

PDH NOW

Hazardous Waste Stabilization and Solidification

PDH: 3.0 Hours

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Hazardous Waste Stabilization and Solidification

1. Course Overview

This course is designed with the outlines of the definition of stabilization and solidification as the terms used in hazardous waste (HW) management and treatment, related regulations and applications of stabilization and solidification in managing HW, elaboration of different mechanisms that are used in HW stabilization and solidification, various technology using reagents to HW stabilization and solidification, discussions of the different types of testing that are used in HW stabilization and solidification to ensure that they meet the federal requirements. Finally, it entails the implementation of HW stabilization and solidification in the field as well as a system design showing stabilization flow-chart. This course is suggested for civil engineers, environmental engineers, hazardous waste regulators, and solid and hazardous waste landfill managers and operators.

2. Learning Objectives

After completing this course, the participants will be able to:

- explain the basics of HW stabilization and solidification.
- compare the cost of stabilization and solidification and disposal
- discuss and interpret different mechanisms of HW stabilization and solidification.
- list and interpret different technologies and reagents used for HW stabilization and solidification.
- elaborate the use of different EPA test methods for HW stabilization and solidification.

3. Introduction

Stabilization and solidification technologies are being applied to:

- a. The treatment of industrial wastes
- b. The treatment of waste prior to secure landfill disposal
- c. The treatment of contaminated land where large quantities of soil containing contaminants are encountered.

Stabilization and solidification are physicochemical processes.

3.1 Definition

Stabilization

- Stabilization is a process employing additives (reagents) to reduce the hazardous nature of a waste by converting the waste and its hazardous constituents into a form that minimizes the rate of contaminant migration into the environment or reduces the level of toxicity.

- Fixation is often used synonymously with stabilization. Stabilization is accomplished through the addition of reagents that:
 - Improve the handling and physical characteristics of waste
 - Decrease the surface area across which transfer, or loss of contaminants can occur
 - Limit the solubility of any pollutants contained in the waste
 - Reduce the toxicity of the contaminants

Solidification

- Solidification is described as a process by which enough quantities of solidifying material, including solids, are added to the hazardous materials to result in a solidified mass of materials. Solidifying the mass is accomplished through addition of reagents that:
 - increase the strength
 - decrease the compressibility, and
 - decrease the permeability of the waste.

Leaching

- Leaching is the process by which contaminants are transferred from a stabilized matrix to a liquid medium such as water.
- The potential contaminant loss from a stabilized mass is usually determined by leaching tests.

3.2 Regulations

- It has been recognized that the disposal of liquid wastes in landfills is an environmentally unsound practice.
- Liquid migrate downward through the landfill, contribute in the generation of leachate, and potentially migrate through defects in the liner system.
- As a consequence of high mobility of liquid hazardous wastes, their disposal in landfills has been prohibited in the United States by RCRA as amended by the HSWA of 1984.
- This ban has resulted increased use of stabilization in order to preclude disposal of liquid wastes.
- The U.S. regulations have thus brought into focus two distinctly different technological objectives for stabilization:
 1. stabilization of materials prior to land disposal
 2. the stabilization of contaminants to be left in place as part of a site cleanup.

3.3 Applications

The 3 major areas of application for stabilization technologies are:

- **Land disposal** – the stabilization of wastes prior to secure landfill disposal
- **Site remediation** – the remediation of contaminated sites

- **Solidification of industrial wastes** – the solidification of non-hazardous, unstable wastes, such as sludges.

Example 1: The total quantity of contaminated soils at a site is 150,000 tons. Evaluate the transportation cost of the landfill option versus the stabilization for the management of the hazardous waste at this site. Each truck can carry 35,500 pounds to nearest suitable landfill at a distance of 740 miles. The trucking cost is \$2.50/mile and the stabilization cost is \$62/ton. Identify the advantages and disadvantages of landfilling for this site.

Example 1: Solutions

$$\text{Stabilization cost} = 150,000 \text{ tons} \times \$62/\text{ton} = \$9,300,000$$

$$\text{Number of trucks} = \frac{150,000 \text{ tons} \times 2,000 \text{ pounds/ton}}{35,500 \text{ pounds/truck}} = 8451 \text{ trucks}$$

$$\begin{aligned} \text{Trucking cost} &= 8451 \text{ trucks} \times 740 \text{ miles/truck} \times \$2.50/\text{mile} \\ &= \$15,634,350 \end{aligned}$$

Stabilization is certainly more cost-effective as the difference in cost is more than \$6.33 million.

Advantages of landfilling: Landfilling may permit actual reclamation of the contaminated land at the site and eliminate one site from the national inventory of contaminated sites.

Disadvantages of landfilling: Valuable landfill space is being used by soils amenable to other treatment, precluding the use of that space by wastes better suited for landfilling.

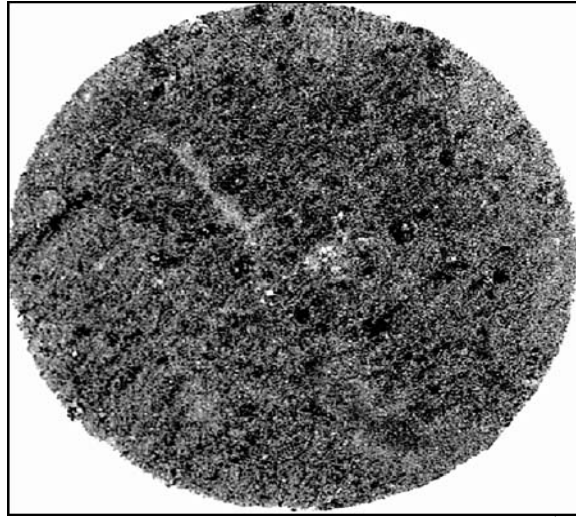
4. Mechanisms

There are six Mechanisms that are used in hazardous waste stabilization and solidification. The mechanisms are:

1. Macroencapsulation
2. Microencapsulation
3. Absorption
4. Adsorption
5. Precipitation
6. Detoxification

4.1 Macroencapsulation

Macroencapsulation is the mechanisms by which hazardous waste constituents are physically entrapped in a larger structural matrix; that is, the hazardous waste constituents are held in discontinuous pores within the stabilized materials. On physical degradation/breakdown of the stabilized material, even to relatively large particle size, the entrapped materials are free to migrate. The stabilized mass may breakdown over time (as measured on a geologic time scale) because of imposed stresses such as freezing and thawing.



Organic waste encapsulated in binder matrix¹

4.2 Microencapsulation

In **microencapsulation**, hazardous waste constituents are entrapped within the crystalline structure of the solidified matrix at a microscopic level. As a result, even if the stabilized materials degrade into relatively small particle sizes, most of the stabilized hazardous wastes remain entrapped.

4.3 Absorption

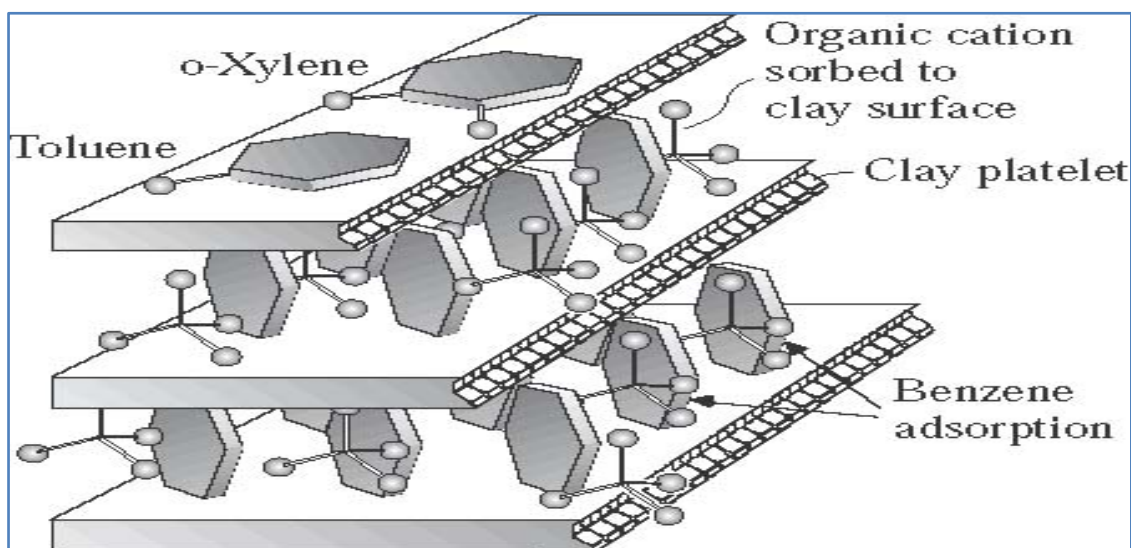
Absorption is the process by which contaminants are taken into the absorbent (solid material) in very much same way a sponge takes on water. As applied in stabilization, absorption requires the addition of solid material to soak up or absorb the free liquids in the waste. This process primarily is used to remove free liquid to improve the waste handling characteristics, i.e. to solidify the waste.

- **The most common absorbents include:**
 - Soil
 - Fly ash

- Cement kiln dust
- Lime kiln dust
- Clay minerals
- Sawdust
- Hay and straw

4.4 Adsorption

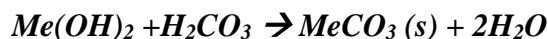
Adsorption is the phenomenon by which contaminants are electronically bonded to stabilized agents within the matrix. It is considered as a surface phenomenon and the nature of the bonding may be through van der Waal's or hydrogen bonding. Unlike macroencapsulation and microencapsulation, where simple particle breakdown may enhance the rate of contaminant migration, additional physicochemical stress is necessary to desorb the material from their adsorbing sites. As a result, the treatment is considered more permanent.



Organic waste adsorbed to an organophilic clay¹

4.5 Precipitation

Certain stabilization processes will precipitate contaminants, resulting in a more stable form of the constituents within the waste. The common precipitate forms are hydroxide, sulfides, silicates, and phosphates that are contained within the stabilized mass as a part of the material structure. This phenomenon is applicable to the stabilization of inorganic wastes such as metal hydroxide sludges.



where, *Me* = metallic cation

4.6 Detoxification

Certain chemical reactions taking place during the stabilization process may result in a waste with reduced toxicity. Detoxification is any mechanisms that changes a chemical constituent into another constituent that is either less toxic or nontoxic. For instance, reduction of **Cr (VI)** state to **Cr (III)** state during stabilization with cement-based materials. Trivalent chromium, **Cr (III)** has a lower solubility and toxicity than hexavalent chromium, **Cr (VI)**.

5. Technology Using Reagents

Stabilization technology can best be compartmentalized by a discussion of the various types of **additives** (reagents) and the corresponding technology used to stabilize the materials. The term **binder** is used to denote a reagent that contributes to the strength gain associated with stabilization. The term **sorbent** is used to denote a reagent that primarily contributes to retaining contaminants in the stabilized matrix.

- **Commonly used additives are:**
 - Cement
 - Pozzolans
 - Lime
 - Soluble Silicates
 - Organically Modified Clays
 - Modified Lime
 - Thermosetting Organic Polymers
 - Thermoplastic Materials
- **S/S (stabilization and solidification) Technology**
 - Vitrification

5.1 Cement

Stabilization of hazardous wastes are frequently done using cement as the principal reagent. The most common cement is Portland cement, which is made by firing a mixture of limestone and clay (or other silicate) in a kiln at high temperatures. The main constituents of Portland cement are tri- and dicalcium silicates. For cement-based stabilization, waste materials are mixed with cement followed by the addition of water for hydration, if necessary because the waste may not have enough water for hydration reaction. The hydration of cement forms a crystalline structure consisting of calcium aluminosilicate. This results in a rock-like, monolithic hardened mass.

5.2 Pozzolans

A pozzolan is a material that can react with lime in presence of water to produce a cementitious material. The reaction of aluminosilicious material, lime, and water results in the formation of a

concrete-like product termed as pozzolanic concrete. Pozzolanic materials include fly ash, ground blast furnace slag, and cement kiln dust. The resulting pozzolanic structures are termed as amorphous aluminosilicates. Like cement-based stabilization, most stabilization applications involving the pozzolans are for inorganic materials. The high pH environment is well suited for waste contaminated with heavy metals.

5.3 Lime

Stabilization of sludges is frequently accomplished through the addition of hydrated lime [calcium hydroxide, $\text{Ca}(\text{OH})_2$]. The resulting reaction with materials included in the waste may result in hydrates of calcium silicate, calcium alumina, or calcium aluminosilicates in the waste. These materials are formed from the reaction of calcium in the lime and aluminosilicates in the waste. Lime-based stabilization is typically best suited for inorganic contaminants and has been widely employed for metal sludges.

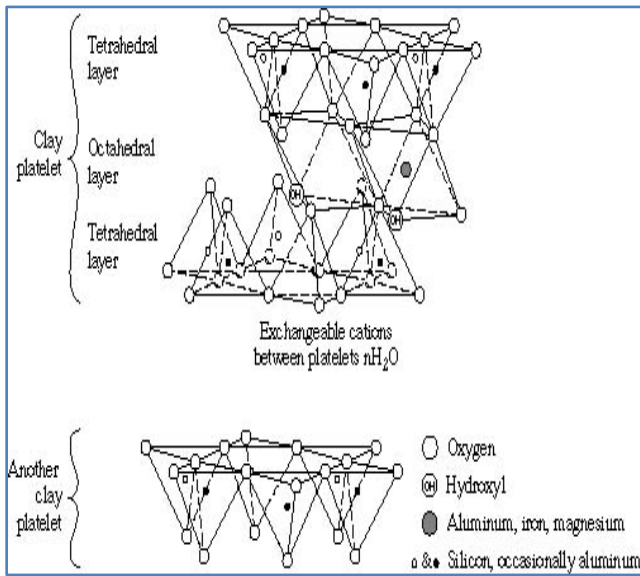
5.4 Soluble Silicate

There are two processes using soluble silicates:

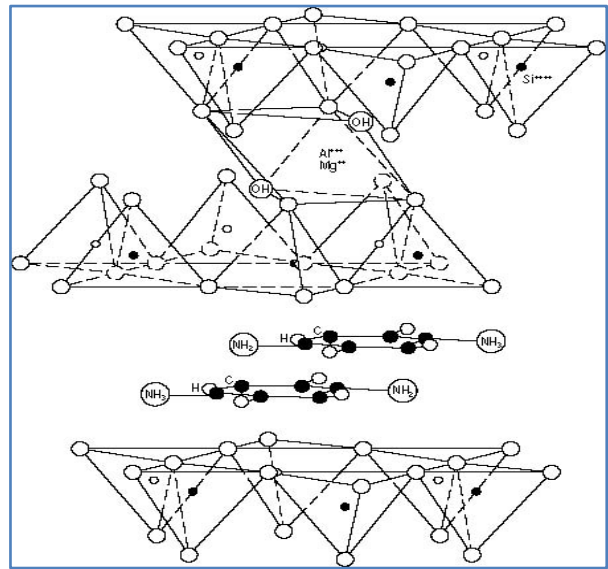
- In **one process**, silica reagents are acidified to form a monosilic acid solution to which metal-bearing wastes are added.
- In **another process**, a combination of liquid soluble silicates and cement form the basis of a process that has been demonstrated to be effective in stabilizing soils contaminated with concentrations of lead, copper, and zinc.

5.5 Organically Modified Clay

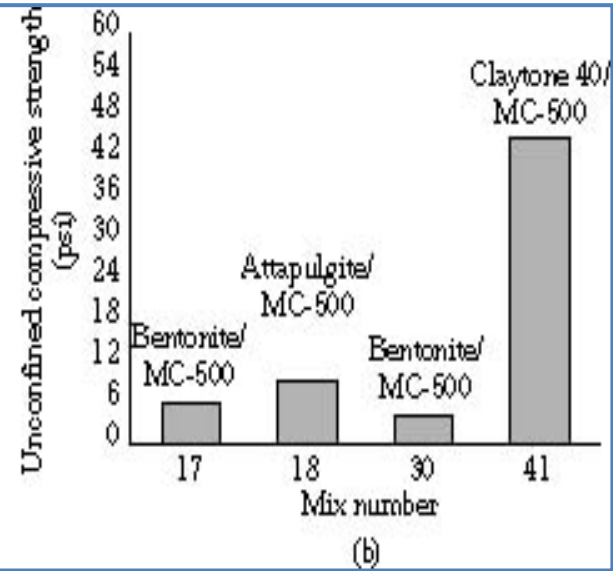
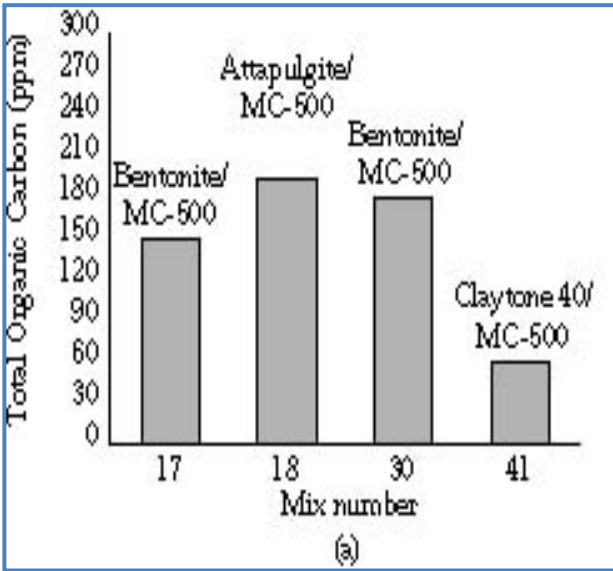
Organically modified clays in conjunction with other stabilization reagents have been used recently in order to entrap organic portion of the waste to be stabilized. Organically modified clays are produced when natural clays (usually organophobic nature) are organically modified to become organophilic. The modification process is accomplished through the replacement of inorganic cations within the clay crystalline mineralogical structures with organic cations, typically quaternary ammonium ions.



Montmorillonitic clay structure¹



Organically modified clay structure¹



Stabilization effectiveness of organically modified clay. Claytone 40 is an organically modified clay from Southern Clay Products Inc. Bentonite and attapulgite are processed, naturally occurring clays. Mix 30 has a larger bentonite content than mix 17¹.

5.6 Modified Lime

Organically modified lime products have been specifically developed for the stabilization of organic wastes. The lime-based process has been developed to convert toxic organic wastes with significant percentage of hydrocarbon to an inert mass. The process uses a calcium oxide-based reagent modified with stearic acid. Heat and water-as-steam are given off during the reaction. The waste is converted to a dry water-repelled (hydrophobic) powder. The material becomes quite strong and relatively impermeable to water. The resulting material is considered suitable as a construction material for road and embankment fill.

5.7 Thermosetting Organic Polymers

This process involves mixing a monomer, such as urea-formaldehyde, that acts as a catalyst to form a polymeric material. A sponge-like mass is formed, trapping solid particles of hazardous waste within the matrix (microencapsulation). Liquid wastes may be left untrapped by this method. The main advantage of this process is that it generally results in low-density material relative to other fixation process. Also, only small quantities of additives are required to solidify wastes.

5.8 Thermoplastic Materials

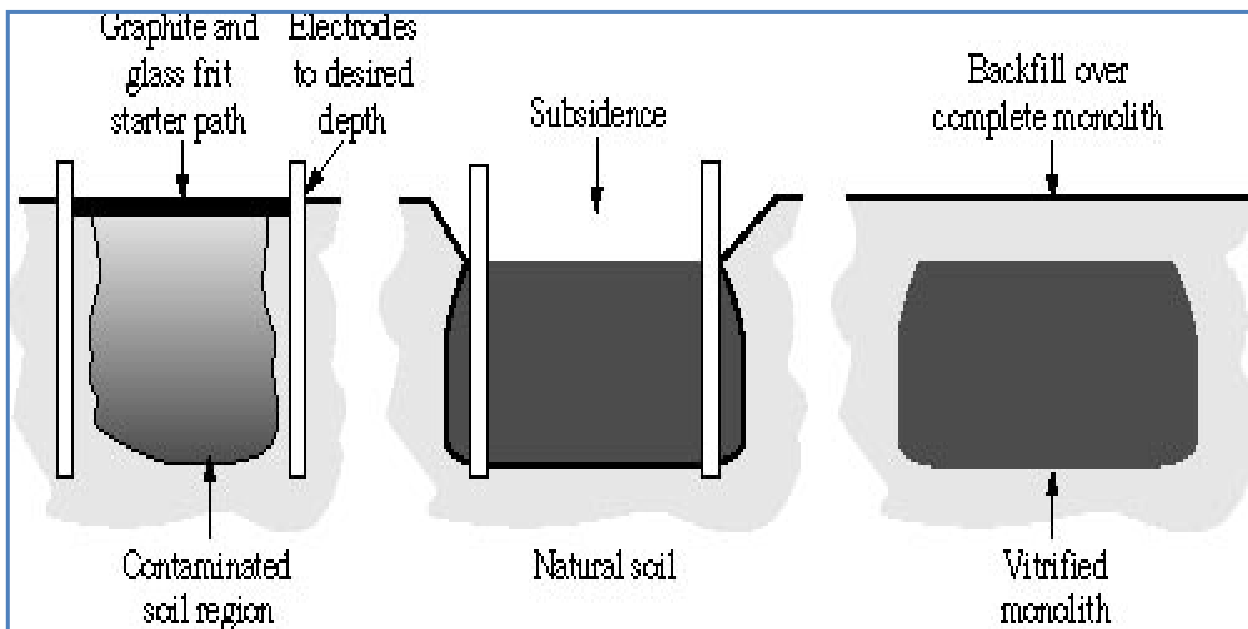
Hazardous waste may be stabilized by blending molten thermoplastic materials with waste at high temperatures. Molten thermoplastic materials include asphalt, paraffin, bitumen, polyethylene, polypropylene, and sulfur. When cooled, the solidified material is characterized as a thermoplastically coated waste and typically containerized (in drum) for ultimate disposal.

5.9 Vitrification

Vitrification involves melting and fusion of materials at temperatures normally in excess of 1,600°C followed by a rapid cooling into a monocrystalline, amorphous form. Vitrification to the management of hazardous wastes has been explored as both an in-situ and an in-plant technique.

5.9.1 In-Situ Vitrification

In the in-situ process, the high temperatures needed to melt the soil into a molten mass are achieved through the application of an electric current. As current flows through soil, heat builds up, eventually causing the soil to melt. On molten, soil becomes more conductive and molten mass becomes a heat transfer medium, allowing the molten mass to grow. The soil is melted at a rate of **3 to 6** tons per hour, giving a rate of melt advance of **1 to 2** inches per hour.



*In situ vitrification*¹

5.9.2 In-Plant Vitrification

This technology has the potential both to treat hazardous waste, particularly contaminated soil, and to produce a product that may be useable (e.g., for road aggregate). This technology uses a glassmaking furnace at 1,600°C. A starter mix of recycled glass, fly ash, and limestone is used to initiate the process. The contaminated soil is then introduced into the furnace for the melting and fusion stages that last a minimum of 5 hours. Air emission and leaching of the residue (glass) need to be considered. Air emission can be captured and treated as necessary for environmental protection by traditional air treatment technologies including ammonia for NO_x, lime for SO_x, and condensation of volatiles in a fractionating pebble bed.

Seiler Pollution Control System has constructed a high temperature vitrification plant designed to recycle hazardous waste into a nonhazardous glass/ceramic product.

6. Testing

In order to determine the effectiveness of the stabilization and solidification (S/S) process **Extraction and Leaching Tests** are performed. The fluid to which the contaminants are leached is called **leachant**. The terms **extraction** and **leaching** are used interchangeably and are, the process by which contaminants are transferred from a solid or stabilized matrix to the leachant. The overall ability of a stabilized material to leach contaminants is termed as **leachability**.

There are number of variables that affect the contaminant concentrations in the leachant:

- Leachant-to-waste ratio
- Surface area of the waste
- Type of leachant
- pH of the leachant
- Contact time
- Extent of agitation
- Number of replacements of fresh leachant
- Extraction vessel
- Temperature

6.1 Extraction and Leaching Tests

- Paint Filter Test
- Liquid Release Test
- Extraction Procedure Toxicity Test (EPTox)
- **Toxicity Characteristics Leaching Procedure (TCLP)**
- American Nuclear Society Leach Test (ANS 16.1)
- Equilibrium Leach Test
- Dynamic Leach Test
- Sequential Leach Test (Sequential Chemical Extraction)
- Multiple Extraction Procedure
- Chemical Test
- Physical and Engineering Property Test

6.1.1 Paint Filter Test

- This test evaluates the absence or presence of liquids in bulk and containerized hazardous waste.
- This test is rapid, economical, easy to conduct, and easy to evaluate.
- In this test, wastes are placed in standard paint filter (**Mesh # 60 ± 5%; \cong 0.25mm**); if liquid is drained by gravity, through the filter **within 5 minutes**, the hazardous waste is considered to contain free liquids and must be treated prior to landfilling.

6.1.2 Liquid Release Test

- The liquid release test determines if a solidified liquid waste is suitable for landfilling.
- The procedures were developed to preclude the use of sorbents such as **sawdust** to “solidify” liquid wastes.
- In this test, a “consolidation” stress is applied to test how readily leachate can be squeezed from a solidified mass.

6.1.3 Extraction Procedure Toxicity Test (EPTox)

- The EP toxicity test, an older regulatory test now phased out as the method to classify wastes by toxicity in the United States, can be used to generate a liquid extract from solid phase.
- A waste is considered EP toxic if its extract has concentrations of any of the eight metals and six pesticides that are greater than the “standards” previously specified in the federal regulations.
- In this test, the solidified monolithic block is crushed to pass a **9.5-mm** sieve.
- A **0.04 M** acetic acid (**pH = 5.0**) leaching solution is used at a liquid-to-solid ratio of **16:1**.
- The extraction takes place over a period of **24** hours with agitation.
- The **liquid extract** is analyzed for specific chemical constituents.

6.1.4 Toxicity Characteristics Leaching Procedure (TCLP)

- The **TCLP** was adopted by EPA on November 7, 1986 under **HSWA 1984** as a regulatory test to replace EPTox Test.
- The **TCLP** is widely used to evaluate the effectiveness of stabilization and later (1990) replaced the **EPTox** test for classification of materials as hazardous or nonhazardous.
- In this test, the stabilized material is crushed to a particle size less than **9.5 mm**.
- The extraction fluid is made with water and acetic acid to a pH of **2.88 ± 0.05** , selected to mimic conditions in a municipal landfill.
- The crushed material is mixed with a weak acetic acid extraction liquid, in a liquid-to-solid ratio of **20:1 by weight**, agitated in a rotary extractor for a period of **18** hours at **30 rpm** and **22°C**.
- After **18** hours of agitation, the sample is filtered through a **0.6 to 0.8 μm** glass fiber filter, and the filtrate is defined as **TCLP extract**. This TCLP extracts is analyzed for a wide variety of hazardous waste constituents including VOC and SVOCs, metals, and pesticide as shown in the Table.
- The results of the extract analysis are compared with the regulatory levels shown in the Table to determine the nonhazardous classification.

TCLP regulatory levels.

Waste Code	Contaminant	Concentration (mg/L)	Waste Code	Contaminant	Concentration (mg/L)
D004	Arsenic	5.0	D032	Hexachlorobenzene	0.1
D005	Barium	100.0	D033	Hexachlorobutadiene	0.5
D018	Benzene	0.5	D034	Hexachloroethane	3.0
D006	Cadmium	1.0	D008	Lead	5.0
D019	Carbon tetrachloride	0.5	D013	Lindane	0.4
D020	Chlordane	0.03	D009	Mercury	0.2
D021	Chlorobenzene	100.0	D014	Methoxychlor	10.0
D022	Chloroform	6.0	D035	Methyl ethyl ketone	200.0
D007	Chromium	5.0	D036	Nitrobenzene	2.0
D023	o-Cresol	200.0	D037	Pentachlorophenol	100.0
D024	m-Cresol	200.0	D038	Pyridine	5.0
D025	p-Cresol	200.0	D010	Selenium	1.0
D026	Total Cresols	200.0	D011	Silver	5.0
D016	2,4-D	10.0	D039	Tetrachloroethylene	0.7
D027	1,4-Dichlorobenzene	7.5	D015	Toxaphene	0.5
D028	1,2-Dichloroethane	0.5	D040	Trichloroethylene	0.5
D029	1,1-Dichloroethylene	0.7	D041	2,4,5-Trichlorophenol	400.0
D030	2,4-Dinitrotoluene	0.13	D042	2,4,6-Trichlorophenol	2.0
D012	Endrin	0.02	D017	2,4,5-TP (Silvex)	1.0
D031	Heptachlor (and its epoxide)	0.008	D043	Vinyl Chloride	0.2

6.1.5 Synthetic Precipitation Leaching Procedure (SPLP)

- Pretty much same as **TCLP**, but the extraction fluid is made 60/40 mix of **H₂SO₄** and **HNO₃** mixed with water to a pH of **5.0 ± 0.05**.
- As in the **TCLP**, the liquid-to-solid ratio is **20:1 by weight**, and the particle size must be less than **9.5 mm**.
- It is believed that the **SPLP** is better suited than **TCLP** to evaluate the effectiveness of in-situ stabilization, as the extraction fluid is more realistic than acetic acid fluid used in the **TCLP**.

6.1.6 American Nuclear Society Leach Test (ANS 16.1)

- The **ANS 16.1** test, also called the **uniform leach test** (similar to International Atomic Energy Agency standard leach test), was developed to determine the leachability of solidified radioactive wastes.
- In this test, a solidified test specimen is rinsed in a leaching medium of aerated demineralized water. Following the **30-second rinse**, the specimen is left unagitated in a nonreactive container (usually glass) for specific time intervals.
- The leaching medium is removed and replaced at various time intervals throughout the **14-day** test period.

- The test yields a number termed **leachability index** that can be related to the diffusion coefficient.

ANS 16.1 Leachability Index Comparison

Species	ANS 16.1 Minimum	ANS 16.1 Maximum	Applied Innovations ANS 16.1
Ni	8	13	21
Cs	7	13	15
U	22	22	22
Tc	10	11	15

6.1.7 Equilibrium Leach Test

- The equilibrium leach test is a batch extraction process that utilizes distilled water as the extraction fluid.
- In this test, a dried sample, grounded to pass through **ASTM Sieve No. 100 (≅ 0.15 mm)**, is mixed with distilled water at **4:1, liquid-to-solid ratio by mass**.
- The mixer is agitated for **7 days**, and filtered extract is analyzed for total dissolved solids (**TDS**).
- Specified chemical analyses are also performed on the filtered extract.

6.1.8 Dynamic Leach Test

- The dynamic leach test, adopted from **ANS 16.1**, is a true leaching test used to determine the mobility of contaminants through a material matrix, by measuring the rate of leachability.
- In this test, a monolithic solidified specimen is immersed in distilled water at a specific volume-to-surface area ratio.
- The specimen is placed in a nylon mesh harness, rinsed, and suspended in containers filled with distilled water.

- Fresh leaching agents are used after certain liquid-solid contact times have elapsed, and the solid and leachate are separated.
- Over a period of **9** days, the leachant is renewed at intervals calculated according to diffuser model.
- The sample may be analyzed for organics and/or inorganics, and the **pH** of the leachant is measured after each transfer.
- The amount leached in each interval, relative to the total amount of contaminant initially present, is determined, and an apparent diffusion coefficient can be calculated.
- With this type of data available, time related behavior, or diffusive transport, can be evaluated and used for the long-term prediction of leaching rate.

6.1.9 Sequential Leach Test (Sequential Chemical Extraction)

- This test attempts to evaluate the leachability of metals from a solid matrix.
- Five successive chemical extractions of inorganics of increasing aggressive (pH varying from **7** to very acidic) are performed to separate the contaminants into five fractions:
 - Ion exchange fraction
 - The surface oxide and carbonate bound metal ions
 - Metal ions bound to iron and manganese oxides
 - Metal ions bound to organic matter and sulfides
 - The residual metal ions
- The first **3 fractions** are classified as being “available for short- and medium-term leaching” and the last **2 fractions** are “unavailable for leaching”.
- In this test, a sample is dried in an oven at 60°C and ground to pass an ASTM No. 325 sieve (**45-µm** opening size).
- A **0.5** gm sample is placed in a polysulfone centrifuge tube and subjected to a series of five successive extraction procedures, each suitable for extracting specific fraction of the metals.
- In each separate extraction, the specific extraction fluid is added, and the mixture is agitated and/or heated for specific time period before being centrifuged to separate the solid and liquid portions.
- Chemical analyses are performed on the liquid portion, the solid portion is rinsed with distilled water, centrifuged, and isolated for use in the next extraction procedure.

6.1.10 Multiple Extraction Procedure

- The multiple extraction procedure provides data on the rate of leachability, as does the dynamic leach test.
- The test attempts to duplicate leaching conditions that a waste would be subjected to form repetitive contact with acid rain at an improperly designed sanitary landfill.
- In this test, the solidified monolithic block is crushed to pass a **9.5-mm** sieve.
- A **0.04 M** acetic acid (**pH = 5.0**) leaching solution is used a liquid-to-solid ratio of **16:1**.

- The extraction takes place over a period of **24** hours with agitation and the liquid extract is analyzed for specific chemical constituents.
- The remaining solid portion is re-extracted nine additional times with a synthetic acid rain extraction fluid, consisting of a **60/40** mixture of **H₂SO₄** and **HNO₃** with a pH of **3.0**.
- Each time, the mixture is agitated for **24 hours** and separated, and the extract is analyzed.
- If the contaminant concentrations in the extracts have increased over the 7th and 8th extractions, the extractions are continued, past the 9 repetition, until the concentrations in extract do not increase.

6.1.11 Chemical Test


The following are the chemical tests that are performed for hazardous wastes:

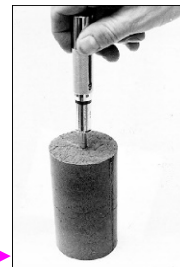
- Total waste analysis
 - ✓ Metals by inductively coupled plasma spectrometry or atomic absorption. Organics by gas chromatography (GC) and mass spectrometry (MS).
- Total organic carbon (TOC)
- Loss of ignition
- pH
- Fourier transform infrared spectra (FTIR)
- Differential scanning calorimetry and thermal gravimetric analysis

6.1.12 Physical and Engineering Property Test

- The following are the physical and engineering properties are tested for hazardous wastes:

- ***Physical properties***

- ✓ Moisture content
- ✓ Wet and dry bulk density
- ✓ Specific gravity
- ✓ Particle size distribution
- ✓ Pocket penetrometer 
- ✓ Microstructural examination by x-ray refraction, optical microscopy, and scanning electron microscopy (SEM)
- ✓ Supernatant formation during curing
- ✓ Rate of setting



- ***Engineering properties***

- ✓ Strength
- ✓ Compressibility (consolidation)
- ✓ Hydraulic conductivity

- **Durability properties**
 - ✓ Wet/dry
 - ✓ Freeze/thaw

7. Field Implementation

There are 3 alternative methods for implementing stabilization technologies in the field. These are:

- In-Drum Mixing Alternatives
- In-Situ Mixing Alternatives
- Plant Mixing Alternatives

7.1 In-Drum Mixing Alternatives

- In this mixing method, the hazardous waste and the reagents are mixed in drum.
- The mixing can be performed remotely by robots.
- After the mixing and stabilization, the drums are sent to the landfill for final disposal.

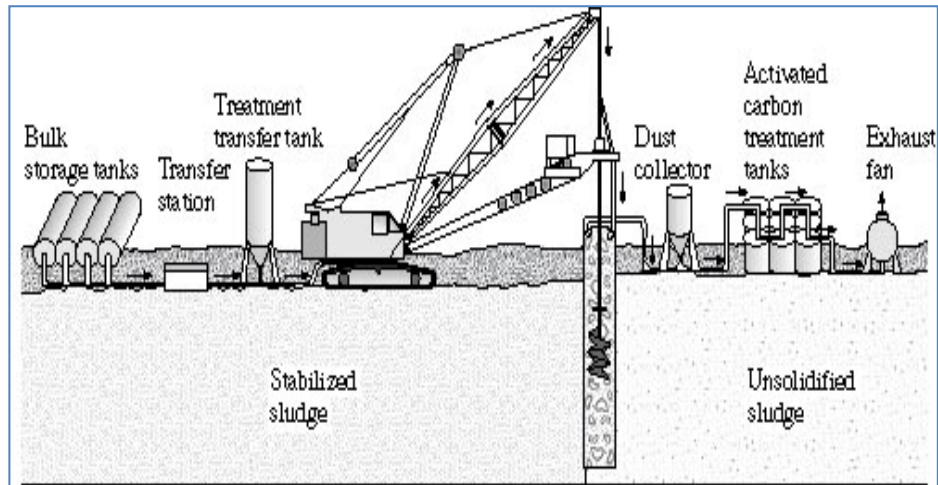
7.2 In-Situ Mixing Alternatives

- In-situ mixing frequently uses commonly available construction equipment to accomplish the mixing process.



In situ mixing process with modified augers¹

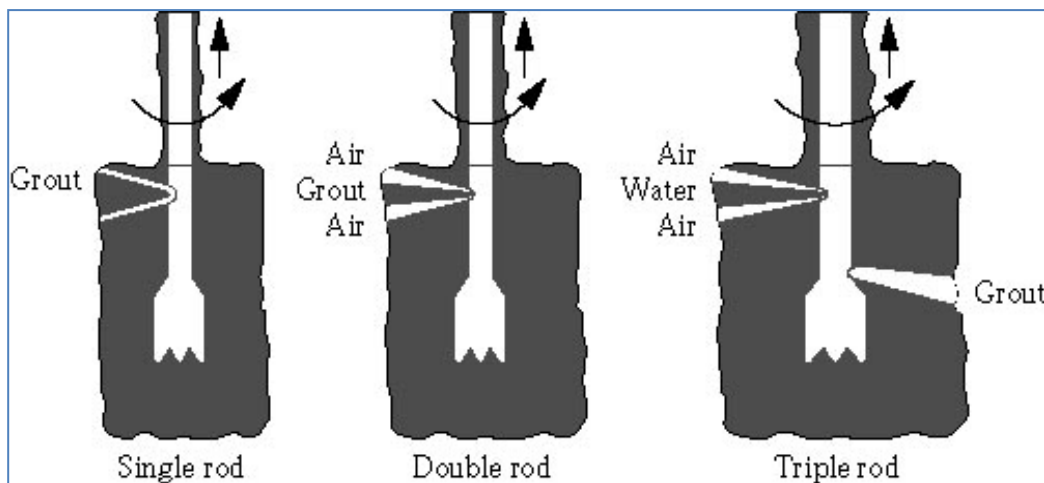
- **In-Situ Mixing Alternatives**



Schematic of an *in-situ* mixing process with modified augers¹

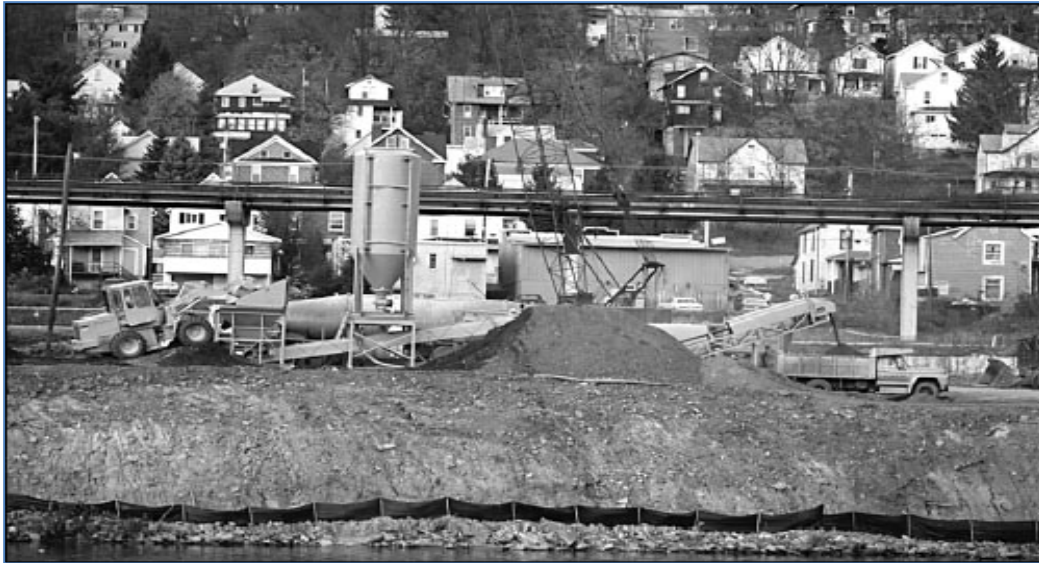
7.3 Plant Mixing Alternatives

- Mechanical mixers are used to blend reagents and the waste either in batch or continuous process.



Typical jet grouting systems¹

- **Plant Mixing Alternatives**

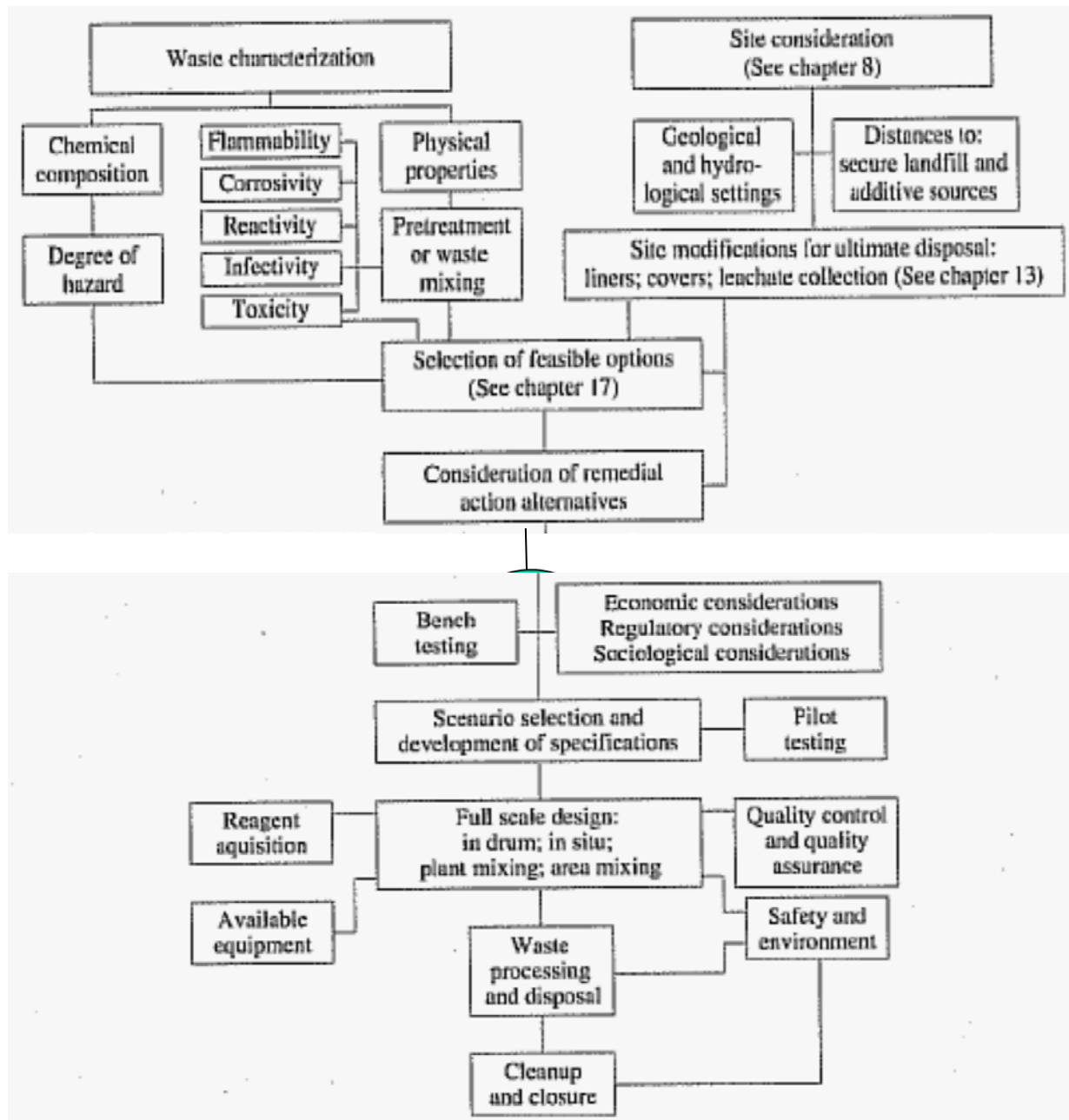


Remote process batch mixing¹

8. System Design

Characterization of both the waste and the site is necessary for the selection and design of a stabilization process. A full-scale field demonstration (**50 to 100 m³**) should be a critical part of the design process for a treatability study. In addition to the mechanisms of stabilization process, the following factors need to be considered:

- Curing time – field and laboratory
- Volume increase/decrease
- Cost – ingredients, labor, and equipment
- Schedule – project duration, weather restrictions
- Type of mixing – batch or continuous
- Heat generation – heat of hydration and other chemical reactions
- Gas generation – loss of volatiles, material porosity, possible toxicity
- Mixing time – field and laboratory, maximum and minimum
- Other restrictions – flash point, explosion potential, fire potential
- Handling characteristics – waste and reagents



Flowchart for stabilization process design

9. Summary

In this course we have defined hazardous waste and several terms and abbreviations related to hazardous waste management, waste management act and provisions/subtitles. We took a look at the evolution of RCRA legislation, components of RCRA, RCRA and its interrelationship to other environmental statutes such as Subtitles C, D, and I. We learned as to how we can identify

hazardous waste, what are the hazardous waste exclusions and exemptions. We also discussed two types of hazardous waste: listed and characteristic hazardous wastes, mixture rule, hazardous waste recycling and universal wastes, hazardous waste generators and transporters, hazardous waste treatment, storage, and disposal facilities (TSDFs), land disposal restrictions, combustion, and permitting for TSDFs. Finally we learned about Part **A** (siting) and Part **B** (detailed design) permitting application submission requirements and **Special Forms of Permits** such as Permit-by-Rule (PBR); Emergency Permits; Research, Development, and Demonstration (RD&D) Permits; Land Treatment Demonstration Permits; Combustion Permits; Post-Closure Permits; and Remedial Action Plans.

10. References

1. Hazardous Waste Management, Michael D. LaGrega, Phillip L. Buckingham, Jeffery C. Evans, and Environmental Resources Management, McGraw-Hill Book Company.
2. Open source from internet (USEPA website)
3. Personal work experiences

+++++ **The End** +++++

Any questions please contact the instructor at makarim@juno.com

Quiz for Hazardous Waste Stabilization and Solidification

1. Hazardous waste stabilization is a process employing additives (reagents) to reduce the hazardous nature of a waste by converting the waste and its hazardous constituents into a form that minimizes the rate of contaminant migration into the environment or reduces the level of toxicity.
 - a. True
 - b. False

2. Solidifying the mass is accomplished through addition of reagents that:
 - a. increase the strength
 - b. decrease the compressibility
 - c. decrease the permeability of the waste
 - d. all of the above
 - e. none of the above

3. Leaching is the process by which contaminants are transferred from a stabilized matrix to a liquid medium such as water.
 - a. True
 - b. False

4. The potential contaminant loss from a stabilized mass is usually determined by _____.
 - a. Toxicity tests
 - b. Leaching tests
 - c. Permeability tests
 - d. All of the above
 - e. None of the above

5. The U.S. regulations have brought into focus two distinctly different technological objectives for stabilization and these are:
 - a. stabilization of materials prior to land disposal
 - b. the stabilization of contaminants to be left in place as part of a site cleanup
 - c. all of the above
 - d. none of the above

6. The 3 major areas of application for stabilization technologies are: **Land disposal** – the stabilization of wastes prior to secure landfill disposal; **Site remediation** – the remediation of contaminated sites; and **Solidification of industrial wastes** – the solidification of non-hazardous, unstable wastes, such as sludges.
 - a. True
 - b. False

7. There are _____ mechanisms for stabilization.

- a. 2
- b. 6
- c. 8
- d. 10

8. Macroencapsulation is the mechanisms by which hazardous waste constituents are physically entrapped in a larger structural matrix; that is, the hazardous waste constituents are held in discontinuous pores within the stabilized materials.

- a. True
- b. False

9. Absorption is the process by which contaminants are taken into the absorbent (solid material) in very much same way a sponge takes on water. This process primarily is used to remove free solid to improve the waste handling characteristics, i.e. to solidify the waste.

- a. True
- b. False

10. Adsorption is the phenomenon by which contaminants are electronically bonded to stabilized agents within the matrix. It is considered as a surface phenomenon and the nature of the bonding may be through van der Waal's force or hydrogen bonding.

- a. True
- b. False

11. Detoxification is one of the stabilization mechanisms that changes a chemical constituent into another constituent that is either more toxic or acutely toxic.

- a. True
- b. False

12. The term **sorbent** is used to denote a reagent that primarily contributes to retaining contaminants in the stabilized matrix.

- a. True
- b. False

13. Which one of the followings is NOT an additive that is used in hazardous waste stabilization

- a. Pozzolans
- b. Soluble Silicates
- c. Sodium chloride slat
- d. Organically Modified Clays
- e. Modified Lime

14. Stabilizations of hazardous wastes are frequently done using cement as the principal reagent.

- a. True
- b. False

15. Pozzolanic materials include fly ash, ground blast furnace slag, and cement kiln dust.
- True
 - False
16. Lime-based stabilization is typically best suited for _____ contaminants and has been widely employed for metal sludges.
- organic
 - inorganic
 - all of the above
 - none of the above
17. Hazardous waste may be stabilized by blending molten thermoplastic materials with waste at high temperatures. Molten thermoplastic materials include asphalt, paraffin, bitumen, polyethylene, polypropylene, and sulfur.
- True
 - False
18. Vitrification involves melting and fusion of materials at temperatures normally in excess of _____ followed by a rapid cooling into a monocrystalline, amorphous form. Vitrification to the management of hazardous wastes has been explored as both an in-situ and an in-plant technique.
- 1,200°C
 - 1,600°C
 - 2,000°C
 - 2,500°C
19. The fluid to which the contaminants are leached is called _____.
- leachate
 - leaching
 - leachant
 - leach
20. The overall ability of a stabilized material to leach contaminants is termed as _____.
- treatability
 - leachability
 - leaking
 - flowability
21. What does TCLP stand for?
- Toxicity Characteristics Leaching Program
 - Toxicity Characteristics Leaching Procedure
 - Total Characteristics Leaching Procedure
 - Total Characteristics Liability Procedure

22. In this test, wastes are placed in standard paint filter (**Mesh # 60 ± 5%; ≅ 0.25mm**); if liquid is drained by gravity, through the filter **within 5 minutes**, the hazardous waste is considered to contain free liquids and must be treated prior to landfilling.

- a. Paint Filter Test
- b. Liquid Release Test
- c. Extraction Procedure Toxicity Test
- d. Equilibrium Leach Test

23. In TCLP test, the crushed material is mixed with a weak acetic acid extraction liquid, in a liquid-to-solid ratio of _____ by weight, agitated in a rotary extractor for a period of 18 hours at 30 rpm and 22°C.

- a. 10:1
- b. 20:1
- c. 30:1
- d. 40:1

24. There are 3 alternative methods for implementing stabilization technologies in the field and these are:

- a. In-Drum Mixing Alternatives
- b. In-Situ Mixing Alternatives
- c. Plant Mixing Alternatives
- d. All of the above
- e. None of the above

25. The 3 engineering properties that are tested for hazardous wastes are:

- a. Strength
- b. Compressibility (consolidation)
- c. Hydraulic conductivity
- d. All of the above
- e. None of the above

26. A particular waste is considered EP toxic if its extract has concentrations of any of the _____ metals and _____ pesticides that are greater than the “**standards**” previously specified in the federal regulations.

- a. 4; 3
- b. 8; 6
- a. 10; 8
- a. 6; 8

27. A _____ is a material that can react with lime in presence of water to produce a cementitious material. The reaction of aluminosilicious material, lime, and water results in the formation of a concrete-like product termed as pozzolanic concrete.

- a. pozzolan
- b. cement
- c. lime
- d. silicate

28. _____ is considered as a surface phenomenon and the nature of the bonding may be through van der Waal's or hydrogen bonding.

- a. Adsorption
- b. Absorption
- c. Physical
- d. Chemical

29. Stabilization and solidification are _____ processes.

- a. physicochemical
- b. adsorption
- c. absorption
- d. chemical