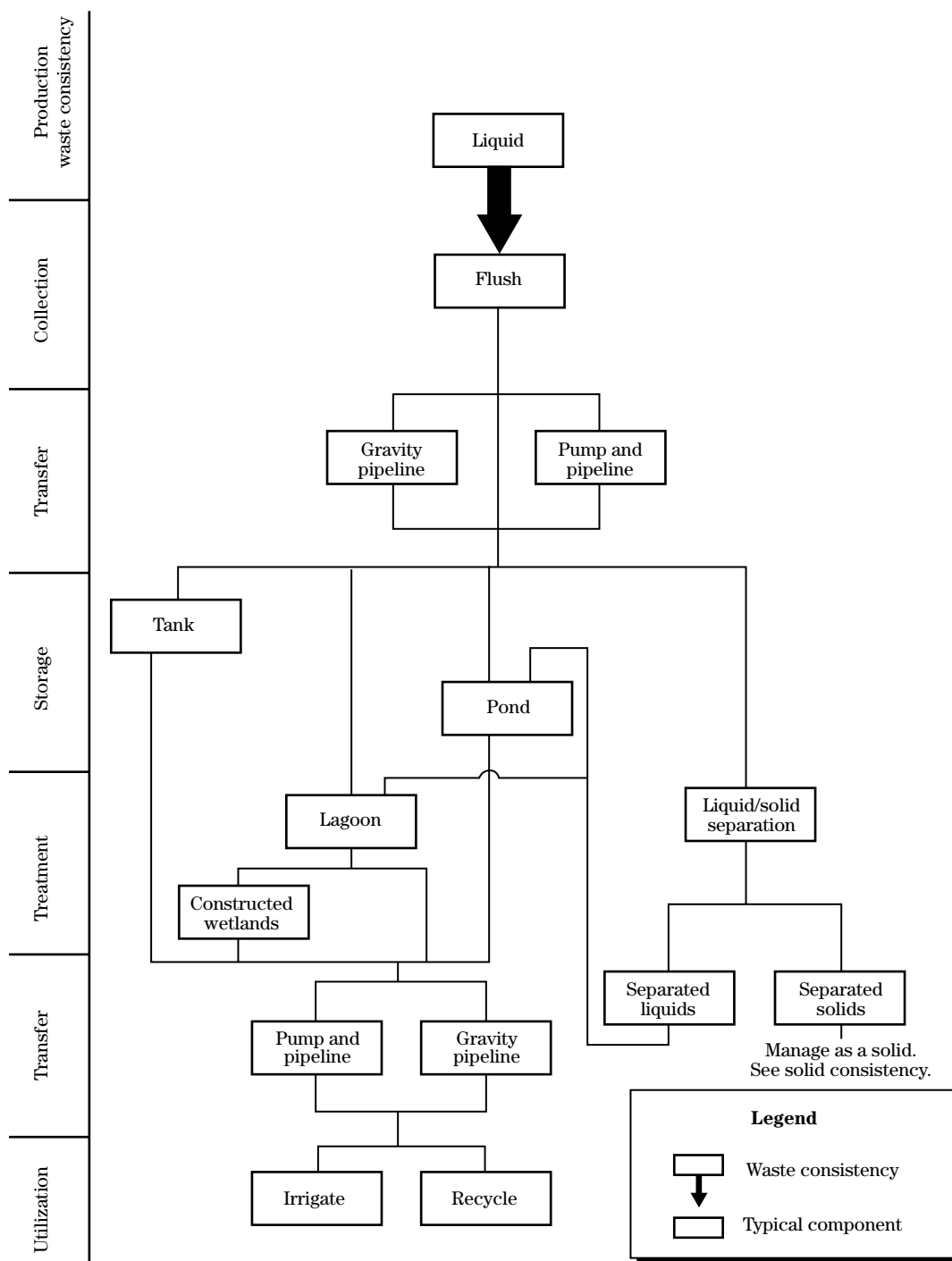
**Figure 12–3**    Waste management system typical collection and transfer component selection matrix
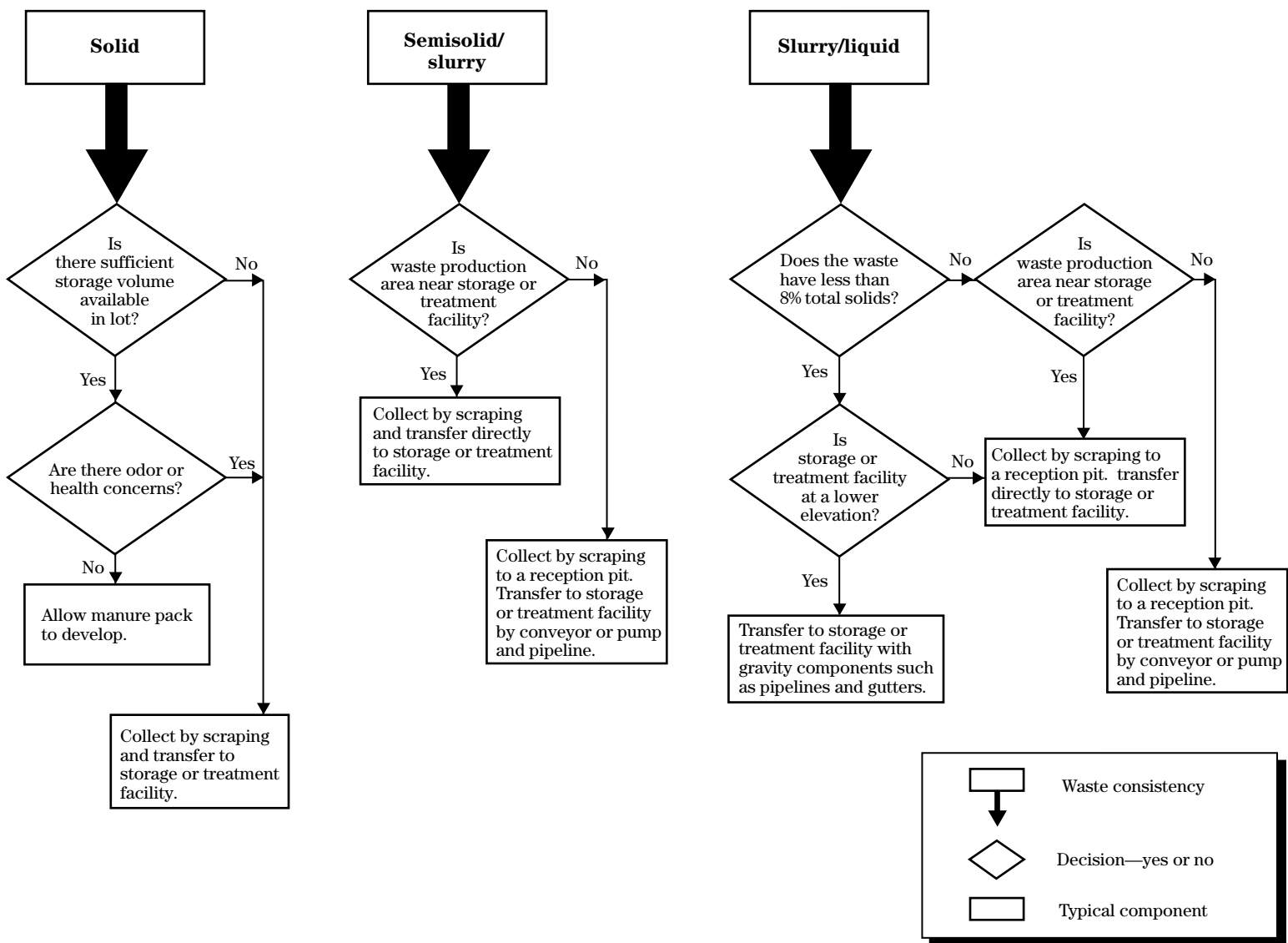
**Figure 12–4**  Waste management system typical storage component selection matrix
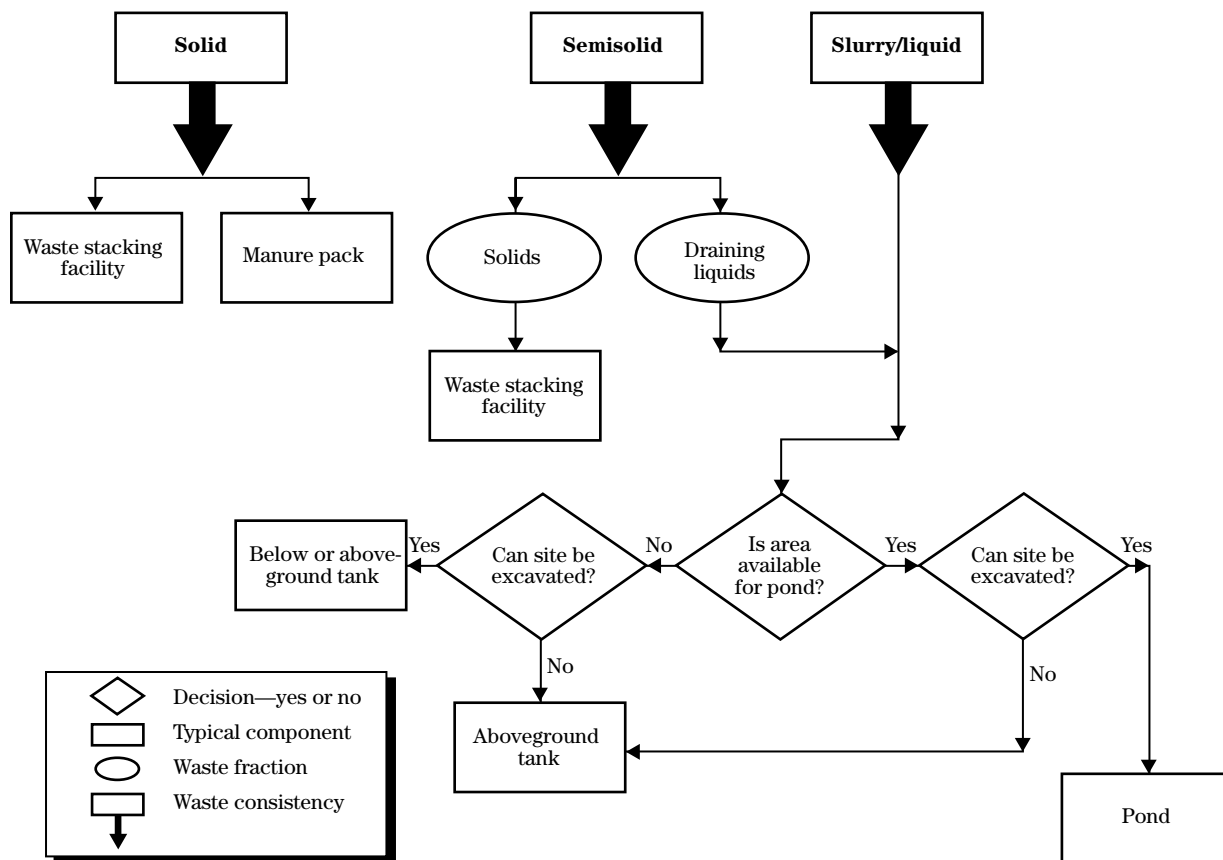


Note: Use of a storage pond also depends on suitable site conditions or use of necessary modifications to achieve stability and allowable maximum seepage criteria.

**Figure 12–5**   Land application typical storage component selection matrix
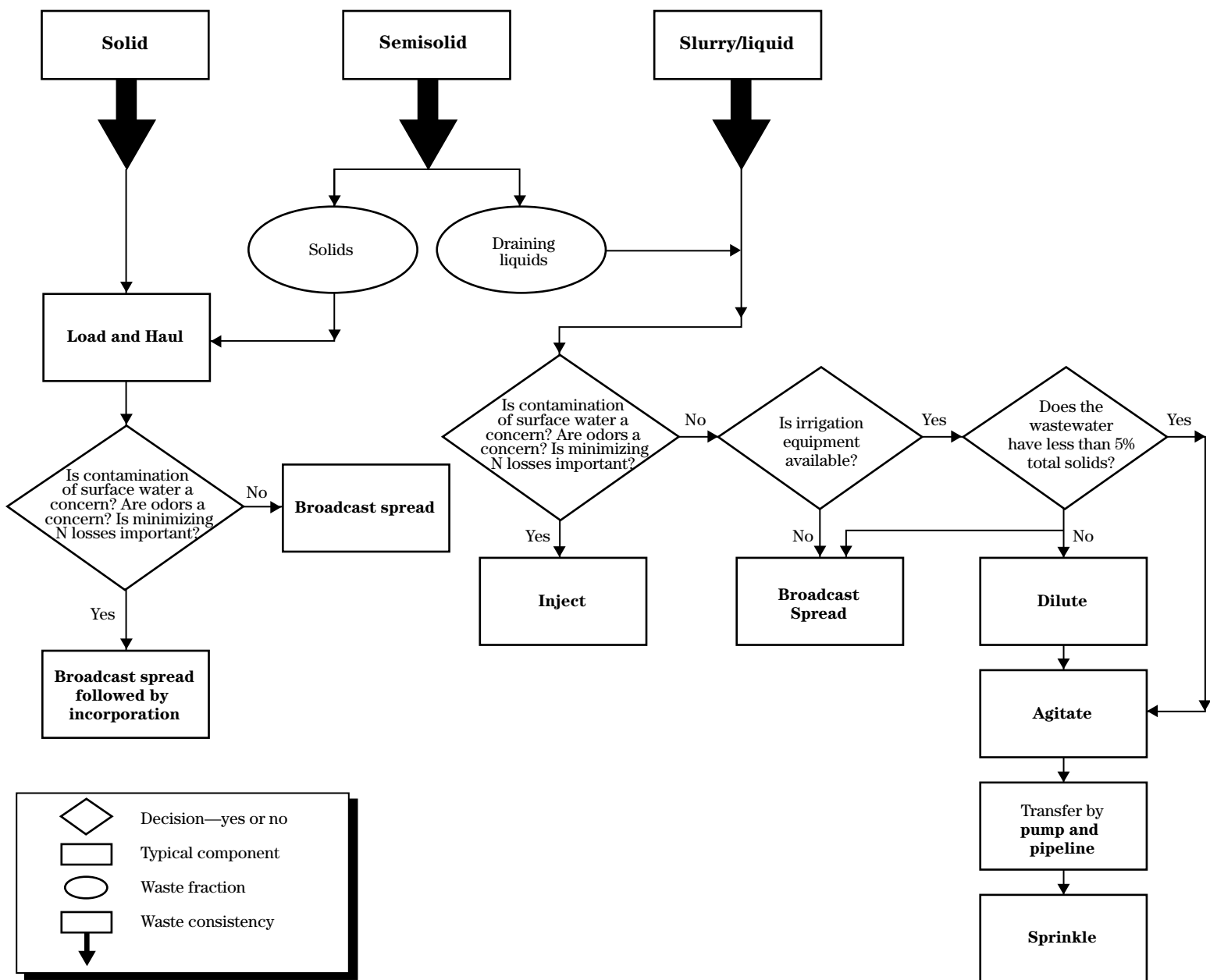
Different models of similar equipment are available. The design and durability needed for an AWMS depends on the consistency and amount of waste and the type and length of storage (see ch. 10 of this handbook). Some examples are:

- A tractor loader used to dig out and load packed solids should be heavier than one used for alley scraping and loadout.

- A 1-horsepower pump used intermittently for liquid milkhouse waste should be designed and constructed differently than a pump that must agitate and lift swine waste that has been stored and settled for several months.

- A spreader for a large feedlot is designed and constructed differently than one for a 50-sow, farrow-to-finish operation.

# 651.1202    Waste production equipment

Equipment associated with waste production is primarily used to modify the form and volume of waste that needs to be handled. In an AWMS, excluding clean water is considered a component of waste production (see ch. 10 of this handbook). Typically, this involves roof gutters, downspouts (fig. 12–6), lined or unlined on-grade waterways or open channels (see ch. 10 of this handbook), and underground pipes and culverts.

## (a) Roof gutters (eave troughs) and downspouts

Although roof gutters require investment and maintenance, they can reduce the total quantity of waste to be handled and result in overall dollar savings for the system. NRCS Conservation Practice Standard (CPS) Code 558, Roof Runoff Management and chapter 10 of this handbook explain sizing of gutters and downspouts. Plastic, aluminum, and galvanized or painted

**Figure 12–6**    Roof gutter and downspout equipment (*Drawing courtesy of Genova Products, Inc.*)



1  Gutter (10 ft lengths)
2  Inside end cap
3  Outside end cap
4  Gutter corner
5  Gutter slip joint
6  Highflo® drop outlet
7  Gutter bracket spacers (wedgies)
8  Debri-shield™
9  Top-notch™ gutter bracket
10  Downspout (10 ft lengths)
11  Front elbow—A-style
12  Side elbow—B-style
13  Downspout bracket
14  Downspout coupler
15  Downspout adapter
16  A/B downspout transition
17  Drip edge (5 ft lengths)
    Drip edge (10 ft lengths)

steel are common gutter and downspout materials. For a given thickness, galvanized steel is the strongest and most durable. Plastic can flex with freeze-up and settling.

Roof drainage equipment generally is supplied through building suppliers. Special fastenings may be needed to attach the equipment to a prefabricated steel building. Local independent fabricators can custom roll-form and install light-gage metal gutter systems onsite for different buildings.

Gutter size is indicated by the top width opening. Style K box gutter is usually made in 4-, 5- and 6-inch widths; half round gutter is made in 4-, 5-, 6-, and 7-inch diameters (fig. 12–6). A gutter is installed to slope slightly toward a downspout and is secured to the building eaves with cast iron, steel, or plastic hangars or with long spikes according to the manufacturer's specifications. Hangars need to be compatible material with the gutters and spaced accordingly. Installing the front top edge of the gutter about 2 inches below the roof edge reduces melt water from backing up under the roofing when the gutter is frozen shut or flooded.

Correct design, installation, and maintenance aid the proper operation of roof gutter and downspout drainage, especially during extreme weather. Regular cleanout of debris and dirt on screens and in gutters and downspouts is essential to prevent their plugging. Expansion and contraction from ice and temperature extremes loosen gutter and downspout supports. Snow and ice slides or buildup damage gutters and downspouts, especially lightweight types. Exterior downspouts are vulnerable to machinery and livestock damage, and some protection may be needed.

Downspouts generally are located at both ends of small buildings (<1,000 ft$^2$ roof drainage). For large buildings, intermediate downspouts on about 30- to 50-foot spacing are installed to drain to a drainpipe or waterway sloping away from the building (see ch. 10 of this handbook). A float-controlled drainage sump storage and pump system is a consideration where there is insufficient slope for gravity flow.

Drip line drains are a viable option to roof gutters, especially where the designer must address freezing, snow damage, or uneven roof lines. As with downspouts, drip line drains must be protected from livestock and vehicle traffic.

## (b) Roof drainage outlets

Use of a waterway or open channel as an outlet for roof gutter and downspouts permits ready maintenance and simple changing when needed. A grassed waterway is sometimes practical. A hard-surfaced drive, lined waterway, or grated open-top concrete gutter (see ch. 10 of this handbook) withstands year-round foot and wheeled traffic. Grated, modular, preformed, drain-trench sections comparable to the U-gutter shown in chapter 10 of this handbook are available that have built-in slope and different strengths and styles of cover grates. Such open-top gutters need periodic cleanout (see CPS Code 620, Underground Outlet).

Underground drainpipe is generally made of corrugated or ribbed polyethylene plastic pipe that has a 4- to 36-inch inside diameter (fig. 12–7).

This drainpipe is economical, lightweight, and durable. An optional smooth inside surface improves flow characteristics and reduces plugging. Plastic drainpipe is available in more than 1,000-foot-long, flexible coils that are up to 6 inches in diameter and in various other coil lengths for other diameters. The smooth-lined pipe and corrugated pipe that is more than 6 inches in diameter are available in 20-foot lengths. Extra instal-

**Figure 12–7**  Corrugated plastic drainpipe (*Photo courtesy of Advanced Drainage Systems*)

lation care is needed for lightweight pipe to reduce crushing from trench protrusions and backfilling. Consult manufacturer's recommendations and NRCS construction engineers for proper installation technique.

Heavy, but strong and durable, concrete drainpipe that is 0.5 foot to 6 feet in diameter is available in standard 8-foot sections. Longer sections can be special ordered. Concrete pipe resists soil movement, heavy crushing loads, and corrosion. Hoist equipment is needed for installing the larger concrete pipe.

Corrugated steel or aluminum culvert is made in 1- to 12-foot diameters and up to 8-gage thickness, depending on size. A 16-gage (0.0598-in) steel is common. (Corrugated and sheet metal thickness is often stated in gage thickness. As the gage number gets larger, the metal is thinner.) The size of the culvert depends on available soil cover or height clearance, flow rate required, and if the outlet can free flow or is submerged.

Various inlet and outlet pieces, corners, and other fittings are available to aid drainpipe performance, safety, and maintenance. A removable, screened outlet, for example, reduces pest entry and plugging. Pipe drains installed belowground need clear identity aboveground to prevent their being misaligned or crushed by heavy loads or accidentally damaged in future excavation. Cleanouts need to be marked so they are noticeable above snowdrifts and weed growth (see CPS Code 620, Underground Outlet).

More information about specific needs and hydraulic and structural design of culvert systems can be found in the NRCS National Engineering Handbook (NEH), Part 650, Engineering Field Handbook (EFH) and Handbook of Steel Drainage and Highway Construction Products (Amer. Iron & Steel Ins. 1993).

# 651.1203    Waste collection equipment

Waste collection systems are described in chapter 9 of this handbook, and components for waste collection at the farmstead in chapter 10 of this handbook. Collection of vegetative wastes involves equipment types such as rakes, stackers, bale bunchers and haulers, brushcutters, and choppers, and a description is not included here.

## (a)   Hand scrapers, shovels, brooms, washers

Common waste collection chores include washing, disinfecting, and cleaning in corners, surfaces beneath fences, along partitions, in alleys, and in stalls or pens. Regularly cleaned, neat-appearing facilities reduce complaints about odors, insects, and other pests (see ch. 8, app. 8A of this handbook). Warm, moist, manures are ideal for pests and need to be frequently and thoroughly removed. Flies, for example, are a noticeable nuisance, especially during warm weather when the egg-to-adult fly cycle is completed within 10 to 14 days.

Shovels, forks, scrapers, brooms, brushes, pressure washers, and related hand tools (fig. 12–8) are needed for small area cleanup.

A variety of hand tool heads and handles are available with handle angle (lie) and length variations for individual needs. A straight-grained ash wood or fiberglass handle provides strength, grip, protection from electric shock, and handling comfort. A short handle with an end D-grip permits heavier lifts and working in close quarters. A long handle provides better leverage for digging and throwing.

Aluminum and plastic shovels are lightweight, rustproof, and nonsparking. The extra investment required and the relatively faster wear compared to steel should be considered in choosing these shovels.

Forks are available with forged flat, oval, or round tempered steel tines in 3-, 4-, 5-, and up to 12-tine (18-in) widths. These forks handle loose or heavy, wet wastes. The flat tines assist in getting under and hold-

**Figure 12–8**    Hand tools used for waste collection
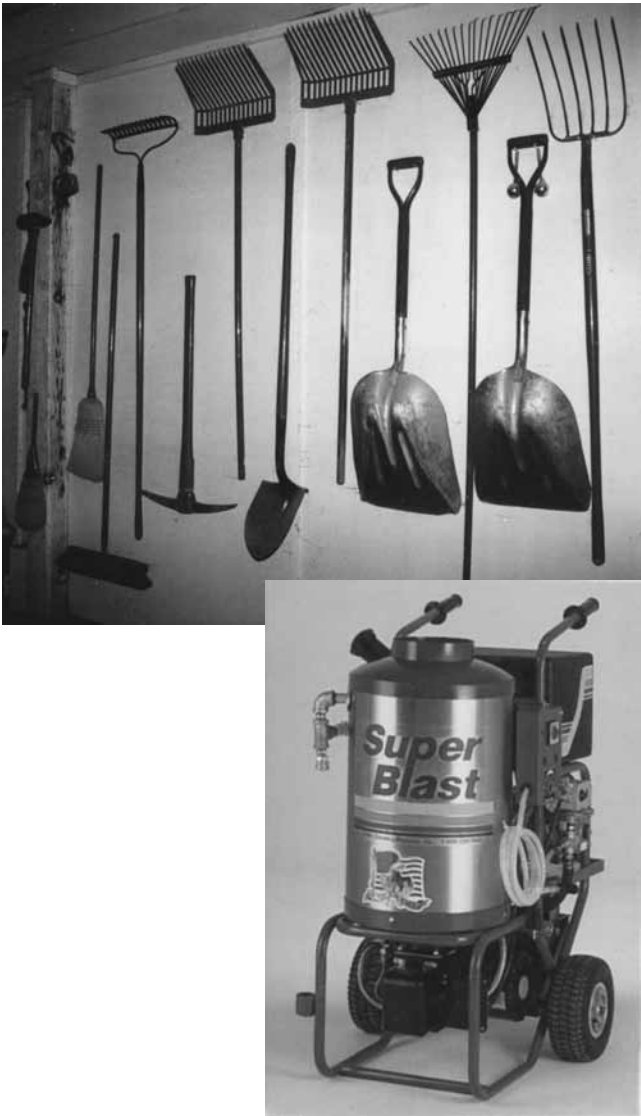


ing coarse, chunky waste. The oval tine is stiff, and the round tine forks do not clog as easily as the flat or oval ones.

A long-handle, relatively heavy floor scraper minimizes the labor of loosening stuck-on materials. Lightweight squeegees and scrapers are designed for cleaning and drying wet, smooth surfaces. A scraper blade that can be reversed when worn doubles the blade life.

Long, upright-handle brooms are used to sweep corners and small spaces, even wet areas. Push brooms that are up to 2.5 feet wide assist fast cleanup of large areas. A broom that has short, flexible bristles is designed for sweeping lightweight dirt and dust from smooth surfaces. The long, stiff bristles are for rough, tough sweeping. Plastic bristles resist moisture and bacteria, but not heat. A secure head for the bristles and handle attachment assists broom durability. The chemical, solvent, fat, and oil resistance of the bristles should also be considered in choosing a broom. A flow-through handle assists in washdown cleaning.

Pressure washers (fig. 12–8), can provide up to 7,000 pounds per square inch (psi) of water pressure to loosen and wash away hard, dried, stuck-on waste.

Washers that have an optional electric, gas, or oil heater can heat the water or produce steam to help speed waste removal (table 12–1). A fuel per hour rat-

**Table 12–1**    Typical pressure washer manufacturer's data

| Horsepower | Volts | Amp | PSI | Gal/min | Hot water |
|---|---|---|---|---|---|
| 1.5 | 115 | 13 | 1,000 | 2.2 | No |
| 2.0 | 115 | 18 | 1,500 | 2.1 | Yes |
| 3.0 | 230 | — | 1,500 | 3.0 | Yes |
| 3.5 | Gas | — | 1,500 | 2.2 | No |
| 5.0 | 230 | — | 2,000 | 4.0 | Yes |
| 5.5 | Gas | — | 2,000 | 3.0 | Yes |
| 6.0 | 240 | — | 2,500 | — | Yes |
| 7.5 | 230 | — | 3,000 | 4.0 | Yes |
| 7.5 | 230 | — | 2,500 | 5.0 | Yes |
| 9.0 | Gas | — | 2,400 | 3.7 | No |
| 11.0 | Gas | — | 3,000 | 4.2 | No |
| 13.0 | Gas | — | 3,000 | 4.0 | No |
| 18.0 | Gas | — | 4,000 | 4.0 | No |

ing is the measure of their efficiency. Power washers may be free standing, permanently installed, or truck-mounted.

Pressure washer selection considerations include:

- cost

- kind of cleaning desired (grease soil)

- pressure durability of the surface to be cleaned

- water supply quality and quantity needs

- cleaner-aid injection

- portability

- hose insulation and length

- heater fuel type

- washer corrosion protection

- available power source

Electric power is convenient, quiet, and generally available, but circuit capacity might be limited. Internal combustion engine-powered washers are useful in a wide range of locations; however, they need adequate exhaust gas ventilation to prevent carbon monoxide (CO) accumulation when used indoors. A freeze protected, in-place pressure washer pipeline, strategically placed in quick-connect plug-in locations for an easily moved pressure washer head, helps in areas that need frequent cleaning.

## (b) Tractor scraper blades

Scraping and collecting wastes with a tractor rear- or front-mounted blade is relatively fast over large, flat areas. Tractor scraping requires operator time, however, and takes a tractor away from other uses.

A rear-mounted tractor scraper blade, 12 to 18 inches in height, permits corner cleanout and smooth, fast, straightaway operation (fig. 12–9).

Available in 4- to more than 10-foot widths, the size selected needs to match the tractor weight, hitch design, hydraulic system, and alley space. The replaceable, high-carbon steel blade used on many tractor rear scrapers is needed to clean off dried, packed-down, or frozen waste. Frequent scraping is needed in subzero weather to reduce frozen waste buildup. A rubber-

edged blade can be used to clean off wet, roughened concrete surfaces, but it slides over stuck-on waste. A diagonal or diamond-shape groove pattern on concrete surfaces reduces slippage and minimizes scraper bounce and metal blade wear (fig. 12–10).

**Figure 12–9** Tractor rear scraper blade with vertical tilt (*Drawing courtesy Worksaver, Inc.*)
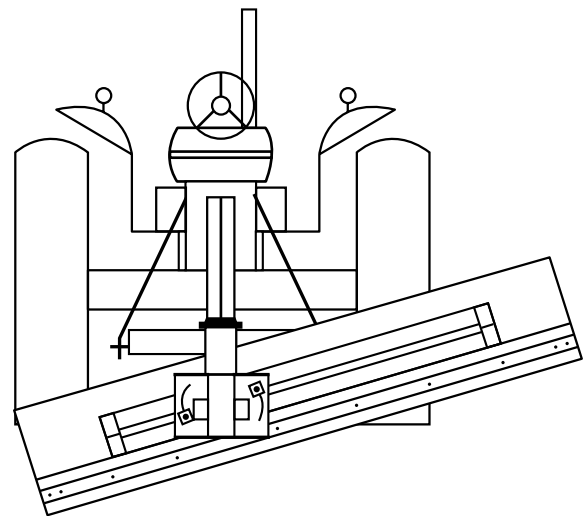


**Figure 12–10** Rubber tire scraper blade/diamond groove concrete (*Photo courtesy of Mensch Mfg.*)

Most rear-mounted scraper blade models can be rotated horizontally right or left, as needed, to direct the waste flow into a row for temporary storage or to simplify loadout. A hydraulic-powered, 3-point hitch is common with rear-mounted scraper blades. Other models can also be tilted and adjusted side-to-side and rotated 180 degrees for reverse pushing (figs. 12–9 and 12–11). Blade curvature and tilt adjustments aid waste flow while scraping.

A 1- to 2-inch depth of semisolid or slurry waste on a paved alley fills a scraper blade and spills out the ends after scraping about a 10-foot length. A box-type scraper (fig. 12–11) can increase scraper travel distance three to five times before end spillage begins. Box-type scraper models have end pieces and up to 32-inch-high blades to hold in waste. Beside mechanical or hydraulic control options, different blade tilting and reversing options are available.

Large (up to 8-ft diameter) discarded earth mover equipment tires can be used to scrape slurry and semisolid waste from long, wet alleys (fig. 12–10). The tires are cut in half with the tire sides removed and are then mounted on the towing frame. They are available as tractor front-end loader push, push-only, and 3-point hitch tow models. There are a wide range of configurations and options available to accommodate different types of equipment and facility needs (fig 12–12). An inside scraper height of 16 inches maximizes the slurry holding capacity without end spillage. A smooth, straight-cut edge on the tire side is essential to avoid scraper blade bounce and leakage.

## (c) Lawn and garden size tractor scraping

A lawn and garden or compact tractor scraper has advantages for access, visibility, and agility over the larger tractors, but the capacity is less (fig. 12–13). The small tractors have a wide selection of other useful

**Figure 12–12**    Configurations of rubber tire scrapers (*Photo courtesy of Mensch Mfg.*)



**Figure 12–11**    Box-type slurry blade scraper; rear-mounted model (*Drawing courtesy Degelman Industries, Ltd.*)



Blade rotation
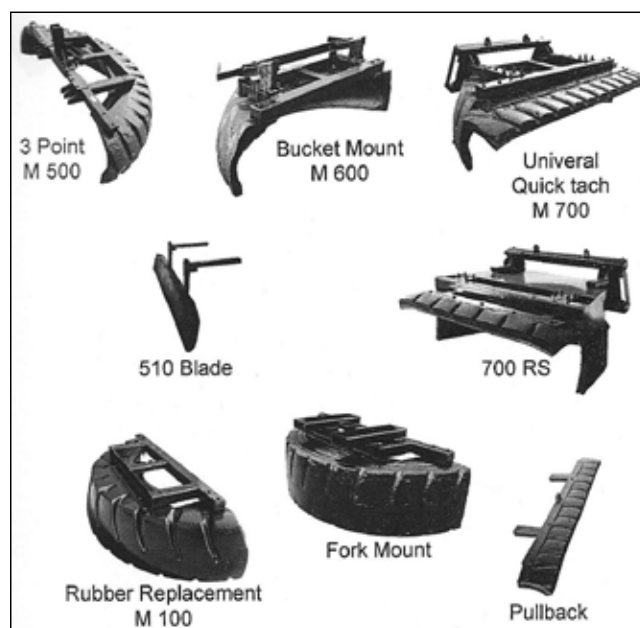
**Figure 12–13**    Lawn and garden tractor scraping equipment (*Photo courtesy of Kubota Tractor Corp.*)

attachments for sweeping, mowing, and dust and dirt collection. Electric, gasoline, and diesel-powered units are available in sizes of up to 25 horsepower.

## (d) Tractor front-end loaders

A tractor front-end loader (fig. 12–14, also see ch. 9 of this handbook) is perhaps the single most used multi-purpose equipment item for waste handling.

Useful for scraping, collecting, and mixing many types of wastes, it is indispensable for loading solid and semisolid wastes for hauling. Various attachments are available for all sizes of tractor power. Typical 30- to more than 100-horsepower agricultural tractors and low clearance, compact tractor loaders are more widely used for waste handling in and around facilities. Live, high-capacity, hydraulic power on tractors is basic to loader development and use. Buckets, forks, blades, and other implements (fig. 12–15) are readily attached to and detached from the loader frame. In addition to the available attachments, the following characteristics should be considered in selecting a tractor front-end loader:

- lift capacity

- breakout force

- lift height

- clearance when dumped

- dump angle and the time needed to raise and lower

The measurements designated in figure 12–14 are standard operational specifications used by manufacturers based on the ASABE Standard S301.4, Front-end Agricultural Loader Ratings (ASABE [c] 2006). These measurements provide a comparison standard for loader selection. For example, a comparison of over 200 typical tractor loader models indicates maximum lift height (A) ranges from about 6 to 21 feet clearance with attachment dumped (B) ranges from 52 to 183 inches, and maximum dump angle (D) varies from 6 to 98 degrees (Hudson 1993).

A loader is often described by the manufacturer in terms of its horsepower and recommended usage. The loader frame design and construction are for light or heavy duty. While many models are rated at about a 2,000-pound capacity, full height lift capacities are available to nearly 5,000 pounds. However, at this capacity, the tractor framework, traction, and overturning are limitations. Elements to consider in selecting a loader are the operator's view, quick attachment, clearances, operating speed, and joystick-type hydraulic control.

**Figure 12–14**    Tractor front-end loader measurements



A    Maximum lift height
B    Clearance with bucket dumped
C    Reach at maximum height
D    Maximum dump angle
E    Reach with bucket on ground
F    Bucket rollback angle
G    Digging depth
H    Overall height in carry position
L    Length of bucket
W    Lift capacity to full height
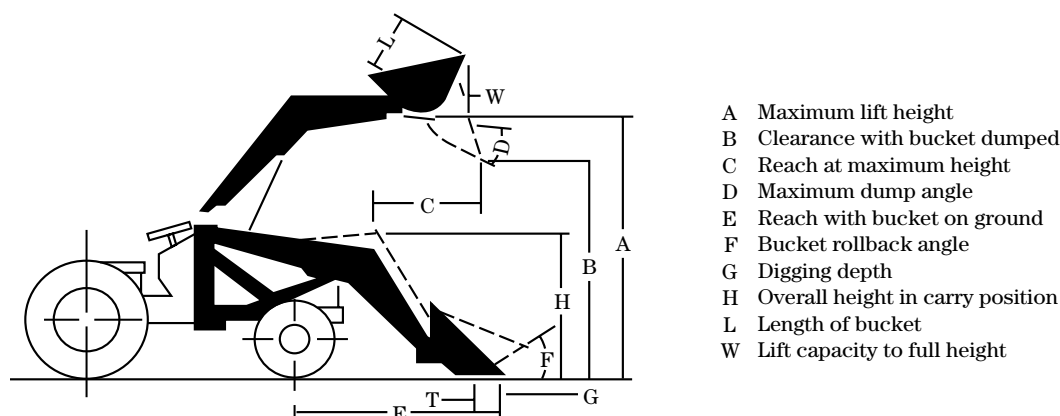
**Figure 12–15**    Tractor front-end loader attachments (*Photos courtesy of Leon Mfg. Co.*)

Blade
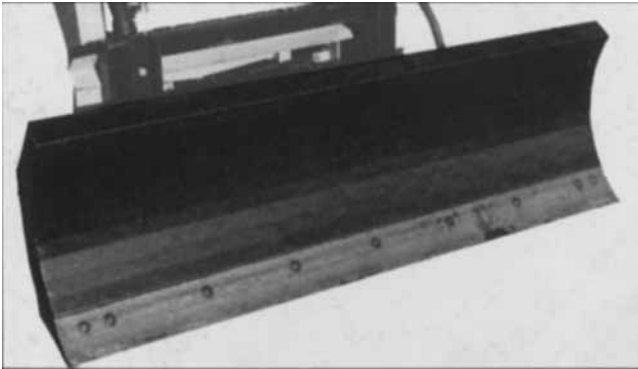


Scoop
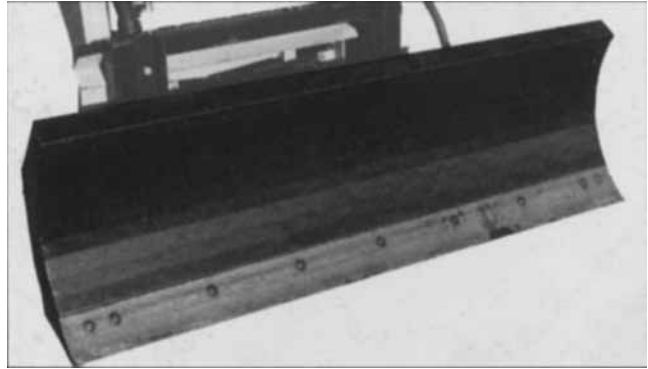


Bucket



Claw
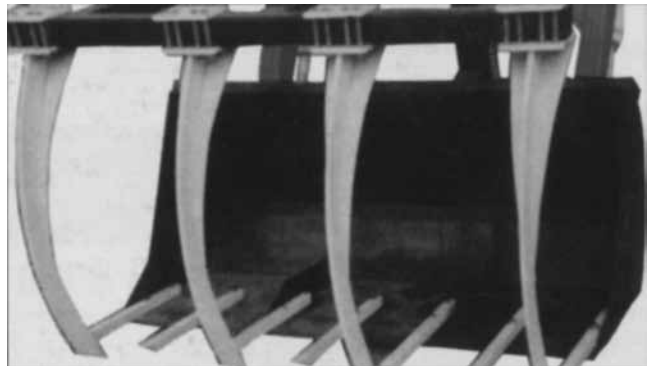


Handler



Fork
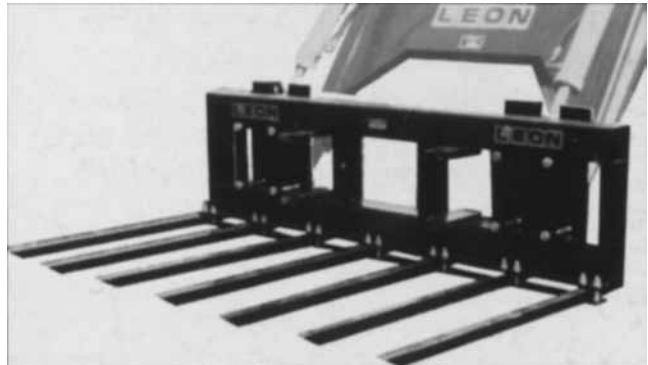
The ASABE Standard 355.3, Safety for Agricultural Loaders, relates basic rules for safe tractor front-end loader operation (ASABE [j]2002). Some of the rules include:

- Four-wheel drive and wide-spaced front tractor wheels are more stable than tricycle-type tractors.

- A loaded bucket reduces rear wheel traction and limits efficient use to areas with slopes of 10 horizontal to 1 vertical or less.

- Usefulness is hindered with building and yard layouts that require backing down long alleys or that have difficult turns.

The following operation and maintenance items are important for efficient front-end tractor loader use:

- tires are properly inflated

- tractor steering and hydraulic systems are maintained

- extra front-end tractor weights are not used

- rear wheel weighting and wide tire setting are in place

- hydraulic pressure relief valve operation should be avoided (hastening fluid breakdown)

- all moving joints are regularly lubricated

## (e)  Skid steer and articulated loaders

Compact skid steer and articulated steer loader tractors are especially designed for scraping and loading semisolid and solid wastes in small spaces (fig. 12–16).

The front-end lifting arms, with a selected attachment, are integral with the tractor. Most skid steer tractors can turn 360 degrees in their own tracks. The longer wheelbase, medium compact, articulated steer tractor loader needs more turn space, but it gives a smoother ride (less spillage) and has a higher reach.

Skid steer loader sizes vary according to horsepower and rated operating load. The Society of Automotive Engineers (SAE) J818 Standard sets their rated operating load at half the tipping load. The tipping load is the most weight the loader can lift without tipping forward. The rated operating load is well within limits of safe operation. The loader can lift more if carefully

handled; however, the rated value is a basis for size comparison. The 1,000- to 1,500-pound capacity range is relatively popular, but loaders that have more than a 6,000-pound lifting capacity are available.

Beside the investment, major considerations in selecting a loader are:

- load rating (capacity and tipping)

- turning radius

- length/width sizes

- power

- noise

- available attachments

Overall height and width clearances are important for maneuverability. A loader bucket width, the same or wider than the tractor width, aids steering when scraping; and reduces tracking spilled waste. Buckets range from 3 to 6 feet wide.

Rubber, steel with rubber pads, and steel grouser tracks are available to fit over the tractor tires. These tracks improve traction and flotation and provide a smoother ride, depending on the working surface.

Manufacturers now make attachments such as, rollers, tillers, power rakes, brooms, and backhoes, for skid steer loaders making them even more versatile.

## (f)  All-wheel drive front-end loader

The investment involved in purchasing a large, high-capacity, all-wheel drive bucket loader (payloader) is justifiable for a year-round, near daily operation (figs. 12–17 and 12–18).

This type loader is best adapted to open yard cleaning and to handling heavy and bulky materials around big work areas with high head space. Durability, high lift, and relatively fast high-capacity operation are major features. Four-wheel drive is basic, with articulated steer or crab steer (4-wheel steering) as options. Available models range from 60 to more 275 horsepower and have a 1- to 8-cubic-yard load carrying capacity. A 5-cubic-yard bucket capacity is common. Loaders with interchangeable buckets and forks generally have less loading capacity than that of the fixed bucket models. Most are diesel powered.

**Figure 12–16**　Skid steer and articulated steer-type loaders (*Drawings courtesy Melroe Co. and Northwestern Motor Co.*)

**Model Dimensions**

|   | T15 | T25 | T50 | T75 |
|---|---|---|---|---|
| A | 82 in (2082 mm) | 83 1/2 in (2121 mm) | 93 in (2362 mm) | 111 in (2819 mm) |
| B | 61 in (1549 mm) | 63 in (1600 mm) | 70 in (1778 mm) | 86 in (2191 mm) |
| C | 48 in (1219 mm) | 52 in (1321 mm) | 58 in (1473 mm) | 72 in (1829 mm) |
| D | 137 in (3479 mm) | 162 in (4115 mm) | 176 in (4770 mm) | 208 in (5283 mm) |
| E | 83 in (2108 mm) | 88 in (2235 mm) | 96 in (2438 mm) | 102 in (2590 mm) |
| F | 104 in (2642 mm) | 110 in (2794 mm) | 120 in (3048 mm) | 138 in (3504 mm) |
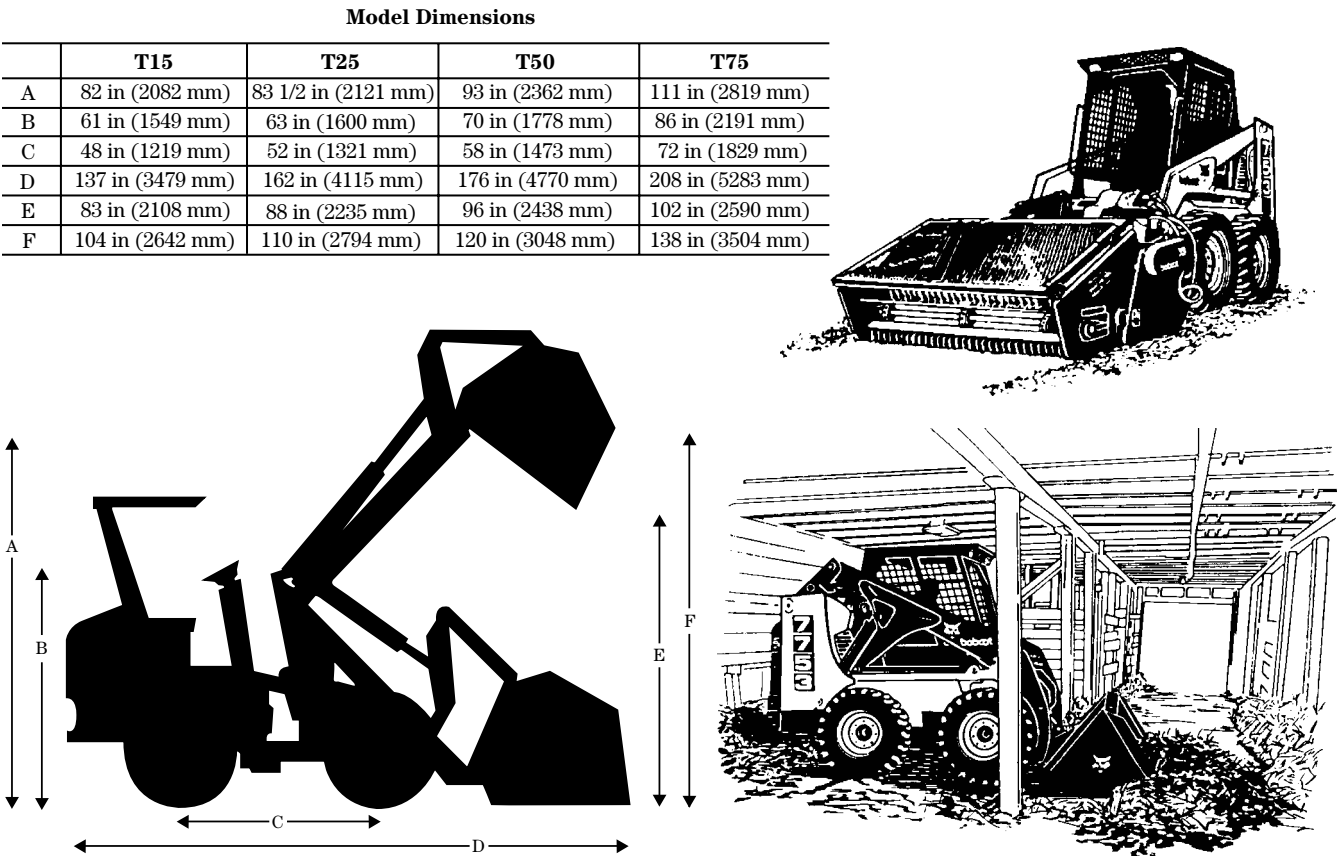


**Figure 12–17**　All-wheel drive (agricultural bucket loader)

A telescoping frame-type boom or bucket loader reduces transmission shifting and much of the wheel movement and speeds up loading and piling (fig. 12–18). The reach is a major feature.

Cattle feedlot cleanout and waste loading are often done using the telescopic, all-wheel drive loader. The operator must be skillful in the use of this loader to efficiently collect waste on an unpaved lot (usually with some wet and some dry areas) and yet leave the compacted waste and soil layer. Shifting gears four times per bucket load while travelling in a forward-reverse, forward-reverse motion and simultaneously steering the loader, plus guiding the vertical movement of the bucket, can be tiring.

The most efficient method for annual waste collection in open, large Texas feedlots was determined to be chisel-plowing the feedlot to reduce chunk sizes, stacking the waste in the pen with a wheel-type loader, and then loading and hauling the waste on trucks. However, this chisel-plow, all-wheel drive loader method can disturb the compacted waste and the soil interface seal needed to protect against nutrient leaching (Sweeten 1984).

## (g) Motor grader

A common road grader and maintainer can be practical for frequent scraping of solid waste buildup on long paved aprons and open yard surfaces. Although a large turn space is needed, this equipment is designed for scraping and has the adjustments, visibility, capacity and other features needed to scrape big areas. In dry climates, the smooth surface left by the grader blade facilitates frequent waste collection. Like the self-propelled, elevator scraper (fig. 12–19), the accurate control of the scraper blade minimizes disturbance of the sealed soil surface layer.

**Figure 12–19** Self-propelled, self-loading elevating scraper-hauler (*Photo courtesy of Caterpillar®*)



**Figure 12–18** Telescopic, all-wheel drive bucket loader (*Photo courtesy of Gehl Co.*)

## (h)  Elevating-type box scrapers

A self-loading, elevating-type scraper-hauler (fig. 12–19) that both loads and hauls is more efficient than an all-wheel drive loader for cleanout of solid waste from large open feedlots with few corners. The ability of the elevating scraper to make a precise cut permits slicing through built-up solid waste while leaving the desired undisturbed waste and soil sealing surface layer. The operator can travel continuously forward in an oval-shaped pattern, rather than the forward and reverse cycles needed with the all-wheel drive loader (Sweeten 1991).

A self-propelled, elevating scraper has an 11- to 25-cubic-yard loading capacity and 100- to 250-horsepower moving capacity.

The wheeled, tractor-towed, conventional box-scraper is useful for collecting loose solid waste in open yards, constructing mounds, and performing drainage-way maintenance (Livestock 1979). The operating capacity generally is lower than that for a comparable sized, self-loading elevating scraper. The farm tractor-towed scraper's capacity ranges from 1 to about 8 cubic yards, and the power needs are about 25 to 450 horsepower, depending on operating speed and hydraulic capacity. Models are available with varied wheel arrangements, height and width clearances, hitching and loading transfer features, dumping or push-off unloading features, cutting depth control, and hydraulics options. A compact adaptation of the elevating scraper for poultry litter agitation and hauling is called a cruster. A useful model for working around the typical facility is about 5 cubic yards and 100-horsepower capacity.

## (i)   Mechanical scrapers for gutters and alleys

Open scrape alley design for semisolid and slurry waste is explained in chapter 10 of this handbook. The relatively light duty cable-drive scraper (fig. 12–20) can use manual or automatic control of a 0.75- to 1.5-horsepower electric motor.

Automatic control is generally set to reverse or shutoff the power when the scrapers reach the end of the set travel distance or overloads from an obstruction. Alley scraping arrangements can be designed so one drive can power several scrapers at once. Operation is quiet, and alley corner turns can be made right or left.

To reduce corrosion and weight, a high-strength stainless steel cable, 3/16 to 5/16 inch in diameter, is used for pulling the scraper. The size used depends on the scraper width and length. Small diameter cable, with adequate strength, is more flexible around corners than larger steel cable, and the investment is less. Cable stretching requires periodic adjustment.

Cable-drive power units are available for alleys that are up to 1,000 feet long. Scraper blades up to 12 feet wide and 8 inches high are available. Most are made from corrosion-resistant steel. Some models have a flexible material on the scraper edge for cleaner scraping of a rough surface.

Scraper speeds of 4 to 8 feet per minute are practical for open alley scraper travel. Speeds to 50 feet per minute are used with slurry waste below a slat floor where there is no foot traffic interference.

Most models scrape one way, then tip or fold up and return empty. Rigid blade models push the waste each way and require a collection gutter at each end

**Figure 12–20**    Cable-drive scraper for open alley or under slat floor (*Photo courtesy of Acorn Equipment Co.*)

of travel. Minimum clearance at blade ends and construction of a uniform alley floor minimize leakage or spillage of scraped waste. A scraper blade pushes only so much semisolids, and then it overflows. Because of this, frequent operation is needed; however, the frequent use increases drive, cable, and scraper wear and hastens floor wear and slipperiness.

A wide and long alley scraper for semisolid waste needs a heavy-duty link chain. The chain generally is set in a preformed groove in the alley floor to pull a 7 to 10-inch-high scraper blade (fig. 12–21; also see ch. 9 of this handbook). The chain drive is similar to that used with a gutter cleaner. Heavy-duty chain links are forged and heat-treated from high carbon steel. Hook-type chain links can flex in all directions. Alloy steel pintle connected chain (similar to a bicycle chain) is used for corrosion resistance and mostly horizontal movement.

A chain drive intermittently operated in wet waste corrodes, wears, and stretches over a few years of use, especially where the alley is long and wide or the waste is dense. This wear demands periodic maintenance of the chain and replacement about every 8 to 12 years.

The concrete of open, scraped concrete alleys is grooved when the alley is constructed or later using a concrete saw. The grooved concrete helps to reduce slipperiness. The grooves are about 0.375 inch wide and deep. They are spaced 4 to 8 inches apart and are diagonal to the scraper travel, which helps to make the scraping smoother and cleaner (fig. 12–22). Too deep or wide grooves interfere with cleaning and disinfecting, which can affect foot health.

In some cases, loose aluminum oxide grit (as on sandpaper) is worked into the surface of the fresh concrete instead of grooving the concrete. The grit is applied at 0.25 to 5 pounds per square foot. Coarse grit of 4 to 6 meshes is recommended. Such grit surfaces increase scraper wear (Barquest et al. 1974).

The widely used gutter, or barn cleaner, designed for collecting semisolid and solid waste, generally uses a continuous, one-way heavy chain drive (fig. 12–23; also ch. 10 of this handbook).

The less-used back and forth shuttle-stroke cable or rod pull type (see ch. 10 of this handbook) costs less than other cleaners and only needs 1 to 2 horsepower and manual control. Its practical use is with a relatively short gutter and slurry waste where up to 140 feet per minute speeds are used.

The heavy-duty one-way driven cleaner requires 2 to 10 horsepower, depending on gutter width, length, and the cleaner speed. The gutter generally is 16 to 18 inches wide. It is usually 12 to 18 inches deep. The gutter chain can be up to 700 feet long. The typical speed for this cleaner is about 20 feet per minute.

**Figure 12–21**  Heavy-duty alley scraper, chain drive (*Photo courtesy of Alfa-Laval Agri, Inc.*)



**Figure 12–22**  Grooved concrete to reduce slipperiness (*Photo courtesy of Mensch Mfg.*)

Scraper paddles that are 2 to 4 inches high and spaced 1.5 to 4 feet apart are available. Higher paddles and closer spacing are required for slurry and liquid waste. Corner-wheel construction, installation, and maintenance are critical because the system experiences major wear in these areas. Reverse turns are located where the unloaded chain runs empty on its return.

## (j)　Conveyors and stackers

Most gutter cleaner equipment has unloading elevator ramp options for piling or stacking solid and semisolid waste onto outside storage piles and aboveground storage tanks (12–23) (also see chs. 8 and 10 of this handbook).

A wheeled undercarriage or overhead cable suspension support of the ramp permits semicircle movement of the elevator for more storage space (fig. 12–24).

A picket dam (see section 651.1204(b)(iii)) or other method (see ch. 9 of this handbook) may be needed for drainage to storage. For additional information, see chapter 10 of this handbook.

Clean-off options for semisolid waste that sticks on paddles are part of gutter cleaner equipment. Melting snow or rainwater drains down an unprotected, inclined conveyor and into the gutter. Some systems provide a sump and pump for handling liquids that drain down the inclined conveyor (fig. 12–25).

An endless chain slat-type conveyor adapts to inclined elevating of scraped or separated solid waste to aboveground storage. It is used as part of the inclined screen solids/liquid separator. Semisolid waste leaks liquid, sticks and dries on the chain and slat surfaces, and dribbles off or freezes on the return. The 5- to 10-horsepower need for a 30-foot lift is less than that required for an auger; however, the capacity is also less because the waste tends to slide or roll back down the incline. Typically, a 5 horizontal to 3 vertical slope is about the maximum elevating angle for a chain-slat conveyor, depending on slat design. A chain-slat speed of 75 to 125 feet per minute is typical.

Slurry and liquid wastes are best directly pumped or conveyed up at a less than 30-degree angle to storage with an enclosed auger. The capacity of an open-top, U-trough auger is increased if the auger is operated at flatter inclines. Although augers are operated at steep slopes with liquid waste, auger power requirements for semisolid waste are high, about 1 horsepower per 2 feet of auger length for a 13- to 16-inch-diameter auger at 200 rotations per minute.

**Figure 12–23**　Heavy-duty alley gutter cleaner with chain drive (*Photo courtesy of Patz Corp.*)
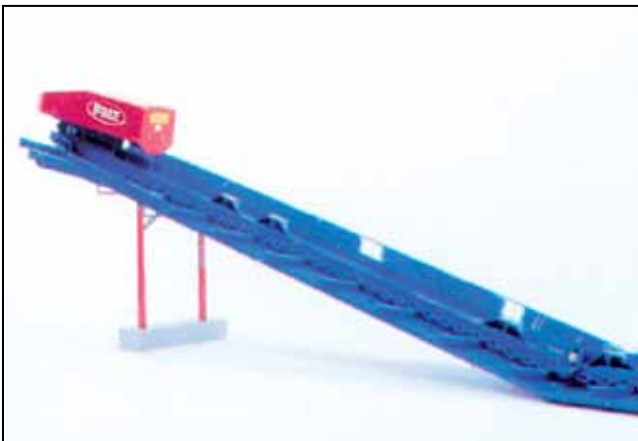


**Figure 12–24**　Moveable gutter cleaner conveyor stacker (*Photo courtesy of Patz Corp.*)

**Figure 12–25**    Elevated gutter cleaner with sump to handle drained liquids (*Drawing courtesy of Patz Corp.*)
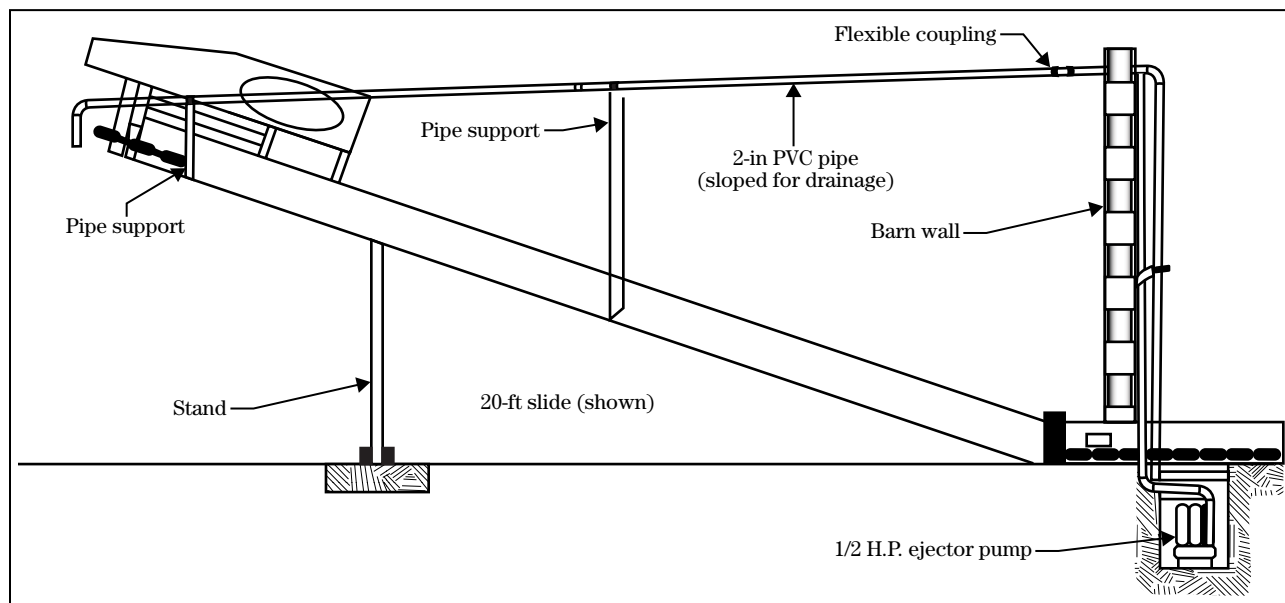


## (k)  Flushed gutters and alleys

Flush gutter and flush alley waste collection uses a relatively large quantity of regularly added flush water for more thorough cleaning. Gutter or alley design and flush water quantity are explained in chapter 10 of this handbook and here in table 12–2. Different applications are shown in chapters 9 and 10. A flush water recycle arrangement reduces the amount of added fresh water.

In lieu of scrapers with mechanical power and control, flushing equipment involves pumps (see section 651.1206(b)), pipes, tanks, drains, and liquid overflow control. Electric power that allows automatic control is often used. A stored flush water release valve needs to deliver flush water to a gutter at the correct flow rate for a necessary length of time (see ch. 10 of this handbook). Several types of gutter or alley flush water storage and release equipment are used. Which to use depends on investment, facility design, flush water demand, and waste quality. The equipment can include:

- tip or dump tanks
- storage tank gate valves
- siphon-release storage tank
- tower-type storage with pipeline or valve flow control

An ordinary stock watering tank, portable plastic tank, or used metal tank is adaptable for flush water storage or release. Aboveground flush water storage

**Table 12–2**    Flush water flow and pipe size (MWPS 1985)—maximum velocity = 2.5 ft/s

| Pump capacity (gal/min) | Minimum pipe diameter (in) |
|---|---|
| 10 | 1.5 |
| 20 | 2.0 |
| 30 | 2.5 |
| 50 | 3.0 |
| 75 | 3.5 |
| 100 | 4.0 |
| 200 | 6.0 |
| 400 | 8.0 |
| 600 | 10.0 |
| 800 | 12.0 |
| 1,000 | 15.0 |

tanks are often locally custom built using poured-in-place or precast reinforced concrete, concrete block, or fiber glass. In flush alley cattle barns, the alley flush water storage tank can also be used as a cattle waterer where fresh water is used. A gate-type flush tank door on the side (fig. 12–26) or flop-up valve on the bottom of the storage can be hand operated or semiautomatic operated using float-controlled weight assist, vacuum pump assist, or air pressure assist. A watertight seal and smooth door or gate operation are elusive features requiring workmanship, durable materials, and maintenance.

Dump-type flush tanks (fig. 12–27; also see ch. 10 of this handbook) are manufactured or can be custom built from a plan. These tanks are relatively low cost and can be readily changed or replaced. Such tanks can automatically dump when steadily filled to an adjustable, overbalance pivot-point. Bearing wear, sticking, tank corrosion, noise, floor space need, and splashed water are considerations when choosing a dump-type flush tank.

Unlike a dump-type flush tank, an automatic siphon flush tank generally has no moving parts (see ch. 10 of this handbook). The operation of this type flush tank is explained in chapter 10 of this handbook. An interruption of flush water flow (e.g., power or pump failure) stops the automatic siphon action. A burping using a compressed air blast through the siphon may then be

needed along with resumed water flow and restart the automatic siphon action. The investment is relatively high for a siphon. Unlike a dump-type flush tank, the siphon can be located overhead with a drop pipe outlet, which eliminates the use of building floor space.

Air leakage and foreign material that restricts flush water flow are siphon operation problems. Siphon flush tanks can be purchased, or they can be constructed from plans (MWPS 1976). Although vulnerable to puncture or cracking, molded glass fiber tanks are noncorrosive. Repair can be difficult. Stainless steel tanks are also noncorrosive, but generally more costly.

An overhead or tower-type flush water storage tank, or reservoir, saves floor space, adds to flush water pressure, and permits large volume flushing by pipes of several gutters from one water source. A sturdy, post-beam or other type tank support system is essential to hold the 2,000 to 5,000 gallons (8 to 21 tons) of overhead flush water storage.

A tall, narrow, aboveground flush water storage tank arrangement (fig. 12–28) is advantageous for large facilities that have several gutters or for several adjoining barns that collectively use a large volume of flush water. Flushing can then be done at different times in the different gutters via pipes and valves from one flush water source. A relatively small-capacity fill pump, automatically operated by float switch over

**Figure 12–26**    Hand-operated storage gate flush control (*Photo courtesy of Agpro, Inc.*)



**Figure 12–27**    Flush water storage tank with dump-type release (*Photo courtesy of Agpro, Inc.*)

several hours, can fill the flush water storage tank. A bottom drain plug is used for periodic or operation shutdown cleanout. Also, an overflow pipe from the tank to a drain is needed as the automatic controlled filler pump shutoff can malfunction.

University of Missouri agricultural engineers have compared the equipment for five ways to release flush water. The study was conducted in their 98- by 202-foot, 160-cow dairy freestall barn (fig. 12–28). The flush water effectiveness was measured from two dump-type flush tanks, two baffled air-controlled valves on pipes, and a partly embedded 12-inch-diameter pipe with seven 3- by 6-inch holes spaced across a 10-foot-wide alley (fig. 12–29). The holes had a 1-foot-long outlet extension and allowed flush water volume to uniformly, but forcefully, exit into the alley as seven smaller streams rather than a large, concentrated stream. In daily flushing, the cleaning done by the spaced-hole flush water discharge was preferable to the dump-type flush tanks and the air-controlled pipe valve flush water dischargers (Patrico 1992).

Direct pumping large volumes of alley flush water from a second stage lagoon or an ample supply of freshwater is common in mild climates. Chapter 10 of this handbook provides more information. Table 12–2 shows the pumping capacity for various pipe sizes. Systems in use are similar to those shown in figure 12–30 (also see ch. 9 of this handbook). Investment and daily operation of a large pump, such as that shown in figure 12–30, may be more practical than installing, operating, and maintaining several dump or siphon flush tanks or a large flush water storage tank. Total water use with a pumped flush system generally is greater than that with dump-type or siphon flush-tanks. A power failure or breakdown of the large-capacity pump interrupts cleaning until repaired or replaced.

Difficulties with flush water waste equipment include:

- pump, tank, and valve maintenance and repair
- metal corrosion
- struvite buildup
- liquid freezing

In subzero climates, correct ventilation (airflow rate, direction, supplemental heating, and temperature

**Figure 12–28**  Tall flush water storage for five flushed alleys (Rural Builder 1992; Patrico 1992)



9-ft by 24-ft
flush reservoir

12-in butterfly valve

12-in flush main

Agpro flush valves
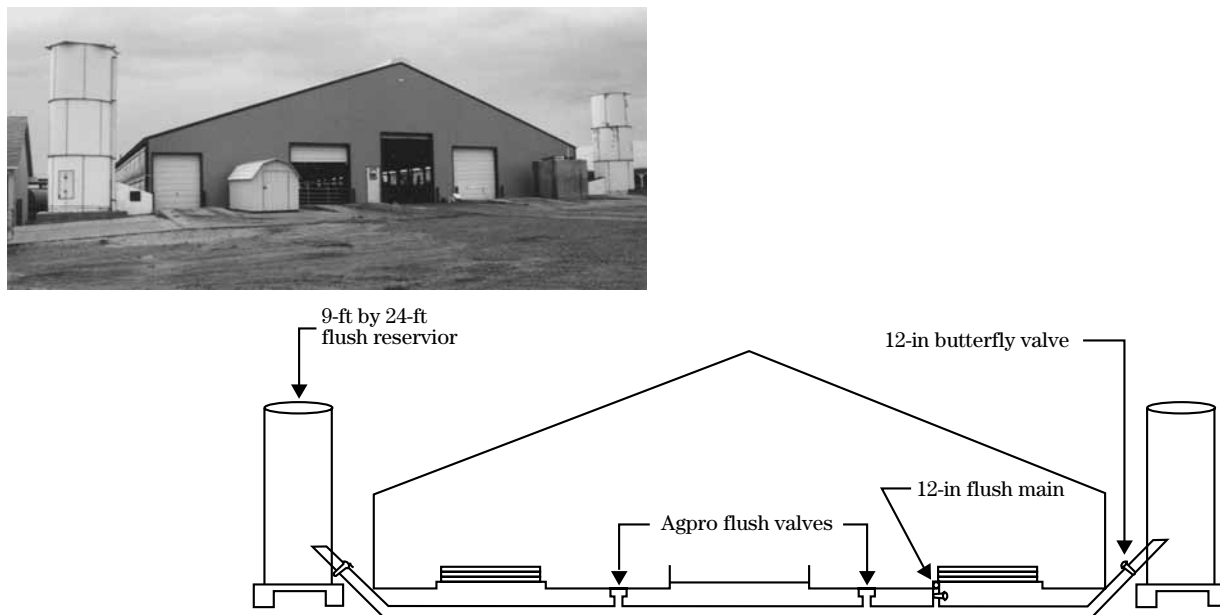
**Figure 12–29**  Flush water alley entry from 3- by 6-inch holes (Rural Builder 1992; Patrico 1992)
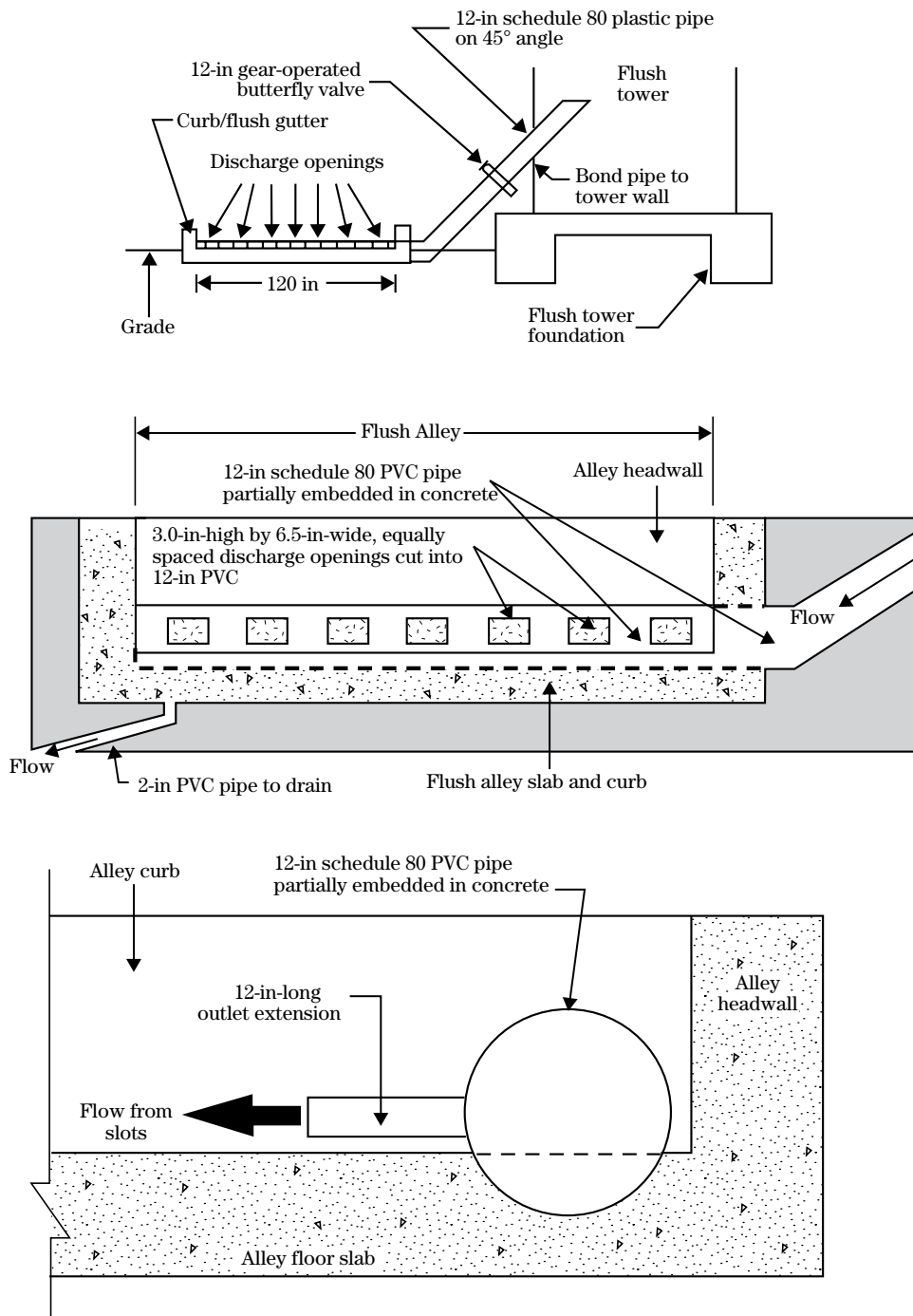
operation) is critical to control building humidity and temper the cold drafts from freshly-pumped, cold flush water. This is especially important for new born and young livestock operations.

A cross gutter or drain that has adequate flow capacity is needed to smoothly carry away a large volume of flush water from an alley or gutter (fig. 12–31; also see ch. 9 of this handbook). The flow into the gutter or drain should be unrestricted. If flow is slowed, flush water backs up and solids separate and block the subsequent flush water.

## (l)   Multiple function equipment

Some pieces of equipment serve multiple functions. They are used for collection of manure at the source and transfer to a storage facility or for transfer from the collection point or storage facility to the utilization area. For example, while they will be covered in a subsequent section, manure spreaders are considered as a utilization component of a waste management system, but they are also used to transfer manure from a collection point or storage area to the application/utilization area.

A piece of equipment that is used for both collection and transfer of manure to a storage facility is a manure vacuum (fig. 12–32).

The basic components of a manure vacuum are a hydraulically controlled variable width scraper, a large diameter hose connected to a vacuum blower, and a storage tank. It can be used to clean barn alleys or paved outdoor feed lots and holding areas and is best suited to handle semisolid or slurry manure containing a minimum amount of long straw bedding. Most models will handle sand laden manure typically found in

**Figure 12–30**   Large-volume, low-pressure flush pump used in a recycle system (*Drawing courtesy of Gorman Rupp Co.*)
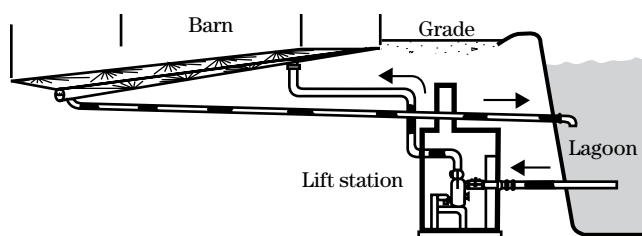


**Figure 12–31**   Cross gutter for alley flush water collection



**Figure 12–32**   Manure vacuum (*Photo courtesy of Mensch Mfg.*)

freestall dairy operations. Some of the advantages of using a manure vacuum are:

- adaptable to barns with differing alley widths

- can be used in multiple locations on an operation eliminating the need for separate handling systems in each barn on the facility

- can transfer manure to a storage or treatment facility no matter where it is located on the operation

- expansion of facilities is not limited by the need to consider manure storage/treatment location

- a barn alley can be cleaned in a single pass as opposed to the required forward and reverse maneuvering of a bucket loader

The primary disadvantage of a manure vacuum as compared to a cable or chain alley scraper or flush system is the time needed for an operator whenever manure is being collected.

# 651.1204 Waste transfer equipment

The movement or transfer of agricultural wastes is described in chapter 9 of this handbook. As further explained in chapter 10, transfer equipment can be an extension of the waste collection equipment. The equipment that has common use either for collection or for transfer of waste is explained in section 651.1203. It includes:

- tractor front-end loader

- skid steer and articulated steer loaders

- all-wheel drive front-end loader

- ramps and bumper walls

- earth mover scrapers

- manure vacuum

Solid waste is commonly transferred a batch or more at a time (i.e., scoopful, wagon load) and at a relatively low rate. It is relatively dense and not easily moved. While batch movement is intermittent, a relatively larger quantity of semisolid, slurry, and liquid waste generally is transferred at one setting with continuous flow-type equipment than with other equipment. Depending on what is calculated and how (e.g., labor, investment, odor, appearance, nutrient), the cost of actual dry matter transferred is probably similar. The liquid portion facilitates waste transfer, but, unless needed for irrigation itself has little value and adds to transfer quantity.

## (a) Augers and conveyors

A standard pitch auger that is 0.3 to 1.5 feet in diameter can be used to transfer solid, semisolid, and liquid wastes. A clean auger intake and relatively tight auger fit within its housing assist throughput. A short pitch, sometimes called *double flight* auger (twice the flighting per foot) aids slurry or liquid waste transfer if operating at relatively steep inclines. Table 12–3 shows how water throughput changes with auger size, speed, power, and elevating angle. With slurry and semisolid wastes, less throughput can be expected than that for liquid waste (MWPS 1975).

Although designed to transfer semisolid waste, power requirements are relatively high for larger augers— about 1 horsepower per 2 feet for an auger that is 13 to 16 inches in diameter and operates at 200 rotations per minute. If stopped when full, auger startup is difficult. A 16-foot-long auger, that is 16 inches in diameter, operating at about a 30-degree incline should have about a 750 gallon per minute throughput when powered with a 7.5-horsepower motor at 200 rotations per minute. Most manufacturers use a plastic liner or pipe housing because it operates smoother and quieter and is resistant to wear and corrosion. Augers up to 40 feet long are available that are designed for slurry and semisolid wastes (fig. 12–33). Some models that are more than 100 feet long and 0.33 to 1 foot in diameter are available for transfer of granular solids such as sand bedding.

**Figure 12–33**    Auger elevator slurry waste conveyor (*Photo courtesy of Berg Equipment Co.*)



**Table 12–3**    Auger (11 ft) speed, power, and capacity for water

| - - - 4-in-diameter auger - - - | | | | - - - 6-in-diameter auger - - - | | | |
|---|---|---|---|---|---|---|---|
| **RPM** | **HP** | **Angle (%)** | **GPM** | **RPM** | **HP** | **Angle (%)** | **GPM** |
| 1,500 | 0.8 | 45 | 32 | 950 | 2.0 | 45 | 80 |
| | | 60 | 17 | | | 60 | 40 |
| | | 90 | 10 | | | 90 | — |
| 1,700 | 1.6 | 45 | 48 | 1,150 | 2.8 | 45 | 180 |
| | | 60 | 33 | | | 60 | 130 |
| | | 90 | 19 | | | 90 | 85 |
| 1,900 | 2.6 | 45 | 66 | 1,300 | 4.0 | 45 | 330 |
| | | 60 | 51 | | | 60 | 255 |
| | | 90 | 30 | | | 90 | 200 |

## (b) Pumps

A variety of air pressure and vacuum pumps, piston-plunger pumps, and either variable or positive displacement pumps move liquid, slurry, and semisolid waste to storage, tankers, or irrigators. Pump selection and rating depend on the amount and type of solids in the waste (see chs. 4, 9, and 11 of this handbook), capacity desired, head or operating pressure needs, and available power. Table 12–4 compares the major characteristics of different pumps used for pumping waste. Because of the many model variations (inlet, outlet, impeller, speed, power) the manufacturers' literature on use and performance of a particular pump needs to be reviewed.

Measures are available to protect a pump and power supply against plugged pipes or nozzles, loss of prime, overheating, and lubricant loss. They include pressure and temperature gages, fuses, circuit breakers, and pressure switches. Lightning grounding is especially needed with exposed pipe irrigation pumping. Pressure surges in the discharge pipe (water hammer) are troublesome in starting high-capacity pump systems. An open valve in the discharge pipeline can be slowly closed to reduce water hammer when pressurizing a system. A surge tank reduces water hammer as well.

The wear on most pump bearings and seals is rapid when pumping waste. The severe pumping conditions also damage controls and valves. Regular lubrication and cleanup extend pump life and performance. A spare pump should be readily available to replace essential pumps in a waste system when they break down.

Pump inlet and outlet pipe configurations affect performance. An inlet or outlet pipe that has a smooth, funnel shaped transition or a gradual corner without a sharp edge or turn, or both, aids flow. This is especially helpful where the flow rate is high. The diameter of the inlet and outlet pipes should match that of the pump openings. A minimum of bends, elbows, and other flow restrictions in the pipeline improves flow and reduces power and plugging.

Exclude foreign material, such as twine, hair, wood pieces, broken iron, afterbirth, stones, and plastic from waste to help prevent plugging and breakage. A screened pump inlet, if used, needs a large screen area with relatively large openings to reduce plugging. A screen is most efficient with liquid waste that has few large solids and at low pumping rates. Locating the pump inlet above the bottom of the waste impoundment and below the surface minimizes inlet plugging (fig. 12–30). Adding dilution liquid to waste aids pumping, but adds to waste quantity, storage space, hauling, spreading, and possible water supply problems.

Pump use and waste handling system performance are assisted by waste storage construction design features. Access space, pumping sump, agitation mixing, proper pump location, and intake protection are needed in addition to the correct pump selection. The solids and liquids in liquid, slurry, and semisolid wastes need to be thoroughly mixed so the solids are not left behind when these wastes enter the pump.

### (1) Variable displacement centrifugal pumps

Centrifugal pumps are variable displacement. They are widely used for waste pumping because of their simplicity and range of capacities. These pumps have a power shaft with an attached impeller that rotates inside an enclosed housing. Gravity-flow liquid enters the housing near the center of the impeller and is forced outward by the rotation of the curved impeller blades (fig. 12–34). The higher velocity at the outer end of the blades and low pressure at the impeller center cause the liquid to flow.

**Table 12–4**   Waste pump characteristics summary (MWPS 1985; Patronsky 1978)

| Pump type | Max. solids (ft) | Agitate dis. (ft) | Pump rate (gpm) | Pump head (ft) | Power (hp) |
|---|---|---|---|---|---|
| High-pressure centrifugal | <10 | 40–60 | 1,000 | 200–300 | 80+ |
| Chopper-agitator | 10–12 | 50–75 | <4,000 | 25–75 | 65+ |
| Impeller agitator | 10–12 | 75–100 | <5,000 | 30–35 | 60+ |
| Submersible | 10–12 | 25–50 | <1,000 | 10–30 | <15 |
| Helical screw | 4–6 | 30–40 | <300 | 200+ | 40+ |
| Hollow piston | 18–20 | — | <150 | 30–40 | <15 |
| Solid piston | 18–20 | — | <150 | 30–50 | <10 |
| Pneumatic | 12–15 | — | <150 | 30–40 | <10 |
| Vacuum | 8–10 | 20–25 | <300 | — | 50+ |
| Diaphragm | 1—12 | — | <300 | 100+ | 25+ |

Intake restrictions or plugging cause air-pockets (cavitation) by the impeller. This reduces flow and can hasten the impeller wear, especially where high-pressure pumps are used at a high speed. Because the pumped liquid can slip past the rotating impeller, the liquid displaced varies—hence the name *variable displacement*. As slippage increases and further lowers efficiency, the pump operating pressure is increased. Pumping capacity, pressure, and power needs depend on design and construction of the impeller, the impeller enclosure, and its inlet and outlet.

Established pump manufacturers design, develop, test, and manufacture a variety of centrifugal pumps for most uses. Models vary by size, impeller type and clearance, pump inlet and outlet, bearing seals, and drive arrangement. Selected models are often recommended by agricultural waste pumping equipment manufacturers that assemble pumping equipment for transfer, agitation, pumpout, and irrigating waste.

A closed impeller is efficient with liquid waste, but plugging with tough, stringy solids and chunks can be troublesome. A closed impeller pump is useful for high-pressure irrigation or recirculating liquid for flushing. A semiopen or open impeller is less efficient, but is also less prone to plugging and is able to handle semisolids. Although generally inefficient, a sloped and curved, semiopen impeller design minimizes flow cavitation and solids plugging. A sharp, hardened, chopper-blade attachment at the pump inlet can break up tough materials ahead of the impeller. The blade must be

kept clean and sharp because a dull blade winds-up stringy materials, which restricts the flow.

Changes in the pressure at which a centrifugal pump operates efficiently can be made by changing the operating speed. However, when this is done the discharge and power required also change. Pump discharge generally increases directly as the speed increases; the pumping head increases as the square of the speed; and the power required increases as the cube of the speed. For example, a pump operating at 500 rpm could be expected to pump twice as much when operated at 1000 rpm. However, it would operate at four times the operating pressure and use eight times the power.

Liquid priming is necessary to start a centrifugal pump. Priming consists of filling the suction pipe and impeller enclosure housing with liquid to expel the air and cause suction as the impeller begins turning. A gate valve on the discharge side and a small hand pump attached to the volute are a usual priming pump arrangement. Holding liquid in the pump when stopped using one-way flow valves also is used, but plugging and leakage are problems. Priming becomes more difficult as a pump wears and air leaks develop around bearings. Some large-capacity pumps have a separate small, powered priming pump. Locating (submerging) the pump in the liquid to be pumped eliminates hand priming (fig. 12–35).

The practical limit of liquid suction for most centrifugal pumps is 22 feet at sea level, 17 feet at 5,000-foot elevation, and 14 feet at 10,000-foot elevation. Pumps will operate beyond these limits, but their performance is seriously reduced by cavitation or nonuniform liquid flow through the pump. Elevation can also affect vacuum pump suction and pumping performance.

**(i) Transfer**
Generally, two types of pumps, submersible and vertical shaft centrifugal, pump liquid and slurry waste from reception storage to long-term storage or separation. The relatively small, submersible, 0.5- to 15-horsepower centrifugal-type (sump) pump (fig. 12–36) is designed to simply sit on the pump chamber floor. It has a flexible power cord and pump outlet pipe. This type pump is messy to use and difficult to service. Industrial and larger models use a raise and lower attachment and hose disconnect.

**Figure 12–34** Centrifugal pump impeller types (MWPS 1985)



Open
impeller

Semiopen
impeller

Closed
impeller

**Figure 12–35**   Hydraulic motor-powered centrifugal chopper pump (*Photo and drawing courtesy of Liquid Waste Technology*)
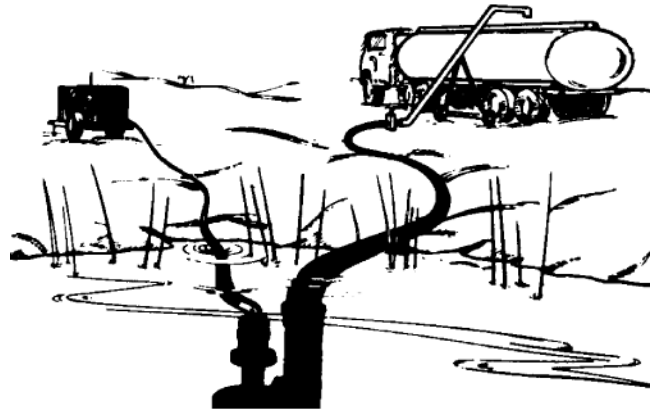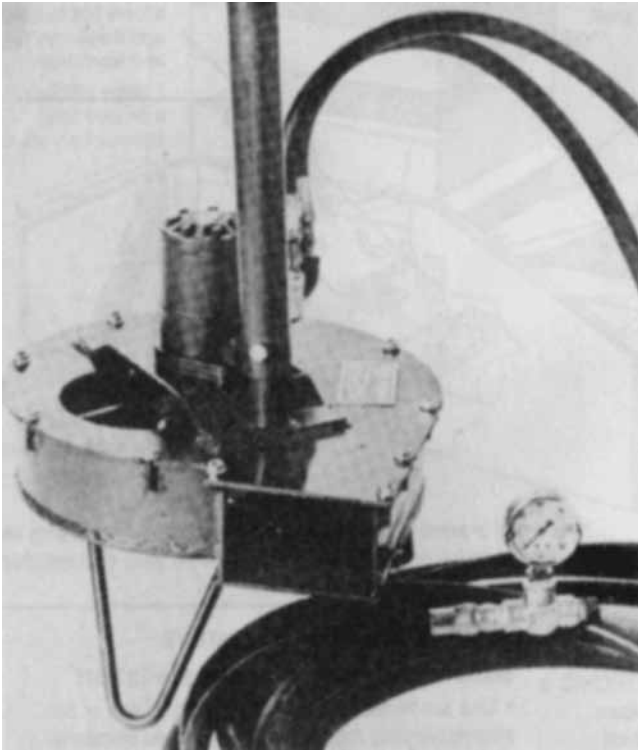
**Figure 12–36**    Submersible and vertical shaft transfer pumps *(Photos and drawing courtesy of GEA Houle, Inc.)*
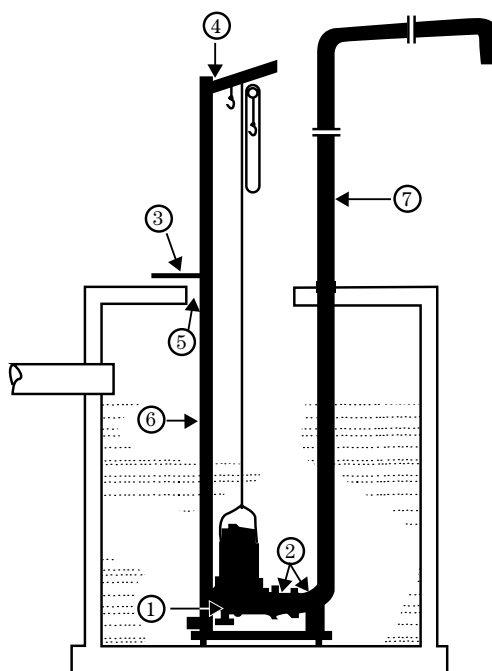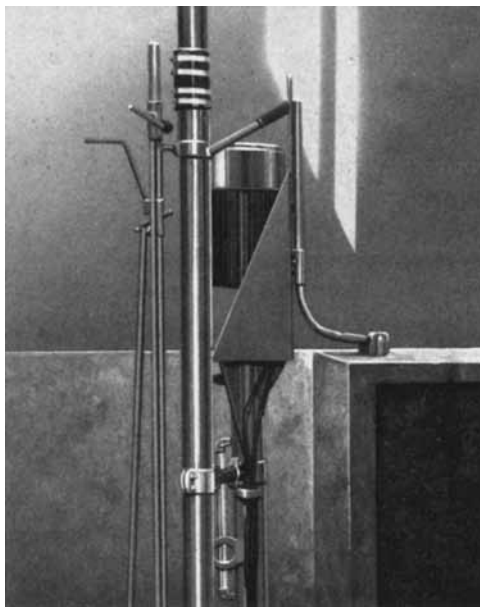


① Submersible electric pump with chopper blades to cut hair, bedding, and other manure solids

② Discharge nozzle and outflow pipe can be uncoupled by rotating control handle ③ at safety platform

③ Control handle

④ Lifting davit with portable chain hoist

⑤ Guide bracket bolted to safety platform or tank top

⑥ Guide bar controls pump position when coupling at ② or hoisting pump ①

⑦ Discharge pipe

The submersible pump is designed and constructed, usually with an electric motor, as a complete water-proof unit to be immersed in the liquid to be pumped. This design makes it self-priming. An automatic on-off float-control switch can be an integral part of the pump unit.

Typically, a submersible centrifugal pump is used to transfer 50 to about 200 gallons per minute of liquid or slurry waste from a sump to a reception tank, solids separator, or lagoon, or to recirculate lagoon water (see ch. 9 of this handbook). Larger models are available. Those that are powered by a hydraulic motor can pump up to 3,000 gallons per minute (fig. 12–34) at high pressures if they are designed and constructed with an enclosed impeller. This equipment is higher cost than the smaller models, but is simpler to use, is portable, and the speed can be readily varied.

A second type transfer pump, used with reception storage, has a 4- to 8-foot-long vertical shaft to the impeller. The motor is above the waste level, and the centrifugal pump is immersed and self-priming (fig. 12–36). Although this pump costs more than the submersible type, the power supply and service are simpler and less messy. However, the motor should be protected from excessive splashing when loading the sump with manure. Models are available that use 0.5 to 40 horsepower motors and have a capacity of up to 2,500 gallons per minute (gal/min) at zero discharge pressure. At least one manufacturer makes a transfer pump with twin 15 to 30 horsepower motors pumping up to 2,200 gallons per minute under low head conditions.

**(ii) Chopper-agitator pump**
The vertical shaft and inclined shaft chopper-agitator pump typically employs a 10- to 20-inch-diameter semi-enclosed impeller. This impeller has a relatively wide clearance, which helps to avoid plugging. See section 651.1205(b) for more details.

Generally, a chopper-agitator pump impeller is individually welded and steel plated. Its bearings and seals are relatively rugged and simple in their design. The impeller runs at relatively low speeds at high volumes and low head.

Although a hot-dipped galvanized coating is more durable, most chopper-agitator pumps are painted. Pumps in various sizes and capacities can pump up

to 4,000 gallons per minute of waste when new. The pumps require 15- to 140-horsepower motors. Some models work to a depth of 12 feet. Most pumps are tractor power take-off (PTO) powered; some use electric or hydraulic motors. PTO power is less investment, but straight shaft alignment is important for smooth operation and minimum power train wear. Trailer tow models are simpler to hitch, move, and park in place. The 3-point hitch models use less space and cost less.

**(iii) High pressure and capacity**
Centrifugal pumps with a horizontal power shaft and closed impeller are available. These pumps are engineered with close tolerances, securely sealed bearings, balanced power shafts, and other features for sustained operation at high rpm's, pressure, and throughput.

Impeller end thrust is high with all the severe operating conditions experienced by operations pumping several million gallons per year. The end thrust forces waste past the seals and into bearings. High-capacity pumps are used for liquid and slurry waste agitation and pumped waste spreading. The 80 to 150 horsepower needed for more than 100 pounds per square inch pressure and 500 to 1,000 gallons per minute throughput is provided by a stationary engine, electric motor, or tractor PTO. A separate primer pump is needed on these models to execute pumping startup. Two such pumps may be used in tandem to overcome pressures in pumping waste several miles via pipeline to a towed injector field spreader or irrigator.

The diaphragm pump (fig. 12–37) is commonly used by custom operators that pump or haul sewage sludge where performance is more important than high capacity. It is also used as a hand-operated primer pump with a high-capacity centrifugal pump. It is a low-capacity (generally less than 300 gal/min) positive displacement pump. It consists of a flexible membrane that moves up and down and intake and discharge check valves. Another common use for this type pump is for an automobile fuel pump and operates similar to the piston in an internal combustion engine. It can operate dry and be relatively trouble free with liquid and slurry wastes.

**(iv) Helical rotor**
A helical rotor, or rotary screw, pump (fig. 12–38) can pump liquid, slurry, and semisolid wastes at pres-

**Figure 12–37** Diaphragm pump (*Photo and drawing courtesy of Protek Specialty Co.*)





sures of up to 450 pounds per square inch. The pump is powered by a PTO or electric motor, so the operation is smooth and quiet. Sand, stones, and the metal hardware, however, prematurely wear out the composition material of the pump chamber. This chamber wear causes leakage that destroys the high positive displacement capability of the pump. Helical rotor pumps are used for slurry waste irrigation pumping. Some models can move up to 300 gallons of waste per minute at 150 pounds per square inch using a 50 horsepower motor.

**(2) Air-pressure and vacuum waste pumping**

An air-pressure (pneumatic) operated semisolid and slurry waste pump uses a well-constructed below-ground collection or holding tank that can be closed and pressurized with compressed air (fig. 12–39). Most tanks are constructed of steel or poured-in-place reinforced concrete. Wastes are scraped into the 1,300-
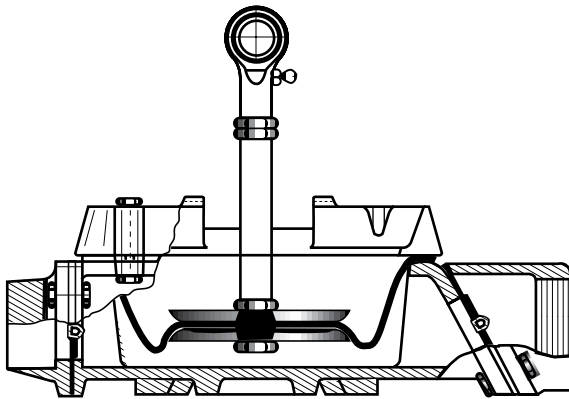
**Figure 12–38** Helical rotor pump
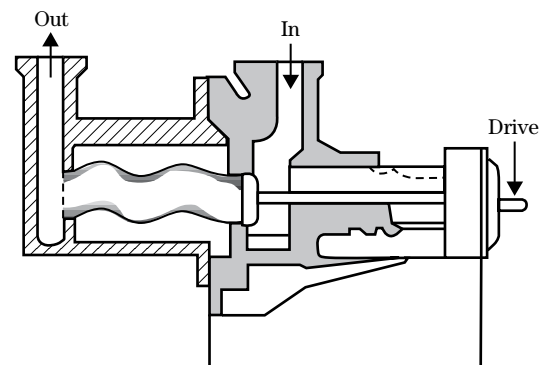
to 1,900-gallon tank through the top opening. When nearly filled, the top is covered and compressed air let into the tank to about 50 pounds per square inch pressure. As pressure increases, the contained waste is forced out past a valve that prevents backflow from the storage. The waste moves under pressure through a 2- to 2.5-foot-diameter steel pipe to storage. At least 3 horsepower of energy is needed to operate the air compressor—a larger compressor speeds airflow.

Although the investment for this type of equipment is relatively high, operating cost is low. Solid waste and freezing can restrict flow, and sand and excess soil in the waste can settle out and buildup in the pipe that leads to the storage tank.

Vacuum rather than air pressure is widely used for handling agricultural wastes. A PTO or hydraulic motor-powered vacuum pump mounted on or inside a tanker spreader agitates and empties a slurry or liquid waste storage. The waste is agitated by simply emptying the loaded tanker back into the storage. The vacuum loaded waste is hauled and field spread with the one unit. Sections 651.1206(b) and 651.1207(a)(3) give further information.

Vacuum pumps are available in varied designs and capacities. Comparable to pumps used for liquids, vac-

uum pumps are rated in cubic feet per minute airflow at different negative pressure (vacuum) levels. The rotary vane type can quickly evacuate a large volume of air with reasonable power—about 10 horsepower per 100 cubic feet per minute down to about 15 inches mercury (or –7.5 psi) of vacuum.

Blower-type vacuum is popular for collecting loose, dry solids where high flow vacuums of less than 10 inches are needed. Applications range from the household carpet vacuum to self-propelled street equipment. Household models simply filter out solids from the air flow. Larger capacity equipment can move the airflow through a cyclone separator where the air escapes out the top and solids drop out the bottom. Models used with agricultural waste collection include those made for a garden or lawn tractor to high-capacity, truck-mounted equipment. Their power needs range from 5 to 50 horsepower with capacity from 50 to 5,000 pounds per hour.

Although this type vacuum is noisy and relatively inefficient, the vacuum waste collection and handling is relatively clean. Screening and sorting of the accumulated waste may be needed depending on its ultimate use.

**Figure 12–39**  Air pressure chamber (pneumatic) waste pump (*Drawing courtesy of GEA Houle, Inc.*)
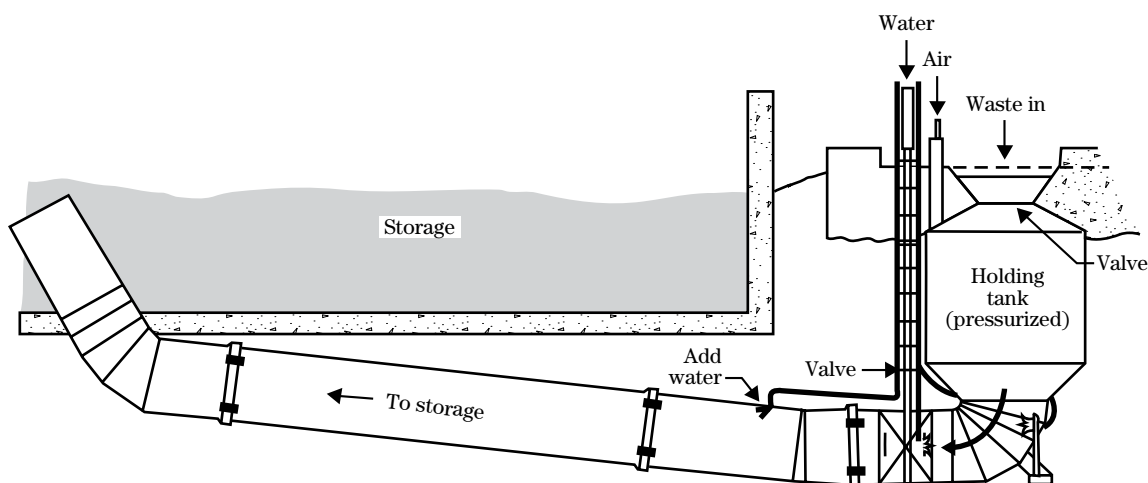
## (3)  Piston-plunger pumps

Piston pumps have been developed to convey slurry, semisolid, and solid waste from a gutter cleaner or reception storage hopper to long-term storage (fig. 12–40; also see ch. 9 of this handbook). The relatively large hopper inlet opening, piston size, and slow operation assist semisolid waste flow. An electric motor-powered mechanical pumpjack or 2-way reversing hydraulic cylinder is used to drive the piston plunger. The positive displacement piston develops high force and moves waste through an 8- to 16-inch-diameter pipe up to 300 feet away. The pipe is generally buried below frostline. Cast iron, steel, or PVC pipe are used depending on pump type and distance. Pipe jointing technique and correct pipe installation are critical. Pump chamber pressures may exceed 100 pounds per square inch, and pipe anchorage must be secure, especially at sharp corners. A pressure relief valve can malfunction, so PVC pipe failure, puncture, collapse, or plugging can be troublesome. This is especially true with solid waste, too-dry waste that expands in the pipe between pumping times, or where the waste is pumped more than 150 feet. A central location permits one piston pump to receive waste from several gutters, alleys, or buildings. Provision is usually made to add water to the waste flowing into the piston chamber. This dilutes waste and aids pipe lubrication. One scheme is to collect gray or other washwater in a sump or tank, then pump or drain this into the waste hopper when the piston pump is operating.

The vertical operated piston pump employs an automatic controlled hydraulic piston that moves up and down through a 3- to 4-foot stroke. It does 1.5 strokes per minute, which can move 60 to 70 gallons per minute of slurry waste (fig. 12–40). A tight-fitting, flexible, lubricated seal around the vertical piston causes it to draw semisolid waste by suction from the fill hopper into the piston chamber. Waste that is solidified, such as frozen chunks or straw, will not flow into the piston chamber. A rounded, smooth hopper is helpful in these situations. A belowground basement, about 7 square feet, is used for the hydraulic pump and fill hopper. It also can be used for maintenance and repair. Although the basement is an extra investment, it frees up space on the main floor.

**Figure 12–40**    Vertical piston plunger waste pump with a pipe anchor (*Drawing courtesy of Berg Equipment Co.*)
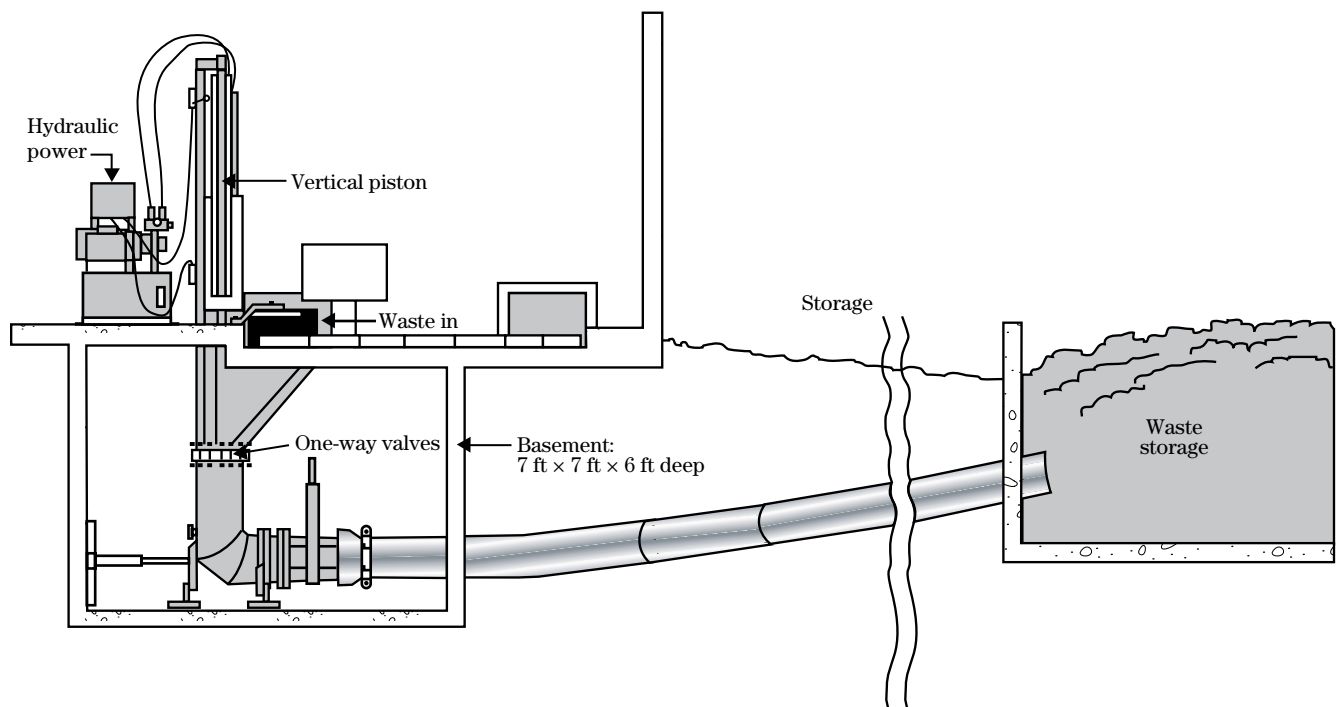
The slant operated piston pump (see ch. 9 of this handbook) uses a hollow piston that is about a 10- by 14-inch rectangle. Slurry waste that is scraped into a floor-level filling hopper flows through the flap valve face of the hollow piston on its return stroke. The flow is caused by gravity. Semisolid waste flow to the piston is aided by gravity via the slanted piston chamber. The piston flap valve closes at the beginning of the next stroke. This forces the waste into and out the discharge pipe. Powered by up to a 15-horsepower electric motor, the mechanical drive pushes waste through the discharge pipe to storage up to 200 feet away. Stroke length is typically 11 to 18 inches. The piston operates at about 25 to 45 strokes per minute, so the potential capacity is about 375 gallons per minute.

This pump is simple to install and maintain; however, it tends to misalign from continuous, high-pressure operation unless correctly installed and anchored. Long straw may plug in the piston valve or the hollow piston.

The horizontal operated piston pump is installed at the bottom of a 6-foot by 12-foot by up to a 10-foot deep basement (see ch. 9 of this handbook). An automatically controlled, hydraulic-powered, solid-faced piston is located in a cylinder at the bottom of a floor level hopper. The piston is about 10 inches in diameter and has a 3-foot stroke. The cylinder fills with semisolid waste that sinks down through the hopper and is drawn in front of the solid piston with the return stoke. On the forward stroke, the waste is pushed out of the cylinder into the discharge pipe past a spring-loaded check valve. On the return stroke, the piston again is pulled completely through the cylinder and past the fill hopper. The spring-loaded check valve prevents waste from flowing back out of the discharge pipe, and the piston suction helps gravity fill the cylinder with waste from the hopper. Operating speed is about 2 to 4 strokes per minute, with a potential pumping capacity of 100 gallons per minute. The relatively slow operation assists the piston return suction (with gravity) to better fill the cylinder with waste.

While PTO-powered pumps are frequently used to transfer manure from a storage facility to a manure spreader or other type of applicator, they are also commonly used for agitation of the manure prior to utilization. As such, they have not been specifically covered in this section. They are covered in more detail in section 651.1205.

# 651.1205    Waste storage equipment

The primary concerns about waste storage include pollution prevention, capacity, cost, durability, nutrient retention, safety, in-use appearance, odors, and expansion. Equipment used with stored waste can be an integral part of the storage (e.g., drive ramp access). The success of equipment use can directly affect how well the storage does its job. Also, some storage equipment use has related alternatives and additional considerations, such as a chopper-agitator pump. Associated equipment, such as loading and unloading access, personnel ladders, covers, and seepage control, is reviewed in this section. Chapters 10 and 13 of this handbook give further information on these concerns.

General selection and design information about waste storage is explained in chapter 10 of this handbook. Additional information about location and management is in chapters 7 and 9. Also, see CPS Code 313, Waste Storage Facility and Code 359, Waste Treatment Lagoon. The ASABE Engineering Practices ASAE 393.3, Manure Storages, and 403.3, Design of Anaerobic Lagoons for Animal Waste Management, include design aspects about storage and related waste equipment (ASAE [l] 1998, ASAE [n] 1998).

## (a)   Storage interior accessing

A paved ramp (see ch. 8 of this handbook) is used for clean out and service access to waste storages. A paved ramp may also be appropriate for structural storage facilities. A corner location takes advantage of the existing minimum slope for installation. Ramp thawing or drying and operating visibility are aided if the ramp is located to receive the maximum exposure of the midday sun.

An access ladder is needed for storage structures that have vertical walls. It is used to observe filling, agitating, and pumping operations and to do periodic maintenance. Safety precautions for ladder construction, anchorage, and access by strangers or children are a must. ASAE Standard S412.1, Ladders, Cages, Walkways and Stairs, explains design and installation recommendations (ASAE [o] 1990 (R2008)). Briefly, the recommendations are:

- Space 16-inch-wide rungs a maximum of 1 foot apart.

- Allow 7 inches of toe space in front of rungs.

- Use a 27- to 30-inch cage clearance about the ladder.

- Provide work landing platform access.

A waste storage ladder location in plain view by others is preferable. A portable ladder stored away from the waste storage can help deter unauthorized access (see chs. 9 and 10 of this handbook). When in use, the portable ladder should be securely attached to the storage structure to prevent it from falling away and stranding the user. A ladder permanently attached to a storage structure needs to terminate beyond ordinary reach or an entry guard or gate must be used. The attached ladder should terminate at a height of more than 8 feet above the ground. A sunlit location for the ladder helps to quickly dry the ladder and is naturally well lighted.

A ladder permanently located inside a waste storage structure obstructs cleaning. It will also corrode and become unsafe as its deterioration is hidden by waste and poor light. A portable ladder, removed and stored when not in use, is a better alternative.

A stored waste depth marker helps to estimate remaining storage capacity, sludge buildup, and other such problems. The marker should be highly visible. It can be a treated 2 by 4 that is painted white and has footage numbers in red. The marker should be securely located in plain view at the edge of the storage and may need to be periodically cleaned to be visible.

Warning and safety signs and related safety equipment recommended for use with waste management equipment are reviewed in section 651.1208.

**Warning: Various gases can be released in volume or otherwise be contained when agitating and pumping wastes in an enclosed space. The displacement of oxygen and/or accumulation of hydrogen sulfide or carbon monoxide is dangerous/fatal. Persons have died after entering an enclosed tanker, storage tank, or waste handling space.**

## (b)  Storage exterior accessing

Waste storage agitation and emptying equipment needs overhead clearance and turning space access (see chs. 9 and 10 of this handbook).

**Example:**

A vertical wall, belowground, semisolid/slurry storage structure that is up to about a 60 feet across and 12 feet deep can be agitated and pumped from one pump station using the same centrifugal-chopper pump used for filling the storage. A circular storage shape agitates in less time and encloses more storage capacity than does an equal perimeter length of a rectangle or other storage shape—everything else being equal.

Tables 12–5a and 12–5b can be used for estimating comparative sizes. For example, to store 21,600 cubic feet of waste would require a storage structure that is a 24- by 100-foot rectangle 10 feet deep (including 1-ft freeboard) or a circular unit that is 52.5 feet in diameter and 10 feet deep (plus 1-ft freeboard for a total depth of 11 ft).

Additional access space or larger agitation equipment is needed for larger storages, especially for semisolid waste. An impeller-type agitator (covered later in more detail; also see ch. 10 of this handbook), centrifugal-chopper pump, and several agitation pump docks or ramps (see ch. 10) are usually needed with large (>100-foot-long) rectangular storage structures.

A straight-line operation for the tractor PTO pump power shaft reduces U-joint wear and fluctuation of speed (fig. 12–41). A level operating area may be needed for gravity lubrication of agitation and pumping equipment.

One of two arrangements is typically used for aboveground storage agitation. One uses a horizontal shaft, centrifugal, chopper-agitator pump mounted on the waste storage tank near the foundation (fig. 12–41). A valve is opened in the storage drainpipe. The pump is then operated to draw waste from the bottom of the storage and pump it up and over the wall and around the top of the storage to agitate the storage contents. This is the only agitation access unless one

**Table 12–5**   Approximate capacities in cubic feet of storage

(a) Rectangular storage (10-ft-long tank)

| Width (ft) | Depth (ft)* | | | | |
|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 |
| 4 | 120 | 200 | 280 | 360 | 440 |
| 6 | 180 | 300 | 420 | 540 | 660 |
| 8 | 240 | 400 | 560 | 720 | 880 |
| 10 | 300 | 500 | 700 | 900 | 1,100 |
| 12 | 360 | 600 | 840 | 1,080 | 1,320 |
| 16 | 480 | 800 | 1,120 | 1,440 | 1,760 |
| 20 | 600 | 1,000 | 1,400 | 1,800 | 2,200 |
| 24 | 720 | 1,200 | 1,680 | 2,160 | 2,640 |

*Allows 1-ft top freeboard

(b) Circular storage (per 1-ft depth)

| Diameter (ft) | Depth* (ft³/ft) |
|---|---|
| 20 | 314 |
| 30 | 707 |
| 40 | 1,257 |
| 50 | 1,963 |
| 60 | 2,827 |
| 70 | 3,848 |
| 80 | 5,026 |
| 90 | 6,358 |
| 100 | 7,850 |

*No freeboard

**Figure 12–41**   Horizontal shaft chopper-agitation pump (*Photo courtesy of Wieser Concrete Products, Inc.*)



or more impeller-agitators are mounted on the inside wall of the storage. In most cases, provision is made for adding dilution water near agitators for mixing of semisolid waste. After agitation, the pumpout valve is switched from agitation, and the pump is used to fill a nearby tanker spreader or to supply an irrigator for more liquid slurry.

The second typical aboveground tank unloading arrangement uses a nearby belowground reception tank. In most cases, this tank is the same one used for waste collection and for top filling the storage (fig. 12–42). To agitate or pump, a valve is opened in the aboveground storage drainpipe so waste drains into the reception pit. A vertical shaft, chopper agitation-type pump, operated in the reception pit, pumps waste up over the wall and top of the tank for agitation, or the pump valve is switched to fill a tanker or supply an irrigator. This second arrangement demands closer attention than that required by the first arrangement during agitation or unloading to assure the reception pit does not overflow. If the reception pit is located within the animal housing facility or other structure, it is important that all animals be removed during agitation and the building thoroughly ventilated to avoid asphyxiation of animals or humans.

A second safety valve in the storage drain is used to ensure against unload valve failure with any storage that is above an open gravity drain. Such accidental draining protection is needed (12–42); also see chapter 9 of this handbook. Local regulations may require a secondary containment dike around an aboveground storage similar to those used for aboveground chemical or petroleum containment. Pumping access, sunlight drying and heating, snow accumulation, and prevailing winds should be considered in locating an agitation station. Agitation and pumping openings for below ground storage need to be sized, spaced, and located to provide agitation access to tank contents, especially corners. A pump sump permits complete emptying of stored waste when desired.

**Figure 12–42**     Reception storage or pumping and aboveground storage (MWPS 1985)
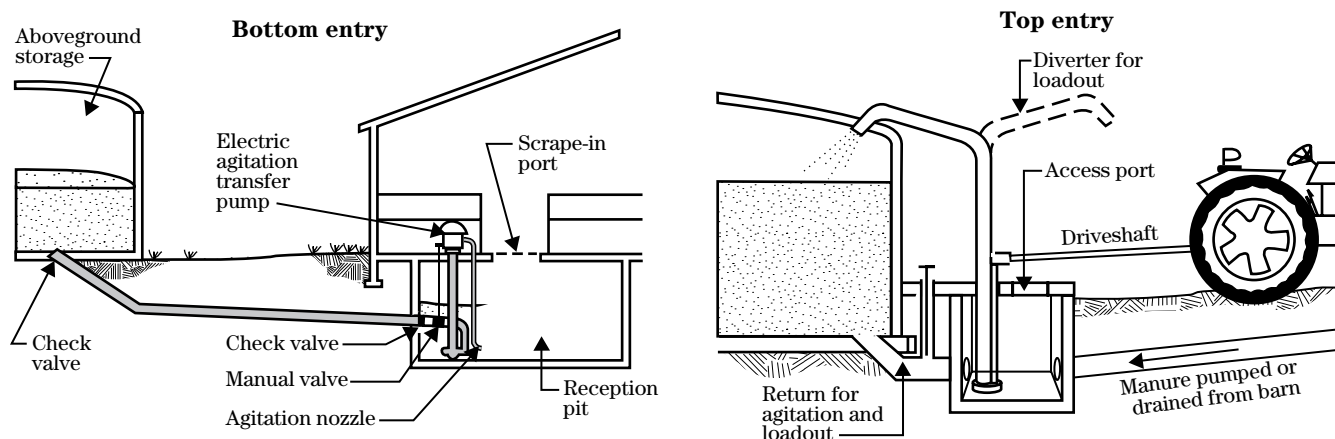


## (c) Storage fencing with gates

A fence with locked gate entry is often used with an earthen basin and other open-top waste storage to control access by people and livestock. See CPS Code 382, Fencing, and chapters 8 and 10 of this handbook for more information. The type of fence should be commensurate with the hazard imposed by the facility.

## (d) Covers, drainage, and runoff control

Covers are placed on manure storage/treatment facilities for several purposes including: odor and air emissions control, rainfall exclusion, and biogas (methane) capture. Permeable covers consist of materials such as straw, light weight expanded clay aggregate (LECA), ground rubber, and geotextile materials and are used primarily for odor control and reduction of air emissions. Impermeable covers may consist of rigid materials such as clear span truss-type rafters, arch rafters or similar traditional roof materials or flexible materials such as high density polyethylene (HDPE) or ethylene propylene diene monomer (EPDM) rubber. Rigid cover materials are typically used on solid manure storage facilities such as poultry litter stacking sheds or dairy stanchion barn manure where high amounts of bedding are used. The primary purpose is to keep the manure dry enough to handle as a solid by excluding rainwater. Interior deterioration of construction materials is a consideration. Pressure preservative treated wood, exterior grade plywood, corrugated asphalt

fiberboard, plastic, fiber glass, and stainless steel are construction alternatives.

Experience indicates that float-supported fabric sheeting, laid onto a holding pond surface and weighted in-place, can be used to collect gas and suppress odor (Melvin and Crammond 1980). Figure 12–43 shows a fabric membrane cover for open-top storage using a float log and weight system. Another alternative for a floating cover is to use closed-cell flotation as shown in figure 12–44. Although lightweight fabric sheeting costs less, the wind can loosen, wear, and blow off a lightweight cover easier than heavier or more permanent covers. Also, accumulated rain and snow on the cover must be accommodated. A cover manufacturer should be consulted on floating plastic cover design and installation (Safley and Lusk 1991).

Barley, oats, durum wheat, and flax straws can be shredded and blown onto a storage's liquid surface using a straw spreader designed for spreading straw along new roadways. Straw is blown directly onto the liquid surface. A 6- to 10-inch-thick layer of good quality barley straw appears to be the most effective material for an unsupported cover. Under a relatively dry climate, one to two applications of this straw will effectively reduce odor for an entire season.

A 1-inch-thick polystyrene float supports a straw cover and keeps it dry for nearly the entire season with excellent odor reduction. The straw/float cover settles

to the bottom as the liquid is pumped out. It can be mixed in with the stored slurry waste and field spread.

The Prairie Agricultural Machinery Institute developed a straw cannon that can blow straw out to 180 feet and discharge a 1,500-pound round bale in about 1.5 minutes (Grainews 1994). Straw mixed with polystyrene pellets enclosed in burlap has also been used as storage pond cover in the Pacific Northwest. Odors were greatly reduced, and the cover can be mixed with the pond contents.

**Figure 12–43**   Fabric membrane cover for open-top storage (Adapted from Safley and Lusk 1991)



**Plan view**

**Section**
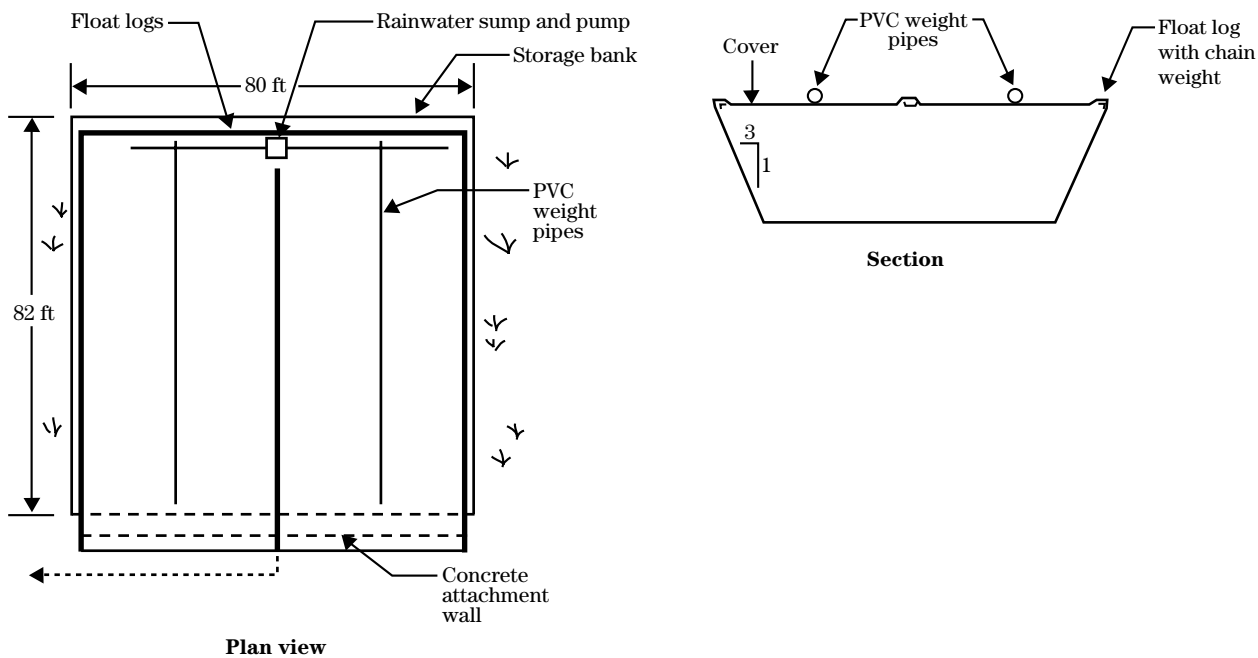
**Figure 12–44**   Closed-cell floating cover (Nicolai and Pohl 2004)

A comparison of cover materials is shown in table 12–6 (Nicolai, Pohl, and Schmidt 2004)

The picket dam or vertical slot wall is used to retain solids while permitting water to run off the waste stacked in an uncovered, ground-level, solid or semi-solid waste storage structure (fig. 12–45). A picket dam is normally considered a component of the transfer function of a waste management system. It is described here, however, because it is an alternative to roofing a stacking facility.

Picket dams are designed to allow runoff from the pile surface at any height within the range allowed by the stacking facility. The dam utilizes vertical slots because they drain and clean better than horizontal slots. The picket dam is located so that a clear drainage path is always away from the face (leading edge) of the pile. Drainage water that exits the dam is collected and transferred to a liquid waste storage facility. Table 12–7 gives construction information for picket dams.

A 6-inch-thick layer of corn cobs on the floor permits seepage from piled semisolid dairy waste to flow to drains in the concrete floor of a rectangular wooden wall waste storage (Barquest et al. 1974).

A perforated riser pipe and/or screened drain is used for runoff and piled waste seepage control (fig. 12–46). PVC plastic or steel culvert with 1- by 4-inch slots are typical. The riser pipe diameter and number of slots needs to match the expected flow rate and the required area of expanded metal screen or spaced-plank flow restrictor required. See CPS Code 587, Structure for Water Control for more information.

**Table 12–6**   Comparison of cover material (Nicolai, Pohl, and Schmidt 2004)

| Type of cover | Material | Effectiveness (%) | | | Life expectancy | Capital cost (US\$/yd$^2$) | Reference |
| | | Odor | $H_2S$ | $NH_3$ | | | |
|---|---|---|---|---|---|---|---|
| Impermeable | Concrete lid | 95 | N/A | N/A | 10-15 years | N/A | 1 |
| | Wood lid | 95 | N/A | 95 | 10-15 years | N/A | 1,2,3 |
| | Inflatable plastic | 95 | 95 | 95 | 10 years | 7-15 | 1,4 |
| | Floating plastic (HDPE) | 60-78 | 90 | N/A | 10 years | 3-5 | 5 |
| Permeable | Straw | 40-90 | 80-94 | 25-85 | Up to 6 months | 0.25-1 | 1,5,6,7,8,9 |
| | Geotextile | 40-65 | 30-90 | 0 | 3-5 years | 1.25-1.6 | 9 |
| | Geotextile + straw | 50-80 | 60-98 | 8-85 | N/A | 1.5-2.6 | 9 |
| | Leca® | 90 | N/A | 65-95 | 10 years | 15.45 | 3,7 |
| | Macrolite® | 60 | 64-84 | N/A | 10 years | 15.45 | 5 |
| References | *1 Mannebeck, 1985* | *4 Zhang and Gaakeer, 1996* | | | *7 Bundy et al., 1997* | | |
| | *2 DeBode, 1991* | *5 Clanton et al., 1999* | | | *8 Jacobson, 1998* | | |
| | *3 Sommer et al., 1993* | *6 Anonymous, 1993* | | | *9 Clanton et al., 2001* | | |

**Figure 12–45**    Picket dam for open-top storage drainage (MWPS 1985)
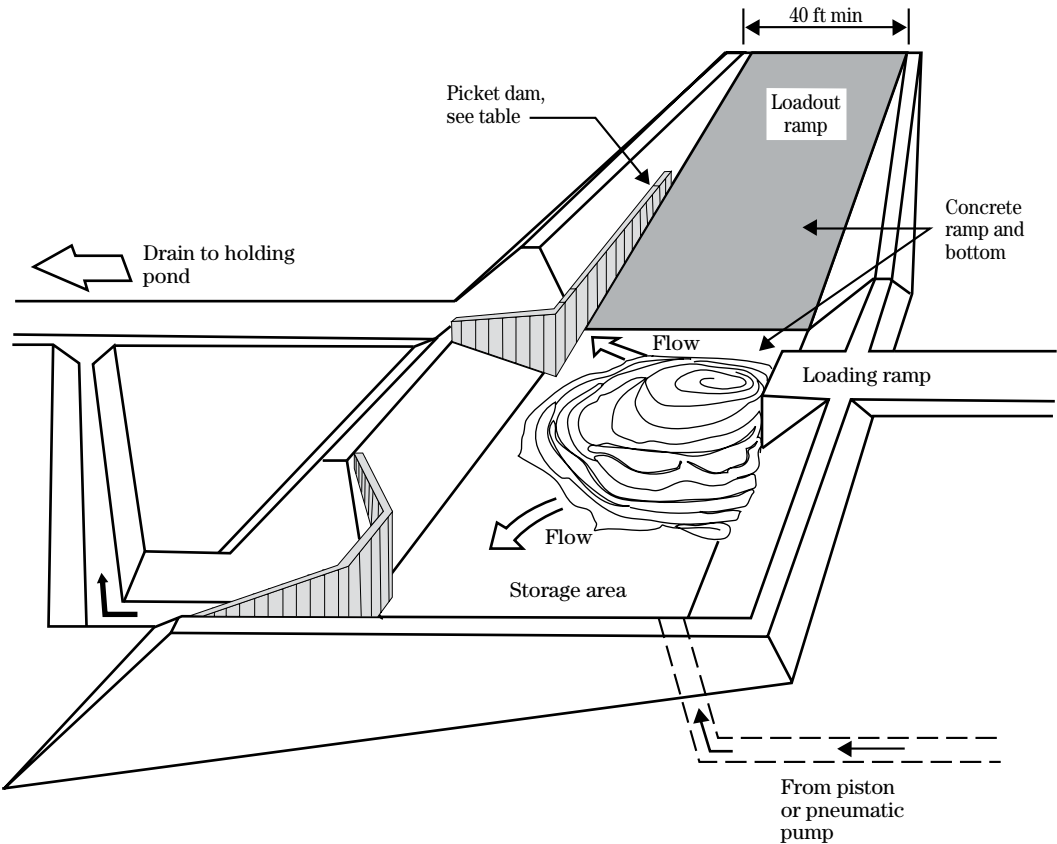


**Table 12–7**    Picket dam construction (MWPS 1985)



| - - - - - - - Posts - - - - - - | | | - - - - - - - Horizontal support - - - - - - - - | | |
| --- | --- | --- | --- | --- | --- |
| | | | **Distance from picket top** | **Size** | **Spacing** |
| **(ft)** | **(in)** | **(ft)** | **(ft)** | **(in)** | **(ft)** |
| 0–4 | 4 by 6 | 5 | 0–4 | 4 by 4 | 3 |
| 5 | 6 by 6 | 4 | 4–6 | 4 by 4 | 2.5 |
| 6 | 6 by 8 | 4 | 6–8 | 4 by 4 | 2 |
| 7 | 8 by 8 | 3 | — | — | — |
| 20 | | | 600 | 1,000 | 1,400 |
| 24 | | | 720 | 1,200 | 1,680 |

\*  Pickets are pressure-preservative treated 2 ft by 6 ft. Posts and horizontal supports are rough-sawn timbers.
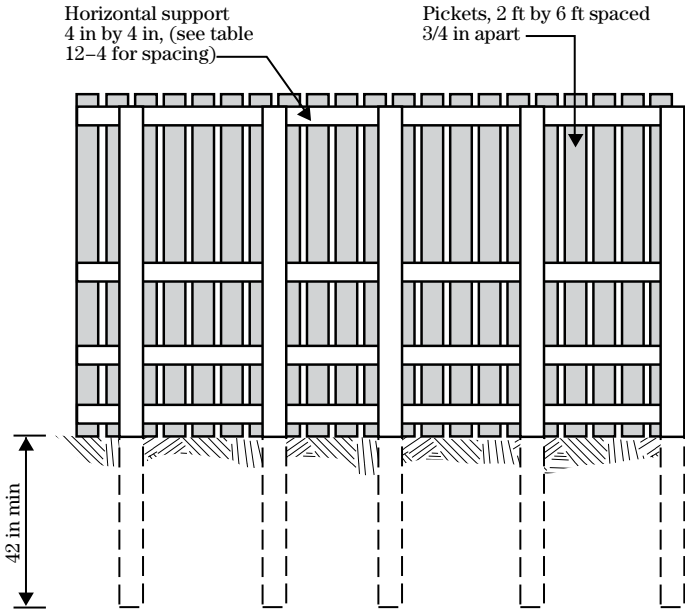
**Figure 12–46**    Perforated pipe runoff seepage outlet
(MWPS 1985)



and ASAE Engineering Practice 340.2, Installation of
Flexible Membrane Linings (ASAE [i] R2008) explain
criteria for different liners. The criteria include:

- availability

- size

- cost

- installation requirements

- durability for punctures, tears, ultraviolet light,
  and rodents and other pests

Safe access for agitation and pumping is needed to
prevent fabric liner damage. Higher demands are be-
ing made on liners as water quality concerns increase
and as liner materials are evaluated and developed for
earth basin agricultural waste storage, chemical con-
tainment, landfill use, and other applications.

A source of current industry information is Geosyn-
thetics Magazine published by the Industrial Fabrics
Association International. Each year, the December/
January issue contains a Specifiers Guide that explains
current information about products and services avail-
able. Figure 12–47 shows a membrane liner.

The NRCS has completed a study about seepage from
earthen storage ponds and waste treatment lagoons
(Moffitt 1993). A part of the study was to determine
the seepage conditions, and another part was to mea-
sure the extent of seepage. One promising technique
is the electromagnetic terrain conductivity meter
(EM–34) that senses the added electrical conductivity
resulting from increase in ion concentrations that may
be caused by waste impoundment seepage. The EM
measurement information can be used along with that
from monitoring wells and soil borings. The Geonics
EM 39TM and companion tool, the natural gamma
probe, measure the incremental conductivity in a bore-
hole. They can indicate if the conductivity anomalies
are in materials that are likely to transmit fluids.

## (e) Storage seepage detection and control

Any earthen waste storage has some seepage or leak-
age (McElroy, et al. 1993). The quality of storage
construction is a major factor affecting the quantity
of seepage. Weak spots or holes in a soil liner, cracks
in concrete, poor joints in wood planking or metal
sheets, and soil or foundation shifting from frost or
moisture changes cause leaks to develop. The small
fines in waste seal soil passages around and below the
storage; however, this may not suffice as the only seal-
ing mechanism because of long-term unknowns, such
as soil movement and repeated surface dryout after
emptying. Compacted soil liners are practical unless
haul distance for suitable soil is prohibitive. These
liners and related expansive clay liners have long been
used for pond water storage. However, aggressive agi-
tation and frequent emptying and filling, makes it dif-
ficult to maintain the integrity of the liner. Reinforced
concrete pumping/agitation pads or plastic-net soil
stabilizer systems used with crushed rock at agitation
sites can protect against this problem. Chapter 10, ap-
pendix 10D, of this handbook gives more information
on clay liners and soil amendments.

Chapter 7 of this handbook describes liquid move-
ment through soil. Because of groundwater quality
concerns, a special lining may be required to assure
leakage is held to acceptable limits. Different kinds
and qualities of liners are used with earthen basin
waste storage. CPS Code 521, Pond Sealing or Lining,

**Figure 12–47** Membrane liner installation for earthen basin (*Photo and drawing courtesy of Hoechst Celanese Corp.*)
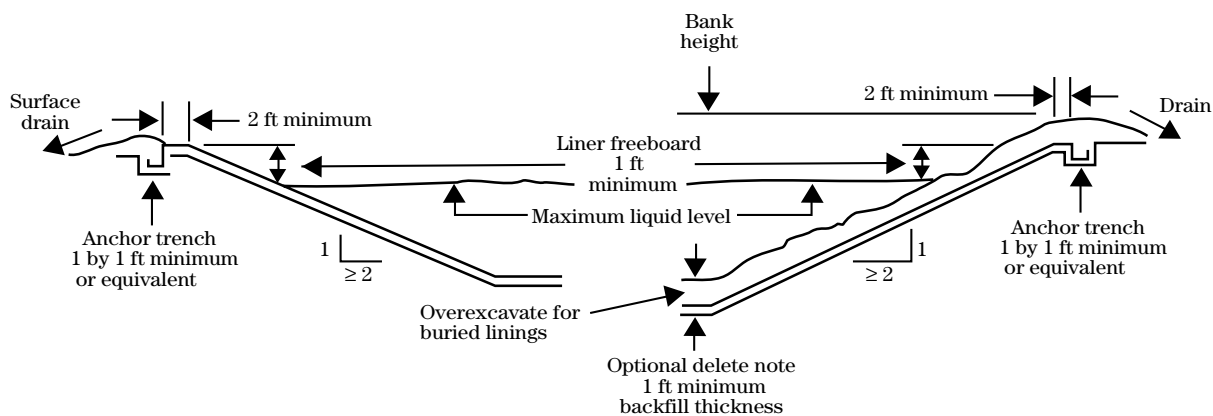
# 651.1206    Waste treatment equipment

A description of the waste treatment function is given in chapter 9 of this handbook. Chapter 10 provides detailed descriptions of several different types of treatment systems, which include use of a wide array of equipment, much of which has been adapted from municipal waste treatment processes. As utilization alternatives or additions to land application are pursued, existing equipment will evolve and new equipment will be developed. As such, it is not the intent of this chapter to provide a comprehensive description of individual pieces of equipment that may be used in a given process, but rather to cover broad categories of equipment that may be used in multiple types of treatment processes and systems. Those categories are: particle size reduction equipment; agitators and mixers; aerators; separators; and dehydrators, incinerators, and gasifiers. Some treatment equipment, such as pumps and blowers, has been covered in previous sections of this chapter. Chemicals may be used to improve the performance of some of the equipment, such as separators, but they will not be covered here.

## (a)    Size reduction

Cutters and shredders are used in agricultural waste treatment primarily to reduce the size of relatively dry materials used for bulking agents in the composting process. Most of this equipment has been adapted from timbering operations. Grinders, sometimes also referred to as comminutors or macerators, are used for both dry and wet materials and are used in agricultural waste treatment primarily to reduce the size of particles in slurry waste to improve its pumping characteristics. Some grinders can also screen and remove solids. This equipment has been primarily developed in the municipal waste treatment sector.

Cutting, shredding, crushing, or grinding reduces the bulk and increases the flowability of relatively dry (>60% dry material) material, such as leaves, roughage, brush, paper, cardboard, cans, and bottles. Waste type, amount of use, power need, investment, noise, dust, and maintenance must be considered in selecting grinder and shredder equipment.

Cutting equipment pushes thin, sharp knives through a usually moist material to reduce its size into uniform pieces. Cutting, as such, results in minimum deformation and rupture of the reduced particles. Equipment with very sharp cutter blades and close tolerances is used with fruit and vegetable processing. Some chipper equipment use heavy knives mounted on a high-speed cylinder that rotates inside a housing. The high-speed cutter/grinder for processing slurry waste also uses this type equipment (fig. 12–48). Unless the blades and cutter bar edges are intensively maintained, cutting equipment performance is more a shearing/tearing action. If this happens, a crushing as well as cutting action occurs, which increases power need, slows throughput, and produces a ragged product.

Shearing is generally used to reduce the size of loose, bulky, tough fibrous material. Brush and some straw chopper equipment usually employ more shearing than cutting to reduce material size A belt-type shear shredder (fig. 12–49) uses a cleated belt operating in a hopper to force material against stationary knives. Material loaded into a receiver hopper feeds a conveyor that in turn drops it onto the cleated belt where it undergoes a continuous raking action to shred the load. Adjustable sweep fingers force oversized pieces back for further shredding while hard stones, metal, and glass are discharged through a trash chute. Engine-powered stationary or tow models are available. Power needs range from 7.5 to 500 horsepower with capacity from 5 to 50 tons per hour, depending on raw product moisture, density, and fineness.

The rotary shear shredder uses two counter-rotating shafts with overlapping hooked cutter discs (fig. 12–50). Cutters draw material down toward shafts at the base of a hopper. The cutters slice the chunks into small pieces until they pass through the spaces between the cutter discs. This process has been adapted to some wood chipper equipment. The piece size depends on cutter size and spacing.

As semisolid waste is forced through relatively close tolerances, it is slurried by chopper-agitation pump impeller (propeller) action during agitation and pumping. See section 651.1204(b)(1)(ii). Stationary knives are included on some models to assist rotating exposed cutter blades to cut twine and other tough fibers (fig. 12–51). The rotating blades also crush or break apart semisolid chunks as they are drawn into the pump impeller. Unless the impeller is plugged, the crushed ma-

**Figure 12–48**    Cutter-shredder for slurry waste (*Photos courtesy of Hydro Engineering, Inc.*)



**Figure 12–49**    Belt-type shear shredder (Rynk 1992)



Area in detail below

Belt shredding action

Adjustable discharge

Feed
conveyor

Cleated belt

**Figure 12–50**    Rotary shear shredder (Rynk 1992)



Hooked cutter discs on
counter rotating shafts
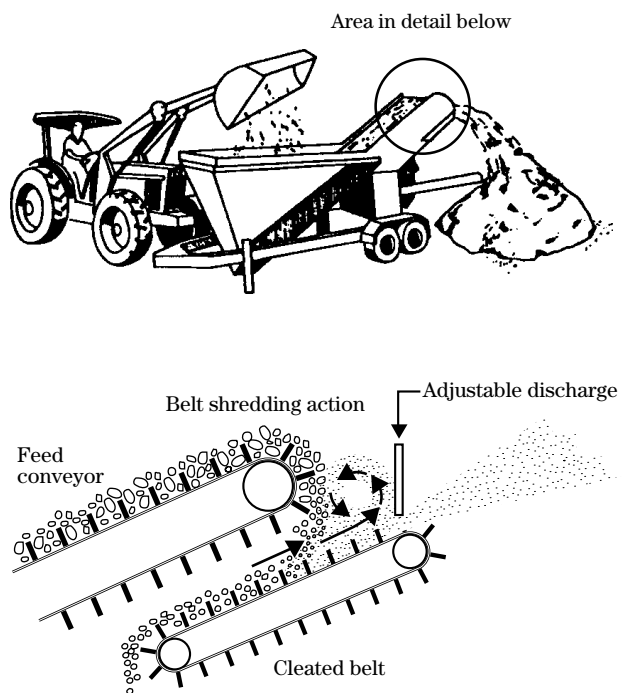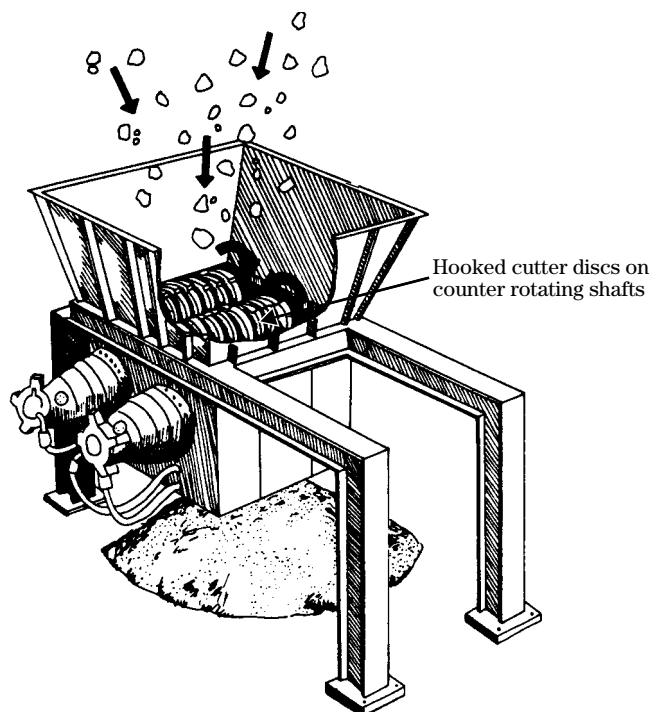
terial is then slurried. A common operator complaint is that twine and plastic wind onto the rotating cutter. Small stones, metal, or other foreign material quickly dulls cutting edges, so high maintenance is needed for satisfactory shearing performance.

The versatile hammermill grinder uses 20 to 50 short, free-swinging, hardened steel strap-irons mounted on a high-speed rotating shaft to hammer or crush solids through a surrounding, close-fitting perforated screen (fig. 12–52). Readily interchangeable screens, each with different-sized openings, are used to produce relatively uniform coarse to fine grinds. Fine grinding needs high power and a slow grinding rate as does higher moisture content (>15%) material. Different models of portable and stationary hammermills are available. These can require 5 to 550 horsepower and can coarse-grind up to 50 tons per hour of dry (≤15% moisture) waste.

Hammermill grinding increases the temperature of the material ground about 10 degrees Fahrenheit. It is increased more with fine grinding and higher moisture content materials. This increased temperature must be considered when the processed waste is stored.

Compared to the cutter and shredder treatment, power and maintenance needs are higher for a hammermill grinder, especially if stones or metal pieces are in the waste.

Widely used on farms to grind livestock feed, the portable grinder-mixer usually employs a 50- to 100-horsepower PTO-powered hammermill in conjunction with a vertical auger-type tank mixer. Larger, much heavier constructed models of this versatile equipment have been developed for high-rate processing of solid waste.

The tub-grinder (fig. 12–53) incorporates a hammermill-type grinder in the floor of the slowly rotating hopper or tub. As the tub rotates, it carries around the material dropped into it. This material eventually

**Figure 12–52**  High-capacity hammermill grinder (Rynk 1992)



Free-swing hammers on rotating shaft

**Figure 12–51**  Cutter blade on chopper-agitator pump (*Photo courtesy of Clay Equipment Corp.*)
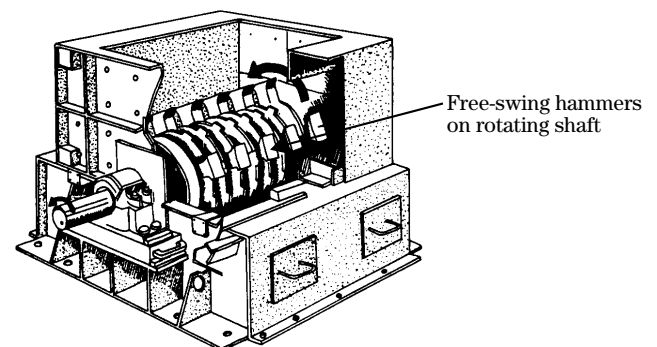


**Figure 12–53**  Large-capacity, engine-powered tub grinder (Rynk 1992)



Rotating tub hopper
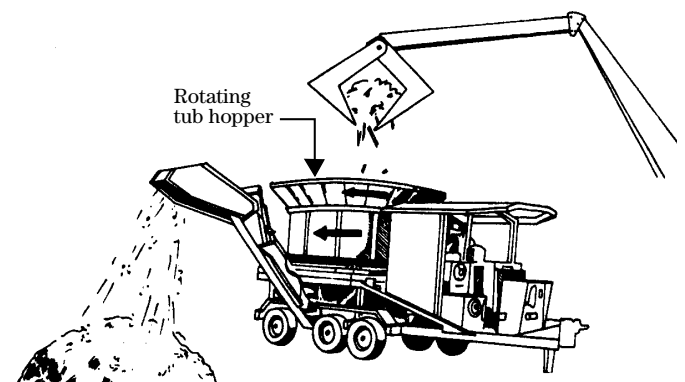
feeds into the hammermill, is ground, and falls into a conveyor below. Tub grinder models are available that require about 70 to 525 horsepower. The smaller models can be PTO-driven, and larger units are industrial diesel-engine powered. Different models employ an intake screen, feeder/hopper, crusher, and various conveyors for separated materials. This equipment can all be on one moveable chassis.

## (b) Agitators, stirrers, mixers

Agricultural wastes usually contain materials of different densities. These tend to separate out during handling, storage, and use, especially with the more slurry waste. Soil and other dense materials settle over time while straw, feathers, and other bulky materials float. Agitation equipment is used to remix the separated materials together for complete product handling, improved aeration, decomposition, and uniform nutrient distribution. Different agitation equipment is available. Selection depends on the waste moisture content, desired agitation capacity, investment, available power, and the waste use.

### (1) Semisolid and slurry waste agitators

Although useful with liquid waste, vacuum tanker agitation usually is insufficient with semisolid waste, especially where there is a surface crust. Chopper-agitator PTO-driven pumps are designed to agitate as well as pump semisolid waste (fig. 12–54). Such alternative equipment use helps reduce the total investment. This one-unit operation, however, may slow down loadout and spreading depending on how agitation progresses. During agitation a diverter valve on the pump outlet is manually set to return the pumped material back into stored waste via a hand operated nozzle that has vertical and horizontal adjustments. To agitate settled solids, a vertical shaft drive chopper-agitator pump usually recirculates and discharges through a nozzle below the stored waste surface. Some models have a second, higher discharge nozzle to agitate a surface crust and an open impeller (propeller) to further break up solids and mix the slurry (fig. 12–55).

Agitation nozzle location and adjustments can be critical, especially for agitating into storage corners. Most 50- to 80-horsepower chopper-agitator pumps can agitate out about 40 feet depending on nozzle design, pump wear, waste consistency, and storage shape. Several moves generally are used to agitate a large

**Figure 12–54**    Vertical shaft PTO-powered chopper-agitator pump (*Photo courtesy of DODA U.S.A., Inc.*)



**Figure 12–55**    Vertical shaft chopper-agitator pump with open-impeller agitator (*Photo courtesy of DODA U.S.A., Inc.*)

rectangular storage. See section 651.1204(b). Agitation and pumping docks are needed with large earthen basin storage to be agitated with a vertical shaft drive chopper-agitator pump. Vertical shaft pumps are most effective for use in relatively small in-ground structural storage facilities. Depending on the grade at the site and the distance from a pumping pit to the storage facility, agitation can be done by recirculating the manure from the storage to the reception pit where the pump is located.

For faster, more effective agitation over a larger area, the open impeller (propeller) agitator has evolved from the vertical shaft drive chopper-agitator pump. Models more than 40 feet long (fig. 12–56) can be PTO or hydraulic motor-powered and 3-point hitch, 2- or 4-wheel trailer-mounted. All-purpose models of impeller-type agitators have a chopper-agitation pump, separate agitation nozzle, and tanker fill pipe (see ch. 10 of this handbook).

Electric motor-powered models that are up to 12 feet long with 15 to 25 horsepower and PTO-driven models

are made for use in vertical wall storages (fig. 12–55). Float-mounted agitator pumps are frequently used for agitating and pumping slurry from larger earthen basin-type storages (fig. 12–57).

**Figure 12–57**    Float-mounted agitator pump (*Photo courtesy of US Farm Systems*)



**Figure 12–56**    Open-impeller agitator (*Photos courtesy of Whatcom Mfg.*)

A hydraulic shifted gearbox is used to select the desired agitation or pumping mode. Most impellers are three steel blades and are from 1 to 2 feet in diameter. Depending on speed, the power needs range from about 35 horsepower for the 1-foot model to about 150 horsepower for the 2-foot, 0.25-inch-thick steel impeller agitators. Impeller size, pitch, and blade number are based on manufacturer experiences.

Agitator location and operation depend on the location and relative amounts of settled and floating materials in the waste. With earthen waste storage ponds, solids generally settle near the storage inlet. With vertical wall storage, they tend to build up in the corners.

Opinions vary on agitation techniques, and little research information is available for different storage shapes, sizes, and depths, although in general, circular storage facilities are more easily agitated/mixed than square or rectangular structures. The corners of rectangular earthen basin storage are often agitated first to break up the surface crust and get the storage contents moving. After the waste has been mixed for several hours and given the available power, durable equipment, and added mix water, stored semisolid waste becomes slurried.

Agitated semisolid and slurry wastes, if allowed to resettle and separate after agitation, are more difficult to re-agitate because solid material becomes finer. In some cases where solids have settled in a semisolid or slurry waste storage, the storage structure may require dredge agitation equipment or manual cleaning. A large dragline dredge is the most effective way to clean out a large open storage.

Settled, packed solids in relatively small semisolid storages can be loosened with correct use of chemical and biological additives and a high volume or pressure of water (>1,000 psi).

## (2) Solid waste agitators/mixers

Stacked or piled waste settles and shrinks as it decomposes and dries. Compost methods use agitation/mixing equipment to mix dry and wet materials and provide airways (aeration) that aid decomposition. For more information on composting, see chapter 10 of this handbook.

A tractor front-end loader or skid steer loader is simplest to use for agitating (scoop-lift-move-dump) the piled compost. Depending on the site conditions and arrangement, operator expertise, and loader bucket size, the windrowed compost turning rates for this technique range from 20 to more than 70 cubic yards per hour.

Agitation quality is affected by the mix of added materials, unevenly wet compost, and strong wind gusts. To aid in uniform mixing, a box spreader, such as that described in section 651.1207(a), potato digger; rock picker; or related elevator laydown-type of equipment can be adapted for agitating windrowed compost. Low profile cruster equipment has been developed to pick up and re-lay (or load) solid bedding litter in large poultry barns (fig. 12–58). This equipment needs 18 to 60 horsepower, depending on the loading rate and litter quality. Loaded litter can be stacked or field spread.

Heavy duty agitation equipment has been developed for agitating windrowed compost to reduce labor, increase output, and provide a uniform mix (figs. 12–59 and 12–60). Tractor tow, PTO-powered, and self-propelled models are available. These windrow turners employ varied agitator designs. They include:

- a large diameter (about 3-ft) auger to move the windrow sideways

- a rotating drum that has spike flails attached in a spiral; the spiral goes under the windrow, lifts it up, and re-lays it

- a wide, high elevating belt that works the same as the rotating drum

The auger type is simplest, but needs relatively high power. Rotary drum types are made in different models that require 65 to 440 horsepower and have a capacity rated from 800 to 4,000 tons per hour. The wide, high elevating belt agitators require from 65 to 125 horsepower and are rated from 2,000 to 3,000 tons per hour. The elevating belt models generally are towed by a tractor and turn or agitate half the windrow in a single pass. This requires tractor drive space between windrows that, in turn, need drainage and maintenance.

Mixing additional materials with wastes is another solid waste handling agitation procedure. Either continuous flow or batch mixing equipment is available. The following factors should be considered in selecting the equipment to use:

**Figure 12–58**    Elevator scraper for solid waste agitation and hauling (*Drawings courtesy of Gregory Mfg. Co.*)
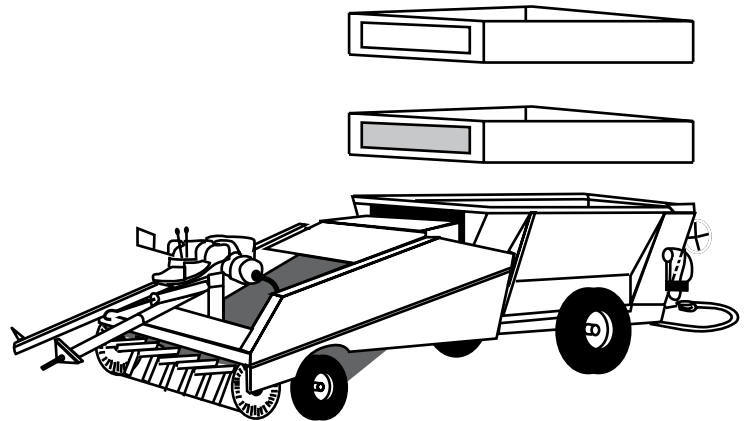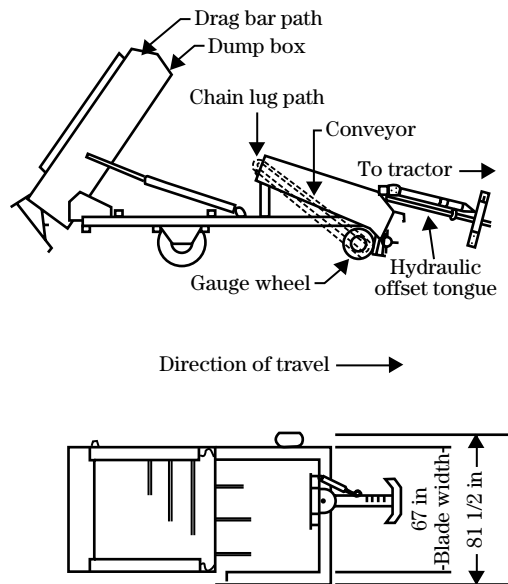


**Figure 12–59**    Windrowed compost agitators/turners (Rynk 1992)
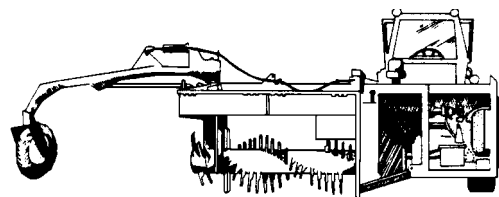


Push-type, self-powered (diesel engine) rotary drum with flails
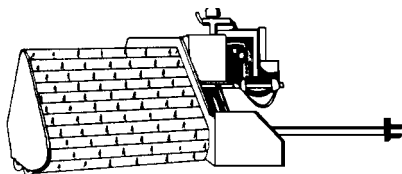
Tractor-towed, self-powered, elevating-face conveyor

**Figure 12–60**    Self-propelled compost turners (*Photo courtesy of Backhus)*



*Photo by Bill Boyd, NRCS*

- capacity

- cost

- material moisture content

- mixing quality

- power

- dust

- noise

An ordinary U-trough auger conveyor operated at an incline can be used as a continuous-flow solids mixer. The materials to be mixed are fed in at the low end of the auger. The conveyed material rolls and mixes when conveyed up an incline of 25 to 45 degrees. The length of conveyor required depends on the materials and mix quality.

The pug mill is a large-capacity, continuous-flow heavy duty mixer used in sludge composting (fig. 12–61). The

mill is generally operated at a stationary site, so materials to be mixed are conveyed over to and metered into the mill. Materials are mixed as they pass through the counter-rotating paddles. Different sized pug mills are available. The throughput rates range from 10 to more than 500 tons per hour with power needs from 10 to more than 50 horsepower, depending on material quality.

Different batch mixer designs for mixing foodstuffs and fertilizers have been adapted to agitate solid waste, such as compost, sludge, straw, and paper. These mixers are mounted on a trailer or truck and use electric, PTO, or engine power. Batch mixers that use rotating horizontal-suspended augers that are 1 to 3 feet in diameter (fig. 12–62) may cost less than reel, paddle, or ribbon mixers, but they have higher power and operating time needs. Power needs range from 10 to more than 50 horsepower for reel mixers rated at 5 to 30 tons per hour. The rotating drum cement mixer has been adapted for solids mixing.

**Figure 12–61**   Pug mill mixer for dense, solid waste (Rynk 1992)
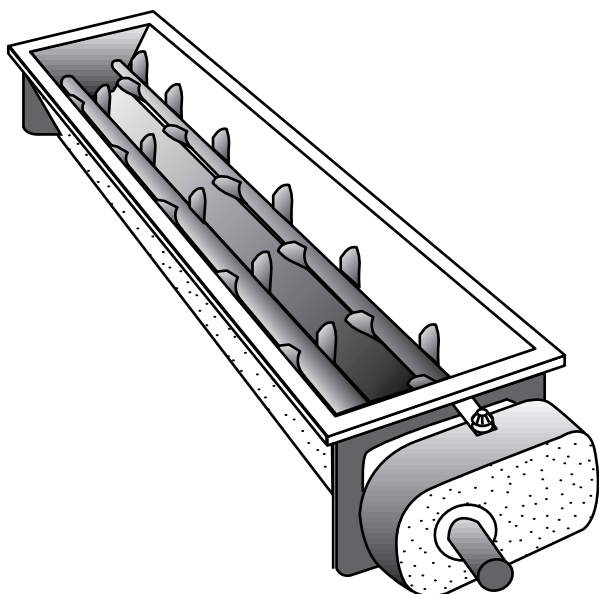


**Figure 12–62**   Batch mixers for solids mixing (*Drawings courtesy of Patz Corp.*)
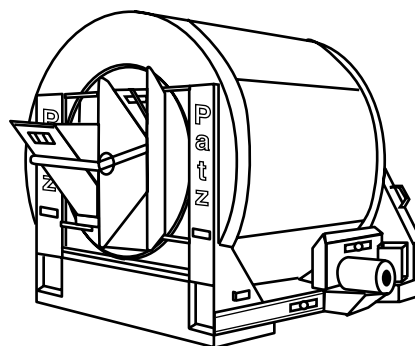


Tumble mixers
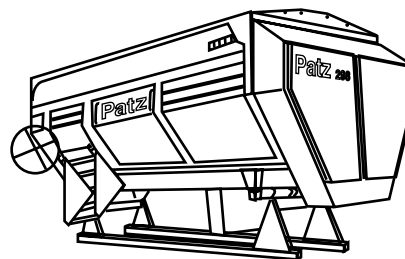


Stationary auger mixers

## (c)  Aerators

The continual forcing or mixing of air with stored waste affects its odor and temperature control as well as the decomposition rate. Equipment has been developed for aeration of solid, semisolid, slurry, and liquid wastes. While the use of agitator equipment with stored waste also aerates, the aeration result is non-uniform and relatively temporary.

### (1)  Slurry and liquid waste aerators
Mechanical aeration of liquid lagoon waste is explained in chapter 10 of this handbook. Beside this kind of development for agricultural waste aeration, the aquaculture industry has varied equipment and experience with liquid aerators used with commercial fish farming as do wildlife agencies working with pond and lake aeration.

Mechanically aerated lagoons combine the odor control advantage of aerobic lagoons with the smaller size requirements of anaerobic lagoons. They are most often used to control odors in sensitive locations or for nitrogen removal where land disposal areas are severely limited. However, use of floating surface aerators to provide oxygen is much more expensive than anaerobic lagoon operation, both in initial cost and maintenance and operating expense. For floating aerators the minimum aeration requirement for odor control at the lagoon surface is about 1 horsepower per 750 to 1,000 square feet of surface area. Use of aeration equipment for complete mixing of the lagoon liquid is normally considered uneconomical and unnecessary except where a high level of odor control is required. An engineer needs to plan equipment needs based on the chemical oxygen demand and the fraction of total nitrogen that can be converted to nitrate by aeration for the design situation.

Floating liquid surface pump aerators use an impeller (propeller) directly connected to an electric motor. This impeller helps pump the liquid upward where it mixes with air and falls back down into storage (fig. 12–63). The pumping and aeration depth is generally less than 4 feet, and the affected area ranges to a 50-foot diameter, depending on the design and power available. Power needs, pump plugging, splash control, and freezing are problems. Liquid and air mixing is usually more effective with the pumped water than with the diffused air-type floating aerator that forces air into the liquid (fig. 12–64). Air is compressible, and liquid is not, so the lighter weight air has more tendency than pumped liquid to take a path of least resistance.

**Figure 12–63**  Floating aerators for liquid waste aeration (*Drawing and photo courtesy of Aeromix Systems, Inc., and Patrick Charles Pty Ltd.*)
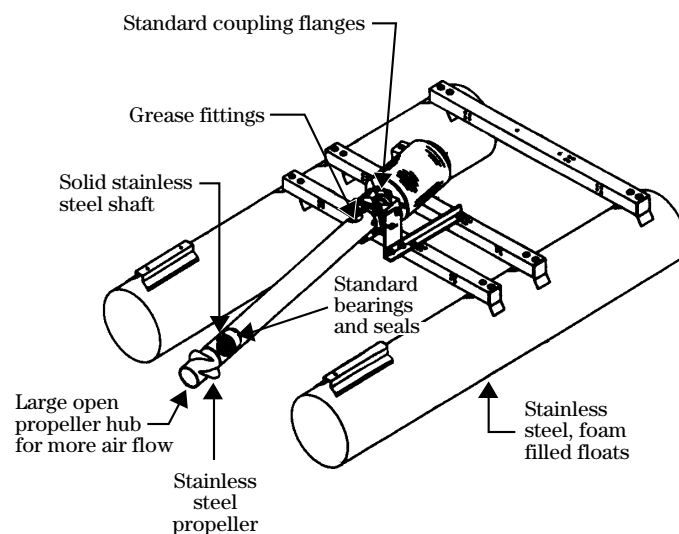
One or more floating aerators are typically strategically spaced over an open lagoon storage surface so that each unit aerates a certain area of designed capacity. These aerators are floated over to the desired location for operation and secured to the storage edge with anchor cables. The anchor cables can support 240-volt power wires; however, the support distance and wire size must be considered.

Diffused aerators that force air into liquid and slurry waste have varied designs. They include one that uses a submerged impeller that mixes air supplied to it via an intake tube with the surrounding stored waste (fig. 12–64). The aerator can be incorporated into an induced air flotation treatment system (fig. 12-65). Another design uses an air blower, located outside the storage area, to force air down a duct or distributor arrangement into the stored liquid below (fig. 12-66).

**Figure 12–64**    Diffused air liquid and slurry aerator (*Photo courtesy of Aeromix Systems, Inc.*)



**Figure 12–66**    Submerged diffused air system with external blower (*Drawing courtesy of Aeromix Systems, Inc.*)
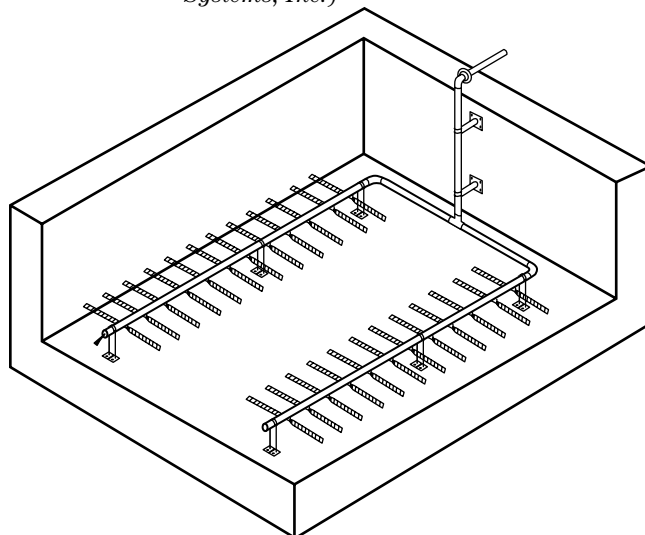


**Figure 12–65**    Diffused air liquid and slurry aerator incorporated into an induced air flotation treatment system (*Drawing courtesy of Aeromix Systems, Inc.*)
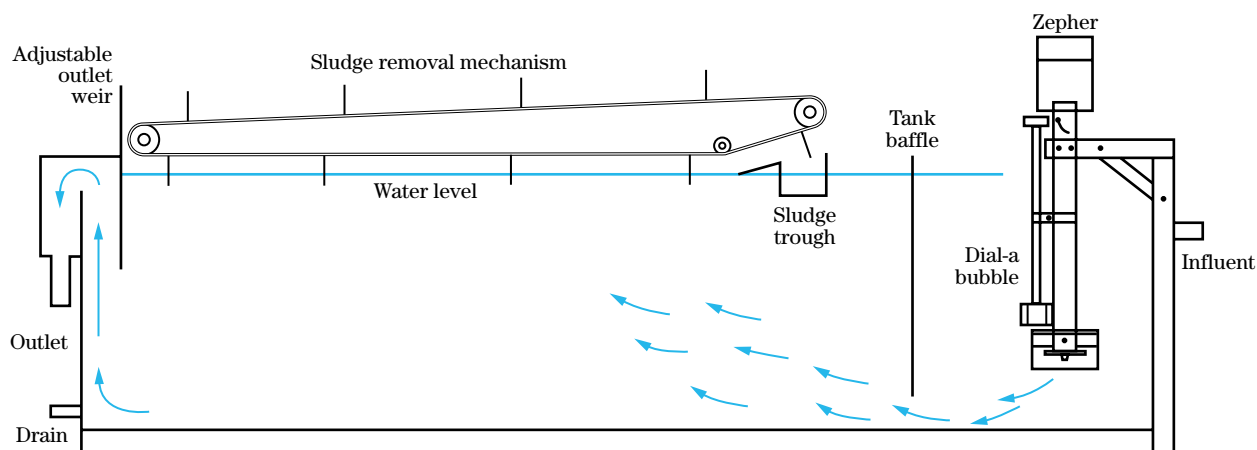
Most diffused aerators have relatively small capacity and horsepower; however, one manufacturer uses a supercharger blower to force air to the directed output of a submerged impeller. Several models are available with up to 10.5 horsepower. Uniform mixing of air with the liquid and plugging of the diffuser hole can be problems.

### (2) Solid waste aerators

Unlike agitated pile or windrow solid waste composting, static pile composting employs natural or forced aeration to control pile temperature and aid aerobic decomposition. Figure 12–67 shows guidelines for perforated duct placement using passive or natural air movement.

For uniform airflow, the key is to establish good structure and pile porosity. Air naturally tends to flow into the open-ended pipes, that are 4 inches in diameter, and out through the 0.5-inch holes on 1-foot centers and then through the pile. This movement is because of the chimney effect of warmed air moving upward out of the pile. A peat moss or similar covering insulates the pile, discourages flies, and aids moisture and odor retention. Ordinary septic or leaching field plastic pipe is used for the air ducts. The pipe holes are placed facing downward to avoid their plugging. The pipes are pulled out when composting is complete. Wind causes dust in an exposed area: however, it assists natural aeration.

Mechanical aeration of a static pile or in-vessel composting system employs an electric motor-powered forced air blower that is temperature controlled. The system design depends on storage shape, airflow quantity, and distribution. Approximate design requirements for temperature conditions are shown in table 12–8. Application of these specifications becomes complicated and is explained in the On-Farm Composting Handbook (Rynk 1992). Additional information on composting can also be found chapter 10, section 651.1005(b)(6) of this handbook as well in the NEH, Part 637, Environmental Engineering, Chapter 2, Composting.

Airflow static pressure for an approximately 6-foot-deep pile of roughage compost can range from 2 to more than 4 inches of water (static pressure), depending on the compost mix, moisture content, and airflow (Keener, Hansen, and Elwell 1993). Fresh compost requires a controlled flow of air to maintain a pile temperature at about 140 degrees Fahrenheit. In practice the blower speed or cycle and the airflow through the duct system must be adjusted or the pile size must vary to suit compost temperature conditions. Because pipe selection and airflow distribution arrangement affect operation performance and costs, especially for a large compost operation, these decisions are critical to the success of the operation, and special design planning is recommended.

**Figure 12–67**    Perforated duct placement for gravity aeration (Rynk 1992)
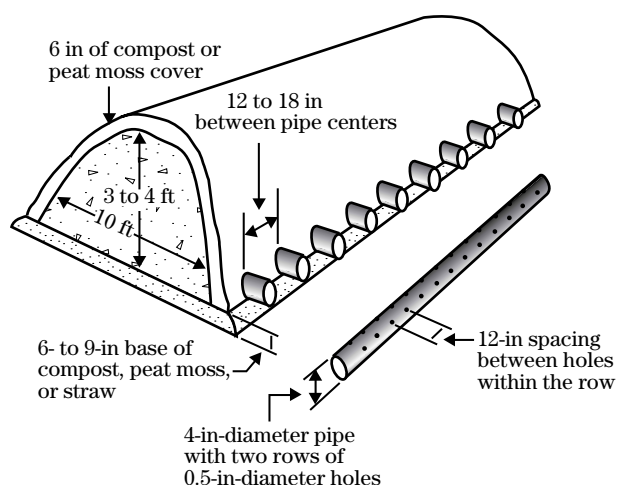


**Table 12–8**    Blower and pipe sizing for pile aeration (Rynk 1992)

| Component | Time-based control | Temperature-based control (130–140 °F) |
|---|---|---|
| Blower horsepower | 0.33–0.5 | 3–5 |
| Airflow (ft³/s per dry ton of waste) | 10 (continuous operation) 25 (1/3 on 2/3 off) | — 100 |
| Pipe diameter (in) | 4 | 6–8 |
| Maximum pipe length (ft) | 75 | 50 |

Blower selection depends on the airflow rate at a needed static pressure, the tolerable noise level, and power availability. Airflow is measured in cubic feet per minute, and static pressure in inches of water column or inches of water. Blower static pressure is affected by:

- depth of the compost—increases linearly for each added foot of depth

- quantity of the airflow ($ft^3$/min/$ft^3$ of compost)— the static pressure triples when airflow doubles

- quantity of the compost—restricted by wet, heavy material, the air moves easily through fluffy, dry, uniform material

- airflow ducts—sharp corners and too small ducts restrict airflow, especially at high rates

Correct blower selection provides the proper airflow amount for the quantity to be aerated. To determine the airflow rate, divide the cubic feet of material by the cubic feet to be aerated.

Electric motor power is nearly exclusively used for blower power with many types of control commonly available. The controls include: on-off, percentage timer, time-clock, thermostat, and variable speed. Motor horsepower is a poor way to compare blowers because the blower performance is determined by its design and the blower horsepower is determined by airflow, static pressure, and blower efficiency. Horsepower needs vary at different combinations of airflow and static pressure, and a maximum horsepower input occurs at a specific combination thereof. The blower motor needs to operate continuously at this maximum requirement for horsepower. Manufacturers can supply this information for their different models.

The axial flow and centrifugal blowers are commonly used for forcing air through materials at relatively high static pressures (fig. 12–68). A wide selection of either blower type is available ranging from about 200 to more than 5,000 cubic feet per minute capacity and at relatively high static pressures. An undersized blower will not control compost temperature. Too large a blower results in too much cooling and erratic compost decomposition. A high air flow rate at a higher static pressure generally is needed at the start of composting. Air flow needs to reduce as decomposition and compost agitation occur, so a means of reducing airflow is needed. Total air flow can be reduced by

careful use of intermittent blower operation, a slower speed, a smaller blower, or by diverting or blocking some air flow. The axial flow blower generally costs less than the centrifugal blower, is less noisy, and is better suited to static pressures below 3 inches.

Equipment for aerating the separated solids from dairy waste has been in use since 1990 at the USDA Dairy Forage Research Farm in Prairie du Sac, Wisconsin (fig. 12–69). Separated solids (about 20% dry matter) are conveyed from the solids/liquid separator and leveled to a depth of 6 feet in a 10- by 12-foot aeration bin. The plastic aeration tubes, which are 5 inches in diameter and have 0.5 inch holes about 1.5 feet apart, are laid on a spacing interval of 3 feet in the concrete floor. One bin is filled during a 3-week period while another bin is aerated. A third bin, previously aerated, supplies periodic bedding needs for stalls.

Recommended improvements for this equipment include (Straub 1993):

- some means to prevent plugging of the air outlet holes in the floor when driven over by a front-end loader to unload

- a way to plug and unplug aeration holes during filling until they are covered with separated material

- a way to assure that the first material in the bin is the first out

Different models of relatively high investment in-vessel composters have equipment adapted to these problems (fig. 12–46).

**Figure 12–68**　　Vane axial and centrifugal aeration blowers



In-line centrifugal fan

Centrifugal fan

Airflow

Inlet

Airflow

Airflow

Axial-flow fan
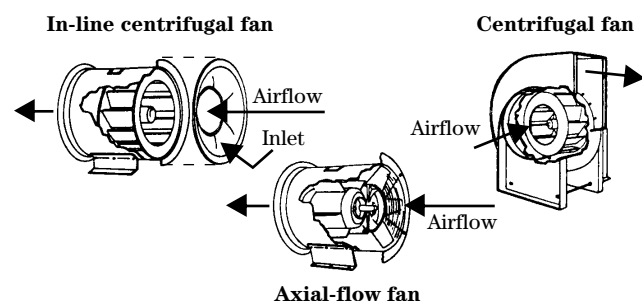
**Figure 12–69**　　Aeration for separated dairy waste solids

**Front view**



**Rear view**



## (d) Separators

Solid separation of manure and related materials is increasingly becoming a common practice in many livestock production operations. There are many reasons for use of a separator as part of an agricultural waste treatment system including:

- reduction of the frequency with which accumulated solids (sludge) must be removed from a storage or treatment facility resulting in an increase in the effective storage period

- facilitation of the operation of a sprinkler irrigation system for land application of the separated liquid fraction

- production or recovery of a reusable by-product such as fiber or sand for bedding

- reutilization of flush water

- partitioning of nutrients to facilitate land application based on crop uptake

- reduction of odors from storage or treatment facilities

Separation relies on physical mechanisms such as gravity, screening, centrifugal force, and pressure. Selection of the appropriate mechanism or combination of mechanisms depends on the shape, density, size, and concentration of the particles involved. Criteria to consider before selecting separator equipment include:

- Waste moisture content—Some separators require dilute slurry, so additional water may be needed, while the solids separated may need to be dried.

- Separator opening size—12 to 30 mesh screens are common for solids and liquid stationary screens. Small openings remove solids, but they also slow the system throughput.

- Throughput rate or capacity—this determines the separator size needed for the system. It is expressed in terms of volume per unit time, such as gallons per minute.

- Maintenance—the equipment must be maintained and mechanical conveyors, pumps, and separators need power with belt or chain drives.

- Costs for peripheral equipment—concrete pavement, separator support, pumps, conveyors, sumps, electric power, and building costs.

- Solids/liquid separator—requires both solid and liquid waste handling equipment.

The type of animal operation involved affects the makeup of the waste to be treated and must be taken into consideration when selecting the appropriate equipment. Chapter 10 of this handbook provides some general guidance on performance of several common types of separators based on the animal species involved and the total solids (TS) concentration of the raw waste. CPS Code 632, Solid/Liquid Waste Separation Facility, table 1, provides a general range of solids capture efficiency for various types of separators. However, before making a final equipment selection, the effectiveness of the separator should be evaluated based on the specific manure to be treated. Two separate studies (Burns and Moody, University of Tennessee 2003; Flemming and MacAlpine, University of Guelph 2003) indicate that the type of the manure and the related TS of the raw rates have major impacts on the separation efficiency and throughputs of screw press separators.

Flocculants and coagulants are frequently used in conjunction with separators to improve efficiency. The most common chemicals used to coagulate and flocculate solids in animal manure and wastewater are organic polymers such as polyacrylamide (PAM), and metal salts such as ferric chloride ($FeCL_3$), alum $Al2(SO_4)_3$) and lime ($Ca(OH)_2$). Detailed discussion of these and other specific chemicals is beyond the scope of this chapter and will not be covered here.

## Mechanical separators

The separation of liquid from solid waste requires some outside action or force to break down liquid tension. Gravity is the most common force utilized since it requires little or no energy input, but pressure and centrifugal force as well as combinations of all these forces are used. For example, a settling tank primarily utilizes gravity while a screw press uses pressure and gravity to separate liquids and solids. While at first glance there appear to be many different types of separators, most of them can be grouped in four general categories:

- settling tanks and chambers

- screens
  - stationary
  - vibrating
  - rotating
- presses
  - belt press
  - roller press
  - screw press
- centrifuge or "cyclonic"

Chapter 10 of this handbook provides schematics of two types of press separators and two types of screen separators.

The capacity or throughput and the efficiency of separators are closely related. If a low efficiency (less separation) can be tolerated, the throughput capacity will be larger. In most cases, high-quality separation is desired. Separator equipment, however, is rated on how fast it operates (gal/min).

Some terms used in discussion of mechanical separators are:

- Influent—"raw waste" or input material that is to be separated—frequently diluted to a specified maximum TS content

- Press-liquor—the separated liquids from a press-type separator

- Press-cake—the separated solids from a press-type separator

### (i) Settling tanks
Settling tanks, alternately known as sedimentation tanks, utilize the action of gravity in order to separate solids from liquids. Their purpose is to slow wastewater flow sufficiently to allow solids to settle out. They are typically made of reinforced concrete, steel, or in some cases, plastic or fiberglass. They may be similar to a domestic waste septic tank and contain a baffle to retain floating solids or they may simply be rectangular or circular structures designed to retain the influent for a specified period of time.

The Midwest Plan Service (MWPS 1985) distinguishes between settling basins and settling tanks. A settling (or sedimentation) basin is a structure designed to settle solids and drain the liquids, with the solids being

periodically scraped and removed from the structure. They are generally open and contain ramps to allow access with a front end loader or similar type of equipment and are made of earth with sloping sides and a concrete bottom or lining. Alternately they may be constructed of vertical reinforced concrete walls and floor. They are described in chapter 10 of this handbook. They are not included here. A settling tank has a constant depth and the contents of the tank are normally pumped on a regular basis.

A settling tank (fig. 12–70) is used with a low-volume, relatively continuous flow of wastewater, such as recirculated lagoon flush water, milkhouse washwater, or produce washwater (MWPS 1985). The design volume is based on a half-hour flow detention time plus space for settled solids. Settled semisolids need to be periodically removed by an in-place scraper or conveyor or agitated and pumped out.

**(ii) Stationary screen**
The stationary inclined screen separator (figs. 12–71 and 12–72) can produce a solids fraction of 12 to 23 percent dry material depending on the TS content of the raw waste and the size of the screen mesh. This separator operates with liquid or slurry waste passing

down and over the screen, permitting liquid waste to pass through the screen and semisolids to pass over the end. In addition to wire mesh, round hole and slot types of separator screens are also common. Often these will have a sharp-edged hole or slot (when new) exposed to the slurry material to be separated. The

**Figure 12–70** Belowground settling tank, liquid/solid separation
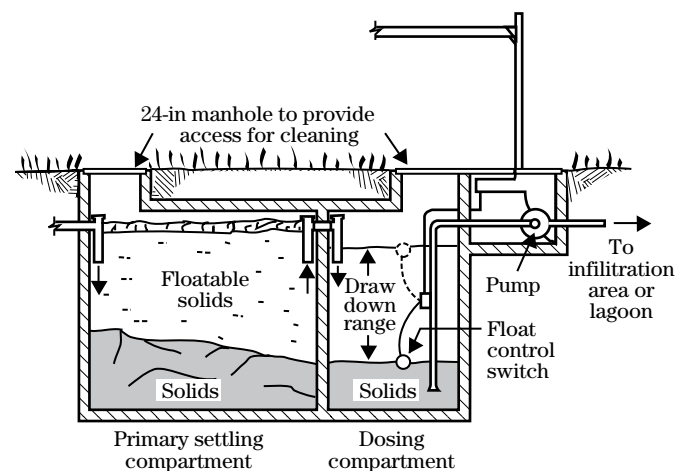
**Figure 12–71** Wedgewire screen with sloped screen separator (MWPS 1975)
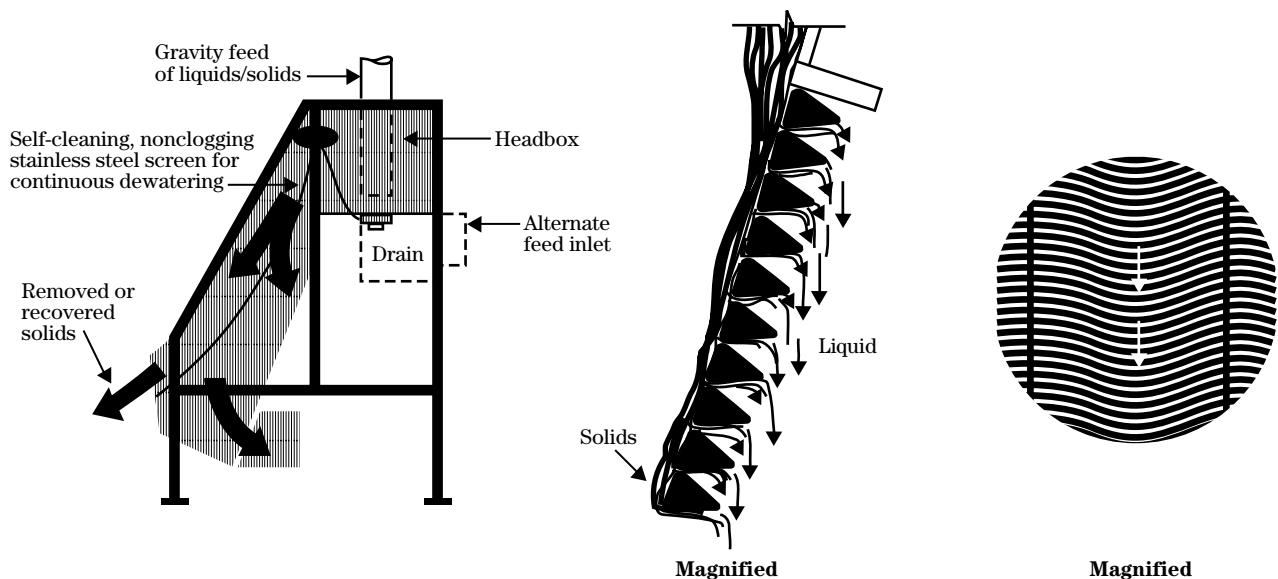
hole diameter or slot width then increases slightly to assist liquid passage through the screen and to minimize plugging also known as blinding. The wedgewire screen, for example, permits smaller solids to readily pass on through once they get through the slot opening.

To reduce screen plugging and blinding, various sizes of screen openings and shapes and flushed, brushed, or scraped screen cleaning equipment are used. The extent of use depends largely on the waste quality. Some operators have found it necessary to periodically wash their screen separator with dilute boric or similar acid to remove solid chemical precipitate buildup (Buchanan, Mote, and Robinson 1993).

Table 12–6 provides information about opening size for rectangular screen openings. Mesh number refers to the number of openings per inch. The larger the mesh number, the smaller the opening. In other words, a 10-mesh screen has 10 openings per inch, a 20-mesh has 20, and so on. The opening size dimension is the actual open distance of one side of the opening and does not include the wire that separates adjacent openings. The screen thickness limits the opening size, spacing, and support framework. A large opening allows more solids to pass through with the liquid, a small opening retains more liquid with solids. The size opening that screens out a major amount of solids is prone to plugging or blinding and needs frequent cleaning. This can affect separation quality.

In addition to collection and agitation pumps, the stationary inclined screen separator (as do most slurry separators) needs a 0.5- to 5-horsepower pump to raise 200 to more than 1,000 gallons per minute of slurry above the screen. To help remove more liquid yet try to maintain throughput, press rollers are incorporated on a stationary inclined screen separator (fig. 12–72). They help produce a solids fraction of 15 to 25 percent dry material. More solids can pass through with the liquids, however, as the roll pressure is increased.

**(iii) Conveyor scraped screen**
There are basically two types of conveyor scraped screen installations. One is installed on a relatively steep incline similar to the gutter cleaner shown in figures 12–24 and 12–25, except there is a screen located in the bottom of the conveyor. The lower end of the conveyor is located in a tank or channel. Slurry material is pulled up the conveyor by a series of bars or flights. The screen in the bottom of the conveyor allows liquid to drain through to a solid trough and run back down into the tank. Solids continue to the end of the conveyor and drop to a stacking pad (fig. 12–73).

The second scraped conveyor installation operates in a similar manner except it is elevated, installed with less of an incline, and loaded using a pump. It is also similar to a gutter cleaner with a screened bottom. Solids drop off the elevated end to a stacking pad and the liquids run to the low end and are drained through a pipeline (fig. 12–74).

For either installation, a 2 to 10 horsepower electric motor is needed to drive the conveyor or drag chain at about 15 to 25 feet per minute. Throughput capacity varies from about 75 to 150 gallons per minute. Separation efficiency is slightly better than that static screen separator depending on how well the separator is operated and maintained. Since there are more mechanical and moving parts, the expense of operation and maintenance is also greater.

**(iv) Rotating screen**
The rotating screen strainer (fig. 12–75) uses a perforated, horizontal cylinder that rotates at about 10 to 35 rotations per minute. The liquid waste to be separated gravity-flows into or onto (different models vary) the end of the rotating cylinder. Solids are pushed along by a rotating helix or scraped off the rotating screen and move out the opposite end. Liquid passes through the

**Figure 12–72**    Static inclined screen separator with incorporated press roller (*Photo courtesy of CADY, Inc.*)



Two stage separator shown with optional anti-splash roll-up canvas

Our platform for manure separator allows to pile fiber up to 14 feet high

**Figure 12–73**   In-channel flighted conveyor (*Photo courtesy of Texas A&M*)



**Figure 12–75**   Rotating screen separator (*Photo courtesy of Accent Mfg.*)



**Figure 12–74**   Pump and pipeline loaded conveyor separator (*Photo and drawing courtesy of Albers Manure Handling Systems, Inc.*)
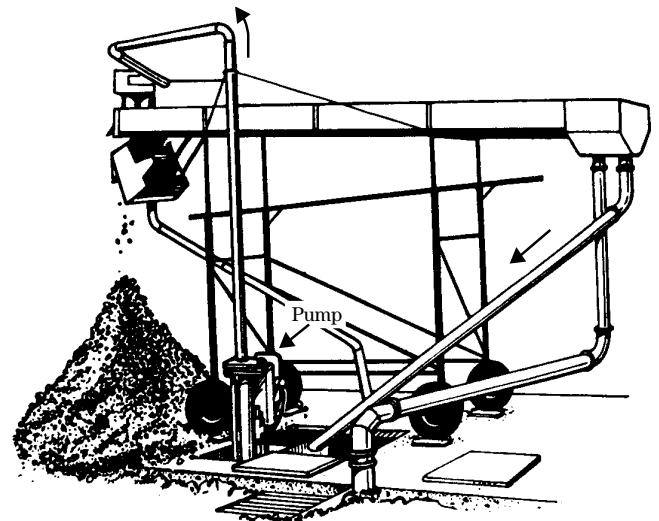


Pump

**Pump and pipeline loaded**

screen and drains to storage. Unless roller pressure is applied (fig. 12–76), the rotating strainer has relatively high volume and relatively low (15–20%) separating efficiency for a single pass. Coupled with a roller press, separation efficiency may be improved to 20 to 40 percent. Models are available with 500 to more than a 10,000 gallon per minute capacity, depending on screen size.

**(v) Vibrating screen**

A vibrating screen (fig. 12–77; also see ch. 10 of this handbook) eliminates some of the clogging problems associated with the static inclined screen, but since mechanical power is needed to cause the screen to vibrate, they are also more expensive to operate and maintain. Unlike the static screens, they are installed horizontally. Material to be separated is conveyed into a wide, shallow container that has a replaceable bottom screen. The container vibrates both vertically and horizontally to move the material over the screen and minimize screen plugging. As the material flows into the vibrating container, the liquid or smaller materials pass through the screen and the large solids work toward the container's edge, fall off, and are removed. Some solids are broken up in vibration and pass through with liquids, lowering the separation efficiency with some materials. Normal separation efficiency for this type of separator is 15 to 30 percent.

**(vi) Screw press**

A screw press separator (figs. 12–78 and 12–79) uses a straight or tapered screw (auger) of fixed or varying pitch contained in a perforated or slotted cylinder. Liquid or slurry waste gravity flows or is force-fed into one end of the rotating screw. As it is forced along by the rotating screw, liquid waste drains through the cylinder enclosure and goes to storage. The semisolids are pushed out the end. Adjusting the end retainer restricts throughput, which forces out more or less of the liquid through the cylinder enclosure. Power need is increased as the quality of separation is increased and the throughput is slowed. A 7.5- to 50-horsepower electric motor is used for throughput of 20 to more than 1,500 gallons per minute depending on the consistency of the waste being processed. A study done at the University of Tennessee (Burns and Moody 2003) on separators from two different manufacturers indicated that the dry-mass capture efficiency goes down as the total solids content of the influent increases. Dry-mass capture efficiency for the study ranged from 10 to greater than 50 percent.

**(vii) Roller press**

A roller press has concave screens and a series of rollers and brushes that press liquid manure against the screens (fig. 12–80). The liquids are squeezed out and the solids remain on the screen.

**Figure 12–76** Rotating screen coupled with roller press (*Photo courtesy of Accent Mfg.*)



**Figure 12–77** Vibrating screen separator (*Photo by Dave Moffitt, retired, NRCS*)

**Figure 12–78**   Screw press-type cylinder separator cross section (*Drawing courtesy of Fan Engineering USA, Inc.*)
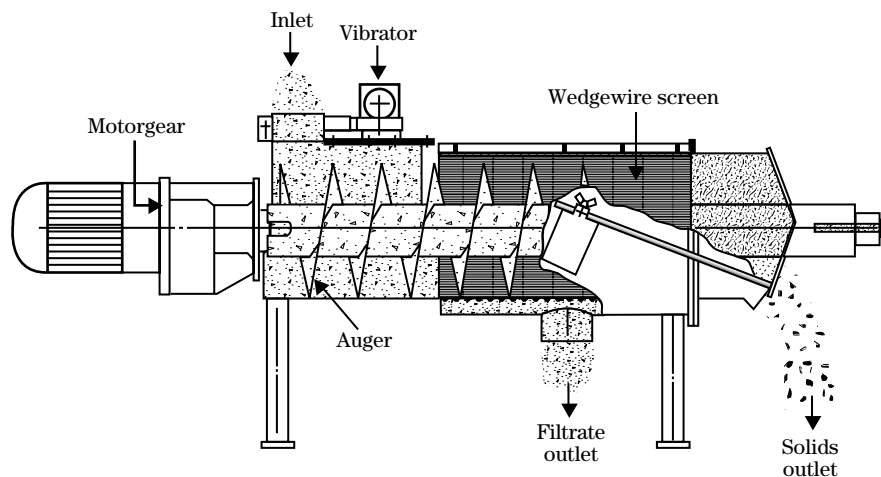


**Figure 12–79**   Screw press-type separator (*Photo courtesy of Dari-tech, Inc.*)

It is similar to clothes wringer-washer. The upper, solid roller may be compressible while openings in the bottom roller permit liquid to drain through and away. The pressure-roller separator is often incorporated and used in combination with the stationary inclined screen and drag conveyor scraped screen separators to help improve their separation efficiency (see fig. 12–76). Rollers are powered by 1.5- to 6-horsepower electric motors. Throughput depends on how tightly the rollers are set together. Total solids capture efficiency can vary from 30 to 50 percent.

**(viii) Belt press**
The belt press separator is similar to the roller press separator. However, instead of liquid draining through the perforated lower roller, the belt itself is made of a pervious material and the liquid is squeezed out as the belt passes between two rollers (see ch. 10 of this handbook). In some cases, the belt is impervious and the liquid runs off to the side of the belt to a collection area. The remaining solids are scraped off the belt to a conveyor. This separator is best suited for filtering out fines from waste with a low concentration of total solids.

**Figure 12–80** Roller press separator (*Drawing and photo courtesy of GEA Houle, Inc.*)
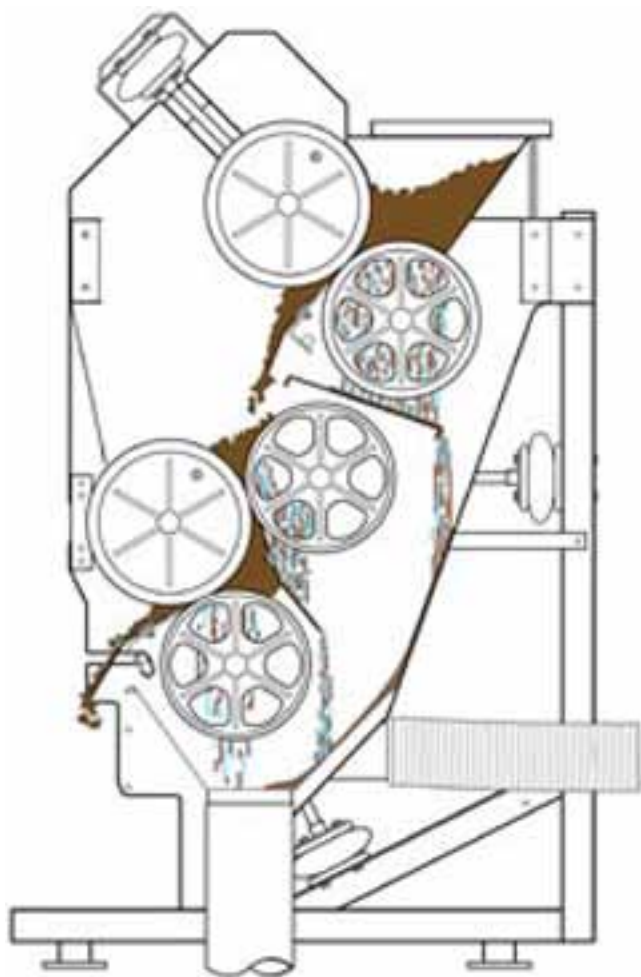
### (ix) Vacuum filter

A vacuum filter, horizontally mounted separator (fig. 12–81) has a cloth fiber cover over a belt or rotating perforated cylinder. An interior vacuum draws liquids out of waste that flows onto the cloth. The liquid passes through and drains away. The solids are scraped off the cloth cover at separation points and are conveyed to storage. Used with municipal and industrial processing, the vacuum filter is relatively efficient. However, throughput is low and filter plugging is a problem with certain solids sizes.

### (x) Centrifugal/hydrocyclone

A centrifugal separator uses centrifugal (outward velocity) force on liquid waste to separate denser solid material from the liquid. They operate best on slurry with a solids content of 5 to 8 percent and consist of a horizontal or vertical cylinder that spins at high speeds. Due to the different densities of the liquids and solids, the liquids and solids accumulate in different layers on the inside wall of the container. In one configuration, the top of the cylinder contains a conical portion. There is also an auger that runs against the inside of the centrifuge and turns at a slightly faster speed. The auger carries the separated solids up the wall of the conical portion of the centrifuge and out the top. This type of centrifuge is referred to as a decanter.

Centrifuges are effective separators and can remove up to 70 percent of the total solids with even greater capture efficiencies when flocculants and polymers are used. They are also the most effective at removing phosphorus from the liquid portion of the waste. How-ever, they are generally have a high initial cost and are more expensive to operate and maintain than many of the other types of separators.

Hydrocyclones are cone-shaped separators that have no moving parts and the necessary vortex motion is performed by the liquid itself. They are configured so that when manure is pumped at an angle into the cylinder (near the top), it swirls at a high speed. The strong swirling motion accelerates the gravity settling of solid particles to the bottom of the cone while the liquid is discharged through a cylindrical tube fixed in the center of the top (Ford and Flemming 2002). Similar to the action of a feed mill dust collector, the liquid waste enters tangentially at the larger diameter of the cone at about 50 pounds per square inch (fig. 12–82). This causes a high velocity swirl or vortex. Semisolid waste particles are propelled to the outside of the vortex and move downward toward the zero pressure outlet at the bottom. Liquid collects at the center and discharges out the top, along with the air. As forces on particles passing through the separator depend on the flow velocity, the operating pressure on the incoming waste affects separation efficiency. This dictates that the nozzle inlet and the cyclone be small to achieve minimum inlet pressure (Auvermann and Sweeten 1992).

### (xi) Geotextile bags

Large geotextile bags are used to dewater manure and sludge from waste treatment lagoons (fig. 12–83). Bags are installed on an impermeable liner with drain trenches running along each side of the bag. Manure or sludge is pumped from the storage/treatment facility into the top of the bag until it is full. The fabric of the bag acts as a filter, allowing liquids to drain while retaining solids. Separation is enhanced by treating the manure or sludge with chemicals prior to pumping it into the bag. Liquids drain from the fabric bag while it is being filled and continue to drain for a period of time after the bag has been filled. The length of time the material is retained in the bag is based on field tests that are done prior to filling the bag. Solids retained in the bag continue to dry and consolidate due to desiccation and evaporation. Liquids are drained to a storage facility to be recycled as flush water or land applied using conventional irrigation equipment. At the end of the treatment period, the bag is cut open and the solids can be land applied based on the nutrient needs of the crop or further processed. There is a significant reduction in the volume of the material to be hauled. Tests have demonstrated that approxi-

**Figure 12–81**    Vacuum filter separator
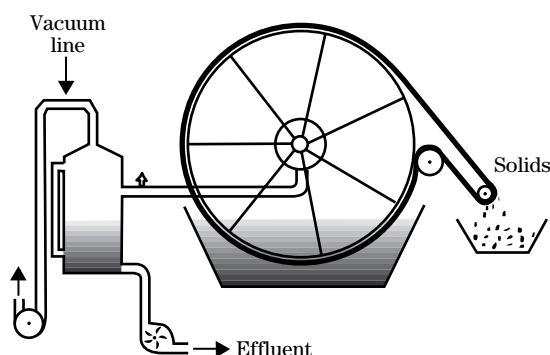
mately 90 percent of the solids can be retained along with more than 90 percent of the phosphorus. Advantages of this type of separation include minimal energy inputs, reduced hauling, nutrient concentration, and reduction of fresh water use due to recycling of separated liquids. The primary disadvantage is the fact that the bags cannot be reused.

**(xii) Sand separators**
It has become a very common practice for dairy operations to use sand as a bedding material for their cows due to animal health considerations. Sand is an inorganic material that does not readily harbor the bacteria that cause mastitis and other bacterial related infections. However, it does have some drawbacks such as accumulation in storage facilities where it settles out and cannot easily be suspended for pumping or loading and excessive wearing on manure pumping and handling equipment. In addition it results in significant volumes of solid material that must be hauled to the field if it is not reclaimed.

While not really another specific category of separator type, sand separators are worth mentioning here since they have evolved from a different industry use than the slurry-type separators already described. Most slurry-type separators have evolved from the municipal waste treatment sector while sand separators have their origins, for the most part, in the mining/quarry industry. As such, they are manufactured with more

**Figure 12–83**    Geotextile bag separator empty and filled



*(Photo by Vic Johnson, Kemira, Inc.)*



*(Photo by John Worley, Kemira, Inc.)*

**Figure 12–82**    Hydrocyclone solids/liquid separator (*Drawing courtesy AgKone, Inc.*)
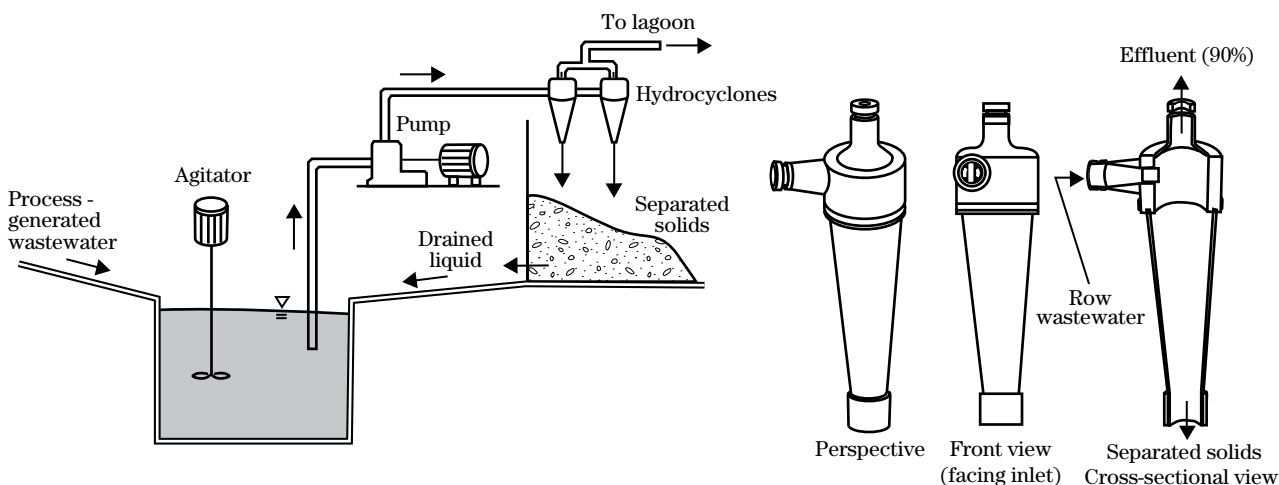
durable moving parts in order to handle the abrasion caused by the sand. The most commonly used sand separators incorporate an inclined auger of some sort powered by a 1- to 10-horsepower electric motor. They are generally coupled with some type of wash/grit chamber to improve separation efficiency. At least one manufacturer produces a rotating screen that is coupled with a screw-press separator.

Advantages of using a sand separator include ability to recycle the sand resulting in a cost savings, reduced wear and tear on manure handling equipment, and reduced hauling of sand resulting in time and cost savings.

## (e) Dehydrators/dryers

Dehydrating, dewatering, or drying waste is explained in chapter 10 of this handbook. Dried waste at about 85 to 90 percent dry material can be stored at normal conditions or packaged and distributed, depending on state laws about fertilizer quality, weed seeds, and disease. Dry, loose material is relatively easy to mix with other products for livestock feed, soil mulch, or fertilizer.

Shallow tray, batch or bin, continuous conveyor belt, rotary drum, and flash dryer equipment employ heated air blown over or through the waste.

The shallow tray dryer involves placing a 3- to 12-inch layer of material to be dried on a mesh screen or perforated metal floor. Hot air is blown through the material until it is dried to the desired level. It is then removed and another tray put on to dry. The continuous shallow bed dryer is similar except the material to be dried is conveyed through the heated airstream. The conveyor movement rate varies according to required drying time and operating temperature. A variation of the tray dryer is a model with a stack of slowly rotating circular trays (fig. 12–84). Material to be processed is introduced into the top of the dryer onto the top tray. After one revolution the material is wiped onto the next lower tray where it is mixed, leveled, and then after one revolution, is wiped to the next tray where the operation is repeated. The trays are contained in an enclosure in which heated air or gas is circulated by internal fans (Wyssmont, Inc.). The dryer can operate with temperatures as low as 60 degrees Fahrenheit

**Figure 12–84**  Circular tray dryer (*Drawings courtesy of Wyssmont, Inc.*)
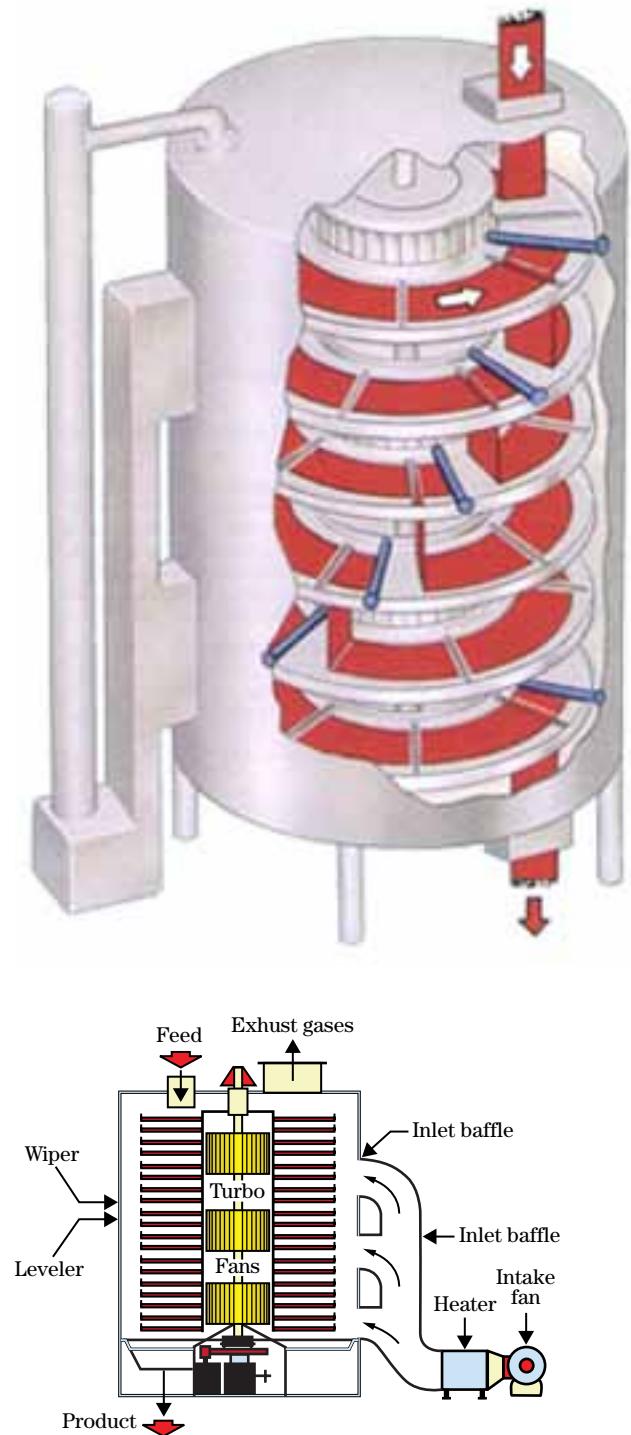
and as high as 1,200 degrees Fahrenheit. It has been successfully used to dry manure.

The rotating drum or inclined cylinder dryer is designed for use with high-capacity agricultural processing and waste drying (fig. 12–85). Wet incoming waste may need to be dewatered via short-term stacking, solid/liquid separator, or remixing with dried waste before entering the rotating drum dryer. This minimizes the formation of rolls or compacted balls as waste tumbles through the dryer. As wet waste moves through the drum, heat from a direct-flame burner is blown through the dryer in the opposite direction. This permits the hottest air to first evaporate water from the exiting drier material. It can be used to dry material with an initial moisture content of 85 percent or less to a final moisture content below 13 percent.

**Figure 12–85**    Rotary drum-type dryer/dehydrator (*Photo courtesy of Zhengzhou Taida Mining and Metallurgy Equipment Co., Ltd.*)
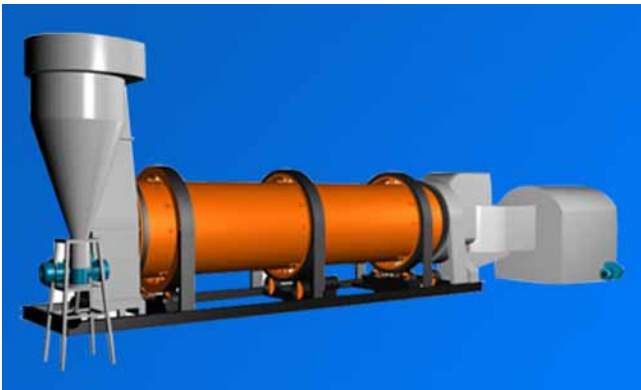


Although efficiency of dryer/dehydration equipment continues to improve, it still requires significant inputs of fuel and power as well as attention to operation and maintenance. It also requires a relatively high initial investment and is therefore best suited for larger operations that need to produce a marketable by-product providing an additional revenue source. Odors from drying waste have been addressed by addition of air scrubbers on the exhaust end of the dryer.

Mechanical drying of undiluted poultry waste has been extensively studied because of its high nutrients and total solids. The high investment and labor costs cause producers to not use mechanical drying of undiluted poultry waste in spite of the value of the final product. Heating air and forcing it through wastes to dry out moisture requires blower power and nearly 1,200 British thermal units (BTU) of heat for each pound of water removed—if done at 100 percent efficiency. A ton of 40 percent dry material hay, for example (representative of some agricultural wastes), needs over 1,100 pounds, or 133 gallons, of water removed to make 90 percent dry material hay that is safe to store. Depending on weather conditions and efficiency, some 2 to 3 million BTU or 15 to 20 gallons of fuel oil equivalent would be needed. Research at Michigan State University indicated that 9.45 gallons of fuel oil were required to remove 1,000 pounds of water from poultry waste. Table 12–9 shows results from mechanically drying different kinds of animal excreta.

A drying system that utilizes the exhaust air from a caged layer production facility has been developed by one manufacturer. The system takes the fresh manure from the barn to a belt drying tunnel on conveyor belts. Once it reaches the belt drying tunnel, the manure is transferred directly into a dosing station. The

**Table 12–9**     Dryer performance with animal excreta (MWPS 1975)

| Excreta source | Fresh excreta (lb/h) | - - Moisture - - | | Fuel | Electricity use | Efficiency (%) |
| | | initial (%) | final (%) | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Poultry | 340 | 76.3 | 11.1 | 2.4 | 4.2 | 72 |
| Bovine+ 2% straw | 243 | 82.4 | 12.0 | 2.6 | 4.2 | 52 |
| Swine | 225 | 72.2 | 12.5 | 2.4 | 4.2 | 44 |

amount of manure that is transported is determined by weight, which is read by electronic load cells. These coordinate the speed of the manure belts inside the barn and in the drying tunnel. The dryer consists of a series of stacked conveyor drying belts that are perforated (fig. 12–86). A uniform layer of manure is spread onto the topmost drying belt using two counter-rotating augers. When the manure reaches the end of the topmost belt, it automatically drops down onto the next conveyor belt and the transport continues until the filling is finished. The belt dryer is located next to the exhaust side of the production facility ventilation fans in an attached protected structure. Warm exhaust air passes over and through the manure before exiting the facility (fig. 12–87). The dried manure passes through a chopper consisting of a rotating shaft with 20 centimeter chain links prior to being removed via conveyor belt. Manufacturer's literature indicates the final product has a 80 to 90 percent dry matter content.

A cyclone dryer has been evaluated for use on livestock manure (Farm Pilot Project Coordination (FPPC)). The dryer, which is actually a separator/dryer, is similar to the hydrocyclone separator described in the previous section but larger. High-velocity air is circulated inside a conical shaped container in a cyclonic manner resulting in collision and impact of particles resulting in separation of material components by differences in their specific gravity and particle size and shape. Most of the contained moisture is atomized and carried away by the airstream. Solids fall from the bottom of the container (fig. 12–88).

Tests run on poultry, swine, dairy, and beef feedlot manure indicated that, on average, the moisture content could be reduced by 30 percent. However, the system experienced plugging problems due to the inconsistent makeup and moisture content of the manure.

**Figure 12–86**    High-capacity drying tunnel (*Drawing courtesy Big Dutchman, Inc.*)



Dosing station

Maunre belt drive

Chopper
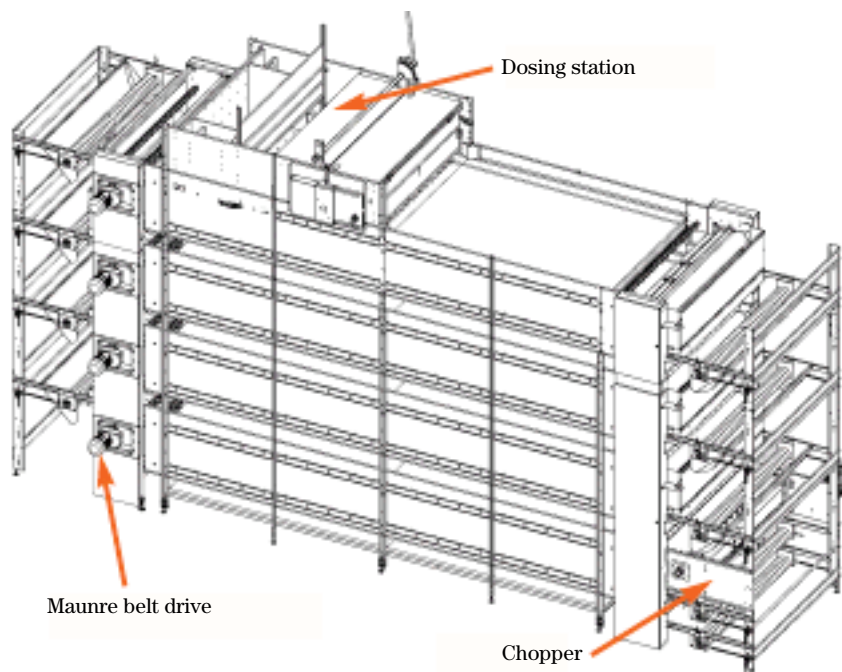
**Figure 12–87** High-capacity drying tunnel installation (*Photo and drawing courtesy of Big Dutchman, Inc.*)
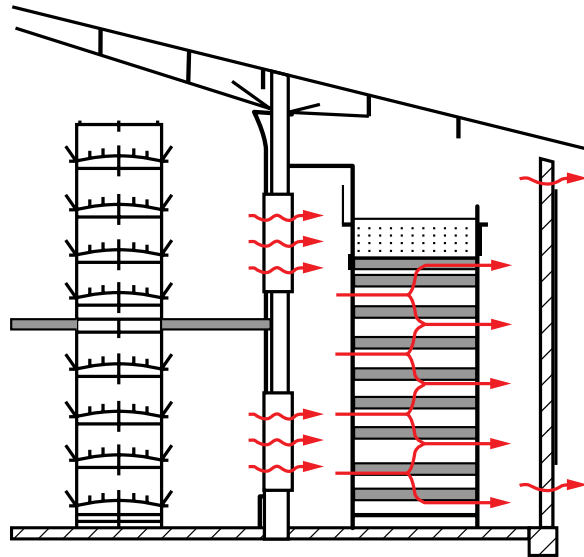


**Figure 12–88** Cyclone dryer (*Photo courtesy of Global Resource Recovery Organization*)

## (f) Incinerators

Incineration equipment is used for destroying dead animals and poultry. This equipment is useful for animal disposal and disease control with confined livestock production and animal health care operations. Incinerators are fueled by liquefied petroleum (LP), natural gas, or fuel oil (#2 diesel oil). They utilize an electric blower to reach temperatures of 1,700 degrees Fahrenheit or higher. Some have second burners on the exhaust for more complete combustion. Most now have automatic ignition and timers to save fuel. Incinerators are available for a 100- to more than 850-pound animal load capacity (fig. 12–89). Suggested incinerator size is that needed to handle one day of animal loss. Burner capacity and door size affect actual use. CPS Code 316, Animal Mortality Facility provides criteria for mortality incinerators. An air-pollution approved incinerator has high investment and operation costs. These incinerators use 3 to 7.2 gallons of LP, 275 to 660 cubic feet of natural gas, or 2.5 to 3.5 gallons of fuel oil per hour. Regular maintenance, cleaning, and ash disposal are required.

## (g) Gasifiers

Gasifiers are also being used in some locations for animal mortality management. A gasifier looks similar to an incinerator, but the process is different in that it takes place in an oxygen starved environment that converts biomass (animal mortalities) to biogas. An outside fuel such as LP or natural gas is used to begin the process. Gasifiers have two chambers: a primary chamber where the biomass is loaded; and a secondary chamber where the supplemental fuel and recirculated biogas is used to create temperatures of 1,470 to 1,830 degrees Fahrenheit. Mortalities are placed in the primary chamber. Heat is transferred from the secondary chamber to the primary chamber through the hearth plate. Biogas is produced as the biomass (animal carcasses) break down in a low oxygen environment. The biogas is used to supplement the outside

**Figure 12–89**    Incinerators for animal mortality management (*Photos courtesy of Agile Mfg., Inc., Anderson, MO, a Subsidiary of CTB, Inc., and R&K Incinerator Co.*)

fuel which reduces the volume of outside fuel required for the process (fig. 12–90). Since it is more efficient to process larger amounts of biomass at one time, a complete system would include the gasifier as well as a refrigeration unit to store mortalities, and a roofed structure to protect the equipment (fig. 12–91). A gasifier has a higher initial cost than an incinerator, but offers the following advantages:

**Figure 12–90**     Gasifier cross section (*Photo courtesy of Brookes Gasification Process (BGP, Inc.)*
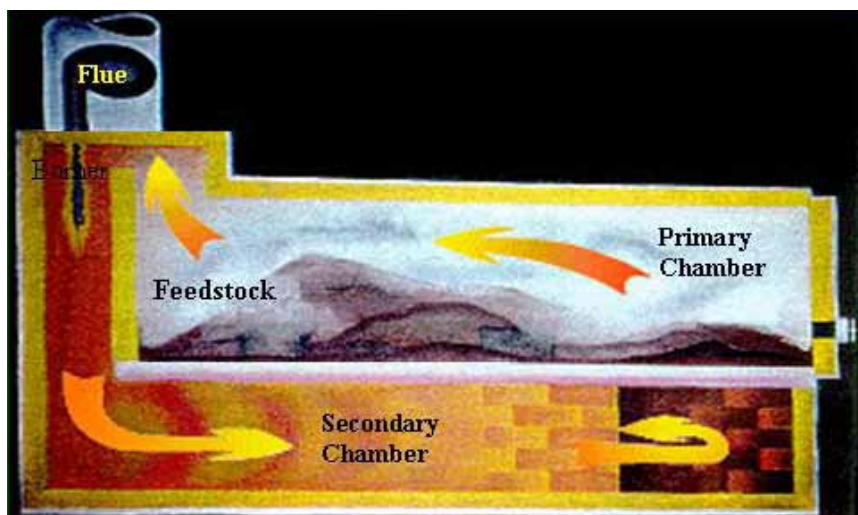


**Figure 12–91**     On-farm gasification system (*Photo by Jeff Porter, NRCS*)
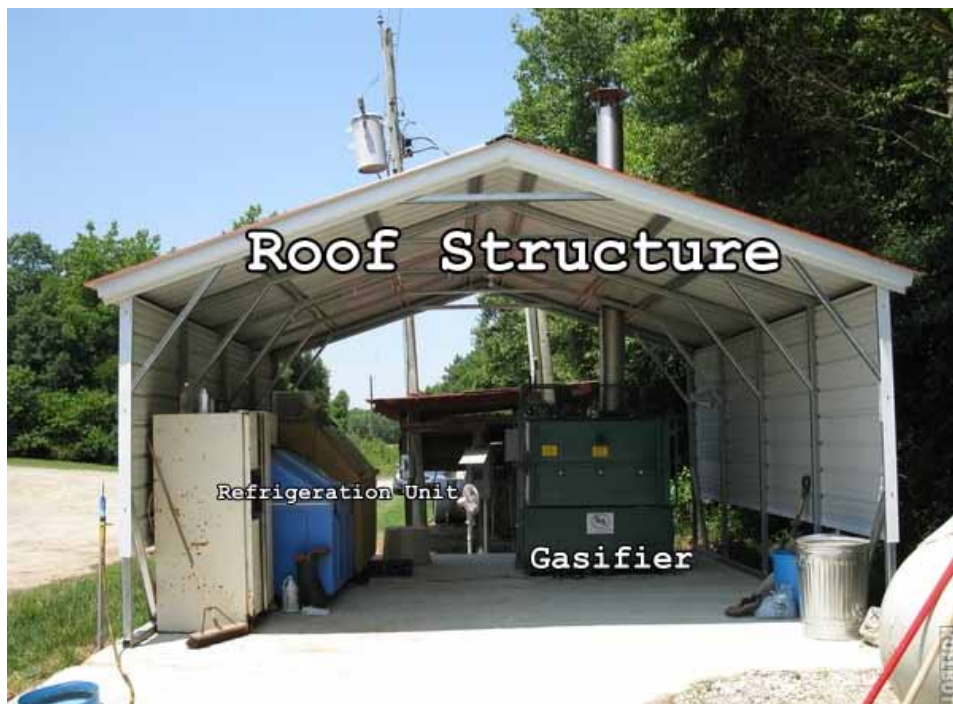
- particulate matter emissions reduced by nearly 90 percent

- other emissions reduced by approximately 50 percent

- fuel consumption reduced by at least 50 percent

The ash produced by the process is inert and contains no bacteria, viruses, pathogens or antibiotics. It contains concentrated nutrients including phosphorus, potassium, and calcium and can be used as a fertilizer. Most of the carbon and nitrogen are discharged through the emissions of the process.

## (h) Pyrolysis

Pyrolysis and gasification are related processes of heating with limited oxygen. In fact, pyrolysis is the first step in the gasification process and ideally would take place in total absence of oxygen. In reality, it is not possible to create an environment totally free of oxygen so the process normally occurs in conditions of extremely limited oxygen availability, lower than that of gasification. As a result pyrolysis produces not only syngas, bio-oil, and ash, but also biochar which is similar to charcoal. The process has been used to make charcoal since ancient times. Recently, fast pyrolysis, which reduces the production of syngas and increased bio-oil, has been used to process poultry litter. Pyrolysis equipment used for treatment of agricultural waste is similar to that used for gasification and is generally based on one of the following processes:

- Augers—hot sand and biomass particles are fed at one end of the auger which mixes the sand and biomass and moves them along.

- Rotating cone—pre-heated hot sand and biomass particles are introduced into a rotating cone.

- Fluidized bed—biomass particles are introduced into a bed of hot sand fluidized by a gas, usually a recirculated product gas (syngas).

- Circulating fluidized bed—biomass particles are introduced into a circulating fluidized bed of hot sand.

For agricultural waste, the process typically operates in a temperature range of 840 to 1,000 degrees Fahrenheit. There have been a number of demonstration and full scale projects implemented in the United States

and around the world. To date, the projects have met with limited success, but the process is worth mentioning here since it is likely to become a more common practice as energy prices increase, equipment is further refined, and environmental regulations related to land application of untreated animal waste become more stringent.

# 651.1207    Waste utilization equipment

Manure can be and has been utilized in many different ways, including, compost, fuel for power generation, production of biogas, production of oil, an organic based commercial fertilizer, recycled as bedding material, organic planting pots, and even a building material. However, it is most frequently used to return organic matter and nutrients to the soil for crop production, i.e., land application. Land application is reviewed in chapters 10 and 11 of this handbook, and biogas production in chapter 10. Pyrolysis (a chemical change brought about by heat), and using waste as fuel are other alternatives, but they have limited applications to date (Annamali et al. 1985; Landen 1992; MWPS 1985). With the exception of poultry litter, direct selling of raw waste is seldom done as timeliness, costs, weed seeds, and disease or organism spread are problems (Clanton 1993).

All of the various uses have different pieces of equipment associated with them many of which have been covered in previous sections of this chapter. An attempt to cover each different piece of equipment used for each purpose would result in a nearly endless list. Therefore, with the exception of a brief section on biogas production equipment, this section will primarily cover equipment used for land application since that method of utilization far exceeds all others.

## (a)  Hauled waste spreading equipment

Hauling or pumping of agricultural waste depends primarily on the per cent solids content of the specific waste being handled. The classification also depends to a certain extent on the livestock species under consideration with the categories being solid, semisolid, slurry, and liquid (fig. 12–92; also see ch. 9 of this handbook).

Solid and semisolid manure is generally hauled to the field and surface spread with incorporation being done some time later using some form of tillage such as a disk or chisel plow. Slurry manure is sometimes hauled to the field, but it can also be pumped using a dragline hose or a stationary or traveling big gun-type irrigator. Some of the hauling and dragline equipment

is set up to directly inject the material into the soil. Slurry applied by pumping is frequently left on the surface, although it should be incorporated into the soil as soon as possible to reduce odors and conserve nutrient value of the manure. Liquid manure also is sometimes hauled, although it is not generally cost effective, but more frequently it is pumped and irrigated using conventional irrigation equipment such as a gated pipe or hand-move, towline, side-roll, or center pivot irrigation equipment with specially designed nozzles.

### (1)  Surface spreading equipment
Equipment used to haul and field spread includes:

- box spreader with floor conveyor/rear beater unload

- V-bottom box spreader with side or rear unload

- flail spreader

- V-box rear unload broadcast spreader

- tanker spreaders

Over the last several years, larger capacity and faster equipment to haul and more uniformly spread solid, semisolid, slurry, and liquid wastes at an optimum time of year have been developed.

This and a growing need for field spreading at sites more distant from the waste production source add to hauling and spreading concerns and influence individual equipment selection.

Decisions about spreading equipment size or type depend on cost, amount and consistency of waste to be handled, haul distances, available spreading time, size of available tractor or truck power and braking, facility door or gate opening sizes, loading height limits, equipment warranty and service, and desired options (splash covers, type of power drive, wheel type, and tire size).

Renting or leasing of hauling, pumping, and spreading equipment can be advantageous for a few days use per year. This affords a way to try different equipment and to maximize the use of limited operating capital. Rental costs can be competitive to annual costs for private ownership of limited-use equipment when all aspects are considered. Another option is to share hauling and spreading equipment with a nearby operator. Compat-

ibility and condition of shared equipment and competition for its use by others are considerations.

Hiring a contractor, commonly called a custom applicator, to load, haul, pump, and spread waste is increasingly common. Although the cost may seem high, when the costs of ownership of equipment that needs to be maintained and the labor required for the producer to apply the manure himself are calculated, it may actually be more cost effective. In addition, application by skilled professionals using high quality equipment may result in better application and more effective use of nutrients.

**(i) Box spreader**
The traditional rear-unload box spreader remains popular for hauling and spreading semisolid and solid waste (fig. 12–93). This equipment requires a relatively low investment and is simple to use. For frequent waste cleanup of small areas and small to average-size operations, hauling and spreading waste in a towed box spreader as a solid material is relatively more convenient and practical than pumping or irrigating the waste. Hitching and filling a box spreader involves less equipment and expertise to organize and operate than does agitation, connecting pipelines, pumping, and using an irrigator. This convenience can affect waste utilization as well as sanitation and appearance of facilities.

**Figure 12–92**  Relative handling characteristics of different kinds of manure and percent total solids
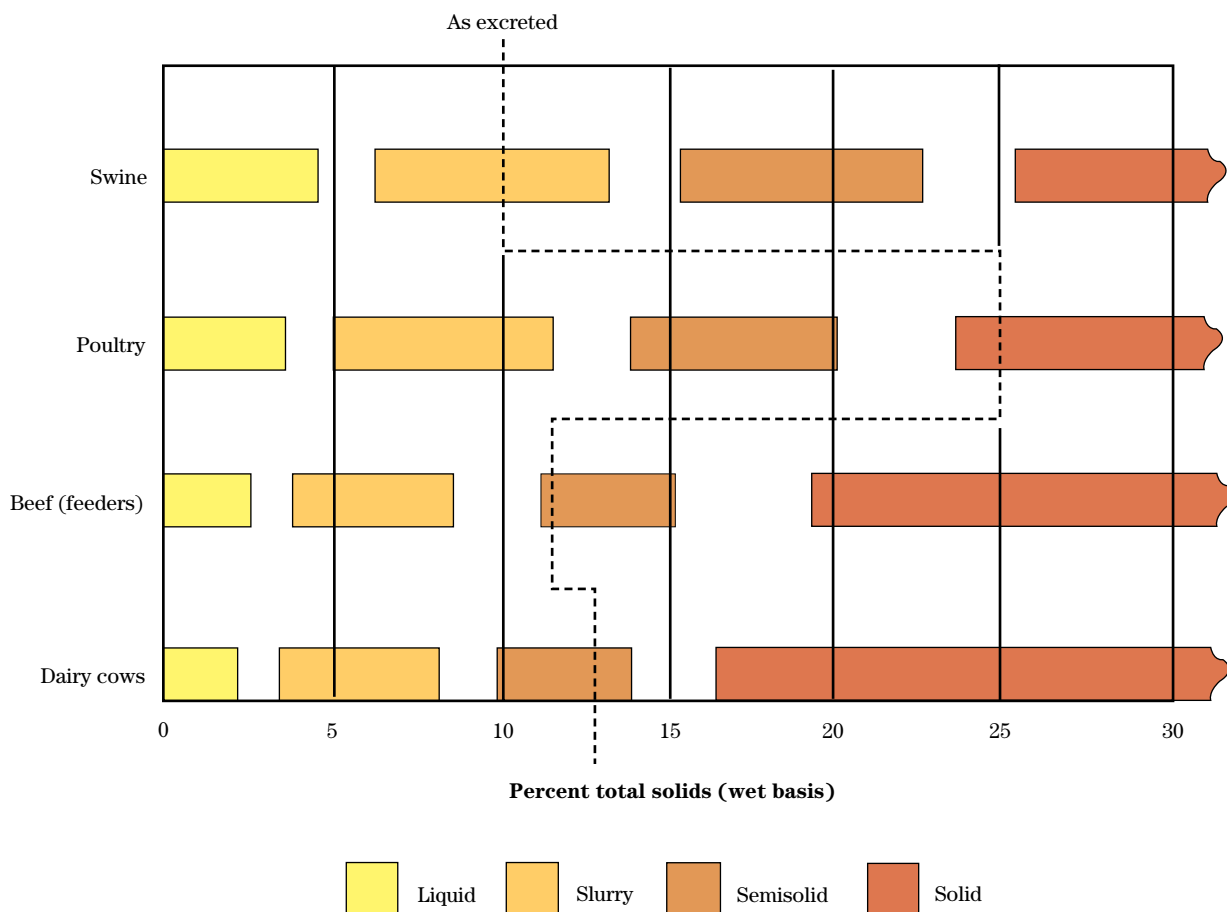
The load capacity of tractor-tow and truck-mounted box spreader models ranges from less than 20 to more than 900 cubic feet on some truck-mounted models. The ASABE Standard ASAE S324.1, Volumetric Capacity of Box Type Manure Spreaders (ASABE [f] 1986(R2008)), is used by manufacturers to provide uniform load capacity ratings (in cubic feet) of different box spreader models. Some advertising materials, however, use bushels, gallons, or tons. See Conversion Factors and Tables of this handbook.

Box spreaders move the manure to the beaters in the rear by one of two methods: a cross-bar chain driven conveyor style system (fig. 12–94) or a hydraulic gate (fig. 12–95) that pushes the manure into the beaters.

**Figure 12–95**    Hydraulic gate-type box spreader (*Photos courtesy of Pik Rite, Inc.*)



**Figure 12–93**    Box spreader (*Photo by Bill Boyd, NRCS*)





**Figure 12–94**    Cross bar conveyor box spreader (*Reprinted with permission of New Holland Agriculture*)

Each of these systems has advantages and disadvantages depending on the type and consistency of the manure being handled. In most cases the conveyor and beaters are driven by the tractor PTO, but in some particularly older models, they are driven by the spreader wheels. Beaters are normally mounted horizontally, but spreaders with vertical beaters are now also being produced (fig. 12–96). According to one manufacturer, the vertical configuration results in a more consistent wide spread pattern and better material break up than the horizontal configuration. Application rates are controlled by the forward speed of the tractor and the speed at which the conveyor or hydraulic gate push the manure into the beaters.

Although best suited for handling of solid manure, a modern box spreader's hydraulic-powered push-end gate unload, beater pan cover, and inward-curved front and side extensions aid cleaner hauling and more uniform spreading of slurry and semisolid wastes. V-bottom and tank spreaders are generally a better choice for handling slurry manure.

Once made of wood, box spreaders are now made of corrosion resistant or treated steel. A polyvinyl plastic plank or glass fiber-sheeted box interior liner aids unloading; however, plastic materials may not be durable in some applications.

Tractor front-end loader damage to a spreader box is a problem in addition to rusting. For older spreaders that have wooden floor planks, rotting is also a problem. Such deterioration and other repair are minimized by careful use, regular cleanup, lubrication, and shelter from weather

There has been limited research on application systems for solid and semisolid manure as compared to liquid and slurry systems, so most of the development of spreader-beater design in the United States has come from field experience. The high/low rear beater configuration on box spreaders that is used to loosen solid waste and move it onto a rotating-spiral distributor beater has given way to a simpler rear shredder that is larger in diameter and has a widespread combination beater. The high/low beater configuration remains popular for large-capacity, truck-mounted box spreaders, but there are also truck-mounted units with the vertical beater configuration (fig. 12–97).

**Figure 12–97**  Truck-mounted box spreader (*Photos courtesy of Farm Shop, Inc.*)





**Figure 12–96**  Box spreader with vertical-mounted beaters (*Photo by Bill Boyd, NRCS*)

Several manufacturers make box spreaders that can be mounted on a trailer to be towed by a tractor or on a truck frame. The advantages of truck spreaders are potentially greater capacity and faster transport to the application area when longer distances are involved.

Hydraulic-lift dump trucks designed to haul gravel and grain can also haul poultry litter and other types of solid manure. Typical capacities of dump trucks used in agriculture range from 4 to 12 cubic yards. Actual weight or volume of waste hauled depends on the waste characteristics and the dump box design. Use should be limited to solid or semisolid manure as most dump truck boxes are not designed to contain slurry or liquid. Material should be covered for road use. Dump trucks should be used for hauling only. Unless modified to accommodate spreading, such use results in poorly distributed, inconsistent application.

**(ii) V-box bottom spreader**
The V-box bottom spreader evolved from a similar rear-unload fertilizer spreader (fig. 12–98) and the side-discharge flail-type spreader (fig. 12–99). The V-bottom fertilizer spreader is most frequently mounted on a truck. It has a variable speed chain driven conveyor on the bottom, similar to box spreader, to deliver the granular material to the rear of the box where it is spread by single or twin high-speed horizontal rotating discs. The flail-type manure spreader consists of a horizontal semicircular tank that is open on the side. It has a PTO-powered central shaft with chains attached about every 6 inches along the length of the shaft. There are hammers attached to the chains, which

when rotated at high speed, sling the manure out of the side. Although there are likely some of these types of spreaders still in operation, they are no longer being manufactured. They are not very effective in spreading liquid slurry manure, have limited capacity and a high power requirement, and poor application uniformity, especially in windy conditions.

V-box bottom spreaders, also referred to as "slingers" currently being manufactured more closely resemble a fertilizer spreader than a flail-type spreader. However, instead of the conveyor in the bottom of the box, they usually have an auger or multiple augers to move the manure to the discharge which is located either on the side (fig. 12–100) or the rear of the spreader (fig. 12–101). An advantage to the rear discharge is reduction of material that may be thrown onto the towing tractor, especially in windy conditions, while an advantage of the side discharge is that it can be used for multiple purposes such as bedding distribution. In addition to moving the manure to the discharge, the augers help to break up clumps in the manure. Models range in size from 200 to more than 1,000 cubic feet for commercial models with corresponding tractor power requirements of 60 to 160 horsepower.

Although these types of spreaders can handle all types of manure, they are most well suited for solid, semisolid, or slurry manure. They will handle liquid manure, but a fully enclosed tank spreader would be a better choice especially if waste is going to be hauled any distance.

**Figure 12–98**    V-bottom rear-unload broadcast spreader (*Photo courtesy of Denair Trailer Co.*)



**Figure 12–99**    Flail-type side unload spreader (Bartok 1994) (*Photo courtesy of Ideal Industries, Inc.*)

**Figure 12–100**   V-box bottom, side slinger spreader (*Photos courtesy of Gehl company and H&S Mfg.*)
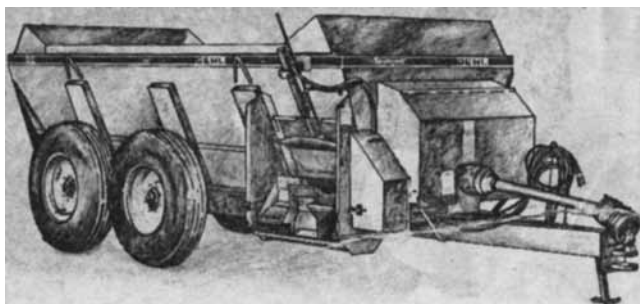






**Figure 12–101**   V-box bottom, rear spreader (*Photo and drawing courtesy of Meyer Mfg. Corp.*)
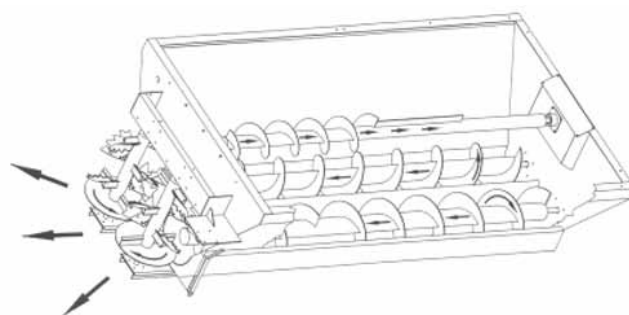
### (iii) Tank-type spreaders

Manure that is approximately 4 percent solids or less is liquid and is best handled with a tank-type spreader if it is going to be hauled. Tank spreaders are also frequently used to handle slurry manure. A tank spreader is basically a steel tank that is mounted on running gear (frame and wheels) to be towed by a tractor or mounted on a truck. While there are other features that set tank spreaders apart, there are primarily two types based on the method by which they are loaded.

The first type requires a separate pump for loading and is frequently referred to as a spreader tanker (fig. 12–102). Spreader tankers are available in sizes from 1,000 to 12,000 gallons for single tank spreaders. One manufacturer makes a unit that allows coupling two smaller tanks together for a total capacity of 15,000 gallons (fig 12–103). The guide for uniform tanker capacity rating (in gallons) among manufacturers is the ASAE Standard S326.1 Volumetric Capacity of Closed Tank Type Manure Spreaders (ASAE [h] 1989 (R2009)).

Options, such as tanker agitation, inside tank access, wheel arrangement and size, injector spreader distributor, and other accessories, can increase the investment cost for this equipment. A sight-glass or other type of level indicator on the tanker, for example, permits ready observation of the tanker content during filling and emptying. A PTO or hydraulic motor-powered recirculating pump or floor auger may be used to continually agitate the contents, which would aid in more uniform spreading, especially with injector spreading. Some models use a spreader discharge located at the top-rear of the tanker. This discharge is supplied by the tanker agitation pump to assist with a wider broadcast spread. This arrangement also minimizes dripping and accidental tank unload. In spite of these benefits, odor concerns have caused most manufacturers to return to unloading at the bottom of the tank if the manure is going to be surface applied. Interior tank access for loading, cleaning, and repair through a top hatch door is simplest; however an end door has minimum hazard for inside air and gas ventilation and is more convenient for repairs.

The second type of tanker used to haul and spread slurry and liquid wastes includes an integral PTO or hydraulic motor-powered air-vacuum pump for loading and unloading (fig. 12–104). For more information on this type pump, see sections 651.1204(b)(2). The addition of this pump makes an "all-in-one" unit. To load the tanker, the vacuum pump empties air down to a pre-set level out of the airtight tank. A transfer hose is then inserted in the stored waste, the load valve is opened, and the waste is drawn up into the tank. The hose is 4 to 6 inches in diameter and 25 feet long. It is made of hard rubber and is relatively stiff. A loading rate at about 200 to 300 gallons per minute is limited to a vertical lift of no more than 12 feet.

**Figure 12–102**    Spreader tanker (*Photo by Bill Boyd, NRCS*)



**Figure 12–103**    Spreader tankers in tandem (*Photo by Bill Boyd, NRCS*)

Although a separate agitation pump is more effective, the vacuum tanker can be used to agitate stored liquid waste by first loading the tanker, then switching the vacuum pump to pressure mode, pressurizing, and then unloading the full tanker load back into the storage. Tanker capacity and size, running gear options, and spreading aids are similar to those of the pump load spreader tanker.

Both types of towed spreaders are now being constructed with tandem wheels mounted with flotation tires to reduce soil compaction and axle load. Some of the larger models have three and even four wheels in tandem on each side of the spreader. Load per axle is usually kept below 12 tons. In comparison, a 600 bushel grain cart may have axle loads as high as 20 tons. Tandem wheels are not, however, without problems. Sharp turns cause extreme axle stress. To address this issue, some manufacturers have developed spreader wheels that turn when the tractor turns (fig. 12–105).

It is not efficient or cost effective to use a towed tanker-type spreader to haul manure very far on the road to get to the application area. To speed up hauling and spreading liquid or slurry waste to distant fields, a semitrailer nurse tanker is used to haul waste from the storage to the towed tank spreader in the field (fig. 12–106). This not only shortens the time it takes to get the manure to the application area, it allows the tractor towed tank spreader to continue working while the semitrailer returns for another load.

Safety precautions need to be taken in the operation of tractor towed tanker spreaders. Safety hazards are related to limited operator view, relatively slow speed, heavy braking needs, and potential for overturning and spillage. Tank-type spreaders continue to get larger challenging the capacity and weight of the tractor required to tow them. Mechanical or hydraulic brakes have become standard on larger models. Still, a high degree of experience and expertise is needed to operate and control the equipment. A moderate sized tank spreader that hauls approximately 5,000 gallons of manure weighs about 26 tons and a minimum 150 horsepower tractor weighing about 17 tons to oper-

**Figure 12–105**  Tank spreaders with directional wheels (*Photo courtesy of GEA Houle, Inc.*)



**Figure 12–104**  Vacuum tank spreader (*Photo courtesy of Calumet*)



**Figure 12–106**  Towed tank spreader being filled from semitrailer nurse tanker truck (*Photo courtesy of Jim Hodel, Inc.*)

ate safely if the spreader does not have brakes. Table 12–10 provides recommendations for spreader capacity and power need. ASAE Standard S318.17 provides guidelines for operation of towed equipment without brakes. A surge trailer brake is designed for forward motion and may not function if the tractor power fails going uphill (ASAE [e] 2009).

Self-propelled tanker spreaders that have large flotation tires are designed to haul large loads for several miles or to use on soft soil (fig. 12–107). Most of these tankers have self-contained, high-capacity vacuum pumps and extra options that are not available with towed tanker models. Sizes range from a 2,000- to more than a 5,000-gallon capacity with advertised spreading rates of about 15,000 gallons per hour with reasonable loading and haul conditions. Operator comfort, control, safety, and day or night operation are favorable features. Year-around use, such as that done by custom operators, can justify the needed investment.

Broadcast spreading waste from either tanker spreader can use a gravity baffle or splash plate or a powered rotating distributor (fig. 12–108). Models that use tanker pump agitation pump contents up and spread them from the top rear of the tanker, which allows more uniform spreading. The agitation pump is generally located under the tanker rear outlet. A hand or hydraulic-operated gate valve is adjusted open to empty the tank. Soil injection spreading is done with either tanker as explained in section 651.1207(2).

**Figure 12–107**  Self-propelled tanker spreader (*Photo Bill Boyd, NRCS*)



**Figure 12–108**  Baffle plate distributor on tanker spreaders (*Photos courtesy of J-Star and Badger Northland, Inc.*)
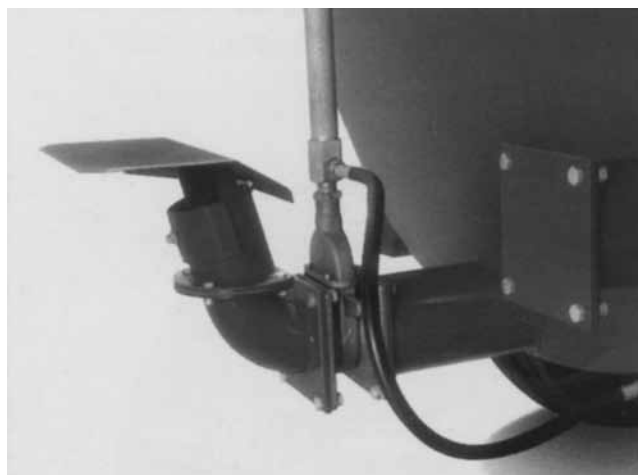


**Table 12–10**  Approximate waste spreader and tractor sizes (NE Dairy 1977)

| Box spreader heaped capacity (ft³) | Minimum tractor horsepower | Tanker capacity (gal) | Minimum tractor horsepower |
|---|---|---|---|
| 150 | 40 | 800 | 60 |
| 200 | 60 | 1,000 | 75 |
| 250 | 75 | 1,500 | 80 |
| 310 | 85 | 2,250 | 90 |
| 390 | 100 | 3,250 | 100 |
| 470 | 130 | 4,000 | — |

Uniform spreading by gravity flow out of a tanker is difficult. The solids can partly block the tank discharge or less waste will flow as the waste depth in the tank decreases. Also, as the load lessens, travel speed changes. Equipment manufacturers have addressed by including computers in the tractor cab that monitor and adjust ground speed and discharge rates using electronic and hydraulic controls on the spreader discharge. Some are also using global positioning systems (GPS) to automatically adjust application rates based on soil productivity classes in the application area. Generally this more sophisticated technology is used when manure is being injected rather than surface spread.

Overall construction strength is critical for a tanker spreader, especially where it has attached soil injector spreading. Generally, 1/4-inch-thick corrosion resistant plate steel (painted) is used to construct the tank. Some manufacturers have started using galvanized steel tanks. As vacuum tanker spreaders age and corrode, too high of an evacuation of the tank can cause an end or side to collapse inward if the evacuation overload control device malfunctions. Regular maintenance, cleanup after use, and covered storage extends tanker life and increases trade-in-value.

Vacuum pumps, moisture traps, pipe couplers, tires, and power shafts need regular attention. Shops that specialize in tanker repair report that a vacuum tanker regularly used for swine waste typically has about a 10-year life. The pump and running gear frequently outlast the tank, although adjustable wheel types (for different row crop spacings) and broken wheel spindles have been problems. Pump seals, vanes, and valves may need replacement depending on the level of regular maintenance provided.

Handling liquid and slurry manure with low solids content can be a high cost option if application areas are located many miles from the production area. Dairy and swine operations that use flushing-type systems produce large volumes of waste with low nutrient concentrations. Capital investment in spreading equipment is high as are power requirements to handle the equipment. Labor and time inputs are also high due to the slow travel speeds in getting to the application areas. In spite of continuing development of equipment to address these issues such as use of "nurse tanks," application costs may greatly exceed value of manure. Producers who find themselves in this situation should probably consider other options such as liquid-solid separation prior to application with recycling of liquids or employment of custom applicators to reduce labor inputs, capital investment, and operation and maintenance costs of equipment. Producers with application areas closer to the production facility might want to consider the drag hose technology covered in the next section.

**(2) Soil injection equipment**

Injecting (also called knifing or chiseling) liquid and slurry waste 3 inches or more into the soil minimizes odor and nutrient losses (Goodrich 1993). Nitrogen loss is significant within 4 to 6 hours after broadcast surface spreading. Chapter 11 of this handbook gives more detailed information on this loss. Injection is necessary, for example, when a nitrification inhibitor is added for N loss reduction of waste or when anhydrous ammonia is added to waste to enhance the N content and better suit crop needs (Sutton, Nelson, and Jones 1983).

Traditional injector spreader equipment can be used on a tanker spreader (figs. 12–103 and 12–107) or directly injected with tractor-mounted toolbar equipment when waste is pumped to the field. A tanker needs the framework constructed for the twisting, bending loads from the attached injectors. Typically, two to six or more injectors are mounted at the rear of a tanker about 2 feet apart. In the past, injectors were sometimes mounted at the front of the tanker or on a toolbar attached on the tractor pulling the tanker to improve depth control, traction, and the operator's view. However, this arrangement interferes with hitching and maneuvering. Also, the pressure of the tractor wheels on the injected soil forces out some of the injected waste, which defeats the purpose of injection. Staggered injector shanks reduce trash plugging, and injector shanks that swivel can make short turns. Some models use adjustable injector depth gage wheels. Most use hydraulic lift to raise or lower the injectors.

The soil surface moisture, field topography, and travel speed affect the power needed to pull a loaded tanker. Injector load is also a consideration and is affected by injector design and operating depth. Figure 12–109 can help to estimate power needs. For example, to pull a loaded 3,000 gallon tanker with four injectors running 4 inches deep in plowed soil at 3 miles per hour would require 80 horsepower $[42 + 10 + (7 \times 4)]$. A Purdue

University study determined an additional 18 horse-power per 8-inch-deep chisel injector was needed at 4 miles per hour. The added power and injector ownership costs were more than offset by the reduced N volatilization loss (Dickey 1978).

Over-application of waste, especially with vertical knife injectors running 8 to 14 inches deep, allows liquid to ooze out and up and then run downhill. Large rocks and hard soils hamper injector depth control, especially where wide blades are used. In loose soil with few stones, shallow-running 1- to 2-foot-wide sweep injector shovels (fig. 12–110) distribute waste out more evenly and use less power.

Disc injector equipment (fig. 12–111) was developed to improve distribution and waste coverage and to re-

**Figure 12–110**     Injector with sweep (*Photo courtesy of Husky Farm Equipment Limited*)



**Figure 12–109**     Approximate power for tanker and per injector (FIS 1974)
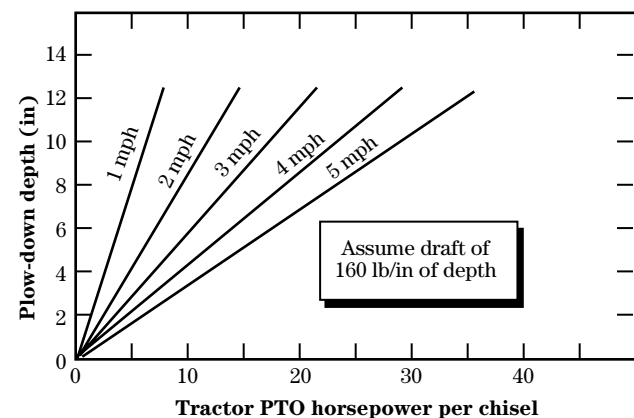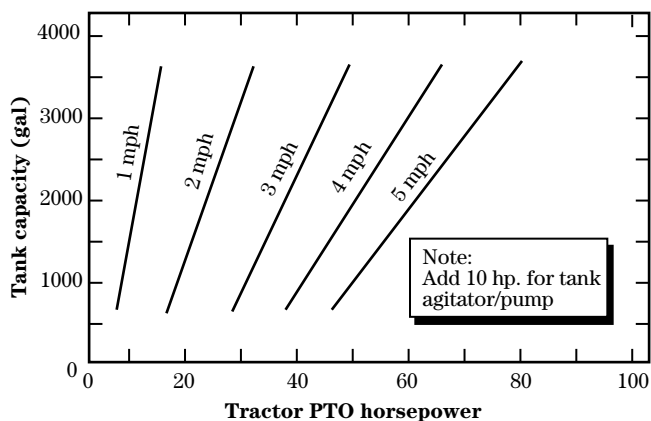


**Figure 12–111**     Vertical disc covers for injected waste (*Photos courtesy of GEA Houle, Inc.*)
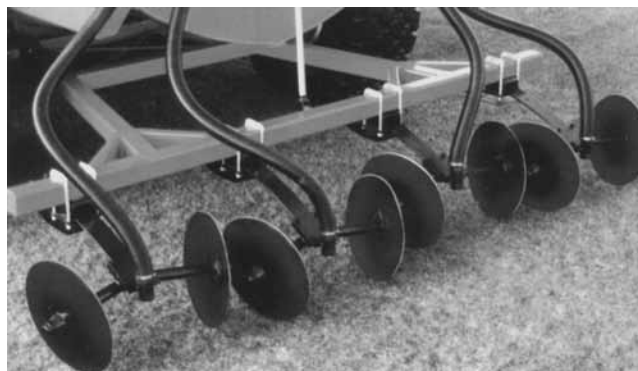
duce power. Rather than a sweep shovel or knife injector, one design uses a gang of convex, fluted-edge disc blades that rotate horizontally under the (soft) soil surface. The waste is injected under the blades as they are pulled along. The blades are 2 feet in diameter. Another design uses two convex disc blades mounted vertically and slightly angled to the travel direction. The manure is covered as it is injected into relatively soft soils.

The effect on crop residue and conservation tillage where wastes are injection spread should be considered. European research has found covering and soil mixing advantages where double press wheels are run behind injector spreaders used in moist sod. Some European countries require municipal sludge be injected when spread, so injecting in sod is common (Warner 1988). Additionally, some European countries require injection of manure to control ammonia emissions. Innovative injection techniques successfully inject slurry to a depth of 2 inches or less with minimum power requirements (Hujsmans 1994). In the United States, several companies are producing equipment to address the apparent incompatibilities of injection and no-till/minimum till. One piece of equipment minimizes soil disturbance by cutting a slot with a single toothed disc, using drop tubes to place the manure into the slot

and then closing the slot with two angle disc also with teeth (fig. 12–112). Another one uses a row of spiked ties, spaced at 3.75 to 7.5 inches apart, to loosen soil and create "pockets of storage" for the manure that is place on the surface using drop tubes. Drop tubes can be set up in front of or behind the tines (fig. 12–113).

## (b)  Pumped waste spreading

As previously mentioned, hauling liquid and slurry wastes long distances using tank spreader-type equipment has several drawbacks. Given that, producers and custom haulers are increasingly moving into drag hose technology. Towed hose systems move manure from storage to field using a pump, pipeline, and soft

**Figure 12–113**  Spiked tine applicator used to minimize soil disturbance (*Photos courtesy of SAF-Holland and Hydro Engineering, Inc.*)





**Figure 12–112**  Disc-type manure injector used to minimize soil disturbance folded for transport (*Photo by Bill Boyd, NRCS*)

hose that is pulled behind the tractor and application equipment (fig. 12–114). The application equipment includes a solid swing pipe (to allow turning) that is hydraulically damped to which the soft hose is attached for delivering manure to either surface or injection components (fig. 12–115). A pump located at the storage facility pumps the manure through a supply pipe which may be solid aluminum irrigation-type pipe, rigid plastic pipe either on the surface or sometimes buried underground, or a flexible plastic pipe also known as "hard pipe" that can be laid out using a large hose reel (fig. 12–116). The supply pipe is usually 3 to 6 inch diameter, although larger or smaller diameter pipes are sometimes used depending on the size of the pump and the pipe material. A flexible, reinforced "soft" pipe, similar to a fire hose is attached

**Figure 12–114** Tractor-towed hose injector spreader (*Drawing and photo courtesy of Hydro Engineering and Dr. P. Goodrich, Univ. of MN*)



**Figure 12–115** Tractor with drag hose application equipment including swing pipe (*Photo by Bill Boyd, NRCS*)



**Figure 12–116** Hose reels for supply line and drag hose (*Photos by Bill Boyd, NRCS*)
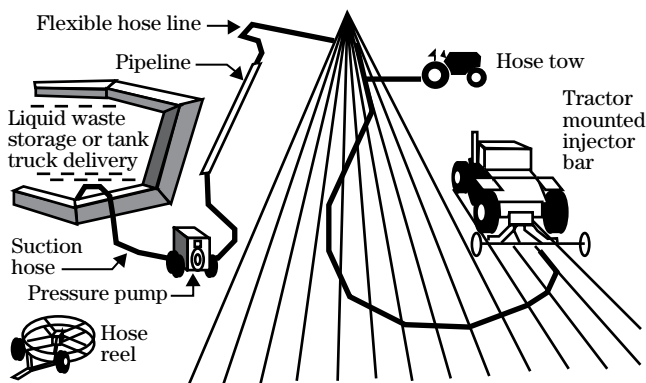
to the supply line on one end and to the swing pipe on the applicator. That is the drag hose and is normally 4.5 or 5 inches in diameter. There is usually a swivel connection at the swing pipe, to which the drag hose is attached, in order to allow the tractor to turn without twisting the drag hose . When first developed, the drag hose was 660 feet long which allowed application of manure on approximately 20 acres with one set or placement of the supply pipe. Longer drag hoses are now available that allow application on up to 65 acres on one set. One manufacturer produces a system that allows using the hard hose as the drag hose allowing application on up to 105 acres per setup. It is a good idea for at least two people to operate the system, one to watch the pump and supply line and the other to operate the tractor and drag hose equipment. The two should have a method of communicating in the event a pipe breaks or any other malfunction occurs. Even if there are two people available, the pump should have an automatic shut-off in the event there is a sudden pressure drop due to a broken pipe. Most systems have a foam ball or cylinder also know as a "pig" that can be pushed through the pipe using a hydraulic compressor or "pig launcher" to clean it out before rolling up the pipe to store it when finished (fig. 12–117). Manure can be surface applied or injected using this equipment. A flow meter on the application equipment allows the operator to know the flow rate of manure being delivered to the system so that the travel speed of the tractor can be adjusted to obtain the proper application rate.

**(1) Surface application equipment**
The equipment used to surface apply manure using the drag hose  system is the same as that used to surface apply manure using a tank spreader, except the manure is delivered to the applicator by the pump at the storage area instead of by the tank. The application equipment is either mounted on a tool bar that attaches to the tractor by the three-point hitch or it is on a frame with wheels that is towed by the tractor. The tool bar mount is relatively simple with two or more nozzles which can apply manure in a 20- to 50-foot-wide pattern. At least one manufacturer produces nozzles with hydraulically controlled splash plate. The distribution pattern of the manure is changed by raising or lowering the splash plate (fig. 12–118).

**Figure 12–118**  Drag hose surface applicator (*Photos courtesy of Cadman Power Equipment and Farmstar, Inc.*)



**Figure 12–117**  Pig launcher cart (*Photo courtesy of Farmstar, Inc.*)

## (2) Soil injection equipment

As with the surface application equipment, the application equipment for the drag hose system is the same as that used with the tank-type spreaders. As previously noted, manure is delivered to the application equipment through the drag hose attached to the swing pipe which is in turn connected to a manifold for distribution through tubing to each of the injectors (fig. 12–119). The pressure coming into the manifold is normally between 15 and 20 pounds per square inch. Uniform distribution of manure in the field is essential to good nutrient management so it is critical that the manifold deliver an equal volume of manure to each of the injectors. Application units may have 4 or as many as 16 injector units applying manure from a 6- to 50- foot spreading width (fig. 12–120).

When directly injecting, a 5- to 6-inch diameter soft hose connected between the pipeline and the field spreading hose, which is 4 to 6 inches in diameter, aids flexing and reduces pumping friction. About 40 acres are covered at one hose setting. A strong, durable hose is needed to withstand the rubbing and turning friction. Attaching the field spreading hose to a distributor manifold that has a leak-proof swivel head on the injector equipment assists turning at field ends, which is difficult with pressurized flow. Waste pumping rate to the injectors needs to be suited to the number of injectors, field travel speed, and soil nutrient needs.

**Figure 12–120**    Drag hose injector (Photo by Bill Boyd, NRCS and courtesy *of Hydro Engineering, Inc.*)





**Figure 12–119**    Distribution manifold (*Photo courtesy of Cadman Power Equipment*)

## (c) Irrigated waste application equipment

Section 651.1204(b) explains characteristics of pumps and pipe used for waste transfer. Slurry waste with up to 10 percent solids can be pumped through a pipeline for several miles to storage or field spreading via gated pipe, irrigator, or towed injector. Less than 10 percent solids is preferred. Agitation before and during pumping is essential to break up and keep solids suspended. Solids sedimentation in low areas of the pipeline and irrigator nozzle clogging are problems. Chopper-agitator pump action and a grinder attachment on the high-capacity centrifugal pump can break apart and help suspend solids to move through the pipeline and irrigator. Dilution may be required. For more information, see chapter 11 of this handbook and section 651.1206(a).

Pumped waste spreading via irrigation is increasing in popularity, especially with operations that spread over a million gallons per year. Pumping minimizes soil compaction and labor and spreading equipment needs. Equipment adaptations continue. For example, gated polyethylene pipe is used to reduce labor, investment cost, and operating power. Also, irrigator low pressure drop nozzles are used to reduce waste spreading odor. More developments are expected as demand grows for pumping equipment to spread waste farther away from storage and to minimize odor complaints.

Wind affects uniform sprinkler spreading and may cause odor complaints from several miles away. With adequate storage, pumped slurry waste spreading (in quantity) is typically done in the spring or fall. Cropland is available during this time, and the seasonal competition for the labor needed for equipment setup, startup operation, and cleanup is less. The fate of the manure constituents must also be considered.

Different irrigation systems are used to spread agricultural wastes. Major selection factors are summarized in table 12–11.

Two or more power units and pumps can be employed during pumped waste spreading operations. This involves:

- One continuously operating chopper or impeller-type agitator pump that is powered by an 80- to over 100-horsepower motor to keep stored solids mixed with liquids (fig. 12–54).

- One similarly powered unit to operate a high-pressure (at least 100 lb/in$^2$) centrifugal pump (sometimes 2 units) to move 200 to more 800 gallons per minute of slurry to the field (fig. 12–121).

- One or two power units to operate the irrigation system.

Labor coordination and communication on starting, stopping, and operating the equipment are needed

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**Table 12–11**    Irrigation system selection factors (Patronsky 1978; Shuyler 1973)

| Factor | Hand move sprinkler | Towline | Side roll | Travel gun | Center pivot |
|---|---|---|---|---|---|
| Effluent solids | Up to 4% solids | Up to 4% solids | Up to 4% solids | Up to 10% | Up to 10% |
| Operation size | Small | Small to medium | Small to medium | All sizes | All sizes |
| Labor need | High | Medium | Medium | Medium to low | Medium to low |
| Initial investment | Low | Low | Medium to high | Medium to high | High |
| Operation costs | Medium | Medium to high | Medium to high | Medium to high | Medium to high |
| Expansion | Purchase more pipe and equipment | Purchase more pipe and equipment | Purchase more pipe and equipment | Purchase more pipe and equipment | Purchase more pipe and equipment |
| Hourly attention | Medium | Medium | Medium | Medium | Low |
| Soil type | Suitable to wide range of intake rates | Suitable to wide range of intake rates | Suitable to wide range of intake rates | Suitable to wide range of intake rates | Suitable to wide range of intake rates |
| Surface topography | Wide | Wide | Limited | Wide | Wide |
| Crop height | Adaptable | Low | Low | Adaptable | Adaptable |

for uniform spreading. Pumps need to be primed, and mixed solids and liquids need to be kept moving to prevent settling and plugging. Pipes need to be rinsed and emptied when irrigation is completed. If this is not done, the retained waste dries or freezes, causing the equipment to plug the next time it is used.

## (1) Pipe and pipeline equipment

Pipe size and friction is explained in chapter 11 of this handbook. Small diameter pipe is made from steel, copper, aluminum, or various plastics. Steel, cast iron, plastic, or concrete pipe is used for culverts, drains, and some pipelines. See section 651.1202(b) for more information. Irrigation pipe greater than 2 inches in diameter is generally made from plastic or aluminum because they weigh less. Hard rubber, which resists vacuum pumping suction or load of towing the irrigation equipment, and flexible fabric pipe, which is pressurized, are used with tanker and irrigator connections.

In pumping applications, pipe from storage to field is coupled with ring lock or kamlock couplers and can be attached to a hose at the field using barb fittings and clamps. Most hoses are 4 to 8 inches in diameter. Pressure ratings on these hoses are 100 to 150 pounds per square inch. Drag hose for towed injector spreading is 4.5 to 5 inches in diameter and is rated at 150 pounds per square inch. This pressure rating is needed to withstand towing stresses.

**Figure 12–121**　　High-pressure centrifugal pump (*Photo courtesy of Cornell Pump Co.*)



The durability of the pipes varies:

- Aluminum is resistant to corrosion, but is easily dented and bent.

- Plastic pipe loses strength with temperature increase. Some plastics become brittle with exposure to sunlight, or they become stiff in cold weather and break.

- Flexible fabric pipes wear through and leak where excessively rubbed when pulled along the ground or where they are wound and unwound from a spool.

CPS Code 430, Pipeline; ASABE Standards; and manufacturers' literature can be consulted for thickness, pressure rating, coupler assembly, and pipe installation requirements.

As liquid flows through a pipe, the liquid drag or friction against the pipe wall restricts the flow. Larger diameter pipe with the same internal roughness has lower friction at a given flow rate and uses less pumping energy. However, the initial investment is higher than that required for a smaller pipe. The friction loss for steel and plastic pipe is shown in table 12–12. The loss is based on the diameter of the pipe and is for transport of water. Slurry waste may have as much as 10 percent more pipe friction losses. Chapter 11 of this handbook has more information on friction loss.

The required pressure to maintain flow is reported in feet (of water) or pounds per square inch. Feet equates to the pressure of a water column of that height (fig. 12–122). A vertical pipe that contains 2.31 feet of water has 1 pound per square inch of pressure at the bottom. Total head, in feet, is converted to pounds per square inch by dividing the feet of head by 2.31. Table 12–12 shows the friction loss in both feet and pounds per square inch. The total drag or friction loss in a pipeline includes pressure losses from pipe length, elbow/reducer fittings, and restrictions (e.g., nozzles). Note in the table the effect that increasing the flow rate has on pressure loss.

At about 2 feet per second velocity, solids settle in low spots along a pipeline. At a velocity more than 5 feet per second, friction loss and water hammer are problems. A velocity of 3 to 6 feet per second is used in pipe diameter selection designs. The velocity of liquid waste in pipes not buried or otherwise anchored in

place should be limited to 5 feet per second. Flushing pipelines with clean water to remove contents after pumping waste prior to disassembling and draining them helps to avoid problems with plugging and reduces friction losses for future application.

### (2) Surface irrigation equipment

Surface irrigation includes flooding, border, furrow, and gated pipe systems. A maximum land surface slope of 2 percent and a high level of management are required to control runoff and obtain uniform wastewater distribution. The low investment, power, and equipment needs of surface irrigation are the trade-offs for the high labor. See CPS Code 443, Irrigation

System (Surface and Subsurface) for more information.

Gated pipe wastewater distribution assists simpler, faster, more uniform wastewater application by gravity (Schnieder, Harrison, and Freeze 1993). Holes are spaced about 30 to 80 inches apart in 30- to 40-foot lengths of aluminum or plastic pipe that is at least 4 inches in diameter (fig. 12–123). The holes, which are about 2 by 6 inches each, have a sliding cover or gate that is opened or closed by hand. These covers are adjusted for uniform gravity discharge all along the gated pipe.

**Table 12–12**  Friction loss in 100 feet for 3- and 4-inch-diameter pipe used to transport water (MWPS 1985)

| | - - - - Steel - - - - | | - - - - Plastic - - - - | | - - - - - Steel - - - - - | | - - - - Plastic - - - - | |
| | I.D. 3.068 in | | I.D. 3.216 in | | I.D. 4.026 in | | I.D. 4.134 in | |
| Gallons per minute | (ft) | (lb/in$^2$) | (ft) | (lb/in$^2$) | (ft) | (lb/in$^2$) | (ft) | (lb/in$^2$) |
|---|---|---|---|---|---|---|---|---|
| 40 | 0.8 | 0.4 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.0 |
| 60 | 1.7 | 0.7 | 0.7 | 0.3 | 0.5 | 0.2 | 0.2 | 0.1 |
| 80 | 2.9 | 1.3 | 1.3 | 0.5 | 00.8 | 0.3 | 0.4 | 0.2 |
| 100 | 4.4 | 1.9 | 1.9 | 0.8 | 1.2 | 0.5 | 0.6 | 0.2 |
| 120 | 6.2 | 2.7 | 2.7 | 1.2 | 1.7 | 0.7 | 0.8 | 0.3 |
| 180 | — | — | — | — | 3.5 | 1.5 | 0.7 | 0.7 |
| 220 | — | — | — | — | 5.1 | 2.2 | 2.4 | 1.0 |

**Figure 12–122**  Total head (ft) equal elevation + pressure + friction
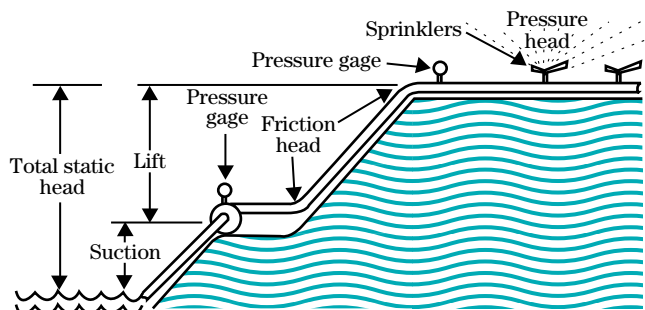


**Figure 12–123**  Gated pipe gravity irrigation (*Photo courtesy of Armin Plastics Corp.*)

In operation, liquid waste is transferred from storage to the field and enters the gated pipe through a valve at one end. Lengths of gated pipe are connected together, and the gate openings (usually every second or third one) are adjusted for uniform outflow along the length of gated pipe (table 12–13). Nonuniform solids distribution in the liquid can be troublesome because dissolved nutrients are carried in the liquid. However, larger solids settle in the pipe, or the nutrients are filtered out by grass where wastewater leaves the gated pipe openings. The spreading arrangement and the size of the pipeline and pump should be considered in selecting a gated pipe system.

**Table 12–13**    Maximum recommended flow rate in openings in gated pipe with holes spaced 30 to 40 inches apart (MWPS 1985)

| Gallons per minute | Land slope (%) |
|---|---|
| 40 | 0.2 |
| 25 | 0.4 |
| 16 | 0.6 |
| 12 | 0.8 |
| 10 | 1 |
| 5 | 2 |

**(3) Hand move sprinkler equipment**

Although messy to handle, the hand move sprinkler is used with small wastewater capacity liquid waste spreading. Equipment needs and the initial investment are low, and the equipment is adjustable to fit various sized fields. See CPS Code 442, Irrigation System (Sprinkler) for more specific information.

One or more laterals are hand-placed onto a mainline and operated as shown in figure 12–124. Each sprinkler has a capacity between 1 and 20 gallons per minute. The needed pump capacity is the sum of all the operating sprinklers. Lateral sets are assembled from hand-moved sections of pipe that has sprinkler nozzles 30 to 40 feet apart. Each sprinkler then theoretically covers a 60 to 80 foot circle. When the laterals are set up and the centrifugal pump is operating, the lateral valve is opened and the system is operated for the required period. The system is then shut off, and the lateral is moved and reset at a new location. The operation is then repeated until completed. As an example, a 1,320-foot-long (0.25-mi) lateral covers about 1.8 acres. It has 22 sprinklers set 60 feet apart. Each sprinkler spreads about 10 gallons of liquid waste per minute (600 gal/h). This amounts to about 0.3 inches per hour on each 60-foot circle. Table 12–14 gives the discharge in gallons per minute for sprinkler nozzles.

**Figure 12–124**    Hand move and towline sprinklers



Handmove sprinkler
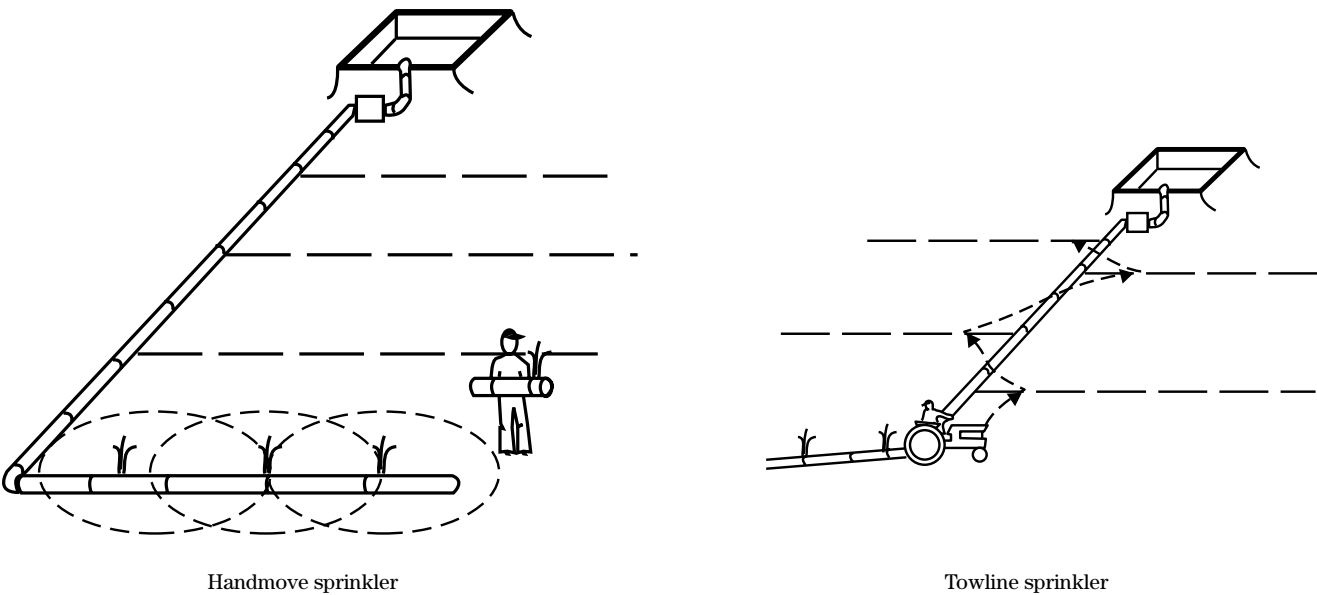
Towline sprinkler

## (4) Towline sprinkler equipment

The towline sprinkler is assembled and operated similar to the hand move sprinkler except that a tractor is used to move the lateral to the next setting (fig. 12–124). The investment is higher for the towline sprinkler, but labor is lower and the acres per hour covered are more than those with a hand move sprinkler. To avoid damage, a main line buried or placed in a shallow ditch is needed for tractor tow travel back and forth. To resist towing stresses, the lateral has strong couplers between sections. Laterals can be up to 1.320 feet long. The moveable equipment is adaptable to varied field sizes; however, the field shape should conform with the lateral length. The towline sprinkler is best used in rectangular fields and where hayland, pasture, or other low-growing crops are grown. Sod strips are best used for sets in till fields.

## (5) Side-roll sprinkler

The side-roll sprinkler's operation and the area covered compare to that of the towed sprinkler. The side-roll is moved or rolled in uniform spaced sets along a mainline (fig. 12–125). Rather than tractor towed, the side-roll sprinkler has wheels about 4 to 7 feet in diameter on about 30-foot spacings that use the lateral pipe as an axle. A 5- to 20-horsepower engine centrally mounted on the side-roll sprinkler is hand-started every few hours. This engine powers about a 660-foot length of the side-roll. It uses a chain drive to roll the section over to the next set.

**Table 12–14**      Sprinkler nozzle discharge in gallons per minute (MWPS 1985)

| Pressure (lb/in$^2$) | Nozzle diameter (in) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3/16 | 1/4 | 5/16 | 3/8 | 1/2 | 3/4 | 1 | 1 1/4 |
| 50 | 7.1 | 12.9 | | | | | | |
| 60 | 7.8 | 14.0 | 22.0 | | | | | |
| 70 | 8.5 | 15.4 | 23.9 | 33.2 | | | | |
| 80 | 9.1 | 16.4 | 25.7 | 35.7 | 61.6 | 154 | 264 | 416 |
| 100 | — | — | — | 40.7 | 68.9 | 173 | 296 | 462 |
| 120 | — | — | — | — | — | 189 | 324 | 511 |

**Figure 12–125**      Side-roll sprinkler
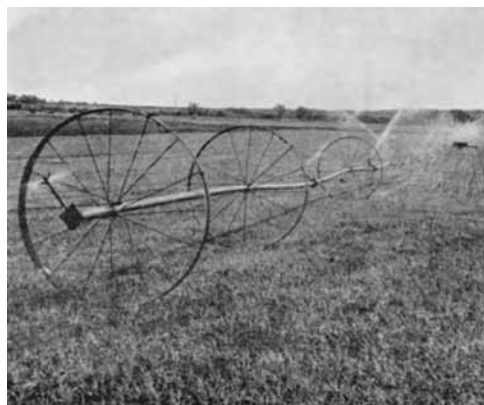
The side-roll sprinkler is relatively messy, slow, and requires frequent attention. It is useful with small operations and for low-growing crops. Lateral alignment is a problem on uneven topography. Disassembly or special wheels are needed for moving the side-roll sprinkler to other locations.

### (6) Stationary big gun sprinkler

A stationary big gun sprinkler is especially applicable with the frequent pump-out of a waste storage pond (<1 million gallons) to different locations (fig. 12–126). The 2- to 4-inch diameter, flexible high-pressure nozzle can pass solids and spread slurry waste over an area that is 100 to 300 feet in diameter (0.2 to 1.5 acres) per setting. The stationary big gun sprinkler requires a moderate investment, is relatively simple to use, and completes the job quickly. However, it requires more labor than the traveling gun sprinkler and is messy to operate. The capacity and power need are comparable to that of the traveling gun. Some problems that have occurred in using this sprinkler are that it is messy to service, does not apply the waste uniformly, does not spread the waste efficiently in strong wind, can easily result in over-application and runoff if forgotten or neglected. Also, odor complaints are common.

The big gun sprinkler is generally mounted on a trailer or 3-point hitch and connected to a moveable hose or pipeline that has been laid down in sections from the waste storage. While agitating the stored waste with a chopper-agitator or impeller agitator, a high-pressure centrifugal pump (see fig. 12–92) pumps the agitated slurry to the big gun. After the desired amount of wastewater application at one set, the high-pressure pump is stopped, the big gun sprinkler is moved (usually with a tractor), and the pipeline is taken up. Then it is reset and the equipment operated at another setting. The uniformity of coverage of a circular or semicircular area depends on management, the nozzle setting, and the wind.

### (7) Traveling gun sprinkler

Traveling gun sprinklers are either cable-tow (soft hose) (fig. 12–127) or hose tow (hard hose)-type (fig. 12–128). The cable-tow irrigator has a gun sprinkler mounted on a wheel cart or skids to which a soft, collapsible, 4- to 5-inch-diameter hose is attached. Before operation, the gun cart, cable, and hose are unreeled across the area to be irrigated. The cable winch end is anchored at the end of the run or lane. Depending on stored waste quality and pumping distance from storage, one or two high-capacity centrifugal pumps feed the irrigator from the agitated waste storage. During operation, the cable is slowly rewound by an auxiliary engine, water motor, water piston, or turbine driven winch that tows the irrigator. Most cable-tow irriga-

**Figure 12–126**   Stationary big gun sprinkler (*Photos courtesy of Hydro Engineering and GEA Houle, Inc.*)

tors that have auxiliary power can be used to apply liquid and slurry wastes, which can plug a water drive sprinkler. The power to pull the traveling gun can be located on the irrigator cart or on the hose reel.

A hose tow traveling gun sprinkler includes a cart or skid-mounted sprinkler gun towed along by a 2- to 4-inch-diameter hard hose. The hose is attached to a powered, slowly rotating take-up and storage hose reel that is parked at the end of the irrigated lane. Before operation the hose reel is parked at the end of the ir-rigated lane or run and the hose is unreeled (with the sprinkler gun) to the opposite end. The flexible hard hose supplies the liquid to the sprinkler and also tows it slowly across the field when wound onto the take-up reel. The hose reel is powered by a turbine, bellows, liquid-piston, or auxiliary engine. Solids in the liquid affect liquid-drives as they do with the cable-tow trav-eling gun sprinkler.

High, low, and multiple sprinkler gun cart designs are available for traveling gun sprinklers. The cart selected depends on crop height and the area to be irrigated. Nozzles are available for irrigating up to a 360-foot swath at more than 1,000 gallons per minute capacity. Table 12–15 gives the nozzle trajectory of a big gun stationary slurry sprinkler. Operating the nozzle in a

partial circle pattern permits operating the gun on dry ground. In some models, the size, length, and winch of the hose allow for irrigating up to 1,320 feet away from the mainline. The normal spacing between lanes is 60 to 70 percent of the sprinkler wetted diameter.

The hard hose maintains its shape and resists tow wear, but is bulky to handle, stiff to use (especially at cold temperatures), and hard to store. The soft hose is more convenient to handle and expands slightly when pressurized, which increases the flow capacity. However, hose twisting and wear are problems when handling or moving the hose, which is necessary when resetting the sprinkler.

Depending on the nozzle, a traveling gun can irrigate up to 20 acres per setting. Adjusting the travel or nozzle affects the application rate. Data for different nozzle types, sizes, and capacities are shown in table 12–15. Either a taper bore or a ring bore nozzle is used for a traveling gun sprinkler. The taper bore nozzle is not adjustable, but spreads farther from the mainline than the ring bore nozzle, which can be adjusted. The 24-degree trajectory is lower than that of the 27-degree and has fewer problems caused by the wind, such as odors. The 27-degree trajectory can clear crops and spread farther out than the 24-degree trajectory.

**Figure 12–127**     Cable-tow big gun irrigator (*Photo cour-tesy of Hydro Engineering, Inc.*)



**Figure 12–128**     Hose-tow big gun irrigator (*Photo courtesy of R&K Pivots*)

Relatively popular for pumped waste spreading, the traveling gun irrigator needs minimal labor, has moderate power need, minimizes soil compaction, and can be moved to different fields and used for other irrigation. The relatively high investment, operator expertise, wind distortion, and odor source for a large surrounding area are major concerns. A traveling boom sprinkler that lays down an irrigated swath under low pressure is available and reduces some of these concerns (fig. 12–129). A study at Washington State University indicated that boom systems had similar distribution uniformity to big gun systems, but were less susceptible to poor uniformity in higher wind conditions. Even so, overlap should be increased in high wind conditions to improve uniformity. Under the same conditions, the application efficiency of the big-guns was about 60 percent compared to 85 percent for boom systems. However, due to lower operating pressure and small orifice sizes, traveling booms are more subject to plugging (Peters 2008).

**Table 12–15**   Irrigation gun pressure, size, and discharge (MWPS 1985)

| | Nozzle trajectory | | | | | | | | | | | | | |
| | 24 degrees | | | | | | | | | 24 degrees | | | | |
| Taper bore (in) | .6 | | .7 | | .9 | | 1.1 | | 1.3 | | 1.5 | | 1.75 | |
| Ring nozzle (in) | | | .86 | | 1.08 | | 1.26 | | 1.41 | | 1.74 | | 1.93 | |
| lb/in² | gal/min | dia. | gal/min | dia. | gal/min | dia. | gal/min | dia. | gal/min | dia. | gal/min | dia. | gal/min | dia. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 74 | 225 | 100 | 250 | 165 | 290 | 255 | 330 | | | | | | |
| 60 | 81 | 240 | 110 | 265 | 182 | 305 | 275 | 345 | 385 | 290 | 515 | 430 | 295 | 470 |
| 70 | 88 | 250 | 120 | 280 | 197 | 320 | 295 | 360 | 415 | 410 | 555 | 450 | 755 | 495 |
| 80 | 94 | 260 | 128 | 290 | 210 | 335 | 315 | 375 | 445 | 430 | 500 | 470 | 805 | 515 |
| 90 | 100 | 270 | 135 | 300 | 223 | 345 | 335 | 390 | 475 | 445 | 626 | 485 | 855 | 535 |
| 100 | 106 | 280 | 143 | 310 | 235 | 355 | 355 | 400 | 500 | 460 | 660 | 500 | 900 | 550 |
| 110 | 111 | 290 | 150 | 320 | 247 | 365 | 370 | 410 | 525 | 470 | 605 | 515 | 945 | 565 |
| 120 | | | 157 | 330 | 258 | 375 | 385 | 420 | 545 | 480 | 725 | 530 | 985 | 580 |
| 130 | | | | | | | | | 565 | 485 | 755 | 540 | 1025 | 590 |

**Figure 12–129**   Traveling boom sprinkler/spreader (*Photo courtesy of Briggs Irrigation*)

## (8) Center pivot sprinkler equipment

A center pivot sprinkler propels itself in a full or part circle from a center anchor or pivot point (fig. 12–130). Different sizes spread liquid waste on a few acres to more than 600 acres per setting. Operable over uneven topography, the center pivot sprinkler uses 100 to more than 150 pounds of pressure per square inch to operate. This requires a 30- to 75-horsepower motor, depending on sprinkler size, construction, and nozzle. A pump is also needed for agitation and to transfer waste from storage to the sprinkler.

Drop tube nozzle distribution reduces the power need and odor problems of other nozzles used, but spreading may be uneven because of the variations in pressure. The driving power to slowly move the center pivot can be from the liquid pressure, an electric motor, or an oil or hydraulic drive wheel located at each of the irrigation pipe supports (towers). Variable speed and optional computer programmed control assist uniform application although wind is a problem. If the irrigator is constructed of aluminum, it requires less moving force, weighs less, and is resistant to corrosion. However, the investment is higher than that for a galvanized steel sprinkler.

The relatively high investment for a center pivot sprinkler is tempered by its relatively low operating labor and speedy and uniform application. Most models are set up and used at only one location; some can be towed to different locations. Typically, one or more center pivot irrigators are regularly used each season to spread agricultural product processing plant liquid waste on growing crops. The sprinkler generally operates 6 to 10 feet above the ground surface for the most efficient spread and crop clearance, so it is vulnerable to high wind and lightning damage. For all but the most dilute types of animal waste, center pivot sprinklers are a poor choice due to plugging and nonuniform distribution patterns for liquid waste with higher solids content. Poor management can easily result in over or under application of liquid waste.

## (d) Biogas production equipment

As explained in chapter 10, section 651.1006(d) of this handbook, biogas production is the anaerobic bacterial decomposition of organic matter into primarily methane ($CH_4$) and carbon dioxide ($CO_2$). Biogas production is well understood from a municipal sewage treatment standpoint and has been successfully done on a commercial basis for many years in the United States and around the world. Anaerobic digester technology was also used in the agricultural sector in Europe and other locations around the world. In the early 1970s interest developed in the United States in using similar technology to extract energy from agricultural waste. Initial system installations met with mixed results. Since that time, technology has evolved and there are many installations that have been operating successfully for years. There are now a significant number of turnkey companies operating in the United States that can provide assistance with all aspects of planning, design, installation, and operation of digesters.

With the exception of the digester itself and a few other components, the equipment used for biogas production has already been covered in previous sections of this chapter. Some of the same equipment that is used for waste handling is also used in conjunction with the anaerobic digester when it is integrated into the system. That equipment includes:

- covers
- scrapers
- pumps
- agitators/mixers
- separators
- waste hauling and spreading equipment

**Figure 12–130**    Center pivot sprinkler (*Photo courtesy of Hydro Engineering, Inc.*)

Waste spreading and hauling equipment is included since the anaerobic digestion process does not significantly change the volume of waste that needs to be handled although it does change the form and availability of the nitrogen in the effluent. It also reduces odor significantly.

Different types of digesters are also explained in chapter 10, section 651.1006(d) of this handbook. While the type of digester installed determines some of the additional equipment that is required, all systems will require utilization equipment such as:

- generator set or micro turbine to convert biogas to electricity

- transformers to connect the system to the power grid

- boilers for heat

- short-term storage for biogas

- flares

Figure 12–131 shows a schematic of a covered anaerobic lagoon installation on a swine farm. Figures 12–132 shows a system schematic and figure 12–133 provides a process train for an ambient temperature anaerobic lagoon on a farrow-to-wean operation that has been operating since 1989 on a North Carolina swine farm.

On this particular operation, the in-ground covered digester was installed ahead of an existing anaerobic waste treatment lagoon. The swine manure is periodi-

**Figure 12–131**    Schematic of covered anaerobic digester (*Drawing courtesy of L. Saele, NRCS, ret.*)

**Swine—covered anerobic lagoon**



cally flushed into the digester which is covered bank-to-bank with a HDPE cover. The cover excludes rainfall and also serves as a low volume temporary biogas storage facility. A pipeline with a small vacuum pump attached carries the biogas to the generator set. It is important that the generator be sized according to the volume of biogas production that is expected. If it is undersized, excess gas will need to be flared if there is no other use for it. If it is oversized, the generator unit will run intermittently causing operation and maintenance issues. Originally, natural gas or LP generator units were used with biogas applications, but the hydrogen sulfide ($H_2S$) in the biogas significantly reduced the operational lifespan of the units even when scrubbers and filters were installed. Units designed specifically for utilization with biogas are now available, although scrubbers are still required to clean up the biogas before use. The generator set on this facility has a 120-kilowatt (kW) capacity, which is larger than it should be based on actual gas production.

On some installations, a microturbine is used instead of a piston-type engine to power the generator. A microturbine is basically a rotary engine that extracts power from combustion of the biogas (fig. 12–134). The advantage of a microturbine is that when operating properly, they have lower emissions and provide a higher operating efficiency than a conventional internal combustion engine.

While it is not shown, this installation also has a boiler that uses the biogas to heat water that is in turn used for warming pads for the young piglets. Boilers generally can use the biogas directly without scrubbing although such an installation will significantly shorten the life span of the burners and increase air emissions. Prior to installation of the digester, the operation used LP gas to heat the warming pads. Use of biogas instead significantly reduced the cost. If there is a need for heat on the operation such as this, use of a biogas fired boiler provides a significant cost savings. Utilizing a heat exchanger, waste heat from the generator set can also be captured.

When waste is flushed into the digester an equal volume of effluent is discharged from it to the anaerobic lagoon. Some of the effluent is run through nitrification/denitrification biofilters. The nitrified effluent is used to grow greenhouse tomatoes. The remainder of the effluent in the lagoon is either recycled or irrigated on cropland.
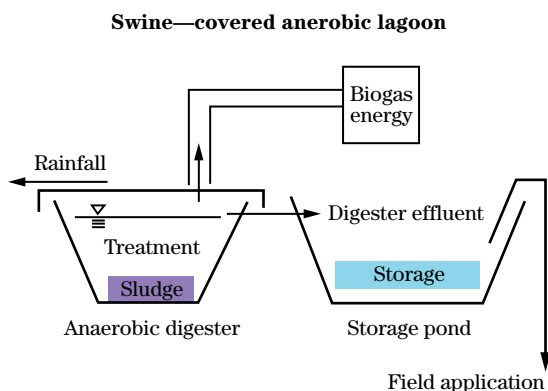
**Figure 12–132**    System diagram for an ambient temperature covered anaerobic digester in North Carolina (*Drawing courtesy of L. Saele, NRCS, ret.*)



**Swine—covered anaerobic logoon**

1   Gestation barns (4)
2   Farrowing barns (2)
3   Digester, ambient temperature
4   Storage pond
5   Biofilters
6   Green houses
7   Irrigated hayland
8   Gas utilization building
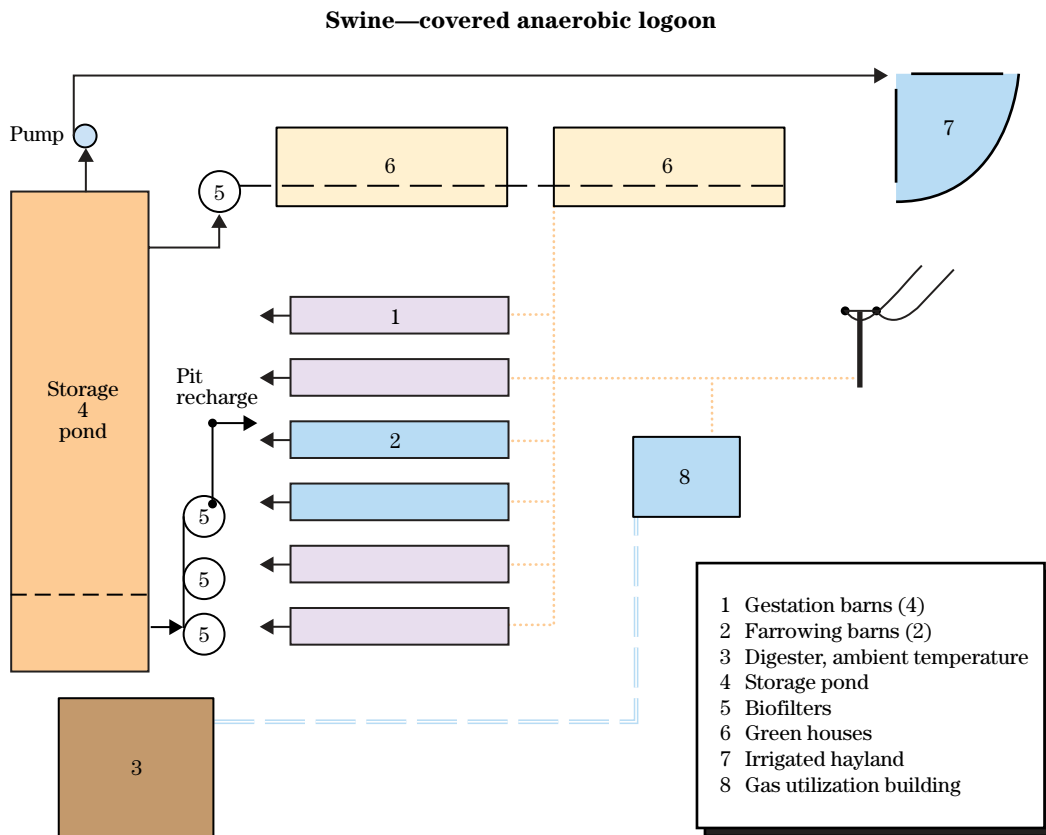
**Figure 12–133**    Process train for covered anaerobic digester on North Carolina swine farm (*Photo courtesy of L. Saele, NRCS, ret.*)



**Ambient temperature in-ground covered anaerobic digester**

A   Waste production
B   Covered anaerobic digester
C   Biogas utilization-generator set
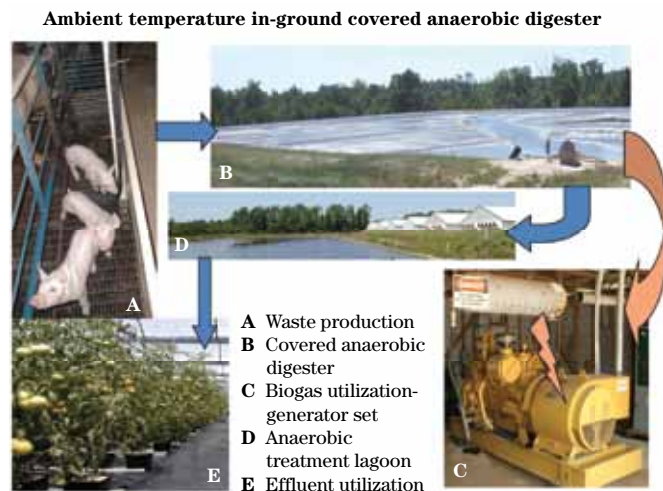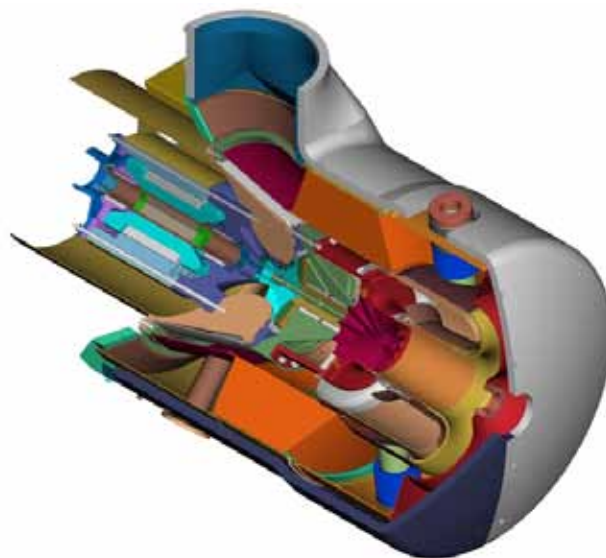D   Anaerobic treatment lagoon
E   Effluent utilization

**Figure 12–134**    Microturbine (*Photo courtesy of Capstone Turbine Corp.*)

One of the pieces of equipment that is not shown in the process train is the flare (fig. 12–135). All biogas production facilities must have a flare to handle excess gas or for operation when the generator set and/or boiler must be taken down for maintenance. The flare should have a wind shroud as well as thermocouples and/or a ultraviolet (UV) flame detector for automatic ignition.

Additional information on biogas production facility planning and design can be found in CPS Code 366, Anaerobic Digester. The AgSTAR Program, a voluntary effort jointly sponsored by the U.S. Environmental Protection Agency (EPA), USDA, and U.S. Department of Energy, also provides a significant amount of good information on their Web site, http://www.epa.gov/agstar.

**Figure 12–135**    Biogas flare (*Photo by Pete Wright, NRCS*)



# 651.1208 Other associated equipment

In addition to the equipment for collection, storage, transfer, treatment, and utilization of wastes described thus far, varied other equipment is used with agricultural waste handling. The pertinent equipment for safety, odor evaluation, gas detection, and water quality is especially important. Equipment from alarms and backhoes to hoists to weigh scales (and more) get involved in typical operations, but they are not included here.

## (a) Safety protection equipment

Agricultural waste handling involves hazards (see chapter 10 of this handbook). Waste handling equipment is often operated alone at all hours of the day and in a dirty, noisy, slippery, remote, semidark location, which is generally a long way from help and medical attention. Safety considerations made when planning facilities are essential and have been briefly included in this chapter. They are covered in depth in chapter 13 of this handbook. Workers should be knowledgeable about hazards, safe operation conditions, emergency procedures, phone numbers, and available medical facilities.

### (1) Signs for safety, danger, and warning situations

Waste handling involves the use of slow moving equipment. The slow moving vehicle (SMV) warning emblem (fig. 12–136) is mounted on the rear of equipment traveling less than 25 miles per hour on public roads. The emblem is mounted 2 to 6 feet above the ground, centered or to the left (whichever is most practical), and pointing upward. ASABE Standard S276.3 explains the specifications about SMV sign construction and use (ASABE [r] 2005). As with any equipment, the sign needs to be in good repair and regularly cleaned.

Somewhat comparable to the SMV emblem is the safety alert symbol for agricultural, construction and industrial equipment (fig. 12–137). As explained by the SAE Standard J284, the uniform symbol is to be used with warning statements, signs, manuals, and educational materials about agricultural equipment. It is not to be used alone.

ASABE Standard S441.3, Safety Signs, is useful for signs needed with agricultural waste handling situations (fig. 12–136). This standard provides design guidelines for uniform safety signs, their situations, format, colors, size, and placement (ASABE [p] 2005). Uniformity in signs assists quick recognition and understanding. Work situation signal words include:

- **Danger—**High probability of death or irreparable injury.

- **Warning—**Hazard exists that could result in injury or death.

- **Caution**—Precaution needed against injury.

**Figure 12–136**     Slow moving vehicle emblem



Red retro reflective border
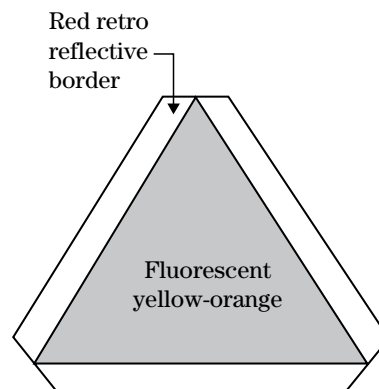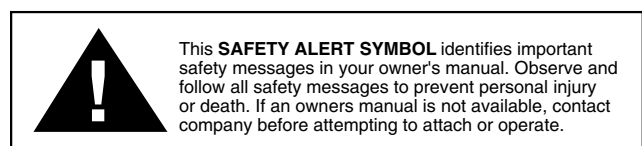
Fluorescent yellow-orange

**Figure 12–137**     Safety alert symbol for agricultural equipment



This **SAFETY ALERT SYMBOL** identifies important safety messages in your owner's manual. Observe and follow all safety messages to prevent personal injury or death. If an owners manual is not available, contact company before attempting to attach or operate.

**Warning** sign situations would be where waste scraping, storage, agitation, or loading take place. ASABE S-441.3 explains that the warning sign needs a black background behind the signal word, which is to be in yellow letters. The message is black lettering on a yellow background. It is printed in 2-inch-high letters so it can be seen from about 80 feet away.

A **Danger** sign to be used near earthen basin waste storages was developed in Pennsylvania (Bowers 1992). This 10- by 14-inch aluminum sign generally follows the ASABE S-441.3 guidelines (fig. 12–138).

Other pertinent ASABE standards for safe use of waste handling equipment include S-354.5, Safety for Farmstead Equipment; and S-355.3, Safety for Agricultural Loaders. These respectively explain guarding, operation, safety needs, and references for their development.

## (2) Fire extinguishers

Local fire departments, insurance agencies, and fire extinguisher sales and service shops are knowledgeable about fire extinguishers. Only a brief explanation is given here.

A full and operable 2A–10BC fire extinguisher (or larger) should be nearby where engines are operated. It will smother trash, paper, petroleum, and electrical fires (Fanning 1984).

Fires and extinguishers are classified as A, B, C, or D according to the material that is burning. Because of the characteristics of the different fires, the extinguisher that works on one type fire may be dangerous or ineffective on another. The classifications are:

- Class A—Combustible solids, such as wood, straw, or rubbish

- Class B—Flammable liquids, such as gasoline, paint, or oil

- Class C—Energized electric equipment, such as motors or switches

- Class D—Combustible metals, such as magnesium and sodium

Fire extinguishers need to be tested by an approved agency. The fire extinguishing potential for the fire classification is rated and put on the label. The rating is a number and letter combination. The letter indicates the fire type, and the number indicates the size of fire the extinguisher will put out (fig. 12–139).

**Figure 12–139**    Fire extinguisher label



**UNDERWRITERS LABORATORIES** INC. ®
LISTED
**DRY CHEMICAL FIRE EXTINGUISHER**
**CLASSIFICATION 2-A: 10-B:C**

**Figure 12–138**    Safety signs format



SIGNAL WORD

PICTORIAL

MESSAGE

**DANGER**
DEADLY MANURE GASES POSSIBLE
DEATH
MAY BE IMMEDIATE!

ENTER PIT ONLY WITH:
• SELF-CONTAINED AIR SUPPLY
• VENTILATION
• RESCUE HARNESS, MECHANICAL
  LIFT, STAND-BY PERSON
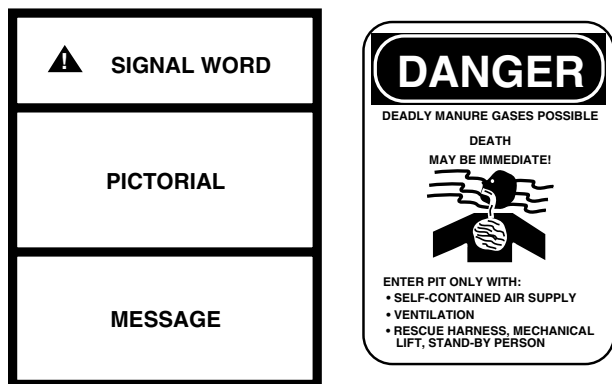
The ratings for Class A fire extinguishers show the relative extinguishing potential of one model compared to another. A 4A extinguisher should extinguish twice as much Class A fire as a 2A. The number on Class B fire extinguishers indicates relative size and the square foot area of deep layer flammable liquid that an average operator can extinguish. For example, a 6B unit should extinguish 6 square feet of deep layer flammable fire. A 6B unit will also extinguish twice as much Class B fire as a 3B.

Class C fires are either Class A or Class B fires with electrical equipment present. The C rating is the same as the Class A or the Class B rating depending on what is burning.

Dry chemical extinguishers are available from 2.5 to 20 pound sizes. The dry powder that smothers the fire is propelled by pressurized nitrogen or carbon dioxide gas. A dry chemical extinguisher is effective on Class B and C fires. It will knock down a Class A fire, which may then need water to completely smother smoldering materials. The remaining dry chemical residue is a disadvantage of using this type extinguisher on a Class A fire.

## (b)  Gases and confined space entry

Air quality in agricultural waste handling systems is explained in chapter 3 of this handbook. Information about safety considerations is included in chapters 10 and 13 of this handbook, as well as here in section 651.1205. Attention continues to focus on the air quality and safety aspects of handling agricultural wastes (Berg 1994). Protection and first aid is a concern for workers and for inspectors, visitors, and especially children.

Depending on employee numbers, family workers, corporate status, and perhaps State rules, the United States Department of Labor, Occupational Safety and Health Administration (OSHA) can become involved with agricultural production operations (U.S. HHS 1990). The OSHA promulgated a standard (Congressional Federal Register 1910.146) dealing with entry into confined spaces in April 1993 (Shutske and Purschwitz 1993). This action may have implications to confined spaces in agricultural related facilities. Included, for example, might be worker training, warning signs, and

safety equipment and its approval and use. Most States have  rules for occupational safety and health in agricultural operations. The State occupational safety and health agency should be contacted to determine applicable regulations. The ASAE EP407 JAN 1992 (R2005) Manure Storage Safety standard sets forth existing known practices on manure storages to minimize hazards associated with manure gases and the potential for drowning at storage sites.

In working with agricultural wastes, an operator at some time will need to enter and work in an enclosed storage or tanker space where there may be dangerous gases or absence of oxygen (Berg 1994). The confined space must be completely force-ventilated with a blower and flexible duct. ASABE Standard S607 OCT2010, Venting Manure Storages to Reduce Entry Risk, provides ventilation rates and durations necessary to reduce risk of entering confined spaces where hazardous gases may collect. If at all possible, employ an experienced person with proper equipment to do the work. Contacts about who can do this should be available through waste equipment suppliers, safety specialists, local emergency rescue concerns, fire departments, law enforcement persons, electric and gas power suppliers, military stations, underwater equipment suppliers, and related agencies. Suppliers and licensed operators should have current rescue procedure information and operable equipment.

The minimum equipment used by a trained person when entering a confined space would be (Shutske and Purschwitz 1993):

- A monitor to test and provide continuous detection capabilities for presence of hydrogen sulfide ($H_2S$), methane ($CH_4$), and oxygen ($O_2$) before and during entry.

- A ventilation blower (1,000 $ft^3$/min) with about 15 feet of flexible ducting that can reach spaces requiring venting.

- A lifeline and harness system (tripod, cable, winch) to allow a helper to quickly remove an entrant in the event of a storage incident.

The same types of equipment are required by the confined space entry guidelines for manure pits (storages) issued in 1990 by the National Institute for Occupational Safety and Health (U.S. HHS 1990).

A portable, electronic gas monitor capable of detecting $O_2$ levels below 19.5 percent, $H_2S$ levels above 15 parts per million, $CH_4$ levels above 10 percent of the lower, explosive limit, and other combustible gases is advised. Most detectors have a calibration kit for that detector. An electronic detector measures the electrical variations of an exposed, special coating on a sensor. The sensor life would be dependent on use, gas concentration, and other environmental factors (fig. 12–140). Many different models are available. A single instrument could use several independent sensors to measure different, respective gases (e.g., $H_2S$, $CO_2$, $O_2$). In addition to a digital display of gas level, such detectors are available with alarm lights, audio alarm, and detachable sensors for remote monitoring.

A hand-held air sampler with different indicator tubes (fig. 12–141) is moderate cost and remains reliable after repeated use. However, this detector is slower to operate than the electronic detector. The sealed sampler tubes are available for sensing different gases. To do a sample, a selected tube is broken open and inserted in the sampler. The plunger is extended to draw a specific quantity of air through the sample tube material, and the change of tube color is compared to a standard chart.

A wetted-paper gas level indicator costs less than any other indicator, but the indication response may be slower. Contamination of this indicator is possible, which then would not give a reliable indication. This indicator can be more cumbersome to use in typical situations involving agricultural wastes.

While self-contained breathing equipment (fig. 12–142) use is often suggested, many people are relatively unfamiliar with how to use it. The concerns with this equipment include high investment cost, need for knowledgeable operation, and correct maintenance, servicing, and replacement parts.

self-contained breathing apparatus (SCBA) equipment is available in different configurations—closed or open circuit, pressure demand, or demand. A closed circuit apparatus removes $CO_2$ from exhaled breath and then restores $O_2$ content from a compressed $O_2$ or $O_2$ generating source. It generally has a longer service life than that of the open circuit apparatus. Open circuit equipment allows exhaled air to escape to the atmosphere and supplies breathing air from a compressed air source.

**Figure 12–140**   Hand-held electronic multigas detector (*Photo courtesy of Neotronics*)



**Figure 12–141**   Air sampler with different gas detection tubes (*Photo courtesy of Sensidyne, Inc.*)

Pressure demand equipment maintains a slight positive pressure in the face piece, which eliminates inward leaking of atmospheric contaminants. This equipment is suitable for Immediately Dangerous to Life and Health (IDLH) environments, whereas the demand device is not suitable. Both types are suitable for $O_2$ deficient environments depending on the service life of the air source. Different kinds of face masks and user head protection can be used with the SCBA.

The OSHA requires workspace respirator equipment to be tested and certified by the National Institute for Occupational Safety and Health (NIOSH). Respirator equipment is either the filtering and conditioning type that uses workspace air without adding anything to it

or the air-supplied type that includes the SCBA. The NIOSH approval is an assurance of quality. However, this approval is for new equipment, so wear, time, or abuse can negate this credibility. If the operator is not sure how to operate this equipment and the user manual is not available, the manufacturer of the equipment or the NIOSH should be consulted for items to check before use.

Relatively low cost outside atmosphere supplied air respirator (SAR) equipment is generally available (fig. 12–143). An air-compressor, supply hose, and light-weight hood or face mask make up this equipment. SAR equipment is designed for use in dusty, humid, smelly, warm, or other such contaminated environments where an adequate supply of oxygen is present. It is not recommended for use in an atmosphere IDLH environment. Selection depends on the compressor capacity (rated in $ft^3/m$), filter quality, and hood supply hose type and length. Equipment is available that has a 5- to 10-minute emergency or exit air bottle attached. This air supply is the critical backup should something happen to the air supply hose.

A tripod is used as the overhead anchorage for a winch hoist. The hoist is attached to a leather or web harness and used to raise and lower a person through a small opening, such as a manhole. A waist belt and shoulder straps have an attached ring at the back. Rescue

**Figure 12–142**    Self-contained breathing equipment (*Photo courtesy of Willson Safety*)



**Figure 12–143**    Supplied air respirator equipment (*Photo courtesy of Gempler's*)

harness and winch hoist equipment should be able to lift at least 500 pounds as it may need to support two persons (fig. 12–144). The winch needs a sturdy, smooth-operating, unwind latch to prevent unwanted release or jamming. The support frame needs workspace clearance for the harness and the person in it.

A rope located by a ramp or storage facility can provide a practical means of emergency escape. A nondegrading material, such as nylon, that is at least 0.75 inches in diameter is suggested. The rope should be knotted at 1-foot intervals (Bowers 1992). The rope can be used by anyone who accidentally falls into a storage to hold onto until help arrives or possibly to climb out.

**Figure 12–144**    Tripod, winch, and harness (*Photo courtesy of D B Industries, Inc.*)



# 651.1209    References

Agriculture Canada. 1980. Canada animal manure management guide. Info. Serv., Agriculture Canada, Ottawa, ON, Publ. 1534, 37 pp.

American Iron and Steel Institute. 1993. Handbook of steel drainage and highway construction products, 4th ed. National Corrugated Steel Pipe Assn., Washington, DC. 518 pp.

American Society Agricultural and Biological Engineers. 1995. ASABE Standards, 42nd ed. St. Joseph, MI. 783 pp.

    a.   S261.7 Design and installation of nonreinforced concrete irrigation pipe systems, pp. 657–661. 1989.

    b.   S263.3 Minimum standards for aluminum sprinkler irrigation tubing, pp. 662–3. 1991.

    c.   S301.2 Front-end agricultural loader ratings, pp.125–6. 1991.

    d.   S317 Improving safety on enclosed mobile tanks for transporting and spreading agricultural liquids and slurry, p. 155. 1991.

    e.   S318.11 Safety for agricultural equipment, pp. 156–9. 1995.

    f.   S324.1 Volumetric capacity of box type manure spreaders-dual rating method, p. 160. 1990 (R2008).

    g.   S325.1 Volumetric capacity of open tank type manure spreaders, p. 161. 1990.

    h.   S326.1 Volumetric capacity of closed tank type manure spreaders, p. 161. 1993.

    i.   EP340.2 Installation of flexible membrane linings, pp. 662–5. 1992.

    j.   S355.1 Safety for agricultural loaders, p. 193. 1991.

    k.   EP379.1 Control of manure odors, pp. 540–41. 1991.

    l.   EP393.2 Manure storages, pp. 549–52. 1991.

m. S394 Specifications for irrigation hose and couplings used with self-propelled, hose dragged agricultural irrigation systems, pp. 709–10. 1991.

n. EP403.2 Design of anaerobic lagoons for animal waste management, pp. 543–6. 1992.

o. S412.1 Ladders, cages, walkways and stairs, pp. 555–58. 1993.

p. S441 Safety signs, pp. 268–83. 1995.

q. EP 470 Manure storage safety, pp. 605–08. 1992.

r. S276.4 Slow moving vehicle identification emblem, pp 104–106. 1994.

s. S350 Safety alert symbol for agricultural equipment, p. 188. 1992.

Andrews, J.E. 1991. Livestock waste management system planning flowchart. ASAE Paper No. 91–2538, St. Joseph, MI.

Annamali, K., A. Madan, J. Sweeten, and D. Chi. 1985. Fluidized bed combustion of manure: experiment and theory. In Agricultural Waste Management and Utilization, Proc. of 5th ISAW, ASAE, St. Joseph, MI. pp. 37–45.

Ashfield, G. 1973. Underground silos for liquid manure. In Dairy Herd Management 10:12, pp. 10–13.

Auvermann, B.W., and J.M. Sweeten. 1992. Evaluation of hydrocyclone solids separation for dairy manure. Agric. Eng. Dep., Texas A&M, College Station, TX. 11 pp.

Barquest, G.D., et al. 1974. Freestall housing and liquid manure management for the entire dairy herd—systems approach, Univ. WI, Marshfield Exp. Farm., Marshfield, WI.

Bartok, J.W. 1994. Fertilizer and manure application equipment. NRAES–57, 152 Riley Robb Hall, Cornell Univ., Ithaca, NY. 23 pp.

Bate, L.A., R.R. Hacker, and P.A. Phillips. 1988. Effect of manure handling on air quality and pig performance in partially slatted floor barns. Can. J. Agric. Eng. 30, 107–110.

Berg, L. 1994. Producer recalls tragic tales of manure pit deaths. National Hog Farmer 39:6, Overland, KS. pp. 24–30.

Bowers, W.J. 1992. Safety components at manure storages. ASAE Paper No. 92–4012. St. Joseph, MI.

Buchanan, J.R., C.R. Mote, and R.B. Robinson. 1993. Struvite control by chemical treatment. ASAE Paper No. 93–4570. St. Joseph, MI.

Bundy, D.S. 1993. Odor management. In Meeting the environmental challenge, Proc. Envir. Symp., Natl. Pork Prod. Council, Des Moines, IA. pp. 41–51.

Burns, R., and L. Moody. 2003. Development of a standard method for testing mechanical manure solids separators. ASAE Paper No. 034131.

Canada Farm Building Plans Service. 1993. Agriculture Canada. Commun. Branch, Ottawa, Ontario, Canada.

Cantine, T. 1992. U.S. Anaerobic farm digester study. Report by ICF Consult., Inc., University City, CA, under contract with the USEPA. 8 pp.

Carlson, G. 1991. A rate control system for slurry spreaders. Swedish Inst. of Agric. Eng., Uppsala, SW, S–750 07.

Christison, G.I., and C. Farmer. 1983. Physical characteristics of perforated floors for young pigs. Canadian Agricultural Engineering 25:1, pp. 75–80.

Clanton, C.J. 1993. Alternative waste management systems. Proc. Livestock Waste Mgt. Conf., Agric. Eng., U. MN, St. Paul, MN. pp. 98–106.

Compost Science. 1964. Dried manure plants flourish. Compost Science 5:1, Rodale Press, Emmaus, PA. p. 31.

Dickey, E.C. 1978. The economics of manure injectors. Dairy Herd Management 15:5, pp. 64–7.

Dumelow, J. 1993. Simulating the cattle foot/floor interaction to develop improved skid resistant floors. Livestock Environment IV, 4th Intl. Symp., ASAE, St. Joseph, MI. pp. 173–180.

Eftink, B. 1986. A dream runs out of gas. Successful Farming, Des Moines, IA. pp. 34–35.

Fanning, R.F. 1984. Fire extinguishers for the farm and home. Agric. Ext. Sta. Cir. AE–825, N.D. State Univ., Fargo, ND. 7 pp.

Farm Pilot Project Coordination (FPPC), Final report: Next generation tempest dryer. Global Resource Recovery Organization, Inc. (GRRO). http://www.fppcinc.org/pdf/reports_grro2.pdf.

Fleming, R., and M. MacAlpine. 2003. Evaluation of mechanical liquid/solid manure separators literature review. Prepared for Ontario Pork, Ridgetown College, University of Guelph, Ridgetown, Ontario, Canada.

Goodrich, P. 1993. Manure application methods to minimize and cost optimize manure value. Proc. Livestock Waste Mgt. Conf., Agric. Eng., Univ. MN, St. Paul, MN. pp. 79–85.

Grainews. 1994. Straw blown over manure lagoon cuts odors. Grainews 20:10, Winnepeg, MB. pp. 15 and 22.

Helsey, D. 1980. Like money in the tank. Dairy Herd Management 17:5, pp. 38–41.

Hudson, J. (ed.). 1993. Loaders: tractor front-mounted (farm type). Implement and Tractor Redbook, pp. 167–180.

Hujsmans, J.F.M. 1994. Personal communication. Agro-Engineering Department, IMAG, Wageningen, The Netherlands.

Huss, M. 1994. Personal communication. Agric. Exp. Sta. Res. Serv., Iowa State Univ., Ames, IA.

Jones, D.D., A.C. Dale, and D.L. Day. 1972. Aerobic treatment of livestock wastes. Grant EC–00244, final report (SW–16rg) for the USEPA, Agric. Eng., Purdue Univ., Lafayette, IN.

Keener, H.M., R.C. Hansen, and D.L. Elwell. 1993. Pressure drop through compost: implications for design. ASAE Paper No. 93–4032. ASAE Pap 934032. St. Joseph, MI.

Kintzer, B., and D.C. Moffitt. Physical manure treatment (solids separation), SERA–17, Minimizing Losses from Agriculture. http://sera17.ext.vt.edu. pp. 1–3.

Koegel, R.G., R.J. Straub, W.P. Delzer, and J.Y. Kim. 1990. Design of a reciprocating press for solid-liquid separation of dairy cattle waste. Proc. of 6th ISAFPW, ASAE, St. Joseph, MI. pp. 269–274.

Landen, R. 1992. Gasification—providing markets for biomass crops. Agricultural Engineer 47:4, Silsoe Bedford, UK 454 DU.

Livestock. 1979. Kansas contractor uses scraper in new money-saving application. Livestock 57:6.

Malzeryd, J. 1991. Evaluation method: manure spreading equipment. Swedish Inst. Agric. Eng., Uppsala, SW.

Martin, J.H. 1978. The oxidation ditch as a dairy cattle waste management alternative. Agricultural Waste Management, Cornell Univ., Ithaca, NY.

Maschhoff, K.D., and A. Muehling. 1985. Using nurse tankers to transport liquid manure to the field from a 650-sow farrow to finish operation. Agricultural Waste Management and Utilization, Proc. of 5th ISAW, ASAE, St. Joseph, MI. pp. 55–62.

McElroy, C.H., D.K. McCook, D.C. Moffitt, and J.D. Rickman. 1993. Evaluating seepage potential from animal waste lagoons. ASAE Paper No. 93–4527. St. Joseph, MI.

McFarland, A.M.S., and J.M. Sweeten. 1993. Odor assessment of open-lot dairies. ASAE Paper No. 93–4553. St. Joseph, MI.

Meiering, A.G., et al. 1975. High temperature drying of animal waste. Canadian Agricultural Engineering 17:2, pp. 75–80.

Melvin, S.W., and R.H. Crammond. 1980. Use of a covered lagoon for odor control and energy recovery. Livestock Waste A Renewable Resource, Proc. of 4th ISLW, ASAE, St. Joseph, MI. pp. 201–5.

Meyer, D.J., and R.K. White. 1978. Gravity drain gutters for swine manure systems. Pork Industry Handb. Leaf. No. 95, Animal Science Dep., Purdue Univ., West Lafayette, IN.

Meyer, V.M. 1992. Flat bottom gravity drain gutters for swine manure. Leaf. PM–1377 (rev.), Agric. Eng., Iowa State Univ., Ames, IA. 4 pp.

Midwest Plan Service. 1975. Livestock waste management with pollution control. MWPS–19, N.C. Reg. Publ. 19, 88 pp.

Midwest Plan Service. 1982. Manure digestion, runoff, refeeding, odors. MWPS–25, 36 pp.

Midwest Plan Service. 1983. Structures and environment handbook. MWPS–1, 11th ed.

Midwest Plan Service. 1985. Livestock waste facilities handbook. MWPS–18, 2nd ed. (rev.), 112 pp.

Midwest Plan Service. 1994. Concrete manure storage handbook. MWPS–36, Iowa State Univ., Ames, IA.

Miller, M. 1993. A shopper's guide to farrowing house flooring. PORK '93, Vance Publ., Shawnee Mission, KS. pp. 18–22.

Miner, R. 1994. Develop odor control strategy. National Hog Farmer Blueprint Series 39:3, Intertec Publ., Overland Park, KS. pp. 12–13.

Moffitt, D.C., J. Rickman, C. McElroy, D. Hendriks, H. Logan, and K. Kroeger. 1993. Do waste treatment lagoons leak? ASAE Paper No. 93–4526. St. Joseph, MI.

Moore, J.A. 1989. Solids liquid separation. Dairy Manure Management, NRAES–31, N.E. Reg. Agric. Eng. Serv., 152 Riley-Robb Hall, Cornell Univ., Ithaca, NY. pp. 178–92.

Moore, J.A., R E. Larson, and E.R. Allred. 1969. Study of the use of the oxidation ditch to stabilize beef animal manure in cold climates. Animal Waste Management, Cornell Univ. Conf. on Animal Waste Mgt., Syracuse, NY. pp. 172–177.

Murphy, T. 1993. Personal communication. Assistant state engineer. U.S. Dep. Agric., Nat. Resourc. Conserv. Serv. Harrisburg, PA.

Nicolai, R., S. Pohl, and D. Schmidt. 2004. Covers for manure storage units, livestock development in South Dakota, Environment and Health, FS925–D, South Dakota Cooperative Extension, pp. 1–6.

Northeast Dairy Practices Council. 1977. Dairy manure management-spreading equipment, guideline NRAES 27:7, Cornell Univ., Ithaca, NY. 4 pp.

Ohta, Y., and M. Iheda. 1978. Deodorization of pig feces by actinomycetes. Applied and Environmental Microbiology 36:3, pp. 487–535.

Patrico, J. 1992. Flush it! Dairy Today, pp. 54–56.

Patronsky, R.S. (ed.). 1978. Agricultural waste field manual. U.S. Dep. Agric., Soil Conserv. Serv. Washington, DC.

Persson, S.P.E., H.D. Bartlett, and A.E. Branding. 1979. Agricultural anaerobic digesters. Agr. Exp. Sta. Bul. 827, PA State Univ., University Park, PA. 50 pp.

Peters, R.T., and D. McMoran. 2010. Boom-type carts vs. big-guns in Northwestern Washington, Washington State Univ. Extension, FS003E, 12 pp.

Prairie Agricultural Machinery Institute. 1993. Hog lagoon odor control. Res. Update 698, PAMI, Humboldt, SK, Canada. 4 pp.

Roos, Kurt. 1994. Personal communication. Director AGSTAR, U.S. Environ. Prot. Agency, Washington, DC.

Rupp, R. 1992. DeLaval introduces odorless manure disposal system. The Farmer, Webb Publ., St. Paul, MN.

Rural Builder. 1992. An experimental barn puts cows first. Rural Builder, Sep. issue, pp. 26–36.

Rynk, R. (ed.). 1992. On-farm composting handbook. NRAES–54, Cornell Univ., Ithaca, NY. 187 pp.

Safley, L.M., and P.D. Lusk. 1991. Low temperature anaerobic digester. Agricultural Engineering, NC State Univ, Raleigh, NC. 14 pp.

Safley, L.M., and P.W. Westerman. 1992. Performance of a low temperature lagoon digester. Bioresource Technology 41:167–175, Elsevier Publ., England.

Schnieder, J.H., S.B. Harrison, and P.B. Freeze. 1993. No discharge gated pipe distribution of feedlot runoff. ASAE Paper No. 93–4566, St. Joseph, MI.

Schulte, D., D.A. Kottwitz, and C.B. Gilbertson. 1985. Nitrogen content of scraped swine manure. Agric. Waste Utilization and Mgt., Proc. 5th ISAW, ASAE, St. Joseph, MI. pp. 321328.

Shutske, J.M., and M.S. Purschwitz. 1993. Costs and issues associated with implementing the confined space standard in waste storage facilities. ASAE Paper No. 93–4571, St. Joseph, MI.

Shuyler, L.R. 1973. Environment protecting concepts of beef cattle waste management. U.S. Environ. Prot. Agency, Proj. No. A04–05, Prog. El. 1B2039, Robert S. Kerr Environ. Res. Lab., Ada, OK.

Sievers, D.M., C.D. Fulhage, and E.L. Iannotti. 1990. Structural and equipment deterioration in an anaerobic digester. Proc. 6th ISAFPW, ASAE, St. Joseph, MI. pp. 84–7.

Straub, R. 1993. Recycle manure for bedding. Wisconsin Agriculturalist, pp. 44 and 46.

Sutton, A.L., D.W. Nelson, and D.D. Jones. 1983. Utilization of animal manure as fertilizer. Coop. Ext. Serv. Circ. 1D–101, Purdue Univ., West Lafayette, IN. 12 pp.

Sweeten, J.M. 1980. Prospects for methane production at cattle feedlots. Agricultural Engineering, Texas A&M Univ., College Station, 20 pp.

Sweeten, J.M. 1991. Cattle feedlot waste management practices. Agric. Ext. Serv. Publ. B–1671, Texas A&M Univ., College Station, TX. 24 pp.

Sweeten, J.M., A.R. Mcfarland, J.E. Sorel, R.O. Gauntt, and D.L. Reddell. 1984. A butanol olfactometer for field measurement of ambient odors. J. Air Pollution Control Assn. 34:1208–13.

Switzky, D. 1982. Fiberglass-covered storage pond cuts odors, keeps neighbors happy. National Hog Farmer 27:84–7, Overland Park, KS.

Switzky, D. 1993. Odor, can additives really cut it? National Hog Farmer 38:5, Overland Park, KS.

Thompson, R.J., and W.J. Bower. 1991. Pennsylvania manure storage study, final report. U.S. Dep. Agric., Soil Conserv. Serv., Harrisburg, PA. 59 pp.

U.S. Department of Health and Human Services (HHS). 1990. Preventing deaths of farm workers in manure pits. NIOSH Alert, Publ. No. 90–103, Natl. Inst. Occup. Safety and Health, Publ. Dissem., Cincinnati, OH. 7 pp.

United Grain Grower. 1974. Engineering notes. United Grain Grower, Farm Info. Serv., Winnipeg, MB Canada. p. 700.

Verdoes, N., et al. 1992. Mechanische mestocheiders als mogelyke schakel in de mestbewerking op bedrijfsneveau. Proefvefslag P1.77, Proefstation voor de Varkenshoudery, Postbus 83, 5240 AB, Rosemalen, The Netherlands. 56 pp.

Vetter, R. 1993. Innovative ideas to utilize animal waste. Meeting the Environmental Challenge, Proc. Environ. Symp., Natl. Pork Prod. Counc., Des Moines, IA. pp. 101–8.