

**EPA 625/1-79-011**

**PROCESS DESIGN MANUAL  
FOR  
SLUDGE TREATMENT AND DISPOSAL**

**U.S. ENVIRONMENTAL PROTECTION AGENCY  
Municipal Environmental Research Laboratory  
Office of Research and Development**

**Center for Environmental Research Information  
Technology Transfer**

**September 1979**

much as 20 to 30 percent between summer and winter. One must design to meet the worst conditions (summer), for without some type of oxygen controller, considerable power is wasted during other times of the year.

TABLE 6-24

AEROBIC DIGESTION LABOR REQUIREMENTS (217)

Plant design flow, MGD	Labor, man hours per year		
	Operation	Maintenance	Total
0.5	100	20	120
1	160	30	190
2	260	50	310
5	500	100	600
10	800	160	960
25	1,500	300	1,800

1 MGD = 3,786 m<sup>3</sup>/day

Other Requirements

Besides manpower and power cost, the designer must consider lubrication requirements. If mechanical aerators are being used, each unit needs to have an oil change once, and preferably twice, a year. Depending on horsepower size, this could be 5 to 40 gallons per unit per change (19-152 l/unit/change). Further, the designer must make sure an adequate inventory of spare parts are available.

-1-

6.4 Lime Stabilization

Lime stabilization is a very simple process. Its principal advantages over other stabilization processes are low cost and simplicity of operation. Evaluation of studies where lime stabilization was accomplished at pH ranges of 10-11, has shown that odors return during storage due to pH decay. To eliminate this problem and reduce pathogen levels, addition of sufficient quantities of lime to raise and maintain the sludge pH to 12.0 for two hours is required. The lime-stabilized sludge readily dewateres with mechanical equipment and is generally suitable for application onto agricultural land or disposal in a sanitary landfill.

No direct reduction of organic matter occurs in lime treatment. This has two important impacts. First, lime addition does not make sludges chemically stable; if the pH drops below 11.0, biological decomposition will resume, producing noxious odors. Second, the quantity of sludge for disposal is not reduced, as it is by biological stabilization methods. On the contrary, the

mass of dry sludge solids is increased by the lime added and by the chemical precipitates that derive from this addition. Thus, because of the increased volumes, the costs for transport and ultimate disposal are often greater for lime-stabilized sludges than for sludge stabilized by other methods.

#### 6.4.1 Process Description

##### 6.4.1.1 History

Lime has been traditionally used to reduce odor nuisances from open pit privies and the graves of domestic animals. Lime has been used commonly in wastewater sludge treatment to raise the pH in stressed anaerobic digesters and to condition sludge prior to vacuum filtration. The original objective of lime conditioning was to improve sludge dewaterability but, in time, it was observed that odors and pathogen levels were also reduced. In 1954, T.R. Komline filed a patent (No. 2,852,584) for a method of processing raw sludge in which heavy dosages of hydrated lime (6 to 12 percent of total dry solids) were added specifically to cancel or inhibit odors. However, only recently has lime addition been considered a major sludge stabilization alternative.

Many studies describe the effectiveness of lime in reducing microbiological hazards in water and wastewater, but the bactericidal value of adding lime to sludge has been noted only recently (219-222). A report of operations at the Allentown, Pennsylvania wastewater treatment plant states that lime conditioning an anaerobically digested sludge to a pH of 10.2 to 11, and then vacuum filtering and storing the cake, destroyed all odors and pathogenic enteric bacteria (233). Kampelmacher and Jansen reported similar experiences (224). Evans noted that lime addition to sludge released ammonia and destroyed coliform bacteria and that the sludge cake was a good source of nitrogen and lime to the land (225).

Lime stabilization of raw sludges has been conducted in the laboratory and in full-scale plants. Farrell and others (226) reported that lime stabilization of a primary sludge reduced bacterial hazard to a negligible value, improved vacuum filter performance, and provided a satisfactory means of stabilizing sludge prior to ultimate disposal. Paulsrud and Eikum (227) determined the lime dosage required to prevent odors occurring during storage of sewage sludges. Primary biological sludges, septic tank sludges, and different chemical sludges were used in the study. An important finding was that lime dosages greater than those sufficient to initially raise the pH of the sludges were required to prevent pH decay and the return of odors during storage. Laboratory and pilot scale work by Counts and Shuckrow (228) on lime stabilization showed significant reductions in pathogen populations and obnoxious odors when the sludge pH was

greater than 12. Counts conducted growth studies on greenhouse and outdoor plots which indicated that the disposal of lime-stabilized domestic sludge on cropland would have no detrimental effect on plant growth and soil characteristics. Disposal of the lime-stabilized domestic sludge at loading rates up to 100 tons dry solids per acre (224 t/ha) on green-house plots and 40 tons dry solids per acre (90 t/ha) on outdoor plots had no detrimental effect on plant growth and soil characteristics.

A full-scale lime stabilization facility was built as part of a 1-MGD (43.8 l/s) wastewater treatment plant in Lebanon, Ohio. Operation began in 1976. A case study of lime treatment and land application of sludge from this plant, along with a general economic comparison of lime stabilization with anaerobic digestion, is available (229).

#### 6.4.1.2 Current Status

As of May 1978, lime treatment is being used to stabilize the sludge from at least 27 municipal wastewater treatment plants in Connecticut. Average wastewater flows treated at these plants vary from 0.1 to 31 MGD (4.4 to 1358 l/s). In most of the plants, incinerators have been either wholly or partially abandoned. While few chemical or bacterial data are available, qualitative observations indicate that treatment is satisfactory. Most of the communities have indicated that they will continue with lime stabilization.

Landfill burial is the most common means of disposal for lime-stabilized sludge. However, lime-treated sludge from eight of the plants in Connecticut is applied onto land. At Enfield, Connecticut, dewatered sludge is stockpiled in large mounds. The sludge is spread onto cornfields when application is compatible with crop cycles and weather conditions. Few nuisances are caused by the practice. Odors have not been a problem, even when piles have been opened for spreading of the sludge. In Willimantic, Connecticut, lime-stabilized sludge is mixed with leaves and grasses. After stockpiling, a portion of mixture is screened and distributed to local nurseries. The remainder is used as final cover for landfill.

#### 6.4.1.3 Applicability

Lime stabilization can be an effective alternative when there is a need to provide:

- Backup for existing stabilization facilities. A lime stabilization system can be started (or stopped) quickly. Therefore, it can be used to supplement existing sludge processing facilities when sludge quantities exceed design levels, or to replace incineration during fuel

shortages. Full sludge flows can be lime-treated when existing facilities are out of service for cleaning or repair.

- Interim sludge handling. Lime stabilization systems have a comparatively low capital cost and, therefore, may be cost effective if there are plans to abandon the plant or process within a few years.
- Expansion of existing facilities or construction of new facilities to improve odor and pathogen control. Lime stabilization is particularly applicable in small plants or when the plant will be loaded only seasonally.

In all cases, a suitable site for disposal or use of stabilized sludge is required:

#### 6.4.1.4 Theory of the Process

Lime addition to sludge reduces odors and pathogen levels by creating a high pH environment hostile to biological activity. Gases containing nitrogen and sulfur that are evolved during anaerobic decomposition of organic matter are the principal source of odors in sludge (228). When lime is added, the microorganisms involved in this decomposition are strongly inhibited or destroyed in the highly alkaline environment. Similarly, pathogens are inactivated or destroyed by lime addition.

High lime dosing of sludge also affects the chemical and physical characteristics of sludge. Although the complex chemical reactions between lime and sludge are not well understood, it is likely that mild reactions, such as the splitting of complex molecules by hydrolysis, saponification, and acid neutralization, occur in the high pH environments created in lime stabilization (228). These reactions reduce the fertilizer value of the stabilized sludge, improve its dewaterability, and change the character of liquid sidestreams. The nature of these chemical changes is described in Section 6.4.3.4.

#### 6.4.2 Design Criteria

Three fundamental design parameters must be considered in the design of a lime stabilization system: pH, contact time, and lime dosage. At this early stage in the development of the process, the selection of the levels of these parameters has been largely empirical. The results of earlier studies now can be used as a starting point, but because of the complexity of chemical interactions that apparently occur in lime treatment of sludge, bench-scale and pilot studies are recommended as part of designing a large-scale system, particularly if substantial departures from these conditions are contemplated.

#### 6.4.2.1 pH and Contact Time

The primary objective of lime stabilization is to inhibit bacterial decomposition and inactivate pathogenic organisms. The extensive use of lime is medicinal; the masking of noxious odors from decaying substances permits uncritical acceptance of its use for sludge treatment. Nevertheless, evidence is needed of its value and of the necessary dose levels and contact times for effective treatment.

The effective factor in lime treatment is evidently the pH level and not just the dose of lime. As with most disinfection processes, the time of exposure (the extensive factor) is equally as important as the pH (the intensive factor). Investigations by Farrell and others (226), Counts and Shuckrow (228), and Noland and others (229), have established time, pH, and processing conditions for producing satisfactory lime stabilization. Process performance is discussed in a subsequent section (Section 6.4.3).

The design objective is to maintain pH above 12 for about two hours to ensure pathogen destruction, and to provide enough residual alkalinity so that the pH does not drop below 11 for several days, allowing sufficient time for disposal or use without the possibility of renewed putrefaction. The recommended design criteria for accomplishing these objectives are:

- Treat sludge in the liquid state.
- Bring the sludge to pH 12.5 by lime addition and maintain pH above 12.5 for 30 minutes (which keeps pH >12 for two hours).

Farrell and others (226) attempted to determine whether the additions of lime that would occur in conditioning of sludge for dewatering would produce adequate stabilization. They mixed liquid sludge with lime for two minutes, and then dewatered the sludge on a Buchner funnel. Their results indicated inadequate bacteriological destruction. Later results by Strauch and others (230) in Denmark and unpublished results at Downington, Pennsylvania (See Section 6.4.4.1) indicate that special reaction conditions or intense mixing of sludge cake with lime can produce satisfactory results.

#### 6.4.2.2 Lime Dosage

The amount of lime required to stabilize sludge is determined by the type of sludge, its chemical composition, and the solids concentration. Table 6-25 summarizes the results of plant-scale tests at Lebanon, Ohio, and shows that lime additions ranging from 6 to 51 percent of the total dry solids in the sludge were required to raise the pH to the levels indicated in the table. These lime dosages were sufficient to keep the sludge pH above

12.0 for 30 minutes. Primary sludges required the lowest dosages, while the highest average dosages were required to raise the pH level of waste-activated sludges. The results of studies conducted by Paulsrud and Eikum (227) agree generally with the Lebanon tests and are displayed in Table 6-26. Iron and alum sludges required the highest dosages. Farrell, and others (226) also found that alum additionally increased the lime requirement and suggested that part of the lime added to alum sludge may be bound as a calcium-aluminum compound.

**TABLE 6-25**  
**LIME REQUIREMENT TO ATTAIN pH 12 FOR 30 MINUTES**  
**AT LEBANON, OHIO (228)**

Sludge type	Solids concentration, percent		Lime dosage, lb Ca(OH) <sub>2</sub> / lb dry solids		pH, average	
	Range	Average	Range	Average	Initial	Final
Primary sludge <sup>a</sup>	3-6	4.3	0.06-0.17	0.12	6.7	12.7
Waste activated sludge	1-1.5	1.3	0.21-0.43	0.30	7.1	12.6
Anaerobically digested mixed sludge	6-7	5.5	0.14-0.25	0.19	7.2	12.4
Septage	1-4.5	2.7	0.09-0.51	0.20	7.3	12.7

<sup>a</sup>Includes some portion of waste activated-sludge.

1 lb/lb = 1 kg/kg.

**TABLE 6-26**  
**LIME DOSES REQUIRED TO KEEP pH ABOVE 11.0**  
**AT LEAST 14 DAYS (226)**

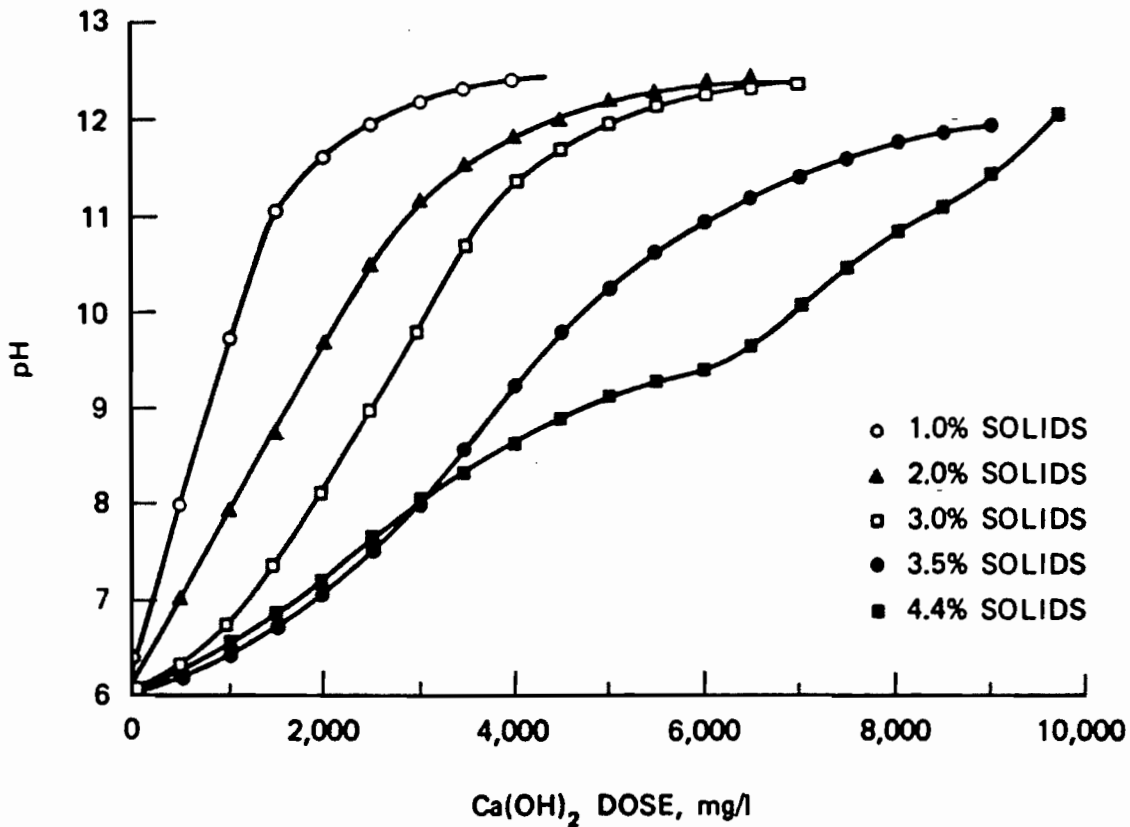
Type of sludge	Lime dose, lb Ca(OH) <sub>2</sub> /lb suspended solids
Primary sludge	0.10 - 0.15
Activated sludge	0.30 - 0.50
Septage	0.10 - 0.30
Alum-sludge <sup>a</sup>	0.40 - 0.60
Alum-sludge <sup>a</sup> plus primary sludge <sup>b</sup>	0.25 - 0.40
Iron-sludge <sup>a</sup>	0.5 - 0.60

<sup>a</sup>Precipitation of primary treated effluent.

<sup>b</sup>Equal proportions by weight of each type of sludge.

1 lb/lb = 1 kg/kg.

Figure 6-44 displays the general relationship between lime dosage and pH for a typical municipal sludge at several solids concentrations. Table 6-26 calculated from data on Figure 6-44, shows that the lime dose per unit mass of sludge solids required to attain a particular pH level is relatively constant. That is, lime requirements are more closely related to the total mass of sludge solids, rather than the sludge volume. Consequently, reduction in volume by thickening may have little or no effect on the amount of lime required, because the mass of sludge solids is not changed.



**FIGURE 6-44**

**LIME DOSES REQUIRED TO RAISE pH OF A MIXTURE OF PRIMARY SLUDGE AND TRICKLING FILTER HUMUS AT DIFFERENT SOLIDS CONCENTRATIONS (228)**

Lime additions must be sufficient to ensure that the pH of sludge does not drop below the desired level after prolonged storage. If insufficient lime is added, the pH will decay as the treated sludge ages (227-229). This phenomenon is displayed on Figure 6-45. Notice that higher lime dosages not only raise the initial pH but, more importantly, prevent, or at least delay, the drop in pH levels. Consequently, in practice, lime doses must be greater than that sufficient to raise the pH to the desired value. In most cases, significant pH decay will not occur if enough lime is added to raise the sludge pH to 12.5 and maintain that value for at least 30 minutes (229).



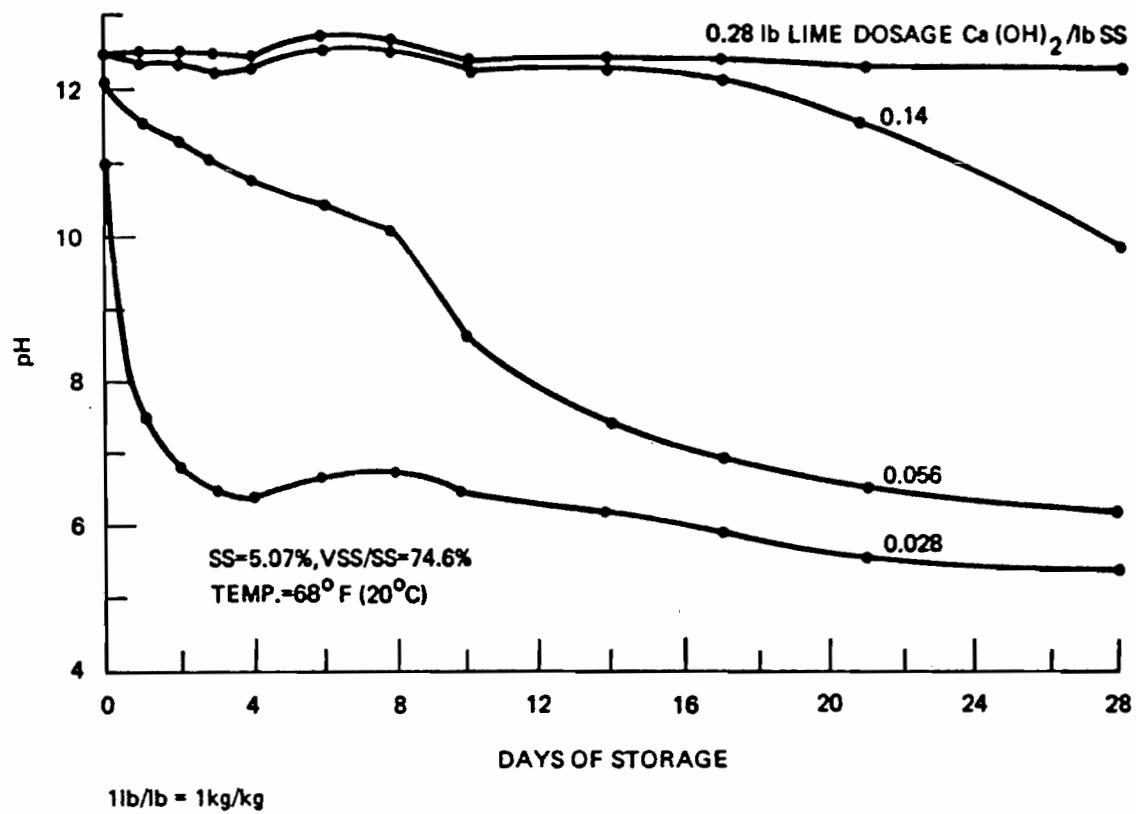


FIGURE 6-45  
CHANGE IN pH DURING STORAGE OF PRIMARY SLUDGE  
USING DIFFERENT LIME DOSAGES

Several mechanisms of pH decay have been proposed and some have been documented (227,228). The initial pH drop results from the uptake of atmospheric CO<sub>2</sub> and slow reactions of hydroxyl ions with sludge solids. The rate of pH reduction is accelerated once the pH reaches a point at which bacterial action can resume production of organic acids through anaerobic microbial degradation.

The foregoing discussion makes it clear that a dose level cannot be defined without reference to the specific sludge. Actual dose levels will have to be determined in bench-scale tests. Approximate levels can be selected from the information above in order to establish size of equipment and to estimate costs.

6.4.3 Process Performance

Lime stabilization reduces odors and odor production potential in sludge, reduces pathogen levels, and alters dewatering, settling, and chemical characteristics of the sludge. The nature and extent of the effects produced are described in the following paragraphs.

### 6.4.3.1 Odor Control

Lime treatment deodorizes sludge by creating a high pH environment in the sludge, thus eliminating or suppressing the growth of microorganisms that produce malodorous gases. In one laboratory study (228), the threshold odor number of raw mixed primary and trickling filter sludges was 8,000, while that of lime-treated sludges ranged between 800 and 1300. The threshold odor number defines the greatest dilution of the sample with odor-free water to yield the least definitely perceptible odor (231). Sufficient lime must be added to retard pH decay because odor generation will generally resume once the pH of the sludge falls below pH 11.0 (220,228).

Hydrogen sulfide ( $H_2S$ ), a malodorous gas present in dissolved form in sludge, is a major cause of sludge odors. Figure 6-46 shows that, as the pH of sludge is raised, the fraction of total sulfide in the  $H_2S$  form decreases from about 50 percent at pH 7 to essentially zero at pH 9. Consequently, above this pH, there is no longer any  $H_2S$  odor.

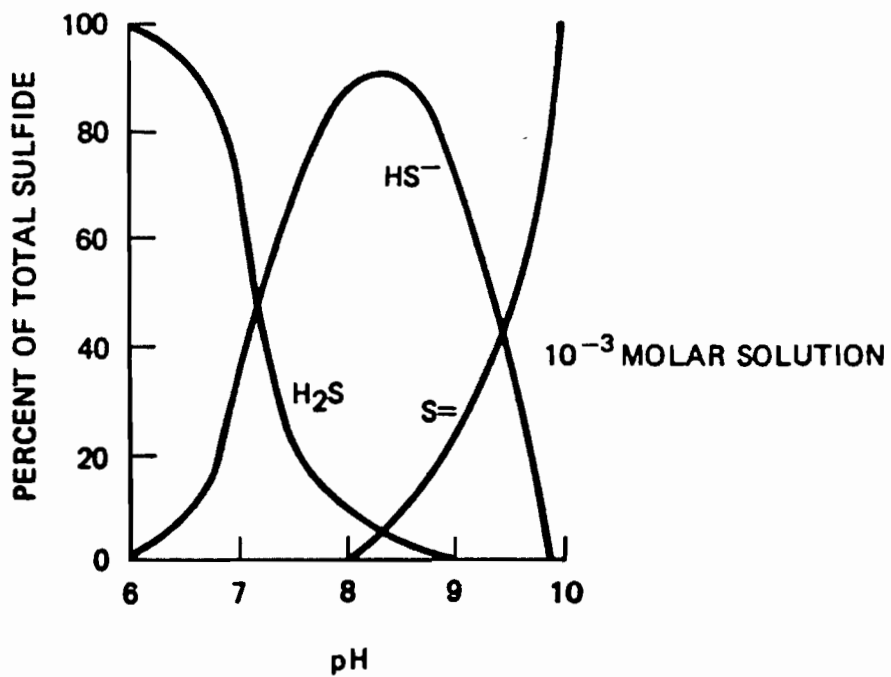


FIGURE 6-46

### EFFECT OF pH ON HYDROGEN SULFIDE-SULFIDE EQUILIBRIUM

During full-scale operations at the Lebanon plant (229), odor was intense when septic raw sludge was first pumped to the lime stabilization mixing tank. Odor intensity increased when diffused air was applied for mixing. When lime was added, the sludge odor was masked by the odor of ammonia, which was stripped from the sludge by the air bubbled through the mixture. The

ammonia odor was most intense with anaerobically digested sludge and was strong enough to cause nasal irritation. As mixing proceeded, the treated sludge acquired a musty, mucus-like odor.

### 6.4.3.2 Pathogen Reduction

Significant pathogen reductions can be achieved in sludges that have been lime-treated to pH 12.0 (228,229). Table 6-27 lists bacteria levels measured during the full-scale studies at Lebanon and shows that lime stabilization of raw sludges reduced total coliform, fecal coliform, and fecal streptococci concentrations by more than 99.9 percent. The numbers of Salmonella and Pseudomonas aeruginosa were reduced below the level of detection. Table 6-27 also shows that pathogen concentrations in lime-stabilized sludges ranged from 10 to 1,000 times less than those in anaerobically digested sludge from the same plant.

**TABLE 6-27**  
**BACTERIA IN RAW, ANAEROBICALLY DIGESTED, AND**  
**LIME STABILIZED SLUDGES AT LEBANON, OHIO (228)**

Sludge type	Bacterial density, number/100 ml				
	Total coliform <sup>a</sup>	Fecal coliform <sup>a</sup>	Fecal streptococci	Salmonella <sup>c</sup>	Ps. aeruginosa
Raw					
Primary	2.9 x 10 <sup>9</sup>	8.3 x 10 <sup>8</sup>	3.9 x 10 <sup>7</sup>	62	195
Waste-activated	8.3 x 10 <sup>8</sup>	2.7 x 10 <sup>7</sup>	1.0 x 10 <sup>7</sup>	6	5.5 x 10 <sup>3</sup>
Septage	2.9 x 10 <sup>8</sup>	1.5 x 10 <sup>7</sup>	6.7 x 10 <sup>5</sup>	6	754
Anaerobically digested					
Mixed primary and waste-activated	2.8 x 10 <sup>7</sup>	1.5 x 10 <sup>6</sup>	2.7 x 10 <sup>5</sup>	6	42
Lime stabilized <sup>b</sup>					
Primary	1.2 x 10 <sup>5</sup>	5.9 x 10 <sup>3</sup>	1.6 x 10 <sup>4</sup>	<3	<3
Waste-activated	2.2 x 10 <sup>5</sup>	1.6 x 10 <sup>4</sup>	6.8 x 10 <sup>3</sup>	<3	13
Septage	2.1 x 10 <sup>3</sup>	265	665	<3	<3
Anaerobically digested	18	18	8.6 x 10 <sup>3</sup>	<3	<3

<sup>a</sup>Millipore filter technique used for waste-activated sludge and septage. MPN technique used for other sludges.

<sup>b</sup>To pH equal to or greater than 12.0.

<sup>c</sup>Detection limit = 3.

Information on virus destruction in sludge by lime stabilization is scant. There are numerous investigations on removal of viruses from wastewater by lime flocculation but little on destruction of viruses by elevated pH. A study by Berg (233) measured the structure of a polio virus in water by pH adjustment alone, and indicate very rapid destruction above pH 11. Similar effects would be expected for other animal viruses.

11

Qualitative observation under a microscope has shown substantial survival of higher organisms, such as hookworms, amoebic cysts, and Ascaris ova, after contact times of 24 hours at high pH (226). It is not known whether long-term contact would eventually destroy these organisms. A more complete discussion of sludge disinfection is contained in Chapter 7.

#### 6.4.3.3 Dewatering and Settling Characteristics

Lime has been used extensively as a conditioning agent to improve the dewaterability of sludge. Trubnick and Mueller (234) presented detailed procedures to be followed in conditioning sludge for filtration, using lime with and without ferric chloride. Sontheimer (235) described the improvements in sludge filterability produced by lime addition. A more detailed discussion of lime conditioning is contained in Chapter 8.

The addition of lime has been shown to improve the filterability of alum and iron primary sludges (226). Specific resistance was reduced by a factor of approximately four, and filter yield was increased by a factor of two when lime conditioning was used. Counts and Shuckrow (228) studied the effect of lime treatment on the filterability of primary sludge and trickling filter sludge but could not detect any consistent trend.

The impact of lime stabilization on sand bed drying of sludge has been examined by several researchers (226,228,229). Lime additions to raw sludge increased the rate of drying at least initially and, in one study, produced a drier final cake. However, lime-treated primary sludge did not dry as fast as either lime-treated or untreated anaerobically digested sludge (229).

The settling of lime-stabilized primary and mixed sludges was enhanced in one study (228), indicating that gravity thickening after lime treatment may be used to reduce the volume of sludge to be dewatered.

#### 6.4.3.4 Chemical Characteristics

Lime stabilization causes chemical changes in the sludge. The nature of these changes is illustrated in Tables 6-28 and 6-29, which compile chemical data from two studies. The general effect of lime addition is a reduction in component concentration. This is caused by both dilution with lime slurry and loss of some volatile sludge components to the atmosphere.

Lime-stabilized sludges have lower concentrations of soluble phosphate, ammonia nitrogen, and total Kjeldahl nitrogen than anaerobically digested sludge from the same plant, as shown in Table 6-28. These lower nutrient levels reduce the agricultural value of the sludge but, assuming nitrogen limits the rate at

which sludge can be applied, would allow more sludge to be applied per acre of land. A reduction in the soluble (filterable) phosphate concentration is caused by the reaction between lime and dissolved orthophosphate to form calcium-phosphate precipitate. For this reason, residual phosphate in the supernatant/filtrate after lime treatment is believed to be largely organic in nature (228). Nitrogen levels can be reduced during lime stabilization if gaseous ammonia is stripped during air mixing of the treated sludge. As the pH of the sludge increases from near neutral to 12, the predominant form of ammonia shifts from the ammonium ion ( $\text{NH}_4^+$ ) to dissolved ammonia gas ( $\text{NH}_3$ ). Some of this gas is carried off by the air bubbled through the sludge for mixing.

-12-

TABLE 6-28

**CHEMICAL COMPOSITION OF SLUDGES AT LEBANON, OHIO, BEFORE AND AFTER LIME STABILIZATION (228)**

Sludge type	Concentration, average, mg/l								
	Alkalinity	Total COD	Soluble COD	Total phosphate	Soluble phosphate	Total Kjeldahl nitrogen	Ammonia nitrogen	Total suspended solids	Volatile suspended solids
<b>Primary</b>									
Before lime addition	1,885	54,146	3,046	350	69	1,558	223	48,700	36,100
After lime addition	4,313	41,180	3,556	283	36	1,374	145	38,370	23,480
<b>Waste activated</b>									
Before lime addition	1,265	12,810	1,043	218	85	711	51	12,350	10,000
After lime addition	5,000	14,700	1,618	263	25	1,034	64	10,700	7,136
<b>Anaerobically digested mixed sludge</b>									
Before lime addition	1,593	66,372	1,011	580	15	2,731	709	61,140	33,316
After lime addition	8,467	58,670	1,809	381	2.9	1,780	494	66,350	26,375
<b>Septage</b>									
Before lime addition	1,897	24,940	1,223	172	25	820	92	21,120	12,600
After lime addition	3,475	17,520	1,537	134	2.4	597	110	23,190	11,390

A direct result of adding lime to sludge is that the total alkalinity will rise to a high value. This can affect the suitability of the treated sludge for land application. The input can be positive or negative, depending on soil conditions at the application site. Data in Table 6-28 indicates the magnitude of change in alkalinity.

Biochemical oxygen demand, chemical oxygen demand, and total organic carbon concentrations increase in the liquid fraction of wastewater sludges when lime is added (228,229). Organic matter is dissolved in the high pH environment. Possible reactions involved include saponification of fats and oils, hydrolysis and dissolution of proteins, and decomposition of proteins to form methanol (228).

Lime stabilization usually does not produce the substantial reductions in volatile matter associated with anaerobic and aerobic sludge digestion. However, volatile solids concentrations decreased by 10 to 35 percent after lime additions in the

plant-scale studies at Lebanon (229), as shown in Table 6-28. Reductions in total solids concentration after lime stabilization were measured by Counts and Shunckrow (228). These reductions, displayed in Table 6-29, are greater than can be accounted for simply by dilution with lime slurry. It may be simply that the lime interfered with the volatile solids analysis. However, reactions between lime and nitrogenous organic matter may cause a loss of sludge solids. Hydrolysis of proteins and destruction of amino acids are known to occur by reaction with strong bases. Volatile substances such as ammonia, water, and low molecular weight amines or other volatile organics may possibly be formed and lost to the atmosphere.

#### 6.4.4 Process Design

A lime stabilization operation is divided into two operations: lime handling and sludge mixing. Lime handling comprises facilities for receiving storing, transporting, feeding, and "slurrying" of the lime. The sludge mixing operation consists of a holding tank provided with mixing. A discussion of design considerations for these two operations follows.

##### 6.4.4.1 Design of Lime Handling Facilities

Lime, in its various forms, is the principal and lowest cost alkali used in industry and wastewater treatment. As a result, a substantial body of knowledge has evolved concerning the most efficient handling of lime. Only the basic elements of lime system design are described in this manual. Detailed information is contained in several references that focus on the selection, handling, and use of lime (236-239).

#### Lime Characteristics

Lime is a general term applied to several chemical compounds that share the common characteristic of being highly alkaline. The two forms commercially available are quicklime ( $\text{CaO}$ ) and hydrated lime ( $\text{Ca(OH)}_2$ ). The characteristics of these two chemicals are summarized in Table 6-30. Lime is a caustic material and can cause severe injury to tissue, particularly to eyes. Equipment must be designed with safe handling in mind; eyewash fountains and safety showers should be provided, and operating procedures should mandate use of proper handling procedures and protective clothing.

Quicklime is derived from limestone by a high temperature calcination process. It consists primarily of the oxides of calcium and magnesium. The grade of quicklime most commonly used in wastewater treatment contains 85 to 90 percent  $\text{CaO}$ .

74  
TABLE 6-29CHEMICAL COMPOSITION OF SLUDGE AND SUPERNATANT  
BEFORE AND AFTER LIME STABILIZATION<sup>a</sup> (227)

Parameter	Primary sludge	Trickling filter humus	Mixed sludge
Whole sludge			
pH			
Before lime addition	6.0	6.3	6.1
After lime addition	12.1	12.3	12.0
Total solids (wt percent)			
Before lime treatment	3.6	3.0	3.6
After lime treatment	3.2	2.7	3.3
Total alkalinity (mg/l as CaCO <sub>3</sub> )			
Before lime addition	1,141	1,151	1,213
After lime addition	6,920	6,240	5,760
Ammonia nitrogen (mg N/l)			
Before lime addition	211	274	192
After lime addition	91	148	87
Organic nitrogen (mg N/l)			
Before lime addition	1,066	1,179	1,231
After lime addition	1,146	995	1,099
Nitrate nitrogen (mg N/l)			
Before lime addition	3	7	16
After lime addition	25	22	31
Total phosphate (mg P/l)			
Before lime addition	342	305	468
After lime addition	302	235	337
Filterable phosphate (mg P/l)			
Before lime addition	92	96	80
After lime addition	32	17	31
Supernatant			
TOC (mg/l)			
Before lime addition	1,000	917	1,175
After lime addition	2,083	1,883	2,250
BOD (mg/l)			
Before lime addition	1,120	964	1,137
After lime addition	1,875	1,981	2,102
Threshold odor number <sup>b</sup>			
Before lime addition	4,889	5,333	933
After lime addition	467	333	67
Total solids (wt percent)			
Before lime addition	0.1	0.1	0.2
After lime addition	0.6	0.5	0.7

<sup>a</sup>Values in this table are averages of three tests for each sludge type.

<sup>b</sup>The greatest dilution with odor-free water to yield the least perceptible odor.

Quicklime is rarely applied directly (that is, in a dry condition) to the sludge. First it is converted to hydrated lime by reaction with water in an exothermic reaction called slaking.





During slaking, the generally coarse CaO particles are ruptured, splitting into microparticles of Ca(OH)<sub>2</sub>. These smaller particles have a large total surface area and are highly reactive. The slaking reaction is carried out under closely controlled conditions to promote maximum lime reactivity.

TABLE 6-30  
CHARACTERISTICS OF QUICKLIME AND HYDRATED LIME

Common name/ formula	Available forms	Containers and requirements	Appearance and properties	Weight, lb/cu ft (bulk density)	Commercial strength	Solubility in water
Quicklime/ CaO	Pebble Crushed Lump Ground Pulverized	80-100 lb moisture- proof bags, wooden barrels, and car- loads. Store dry; maximum 60 days in tight container - 3 months in mois- ture-proof bag.	White (light gray, tan) lumps to powder. Unstable, caustic irritant. Slakes to hydrox- ide slurry evolving heat (490 Btu/lb). Air slakes to CaCO <sub>3</sub> . Sat. sol. approximately pH 12.5	55 to 75; to calcu- late hopper capa- city - use 55; Sp. G., 3.2-3.4.	70 to 96 percent CaO (Below 88 percent can be poor quality)	Reacts to form Ca(OH) <sub>2</sub> each lb of quicklime will form 1.16 to 1.32 lb of Ca(OH) <sub>2</sub> , with 2 to 12 percent grit, depending on purity.
Hydrated lime/ Ca(OH) <sub>2</sub>	Powder (Passes 200 mesh)	50 lb bags, 100 lb barrels, and car- loads. Store dry; maximum one year.	White, 200-400 mesh; powder free of lumps; caustic, dusty irritant; ab- sorbs H <sub>2</sub> O and CO <sub>2</sub> from air to form Ca(HCO <sub>3</sub> ) <sub>2</sub> . Sat. sol. approximately pH 12.4.	25-40; to calculate hopper capacity - use 30; Sp. G., 2.3-2.4	Ca(OH) <sub>2</sub> - 82 to 98 percent; CaO - 62 to 74 percent (Std. 70 percent)	10 lb/1,000 gal at 70°F 5.6 lb/1,000 gal at 175°F

1 lb = 1.454 kg  
100 Btu/lb = 55 kg-cal/kg  
1 lb/cu ft = 16 kg/m<sup>3</sup>  
1 lb/1,000 gal = 0.120 g/l

If slaking is done by the lime manufacturer, hydrated lime is delivered to the wastewater treatment plant. The manufacturer adds only enough water for hydration, producing a dry Ca(OH)<sub>2</sub> powder. At the waste treatment plant, the powder is then slurried with more water prior to mixing with sludge. Alternatively, slaking may be carried out at the wastewater treatment plant; the delivered product is, therefore, quicklime. In this case, the lime is slaked, then diluted (if necessary) prior to process application.

Direct addition of dry quicklime to sludge and without the use of a separate slaker, is practiced in Denmark in at least ten Swedish treatment plants. Potential advantages are the elimination of slaking equipment and the generation of heat, which can improve pathogen reduction and speed dewatering through evaporation. In one case (230), direct additions of dry quicklime were made to raise sludge pH above 13.0 and bring the temperature to 176°F (80°C). Salmonella and intestinal parasites were killed within two hours. Heat generated by slaking of quicklime does not raise temperature significantly unless the sludge is dewatered and the lime dose is high--on the order of 400 to 800 lb per ton dry solids (200-400 kg/t).

The decision whether to purchase quicklime or hydrated lime in a particular situation is influenced by a number of factors such as size of treatment facility, material cost, and storage

requirements. The cost of hydrated lime is about 30 percent greater than the cost of quicklime with an equivalent calcium oxide content. The difference is due to the higher production and transportation costs for hydrated lime. Nevertheless, hydrated lime is preferred for small-scale operations mainly because its use eliminates the labor and equipment required for slaking. Hydrated lime is also more stable and therefore is easier to handle and to store. When lime use exceeds three to four tons per day (3,000-4,000 kg/day), quicklime should be considered because of its inherent economy (236). Selection of the type of lime to be used should be based on a detailed economic analysis, taking into account all the unique factors of the particular application.

Both quicklime and hydrated lime react spontaneously with atmospheric CO<sub>2</sub>.



In addition, quicklime can be slaked by the water vapor in the air.

These reactions cause two problems:

- Lime quality is degraded because the reaction product, CaCO<sub>3</sub>, is ineffective in raising pH.
- The partial reaction with CO<sub>2</sub>, and in the case of CaO, with water vapor, causes caking. This interferes with lime slaking and feeding.

Thus, lime storage, slaking, and feeding equipment should be sealed to as great a degree as possible to prevent contact of lime with atmospheric CO<sub>2</sub> and water vapor.

Delivery and Storage of Lime

Lime can be delivered either in bags or in bulk. The choice depends mostly on the rate of chemical use at the treatment plant. Bagged lime costs about 20 percent more than bulk lime, but it is generally preferred where daily requirements are less than 1000 to 1500 pounds of lime per day (236). At this small scale, handling and storage of bagged lime is relatively simple, involving manual labor or simple mechanical aids. As the scale of operation increases, it becomes more efficient and economical to use bulk lime, which can be delivered in large quantities, transported in mechanical or pneumatic conveying systems, and stored in weather-tight bins or silos.

Bagged lime must be stored under cover to prevent rain from wetting the bags. Proper handling is especially important when quicklime is used, because it is highly reactive with water,

producing heat and swelling that can cause the bags to burst. Because heat can be generated during accidental slaking of quicklime, bags should never be stored close to combustible materials.

Hydrated lime may be stored under dry conditions for periods up to a year without serious deterioration by reaction with atmospheric CO<sub>2</sub> (recarbonation). Quicklime deteriorates more rapidly. Under good storage conditions, with multiwall moisture-proofed bags, quicklime may be held as long as six months, but in general should not be stored for more than three months (236).

Bulk quicklime and hydrated lime can be stored in conventional steel or concrete silos or bins. The storage facilities must be airtight to prevent slaking and recarbonation. Pebble quicklime is free-flowing and will discharge readily from storage bins if the hopper bottoms have a minimum slope of 60 degrees from the horizontal. Pulverized quicklime and especially hydrated lime have a tendency to arch and therefore require some type of mechanical or aeration agitation to ensure uniform discharge from storage bins. Detailed descriptions of the various types of flow-aiding devices can be found elsewhere (236,240).

Storage facilities should be sized on daily lime demand, type and reliability of delivery, future chemical requirements, and an allowance for flexibility and expansion. As a minimum, storage should be provided to supply a seven-day lime demand; however, sufficient storage to supply lime for two to three weeks is desirable. In any case, the total storage volume should be at least 50 percent greater than the capacity of the delivery railcar or truck to ensure adequate lime supply between shipments (236).

Lime Feeding

Lime is nearly always delivered to the sludge mixing vessel as a Ca(OH)<sub>2</sub> slurry (milk-of-lime). This facilitates transport to the point of application and improves lime dispersion and reaction efficiency. The exact series of steps through which dry lime is wetted and introduced to the sludge varies according to such factors as the scale of the operation, the type of lime purchased, and the method of storage. The following paragraphs outline the basic lime-feeding schemes. The discussion is largely derived from a bulletin published by the National Lime Association (236), which should be referred to for more detail.

Feeding of Hydrated Lime - In small treatment plants where bagged hydrated lime is purchased, the dry chemical is simply mixed with water in a batch tank and metered to the sludge mixing tank as required. Solutions of lime are not corrosive, so that an unlined steel tank is sufficient for mixing and storage of the slurry. Hydrated lime is fed as a 6 to 18 percent Ca(OH)<sub>2</sub> slurry by weight, the percentage depending on the application and

on operator preference. The milk-of-lime can be discharged to the sludge in one batch or metered continuously to the basin through a solution feeder.

In larger operations, where hydrated lime is stored in bulk, a more automated mixing and feeding scheme is appropriate. A dry chemical feeder is used for continuous delivery of a measured amount of dry lime to a dilution tank. The feeder is often positioned directly at the base of the bulk storage bin to minimize dry lime transport distance.

Two general types of automated dry feeders are available:

- Volumetric feeders, which deliver a constant, preset volume of chemical in a unit of time, regardless of changes in material density.
- Gravimetric feeders, which discharge a constant weight of chemical in a unit of time.

Gravimetric feeders cost roughly twice as much as volumetric feeders with an equivalent capacity and require more maintenance, but they are more accurate. Most manufacturers of gravimetric feeders will guarantee a minimum accuracy of within one percent, by weight, of the set rate. Volumetric feeders, on the other hand, may have an error of 30 percent by weight, due to the varying bulk density of hydrated lime. Gravimetric feeders are preferred because of their greater accuracy and dependability, but the less expensive volumetric type may be sufficient when limited funds are available, when greater chemical feeding accuracy is not required, or when a reduced degree of maintenance is desirable.

Dry hydrated lime is delivered to a dilution tank that is often fitted directly onto the feeder. The tank is agitated by either compressed air, water jets, or impeller type mixers. The lime slurry is then transferred to the sludge mixing basins. This transfer operation is the most troublesome single operation in the lime handling process. The milk-of-lime reacts with atmospheric  $\text{CO}_2$  or carbonates in the dilution water to form hard, tenacious  $\text{CaCO}_3$  scales, which, with time, can plug the transfer line. Because the magnitude of this problem is in direct proportion to the distance over which the slurry must be transferred, lime feeder facilities should be located as close as possible to the lime/ sludge mixing tanks. Pumping of the lime slurry should be avoided (if possible, gravity transfer should be used), and all apparatus should be accessible for cleaning. Scaling in lime slurry systems has been prevented through the use of a chemical additive that interferes with crystal formation. Design features and operating techniques used successfully for milk-of-lime transfer are described in detail in reference 236.

Direct addition of dry hydrated lime to centrifuge cake was tested in a pilot-scale study at the wastewater treatment plant in Downingtown, Pennsylvania. An undigested mixture of primary and secondary sludges was dewatered to a solids concentration of 20 percent, and then blended with powdered  $\text{Ca}(\text{OH})_2$  for ten minutes in a twin-paddle mixer. Addition of 200 pounds of hydrated lime per ton dry (100 kg/t) raised sludge pH to 11.8, reduced pathogen levels to below the detection limit, and controlled odor and fly problems.

Slaking and Feeding of Quicklime - Feeding of quicklime is similar to that for hydrated lime, except that there is an additional step, slaking, in which the quicklime reacts spontaneously with water to form hydrated lime. Bagged quicklime can be slaked in batches by simply mixing one part quicklime with two to three parts water in a steel trough while blending with a hoe. Proportions should be adjusted so that the heat of the reaction maintains the temperature of the reacting mass near 200°F (93°C). The resulting thin paste should be held for 30 minutes after mixing to complete hydration. Manually operated batch slaking is a potentially hazardous operation and should be avoided if possible. Uneven distribution of water can produce explosive boiling and splattering of lime slurry. Use of protective equipment should be mandatory. For small plants, the potential gain in using the lower-priced quicklime is smaller, because lime consumption is smaller. Use of slaked lime is safer, simpler, and requires less labor.

Continuous slaking is accomplished in automated machines that also dilute and degrit the lime slurry. Several types of continuous slakers are available. They vary mainly in the proportion of lime to water mixed initially. A volumetric or gravimetric dry chemical feeder is used to measure quicklime as it is moved from bulk storage to the slaker. Since quicklime is available in a wide range of particle sizes, it is important to match the dry feeder with the type of quicklime to be used in the particular application.

6.4.4.2 Mixing Tank Design

A tank must be provided for mixing raw sludge with lime slurry and then holding the mixture for a minimum contact time. Many of the currently operating lime stabilization facilities do not have tanks with sufficient capacity to hold sludge for more than a few minutes. Although these operations generally have been successful, the acceptability of very short detention times has not been conclusively demonstrated. Because of the uncertainty surrounding this practice, it is recommended that all lime stabilization facilities include a tank large enough to hold the lime sludge mixture for 30 minutes. The pH of the reacted mixture should exceed 12.5 during this period.

The following paragraphs discuss two aspects of mixing tank design - tank sizing and mixing. To determine tank size, a designer must first select a flow mode. The following section on tank sizing describes flow modes. The subsequent section on tank mixing covers the general types of mixers and suggests criteria for sizing mixing systems.

### Tank Sizing Considerations

Mixing tanks can be operated as either a batch process or continuous flow process. In the batch mode, the tank is filled with sludge, and then sufficient lime is added to maintain the pH of the sludge-lime mixture above 12.5 for the next 30 minutes. After this minimum contact time, the stabilized sludge can be transferred to dewatering facilities or to either tank trucks or a pipeline for land application. Once the holding tank is emptied, the cycle begins again.

In the continuous flow mode, the pH and volume of sludge in the holding tank are held constant. Entering raw sludge displaces an equal volume of treated sludge. Lime is added continuously, in proportion to the flow of incoming raw sludge, and thus, the holding time would vary. The lime dose must be sufficient to keep the contents of the tank at a pH of 12.5. Often the daily cycle of sludge production does not match the pattern of sludge disposal. In this case, a system could be operated on a semi-continuous basis, where the quantity of sludge in the tank fluctuates through the day. Here the treatment tank would be used as a buffer between sludge production and disposal.

It is most common to operate lime stabilization systems in the batch flow mode. Batch operations are very simple and are well suited for small-scale, manually operated systems. When adequate capacity is provided, the mixing tanks can also be used to gravity thicken the lime-treated sludge before disposal. In very small treatment plants, tank capacity should be adequate to treat the maximum-day sludge production in one batch. This is because small plants are generally operated only during the day, and it is usually desirable to stabilize the entire day's sludge in one batch. Larger plants are more likely to be manned round-the-clock. Because sludge can be processed over the whole day, stabilization tanks can be relatively smaller.

Continuous-flow stabilization systems require automated control of lime feeding and therefore are usually not cost-effective for small-scale operations. The primary advantage of continuous-flow systems over batch systems is that a smaller tank size may be possible. Capacity does not have to be provided for storage of sludge between batches. Instead, the mixing tank must only be large enough to ensure that all sludge particles are held at high pH for a contact time sufficient to destroy odor and disease-producing organisms.

The most important design parameter for a continuous flow, well-mixed reactor is the nominal detention time (defined as tank volume divided by volumetric input flow rate). Unlike a batch tank, where contact time of all particles is the same, some particles in a well-mixed, continuously fed tank escape after relatively short contact. Thus, 30 minutes of pH at 12.5 in a batch mixer might not be the same as 30 minutes residence time in a well-mixed, continuously fed reactor.

In making a recommendation for detention time, the nature of the treatment that occurs must be considered. Unlike some treatments, such as irradiation, the treatment does not stop after the treated sludge leaves the vessel. If pH is 12.5 as the sludge leaves the mixing tank, it remains at this pH after leaving. Consequently, a 30-minute detention time in a continuously fed, well-mixed reactor is adequate, provided the pH is measured in an exit line. If pH of the limed sludge appears to fall too rapidly upon standing, it is a simple matter to move the pH sensor and to control lime feed rate to a position further downstream.

Thickening of raw sludge before lime addition will reduce the mixing tank capacity requirement in direct proportion to the reduction in sludge volume. However, the lime requirement will be reduced only slightly by prethickening, since most of the lime demand is associated with the solids (227), and total solids mass is not changed by thickening.

### Tank Mixing

Lime/sludge mixtures can be mixed with either diffused air or mechanical mixers. The agitation should be great enough to keep sludge solids suspended and to distribute the lime slurry evenly and rapidly. Both diffused air and mechanical systems can provide adequate mixing, although the former has been more commonly used in pilot studies and full scale operations. In addition to their mixing function, sparger air systems supply oxygen and, thereby, can be used for sludge aeration before the sludge is dosed with lime. If storage of unlimed sludge is contemplated, the designer should check that the air requirement for mixing is sufficient to meet the oxygen demand of the sludge. Oxygen requirements are discussed in the section on aerobic digestion.

There are disadvantages to both types of mixing systems. Mechanical mixers are subject to fouling with rags, string, and other debris in the sludge. Although air spargers may clog, fouling problems are greatly reduced by mixing with air. Ammonia will be stripped from the sludge when mixing is done with diffused air, producing odors and reducing the fertilizer value of the treated sludge. However, if nitrogen levels limit land application rates, this stripping of ammonia will reduce land requirements for disposal. A further, although probably minor,

problem with air mixing is that  $\text{CO}_2$  is absorbed by the sludge/lime mixture, tending to raise the quantity of lime required to reach the desired pH. The selection of the method of mixing should be based on the factors described above, coupled with an economic evaluation.

With air mixing, coarse bubble diffusers should be used, mounted along one of the tank walls to induce a spiral-roll mixing pattern. An air supply of 20 to 30 scfm per 1,000 cubic feet ( $20\text{-}30 \text{ m}^3/\text{min} / 1,000 \text{ m}^3$ ) is required for adequate mixing (241). If the mixing tank is enclosed, ventilation should be sufficient to remove odorous gases stripped from the sludge during mixing. In many cases, these gases should be treated in an odor control unit before being discharged into the atmosphere.

Mechanical mixer specifications for various tank sizes are presented in Table 6-31. Sizing is based on two criteria: maintaining the bulk fluid velocity (defined as the turbine agitator pumping capacity divided by the cross sectional area of the mixing vessel) above 26 feet per minute (8.5 m/min), and using an impeller Reynolds number greater than 1,000. The tank/mixer combinations in Table 6-31 are adequate for mixing sludges with up to 10 percent dry solids and viscosity of 1,000 cp. Impellers on mechanical mixers should be designed to minimize fouling with debris in the sludge.

#### 6.4.5 Costs and Energy Usage

Engineering decisions are commonly based on a comparison of costs for feasible solutions. Energy considerations are now also becoming important in the decision-making process. This section discusses costs and energy usage for lime stabilization systems.

##### 6.4.5.1 Capital and Operating Costs

Cost estimates for the construction and operation of three different size lime stabilization systems are summarized in Table 6-32. A comparison of these costs shows that there is a large economy of scale, especially for the capital costs. Operation and maintenance expenses, particularly those for lime, are more closely related to the quantity of sludge treated.

Comparisons of the cost of lime treatment with other stabilization methods must take into account that the addition of lime increases the quantity of solids to be handled after stabilization. In contrast, sludge solids actually decrease during anaerobic and aerobic digestion. This difference between stabilization methods can have an important effect on costs for final disposal of sludge. The magnitude of this cost differential is site-specific and depends on such factors as the method of disposal and the distance to the disposal site.



TABLE 6-31

MECHANICAL MIXER SPECIFICATIONS FOR SLUDGE SLURRIES (228)

Tank size, gal	Tank diameter, ft	Motor size, hp	Shaft speed, rpm	Turbine diameter, ft
5,000	9.5	7.5	125	2.7
		5	84	3.2
		3	56	3.6
15,000	13.7	20	100	3.7
		15	68	4.4
		10	45	5.3
		7.5	37	5.6
30,000	17.2	40	84	4.8
		30	68	5.1
		25	56	5.5
		20	37	6.8
75,000	23.4	100	100	5.2
		75	68	6.2
		60	56	6.6
		50	45	7.3
100,000	25.7	125	84	6.0
		100	68	6.5
		75	45	7.8

Assumptions:

- Bulk fluid velocity >26 ft/min. (8.5 m/min.).
- Impeller Reynolds number >1,000.
- Mixing tank configuration.
- Liquid depth equals tank diameter.
- Baffles with a width of 1/12 the tank diameter, placed at 90 degrees spacing.

Mixing theory and equations after References 155 and 242.

- 1 gal = 3.785 l
- 1 ft = 0.305 m
- 1 hp = 0.746 kW

6.4.5.2 Energy Usage

Energy is required during both the construction and operation of a lime stabilization system. During operation of a lime stabilization facility, the principal direct use of energy is electricity for mixing the lime/sludge mixture. A rough estimate of the annual energy requirement for mixing with diffused air is 290 kWh per year per cfm of blower capacity (based on continuous duty). This estimate was made assuming a six psig (0.4 kg/m<sup>2</sup>) pressure boost, standard inlet conditions, and an overall compressor/motor efficiency of 60 percent. One horsepower of mechanical mixing requires about 6,500 kWhr of electricity per year. These mixing energy demands can be expressed in terms of a primary fuel requirement (that is, fuel oil, coal, natural gas) by applying a conversion factor of 10,700 Btu (2,700 kg-cal) per kWh of electricity. This factor assumes a fuel conversion efficiency of 35 percent at the power plant and a transmission efficiency of 91 percent.

TABLE 6-32

ESTIMATED AVERAGE ANNUAL COSTS FOR LIME STABILIZATION FACILITIES<sup>a</sup> (228)

Item	Treatment plant capacity, mgd		
	1	4	40 <sup>e</sup>
Capital <sup>b</sup>	10,500	30,100	87,200
Operation and maintenance <sup>c</sup>	12,600	35,900	257,400
Total	23,100	66,000	344,600
Unit cost <sup>d</sup> , (dollars/ton dry sludge solids)	54.17	39.27	20.51

<sup>a</sup>All costs expressed in 1978 dollars.

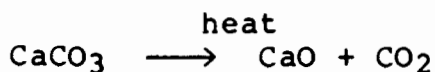
<sup>b</sup>Amortized over 30 years at 7 percent. Includes cost of all buildings, equipment, and piping for lime storage and funding, and for sludge mixing and lagoon storage, except as noted.

<sup>c</sup>Average lime dose of 0.2 lb Ca(OH)<sub>2</sub>/lb dry solids. Hydrated lime (47 percent CaO, \$44.50/ton) used in the 1-mgd system, otherwise, quicklime (85 percent CaO, \$40/ton). All labor at \$6.50/hr. Does not include cost for transport and disposal.

<sup>d</sup>Primary plus waste-activated sludge, 2,300 lb dry sludge solids produced/mil gal of wastewater treated (1.20 x 10<sup>-4</sup> Kg/m<sup>3</sup>).

<sup>e</sup>Includes sludge thickening but not lagoon storage.

Large amounts of energy are used in the production of quicklime. Quicklime (CaO) is produced by burning limestone (CaCO<sub>3</sub>) in kilns. This process, termed calcination, is illustrated in the following reaction:



The current national average energy consumption for all quicklime production is about 7.0 million Btu per ton of quicklime (1.9 x 10<sup>6</sup> kg-cal/metric ton) (243). This figure is decreasing since

modern plants, using large and more efficient kilns, should be able to produce one ton of quicklime with about 5.5 million Btu ( $1.5 \times 10^6$  kg-cal/metric ton).

#### 6.4.6 Design Example

This section illustrates the layout and sizing of the major components in a lime stabilization system. For this example, it is assumed that the treatment plant has a capacity of approximately 8 MGD (350 l/s) and provides secondary treatment to typical municipal wastewater. A mixture of primary sludge and thickened waste-activated sludge is to be stabilized with lime, then mechanically dewatered, and ultimately spread onto land.

##### 6.4.6.1 Design Loading

Sludge production estimates for two flow conditions, average and peak day, are listed in Table 6-20 (provided previously in the anaerobic digestion section). The peak-loading is listed because critical components must be sized to meet this critical condition. Chapter 4 provides a discussion of the procedure to determine sludge production values. Sludge solids concentrations and the resulting sludge volumes are also included in Table 6-20.

##### 6.4.6.2 System Description

The conceptual design for the lime stabilization system is presented on Figure 6-47. Prior to stabilization, all sludge is passed through an in-line grinder. This conditioning improves sludge mixing and flow characteristics, protects downstream pumping and dewatering equipment, and eliminates unsightly conditions (such as rags, sticks, plastic) at the disposal site. Two batch mixing tanks are provided, each with the capacity to treat the total sludge produced in an eight-hour shift during peak day conditions. While one tank is filling, sludge in the other is dosed with lime, mixed for 30 minutes, and then discharged to the dewatering equipment. Since the mixing tanks are sized for peak conditions, they can provide some short-term storage for treated sludge during periods of lower loading. Design of an actual facility should take into consideration the operating schedule for dewatering and disposal.

In this example, it is assumed that dewatering is operated continuously and therefore only minimal inline storage is required. However, if dewatering equipment was operated for two shifts, and serviced during the third, at least eight hours of storage would be required.

Air discharged through coarse bubble diffusers is used to mix the sludge with the lime slurry. Air mixing is started as raw sludge

is first added to the tank to keep the sludge from turning septic and producing odors. When the tank is filled, lime is added and mixing is continued for at least 30 minutes.

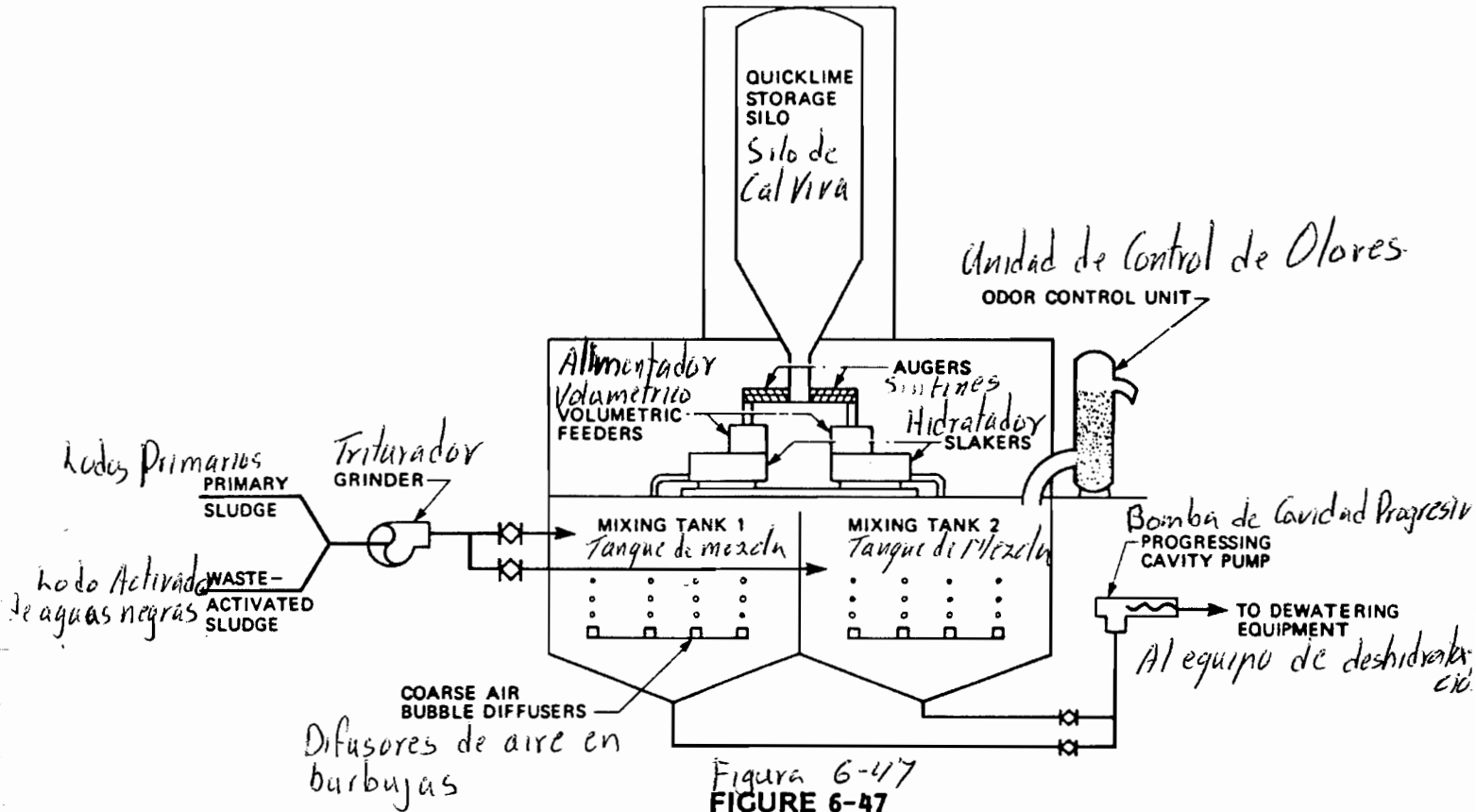


Figura 6-47  
FIGURE 6-47

**CONCEPTUAL DESIGN FOR A LIME STABILIZATION FACILITY**  
*Concepto de Diseño para una Planta de Estabilización con Cal*

To reduce odors, the mixing tanks are covered, and gases stripped from the sludge during mixing are removed in an odor control unit. This unit is a packed bed scrubber. The scrubbing solution is dilute sulfuric acid. Ammonia gas is absorbed by the sulfuric acid solution. All wetted parts are constructed of acid-resistant materials.

Quicklime is used in this installation. A bulk storage silo, with capacity to hold a 30-day lime requirement under average conditions, supplies lime to two volumetric feeders. Each feeder measures out quicklime to a slaker, where the lime is hydrated, slurried, and discharged into the mixing tank. The lime dose is sufficient to maintain the sludge above pH 12.5 for 30 minutes.

6.4.6.3 Component Sizing

Mixing Tank

Sizing criterion:

Conditions.

Volume requirement (V):

Peak-day sludge production shown in Table 6-21.

$$\begin{aligned}
 V &= \frac{8 \text{ hr/tank}}{24 \text{ hr/day}} (6010 \text{ cu ft/day} + 3430 \text{ cu ft/day}) \\
 &= 3,150 \text{ cu ft/tank} \\
 &= (89 \text{ m}^3/\text{tank})
 \end{aligned}$$

Tank surface area (A):  
(Assume 10 feet liquid depth)

$$\begin{aligned}
 A &= \frac{3,150 \text{ cu ft}}{10 \text{ ft}} = 315 \text{ ft}^2 \\
 &= \cancel{39.3} \text{ m}^2 \text{ 29.98}
 \end{aligned}$$

Tank dimensions:  
(Assume 2 feet freeboard)  
18 ft x 18 ft x 12 ft  
(5.4 m x 5.4 m x 3.7 m)

Air mixing system

Sizing criterion:

30 cfm/1,000 cu ft

Blower capacity (Q):  
(One blower per tank)

$$\begin{aligned}
 Q &= \frac{(3,150 \text{ cu ft})}{\text{tank}} (30 \text{ cfm}/1,000 \text{ cu ft}) \\
 &= 95 \text{ cfm/blower} \\
 &= (2.6 \text{ m}^3/\text{min}/\text{blower})
 \end{aligned}$$

Lime Storage

Sizing criterion:

30-day storage during average loading.

Quicklime characteristics:

Purity -	90 percent CaO
Bulk density -	55 lb/cu ft

Lime dosage:

- Primary sludge - 0.12 lb Ca(OH)<sub>2</sub>/lb dry solids
- Activated sludge - 0.30 lb Ca(OH)<sub>2</sub>/lb dry solids

Average daily lime requirement (W):

Expressed as hydrated lime -

$$\begin{aligned}
 W_{CaOH_2} &= (10,000 \text{ lb/day}) \left( \frac{.12 \text{ lb}}{\text{lb}} \right) + (5,000 \text{ lb/day}) \left( \frac{.30 \text{ lb}}{\text{lb}} \right) \\
 &= 2,700 \text{ lb Ca(OH)}_2/\text{day} \\
 &= (1,230 \text{ kg/day})
 \end{aligned}$$

Expressed as purchased quicklime (90 percent purity) -

$$\begin{aligned}
 W_{CaO} &= (2,700 \text{ lb Ca(OH)}_2 \text{ day}) \left( \frac{56 \text{ lb CaO/Mole}}{74 \text{ lb Ca(OH)}_2/\text{mole}} \right) \left( \frac{100}{90} \right) \\
 &= 2,270 \text{ lb CaO/day} \\
 &= (1,030 \text{ kg/day})
 \end{aligned}$$

Storage requirement (V<sub>S</sub>):

$$\begin{aligned}
 V_S &= \frac{2,270 \text{ lb/day}}{55 \text{ lb/cu ft}} (30 \text{ days}) \\
 &= 1,240 \text{ cu ft} \\
 &= (35 \text{ m}^3)
 \end{aligned}$$

Slaker:

Sizing criterion:

Ability to dose one batch in 15 minutes.

Slaker capacity (C):

$$\begin{aligned}
 C &= \frac{2,270 \text{ lb CaO/day}}{3 \text{ batches/day}} \frac{(1 \text{ batch})}{(15 \text{ min})} \\
 &= 50 \text{ lb CaO/min} \\
 &= (23 \text{ kg/min})
 \end{aligned}$$

*Fin de traduccion*

6.5 Chlorine Stabilization

Stabilization by chlorine addition was developed as a proprietary process and is marketed under the registered trademark "Purifax." The chlorine stabilization process is applied to wastewater treatment plant sludges and sidestreams to reduce putrescibility and pathogen concentration. The process has also been used to improve the dewaterability of digested sludge and to reduce the impact of recycled digester supernatant on the wastewater treatment systems. Because chlorine reactions with sludge are very

rapid, reactor volumes are relatively small, reduced system size and initial costs. The process results in no appreciable destruction of volatile solids, and unlike anaerobic digestion, yields no methane gas for energy generation and little sludge mass reduction.

Chlorine-stabilized sludges are buff-colored, weak in odor, sterile, and generally easy to dewater, either mechanically or on drying beds. The stabilized sludge has been used as a soil conditioner. However, there is concern about its use on cropland and its disposal in landfills because of its high acidity, high chloride content, and potential for releasing chlorinated hydrocarbons and heavy metals. The stabilized sludges are corrosive unless pH has been adjusted. Process equipment that comes into contact with sludges that have not been neutralized must be constructed of acid-resistant materials or be coated with protective films.

### 6.5.1 Process Description

Chlorine treatment stabilizes sludge by both reducing the number of organisms available to create unpleasant or malodorous conditions and making organic substrates less suitable for bacterial metabolism and growth. Some of the mechanisms responsible are oxidation, addition of chlorine to unsaturated compounds, and displacement of hydrogen by chlorine.

The immediate reaction from addition of gaseous chlorine to water is shown below:



In the chlorine stabilization process, sufficient acid is produced to reduce the pH of the sludge to a range of 2 to 3. Dissociation of HOCl to H<sup>+</sup> and OCl<sup>-</sup> is suppressed by low pH and therefore is not significant. Cl<sub>2</sub> and HOCl are highly reactive and powerful bactericides and viricides. The chloride ion has no disinfection capability.

The process stream immediately following the chlorine addition is substantially a chlorine solution containing sludge. The solution contains (in molecular form) as much as ten percent of the total chlorine species present. The predominant species in solution is undissociated HOCl. HOCl and Cl<sub>2</sub> react with sludge to oxidize ammonia to chloramines and organic nitrogen to organic chloramines. Other reduced ions, such as Fe<sup>+2</sup> and S<sup>-2</sup>, are oxidized at the same time. Some of the oxidized end products, such as chloramines and organic chloramines, are germicidal and viricidal (244).

The chlorine stabilization unit consists of a disintegrator, a recirculation pump, two reaction tanks, a chlorine eductor, and a pressure control pump. A chlorine evaporator and/or a