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Chapter 9

Chemical Storage, Handling, and Feeding

INTRODUCTION

This chapter focuses on the operation and maintenance of equipment used in the handling, storage, and feeding of chemicals for wastewater treatment. Chapter 24, Physical–Chemical Treatment, describes some specific uses of chemicals to improve wastewater treatment. Chemical addition must be evaluated for each specific treatment process while considering its potential effect on downstream treatment units and effluent toxicity. The procedures for choosing chemicals and chemical dosages are discussed under specific treatment processes in other chapters of this manual, in *Design of Municipal Wastewater Treatment Plants* (WEF and ASCE, 1998) and in *Control of Odors and Emissions from Wastewater Treatment Plants* (WEF, 2004).

CHEMICAL APPLICATION SYSTEMS

All chemicals, whether solid, liquid, or gas, require a feeding system to accurately and repeatedly control the amount applied. Effective use of chemicals depends on accurate dosages and proper mixing. The effectiveness of certain chemicals is more sensitive to dosage rates and mixing than that of others. The design of a chemical feed system must consider the physical and chemical characteristics of each chemical used for feeding, minimum and maximum ambient or room temperatures, minimum and maximum wastewater flows, minimum and maximum anticipated dosages required, and the reliability of the feeding devices. Chemical feed systems typically consist of transferring the chemical from the supplier to the plant storage area, storing the chemical, mixing the chemical with water (occasionally not done), and calibrating the chemical/solution feed rate.

The capacity of the system, potential delivery delays, and chemical use rates are important considerations in both storage and feeding. Storage capacity must take into account the economical advantages of bulk quantity purchases versus the disadvantages of construction cost, spill potential, and chemical degradation with time. Smaller shipments generally result in higher unit chemical costs, increased transportation costs, and greater handling (labor) costs at the treatment plant facility. However, bulk storage and feeding facilities typically require more equipment and/or larger equipment, resulting in higher costs associated with construction and operation of the facility. Storage tanks or bins for solid chemicals must be designed to allow the correct angle of repose of the chemical and to provide its necessary environmental requirements, such as temperature and humidity. Size and slope of feeding lines are important considerations. The selection of materials used for construction of storage tanks, feed equipment, pumps, piping, and valves are also extremely important because many chemicals are corrosive to many materials.

Chemical feeders are sized to meet the minimum and maximum feeding rates required. Manually controlled feeders typically have a common feed turndown range of 10:1 that can be increased to approximately 20:1 with dual-control systems. To provide operational flexibility, the operator should consider future design conditions when selecting the appropriate ranges for chemical feed rates. A common problem is not being able to adjust the pump to low enough feed rates. Chemical feeder control can be manual, automatically proportioned to flow, or dependent on a process parameter (such as pH). A combination of any two of these can also be used. If manual control systems are specified with the possibility of future automation, the feeders selected should be convertible with a minimum of expense. Standby or backup units are generally desirable but may not be necessary for each type of feeder used unless required by the regulating authority. The location and sizing of the chemical feed addition should provide sufficient operational flexibility for potential changes in wastewater quality. Designed flexibility in hoppers, tanks, chemical feeders, and solution lines is the key to maximum benefits at the least cost.

Because dry chemical characteristics vary considerably, the feeder must be selected carefully, particularly in a smaller-sized facility where a single feeder may be used for more than one chemical. Overall, the operator should make provisions to keep all dry chemicals cool and dry. Maintaining a low humidity is particularly important, as hygroscopic (water absorbing) chemicals may become lumpy, viscous, or even rock hard. Other chemicals that absorb water less readily become sticky from moisture on the particulate surfaces, causing increased bridging in hoppers. Typically, only limited quantities of chemical solutions should be made from dry chemicals at any one time because the shelf life of the diluted chemical, especially polymers, may be short. The operator should consult the chemical supplier about the recommended shelf life for each particular chemical and/or chemical solution.

The operator should keep dry chemical handling areas and equipment as dry as possible. Otherwise, moisture will affect the chemicals' density and may result in underfeed. Also, the effectiveness of dry chemicals, particularly polymers, may be reduced. Dust-removal equipment should be used at shoveling locations, bag dump stations, bucket elevators, hoppers, and feeders for neatness, corrosion prevention, and safety reasons. Collected chemical dust may often be used with stored chemicals.

SAFETY CONSIDERATIONS

Many chemicals used in wastewater treatment plants can be extremely hazardous when not stored, handled, or used properly. Plant operators should always check with state regulatory and local emergency management agencies for reporting and plan development requirements. Federal regulations require that a material safety data sheet

(MSDS) be available to employees. The MSDS provides information on the chemical, including hazards and safety procedures to be used when handling it. The MSDS should be kept in the area where the chemical is used and also on file in a central location at the plant. Operators must use the correct safety equipment and follow the safe handling procedures described in the MSDS. This would include using personal protective equipment such as face shields, eyewear, and protective clothing. Further, the plant should be adequately equipped with emergency eyewashes and showers, dust suppression equipment (for dry chemical systems), and secondary containment structures (for liquid chemical or solution systems).

Table 9.1 presents a summary of the physical properties and the principal safety considerations for handling chemicals typically used in a wastewater treatment plant. Table 9.2 summarizes uses, feed-system types, operating considerations, and other precautions for those same chemicals. For complete instructions, the operator should consult the MSDS for a specific chemical.

RISK MANAGEMENT

Some gaseous chemicals such as chlorine, sulfur dioxide, or ammonia are hazardous if released to the atmosphere. Compliance with all federal, state, and local regulations is required for the storage of certain chemicals and reporting procedures involved with spills, leaks, and disposal of chemicals. The U.S. Environmental Protection Agency's (U.S. EPA's) Risk Management Program (RMP) rule is specifically concerned with the accidental release of hazardous compounds. The rule was required as part of the Clean Air Act amendments of 1990 (Section 112r) (Prevention, 2002) and requires facilities to identify hazards and manage risks. Both the U.S. EPA and the Occupational Safety and Health Administration (OSHA) have similar regulations for the prevention of hazardous chemical release. The U.S. EPA's RMP generally addresses the protection of public health and the environment, whereas OSHA's Process Safety Management standard is intended for employee protection from chemicals in the workplace (29 CFR 1910.119) (Occupational, 2003).

U.S. EPA's RMP applies to wastewater facilities with processes using chemicals stored above certain threshold quantities. A facility that handles, produces, or stores any of the chemicals indicated in Table 9.3 equal to or above the regulated threshold limits is likely subject to all provisions of the rule. For a complete list of regulated toxic substances and threshold quantities for accidental release prevention, consult 40 CFR 68.130 (Tables 1 through 4) (List, 2003).

If these thresholds are exceeded, the facility operator must document serious accidents (five-year history), analyze worst-case chemical releases, contact and coordinate

TABLE 9.1 Wastewater treatment chemicals—physical properties and safety considerations.

Chemical name	Synonyms	Physical properties	Safety considerations
Ammonia	Anhydrous ammonia	Boiling point = −33.4 °C (−28.1 °F) highly soluble in water. LEL [a] = 15%, UEL [b] = 28%. Ammonia gas is lighter than air. Colorless gas with pungent, suffocating odor.	Contact with liquid causes severe burns. Extremely irritating to eye and lung tissue. Highly reactive with chlorine, acids. Odor is detectible at 5 ppm, irritating at 25 to 50 ppm. Moderate fire hazard. Ammonia in air and ammonia with chlorine are potential explosion hazards.
Chlorine		Poisonous, reactive, greenish-yellow gas. Boiling point = −34 °C (−29 °F). Slightly soluble in water. Chlorine gas is heavier than air.	Chlorine reacts with moisture to form acids. Very irritating and corrosive to eyes, mucous membranes, and teeth. Acute respiratory distress and asphyxiation can result from exposure. Reacts with many materials to cause fires and explosions.
Chlorine dioxide		Red-yellow or orange gas with a pungent odor. Oxidizer, bleaching agent. Boiling point = 10 °C (50 °F).	Irritates respiratory system. Avoid inhaling. Will damage eyes. Inhalation poison. Violently reacts with organic matter. Explosion hazard. Unstable in sunlight.
Defoamers	Antifoam agents	Many commercial products available. Properties vary.	Some antifoam agents may be corrosive or flammable. Avoid contact with eyes and skin. Avoid breathing vapors.
Ferric chloride	Iron trichloride, ferric trichloride, ferric perchloride	Available in solid and liquid solution; sp gr of solution, 1% = 1.0084; 45% = 1.487. Very soluble in water. Solutions above 33% will crystalize.	Corrosive liquid. Avoid contact with eyes and skin. Moderately toxic. Inhalation of mist will irritate throat and upper respiratory tract. Releases large amount of heat when anhydrous solid is diluted with water.
Ferric sulfate	Iron sulfate	Corrosive in liquid solution.	Avoid contact with eyes and skin.

Table 9.1 Wastewater treatment chemicals—physical properties and safety considerations (*continued*).

Chemical name	Synonyms	Physical properties	Safety considerations
Hydrochloric acid	Muriatic acid, hydrogen chloride, chlorohydric acid	Normally available as a solution in concentrations of 31% and 35%; sp gr of solutions are 31% = 1.16 and 35% = 1.18. Highly volatile liquid. Gas vapor is heavier than air.	Highly corrosive liquid and gas. Avoid contact with skin, eyes, and especially respiratory systems. Hydrochloric acid is detectable at 0.1 to 5 ppm, irritating at 5 to 10 ppm. Highly reactive. Liberates potentially explosive hydrogen gas or chlorine gas at high temperatures or on contact with metals. Incompatible with concentrated sulfuric acid.
Hydrogen peroxide	Peroxide, hydrogen dioxide	Boiling point of pure liquid = 151 °C (304 °F). Very reactive and potentially unstable. Powerful oxidizer and corrosive. Available commercially in 30, 35, 50, and 70% solutions. Typically stored in concentrations of 50% or less; sp gr of solutions are 30% = 1.112 and 50% = 1.196.	Irritates skin, eyes, and mucous membranes. Avoid breathing mist. Highly reactive. Incompatible with most metals and organic material. Dangerous fire and explosive hazard in higher concentrations. Dust or metal contamination of solutions can result in violent decomposition and potential failure of storage tank.
Lime	Calcium hydroxide, hydrated lime, calcium oxide, quicklime	Solid, white powder with bitter taste. Slightly soluble in water. Dry form of quicklime has great affinity for water and liberates large amount of heat when mixed.	Irritating to skin and lungs. Dust problem can result from handling solid. Use dust mask and goggles.
Ozone	Triatomic oxygen	Colorless gas with a boiling point = –112 °C (–169 °F).	Oxidizing agent, irritant and toxic. Can irritate eyes, mucous membranes, and respiratory system. ACGIN TWA = 0.1 ppm in air. Odor detectible at 0.01 ppm. Incompatible with oils and other combustible materials. Can intensify fires.
Polymers	Anionic, cationic, non-ionic polymers,	Many available in dry and concentrated forms.	Some polymers are corrosive in water. Some are extremely viscous and slippery. Avoid contact with eyes and skin. Use caution when preparing solutions.
Potassium permanganate	Permanganate of potash	Strong oxidant with a characteristic purple color. Bulk density of between 90 and 100 lb/cu ft.[c]	Toxic. Suspected poison. Can react with organics, peroxides, and sulfuric acid. Can form chlorine when in contact with hydrochloric acid. Avoid contact with eyes and skin. Avoid breathing dust. Can react violently and explosively with organic materials. Contact with wood may cause a fire.
Sodium bisulfide	Sodium hydrogen sulfide, sodium hydrosulfide, sodium sulfhydrate	White to yellow flakes with hydrogen sulfide odor (rotten eggs).	Irritates eyes, skin, and mucous membranes. Avoid contact, especially with eyes. Contact with acids will generate toxic hydrogen sulfide gas.
Sodium hydroxide	Caustic, caustic soda, soda lye	Available in dry solid and solution. Melting point of 50% solution = 11.6 °C (53 °F); sp gr of 50% solution = 1.53.	Very corrosive to body tissues. Avoid inhaling dust or mist. Mixing with water can release large quantities of heat. Incompatible with acids and some metals such as tin, zinc, and especially aluminum.
Sodium hypochlorite	Chlorine bleach	Pale-yellow or greenish liquid solution with chlorine odor. Available in 5%, 10%, and 15% solutions.	Strong oxidizer and corrosive to eyes and mucous membrane tissues. Avoid contact with eyes and skin and avoid breathing fumes and mist. Decomposes to chlorine and sodium oxide when heated. Incompatible with acids, ammonia, organics, and some metals. Store out of direct sunlight.

TABLE 9.1 Wastewater treatment chemicals—physical properties and safety considerations (*continued*).

Chemical name	Synonyms	Physical properties	Safety considerations
Sulfur dioxide	Sulfurous anhydride, sulfurous oxide	Colorless gas with strong suffocating odor. Boiling point = –10 °C (14 °F). Heavier than air.	Gas is irritating to mucous membranes and toxic. Inhalation poison. Odor detected at 0.5 pm. OSHA[d] TWA limit of 2 ppm. Avoid breathing. Will form an acid mist with water vapor.
Sulfuric acid	Hydrogen sulfate, vitriol, oil of vitriol	Colorless, clear, oily liquid. Available in several concentrations but typically used as 93% solution; sp gr of 93% solution is 1.834.	Highly corrosive. Can burn and char skin when exposed. Especially harmful to eyes. Releases a large amount of heat when diluted with water. Can react with organics, chlorates, permanganates, fuminates, or powdered metals, causing fires or explosions.

[a]LEL = lower exposure limit.
[b]UEL = upper exposure limit.
[c]lb/cu ft × 16.02 = kg/m^3.
[d]OSHA = Occupational Safety and Health Administration.

TABLE 9.2 Wastewater treatment chemicals—operating considerations.

Chemical name	Uses	Feed system type	Operating considerations	Other comments
Ammonia	Nutrient addition, disinfection	Gas	Handle cylinders with care. Ventilate top of storage rooms.	Never use copper or brass in ammonia service. Iron or steel is satisfactory.
Chlorine	Disinfection, taste and odor control	Gas	Store chlorine containers in a cool, dry, well-ventilated area. Use care when handling chlorine containers.	Use rag dipped in ammonia water to detect leaks. Do not put water directly on a leak.
Chlorine dioxide	Disinfection	Gas	Typically generated on site.	
Defoamers	Controlling foaming in activated sludge systems or in ponds	Liquid		
Ferric chloride	Sludge conditioning, coagulation, phosphorus removal	Solid or liquid		Corrosive to most metals, especially aluminum, copper, and carbon steel, and to nylon.
Ferric sulfate	Coagulation, phosphorus removal	Solid		
Hydrochloric acid	Neutralization	Liquid		Iron or steel is not satisfactory in hydrochloric acid service.
Hydrogen peroxide	Odor control, supplemental dissolved oxygen, control of bulking	Liquid	Store in cool area. Keep away from combustible materials.	Iron and steel are unsatisfactory in hydrogen peroxide service. Avoid copper. Stainless steel, aluminum, and some plastics perform well.
Lime	Coagulation, pH adjustment, sludge conditioning, phosphate removal	Solid	Lime slakers produce large amounts of heat and must be watched carefully for excessive heat buildup. Absorbing water can cause caking or swelling.	

TABLE 9.2 Wastewater treatment chemicals—operating considerations (*continued*).

Chemical name	Uses	Feed system type	Operating considerations	Other comments
Ozone	Odor control, disinfection	Gas	Typically generated on site.	
Polymers	Coagulant, filter aids, sludge conditioning	Solid or liquid		Iron or steel typically are not satisfactory.
Potassium permanganate	Taste and odor control, iron removal	Solid	Do not store in open containers. Avoid mixing with combustible materials.	Contact with wood can cause fire.
Sodium bisulfide	Dechlorination, chromium treatment, pH control, bactericide	Solid	Reacts with acids to form hydrogen sulfide gas, which is both flammable and toxic.	
Sodium hydroxide	pH control, odor control, cleaning	Liquid	Concentrated caustic freezes at high temperatures. Plugged or frozen caustic lines increase risk of exposure.	Do not use near aluminum. Galvanized piping is not suitable for caustic service.
Sodium hypochlorite	Disinfection, odor control	Liquid	Can decompose in storage. Keep away from light and heat.	
Sulfur dioxide	Dechlorination, pH control, chrome reduction	Gas	Will reliquify in system piping if allowed to cool.	Can be more corrosive than chlorine if wet at elevated temperatures.
Sulfuric acid	pH control	Liquid	Store in dry containers.	Iron and steel is permissible in concentrated sulfuric acid service, but dilute sulfuric is very corrosive to steel.

TABLE 9.3 Partial list of regulated toxic substances and threshold quantities for accidental release prevention.

Chemical name	Chemical abstracts service (CAS) no.	Threshold quantity (lb)
Chlorine	7782-50-5	2500
Ammonium (anhydrous)	7764-41-7	10 000
Ammonia (aqueous with concentration 20% or greater)	7764-41-7	20 000
Sulfur dioxide (anhydrous)	7446-09-5	5000
Propane	74-98-6	10 000
Methane	74-82-8	10 000

local emergency response personnel, and submit a RMP to governmental agencies, state emergency response commissions, and local emergency planning committees. A prevention program within the RMP includes the identification of hazards, documented operating procedures, training programs for personnel, maintenance requirements, emergency response programs, and complete accident investigation. When storing more than a specific quantity of gaseous chemicals such as chlorine or sulfur dioxide, requirements for secondary containment and emergency scrubber systems should be considered to prevent or minimize the spread of chemical releases. Emergency response procedures should be developed in cooperation with local emergency officials. Federal regulations require that local emergency planning agencies be notified when specific amounts of certain chemicals are stored (see Chapter 5, Occupational Safety and Health, for further discussion).

UNLOADING AND STORING CHEMICALS

Special precautions are necessary for the safe unloading and storage of chemicals. Because a complete discussion of these precautions would be impractical, the operator must obtain such information directly from the chemical manufacturer or supplier for each chemical storage and handling system within the treatment plant.

UNLOADING CHEMICALS. In general, chemicals are delivered to a wastewater treatment plant in dry, liquid, or gaseous form. Liquid chemicals can be in various combinations of phases and viscosity. For instance, liquid polymers are available in single-phase liquids, multiphase emulsions, Mannich (a special type of highly viscous solution polymer), and gel. Chemicals are also delivered in a variety of containers, including bags, drums, totes, cylinders (gas), ton containers, bulk trucks, and railroad tank cars. Dry chemicals are generally available in either bagged, drummed, mini-bulk, or bulk form. Mini-bulk includes super sacs or bulk bags. When daily requirements are small, bagged chemicals are preferred because their handling and storage are relatively simple, involving either manual labor or mechanical handling. Bagged chemicals, delivered either in loose bags or on pallets in trucks or boxcars, are transferred to storage by hand lifts or forklift. For loose bags, conveyors may be used if there is a long distance between the unloading point and the storage area. For bag shipments on pallets, using a forklift to move the loaded pallets to storage and then to the point of use reduces the manual labor. Drums contain more chemical (typically approximately 181 kg [400 lb] per drum) than bags but are more difficult to handle. Mechanical drum movers and dumpers are available and can be used were chemical is received in drum form.

For intermediate usage rates and where chemicals can be purchased in mini-bulk form, super sacs or bulk bags can be used to reduce the amount of manual labor involved. Mini-bulk containers typically contain 907 kg (1 ton) of chemical, which equals approximately forty 23-kg (50-lb) bags. Feed equipment for mini-bulk containers generally includes support frames to hold the container above the feeder and valves on the bag and/or feeder to control the flow of chemical into the feeder. In addition, forklifts generally are used to move the bags to and from storage and to lift the bag into a support frame located over the feeder. Therefore, forklift access to the feeder through adequately sized aisles and/or roll-up doors is required. Even though the cost of feed equipment and operating space requirements can be somewhat more for mini-bulk containers than for bags or drums, the amount of manual labor required for chemical handling can be reduced.

Bulk shipments of dry or liquid chemicals are delivered in trucks or by rail in boxcars and hopper cars. Bulk unloading facilities typically must be provided at the treatment plant. Rail cars constructed for top unloading will require an air-supply system and flexible connectors to pneumatically displace the chemical from the car. Bottom unloading can be accomplished by using a transfer pump or a pneumatic transfer system. The U.S. Department of Transportation (U.S. DOT) regulations concerning chemical tank car unloading should be observed.

Bulk unloading areas should be arranged to contain the chemical for recovery, neutralization, or disposal in case of a spill. Spill control measures such as spill booms and mats, neutralization chemicals, and waste disposal drums should be readily available near the unloading area. Special training is required for operators responsible for spill response. All unloading areas should be level and allow tank trucks to pull away in a forward direction. Pavement design for heavier truckloads may require the use of concrete for roads and the unloading area. In addition, consideration must be given to

appropriate truck turning radius. Before any unloading operation, the operator should verify that the storage tank will hold the contents of the tank car or tank truck and that the tank is well vented. When transferring with air, an air surge will occur at the end of the product transfer, so it is important to have properly sized relief vents. Level indication at the unloading station is highly recommended to help the operator monitor the filling operation and avoid overfilling a bulk tank. Generally, a quick-disconnect should be provided at the unloading station for connection to the supply hose from the chemical tank car or truck. Consulting with the chemical vendor will help the operator determine the type and size of quick-disconnect needed to simplify the chemical transfer.

Properly trained employees must supervise all unloading operations. If the operator must leave the transfer operation, the operation should be shut down. The operator must use protective eyewear, gloves, and clothing during the unloading operations. Emergency showers and eyewashes should be adjacent to the unloading station area and tested at least monthly for proper operation. In addition, smoking should not be allowed in any chemical unloading area, and unloading should be done during daylight hours unless adequate lighting is provided for nighttime unloading operations.

Both U.S. DOT and the U.S. Coast Guard classify chlorine, ammonia, and sulfur dioxide as nonflammable compressed gases. As such, when shipped in the United States by rail, water, or highway, they must be packaged in containers that comply with both U.S. DOT and U.S. Coast Guard regulations regarding loading, handling, and labeling.

Chlorine gas is commonly available in 45- and 68-kg (100- and 150-lb) steel cylinders; in 907-kg (1-ton) steel containers; and (for large quantities) in railroad tank cars, tank trucks, or barges. *The Chlorine Manual* (The Chlorine Institute, Inc., 1986) addresses in detail the appropriate loading and handling of chlorine containers.

Various mechanical devices, such as skids, troughs, and up-ending cradles, simplify handling of 68-kg (150-lb) chlorine cylinders. When unloaded from trucks or platforms, cylinders must not be dropped to ground level. If cylinders must be lifted or lowered and an elevator is not available, specially designed cradles or carrying platforms in combination with a crane or derrick are recommended. Chains, lifting magnets, and rope slings that encircle the cylinders are unsafe and should not be used. For lateral movements, a properly balanced hand truck is useful. Cylinders being moved should always have valve-protection hoods in place. Because these hoods are not designed to hold the weight of cylinders and their contents, the cylinders should never be lifted by their hoods.

Ton containers may be moved by various methods, including rolling, a crane hoist monorail system, or by specially fitted trucks or dollies. When it is necessary to lift them, as from a multiunit railroad car or truck, it is good practice to use a suitable lift clamp or lifting beam in combination with a hoist or crane with at least a 1814-kg (2-ton) capacity.

Receiving and unloading areas and safety precautions applicable to handling single-unit railroad tank cars, tank trucks, or other shipping containers are subject to federal, state, and local regulations.

STORING CHEMICALS. The equipment used for storing and handling chemicals varies with the type of chemical used, form of the chemical (liquid or dry), quantity of chemical, and plant size.

Storage tanks and vessels must be labeled to show their contents. Each tank and/or storage area should be clearly labeled indicating both the contents and the National Fire Protection Association (NFPA) Hazard Identification System (National Fire Protection Association, 2001).

The layout and design of a chemical storage area must comply with all local codes and ordinances. Storage areas for chemicals should be clean, temperature controlled, properly ventilated, and protected from corrosive vapors. In some cases, humidity control also may be necessary, especially with dry chemicals. Cylinders and ton containers should be stored in a fire-resistant building away from heat sources, flammable substances, and other compressed gases. Storage and use areas should be equipped with suitable mechanical ventilators for normal occupancy and proper controls and leak-detection equipment to contain and hold extremely hazardous gases. State and local ordinances that have adopted all aspects of the NFPA guidelines will require scrubbers. Additional discussion regarding chlorine and sulfur dioxide emergency gas scrubbers is presented in Chapter 26, Effluent Disinfection. Sulfur dioxide scrubbers are similar to those used for chlorine. At some locations, secondary containment of individual bulk containers can be provided in place of scrubbers. In all cases, however, it is always a good practice to equip gas storage areas with proper ventilation control (i.e., normal ventilation is terminated when a leak is detected) and emergency gas scrubbing equipment (typically sized to neutralize the largest single container). Cylinders and ton containers should not be stored outdoors. Both local and remote alarms should be provided to alert the operator of any potential leak of chemicals such as chlorine, sulfur dioxide, and ammonia in both storage and use areas.

Bulk Storage. Figure 9.1 presents a typical packaged-type bulk-storage tank (or bin) for dry chemicals. Dust collectors should be provided on both manually and pneumatically filled tanks. Airborne chemical dust is not only hazardous to employee health, but also may be an explosion hazard. The construction material for the storage tank

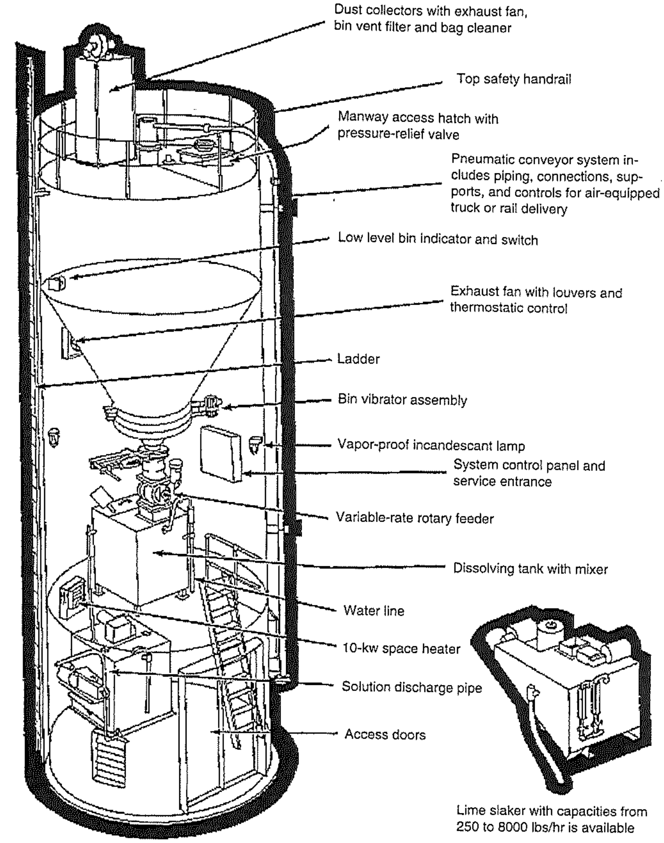


FIGURE 9.1 Typical packaged-type bulk storage tank and accessories (lb/h × 0.453 6 = kg/h) (National Lime Association, 1995).

and the required slope and baffling at the outlet may vary with the type of chemical stored. Some dry chemicals, such as lime, require airtight bins to reduce the potential for moisture within the storage vessel. Bulk storage tanks for dry chemicals are often equipped with bin vibrators to lessen chemical bridging in the storage vessel.

Bulk-storage tanks for liquid or dry chemicals should be sized according to normal (average) chemical feed usage rates, shipping time required, and quantity of shipment. The total storage capacity should be at least between 1.25 and 1.5 times the largest anticipated supplier shipment and should provide at least a 15- to 30-day supply of the chemical at the design average usage. Gas storage areas also should be sized to accommodate a sufficient number of cylinders and bulk containers to provide similar supply volumes based on average chemical feed usage rates. In many cases, the minimum number of storage days is dictated by regulatory requirements. Storage tanks for most liquid chemicals can be either inside or outside. However, outdoor tanks must be insulated or heated or both if the chemical can crystallize or become sufficiently viscous to impede chemical flow at the minimum ambient temperature for that specific geographic location. In addition, outdoor tanks should be constructed of materials that are resistant to both deterioration from ultraviolet (UV) light and cracking because of wide variations in external temperatures. All liquid storage tanks must have an air vent to avoid excessive pressure or vacuum in the tank. Vents for chemical systems should be carefully located so that air ventilation intakes are not affected. In addition, the vent should not be in an area that can be routinely accessed by personnel. Some liquids, such as hydrochloric acid with a vent scrubber, also should have a pressure- and/or vacuum-relief valve or system to protect the tank from excessive pressure or vacuum if the normal vent path becomes plugged.

Leak Detection. Liquid-storage tanks generally are located at ground level and should include secondary containment for both catastrophic and minor leaks. Secondary containment, such as concrete structures or double-walled tanks, should be provided for spills and/or leaks of chemicals. Containment volume should be a minimum of the largest bulk storage tank volume plus an additional 10%. Whenever possible, pump control panels should be outside the containment area and valves located so that they are operable and accessible from outside the containment area. Pumps and other equipment should always be elevated on concrete pads to avoid damage from minor leakage. Automated leak-detection interlocked with alarm systems can be included in the secondary containment areas for bulk storage tanks. The detection of the chemical fluid allows an operator to be notified of potential problems at storage areas. In addition, regularly scheduled (as frequent as daily) visual inspections should be conducted within containment areas to confirm that spills or leaks have not occurred. The plant should avoid installing chemical storage tanks underground, if possible, and provide secondary containment or double-walled tanks with leak detection systems if underground installation must be used. Without secondary containment, soil and groundwater contamination could result if a leak occurs.

Two relatively common pressurized liquid feed systems are flooded suction systems with an overhead storage tank (Figure 9.2) and suction lift systems using ground

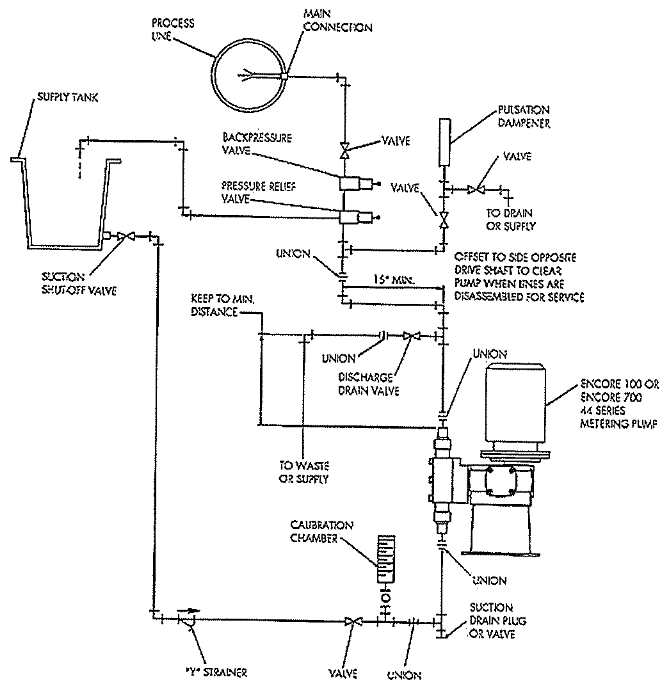


FIGURE 9.2 Flooded suction system (USFilter/Wallace and Tiernan) (in. × 25.40 = mm).

storage (Figure 9.3). Figure 9.2 shows an overhead storage system used to gravity feed the chemical metering pump. A rotodip-type feeder or rotameter can be used for a gravity feed system also. Figure 9.3 shows a ground storage system with a suction lift transfer pump. The metering pump (diaphragm type) is often used for pressure-feed systems.

Bag, Drum, and Tote Storage. Typically, the determination of what type of storage method is acceptable will depend on plant size, average chemical feed usage rates, chemical storage space available, and the amount of labor that can be allocated to chemical handling. Small plant facilities may only use bags or drums (or possibly totes) to meet an adequate chemical storage. As stated earlier, chemical storage should provide a minimum of 15 to 30 days of chemical storage at average chemical feed us-

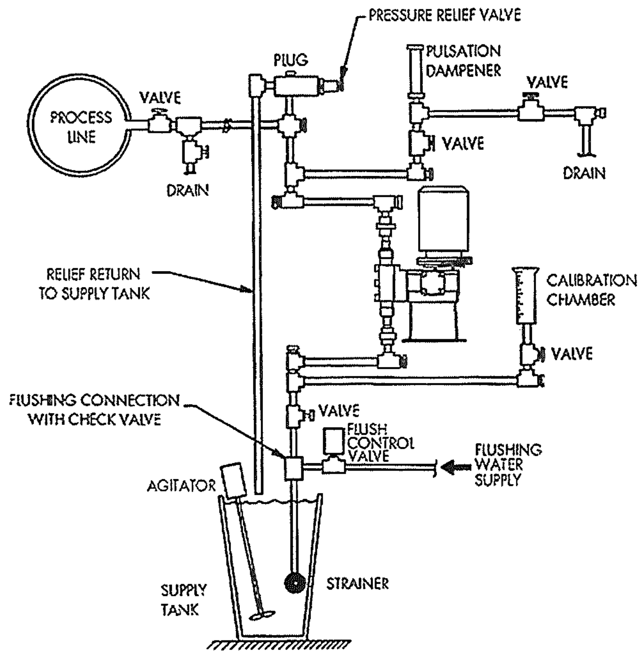


FIGURE 9.3 Suction lift system (USFilter/Wallace and Tiernan).

age rates. Small plants may have sufficiently low average chemical feed usage rates that the small number of bags, drums, or totes required may not take up much storage space and may not require much labor for handling. However, large plant facilities, with larger average chemical feed usage rates, will require bulk storage tanks to minimize the amount of storage space required to meet minimum storage requirements and the amount of labor required for chemical handling. Bulk storage systems use additional material-handling equipment to provide a more efficient, less labor intensive, and less costly approach to chemical handling as compared with storing and handling a significant number of chemical bags or drums or totes. For an intermediate size of plant, bulk bags or totes can provide a cost-effective approach to chemical handling compared with bulk storage or bag/drum storage. For an intermediate size of plant, the amount of labor required to handle the larger containers is typically less than the

labor required to handle the many bags or drums because fewer of the larger containers must be handled. The larger container size also can require less storage space to maintain minimum chemical inventories. However, bulk bags or totes do require some additional chemical handling equipment (compared with handling bags/drums) to handle the large size of container. However, the amount of additional equipment required is typically less than the additional equipment required for bulk storage systems.

Typically, bags, drums, or totes are stored in a dry, temperature-controlled, low-humidity area and should be used in proper rotation: first in, first out. Bags should be stored off the floor level and liquid drum or tote storage areas must be properly contained in case of a spill. Bag- or drum-loaded hoppers are frequently sized for a storage capacity of eight hours at the nominal maximum feed rate, so personnel are not required to fill or charge the hopper more than once per shift.

Cylinder and Ton Container Storage. Whether in storage or in use, cylinders (68-kg [150-lb]) need proper support to prevent accidental tipping. Cylinders should be supported by chaining or anchoring to a fixed wall or support and should be readily accessible and removable. Bulk containers should be stored horizontally, slightly elevated from the floor level, and blocked to prevent rolling. Monorails are often used for movement of bulk containers within the storage area. In addition, beams may be used as a convenient storage rack for supporting both ends of the containers. Bulk containers should not be stacked or racked more than one high. Chlorine cylinders and containers should be protected from impact, and handling should be kept to a minimum. Full and empty cylinders and bulk containers should be stored separately and tagged or identified according to their disposition.

Chaining or anchoring chlorine cylinders in place during use is also important. Chlorine piping, cylinder connections, and other equipment could be damaged during any type of movement if not properly anchored.

Proper, forced, mechanical ventilation in storage and feed areas is important for the safety and health of operating personnel. If the gas is heavier than air, such as chlorine, ventilation should be drawn from the floor. On the other hand, if the gas is lighter than air, such as ammonia, the ventilation should be drawn from near the ceiling. One air change per minute (60 air changes per hour) is considered adequate ventilation when personnel occupy chlorine storage and feed areas, per *Recommended Standards for Wastewater Facilities* (Great Lakes, 1997). The International Fire Code suggests a ventilation rate of approximately 5.08×10^{-3} $m^3/m^2{\cdot}s$ (1 cfm/sq ft) of building, but this yields fewer air changes per hour (International Fire Code, 1999). Typically, room ventilation is automatically activated (through the use of door switches or other means to detect entry) when the room or area is occupied by plant operators. The point of ventilation discharge should be carefully placed so it does not exhaust near other air inlets or occupied external areas. In addition, where required by law, gas scrubbers may be necessary in the ventilation discharge. Ventilation rates for discharge to an emergency scrubber are typically based on the rupture of the single largest container. For example, the release from a 907-kg (1-ton) container rupture would typically require a ventilation rate of 1.42 m^3/s (3000 cfm).

Leak detection and containment in the storage and feed areas are extremely important. Automatic leak-detection equipment for chlorine gas and sulfur dioxide are effective in detecting relatively small concentrations of the subject chemicals. Interlocks should be provided that shut down the normal ventilation in the event that a leak is detected. Local and remote alarms are typically initiated and the emergency scrubber and fan are started. Leak-repair kits, self-contained breathing apparatus meeting the requirements of the National Institute for Occupational Safety and Health, and all other safety equipment should be available outside the storage/feed area and properly maintained. Only operating personnel that have been thoroughly trained and certified in emergency response should be involved in a chemical-handling emergency.

Chemical Purity. Typically, technical grade chemicals are used in wastewater treatment to minimize the chemical purchase costs. High-purity chemicals are not required and can significantly increase the cost for chemicals. However, care must be exercised to avoid chemicals that contain excessive quantities of hazardous impurities that could result in wastewater treatment plant upsets or violations of the wastewater treatment plant effluent limitations. The effluent limitations that could be exceeded may be either an actual numerical limit listed in the effluent permit for each individual hazardous compound or a limit based on a whole effluent toxicity (WET) test. A very low concentration of many hazardous compounds, such as heavy metals, can be toxic to the biological organisms used in the WET test, resulting in test failure and associated violation of the effluent limitation. For heavy metals such as lead, mercury, copper and zinc, the wastewater treatment plant can have very low effluent limitations and the typical wastewater treatment processes will not be able to adequately remove these compounds to meet the very stringent limits. In addition, many heavy metals can accumulate in the sludge generated by the wastewater treatment processes. Other chemicals such as chlorine and sulfur dioxide can be detrimental to the discharge water quality. Low concentrations of chlorine exhibit effluent toxicity and sulfur dioxide can deplete dissolved oxygen. The actual quantity of allowable contaminate will depend on any effluent limitation and the maximum quantity of chemical used at the wastewater treatment plant.

Once the chemical is received at the treatment plant, care should be exercised to avoid contamination of the chemical. Material safety data sheet documents and supplier instructions should be consulted to determine types of contamination that must be avoided. Depending on the chemical, contamination can result in significant degradation of the effectiveness of the chemical and, in some cases, the formation of extremely hazardous and even life-threatening conditions in the plant. For example, metal contamination (such as rust) in hydrogen peroxide can destroy significant quantities of active chemical and even result in an explosive release of gas.

TROUBLESHOOTING. Chemical unloading and storage systems can have operating problems. Table 9.4 presents a brief troubleshooting guide for chemical unloading and storage systems that will help the operator to identify problems and develop possible solutions.

PUMPING, PIPING, AND HANDLING MATERIALS

Piping and accessories for transporting and feeding various chemicals should be provided only after specific chemicals have been selected for use in the wastewater treatment plant. The operator should use only materials that are compatible with each

TABLE 9.4 Troubleshooting guide for chemical unloading and storage systems.

Observations	Checks and remedies
Pneumatic conveying (low pressure)	
Material not moving from car or truck to silo.	Check pressure at blower. If high, line may be plugged. Shut off, discharge to system, clear line, and restart.
	If pressure is normal or low, material is not entering conveying line. Check discharge gate on truck or rail car.
Dust discharging from silos.	Ensure that dust filter on silo is operational.
	Check dust filter for broken or torn bags or tubes.
	Ensure that silo dust filter capacity is sufficient for blower discharge.
Bucket elevators and screw conveyors	
Material backing up at inlet.	Listen to determine whether system is operating. If so, reduce amount at inlet to unit and continue.
	If unit is stopped but motor is running, check for broken shear pins.
	If motor is tripped out, check for broken or overloaded conveyor.

chemical. For example, many chemical-handling systems require special materials for construction and special types of piping; tubing; and transport channels, pumps, valves, and gaskets. Table 9.5 gives a summary of tank, pump, piping, and valve materials compatible with several commonly used chemicals and offers an overview on general material compatibility for these chemicals. The operator should always consult equipment manufacturers and chemical suppliers before selecting materials of construction. Sodium hypochlorite is one of many chemicals that require special handling precautions. As an example of material selection consideration, more detailed information on feeding and handling equipment for this chemical is listed in Table 9.6.

TABLE 9.5 Materials of construction—chemical handling facilities.

Chemical	Tanks	Pumps	Pipe	Valves
Alum	FRP[a]	Nonmetallic	PVC,[b] CPVC,[c] FRP	Nonmetallic
Chlorine	Steel cylinders	N/A	Carbon steel to vaporizer	Carbon steel
Ferric chloride	FRP, rubber-lined steel	Nonmetallic or rubber lined	FRP, CPVC, PVC, rubber-lined steel	Rubber-lined, CPVC
Ferrous sulfate	FRP	Nonmetallic	PCV, CPVC, FRP	Nonmetallic
Hydrogen peroxide	Aluminum alloy 5254, Type 316L stainless steel	Type 316 stainless steel, Teflon	Aluminum, Type 316L stainless steel	Type 316 stainless steel, Teflon
Methanol	Carbon steel	Cast steel	FRP, carbon steel	Carbon steel
Ozone	N/A	N/A	Type 316 stainless steel	CF-8M
Polymers	FRP	Nonmetallic	PVC, CPVC	Nonmetallic
Sodium bisulfite	FRP	Nonmetallic	PVC, CPVC, FRP	Nonmetallic or plastic lined
Sodium hydroxide	FRP, special construction	Stainless or carbon steel	CPVC, FRP, stainless steel	Stainless steel, nonmetallic
Sodium hypochlorite	FRP, special construction	Nonmetallic	FRP, CPVC	Nonmetallic or plastic lined
Sulfur dioxide	Carbon steel	N/A	Carbon steel	Carbon steel
Concentrated (93%) sulfuric acid	Phenolic lined steel	CN-7M (Alloy 20)	Type 304 stainless, 1.8 m/s maximum	CN-7M for throttling, CF-8M for shut-off

[a]FRP = fiber-glass-reinforced plastic.
[b]PVC = polyvinyl chloride.
[c]CPVC = chlorinated polyvinyl chloride.

TABLE 9.6 Materials suitable for use with sodium hypochlorite (The Chlorine Institute, 2000).

Components	Materials of construction compatible with sodium hypochlorite solutions
Rigid pipe	Lined (PP,[a] PVDF,[b] PTFE[c]) steel, CPVC[d]/PVC[e] (Sch 80) and titanium
Fittings	Same as rigid pipe
Gaskets	Viton™
Valves	PVC, CPVC, PP
Pumps (centrifugal)	
Body	Nonmetallic (PVC, TFE, Kynar, Tefzel, Halar)
Impeller	Same as body
Seals	Silicon carbide
Storage tanks	Rubber-lined steel, fiber glass, and HDPE[f]

[a]PP = polypropylene.
[b]PVDF = fluorinated polyvinylidene.
[c]PTFE = polytetrafluoroethylene.
[d]CPVC = chlorinated polyvinyl chloride.
[e]PVC = polyvinyl chloride.
[f]HDPE = high-density polyethylene tanks.

Because of the concern about chemical leaks and spills from system piping, recent trends show that the use of double-walled pipe (with leak-detection sensors) or single-walled pipe placed in a containment trough or trench should be given serious consideration in the design of new systems. A variety of issues involving safety, legal liability, government legislation, insurance risk issues, and so forth, may require the use of double-contained piping systems to reduce soil and groundwater contamination and to protect plant personnel from leakage of hazardous chemicals from conventional piping systems. Providing systems with double containment will avoid serious leaks or spills from the chemical piping. Double-walled pipe-containment systems are designed to contain a leak as it occurs, detect the leak, and alarm the plant operators.

Frequently, welded pipe and fittings are used for hazardous chemical piping whenever possible and recommended to minimize the potential for leaks. Plastic materials generally can be solvent welded, heat welded, or heat fusion bonded. Metallic materials can be heat welded, such as electric arc, or brazed. If flanges must be used, then specially designed secondary containment bags that fit around the flange or shields can be used to contain any chemical spray from leaks.

Chemical piping should include an adequate number of valved drain locations to allow chemical to be drained from piping, valves, and equipment before removal for maintenance. Each valve should include a removable cap to minimize leakage through the valve before and after use.

CHEMICAL FEEDING SYSTEMS

This section discusses gas, liquid, and solids feeding systems with on-site generation. Table 9.7 lists types of feed systems for specific chemicals. A complete chemical addition system for any given process unit has provisions for receiving and storing the chemical, transferring and metering the chemical, and mixing and injecting the chemical to the process stream.

GAS FEEDERS. Chemicals fed as a gas include chlorine, ammonia, and sulfur dioxide. Typically, these chemicals are transported and stored as a liquefied, compressed gas and then metered or fed to the wastewater treatment process as a gas.

Description of Equipment. If chlorine or sulfur dioxide is drawn as a liquid, an evaporator is used to vaporize the chlorine. An example of an evaporator system is shown in Figure 9.4. A chlorine evaporator consists of a chlorine chamber in a hot-water bath tank. Liquid chlorine is fed to the chamber, the heat vaporizes it, and gaseous chlorine is delivered to the point of application (White, 1986). An electric heater, recirculating hot-water bath, or steam can supply heat to the evaporator. Typical operating problems associated with evaporators are frosting or icing because of liquid particles being entrained with the gas leaving the chamber, scaling outside the chamber, and concentration of impurities in the chlorine inside the chamber. Frosting or icing is caused by demand exceeding the capacity of the evaporator and can be alleviated temporarily by reducing chlorine flow. Scaling and impurities will reduce the capacity of the evaporator. Regular shutdowns for cleaning will help prevent unscheduled service interruptions resulting from scaling and impurities.

Gas feeders are classified as either solution feed or direct feed. Solution-feed, vacuum-type feeders are most commonly used in chlorination and in dechlorination with sulfur dioxide (White, 1986). An example of vacuum-type feeders is shown in Figure 9.5. A gas can also be fed in a pressure system (Figure 9.6), but a vacuum system is preferred because of safety issues. Some state regulations, in fact, will allow only remote vacuum systems to eliminate releases from pressurized gas systems.

The main advantage of a gas-feed system is the relative simplicity of the transfer and feed system. Often, the vapor pressure of the material itself can be used to transfer the material, greatly reducing the equipment requirements.

The chemical can be injected directly to the process as a gas; however, there are several potential problems associated with direct feed. Some wet gases are extremely corrosive, leading to maintenance and reliability problems with the mixer. Also, direct-feed systems could allow water to back up into the gas lines at low gas feeds, damaging the equipment.

TABLE 9.7 Chemical-specific feeding recommendations (*Wastewater Treatment*, 1997).

Common name/ formula use	Best feeding form	Chemical-to-water ratio for continuous dissolving[a]	Types of feeders	Accessory equipment required	Suitable handling materials for solutions[b]
Alum: $Al_2(SO_4)_3{\cdot}XH_2O$ Liquid 1 gal 36°Be = 5.38 lb of dry alum: 60 °F Coagulation at pH 5.5 to 8.0 Sludge conditioner Precipitate PO_4	Full strength under controlled temperature or dilute to avoid crystallization Minimize surface evaporation; causes flow problems Keep dry alum below 50% to avoid crystallization	Dilute to between 3 and 15% according to application conditions, mixing, etc.	*Solution* Rotodip Plunger pump Diaphragm pump 1700 pump Loss in weight	Tank gauges or scales Transfer pumps Storage tank Temperature control Eductors or dissolvers for dilution	Lead or rubber-lined tanks, Duriron, FRP,[c] Saran, PVC-1, vinyl, Hypalon, epoxy, 16 SS, Carpenter 20 SS, Tyril
Aluminum sulfate: $Al_2(SO_4)_3{\cdot}14H_2O$ (alum, filter alum) Coagulation at pH 5.5 to 8.0 Dosage between 0.5 and 9 gpg Precipitate PO_4	Ground, granular, or rice Powder is dusty, arches, and is floodable[d]	0.5 lb/gal Dissolver detention time 5 min for ground (10 min for granules)	*Gravimetric* Belt loss in weight *Volumetric* Helix Universal *Solution* Plunger pump Diaphragm pump 1700 pump	Dissolver Mechanical mixer Scales for volumetric feeders Dust collectors	Lead, rubber, FRP, PVC-1, 316 SS, Carpenter 20 SS, vinyl, Hypalon, epoxy, Ni-resistant glass, ceramic, polyethylene, Tyril, Uscolite
Ammonia anhydrous: NH_3 (ammonia) Monel, Chlorine-ammonia treatment Anaerobic digestion Nutrient	Dry gas or as aqueous solution: see "Ammonia, aqua"	—	Gas feeder	Scales	Steel, Ni-resistant, 316 SS, Penton, Neoprene

TABLE 9.7 Chemical-specific feeding recommendations (*Wastewater Treatment*, 1997) (continued).

Common name/ formula use	Best feeding form	Chemical-to-water ratio for continuous dissolving[a]	Types of feeders	Accessory equipment required	Suitable handling materials for solutions[b]
Ammonia, aqua: NH_4OH (ammonium hydroxide, ammonia water, ammonium hydrate) Chlorine-ammonia treatment pH control Nutrient	Full strength	—	*Solution* Loss in weight Diaphragm pump Plunger pump Bal. diaphragm pump	Scales Drum handling equipment or storage tanks Transfer pumps	Iron, steel, rubber, Hypalon, 316 SS, Tyril (room temperature to 28%)
Calcium hydroxide: $Ca(OH)_2$ (hydrated lime, slaked lime) Coagulation, softening pH adjustment Waste neutralization Sludge conditioning Precipitate PO_4	Finer particle sizes more efficient, but more difficult to handle and feed	Dry feed: 0.5 lb/gal maximum Slurry: 0.93 lb/gal (i.e., a 10% slurry) (light to a 20% concentration maximum) (heavy to a 25% concentration maximum)	*Gravimetric* Loss in weight Belt *Volumetric* Helix Universal *Slurry* Rotodip Diaphragm Plunger pump[e]	Hopper agitators Non-flood rotor under large hoppers Dust collectors	Rubber hose, iron, steel, concrete, Hypalon, Penton, PVC-1 No lead
Calcium hypochlorite: $Ca(OCl)_2{\cdot}4H_2O$ (H.T.H., Perchloron, Pittchlor) Disinfection Slime control Deodorization	Up to 3% solution maximum (practical)	0.125 lb/gal makes 1% solution of available Cl_2	*Liquid* Diaphragm pump Bal. diaphragm pump Rotodip	Dissolving tanks in pairs with drains to draw off sediment Injection nozzle Foot valve	Ceramic, glass, rubber-lined tanks, PVC-1, Penton, Tyril (room temperature), Hypalon, vinyl, Usolite (room temperature), Saran, Hastelloy C (good) No tin
Calcium oxide: CaO (quicklime, burnt lime, chemical lime, unslaked lime) Coagulation Softening pH adjustment Waste neutralization Sludge conditioning Precipitate PO_4	0.25 to 0.75 in. pebble lime Pellets Ground lime arches and is floodable Pulverized will arch and is floodable Soft burned, porous best for slaking	2.1 lb/gal (range from 1.4 to 3.3 lb/gal according to slaker, etc.) Dilute after slaking to 0.93 lb/gal (10%) maximum slurry	*Gravimetric* Belt Loss in weight *Volumetric* Universal Helix	Hopper agitator and non-flood rotor for ground and pulverized lime Recording thermometer Water proportioner Lime slaker High-temperature safety cut-out and alarm	Rubber, iron, steel, concrete, Hypalon, Penton, PVC-1
Carbon, activated: C (Nuchar, Norit, Darco, Carbodur) Decolorizing, taste and odor removal Dosage between 5 and 80 ppm	Powder: with bulk density of 12 lb/cu ft Slurry: 1 lb/gal	According to its bulkiness and wetability, a 10 to 15% solution would be the maximum concentration	*Gravimetric* Loss in weight *Volumetric* Helix Rotolock *Slurry* Rotodip Diaphragm pumps	Washdown-type wetting tank Vortex mixer Hopper agitators Non-flood rotors Dust collectors Large storage capacity for liquid feed Tank agitators Transfer pumps	316 SS, rubber, bronze, Monel, Hastelloy C, FRP, Saran, Hypalon
Chlorine: Cl_2 (chlorine gas, liquid chlorine) Disinfection Slime control Taste and odor control Waste treatment Activation of silica[f]	Gas: vaporized from liquid	1 lb to 45 to 50 gal or more	Gas chlorinator	Vaporizers for high capacities Scales Gas masks Residual analyzer	*Anhydrous liquid or gas* Steel, copper, black iron *Wet gas* Penton, Viton, Hastelloy C, PVC-1 (good), silver, Tantalum *Chlorinated H_2O* Saran, stoneware, Carpenter 20

Common name/ formula use	Best feeding form	Chemical-to-water ratio for continuous dissolving[a]	Types of feeders	Accessory equipment required	Suitable handling materials for solutions[b]
					SS, Hastelloy C, PVC-1, Viton, Uscolite, Penton
Chlorine dioxide: ClO_2 Disinfection Taste and odor control (especially phenol) Waste treatment 0.5 to 5 lb $NaClO_2$ per mil. gal H_2O dosage	Solution from generator Mix discharge from chlorinizer and $NaClO_2$ solution or add acid to mixture of $NaClO_2$ and NaOCl. Use equal concentrations: 2% maximum	Chlorine water must contain 500 ppm or more of Cl_2 and have a pH of 3.5 or lower Water use depends on method of preparation	*Solution* Diaphragm pump	Dissolving tanks or crocks Gas mask	*For solutions with 3% ClO_2* Ceramic, glass, Hypalon, PVC-1, Saran, vinyl, Penton, Teflon
Ferric chloride: $FeCl_3$ - anhydrous $FeCl_3 \cdot 6H_2O$ = crystal $FeCl_3$ - solution (Ferrichlor, chloride, or iron) Coagulation pH 4 to 11 Dosage: 0.3 to 3 gpg (sludge conditioning 1.5 to 4.5% $FeCl_3$) Precipitate PO_4	Solution or any dilution up to 45% $FeCl_3$ content (anhydrous form has a high heat of solution)	*Anhydrous to form:* 45%: 5.59 lb/gal 40%: 4.75 lb/gal 35%: 3.96 lb/gal 30%: 3.24 lb/gal 20%: 1.98 lb/gal 10%: 0.91 lb/gal (Multiply $FeCl_3$, by 1.666 to obtain $FeCl_3 \cdot 6H_2O$ at 20 °C)	*Solution* Diaphragm pump Rotodip Bal. diaphragm pump	Storage tanks for liquid Dissolving tanks for lumps or granules	Rubber, glass, ceramics, Hypalon, Saran, PVC-1, Penton, FRP, vinyl, epoxy, Hastelloy C (good to fair), Uscolite, Tyril (Rm)
Ferric sulfate: $Fe_2(SO_4)_3 \cdot 3H_2O$ (Ferrifloc) $Fe_2(SO_4)_3 \cdot 2H_2O$ (Ferriclear) (iron sulfate)	Granules	2 lb/gal (range) 1.4 to 2.4 lb/gal for 20-minute detention (warm water permits shorter detention)	*Gravimetric* Loss in weight *Volumetric* Helix Universal *Solution*	Dissolver with motor-driven mixer and water control Vapor remover solution tank	316 SS, rubber, glass, ceramics, Hypalon, Saran, PVC-1, vinyl, Carpenter
Coagulation pH 4 to 6 and 8.8 to 9.2 Dosage: 0.3 to 3 gpg Precipitate PO_4		Water insolubles can be high	Diaphragm pump Bal. diaphragm pump Plunger pump Rotodip		20 SS, Penton, FRP, epoxy, Tyril
Ferrous sulfate: $FeSO_4 \cdot 7H_2O$ (Copperas, iron sulfate, sugar sulfate, green vitriol) Coagulation at pH 8.8 to 9.2 Chrome reduction in waste treatment Wastewater odor control Precipitate PO_4	Granules	0.5 lb/gal (dissolver detention time 5 min minimum)	*Gravimetric* Loss in weight *Volumetric* Helix Universal *Solution* Diaphragm pump Plunger pump Bal. diaphragm pump	Dissolvers Scales	Rubber, FRP, PVC-1, vinyl, Penton, epoxy, Hypalon, Uscolite, ceramic, Carpenter 20 SS, Tyril
Hydrogen peroxide: H_2O_2 Odor control	Full strength or any dilution	—	Diaphragm pump Plunger pump	Storage tank, water metering and filtration device for dilution	Aluminum, Hastelloy C, titanium, Viton, Kel-F, PTFE, chlorinated polyvinylchloride (CPVC)
Methanol: $CH_3 \cdot OH$ Wood alcohol denitrification	Full strength or any dilution	—	Gear pump Diaphragm pump	Storage tanks	304 SS, 316 SS, brass, bronze, Carpenter 20 SS, cast iron, Hastelloy C, buna N, EPDM, Hypalon, natural rubber, PTFE, PVDF, NORYL, Delrin, CVPC

TABLE 9.7 Chemical-specific feeding recommendations (*Wastewater Treatment*, 1997) (*continued*).

Common name/ formula use	Best feeding form	Chemical-to- water ratio for continuous dissolving[a]	Types of feeders	Accessory equipment required	Suitable handling materials for solutions[b]
Ozone: O_3 Taste and odor control Disinfection Waste treatment Odor: 1 to 5 ppm Disinfection: 0.5 to 1 ppm	As generated Approximately 1% ozone in air	Gas diffused in water under treatment	Ozonator	Air-drying equipment Diffusers	Glass, 316 SS, ceramics, aluminum, Teflon
Phosphoric acid, ortho: H_3PO_4 Boiler water softening Alkalinity reduction Cleaning boilers Nutrient feeding	50 to 75% concen- tration (85% is syrupy; 100% is crystalline)	—	*Liquid* Diaphragm pump Bal. diaphragm pump Plunger pump	Rubber gloves	316 SS (no F) Penton, rubber, FRP, PVC-1, Hypalon, Viton, Carpen- ter 20 SS, Hastelloy C
Polymers, dry High-molecular-weight synthetic polymers	Powdered, flattish granules	Maximum con- centration 1% Feed even stream to vigorous vortex (mixing too fast will retard colloidal growth) 1 to 2 hours detention	*Gravimetric* Loss in weight *Volumetric* Helix *Solution* *(Colloidal)* Diaphragm pump Plunger pump Bal. diaphragm pump	Special dispersing procedure Mixer: may hang up; vibrate if needed	Steel, rubber, Hypalon, Tyril Noncorrosive, but no zinc Same as for H_2O of similar pH or accord- ing to its pH
Polymers, liquid and emulsions[g] High-molecular-weight synthetic polymers Separan NP10 potable grade, Magnifloc 990; Purifloc N17 Ave. Dosage: 0.1 to 1 ppm	*Makedown to:* Liquid 0.5 to 5% *Emulsions:* 0.05 to 0.2%	Varies with charge type	Diaphragm pump Plunger pump Bal. diaphragm pump	Mixing and aqueous tanks may be required	Same as dry products
Potassium permanganate: $KMnO_4$ Cairox Taste odor control 0.5 to 4.0 ppm Removes Fe and Mn at a 1-to-1 ratio	Crystals plus anticaking additive	1.0% concentra- tion (2.0% maximum)	*Gravimetric* Loss in weight *Volumetric* Helix *Solution* Diaphragm pump Plunger pump Bal. diaphragm pump	Dissolving tank Mixer Mechanical	Steel, iron (neutral and alkaline), 316 SS, PVC-1, FRP, Hypalon, Penton, Lucite, rubber (alkaline)
Sodium aluminate: $Na_2Al_2O_4$, anhydrous (soda alum) Ratio Na_2O/Al_2O_3 1/1 or 1.15/1 (high purity) Also $Na_2Al_2O_4{\cdot}3H_2O$ hydrated form Coagulation Boiler H_2O treatment	Granular or solution as received Standard grade produces sludge on dissolving	Dry 0.5 lb/gal Solution dilute as desired	*Gravimetric* Loss in weight *Volumetric* Helix Universal *Solution* Rotodip Diaphragm pump Plunger pump	Hopper agitators for dry form	Iron, steel, rubber, 316 SS, Penton, concrete, Hypalon
Sodium bicarbonate: $NaHCO_3$ (baking soda) Activation of silica pH adjustment	Granules or powder plus TCP (0.4%)	0.3 lb/gal	*Gravimetric* Loss in weight Belt *Volumetric* Helix Universal *Solution* Rotodip Diaphragm pump Plunger pump	Hopper agitators and non-flood rotor for powder, if large storage hopper	Iron and steel (dilute solu- tions: caution), rubber, Saran, SS, Hypalon, Tyril

TABLE 9.7 Chemical-specific feeding recommendations (*Wastewater Treatment*, 1997) (*continued*).

Common name/ formula use	Best feeding form	Chemical-to-water ratio for continuous dissolving[a]	Types of feeders	Accessory equipment required	Suitable handling materials for solutions[b]
Sodium bisulfite, anhydrous: $Na_2S_2O_5$ ($NaHSO_3$) (sodium pyrosulfite, sodium meta-bisulfite) Dechlorination: about 1.4 ppm for each ppm Cl_2 Reducing agent in waste treatment (as Cr)	Crystals (do not let set) Storage difficult	0.5 lb/gal	*Gravimetric* Loss in weight *Volumetric* Helix Universal *Solution* Rotodip Diaphragm pump Plunger pump Bal. diaphragm pump	Hopper agitators for powdered grades Vent dissolver to outside	Glass, Carpenter 20 SS, PVC-1, Penton, Uscolite, 316 SS, FRP, Tyril, Hypalon
Sodium carbonate: Na_2CO_3 (soda ash: 58% Na_2O) Water softening pH adjustment	Dense	Dry feed 0.25 lb/gal for 10-minute detention time, 0.5 lb/gal for 20-minute Solution feed 1.0 lb/gal Warm H_2O and/or efficient mixing can reduce retention time if material has not sat around too long and formed lumps—to 5 min	*Gravimetric* Loss in weight *Volumetric* Helix *Solution* Diaphragm pump Bal. diaphragm pump Rotodip Plunger pump	Rotolock for light forms to prevent flooding Large dissolvers Bin agitators for medium or light grades and very light grades	Iron, steel, rubber, Hypalon, Tyril
Sodium chlorite: $NaClO_2$ (technical sodium chlorite) Disinfection, taste, and odor control Industrial waste treatment (with Cl_2 produces ClO_2)	Solution as received	Batch solutions 0.12 to 2 lb/gal	*Solution* Diaphragm Rotodip	Chlorine feeder and chlorine dioxide generator	Penton, glass, Saran, PVC-1, vinyl, Tygon, FRP, Hastelloy C (fair), Hypalon, Tyril
Sodium hydroxide: NaOH (caustic soda, soda lye) pH adjustment, neutralization	Solution feed	NaOH has a high heat of solution	*Solution* Plunger pump Diaphragm pump Bal. diaphragm pump Rotodip	Goggles Rubber gloves Aprons	Cast iron, steel For no contamination, use Penton, rubber, PVC-1, 316 SS, Hypalon
Sodium hypochlorite: NaOCl (Javelle water, bleach liquor, chlorine bleach) Disinfection, slime control Bleaching	Solution up to 16% Available Cl_2 concentration	1.0 gal of 12.5% (available Cl_2) solution to 12.5 gal of water gives a 1% available Cl_2 solution	*Solution* Diaphragm pump Rotodip Bal. diaphragm pump	Solution tanks Foot valves Water meters Injection nozzles	Rubber, glass, Tyril, Saran, PVC-1, vinyl, Hastelloy C, Hypalon
Sulfur dioxide: SO_2 Dechlorination in disinfection Filter bed cleaning Approximately 1 ppm SO_2 for each ppm Cl_2 (dechlorination) Water treatment Cr^{+6} reduction	Gas	—	*Gas* Rotameter SO_2 feeder	Gas mask	Wet gas: Glass, Carpenter 20 SS, PVC-1, Penton, ceramics, 316 (G), Viton, Hypalon

TABLE 9.7 Chemical-Specific Feeding Recommendations (Continued)

Common name/ formula use	Best feeding form	Chemical-to-water ratio for continuous dissolving[a]	Types of feeders	Accessory equipment required	Suitable handling materials for solutions[b]
Sulfuric acid: H_2SO_4 (oil of Vitriol, Vitriol) pH adjustment Activation of silica Neutralization of alkaline wastes	Solution at desired dilution H_2SO_4 has a high heat of solution	Dilute to any desired concentration: NEVER add water to acid but rather always add acid to water	*Liquid* Plunger pump Diaphragm pump Bal. diaphragm pump Rotodip	Goggles Rubber gloves Aprons Dilution tanks	*Concentration >85%:* Steel, iron, Penton, PVC-1 (good), Viton *40 to 85%:* Carpenter 20 SS, PVC-1, Penton, Viton *2 to 40%:* Carpenter 20 SS, FRP, glass, PVC-1, Viton

[a]To convert g/100 mL to lb/gal, multiply figure (for g/100 mL) by 0.083. Recommended strengths of solutions for feeding purposes are given in pounds of chemical per gallon of water (lb/gal) and are based on plant practice for the commercial product.
The following table shows the number of pounds of chemical to add to 1 gallon of water to obtain various percent solutions:

% Solution	lb/gal	% Solution	lb/gal	% Solution	lb/gal
0.1	0.008	2.0	0.170	10.0	0.927
0.2	0.017	3.0	0.258	15.0	1.473
0.5	0.042	5.0	0.440	20.0	2.200
1.0	0.084	6.0	0.533	25.0	2.760
				30.0	3.560

[b]Iron and steel can be used with chemicals in the dry state unless the chemical is deliquescent or very hygroscopic, or in a dampish form and is corrosive to some degree.
[c]FRP, in every case, refers to the chemically resistant grade (bisphenol A+) of fiber-glass-reinforced plastic.
[d]*Floodable* as used in this table with dry powder means that, under some conditions, the material entrains air and becomes "fluidized" so that it will flow through small openings, like water.
[e]When feeding rates exceed 100 lb/h, economic factors may dictate use of calcium oxide (quicklime).
[f]For small doses of chlorine, use calcium hypochlorite or sodium hypochlorite.
[g]Informtion about many other coagulant aids (or flocculant aids) is available from Nalco, Calgon, Drew, Betz, North American Mogul, American Cyanamid, Dow, etc.
Note: gal × 3.785 × 10^{-3} = m^3; in. × 25.40 = mm; lb/cu ft × 16.02 = kg/m^3; lb/gal × 0.119 8 = kg/L; and ppm = mg/L.

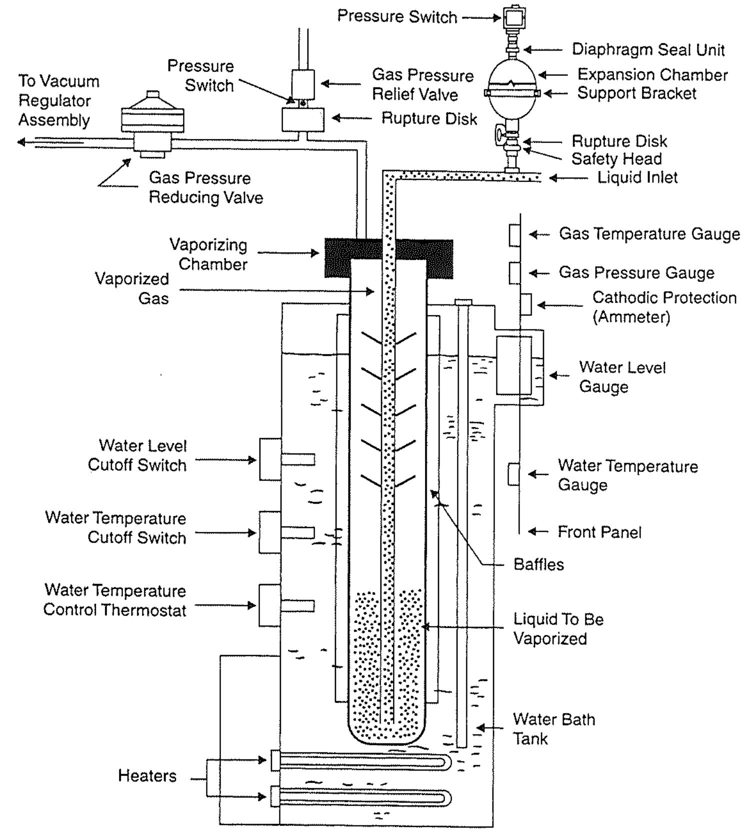
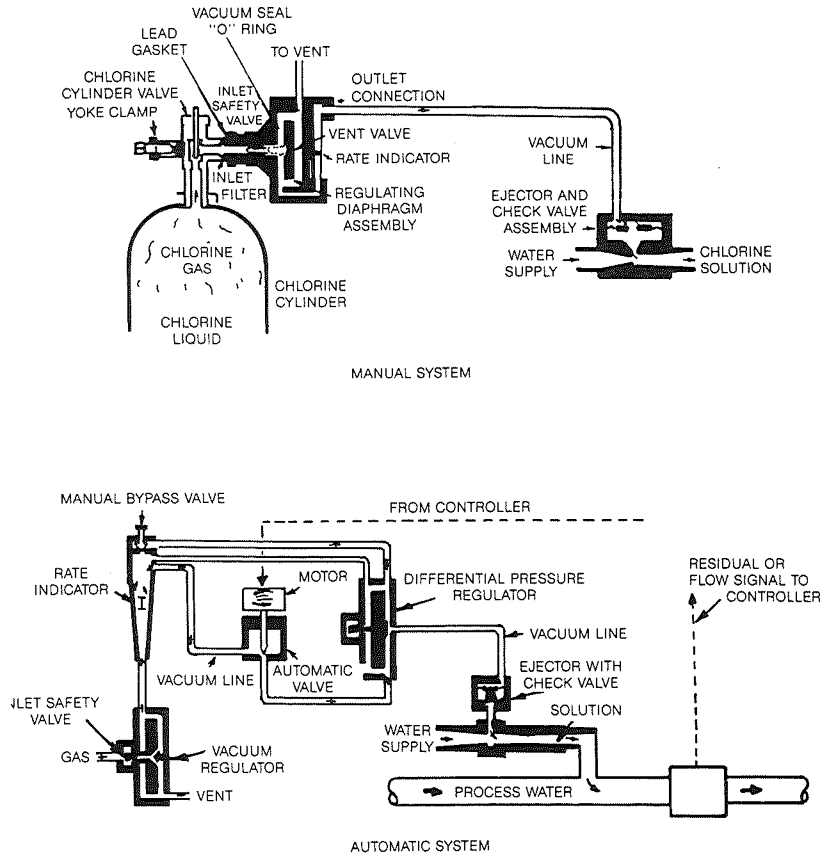


FIGURE 9.4 Typical gas evaporator.

Most typical gas-feed systems mix the gas with water in an eductor (injector) to form a solution before injecting it to the process. The advantage of a solution-feed system is that it can limit corrosion problems to a small piece of equipment, such as an ejector, that can be coated economically or be made of corrosion-resistant materials.

The mixing of the solution with the process stream is a critical aspect of solution feeding. Without adequate mixing, the solution can lose much of its effectiveness, caus-



E 9.5 Typical gas vacuum-feed systems.

ing overfeeding of the chemical and even process upsets in extreme situations. Careful selection of the injection point is required so that adequate mixing in the plant can be achieved. Under some highly turbulent conditions, adequate mixing within a pipe can require a pipe length as short as 10 pipe diameters. In-line static mixers also can be used to enhance mixing; however, consideration should be given to the mixing appli-

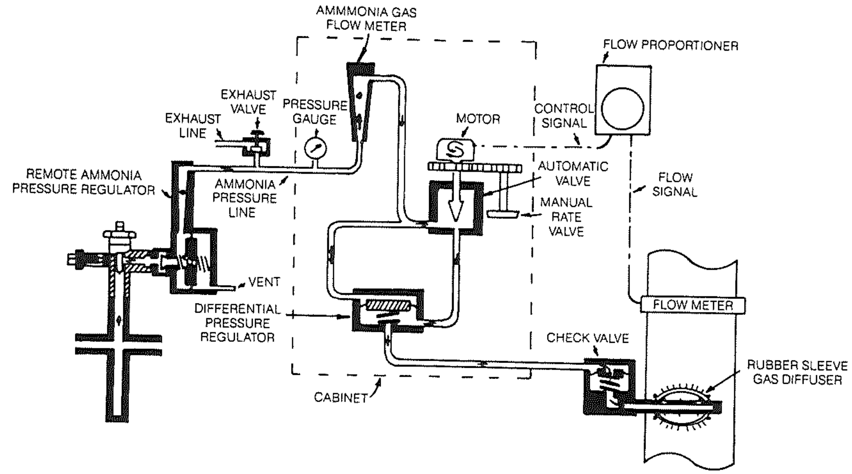


FIGURE 9.6 Typical ammonia gas pressure-feed system.

cation because certain process streams could foul the mixer and render it ineffective or nonoperational. In addition, the effect on any process control systems should be evaluated before using only a static mixer. Static mixers can provide good axial mixing across the diameter of the pipe but generally provide little, if any, radial or longitudinal mixing. Frequently, chemical feed systems use diaphragm-type chemical metering pumps that provide a pulsing flow and not a continuous flow. Therefore, if the control parameter, such as pH, is measured after the static mixer, the measured pH may show significant fluctuations with each flow pulse delivered by the pump. These control parameter fluctuations may prevent proper operation of the control system unless a mixed tank is used to smooth out the control parameter fluctuations. For injection to larger-diameter pipes, a pipeline diffuser can be used to inject the solution evenly across the diameter. Solution injected at a tee or saddle may tend to stay along the wall of the pipe and not enter the bulk fluid at the center of the pipe.

Pumps and valves can aid mixing. A hydraulic jump is sometimes used to mix chemical solutions with the process but requires careful analysis of hydraulic conditions under all possible flow regimes that may occur. Static mixers are used to improve mixing efficiencies. Mechanical devices such as vertical mixers, in-line mixers, and side-entry mixers can also be installed.

Operational Considerations. Operational problems with sulfonators, chlorinators, and ammoniators can generally be traced to problems with the operation of the injector or clogging of the feed equipment by impurities. When problems occur in feeding with vacuum-type feeders, the operator should check the injector water supply to ensure that it conforms with the flowrate and pressure required by the equipment. If the injector is operating properly and producing sufficient vacuum, the operator should trace back through the vacuum system to the metering equipment, looking for an obstruction in the gas supply system. Automatically controlled systems can have a control malfunction that will drive the rate control device closed when it should be open. In that case, the unit should be switched to manual control until the automatic controls can be repaired.

Another operational consideration concerns verifying the amount of chemical fed each day. Gas cylinders should be mounted on scales and their loss in weight noted each day to determine the amount of chemical feed and check the chemical flow meter reading. Cylinder weighing also allows the operator to anticipate an empty cylinder and change it promptly without interrupting treatment. Equipment scales are available to handle multiple cylinders and automatic switch-over from an empty cylinder to a full cylinder.

LIQUID FEEDERS. Sodium hypochlorite, some polymers, phosphoric acid, and ferric chloride are typically examples of chemicals fed as liquids. Caustic soda (sodium hydroxide) and hydrogen peroxide are also fed as liquids but are not commonly used in municipal wastewater treatment plants. Like the gas systems, liquid-feed systems have some means of receiving and storing the chemical, transporting and measuring it, and mixing and injecting it to the process. Liquid systems generally require pumps for conveyance.

The use of sodium hypochlorite (NaOCl) solution has become more prevalent in many plants today as a replacement for chlorine gas (Cl_2) as a disinfectant. There are certain advantages in the use of hypochlorite, such as safety issues, but it is important to consider some basic factors before converting to a liquid hypochlorite feed system. For example, to replace a 907-kg (1-ton) container of chlorine, at least 7.6 m^3 (2000 gal) of hypochlorite solution may be required. Hypochlorite solutions decompose over time and lose available chlorine for disinfection, so storage considerations are extremely important. In addition, there are several chemical differences. Hypochlorite solutions exhibit high pH (greater than 12) and add alkalinity to the water; however, chlorine creates an acidic solution when added to water and decreases the alkalinity.

Because chlorine gas is highly toxic, sodium hypochlorite provides an alternative even though the solution is corrosive and is a severe skin and eye irritant. One important safety consideration when using sodium hypochlorite is proper venting. Certain metals can cause the sodium hypochlorite solution to decompose to oxygen and salt. Pressure buildup in tanks, piping sections, and valves can be a concern if not properly vented.

Description of Equipment. A typical solution-feed system consists of a bulk storage tank, transfer pump, day tank (sometimes used for dilution), and liquid feeder. Some liquid chemicals can be fed directly without dilution, and these may make the day tank unnecessary, unless required by a regulatory agency. Nonetheless, dilution water can be added to prevent plugging, reduce delivery time, and help mix the chemical with the wastewater. However, sometimes, the dilution water can have adverse chemical effects. For instance, dilution water that has not been softened can potentially cause calcium carbonate scale to build up on the piping. Special consideration should be given to the final water chemistry of the solution before adding dilution water. Figure 9.7 shows a typical solution-feed schematic.

Liquid feeders are typically metering pumps. Metering pumps are generally of the positive-displacement type using either plungers or diaphragms. An example of a diaphragm pump is presented in Figure 9.8. For details on pump maintenance and operation, the operator should consult the pump manufacturer's literature or the *Metering Pump Handbook* (McCabe et al., 1984). Positive-displacement pumps can be set to feed over a wide range (10:1) by adjusting the pump stroke length. In addition, the feed range can sometimes be extended by adjusting the pump speed as well. Sometimes control valves and rotameters may be sufficient; in other cases, the rotating dipper wheel-type feeder may be satisfactory. For uses such as lime slurry feeding, centrifugal pumps with open impellers or double-diaphragm pumps can be used. The type of liquid feeder used depends on the viscosity, corrosivity, solubility, suction, discharge head, and internal pressure-relief requirements.

The chemical addition rate can be set manually by adjusting a valve or the stroke/speed on a metering pump. The operators should obtain or develop a set of calibration curves showing the percent of full stroke versus the pump discharge. Alternatively, those adjustments can be made automatically with instrumentation. Automatic-feed systems can be designed to control the feed flow based on a process variable such as influent flow, residual chlorine concentration, or pH. For instance, a control scheme could pace the pump speed based on wastewater flow and use another measured parameter to "trim" the pump stroke. Whatever the control scheme used, to ensure control of the chemical addition the operator needs to carefully check the process treatment units, maintain storage and day tank inventories, and understand the equipment.

Pressure relief should be provided for positive-displacement metering pumps to prevent line failures if all discharge valves or pump isolation valves are closed. Evi-

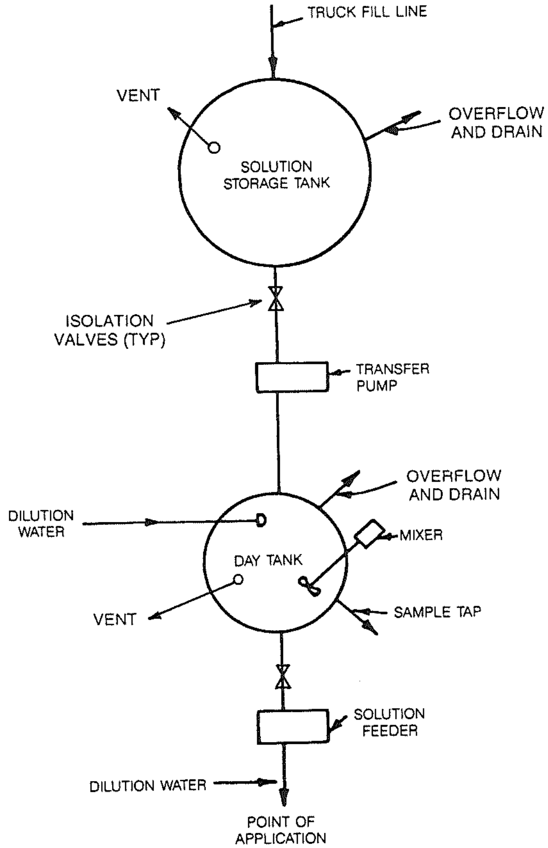


FIGURE 9.7 Typical solution-feed system.

dence of discharges from expansion-relief valves should be reported at once and the cause investigated and corrected. Backpressure valves are also required with positive-displacement pumps to ensure proper pressure differential between the suction and discharge valves and to provide sufficient backpressure to seat the pump discharge check valve. Most metering pumps should have a 34- to 69-kPa (5- to 10-psi) differen-

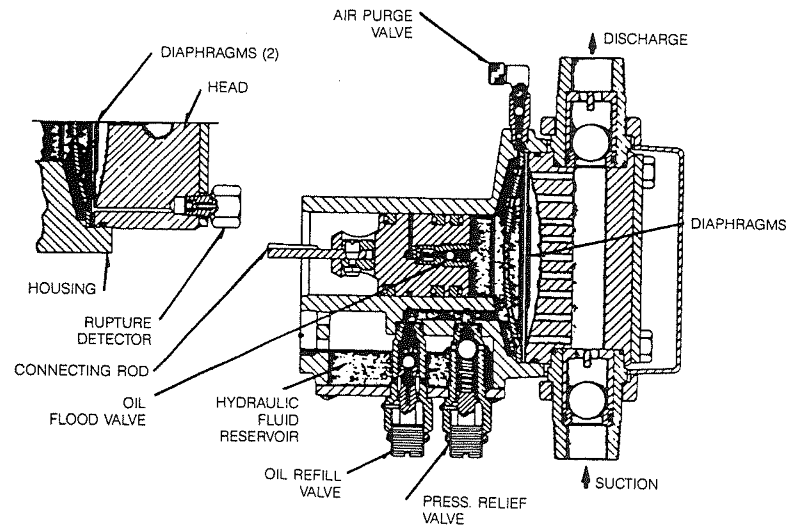


FIGURE 9.8 Diaphragm pump.

tial across the valves. If this differential is not available, the installation of a backpressure valve can develop additional head pressure close to the pump discharge connection (McCabe et al., 1984). A good liquid-feed system also includes valving so that the lines, pumps, and meters can be isolated from the process, cleaned and/or drained, and prepared for maintenance.

In addition, the operator should make provisions for other accessories as part of a chemical metering pump system using positive-displacement pumps. The installation of a pressure gauge in the discharge line is used for monitoring pressure at the pump and for assisting with setting relief-valve pressures or charging pulsation dampeners (McCabe et al., 1984). Pulsation dampeners are typically located in the discharge piping as close to the pump discharge connection as possible. Dampeners are also sometimes placed in the suction side of the pump. The location of the discharge pulsation dampener is critical to absorb the maximum fluid accelerations created by a positive-displacement pump. The pulsation dampener should be isolated with a valve to allow for maintenance. Most plastic pipe chemical-feed systems should include provisions for pulsation dampeners.

Polymers added to aid settling often require special attention for adequate mixing. For optimum performance, the manufacturer's instructions for preparing the dilute solution and locating the addition point should be followed explicitly. These instructions may include an initial dilution of the polymer with water followed by an hour or more of mixing to age the polymer before feeding the solution. Feeding a polymer solution that has not been properly aged will reduce the chemical's effectiveness and increase processing costs. A second dilution may be required just before injecting the polymer solution to the process.

Operational Considerations. Chemical and liquid feeders, such as metering pumps, can have many operating problems that prevent the feeder from delivering the correct amount of chemical. To monitor feeder delivery, all liquid feeders, especially metering pumps, should be equipped with a calibration cylinder. The cylinder can be either empty or full, and the time needed to empty or fill the cylinder should be noted. By knowing the volume of the calibration cylinder and the time for filling or emptying the cylinder, the operator can calculate the exact pump output. This determination serves as a check on the pump capacity.

Many metering pump systems handle chemicals that coat or build a layer of residue or slurries that can settle out solids during operation. Strainers are helpful in removing large particulate, but the operator must keep these cleaned. Periodic flushing to remove residues and deposits is often required. Piping and valve arrangements should allow the system to be isolated so that a clear liquid, such as water, can be used to pressurize the system for flushing the residue or solid buildup. Such flushing systems can be operated manually using hand-operated valving or can be automatically operated using solenoid valves with a timer control system. Systems where the metering pumps and piping are periodically shut down will require flushing connections to remove solids. In addition, an allowance for tees and wye cleanouts should be included for the piping system where longer horizontal piping runs cannot be adequately flushed.

A metering pump will lose capacity and become erratic when the suction or discharge valves become worn or when poor hydraulic conditions exist. These conditions will be indicated by the cylinder test described above. Also, debris in the chemicals being fed may obstruct or block the check valves, thus impeding their operation and decreasing the pump's performance.

Some chemicals such as hydrogen peroxide and sodium hypochlorite need metering pumps specially designed to handle offgassing. Offgassing is gas produced from the chemical during storage and feeding. Other types of offgas-relief systems can be incorporated to the feed pump piping also.

DRY CHEMICAL FEEDERS. Lime, alum, and activated carbon are typical of the kinds of chemicals used with a dry chemical-feed system. These systems are complex because of their many storage and handling requirements. The simplest method of feeding dry or solid chemicals is by hand. Solid chemicals may be preweighed and added or poured by the bagful into a dissolving tank. This method generally applies only to small plants where dry chemical-feed equipment is used.

Description of Equipment. A dry installation (Figure 9.9) consists of a feeder, a dissolver tank, and a storage bin or hopper. Dry feeders are of either the volumetric or gravimetric type. Volumetric feeders are generally used only where low initial cost and low feed rates are desired, and less accuracy is acceptable. These feeders deliver a constant, preset volume of chemical and do not respond to changes in material density. The volumetric feeder is initially calibrated by trial and error and then readjusted periodically if density of the material changes.

Most volumetric feeders are included in the positive-displacement category. All designs of this type use some form of moving cavity of a specific or variable size. A belt, screw, or auger can provide the cavity. The chemical falls into the cavity and is almost fully enclosed and separated from the hopper's feed. The rate at which the cavity moves and empties and the cavity size govern the amount of chemical fed (National Lime Association, 1995). Some types of volumetric feeders can be subject to flooding. This can be especially important for those feeding from bins or large hoppers. Flooding occurs when chemical is forced through the feeder (such as by chemical weight or momentum) in an uncontrolled fashion such as through the center of a helical screw auger. Rotary valves or other devices may be required upstream of these feeders to prevent a flooding condition.

When extreme accuracy and reliability are required, the gravimetric or weigh feeder is recommended. Most of the feeding principle differences lie in the system of scales, levers, and balances necessary to maintain a continuous flow of material at a predetermined weight versus time rate. Although the material may change in form, size, or density, the gravimetric feeder automatically compensates for the difference.

Gravimetric feeders take many forms but generally are classified into three groups: the pivoted-belt group, the rigid-belt group, and the loss-in-weight group. Gravimetric feeders are not "official" scales. The feeder feeds first and then checks and adjusts the feed through weighing (National Lime Association, 1995). For feeding critical processes, weigh feeders should be checked periodically as noted in the discussion of operational considerations.

Slide gates, knife gate valves, or other devices are typically installed between the bin or hopper and the feeder. These devices allow the feeder to be isolated from the bin

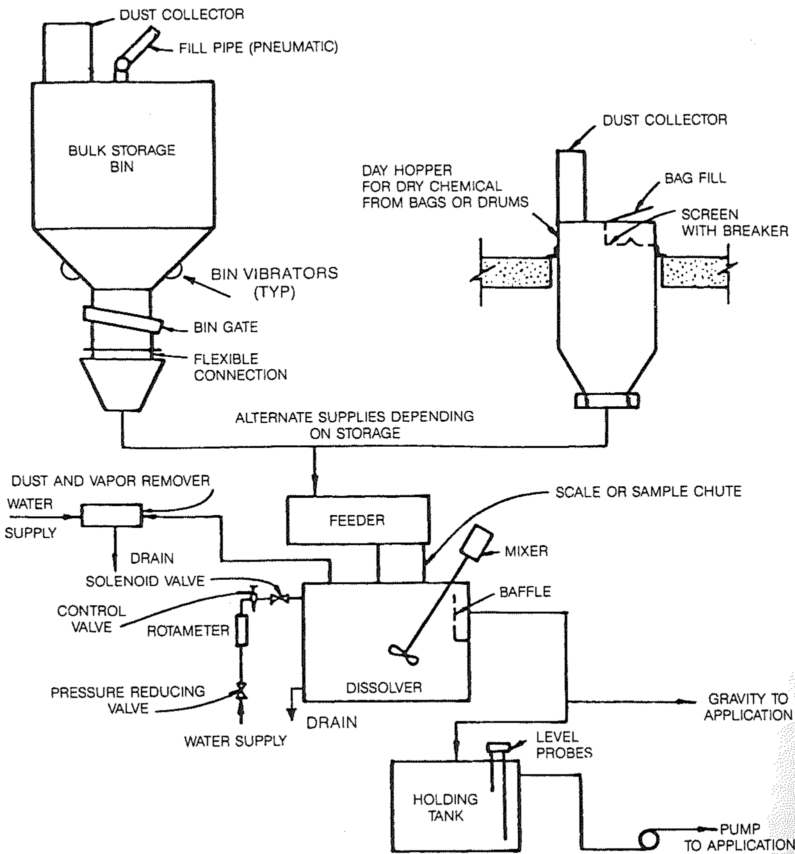


FIGURE 9.9 Typical dry-feed system.

or hopper so that the feeder can be maintained or replaced without emptying the bin or hopper. A flexible coupling also is frequently installed below the gate or valve to isolate vibrations produced by the feeder.

Dissolvers are a key component of dry-feed systems because any metered chemical must be wetted and mixed with water to provide a chemical solution free of lumps

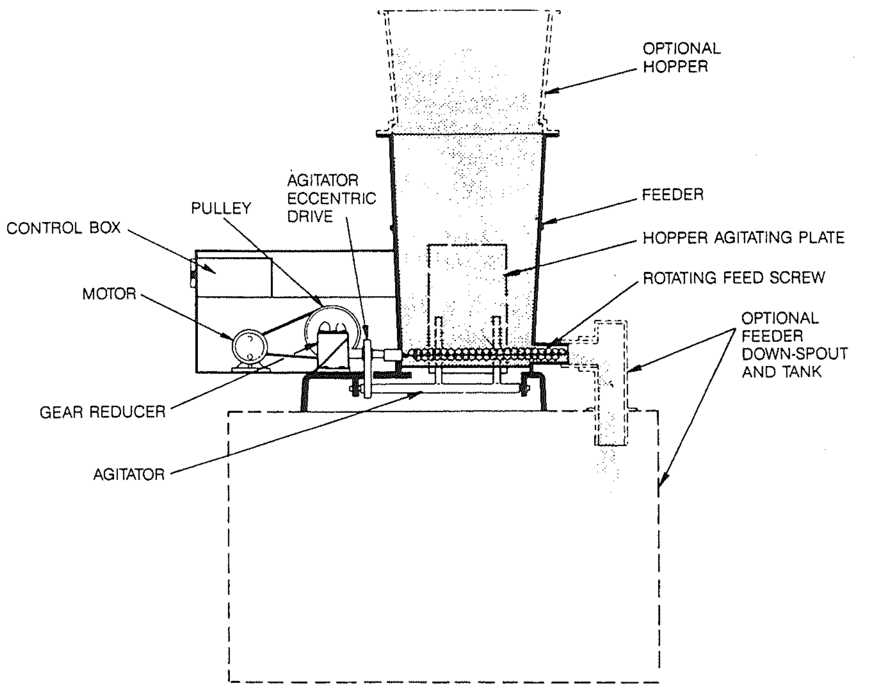
and undissolved particles. Most feeders, regardless of type, discharge their material to a small dissolving tank equipped with a nozzle system or mechanical agitator, depending on the solubility of the chemical being fed. The surface of each particle needs to be completely wet before it enters the feed tank to ensure thorough dispersal and avoid clumping, settling, or floating. When feeding some chemicals, such as polymers, into dissolvers, care must be taken to keep moisture inside the dissolver from backing up into the feeder. Moisture or moist air in the feeder can collect on the surface of the dry chemical in the feeder and result in clumps of chemical that clog the feeder. Methods of isolation can be used between the feeder and dissolver or heaters can be installed in the feeder to dry any moisture that gets into the feeder.

A dry chemical feeder can, by simple adjustment and change of speed, vary its output tenfold. The dissolver must be designed to closely match its application. A dissolver suitable for handling a feed rate of 4.5 kg/h (10 lb/h) may not be suitable at a rate of 45 kg/h (100 lb/h). Typically, the dissolver must provide a minimum detention time to allow the chemical to properly dissolve and must operate with a chemical concentration less than a maximum chemical concentration. The maximum chemical concentration must be below the chemical solubility in the water used to dissolve the chemical. Therefore, even though the chemical feeder may be made to feed a much higher feed rate, the dissolver may not be large enough to provide the minimum detention time or maximum chemical concentration required for proper dissolving. However, long detention times in dissolvers also should be avoided to minimize the delay between changing the feeder feed rate and a change in dosage of chemical in the wastewater. The longer the detention time, the longer the delay and the higher the potential for either adding too much or too little chemical for a period of time.

Most dry feeders are of the belt, grooved-disk, screw, or oscillating-plate type. The feeding device (belt, screw, disk, etc.) is typically driven by an electric motor. Many belt feeders, particularly the gravimetric type, also contain a material flow-control device such as a movable gate or rotary inlet for metering or controlling flow of the chemical to the feed belt. An example of a screw-type volumetric feeder is shown in Figure 9.10.

Operational Considerations. Dry chemical-feeder output should be checked periodically by taking a "catch". That is, the output from the feeder is caught in a pan or similar device for a known period (such as one minute) and then the pan is weighed. The chemical output per day can then be calculated based on the precise measure of the amount added during the short interval.

A feed curve for the particular feeder should be developed, determining relationships between the capacity setting on the machines and the actual kilograms (pounds) fed per hour. The "catch" can then verify the expected capacity from the feed curve.



URE 9.10 Typical helix-or screw-type volumetric feeder.

ON-SITE GENERATION. Generation of chemical at the treatment plant site has limited application but is available for some chemicals such as sodium hypochlorite. On-site generation can have a number of advantages over chemical delivery and storage. On-site generation can eliminate the dependence on commercial chemical suppliers and concerns associated with transportation, handling, and storage of chemical. In addition, on-site generation can reduce or eliminate degradation that may occur during chemical storage.

Sodium hypochlorite is a chemical that can be generated at the treatment plant site and can be generated on demand through the electrolysis of a brine solution. Figure 9.11 shows a flow diagram of one system that is available to generate hypochlorite.

Standard skid-mounted generation units are available, as shown in Figure 9.12, that can be installed in the treatment plant. Local regulatory issues can limit the use of chlorine gas, requiring the use of sodium hypochorite for disinfection. Because sodium hypochlorite can experience significant degradation during storage, on-site generation can potentially reduce the total quantity of hypochlorite used and potentially the total chemical cost when compared to off-site purchase. However, a site-specific cost analy-

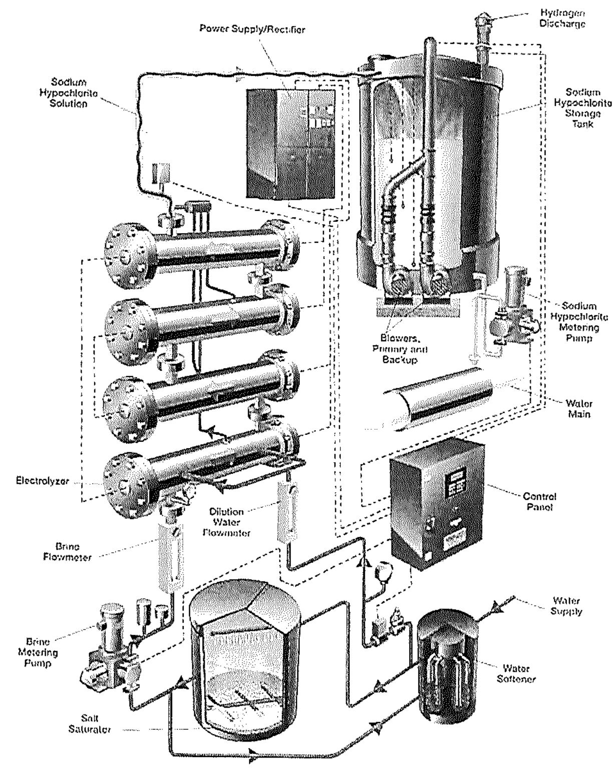


FIGURE 9.11 Flow schematic for on-site hypochlorite generation.

- Keep spill cleanup supplies, neutralizers, etc., fully stocked and accessible in the event of a minor leak.
- Periodically clean and calibrate level measurement and indication instrumentation in liquid and dry storage tanks.
- Periodically check alarm interlocks for low and high levels in tanks.
- Equip tanks with drain connections and isolation valves. Use of lockable drain valves is recommended.
- Equip tanks for OSHA-approved access (ladders, platforms, etc.) to monitor and maintain level instruments, vents, dust collectors, etc.
- Humidity control is critical for dry bag storage areas. Purchasing bagged chemicals with interior plastic liners is recommended.
- Exercise care when "cracking" drum bungs in the event of excess pressure.
- Periodically check and exercise chlorine (and sulfur dioxide) emergency gas scrubbing equipment, including but not limited to fans, controls, and chemical neutralizers.
- Use eductors for dry chemical makeup.
- Confirm adequate makeup water pressure and capacity.
- Confirm mixing requirements with the chemical supplier (i.e., slow speed mixing for polymer is generally required; however, the mixer must be able to generate sufficient torque to handle the higher viscosity).
- Use the appropriate respiratory protection equipment, as required, for chemical makeup to provide protection from dusting, acid flumes, etc.
- Equip mix tanks with drain connections and isolation valves.
- Inspect and clean mixing equipment and level instrumentation for buildups. This is very important for chemicals such as lime.
- Install calibration columns to verify feed rate accuracy from metering pump equipment.
- Provide isolation valves and drain valves, such as at the pump suction, for ease of maintenance and equipment removal.
- Inspect the condition of foot valve operators and suction piping. Excessive wear, corrosion, etc., may cause chemical metering pump systems to lose prime and not function properly.
- Minimize the length of suction and discharge piping when feeding lime slurry. Calcium carbonate buildup is a significant issue and a significant maintenance problem.
- Provide flush connections for cleaning and maintaining water slurry feed piping systems for chemical such as lime.
- Locate the chemical-feed system as close as possible to the feed application point.

- As a good operating practice, consider developing a spill prevention and countermeasures control plan (SPCC) for all chemicals even though federal regulations currently require a SPCC for petroleum and petroleum-derivatives only.
- Verify chemical compatibility with the materials of construction for pumps, piping, fittings, valves, tubing, gaskets, seals, etc. Consult the chemical supplier for guidance associated with proper material selection.
- Label, in accordance with federal and state regulations, all chemical storage tanks for hazard identification by plant personnel and emergency response personnel (fire department, hazardous material team, etc.).

CHEMICAL DOSAGE CALCULATIONS

Presented below are several examples of chemical dosage calculations, each based on the following equation:

$$\text{Dosage, ppm} = \frac{(\text{kg chemical/d [lb/d]})}{(\text{mil. kg wastewater treated/d [lb/d]})} \tag{9.1}$$

The alternate form of the above equation is

$$\text{kg chemical/d (lb/d)} = (\text{dosage, ppm}) \times (\text{mil. kg wastewater treated/d [lb/d]}) \tag{9.2}$$

This calculation method applies to any chemical measured in kilograms per day (pounds per day).

Example 9.1. Calculate the chlorine dosage in ppm.

Given:

Average daily wastewater flow treated = 1890 m^3/d (0.5 mgd)

Average daily chlorine use = 6.80 kg/d (15 lb/d)

Solution:

In metric units

$$\begin{aligned}\text{Dosage, ppm} &= \frac{(\text{kg chemical/d})}{(\text{mil. kg wastewater treated/d})}\\ &= \frac{(6.80\ \text{kg/d})}{(1890\ \text{m}^3/\text{d} \times 0.001\ \text{mil. kg/m}^3)}\\ &= \frac{(6.80\ \text{kg/d})}{(1.89\ \text{mil. kg/d})} = 3.6\ \text{ppm}\end{aligned}$$

In U.S. customary units

$$\text{Dosage, ppm} = \frac{(\text{lb chemical/d})}{(\text{mil. lb wastewater treated/d})} = \frac{(15\ \text{lb/d})}{(0.5\ \text{mgd} \times 8.34\ \text{lb/gal})} = \frac{(15\ \text{lb/d})}{(4.17\ \text{mil. lb/d})} = 3.6\ \text{ppm}$$

Example 9.2. Calculate the dosage of ferric chloride used as a coagulant for primary clarification.

Given:

Average daily flow rate = 21 200 m^3/d (5.6 mgd)
Ferric chloride use = 151.4 L of 40% by weight solution/d (40 gal of 40% by weight solution/d)
1 L (gal) of 40% solution = 1.33 kg (11.1 lb)

Solution:

In metric units

$$\text{Dosage, ppm} = \frac{(\text{kg chemical/d})}{(\text{mil. kg wastewater treated/d})} = \frac{151.4\ \text{L/d} \times 1.33\ \text{kg/L} \times (40\%/100)}{(21200\ \text{m}^3/\text{d} \times 0.001\ \text{mil. kg/m}^3)} = \frac{(80.5\ \text{kg/d})}{(21.2\ \text{mil. kg/d})} = 3.8\ \text{ppm}$$

In U.S. customary units

$$\text{Dosage, ppm} = \frac{(\text{lb chemical/d})}{(\text{mil. lb wastewater treated/d})} = \frac{40\ \text{gal} \times 11.1\ \text{lb/gal} \times (40\%/100)}{(5.6\ \text{mgd} \times 8.34\ \text{lb/gal})} = \frac{177.6\ \text{lb/d}}{46.7\ \text{mil. lb/d}} = 3.8\ \text{ppm}$$

Example 9.3. If the 3.8-ppm dosage were increased to 6 ppm with the same wastewater flow, how many liters per day (gallons per day) of ferric chloride would be needed?

Solution:

In metric units

$$\text{Liters of chemical needed} = \frac{6\ \text{ppm}}{3.8\ \text{ppm}} \times 151.4\ \text{L/d} = 239\ \text{L/d}$$

In U.S. customary units

$$\text{Gallons of chemical needed} = \frac{6.0\ \text{ppm} \times 40\ \text{gal}}{3.8\ \text{ppm}} = 63.2\ \text{gal}$$

Example 9.4. Calculate the concentration percentage (strength) of a diluted polymer batch.

Given:

Polymer used = 68 L/d (18 gal)
kg polymer/L (lb polymer/gal) = 1.25 (10.4)
Water used = 7570 L/d (2000 gal)

Solution:

In metric units

$$\text{Batch concentration, \%} = \frac{\text{kg polymer}}{\text{kg polymer} + \text{kg water}} \times 100 = \frac{68\ \text{L/d} \times 1.25\ \text{kg/L}}{(68\ \text{L/d} \times 1.25\ \text{kg/L}) + (7570\ \text{L/d} \times 1\ \text{kg/L})} \times 100 = \frac{85\ \text{kg/d}}{85\ \text{kg/d} + 7570\ \text{kg/d}} \times 100 = \frac{85\ \text{kg/d}}{7655\ \text{kg/d}} \times 100 = 1.1\%$$

In U.S. customary units

$$\text{Batch concentration, } \% = \frac{\text{lb polymer} \times 100}{\text{lb polymer} + \text{lb water}}$$
$$= \frac{18 \text{ gal} \times 10.4 \text{ lb/gal} \times 100}{(18 \text{ gal} \times 10.4 \text{ lb/gal}) + (2000 \text{ gal} \times 8.34 \text{ lb/ gal})}$$
$$= \frac{187.2 \text{ lb} \times 100}{187.2 \text{ lb} + 16\ 680 \text{ lb}}$$
$$= 1.1\%$$

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