Alkaline hydrolysis

Summary

Definition and objectives

Alkaline hydrolysis of carcasses is a process by which heat and pressure dissolve and sterilize animal carcasses in a strong solution of sodium or potassium hydroxide. An alkaline hydrolysis system can completely decontaminate infected tissue.

The objectives of alkaline hydrolysis are to:

- Inactivate pathogens and prions such as transmissible spongiform encephalopathy (TSE)
- Convert dead animals into a sterile solution or dried material that has less potential for environmental pollution than before treatment

The ultimate goal of the alkaline hydrolysis process is to convert animal carcasses into environmentally safe materials while avoiding negative public perception.

This system costs less to operate than do other carcass disposal methods such as incineration. The mechanical components of this process are highly durable.

Alkaline hydrolysis can occur in fixed or mobile facilities. When choosing between these two types of facility for disposing of animal carcasses, several factors should be considered, including cost, transportation, agent suitability, environmental risk, disposal capacity, procedure speed and the availability of resources (Table 1).

Alkaline hydrolysis

Summary

Table 1. Considerations for choosing an alkaline hydrolysis system.

Consideration	Fixed alkaline hydrolysis	Mobile alkaline hydrolysis
Application	Animal	Animal
Transportation concerns	Yes	No
Agents inactivated	Viruses, bacteria and TSE[3]	Viruses, bacteria and TSE[3]
Disposal capacity[1]	Low	Low
Environmental risk	Low	Medium
Regulatory restrictions	Low	Medium
Cost[2]	Lower rent but higher operation cost	Higher rent but lower operation cost
Availability of resources	Low	Low
Procedure speed	High	High

[1] Animal mortality (tons): Low < 100 t < Medium < 300 t < High

[2] The initial investment of mobile alkaline hydrolysis is higher than that of fixed alkaline hydrolysis because of the higher rent cost of mobile facilities. However, the transportation cost of mobile alkaline hydrolysis is lower, thereby reducing the operation cost.

[3] TSE = transmissible spongiform encephalopathy

Unless specified, the descriptions on the next few pages apply to both fixed and mobile facilities (Figs. 1, 2 and 3).

Figure 1. A tissue digester in a fixed alkaline hydrolysis facility. *(Photo courtesy of Waste Reduction by Waste Reduction Inc., Indiananapolis, IN)*

Figure 2. A carcass digester in a fixed alkaline hydrolysis facility. *(Photo courtesy of Waste Reduction by Waste Reduction Inc., Indiananapolis, IN)*

Figure 3. The crushable bone and teeth remaining from a carcass digester in a fixed alkaline hydrolysis facility. *(Photo courtesy of Waste Reduction by Waste Reduction Inc., Indiananapolis, IN)*

Alkaline hydrolysis

Summary

General description

The method of the alkaline hydrolysis process to treat carcasses depends on the kind of contamination:

- To inactivate **microbial pathogens,** the carcasses must be heated to 212 °F and pressurized at 15 pounds per square inch for 3 hours.
- To destroy **TSE, including bovine spongiform encephalopathy,** the carcasses must be heated to 300 °F and pressurized at 70 pounds per square inch for 6 to 8 hours.

Alkaline hydrolysis processes occur in hot oil or in steam-jacketed, insulated, stainless-steel pressure vessels with automatic or manual control systems. The process breaks large molecules of organic matter into smaller molecules (amino acids, sugars and fatty acids). Destroyed during this process are all pathogens, including the protein coats of the viruses, the peptide bonds of the prions, and vegetative and spore-forming bacteria.

The pH level of the treated material drops from 14 at the beginning of the process to about 11 at the end. The pH level at the end of the alkaline hydrolysis process highly depends on the total amount of operation time, the amount of fat in the carcass (a higher fat content can result in a lower pH) and other factors such as the buffering of the alkaline solution by the carcass.

The vessels used in the process may be equipped with devices to measure the weights of the carcasses, water and alkali powder, and to measure and control the temperature, pH, pressure and the amount of time needed for steril-

ization. The mixed materials are agitated and heated consistently either by mechanical mixers or by steam and alkaline circulation systems.

Containers are provided for the bone pieces and indigestible materials such as cellulose, latex and metal, which are separated from the final effluent. The wetted parts of the digester are stainless steel or Teflon, which can tolerate high temperatures and strong acidic or alkaline solutions.

Some materials are resistant to alkaline hydrolysis digestion, including bulk cellulose (such as paper, strings, undigested plant fiber and wood shavings) and the inorganic content of the fecal matter associated with the carcasses. However, the process completely sterilizes these indigestible materials.

The carcass digestion process occurs in a completely sealed environment; very little gas is emitted into the air. Odors are released for a short period during carcass loading and unloading.

The biochemical oxygen demand (BOD) of the final effluent is very high because of the high concentrations of organic matter. The BOD may reach 0.58 to 0.83 pounds per gallon (70,000 to 100,000 milligrams per liter). It can be diluted by adding water or a low-BOD solution. It may be disposed of into the sewer system after local wastewater treatment authorities have been consulted.

The pH of the final liquid effluent should be reduced to about 9 by adding carbon dioxide or industrial acid (such as acetic acid) before land application.

Because the mobile alkaline hydrolysis units do not require that the carcasses be transported, the disposal process is considerably faster than for fixed facilities. However, it may not be possible to deploy these units into the field quickly for massive amounts of animal carcasses.

Coordination and jurisdictional considerations

The decision to use alkaline hydrolysis as a carcass disposal option should be made jointly by the members of the incident command structure established by local or state authorities.

Alkaline hydrolysis should be undertaken only with explicit approval by the institutions and agencies that are competent in making determinations about protecting the environment.

States have ranked preferred methods for carcass disposal, and the incident command structure must use the preferred options before undertaking alkaline hydrolysis activities.

If the carcasses are to be transported to nearby counties for alkaline hydrolysis, the incident command structure must consider the added problems of transportation safety and contamination of other property. Local authorities must have an inter-county memorandum of understanding in place so that the carcasses can be easily transported to the nearest facility for alkaline hydrolysis.

Pollution and other property damage considerations

The exercise of police power gives governmental entities and agencies wide discretion in making decisions about carcass disposal to protect public health. However, the exercise of this power does not shield governmental entities against nuisance actions if the proper precautions are not taken.

The two main problems with alkaline hydrolysis are waste and odor, both of which could trigger nuisance or other kinds of lawsuits. Sovereign immunity may not be a defense to such an action.

The decision to use alkaline hydrolysis must be made by the appropriate technical group within the incident command structure because injury to people or property could prompt suits similar to those based on nuisance.

Planning considerations

To operate successfully, alkaline hydrolysis units require more skill and expertise than do some of the other disposal methods, such as burial. At least two technicians per shift for each alkaline hydrolysis system must be trained and equipped for operation, safety and biosecurity.

The personnel must be trained in safe handling of the animal carcasses, prevention of cross contamination, processing procedures, and decontamination of the equipment and the site during and after processing.

Issues that must be considered include those related to handling, packing and storing the carcasses as well as conveying them to the alkaline hydrolysis (mainly fixed alkaline hydrolysis) site. For more information, see the Transportation section of the "General Considerations" chapter of this guide.

Provide the appropriate amounts of sodium or potassium alkaline materials at about 10 percent of the carcass weight if it is in dried form or 20 percent of the carcass weight if it is in liquid form. If potassium hydroxide is used, the fertilizer value of the effluent will increase for land use.

Make sure that the vessels in the alkaline hydrolysis units can tolerate pressures of up to 100 pounds per square inch as recommended by the American Society of Mechanical Engineers. TSE-infected carcasses need a vessel pressure of no more than 70 pounds per square inch. Failure to comply with this rule may result in serious injury or death.

Provide diesel fuel for electricity generation and propane for steam production. Gener-

ally, 1 pound of steam is needed to sterilize 1 pound of carcass.

Sufficient water must be provided for the alkaline hydrolysis process, for steam generation and for the washing and rinsing processes. Although soft water is needed to generate steam from the boiler, clean water from lakes, ponds and rivers may be used for washing, rinsing and using carcass hydrolysis. Any surface water may be used to dilute the final effluent. Table 2 shows the water consumption and final effluent production for alkaline hydrolysis of 1,000 pounds of carcasses.

Additional energy will be required if you plan to dehydrate the final effluent which may contain up to 90 percent moisture. To minimize the foaming problem during the dehydration process, reduce the pH of the effluent to about 6 by adding acid or carbon dioxide before drying it.

The dried weight (inorganic and mineral content) of the final effluent is about 2 percent of the total carcass weight and can be used for land application. Coordinate in advance and plan for the land disposal of the final effluent and solids with county and state regulatory agencies, USDA Natural Resources Conservation Service and university Extension agronomists.

Plan to use the effluent directly as a substrate in an anaerobic digester and the solids (mainly bone and teeth, which can easily be crushed into a fine powder) as nitrogen and mineral sources in compost, or dispose of the effluent at a public landfill.

Table 2. Capacities and dimensions for fixed alkaline hydrolysis and mobile alkaline hydrolysis systems.

Alkaline hydrolysis options	Carcass digestion capacity[a]	Minimum installation area	Water consumption for 1,000 lb of carcasses[b]	Effluent production for 1,000-lb carcasses
Fixed alkaline hydrolysis	2,000–10,000 lb/8 ha	1,000 ft^2	60–240 gal[b]	120–300 gal
Mobile alkaline hydrolysis	4,000 lbs/8 ha	300 ft^2	60–240 gal[b]	120–300 gal

[a] For higher carcass capacities, it is better to use fixed and mobile alkaline hydrolysis units in a modular pattern rather than using units with higher capacities. This is because they can be operated sequentially; they use less energy and labor; and they are easier to manage than are larger units.

[b] Water consumption will be minimized if the alkaline hydrolysis systems use more alkali and have a longer period of time for hydrolysis, and if the carcasses are shredded instead of intact and contain a highly agitated mixture of materials. More water is required for inactivating carcasses infected with TSE than for those infected with bacteria.

Fixed alkaline hydrolysis procedures

Follow the operator's manual for fixed alkaline hydrolysis systems. Assign two trained operators per shift, one to control and manage the carcass feeding, processing and off-loading; the other to manage the boiler, generators and the alkaline and water storage systems.

Operate the entire system for at least 1 hour without feeding in any carcass materials to ensure the proper and smooth operation of the processing equipment, including the steam generator, digester, mixer or circulation pump, and controlling devices.

For proper operation of a fixed alkaline hydrolysis system, make sure that the following processes occur in this order:

1. The carcasses are loaded into the hopper of the fixed alkaline hydrolysis system and their weights are measured by the built-in load cells.
2. The carcasses are fed into the vessel.
3. The feeders of the different materials add the required amount of alkaline solution and water to the vessel.
4. The vessels are properly sealed, and the heating process occurs in a completely enclosed environment.
5. The final effluent is tested for temperature, pH and suspended solids before disposal.

Follow local and federal guidelines, and adjust the pH, temperature and biological oxygen demand of the solution.

Fixed alkaline hydrolysis units operate at high pressure. The equipment must be designed, maintained and used in strict accordance with industrial and state guidelines. Failure to do so may result in an explosion, causing serious injury or death.

Mobile alkaline hydrolysis procedures

Assign skilled drivers with the appropriate driving permits to maneuver the mobile alkaline hydrolysis units. These drivers are in addition to the technicians required to manage the mobile alkaline hydrolysis process.

Plan to provide up to two truck trailers and an adjunct truck/feeder for mobile alkaline hydrolysis. The first trailer is for mounting the grinder and cooker/conveyor; the second is for an oil heater or steam generators along with a feed conveyor system. The truck/feeder carries an alkaline supply system. Truck containers will also be needed to collect and transport the final effluent to a disposal site.

Propane and water tanks will be needed for a 400-horsepower on-site steam generator. Equip the mobile alkaline hydrolysis with an electric generator of sufficient horsepower to provide electricity for various functions of the unit and for illumination.

Store the final effluent in a container equipped with a heating system to prevent freezing during winter. To dispose of the end product, follow the procedures outlined in the fixed alkaline hydrolysis section of this guide.

Figure 4. Schematic of a mobile alkaline hydrolysis system with two auxiliary trucks. *(Photo courtesy of Waste Reduction by Waste Reduction Inc., Indiananapolis, IN)*

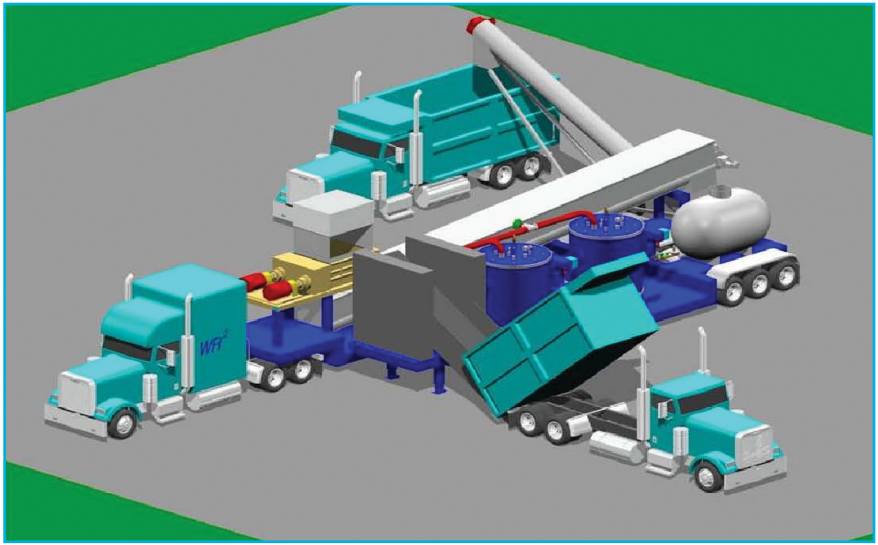

Figure 5. Schematic of a mobile alkaline hydrolysis system with the main components of high capacity of 0.5 x 10^6 pounds per 8 hours. *(Photo courtesy of Waste Reduction by Waste Reduction Inc., Indiananapolis, IN)*

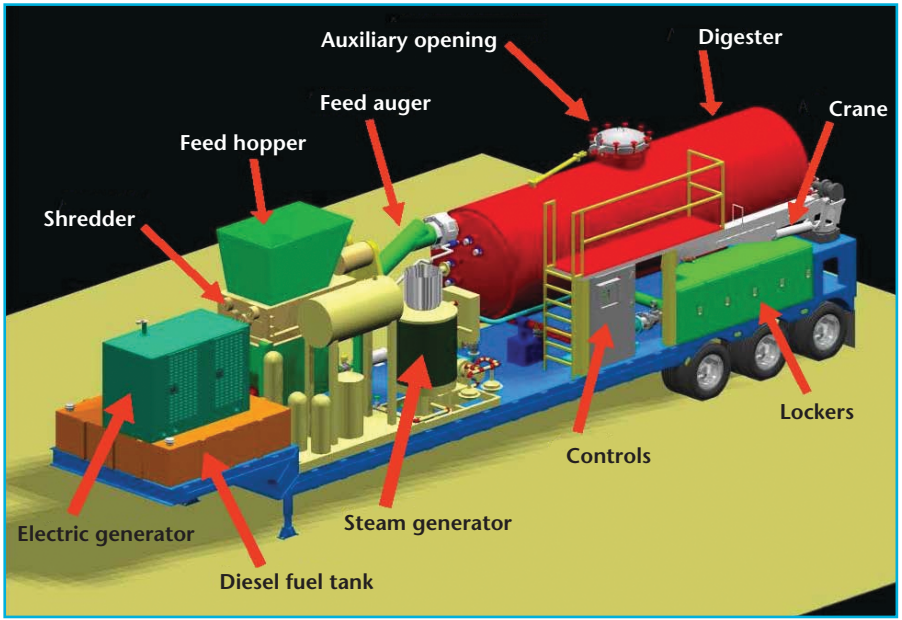

Figure 6. A mobile alkaline hydrolysis unit. *(Photo courtesy of Waste Reduction by Waste Reduction Inc., Indiananapolis, IN)*

Table 3. Personal protective equiment guidelines for alkaline hydrolysis.

Nature of work	Mask/Respirator[a,b,c]		Protective clothing[a]	Eye/hearing protection[a]	Gloves[a]	Head/foot protection
	Zoonotic agent	Non-zoonotic agent				
Direct handling of contaminated material	Disposable particulate respirator (N95, N99 or N100); half or full facepiece	None recommended unless for foot-and-mouth disease	Impermeable to caustic liquids (such as Dupont Tychem® QC); consider based on heat situation	***Eyes:*** Full facepiece respirator or indirectly vented goggles; contact lenses should not be worn under goggles or safety glasses; consider prescription safety goggles; face shield unless wearing a full facepiece respirator	***Gloves:*** Heavy duty (15–18 mil) chemical resistant gloves that can be disinfected or disposed	***Feet:*** For workers handling carcasses, steel-toe/steel shank waterproof boots; for others, steel-toe work shoes or boots ***Head:*** Hard hat
No direct handling of contaminated material, but potentially in contact with caustic chemicals	None recommended	None recommended	Overgarment impermeable to caustic liquids (such as Dupont Tychem® QC)	***Eyes:*** Splash-proof, indirectly vented goggles; face shield	Same as above	***Feet:*** Steel-toe work shoes or boots ***Head:*** Hard hat

[a] See *www.safetyequipment.org* for a list of vendors from OSHA

[b] For information on a full respiratory protection program, see *www.osha/gov/SLTC/respiratoryprotection/index*.

[c] Regulations governing use of personal protective equipment in hazardous waste operations can be found at 29 CFR 1910.134 and 29 CFR 1910.156 and are summarized in the "General Considerations" chapter of this guide.

Diseases of concern

Viruses and non-spore-forming bacteria: Alkaline hydrolysis is an effective method for eliminating viral and non-spore-forming bacteria.

Precautions must be taken to prevent inhalation of airborne pathogens. Personal protective equipment is essential for worker safety while the carcasses are being transported and handled on site.

Diseases for which alkaline hydrolysis processes are appropriate include highly pathogenic avian influenza, contagious bovine pleuropneumonia, brucellosis, foot-and-mouth disease, glanders, Japanese encephalitis, Q fever, Rift Valley fever, rinderpest, African swine fever, classical swine fever, tularemia and vesicular stomatitis.

Spore-forming bacteria: Alkaline hydrolysis is an effective method of disposal to control the spread of spore-forming bacteria.

Diseases of concern include anthrax.

Prions (TSEs): Alkaline hydrolysis is an effective method of disposal; however, material suspected of being contaminated with TSEs should be digested for no less than 6 hours.

Diseases include bovine spongiform encephalopathy, chronic wasting disease and scrapie.

Notes on safety

Heat stress: See guidelines on heat stress in the Safety section of the "General Considerations" chapter of this guide.

First aid: First aid should be available to employees at all times.

Safety observers: It is dangerous to move contaminated plant and animal materials around large volumes of heated sodium hydroxide; **use a safety observer.**

Chemical hazards: Provide safety showers and emergency eyewash stations within 20 feet of each alkaline hydrolysis unit; caustic chemical burns are exceptionally hazardous and can cause irreparable damage to the eyes within seconds if not removed using copious amounts of water **for at least 15 minutes.** Workers exposed to **any** amount of sodium hydroxide in their eyes should use the eyewash station and report to an emergency room.

Ventilation: Although alkaline hydrolysis reactors use enclosed pressure vessels, the area surrounding the vessel should be adequately ventilated.

Pressure vessels: Alkaline hydrolysis pressure vessels operate under high pressure and temperature. The risk of injury resulting from failure of a vessel is significant; follow all manufacturer directions carefully.

Groundwater pollution

Facilities accepting contaminated material may be fixed sites on heavily trafficked public or private property (such as a university campus). Moving non-zoonotic-contaminated plant or animal materials onto these sites should be planned carefully.

Although the movement of carcasses contaminated with non-zoonotic materials does not present a human health hazard, a significant effort must go into public awareness and public relations activities well before moving any carcasses to the site. Such facilities should not be used for disposal of large amounts of carcasses contaminated with zoonotic agents or TSEs.

Vehicles and personnel must be decontaminated before the vehicles leave the disposal site. See additional material in the Safety and Biosecurity section of the "General Considerations" chapter of this guide.

If performed according to this guide, releasing effluent poses no threat to public health; however, a public relations plan should be in place before disposing of any effluent in a public sewer system. Disposal should be performed fully in conjunction with state and local health department authorities.

Control of effluent discharge

Close coordination with state and local health and public works authorities is essential before any effluent is released into a public sewer system.

Effluent should be tested and monitored before release into a sewage system. A pH range of 10.0 to 11.5 is generally acceptable throughout the United States but may vary by jurisdiction. Effluent must be released at or above 374 °F (190 °C) to ensure that the effluent will not solidify.

Soil pollution

Alkaline hydrolysis poses no soil pollution concerns unless the effluent disposal is not controlled.

Some tissue, such as bone and teeth, will remain after the alkaline hydrolysis process is complete. This material can be ground and disposed of in landfills as solid waste in accordance with state and local solid waste regulations.

All waste will be monitored and tested before shipment of potentially dangerous materials.

Air pollution

There are no notable emissions associated with alkaline hydrolysis. Gas release is not significant either as a health hazard to the public or as a nuisance gas.

Air pollution concerns are limited to the on-site workers, who will need personal protective equipment to minimize their exposure to the airborne or aerosolized agents.

Costs and issues

The cost breakdown relating to alkaline hydrolysis follows the general specifications from the "General Considerations" chapter of this guide.

The direct cost consists of fixed cost, including depreciation and financing costs, and variable costs for the use of labor, alkali, steam, sewer disposal, electricity, landfill materials, transport, maintenance and repair.

The direct fixed cost and the variable costs depend on the facility's capacity (Tables 4–6). For specific indirect cost items, see the "General Considerations" chapter of this guide.

Table 4. Initial investment and direct fixed cost estimates for a tissue digester with 2,000-pound capacity per cycle.

Initial investment[a]	**Investment (2,000-lb digester capacity: 0.25 ton/hr)**
Digester unit	$400,000
Installation cost	$200,000
Remodel sampling rooms and redirect pipes	$225,000
Dehydration and odor control system	$300,000
Total	**$1,125,000**

Fixed annual cost	
Depreciation (20 years)	$56,250
Interest (6%)	$67,500
Total	**$123,750**

[a] **Source:** *http://www.co.larimer.co.us/boards/minutes/Aug03Min.htm.* There is no initial investment breakdown for a 10,000-pound digester.

Table 5. Estimates of direct variable costs by weight and mortality for a 2,000-pound digester.

2,000-lb equipment						
	Cost per ton	**Cattle**	**Calves**	**Weaned hogs**	**Preweaned hogs**	**Others (sheep, lambs, goats)**
Average weight per mortality (lb)		750	266	133	6	77
Alkali	$49.50	18.56	6.58	3.29	0.15	1.91
Electricity	$1.00	0.38	0.13	0.07	0.00	0.04
Water	$1.84	0.69	0.24	0.12	0.01	0.07
Steam	$20.40	7.65	2.71	1.36	0.06	0.79
Sewer	$1.65	0.62	0.22	0.11	0.00	0.06
Landfill	$1.09	0.41	0.14	0.07	0.00	0.04
Repairs and maintenance	$40.00	15.00	5.32	2.66	0.12	1.54
Labor	$22.00	8.25	2.93	1.46	0.07	0.85
Transportation	n/a	n/a	n/a	n/a	n/a	n/a
Variable cost per ton	**$137.48**					
Variable cost per carcass		**$51.56**	**$18.27**	**$9.14**	**$0.41**	**$5.30**

Source: *http://www.wr2.net/sales/cost_calculator.html*

Table 6. Estimates of direct variable costs by weight and carcass for a 10,000-pound digester.

10,000-lb equipment						
	Cost per ton	**Cattle**	**Calves**	**Weaned hogs**	**Preweaned hogs**	**Others (sheep, lambs, goats)**
Average weight per carcass (lb)		750	266	133	6	77
Alkali	$49.50	18.56	6.58	2.99	0.15	1.91
Electricity	$1.00	0.38	0.13	0.07	0.00	0.04
Water	$1.84	0.69	0.24	0.12	0.01	0.07
Steam	$20.40	7.65	2.71	1.36	0.06	0.79
Sewer	$1.65	0.62	0.22	0.11	0.00	0.06
Landfill	$1.09	0.41	0.14	0.07	0.00	0.04
Repairs and maintenance	$40.00	15.00	5.32	2.66	0.12	1.54
Labor	$0.92	0.34	0.12	0.06	0.00	0.04
Transportation	n/a	n/a	n/a	n/a	n/a	n/a
Variable cost per ton	**$116.40**					
Variable cost per carcass		**$43.65**	**$15.46**	**$7.44**	**$0.34**	**$4.49**

Source: *http://www.wr2.net/sales/cost_calculator.html*

Figure 7. Formulas to estimate the direct variable cost relating to alkaline hydrolysis.

The **direct variable cost (DVC)** using a tissue digester with a 2,000-pound capacity:

- **By number of carcasses:**

$$DVC = 51.56Q_{cattle} + 18.27Q_{calves} + 9.14Q_{weaned\ hogs} + 0.41Q_{preweaned\ hogs} + 5.30Q_{others}$$

Where Q_i is the total mortality of animal category *i.*

- **By weight:**

$$DVC = 137.48(W_{cattle} + W_{calves} + W_{weaned\ hogs} + W_{preweaned\ hogs} + W_{others})$$

Where W_i is the total weight in tons of animal category *i.*

(Figure continued on next page)

Figure 7. *(Continued)*

The **direct variable cost (DVC)** using a tissue digester with a 2,000-pound capacity:

- **By number of carcasses:**

$$DVC = 43.65Q_{cattle} + 15.46Q_{calves} + 7.44Q_{weaned\ hogs} + 0.34Q_{preweaned\ hogs} + 4.49Q_{others}$$

Where Q_i is the total mortality of animal category *i.*

- **By weight:**

$$DVC = 116.40(W_{cattle} + W_{calves} + W_{weaned\ hogs} + W_{preweaned\ hogs} + W_{others})$$

Where W_i is the total weight in tons of animal category *i.*