

Simplified soil washing processes for a variety of soils

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Abstract

A soil washing process is described in which high shear mixing, sprays, hydrosizing, flotation, and screening are integrated to countercurrently clean sand, silt and clay. Chemical techniques are summarized that can be used to remove selected contaminants from the soil and then clean the wash water for reuse. Descriptions of simple and complex processes, and a recent project are used to illustrate the points: (1) Soil washing is not a single process, but a collection of unit operations assembled for each project; (2) all process must be coordinated for the project to be successful; and (3) combining techniques in a few pieces of equipment debottlenecks soil washing. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Soil washing; Processes; Simplified

1. The soil washing process

Soil washing processes are described in numerous papers and a recent book [1]. The evolution and use of this company's process is described in four papers [2–5]. The purposes of the present paper are to expand on these earlier publications by (1) promoting the concept that soil washing is not one process, but a combination of techniques that clean the soil and (2) providing examples of treatments for a limited number of problems. Fig. 1 illustrates modules in soil washing process. Discrete groups of equipment include the following.

(1) The soil preparation module for removal and cleaning of oversize material and debris.

(2) A soil washing module to remove the contaminants. The washing module can be subdivided further into equipment for washing sand and fines (generally < 200-mesh,

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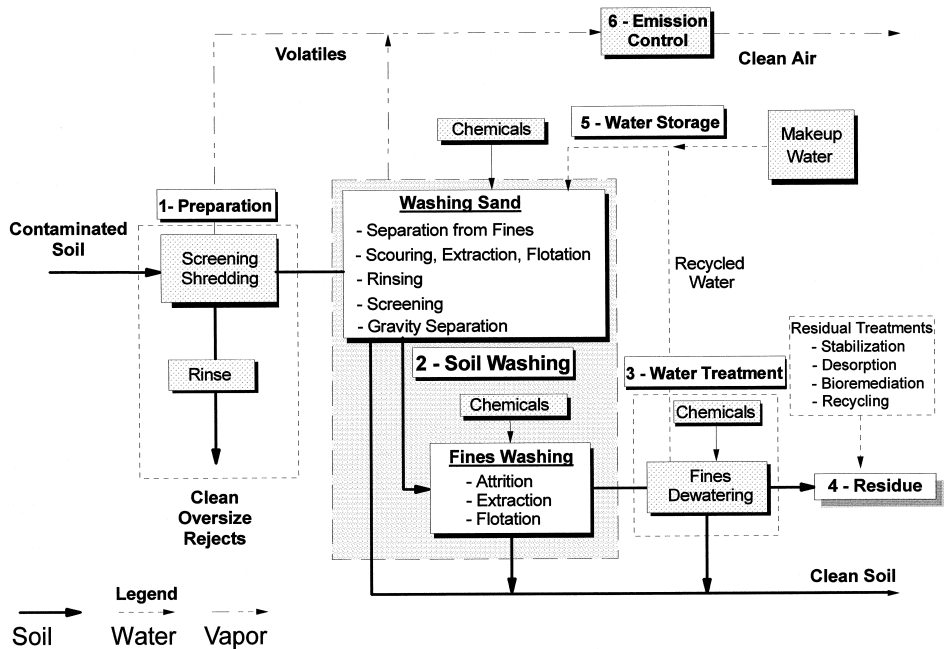


Fig. 1. Flow chart for generic soil washing process.

74- μms). This division has developed [1] because lower surface area, larger sand grains are easier to process than the fines fraction, which has one to three orders of magnitude larger surface area than the > 200 mesh sand. If the fines are contaminated, they can be more difficult to clean.

(3) The wastewater treatment module in which the dispersed soil and contaminant are removed from the water.

(4) A residual management module. Soil washing either removes the contaminant from the soil or concentrates contaminants in the fines. Thus, the contaminated material must either be recycled, desorbed, bioremediated or stabilized for landfilling.

(5) A volatile emissions control module.

(6) The wash water storage and management module. Some processes recycle more than a million gallons of water per day. The water can be heated and fresh makeup water must be added, since the washed soil contains more water than the feed soil.

The overall soil washing process can be simple or sophisticated, but it must be well thought out in order to combine high productivity with low processing and capital or equipment rental costs.

1.1. The soil washing module

The soil washing described here begins by first breaking up the soil in an attrition scrubber and separating the sand in sandscrews that combine countercurrent spray washing of the soil with hydrosizing and flotation to remove fines and contaminants

from a soil slurry. This minimizes the volume of water that must be managed. Then, countercurrent hydrosizing and flotation are used to clean the 20- to 70- μm fraction. Finally, countercurrent washing can sometimes be used to extract metals or light hydrocarbons from the sub-20- μm ‘clay’ fraction.

A drawing of such a process is presented in Fig. 2. This process differs from those offered by many companies in that the equipment is modified sand washing equipment rather than equipment designed for the mining industry. Because of its origins, this process is very mobile, uses much less water and power, is more adaptable to different conditions, and is more tolerant of debris found in surface soil than mining equipment designed to process crushed ore. While mining equipment does an excellent job in its industry, each component is focused towards a specific task which it faithfully executes at fixed sites for years. However, soil washing processes are mobile and operate for two to three months at a time with limited support facilities. Thus, the ideal soil washing process is one which minimizes capital, setup time, training of crews, and the number of unit operations.

1.1.1. Sand washing

The practice of using sandscrews for removal of undesirable materials was developed in the sand/gravel industry and in grinding loops in the mining industry. These sandscrews separate lighter material from a coarser or denser fraction that has a higher settling velocity. In this process, the soil matrix is initially torn apart in an attrition scrubber, reducing the viscosity of the slurry, so that the sand settles quickly.

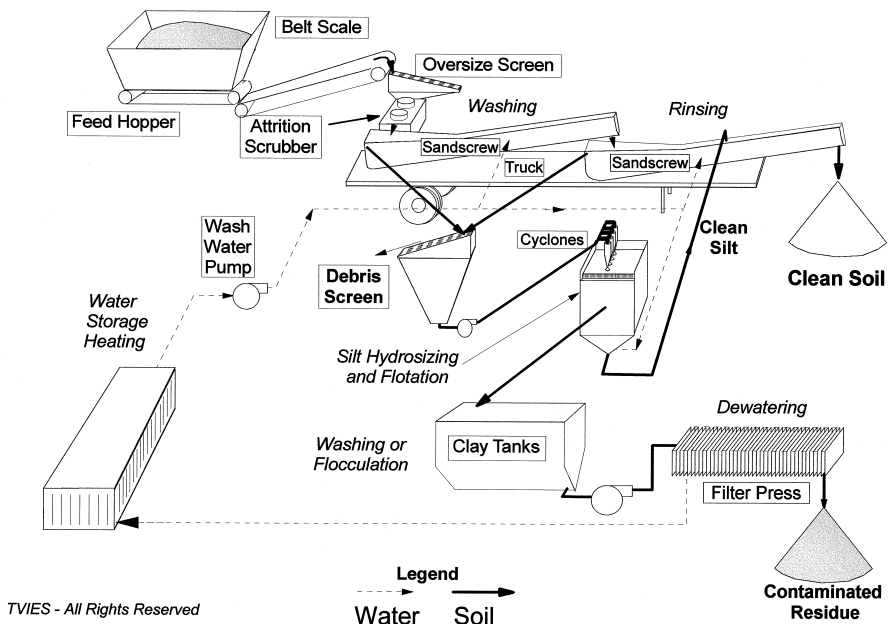
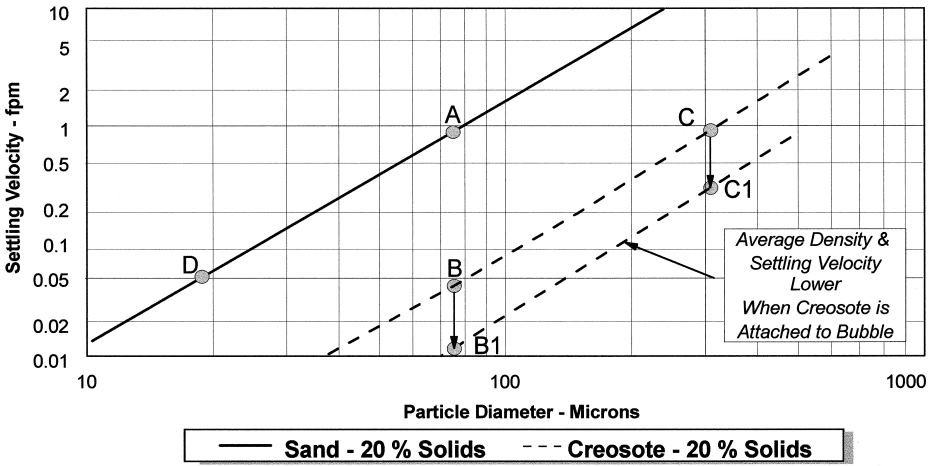


Fig. 2. Generic TVIES soil washing process.



- 1) 200 Mesh Creosote and Sand (pt. A & pt. B) Can Be Separated by Hydrosizing in Water Since Settling Velocities Differ
- 2) Larger Creosote (pt. C or pt. B) Settles at Same Rate as Smaller Sand (pt. A or pt. D)
 - Unless it is Attached to and Floated by an Air Bubble, (pt. C1 or pt. B1)

Fig. 3. Hindered settling velocity for sand grains and creosote particles.

Fig. 3 summarizes the hindered settling velocity calculated for 20% slurries [6] of sand, silt and dried creosote. The figure shows that the settling velocity of 75- μm (200 mesh) sand (point A) is 0.79 ft/min (fpm), while the settling velocity of 75- μm creosote particles (point B) is 0.042 fpm. The settling velocity of a 75- μm sand grain is the same as that of a 295- μm creosote particle (point C). This means that equal size creosote and sand grains can be segregated by gravity in a pool of moving or rising water. The lighter particle will be carried away by water while the heavier particle remains. Air bubbles increase the volume of larger creosote particles (point C1) that would settle without air at the same rate as smaller sand grains, thereby facilitating their removal.

Thus, a sandscrew that includes a hydrosizing/flotation pool can separate > 200-mesh sand from fine sand, silt, clay and creosote particles or contaminated woody debris as long as enough water is used to maintain a dilute slurry. The water in the equipment described here for soil washing comes from three sources: (1) dilution water mixed with the soil in an attrition scrubber preceding the sandscrew, (2) hydrosizing water added to the pool of the sandscrew, and (3) wash water from spray jets that countercurrently flush contaminants from the soil. Combing high shear mixing, hydrosizing, flotation and sprays removes 80 to 90% of the contamination from the sand in a single step.

1.1.2. Screening

Selective use of screens to remove trash or floatable debris is also important. For instance, fine mesh screens in Fig. 2 are used to remove floating debris between the sandscrew and hydrosizer. In addition, profile wire screens are useful to remove 30- to

50- μm debris from the overflow of the hydrosizer/flotation cells before it can be concentrated in the fines. The most important design criteria for screens is that they be very durable, since the cost of replacing screens can be one of the largest costs in a project.

1.1.3. Silt washing

Silt, clay, and debris flowing over the weirs of sandscrews are pumped to hydrosizing and flotation equipment after most of the floatable debris is removed with a 50- to 150-mesh screen. Countercurrent extraction in settling tanks and hydrosizers are well-known techniques [7,8]. This process includes several flotation/hydrosizing cells in series. As Fig. 3 shows, flotation and hydrosizing are complementary processes since a 75- μm creosote particle that is attached to an air bubble (point B1) can be separated from 20- μm grains of silt (point D) in rising water.

1.1.4. Clay washing

Soil particles finer than 20 μms can also be washed, but only if the contaminant can be solubilized in the water, a suitable extractant, or separated by flotation. Metals like lead, mercury, cadmium, zinc or uranium are extractable [2–4,9]. Organic chemicals with high water solubilities (i.e. benzene) or those that partition into a surfactant micelle can also be extracted from clay. Clay wash equipment has been built that combines pulp remixing, flotation, and clarifier sections into a single apparatus. Several of these clay tanks are used in series to wash the clay. The extracted pulp which settles in one clay tank is countercurrently washed by being pumped to the next clay tank for remixing, extraction or flotation, and clarification.

1.1.5. Specialized equipment

Properties of contaminants such as density, magnetic susceptibility, and surface chemical properties are valuable in remediation processes. Density, for instance, is useful for removing contaminants like mercury, lead and the actinides. The equipment used for this purpose are jigs or gravity tables and spirals. These are described in detail elsewhere [8]. Jigs and tables work because dense particles, like bullet fragments and battery chips, separate better from sand when rhythmically shaken in water than when hydrosizing alone is used. Spirals work because centrifugal force separates lighter particles from the denser contaminant.

Magnetic segregation can remove metals with appreciable magnetic susceptibilities from sand. Magnets work on the principle that ferromagnetic or magnetic materials (susceptibility 0.0005 to 0.02 erg [10]) are attracted to the magnet, while sand (susceptibility -0.00003 erg) is repelled. Some foundry and scrap yard slags contain substantial amounts of copper, lead, arsenic, and chrome. These can be removed from the soil with inexpensive magnetic rolls on conveyers. Separation of plutonium (susceptibility 0.00175 erg) requires a rare earth magnet with a field of 20000 G.

Flotation [11] relies on giving the surface of the contaminant either a positive charge or shielding negative charges on the surface so that the contaminant attaches to an air bubble or to a droplet of oil which will float. The technique is used in the mining industry to separate useful minerals from ground rock. Fig. 4a and b illustrate this principle. Fig. 4a shows that pH adjustment alone can give oil and silica the same

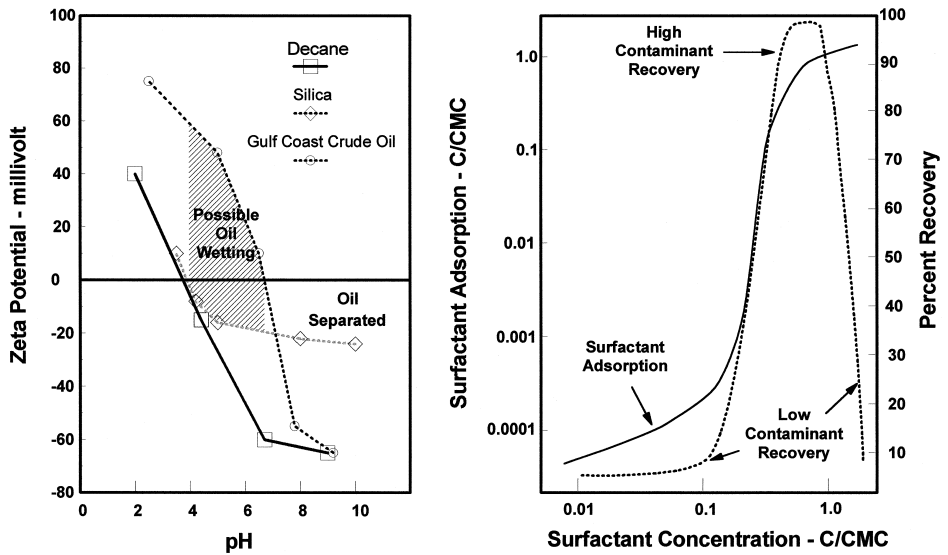


Fig. 4. (a) Effect of pH of surface charges. (b) Effect of surfactant concentration on surface charges.

surface charge thereby aiding dispersion in water. Light hydrocarbons like gasoline, diesel and many fresh crude oils oil spread around air bubbles, while aged crude oil or trichloroethylene are only attached as discrete drops. Fig. 4b shows that adding very small quantities of surfactants at a concentration of 30 to 70% of their critical micelle concentration can give the surface of a contaminant like lead oxide a different charge than sand. The contaminant is separated because it attaches to air bubbles or drops of oil and floats to the surface.

1.1.6. Hot water washing

This soil washing process generally uses hot water. Hot water helps to liquefy and treat tarry wastes. The effect of temperature on the viscosity of hydrocarbons is well documented [12], and increasing temperature from 25 to 65°C reduces the viscosity of a 5000-cp oil to 100 cp. Higher temperature can also invert viscous water in oil emulsions, reducing the viscosity and the dispersing the oil in water for eventual recovery.

Washing in hot water accomplishes three other purposes. First, surface attractive forces are reduced [13]. This makes it easier to disperse the soil in the high shear mixers, hydrosizers and pumps in the process. Next, solubilities of metal salts increase [14]. Generally, the solubility of a metal salt doubles or triples as the temperature is raised from 20 to 65°C. Finally, chemical reactions are much faster at higher temperature: Typical reaction rates double every ten degrees Celsius. Thus, raising the temperature 40°C increases the rate by a factor of 16.

1.1.7. Efficiency of the process

There are three maxims in soil washing: (1) Most projects will involve washing soil with substantial organic material and clay content (i.e., normal soil); (2) While sand is probably the easiest fraction to clean, finer fractions can also be cleaned; and 3) The

process that requires the least water, power and equipment is a countercurrent washing process. This is important, since most projects are not large enough or prices high enough to justify complex equipment, long setup times or permanent crews.

Thus, equipment has been built that:

1. does not have to be removed from its trucks,
2. cleans soil held together by clays and organic material,
3. uses less than 200 gal/min (gpm) of water,
4. uses 125 horsepower (hp), and
5. uses three pumps

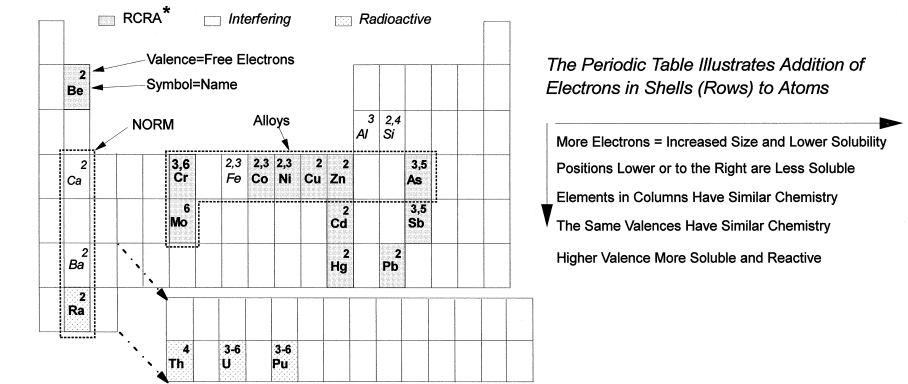
to process 30 tons/h (tph) of > 20- μ m soil and can also clean clay. Some other processes [1] require 900 to 1000 gpm of water, 1000 hp, reject the fines (i.e., 30 to 70% of cropland soil) and have several stories of steel framework support.

The process described here is very efficient because vigorous mixing breaks up the organic and clay matrix holding the sand and silt in the soil, allowing hydrosizing and air flotation to be used in sandscrews. Consequently, 50 to 90% of the soil can be removed from the water using only 120 gpm of water and 60 hp. The rest of the soil can be cleaned in small equipment.

1.2. Chemicals for soil washing

1.2.1. Metals

The chemical techniques for metal remediation can be organized by considering the periodic table (Fig. 5) to emphasize how the atomic structure of metals controls



- Ca, Cd, Cu, Fe, Hg, Pb and Zn (Valence +2) Have Similar Chemistry
 - Soluble in Acid (low pH), Insoluble in Base (High pH), Ion Exchange Works
 - Lead (Pb) and Mercury (Hg) are Very Dense and Settle in Jigs and Cyclones
- Cr^{VI} Very Soluble, Mobile and Reactive, Cr^{III} Insoluble and Inert
- As^{III} and As^V Form Sparingly Soluble Cements
 - Base then Acid Treatment with Attritioning Can Work
- Ra, and Th Relatively Insoluble - Uranium Soluble in Hot Bicarbonate - Pu Paramagnetic

* RCRA = Resource Conservation Recovery Act Interfering Metals = Common Soil Minerals

Fig. 5. Position of RCRA and common radioactive metals in the periodic table of elements.

solubility and chemistry. The periodic table represents how electrons are added to atoms. Each column represents addition of an electron to a shell and each row represents another shell of electrons.

This means that atoms in the lower rows and toward the right side of the table are heavier and less soluble than atoms to the left and higher in the table. For instance, metals like beryllium and chrome^{VI} are very soluble, while lead and arsenic compounds are quite insoluble. Thus, there are more sites where lead and arsenic must be remediated than sites where chrome and beryllium remain.

1.2.2. Valence of an element

The valence of the atom (reported in the upper right corner of each box) represents the number of free electrons; atoms with the same valence have similar chemistry. For instance, metals with a valence of two are generally soluble at acidic pH and are recovered from solution as a sulfide; at basic pH they are recovered as carbonate or hydroxide. Thus, mercury (Hg), lead (Pb) or cadmium (Cd) can be remediated using a combination of acid extraction, chelation and/or ion exchange [3]. Ion exchange enhances acid extraction, since the extraction of more abundant soil metals like calcium (Ca), iron (Fe), and aluminum (Al) are suppressed. When metals absorb into the clay via ion exchange, they can be extracted from the clays by reversing the process, making lead, mercury and cadmium good candidates for removal from all of the soil.

1.2.3. Multiple valences

Arsenic (As) is an example of a metal with two valence states that require separate remediation techniques. The two valences result when oxidized wood treating chemicals [chromated copper arsenate (CCA)] or herbicides (methyl arsenate) are reduced in anaerobic zones of the soil. While chrome (Cr) and copper (Cu) from CCA are soluble and are reduced to less soluble forms slowly enough that they can be dispersed after several decades, arsenate from CCA reacts quickly with iron and calcium in the soil and is left behind. The product formed is chemically similar to cement and can be difficult to remediate. Oxidation or reduction to extract arsenic is difficult because the oxidation state of all of the soil must be changed to affect a small concentration of arsenic. However, combining attrition scrubbing with a two step base/acid extraction can be effective.

1.2.4. Alloys

Copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co), manganese (Mn), chrome (Cr) and other metals may be alloyed with iron, at shops, scrap yards, or foundries. It is easy to confirm this since the concentration of contaminants correlates almost exactly with the increased iron concentration in the soil. Remediation of alloys is accomplished by physical, not chemical means.

1.2.5. Radioactive metals

Uranium (U) contaminates mines and processing sites. Fortunately, carbonate salts of uranium are fairly soluble, and uranium can be remediated by carbonate/bicarbonate treatment [9]. At some mines, the uranium can be injected into an underground

formation. It might also be economic to recover this valuable metal. Other radioactive metals like plutonium (Pu), radium (Ra), and thorium (Th) are too hazardous to concentrate in a soil washing operation. These can be separated into a smaller fraction of the soil for recovery in a more secure facility.

1.3. Surfactants and soil dispersants

Soil dispersants work by either changing or masking the surface electrical charges of the soil, like the flotation chemicals described previously, so that the soil will disperse in water. The dispersant used depends on the contaminant to be remediated and its dispersion mechanism in the soil. Normally, alkaline chemicals are used to disperse the soil and segregate by size. If acidic conditions (that flocculate the soil) are required to extract lead, mercury or cadmium, chemicals can be added that adsorb on the soil and enhance the dispersion [3]. If hydrocarbons are present, surfactants can help disperse soil.

There are many classes of surfactants. *Water soluble surfactants* disperse all solids and immiscible liquids in water, but make water cleanup difficult. Surfactants that form *microemulsions* solubilize hydrocarbons, but are used at high concentration, need a cosolvent, and a temperature cycle to work. *Oil soluble surfactants* work at low concentrations because they penetrate an adsorbed oil layer and facilitate water recycling. *Polymeric demulsifiers* are a special class of oil soluble surfactants [15]. These efficiently coat the surface of a soil particle and reconnect microscopic water layers on the surface of undried soil. However, they are insoluble in water and are used when blended with other chemicals and a cosolvent.

Many natural materials are surfactants, and many are proteins. Improved surfactants can be synthesized from natural ingredients like sugars and proteins [5].

2. The water treatment module

Recycling water in a soil washing project can be more difficult than the soil washing itself and requires considerable expertise. When cleaning 30 tph of soil with 30% fines, 9 tph of solids must be removed from the water. This can have a major impact on operations.

2.1. Removing particles (fines)

Soil washing disperses the finest soil into the water by masking or changing the surface charges on the soil. When water is recycled, the process is reversed: This gives opposite charges to the particles so that they attract each other like opposite poles of a battery (i.e., flocculate). As the 'floc' grows, large particles sink as described in Fig. 3, while small particles remain dispersed. Thus, efficiently recycling water depends on rapid floc formation. Three basic techniques for flocculating dispersed soil are:

1. reducing the pH to the 4 to 5 range to generate opposite charges on the edges and faces of clay particles, promoting flocculation and settling,

2. adding acidic cationic metal salts to bridge between negatively charged particles, and
3. adding ionic polymers to bridge between particles.

Combinations of the three techniques are also used. Having more fines means that more chemical is used to clean the water. Thus, if 25 tph of soil is being washed and 4% fines (1 tph) costs US\$1.40 per ton, 20% fines could cost at least US\$7.00 per ton to flocculate.

Centrifuges, belt presses and filter presses are used to dewater the fines. This equipment is expensive to own and maintain or to rent, requires experienced workers to operate, and the equipment and manpower cost of cleaning the water can exceed the cost of chemicals.

2.2. *Removing of soluble contaminants*

When metals or hydrocarbons are dissolved in the water, they must be precipitated before the water is recycled. Lead, mercury and cadmium are good examples of acid extractable metals, while pentachlorophenol is a hydrocarbon that becomes very soluble at elevated pH. Describing techniques to remove soluble chemicals is outside the scope of this paper. However, cost is a major concern. As an example, it is prohibitively expensive to use ion exchange to remove soluble metals or activated carbon to remove soluble hydrocarbons in a soil washing process. These are only used in conjunction with another less expensive technique.

3. Examples soil washing processes

3.1. *Designing a simple process*

The following two examples illustrate how the complexity of a soil washing process can change as soil type changes. Two examples of rifle range remediation are considered. The first is at a sandy site with less than 5% fines. The second is at a site with more than 30% clay. While both processes work well, the second costs several times as much to operate.

3.1.1. *Lead in coarse sand*

Wet screening and dewatering in sandscrews can meet the remediation criteria. A flow diagram of a washing process is shown in Fig. 6. This process for a sandy soil with low organic content that disperses easily in water consists of (1) spray washing sand through a 3–6 mm screen large enough to pass 30 tph of solids, (2) washing, hydrosizing and drying sand in a sandscrew, then (3) dewatering the finer soil. The finer soil can be dewatered with a belt press, centrifuge, filter press, or screen.

3.1.2. *Lead in class A crop land soil*

Good cropland soil contains 30% clay and several percent organic material. Lead will absorb in the clays, so soil washing should clean the clays. Processes that include screening, segregation by density, extraction with chemicals, and precipitation of

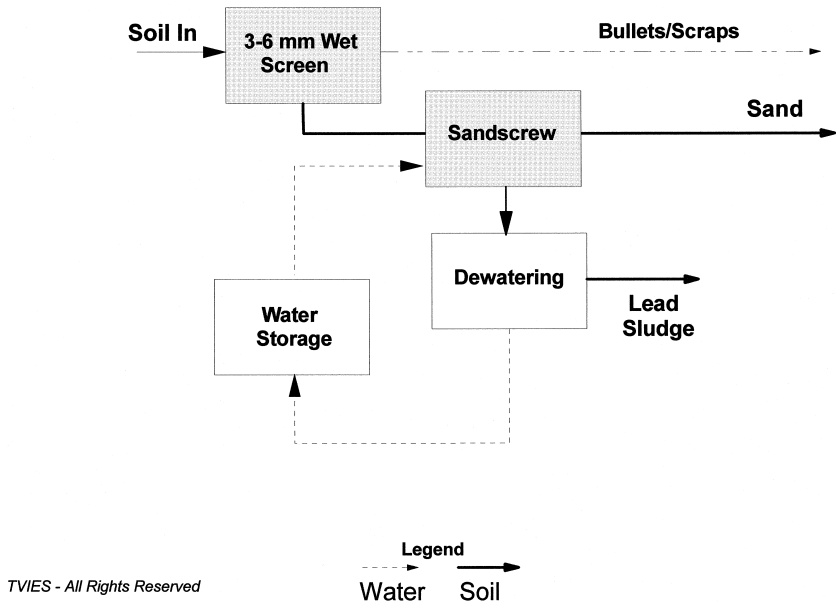


Fig. 6. Segregation of bullet or battery fragments from sandy soil.

extracted lead have been demonstrated [16]. The flow diagram in Fig. 7 illustrates unit operations for extracting lead from soil at the rate of 20 tph using chemicals and 200°F wash water.

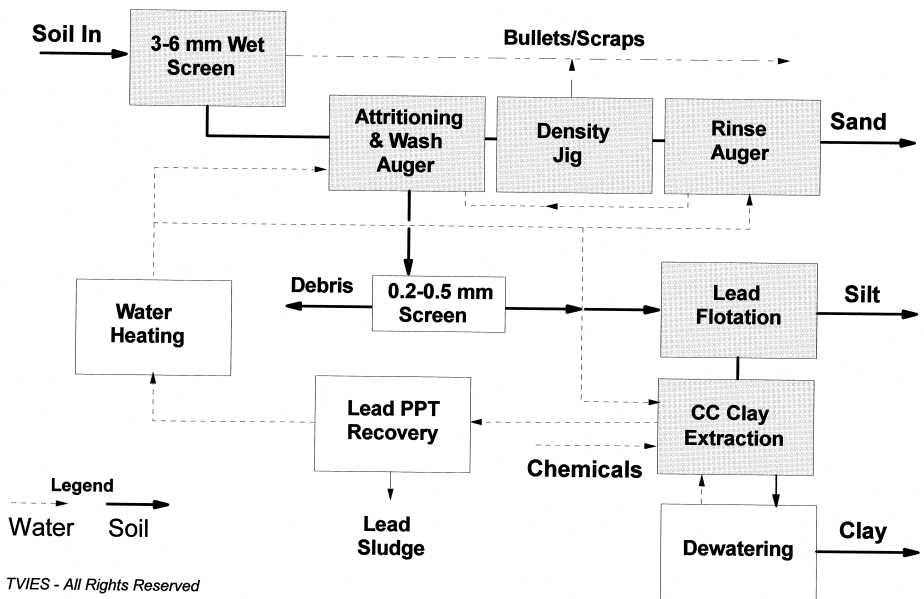


Fig. 7. Process for segregation of lead by size and density with extraction of absorbed lead from silt and clay.

The soil is shredded and screened before falling into an high-shear mixer, then a sandscrew. The sandy component is pushed by the sandscrew to a density jig to remove lead particles. The overflow of the density jig is rewashed and dewatered in another sandscrew, while the underflow is concentrated for disposal. Silt, fine sand, and debris flowing out the back of the sandscrew drop into an extraction loop. The underflow of the hydrosizers is dewatered and recombined with the sand.

The overflow from the hydrosizers flocculates at pH 4 to 5 and is pumped through several clay extraction tanks. The flocculated clay settles and is pumped into dewatering equipment. The overflow from the clay extraction tanks is combined at the lead recovery equipment with water returned from the dewatering equipment. Extracted lead is precipitated and filtered from the water. It should be clear that the extra equipment, chemicals and manpower used for this process raises the cost substantially.

3.2. Creosote remediation—a project history

3.2.1. Background

Cape Fear Wood Preserving operated on 41 acres of land near Fayetteville, NC from 1953 until 1983. Ten acres were contaminated by creosote and CCA (chromated copper arsenate). Facilities at the site consisted of a railroad unloading site, creosote storage pit, and treating sites for both creosote and CCA. These occupied a fraction of an acre but were highly contaminated. The remainder of the site was contaminated by attrition of dried creosote throughout the site or by flow down a drainage ditch and is much less polluted. Cleanup criteria were 100 ppm polyaromatic hydrocarbons (PAH), 2.5 ppm carcinogenic PAH (cPAH), 94 ppm Cr and 88 ppm As. The feed soil averaged 283 ppm PAH, 30 ppm cPAH, 48.7 ppm Cr and 18.5 ppm As. Almost 20% of the soil is finer than 74 μm .

3.2.2. Soil washing process

The soil washing process at the site [5] consisted of:

- an attrition scrubber to break up soil matrix and to mix water and chemical with the soil,
- a sandscrew to separate clay and organic debris from the sand,
- two parallel sandscrews to rinse more debris and fines from the sand,
- a 50-mesh debris screen to remove contaminated organic debris from the process water,
- cyclones to separate > 200-mesh sand from fines that were sent to
- three, 4 yard³ filter presses for dewatering fines.

The process was optimized by washing 2845 tons of soil from a stockpile selected to represent all areas at the site. The initial phase of the project was to test the process and optimize coordination between the soil washing portion and water treatment section of the process. Soil washing with sandscrews is a continuous process, but dewatering fines with filter presses is a batch process. Thus, coordination is essential for successful 24-h/day operation. After this original soil was successfully cleaned to the targets listed above, the process was demonstrated by washing 2650 tons of other soil excavated during a required 5-day test of continuous operations.

3.2.3. Soil washing results

In this phase, the process was formally demonstrated by cleaning 1900 yards³ of soil in 5 days (i.e., at over 20 dry tph). Results for this phase of soil washing at Cape Fear are reported in Table 1.

The data in Table 1 show the following.

(1) The raw soil feed rate was 24.7 tph, corresponding to 21.6 tph of dry soil fed to the process. This feed rate was reduced from 30 tph so that the filter presses could dewater the fines produced.

(2) Of the > 200-mesh sand fed to the process, 95.7% reported to the clean sand pile. The material removed at the 50-mesh debris screen contained no sand. Less than 5% of the solids in the screen underflow were > 200-mesh.

(3) Of the dry soil fed, 77.3% reported as clean sand in the demonstration test, in spite of the fact that almost 20% of the soil was < 200-mesh.

(4) The concentrations of PAH's in the soil were reduced by more than 93%, while the carcinogenic PAH's were reduced by 89%.

(5) The soil washing equipment operated 81.4% of the time, having to shut down primarily for the filter presses to catch up with the soil washing process.

The process achieved all goals except the cPAH cleanup criteria. The reason for not reaching that goal is still unexplained. However, it is interesting that the cPAH concentration in the clean sand did not correlate with the concentration in the feed. The cleanest soil was produced when the feed was the most contaminated. This might seem confusing. However, the highest concentration of cPAH's in the clean soil corresponded to a doubling of the ratio of cPAH's to PAH's in the feed soil and an increase in debris during 2 days of the project. Four out of five piles in those 2 days exceeded the cPAH cleanup goal by factors of two to three. The cPAH concentration of those four piles was high enough to raise the average above the cleanup goal.

The residual cPAHs in that sand were remarkably resistant to remediation. For example, when that sand was rewashed, total PAH's were reduced by 50%, but cPAHs were not reduced. This implies that the carcinogenic PAHs are strongly absorbed onto the sand. That is possible since carcinogenic PAHs are angular molecules and therefore more polar than symmetric noncarcinogenic PAHs. This may mean that the cPAHs are

Table 1
Summary of the process mass balance for soil washing at cape fear

Tons of soil fed	2650
Percent moisture	12.8
Percent debris, estimated dry weight	0.19
cPAH/PAH in feed, ppm	30.4/283
Soil fed, tph	24.7
Utilization, percent on stream	81.4
Percent clean dry sand produced	77.3
cPAH/tPAH in cleaned sand, ppm	3.41/20.0
Benzo (a) pyrene in cleaned sand, ppm	0.29
Percent filter cake and silt	22.7
cPAH/tPAH in cake and silt, ppm	181 and 1500

absorbed onto the sand before the noncarcinogenic PAHs when the creosote was still a liquid and are simply removed last.

4. Soil washing operations

The purpose of this paper has been to promote the understanding that soil washing is not one process, but rather a varying collection of unit operations that must be streamlined. A well-designed process can be efficient. For instance, one operator and two sandscrews can wash 30 tph of soil that is 80% sand. However, dewatering the remainder could require five or six workers.

The process described herein combines flotation and hydrosizing with high shear mixing and spray washing in three types of equipment which can clean most soil types. The foregoing discussion pointed out that properties of the contaminant (i.e., magnetic susceptibility, density, surface properties, and electron affinities) can be used to aid separation. Different equipment and chemicals are used to remediate a variety of problems, and no one process corrects all problems. The complete process must be streamlined since all operations must be coordinated.

This includes integrating the soil washing module with the water treatment module. The cost of removing each additional ton of fines from the wash water is several dollars. If the soil washing operation makes water cleaning more difficult, that cost escalates.

5. Conclusion

The preceding discussion affirms the following factors.

- Soil washing using countercurrent washing in sandscrews, flotation/hydrosizers and clay wash tanks can clean a variety of soils including those containing more than 30% clay.
- Other physical separation techniques that help to clean soil include separation by magnetic properties, density or differences in surface electrical charges.
- A variety of chemicals enhance the physical separation processes that remove most of the contaminants and extract absorbed contaminants or strip adsorbed contaminants from the soil.
- The water cleaning process must reverse the soil washing process that disperses the soil. Thus, the washing processes must not adversely affect water recycling.
- Since several unit operations are combined to make a complete efficient soil washing process, coordination and experience are very important.

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