

Topic Number 43  
Treatment of Hazardous Materials

LIME TREATMENT OF LIQUID WASTE CONTAINING  
HEAVY METALS, RADIONUCLIDES, AND ORGANICS

Part I - Processes for Treatment

by

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Revision I

## Abstract

Lime is well known for its use in softening drinking water and the treatment of sewage waste. Lime is becoming important in the treatment of industrial wastewater and liquid inorganic hazardous waste; however, there are many questions regarding the use of lime for the treatment of liquid hazardous waste.

## Introduction

Under the proposed rule on Land Disposal Restrictions 40 CFR 260 of January 14, 1986, there have been many changes and revisions for the disposal of liquid wastes. Liquid hazardous wastes, including free liquids associated with sludge, can no longer be put in a landfill without treatment. The current criteria for determining the "free liquids" is to use the Paint Filter Liquid Test (Method 9095) which was promulgated on April 30, 1985.

The liquid portion (free liquids) of a sludge may not contain metals in a concentration greater than or equal to the following:

<u>Metal</u>	<u>mg/l</u>
As(+3)	500
As(+5)	500
Cd(+2)	100
Cr(+3)	500
Cr(+6)	500
Hg(+2)	20
Ni(+2)	134
Se(+4)	100
Se(+6)	100
Tl(+3)	130

The metals listed above are usually found in an acidic medium and must undergo a treatment process before they can be disposed of in a landfill. The treatment of radionuclides and organic waste may also undergo some of the same steps outlined below.

### Treatment Process

Neutralization ---> Precipitation ---> Solidification

One method of treating this liquid waste is to use a neutralizing material. Lime is often recommended because the calcium cation is an environmentally safe binder since most of the salts formed at a neutral pH are insoluble after precipitation. Other alkalies such as sodium hydroxide form soluble salts after precipitation at a neutral pH and may cause an environmental problem when neutralizing an acidic metal waste.

Also, lime is often the chemical of choice for neutralizing acidic metal wastes because of its great effectiveness and low cost. As the pH of an acidic metal liquid begins to increase because of lime treatment, most metal cations will precipitate into a hydroxide sludge of low solubility. Once this sludge has formed, it must undergo further treatment to insure that the metallic sludge is completely harmless to the environment.

On May 9, 1985 the EPA Office of Solid Waste and Emergency Response issued a Statutory Interpretive Guidance on the treatment of bulk hazardous waste. The agency has prohibited the use of an absorbent material that does not chemically stabilize or solidify a bulk hazardous waste. Examples listed as absorbents by the EPA are vermiculite, fuller's earth, bentonite, fly ash, fine-grained sand, shredded paper and sawdust.

The material specified for treatment is an adsorbent that "binds the liquid waste through a chemical reaction (e.g. hydration) rather than through a physical process." The two listed stabilization adsorbents are portland cement, and pozzolans and lime.

When considering the cost of using an adsorbent, pozzolans and lime are always less expensive to use than portland cement. Pozzolanic adsorbtion is based on the reaction of lime and a fine-grained siliceous material (e.g. flyash) that combines to form a cementitious solid.

Currently, some generic and patent solidification techniques are used for the adsorbtion of liquid waste. Please see the patent in the list of references.

### Processes: Neutralization and Precipitation

Both neutralization and precipitation are chemical processes where metal cations reacts with a hydroxide anion. This is the process of adding an hydroxide ion which then precipitates the metals. The process of coagulation is both a physical and chemical process. Through the attraction of cation for anions, the suspended solids group together to form a floc. This is accomplished through the process of small particles colliding together under the mild turbulent conditions found in a stirred tank. Next, all of the precipitated material can be removed from the stirred tank to yield a material with a concentration of 20-50% solids. This process of precipitation can be reversed by mixing the sludge with a low concentration of acid at pH=5.0. The addition of lime to an acidic metal waste creates a hydroxide sludge, while the further addition of acid to this sludge brings down the pH to produce an acidic metallic waste. Hence, once an acidic metallic sludge has been treated with lime, it must undergo further treatment to prevent the leaching of metals.

### Processes: Solidification of Inorganics

In order to render this material harmless to the environment, it is necessary to go through the process called solidification. The distinction between absorbtion and adsorbtion defines whether a sludge is solidified. Absorbtion is a physical process that does not chemically stabilize a waste material, versus adsorbtion which is a final chemical reaction to form a cementitious precipitated sludge.

As stated earlier, the EPA has prescribed the use of a pozzolan and lime to be an effective chemical stabilizing material. The metal sludge in the presence of free water will combine with more lime plus the addition of flyash to form a solid block. The lime reacts with fine-grained siliceous material and the metal hydroxide then becomes part of the structure. This is the general process for inorganic waste treatment. The process treatment is identical for radionuclides.

### Processes: Organic Waste Treatment

Organic waste material that does not have a neutral pH can undergo the process of neutralization and precipitation. In this instance, the organic waste can have further treatment to become part of a lime and pozzonalic structural matrix.

### Types of Lime for Liquid Waste Treatment

Many types of limes are available for neutralization, precipitation and solidification. The two main categories of lime are quicklime and hydrated lime. Quicklime consists of calcium and magnesium oxide from the calcination of limestone. There are three forms of quicklime currently available in this country:

High calcium quicklime - usually containing 90 to 95 percent calcium oxide, and 0.5 to 2.5 percent magnesium oxide.

Dolomitic quicklime - usually containing 55 to 60 percent calcium oxide, and 35 to 40 percent magnesium oxide.

Magnesium quicklime - usually containing 85 to 90 percent calcium oxide, and 5 to 10 percent magnesium oxide.

Commercial hydrated lime is a dry powder obtained by treating quicklime with sufficient water to satisfy its chemical affinity for water, thereby converting most of the metal oxides to metal hydroxides.

High calcium hydrated lime - high calcium quicklime produces a hydrated lime containing generally 72 to 74 percent calcium oxide and 23 to 24 percent water.

Dolomitic hydrated lime (normal) - under atmospheric hydrating conditions only the calcium oxide fraction of dolomitic quicklime hydrates, producing a hydrated lime of the following chemical composition: 46 to 48 percent calcium oxide, 33 to 34 percent magnesium oxide, and 15 to 17 percent water.

Dolomitic hydrated lime (pressure) - this lime is produced from dolomitic quicklime under pressure, which results in hydrating almost all of the magnesium oxide as well as all of the calcium oxide, producing the following chemical composition: 40 to 42 percent calcium oxide, 29 to 30 percent magnesium oxide, and 25 to 27 percent water.

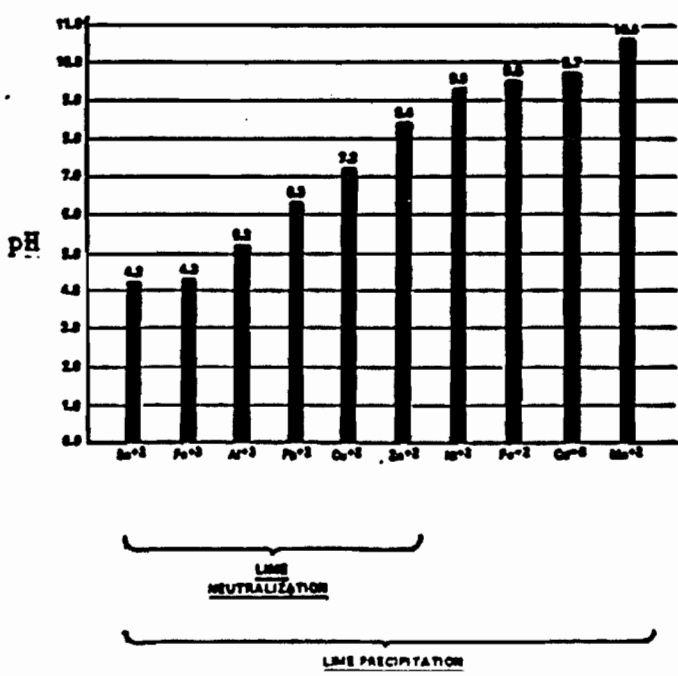
Precipitation of Metals

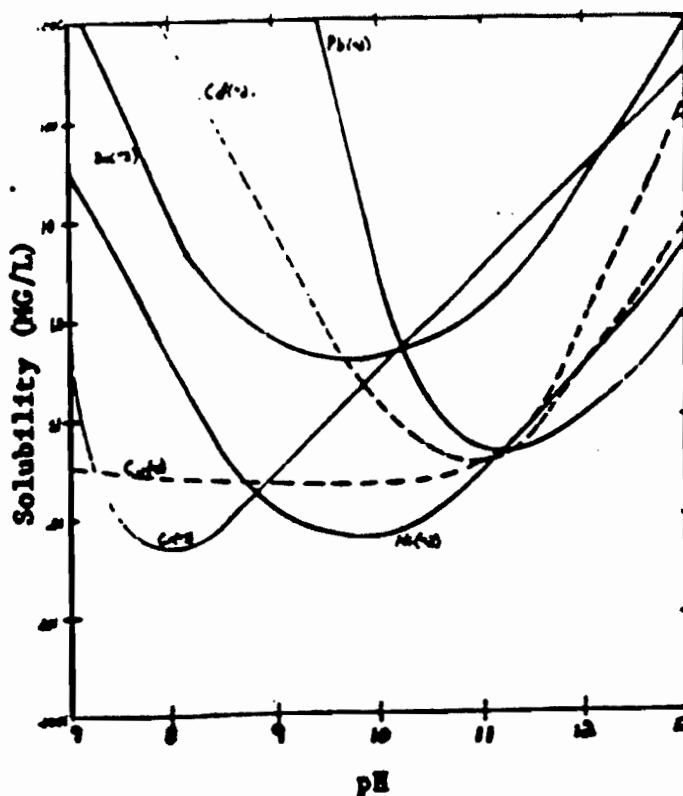
Since the overall steps are clarified, the detailed process of inorganic and organic waste treatment can be explained. The following shows the pH at which metal cations begin to precipitate:

<u>Ion</u>	<u>pH</u>	<u>Ion</u>	<u>pH</u>
Fe(+3)	2.0	Ni(+2)	6.7
Al(+3)	4.1	Cd(+2)	6.7
Cr(+3)	5.3	Co(+2)	6.9
Cu(+2)	5.3	Zn(+2)	7.0
Fe(+2)	5.5	Mg(+2)	7.3
Pb(+2)	6.0	Mn(+2)	8.5

Figure 1 shows the actual range of pH where neutralization and precipitation occur. Notice that zinc(+2) will precipitate at a pH = 8.4, while cadmium will not precipitate until a pH = 9.7 is reached. Figure 1 is taken from reference #15

Fig. 1-Minimum pH Value for Complete Precipitation of Metal Ions as Hydroxides





Solubilities of Metal Hydroxides  
At Alkaline pH

Figure 2

The lowest solubility limit of a metal ion may not be reached until the pH of the particular metal sludge is half to a whole unit above the pH where precipitation begins to occur. A good example is the divalent zinc ion. The zinc metal will completely precipitate when a pH of 8.4 is reached. However, Figure 2 shows that the maximum insolubility of the zinc cation is reached at pH = 10. Also, if the pH of a metal sludge increases above pH=12, the precipitated zinc hydroxide will become slightly more soluble. Therefore, the conclusion that all sludge will precipitate at the same pH is not true. A sludge containing a combination of metals will have some metal cations in their most insoluble stage at the precipitating pH while other metal cations will not be as insoluble. But certainly these metals will be precipitated and insoluble as far as a sludge consistency is concerned. A good example is a waste sludge from a metal canning operation. The metal sludge will contain a variety of constituents and the curve observed for maximum insolubility of the metals will show a shift from that indicated in Figure 2. Figure 2 is taken from reference #8.

The percentage precipitation of a metallic liquid waste with a lime treatment process are shown in Table 3 and Figure 4 in Appendix A. Appendix A contains many examples of treatment applications for the precipitation of metals.

### Precipitation of Radionuclides

This process is very similar to the treatment of heavy metals. It is important to note that lime does precipitate radium, strontium, uranium and yttrium.

Removal of these elements is dependent upon pH. A good example is uranium-228. At pH=6, only 60% can be precipitated. At a pH=10, more than 95% of the uranium cation can be precipitated.

Similarly, the solubility curve of radium-226 in the presence of phosphoric acid is shown in Figure 3. With lime treatment at a pH greater than or equal to 10, the maximum solubility of the radium ion is less than 0.25 pCi/liter. Based on the general laws of chemistry, it can be easily postulated that elements 56 through 71, and elements 88 through 103 can be precipitated with lime at a pH=9 or above. Figure 3 is taken from reference #6

### Solidification

#### Metals

Metals can be solidified with a pozzolan and lime after the waste has been precipitated. Metal hydroxides and calcium salts will combine with flyash and lime in the presence of water to form a cementitious product. A good method of demonstrating this to make a sample is shown below:

Final Solid = Lime + Flyash + Waste + Water

Lime = 5 to 10% by dry weight

Flyash = 50 to 65% by wet weight

Waste = 8 to 19% by wet weight

Water = 10 to 60% of original sludge by weight

#### Organic Waste Treatment

For an organic sludge, lime and flyash are used to solidify the organic waste. A good example is to make a sample. The typical mixture ratio for the final treated solid is shown by the following equation:

Final Solid = Lime + Flyash + Waste + Water

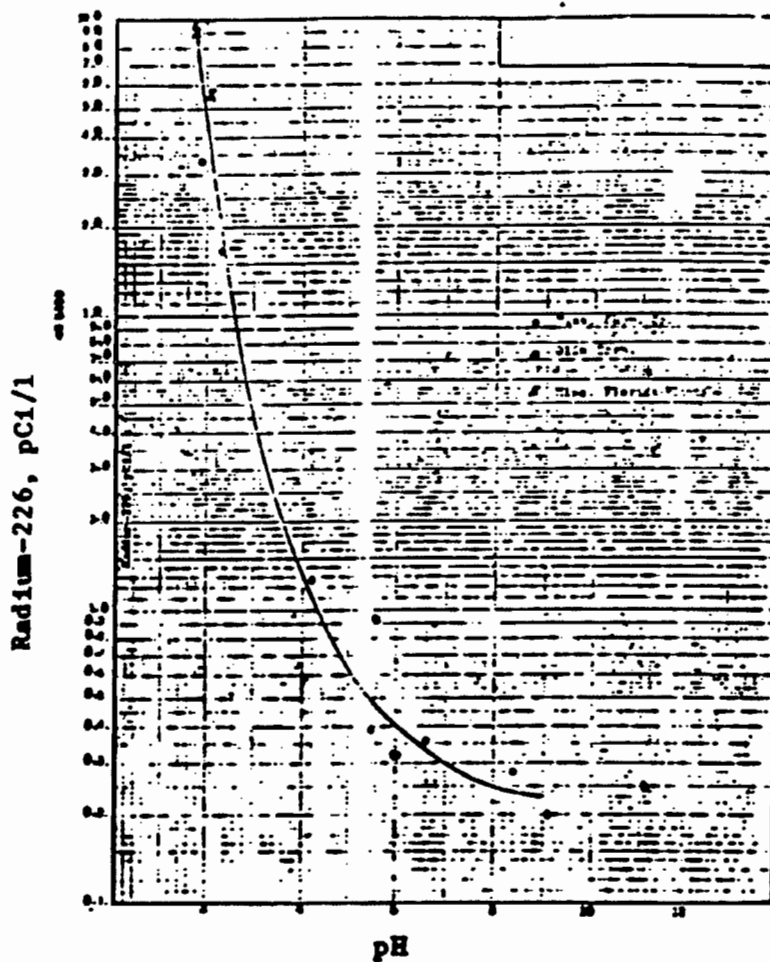
Lime = 5 to 15% by weight

Flyash = 50 to 65% by weight

Waste = 8 to 19% by weight

Water (for binding reaction) = 10 to 20%

EPA Document



Relationship of pH and Radium-226 Concentration in Phosphoric Acid "Contaminated Water" Bench Tests.

Figure 3



Appendix A  
Metals & Non-Metals

Examples of Materials that can be Treated with Lime

I. Lime can be used for the treatment of potable water to meet National Interim Primary Drinking Water Contaminant Levels. Also, lime can be used to treat a liquid hazardous waste containing metals. Under the new EPA guidelines for the disposal of liquids containing heavy metals, lime is the material of choice for neutralization and precipitation. The following table compares the various regulatory limits for the treatment of an aqueous medium.

Table 2  
TREATMENT OF METALS IN AN AQUEOUS MEDIUM

	MCL's: National Interim Primary Drinking Water Maximum Contam- inant Levels	EP Toxic Test Maxi- mum Levels for solid waste	California List for Liquids in a Hazardous Sludge
	mg/l	mg/l	mg/l
Arsenic, (As+3,As+5)	0.05	5.0	500
Barium, (B+2)	1.0	100	----
Cadmium (Cd+2)	0.010	1.0	100
Chromium, (Cr+3)	0.05	5.0	500
Lead, (Pb+2)	0.05	5.0	500
Mercury, (Hg+2)	0.002	0.2	20
Nitrate (NO-3)	10	----	----
Nickel, (Ni+2)	----	----	134
Selenium (Se+4,Se+6)	0.01	1.0	100
Silver (Ag+2)	0.05	5.0	----
Thallium, (Tl+3)	----	----	130
Fluoride, (Fl-1)	2.4	----	----

Description of Neutralization Processes

ARSENIC

The first cation on the list is arsenic; it can be found either in the As(+3) (arsenite) or As(+5) (arsenate) valence state.

Aluminum sulfate (alum) or ferric sulfate coagulation at a

concentration of (20-30 mg/l) can achieve 90% removal of As(+5) at a concentration of 0.3 mg/l. At a pH greater than or equal to 10.8, lime can remove 95% of a liquid containing (0.1 - 10.0) mg/l of arsenate.

Arsenite (As(+3)) is more difficult to coagulate. Alum (30 mg/l) can only remove 20% at a pH between 5.5 and 9.0, while ferric sulfate (30 mg/l) removes less than 60% of 0.3 mg/l of arsenite.

Lime is more effective at a pH greater than or equal to 10.8 to remove 70% of 0.3 mg/l of arsenite.

With chlorine, arsenite can be oxidized to arsenate. However, in highly organic water, this promotes the formation of chloroform or tri-chlorinated methane. Hence, the use of chlorine to oxidize arsenite to arsenate for greater removal can be a disadvantage to a treatment scenario.

### BARIUM

Barium is an important metal contaminant. Alum and ferric chloride coagulation are not effective for barium removal.

Lime softening can achieve greater than 90% removal of Ba(+2) in the pH range between 11 to 10 in a concentration of 7 - 8.5 mg/l of Ba(+2).

### CADMIUM

Cadmium, a well known industrial contaminant, is found in the +2 valence state. Lime softening can achieve a 98% removal of a 0.3 mg/l of cadmium in the pH range of 8.5 to 11.3. Cadmium is extremely soluble below pH = 7.

There is evidence that cadmium coagulation with dolomitic lime is a 99% efficient at removing cadmium. This is reported by Schiller and Khalafalla in "Magnesium Case for Improved Metals Removal".

Alum coagulation is reported to remove a maximum of 40% cadmium (0.3 mg/l), at a pH equal to 8. However, in turbid water, alum coagulation can drop to 20% removal of cadmium. Ferric sulfate can remove 90% of 0.3 mg/l of cadmium at pH equal to 8. However, at pH equal to 7.2, cadmium removal drops to 20%.

### CHROMIUM

Chromium is found in two valence states: Cr(+3) and Cr(+6). In an aqueous solution Cr(+3) will exist as a cation and Cr(+6) is an anion form as  $\text{Cr}_2\text{O}_4(-2)$  and dichromate  $\text{Cr}_2\text{O}_7(-4)$ . The Cr(+6) hexavalent form is the most toxic and the most likely pollutant in water.

Lime, alum, or ferric sulfate are all capable of removing chromium [Cr(+3)] in excess of 90%. With a pH between 10.6 and 11.3, 98% removal of (0.15 mg/l) of Cr(+3) can be achieved by lime coagulation.

For Cr(+6) removal, it is better to reduce the Cr(+6) to Cr(+3). A coagulant such as ferrous sulfate is capable of reducing Cr(+6) to Cr(+3) as the ferrous oxidizes to ferric iron. Adjusting the pH with lime immediately after coagulation is necessary to provide time for the reduction of Cr(+6) to Cr(+3). A 99% removal of Cr(+6) can be achieved with pH adjustment after reduction to Cr(+3).

### LEAD

The carbonate and hydroxide forms of lead are very insoluble. Ferric sulfate and alum coagulation can achieve 97% removal of a lead concentration (0.15 mg/l). At higher lead concentrations alum can only achieve 80% removal, while ferric chloride can still achieve high removal.

However, lime can remove more than 98% of a 0.15mg/l Pb(+2) in a pH range between 8.5 to 11.3.

### MERCURY

Mercury is found in two forms of its valence +2 state. The inorganic form is known to be less toxic and will be described first. Alum and ferric chloride can be used to coagulate Hg(+2) (inorganic). Ferric sulfate coagulation is best at a pH equal to 8 for 97% removal of 0.05 mg/l of Hg(+2) (inorganic). Alum coagulation is less effective; at a pH = 7, a maximum of 47% of Hg(+2) (inorganic) of 0.05 mg/l, can be removed.

Lime is very effective for inorganic Hg(+2). In the pH range of 10.7 to 11.4, 60 to 80% of a 0.5 mg/l Hg(+2) can be removed. At a pH of 9.4, only a 30% removal can be expected.

The organic form is more commonly found and it is more toxic. Organic Hg(+2) is much harder to remove than the inorganic compound. In turbid water, alum and ferric sulfate can remove up to 40% of the Hg(+2) present. Lime is not an effective coagulant for organic Hg(+2) at any known pH.

### SELENIUM

Selenium is found in two valence states, Se(+4) (selenite) and Se(+6) (selenate). Selenium can be found in an aqueous solution as  $\text{SeO}_3(-2)$  (selenite) or  $\text{SeO}_4(-2)$  (selenate).

Ferric sulfate is most effective at a pH equal to 5.5 for an 85% removal of 0.03 mg/l Se(+4). At higher pH, removal of selenium decreases. Alum coagulation is less effective with a maximum removal of 32% of a selenite.

Lime can remove up to 45% of a 0.03 mg/l Se(+4) at a pH equal to 11.

At a low pH equal to 5.5, ferric chloride is more effective for Se(+4) and at a pH greater than or equal to 11 lime is more effective.

### SILVER

Silver is found in the valence state Ag(+2). Alum and ferric sulfate coagulation is effective at a pH range between 6 and 8 for a 70% removal of 0.15 mg/l of Ag(+2) in an aqueous waste.

Lime is more effective for Ag(+2) coagulation; at pH greater than or equal to 11.5, 90% removal of a 0.15 mg/l of Ag(+2) can be achieved.

### NICKEL

The most common form of nickel is (+2) valence state. When lime is added to nickel the hydroxide of nickel will precipitate very well. At a pH between 9.5 to 10.0, the solubility of nickel hydroxide is 0.01 mg/l.

### COPPER

A common valence state of copper is the (+2) valence state. In the pH range between 7.0 and 11.0, the hydroxide solubility of Cu(OH)<sub>2</sub> is .05 mg/l.

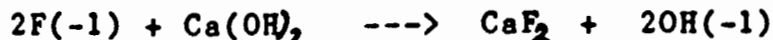
### ZINC

Lime can also do a tremendous job in removing zinc from a waste stream. Zinc is commonly found in the (+2) valence state. Zn(OH)<sub>2</sub> in the pH range of 9 to 11 has a solubility of 1.0 mg/l.

### FLUORIDE

Fluoride is not a metal; however, it is found to be a natural occurring contaminant in the raw water of many communities. There is considerable controversy over the allowable limit of fluoride [F(-1)] allowable in drinking water. An old argument has been that in low concentrations, fluoride is needed for the prevention of dental decay.

The maximum fluoride level allowable in drinking water is set at approximately 2 mg/l at 63° F. Fluoride is normally removed during potable water treatment as a side reaction.



## PHOSPHATE

Phosphate is a well-known industrial pollutant that is known to cause eutrophication of fresh-water lakes when in a high concentration. A pH equal to 11 must be reached to reduce phosphate concentration significantly. A concentration of 300 mg/l of  $\text{Ca}(\text{OH})_2$  can reduce residual phosphate to below 5.0 mg/l. Below a pH of 11, the common phosphate residue is tri-calcium phosphate  $\text{Ca}_3(\text{PO}_4)_2$ .

At a pH of 11 or greater, then the primary compound formed is hydroxyapatite [ $\text{Ca}_5\text{OH}(\text{PO}_4)_3$ ]. Hydroxyapatite will form a microfloc, and may be treated with a coagulant.

Also, by using lime to achieve a pH of 11.0, the chemical oxygen demand (COD) of a wastewater can be reduced from 400-600 mg/l to a level below 200 mg/l.

## SULFITE and SULFATE

Sulfite ( $\text{SO}_3^-$ ) and sulfate ( $\text{SO}_4^-$ ) are the common by-product ions of reactions with sulfurous and sulfuric acid. Also, these ions are the by-product of sulfur emissions from coal burning power plants. Currently, there is an excess of 1.3 million tons of lime used for the treatment of these two ions. Calcium sulfite is considered to be very insoluble, while calcium sulfate is relatively insoluble. The sulfate ion is often found in pickle liquor sludge.

### Exempli Gratia

#### I. Pickle Liquor

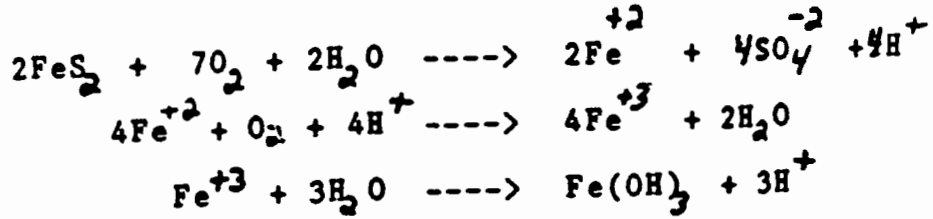
This is classified as RCRA waste K063. Treating pickle liquor with lime results in the formation of three common calcium salts:  $\text{CaSO}_4 \cdot 1/2(\text{H}_2\text{O})$  Plaster of Paris;  $\text{CaSO}_4 \cdot 2(\text{H}_2\text{O})$  gypsum;  $\text{CaSO}_4$  anhydrite. The other compounds are metal hydroxides which such as  $\text{Fe}(\text{OH})_2$  and  $\text{Fe}(\text{OH})_3$ . A common treatment method is to use flyash or cement kiln dust along with an excess of lime (3 parts lime; 1 part cement kiln dust; 20 parts acid sludge by weight). In this treatment scenario, the neutralization, precipitation, and solidification occurs in one step.

#### II. Gold Mining Drainage

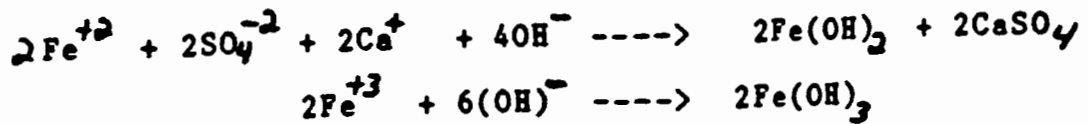
In the gold industry, the gold ore often contains pyrite at a concentration of 9 grams per ton. The pyrite content may contain between one and three percent sulfur. The pyrite bacteriologically oxidizes to yield sulfuric acid. This oxidation process is similar to the acid mine drainage found in the coal mining industry where pyrite is also a contaminant. Lime is the preferred material for the neutralization of this acidic waste.

### III. Coal Mining Drainage

Coal mining operations often have tremendous amounts of acid drainage because coal contains pyrite and marcasite. When a coal pile is exposed to oxygen, the pyrite ( $FeS_2$ ) will oxidize to produce acid ( $H^+$ ), ferrous iron ( $Fe^{+2}$ ) and sulfate ( $SO_4^{-2}$ ). The ferrous iron will oxidize to ferric iron as shown below.

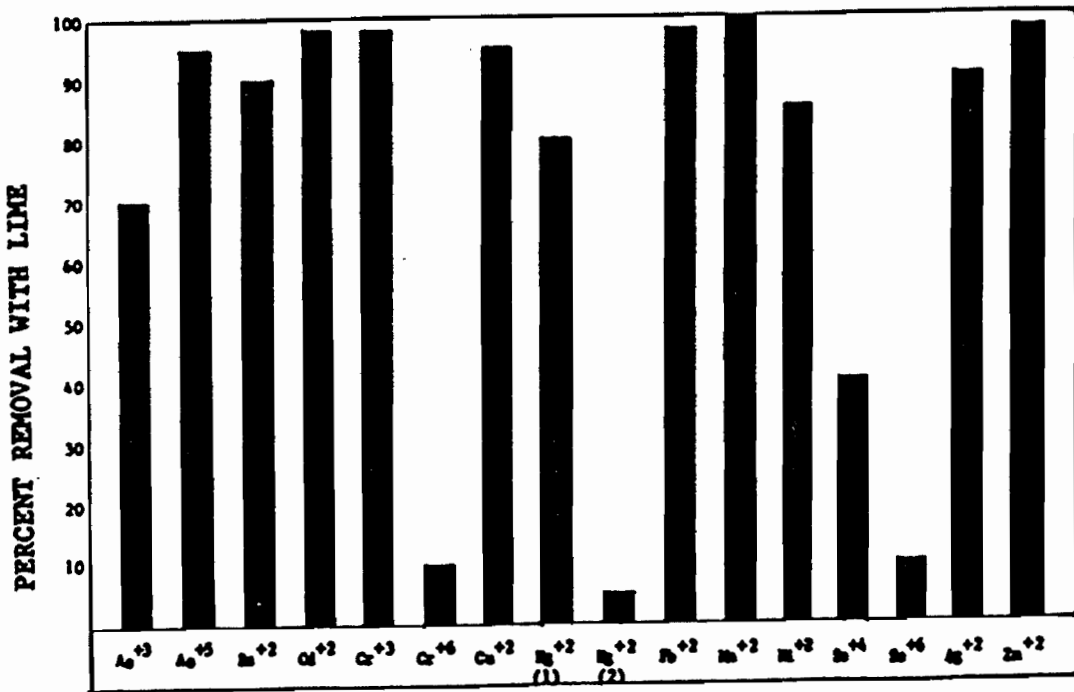


Hence, hydrated lime,  $Ca(OH)_2$ , will undergo the following reaction with pyritic acid mine drainage:



### IV. Metal Recovery from Ore

Similarly, in the mining of copper and zinc, sulfuric acid is used to leach the metal from the ore. Lime is then used to treat the spent sulfuric acid waste.



(1) Inorganic  
(2) Organic

Metals Precipitation

Appendix A  
TABLE 3

Metal's Hydroxide: What is the removal of a particular metal that can be expected at a given pH range.

	<u>Impurity Concentration</u>	<u>pH</u>	<u>Removal Efficiency</u>
Arsenite (+3)	(0.3 mg/1)	$\geq 10.8$	70%
Arsenate (+5)	(0.1-10.0 mg/1)	$\geq 10.8$	95%
Barium (+2)	(7-8.5 mg/1)	$11 \geq \text{pH} \geq 10$	90%
Cadmium (+2)	(0.3-10.0 mg/1)	$11.3 \geq \text{pH} \geq 8.5$	98%
Chromium (+3)	(0.15 mg/1)	$11.3 \geq \text{pH} \geq 10.6$	98%
Chromium (+6)	Best to reduce with ferrous sulfate and then maintain $8.5 \geq \text{pH} \geq 7$ so that a floc may form		
Lead (+2)	(0.5 mg/1)	$11.3 \geq \text{pH} \geq 8.5$	98%
Hg(+2) inorganic	(0.5 mg/1)	$11.4 \geq \text{pH} \geq 10.7$	70%
Hg(+2) organic		lime is not effective	
Se (+4) selenite*	(0.03 mg/1)	pH = 11	40%
Se (+6) selenate		Line is not effective	

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	<u>pH</u>	<u>Maximum Concentration</u>
Zn (+2)	pH = 10	0.8 mg/1
Cu (+2)	$11 \geq \text{pH} \geq 7$	0.05 mg/1
Ni (+2)	pH = 9.8	0.01 mg/1
Cr (+3)	pH = 8.0	0.01 mg/1
Cd (+2)	pH = 11.0	0.08 mg/1
Pb (+2)	pH = 11.0	0.1 mg/1

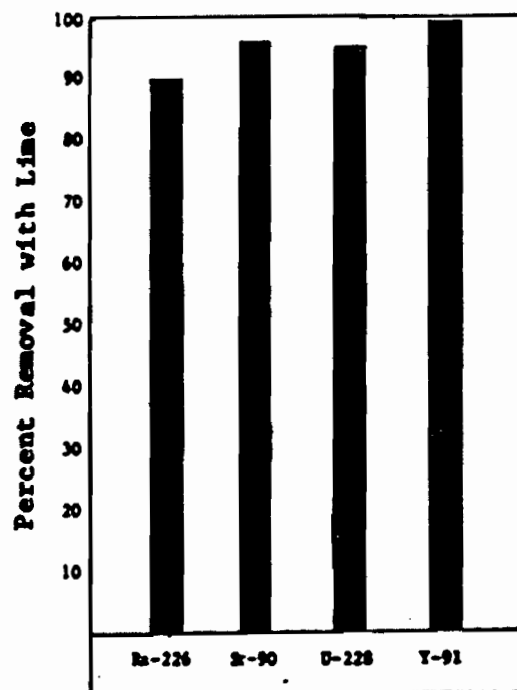
\*Ferric Sulfate is more effective at pH = 5.5 for 85% removal of 0.03 mg/1 (Se+4).

### Appendix B Radionuclides

A common example of radionuclides from industry is the mining of phosphate for the production of fertilizer. Radium 226 is a common by-product that is associated with the mining of phosphate. Radium-226 can be removed through the process called double liming. The curve of precipitation versus pH for Radium-226 is given in Figure 3.

Table 4

<u>Radioactive Element</u>	<u>pH For Best Removal</u>	<u>Efficiency of Removal</u>
Radium-226	pH $\geq$ 10	90%
Strontium-90	pH $\geq$ 10	96%
Uranium-228	pH $\geq$ 10	95%
Yttrium-91	pH $\geq$ 10	98%



Radioactive Elements  
Precipitation

Figure 5



## Appendix C

### Organic Waste Treatment

The following information is taken from a patent granted to the Conversion Systems Inc., for more information, see the list of references. The following is a description of organic sludges that can be treated with a pozzolan and lime.

I. Petroleum Sludge from Petroleum Refinery Units (API separator sludge), pump leakage, surface runoff, spilled lubricants, and waste liquids from housekeeping maintenance tasks (pesticide residue). This sludge will often compromise some of the following organic fractions:

On a wet weight basis, 20% sludge can be mixed in with the pozzolanic material.\*

- A. Alkanes
  - 1. Octane (Constituent of Gasoline)
  - 2. Nonanes
  - 3. Decanes
- B. Cycloalkanes
  - 1. Cyclooctan (Constituent of Gasoline)
- C. Alkyl benzenes
  - 1. Ethylbenzene
  - 2. Propylbenzene
- D. Kerosene
- E. Furnace Oil
- F. Diesel Oil
- G. Aromatics (usually  $C_6$  to  $C_{12}$ )
- H. Polynuclear Aromatics

II. Acrylic Emulsion Waste from the production of acrylic resins (e.g. acrylate) and emulsions.

On a wet weight basis, 14% sludge can be mixed in with the pozzolanic material.\*

- A. Acrylic Paint Sludge

III. Watery waste from demilitarized nerve gas and obsolete chlorinated pesticides decommissioned by the U.S. Army. These

watery wastes contain some of the following.

On a wet weight basis, 20% sludge can be mixed in with the pozzolanic material:\*

- A. Aldrin
- B. Isodrin
- C. Dieldrin
- D. Endrin
- E. Diisopropylmethylphosphonate
- F. Dimethylphosphonate
- G. P-Chlorophenylmethylsulfoxide
- H. P-Chlorophenylmethylsulfone

IV. Coking tar which is the by-product from the quenching of volatile gas during the coking process. Coking is where coal undergoes destructive distillation. Coking tar is composed of the following various organic materials:

On a wet weight basis, 20% sludge can be mixed in with the pozzolanic material.\*

- A. Benzene
- B. Toluene
- C. Xylenes
- D. Cumenes
- E. Coumarone
- F. Indene Naphthalene
- G. Acenophthene
- H. Methylnaphthalenes
- I. Fluorene
- J. Phenol
- K. Cresol
- L. Pyridine
- M. Picolines
- N. Anthracene
- O. Carbazole
- P. Quinolines
- Q. Phenanthrene

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\* Care should be taken that the sludge containing greater than 8% by weight of any single organic compound listed may take longer than 28 days to reach the maximum strength developed in the pozzolanic reaction. A good example of this is the rule that when sugar is added to pozzolans or portland cement, the reaction is retarded, but the cementitious reaction does go to completion

## REFERENCES

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