

# technical bulletin

CL:AIRE technical bulletins describe specific techniques, practices and methodologies currently being employed on sites in the UK within the scope of CL:AIRE technology demonstration and research projects. This Bulletin describes the principles behind soil washing technology for contaminated materials.

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## Understanding Soil Washing

### 1. INTRODUCTION

Soil washing is a remediation technology which has become well established in The Netherlands, Germany, Belgium, Switzerland and more recently in other areas of Europe, North America, and Japan for the treatment of organically- and inorganically-contaminated soils (Pearl and Wood, 1994). It has also been used in the USA and Germany for the treatment of radioactively contaminated soils. In recent years there have been a number of applications in the UK - these being as pilot-scale trials and as full-scale operations (e.g. CL:AIRE, 2003). Full-scale applications include Basford Gasworks and Woolwich Arsenal remediation projects - both of approximately 100,000 m<sup>3</sup>, and more recently Carlisle and High Wycombe gasworks - being approximately 5,000-10,000 m<sup>3</sup>. Pilot-scale operations have included work by Warren Spring Laboratory and AEA Technology (on heavy metal and organic contaminated soil), UKAEA (on radioactively contaminated soil), Shanks (on polycyclic aromatic hydrocarbon (PAH) contaminated soil) and East Midlands Development Agency (on soils from Avenue Cokeworks).

As the impact of Landfill Regulations 2002 starts to bite, more widespread application of the technology is expected through applications on-site, at centralised treatment centres and possibly in treatment "hubs".

Fundamentally, soil washing is a volume reduction/waste minimisation treatment process where (i) those soil particles which "host" the majority of the contamination are separated from the bulk soil fractions, or (ii) contaminants are removed from the soil by aqueous chemicals and recovered from solution on a solid substrate. In either case, the separated contaminants then go to hazardous waste landfill (or occasionally are further treated by chemical, thermal or biological processes). By removing the majority of the contamination from the soil, the bulk fraction that remains can be:

- recycled on the site being remediated as relatively inert backfill;
- used on another site as fill; or
- disposed of relatively cheaply as non-hazardous material.

It should be remembered that "removal of the majority of the contamination from the soil" does not mean that the contaminant-depleted bulk is totally contaminant-free. Thus, for soil washing to be successful, the level of contamination in the treated-bulk must be below a site specific action limit (e.g. based on risk assessment).

Cost effectiveness with soil washing is achieved by offsetting processing costs against the ability to significantly reduce the amount of material requiring costly disposal at a hazardous waste landfill.

Typically the cleaned fractions from the soil washing process should be >70-80% of the original mass of the soil but, where the contaminants have a very high associated disposal cost, and/or where transport distances to the nearest hazardous waste landfill are substantial, a 50% reduction might still be cost effective. There is also a generally held opinion that soil washing based on physical separation processes is only cost effective for sandy and granular soils where the clay and silt content (particles less than 0.063 mm) is less than 30-35% of the soil. Soil washing by chemical dissolution of the contaminants is not constrained by the proportion of clay as this fraction can also be leached by the chemical agent. However, clay rich soils pose other problems such as difficulties with materials handling and solid-liquid separation (Pearl and Wood, 1994).

Full-scale soil washing plants exist as fixed "centralised" treatment centres, or as mobile/transportable units. With fixed centralised facilities, contaminated soil is brought to the plant, whereas with mobile/transportable facilities, the plant is transported to a contaminated site and soil is processed on the site. Where



Fig.1: Mobile soil washing plant (Courtesy of DEC NV)

mobile/transportable plant is used (Figure 1), the cost of mobilisation and demobilisation can be significant. However where large volumes of soil are to be treated, this cost can be more than offset by reusing "clean" material on the site (therefore avoiding the cost of transport to an off-site centralised treatment facility, and avoiding the cost of importing clean fill). Full-scale applications of soil washing in the UK to date have mostly been with mobile/transportable equipment, although a "permanent" treatment centre has recently been built at Port Clarence, Teesside (Edie, 2007). In addition, semi-permanent or hub facilities (e.g. the CLUSTER concept) are being considered by a number of companies.

### 2. PRINCIPLES, CONSIDERATIONS AND EVALUATION

#### 2.1 Main Principles of Operation

As mentioned in the above section, soil washing is a volume reduction/waste minimisation treatment technology based on physical and/or chemical processes.

With "physical" soil washing, differences between particle grain size, settling velocity, specific gravity, surface chemical behaviour and rarely magnetic properties are used to separate those particles which "host" the majority of the contamination from the bulk which are contaminant-depleted. The equipment used is standard mineral processing equipment - which is more generally used in the mining industry.

With "chemical" soil washing, soil particles are cleaned by selectively transferring the contaminants on the soil into solution. This is achieved by mixing the soil with aqueous solutions of acids, alkalis, complexants, other solvents and surfactants. The resulting cleaned particles are then separated from the resulting aqueous solution. This solution is then treated to remove the contaminants (e.g. by sorption on activated carbon or ion exchange).

The most common applications of soil washing have been based on physical processes. This mainly reflects the higher costs of chemical soil washing - mostly as a consequence of cost of reagents and of the treatment of the contaminant-loaded solutions.

#### 2.2 Soil-Contaminant Associations

The association of the contaminant to the soil particle is fundamental to the application of soil washing. Typical soil-contaminant associations are shown in Figure 2.

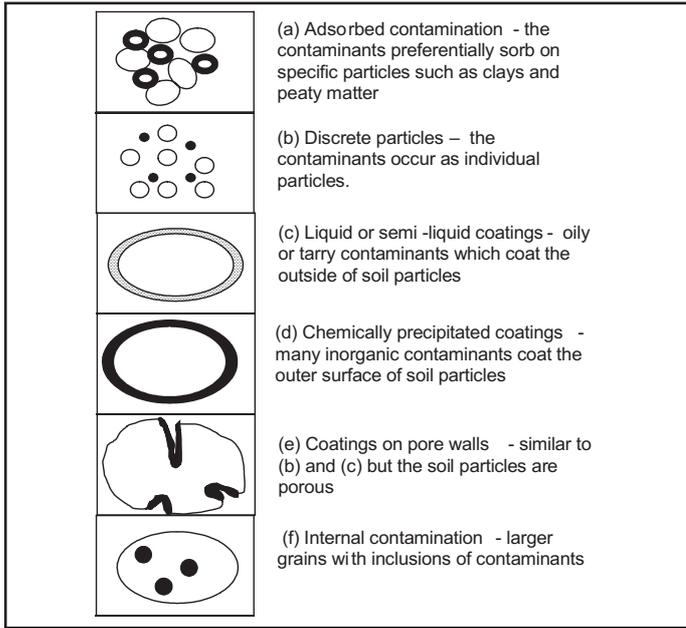


Fig.2: Soil-contaminant associations.

Figures 2(a) and 2(b) illustrate contaminants which selectively sorb on a particular type of soil constituent, or which occur discretely. These types of particles are generally amenable to physical separation processes. Examples include many organic contaminants which preferentially bind to the organic peaty matter of the soil, or of PAH contamination which occurs in coke residues. In both these cases, the physical differences between peaty matter, or coke residues, and the majority of the other soil particles enables the soil to be treated - provided that the soil is firstly disaggregated and the particles suspended in water.

In Figures 2(c) and 2(d), the contaminants coat the outside of particles and can be removed from the relatively uncontaminated core of the particle by abrasion (attrition scrubbing) or by chemical dissolution. Examples include contaminant-rich iron oxide coatings or contaminant-rich clays which bind to the outer layers of particles.

Figure 2(e) shows contaminants which penetrate into porous materials. Particle crushing is thus required to expose the contaminant surface so that it is amenable to attrition scrubbing or to chemical dissolution.

In Figure 2(f) the contamination occurs as an intimate part of the particle. Significant crushing will be required to enable the contamination to become accessible. This can be expensive and can significantly reduce cost effectiveness.

**2.3 Laboratory Treatability Tests and Pilot-Scale Trials**

A preliminary assessment of treatment of soils by soil washing involves carrying out a number of relatively simple laboratory treatability tests on kilogram quantities of soil (See Table 1).

In some cases, these preliminary tests are followed by pilot-scale tests where tonnage quantities of soil are processed in smaller scale soil washing equipment, or are processed as a "batch" in an existing commercial operation. Pilot-scale testing reduces the risk of failure of processing thousands of tonnes of soil in full-scale operation. Pilot-scale testing also gives an insight into potential difficulties in materials handling and solids dewatering.

**2.4 Process Water**

All soil washing processes use water. The water has a number of functions:

- to disaggregate the soil;
- to suspend the soil particles such that separation equipment performs effectively and efficiently; and
- with chemical soil washing, to dissolve or solubilise the contaminants.

Water quality management during processing is very important as water is recycled. Efficient water management not only reduces the overall amount of water used during processing, but also ensures that any contaminants that are transferred into the water during the process do not recontaminate clean products.

To maintain good water quality it may be necessary to treat all, or a proportion of the water before recycling (using processes such as oil-water separation, ion exchange, precipitation, and sorption on activated carbon).

**Table 1: Treatability tests**

Treatability tests are carried out on ~kilogram quantities of soil from a site. The tests are based on particle separation, or contaminant dissolution.

**(a) Particle Separation Tests**

Tests for evaluating particle separation techniques use laboratory equipment to segregate fractions of the soil based on differences in:

- grain size;
- settling velocity;
- specific gravity;
- surface chemical properties; and
- (rarely) magnetic properties.

(Bovendeur, 1993; Hoek *et al.* 2000; Pearl and Wood, 1993, 1994; Pruijn *et al.* 1997; Pruijn and Groenendijk, 1993).

| Property                    | Laboratory Test  |
|-----------------------------|--|
| Grain size                  | Wet sieving through a number of screens.                     |
| Settling velocity           | Hydrocycloning or cyclonizing with laboratory units.         |
| Specific gravity            | Float and sink tests using liquids of different densities.   |
| Surface chemical properties | Laboratory froth flotation tests.                            |
| Magnetic properties         | Laboratory magnetic separation at different field strengths. |

In addition, the effects of removing surface coatings can also be evaluated using laboratory abrasion/attrition scrubbing equipment.

The objective of these physical treatability tests is to ascertain (i) whether "clean" fractions can be produced and (ii) whether the proportion of this clean material relative to the original mass of the soil is sufficiently large to make full-scale treatment viable.

**(b) Contaminant Dissolution or Solubilisation Tests**

Contaminant dissolution tests involve extracting the contaminants from the soil with acids, alkalis, complexants, various solvents and surfactants. The tests should not only assess how much of the contaminant is transferred into an aqueous phase, but should also aim to assess how much of the soil components themselves dissolve. Ideally a reagent should selectively dissolve the contaminants with the minimum dissolution of the soil components. (A significant dissolution of soil components will substantially add to the cost of the treatment of the aqueous phase).

In these tests, either the whole soil below a certain size range e.g. 2 mm, or fractions from grain size separation tests, are reacted with the above reagents. The resulting soil is then analysed to see whether it reaches the remediation clean-up target.

*Note on the Soil Samples Used for the Treatability Tests*

Where the soils on a site are relatively diverse in type and where the contamination levels vary widely, it is important that the laboratory tests are carried out on sufficient numbers of samples to be representative of the size of the contaminated land problem on the site. This may mean that only some areas of the site are amenable to soil washing - which may still be economically viable.

Although water is recycled, soil washing is a net consumer of water - mainly because the products from the process contain a higher moisture content than the original soil. Thus, with many physical washing systems, the costs associated with water treatment are generally minimal because clean top-up water has to be added to the process to maintain the overall water inventory. Any contaminants transferring into the process water will thus be diluted. If some contaminants do begin to build-up in the process water, a portion can be bled-off and treated.

With chemical soil washing, water treatment costs can be significant as most of the contaminants will be transferred into the process water, and the whole of the water stream will require treatment before discharge. Together with the cost of the chemical reagents used, this accounts for why most commercial soil washing systems are based on physical processes.

**2.5 Separation Equipment**

The type of equipment used for most soil washing processes has generally come from the mineral processing industry (Table 2).

**Table 2: Commercially available physical separation equipment**

| Exploitable Feature                | Process Equipment   |
|------------------------------------|---|
| Size                               | Vibratory Screens (sieves)<br>Sieve Bends<br>Trommel (rotary) screens                             |
| Hydraulic Size (Settling Velocity) | Classifiers<br>Hydrosizers<br>Hydrocyclones   |
| Specific Gravity                   | Jigs<br>Sluices<br>Dense Media Separators<br>Spirals<br>Shaking Tables                            |
| Surface Chemistry                  | Froth Flotation Systems   |
| Magnetic Susceptibility            | Low Intensity Magnetic Drums<br>Induced Magnetic Separators<br>High Intensity Magnetic Separators |

The simplest soil washing processes are generally based on the removal of the fine fractions from the soil (which in many cases contain the majority of the contamination). These designs therefore include processes such as screening, classification and solids dewatering. More complex designs are aimed at removing other contaminated fractions from the soil such as contaminated carbonaceous matter and coke, iron oxides, metal fragments and coating layers of various substances. These designs include screening, attrition scrubbing, classification, separation using specific gravity separators and froth flotation, and solids dewatering. More rarely, some designs may also include chemical leaching and treatment of the leach solution. Many soil washing companies use relatively modular equipment configurations which can be adapted as required, to incorporate additional equipment.

**3. COMMERCIAL OPERATIONS**

Commercial soil washing operations typically have a throughput of 20-100 tonnes/hour. Within a commercial soil washing plant a number of stages can be identified (Pearl and Wood, 1994; Pruijn *et al.* 1997; Pruijn and Groenendijk, 1993). These stages (not necessarily in the order presented) involve:

(1) Removal of coarse debris (e.g. greater than 150 mm) using a grizzly screen (a series of widely spaced bars);

(2) Disaggregation of the soil particles using water sprays, log or sword washers, and tumbling scrubbers. Acids, alkalis, complexing agents, surfactants and dispersants can be added at this stage to transfer the contaminant totally or partially into the aqueous phase. Where contamination occurs in the coarsest fractions, it may also be necessary to crush the particles so that the contaminants are released from the bulk, or are in a form that is more easily solubilised using the various additional reagents;

(3) Removal of those contaminants that occur as coatings on sand and gravel particles using high intensity attrition scrubbing, high pressure water sprays, centrifugal acceleration or vibration. Acids, alkalis, complexing agents, surfactants and dispersants can again be added at this stage to aid the process;

(4) Sizing and classification using screens and hydrocyclones to separate a coarse gravel and debris fraction, a sand fraction, a coarse silt fraction and a clay and fine silt fraction. In many cases, the coarse gravel fraction is relatively contaminant free and requires no further treatment. However, where the level of contamination in this coarse fraction exceeds the target requirement, it is crushed and blended with incoming fresh feed. Clays and fine silt generally contain elevated levels of the contaminants and are removed as a contaminant concentrate without further segregation;

(5) Further physical or chemical removal of the contaminants from particles by exploiting differences in specific gravity, magnetic properties, surface chemical properties (using froth flotation), other physically exploitable features, or solubility in acids, alkalis or complexing and oxidizing agents;

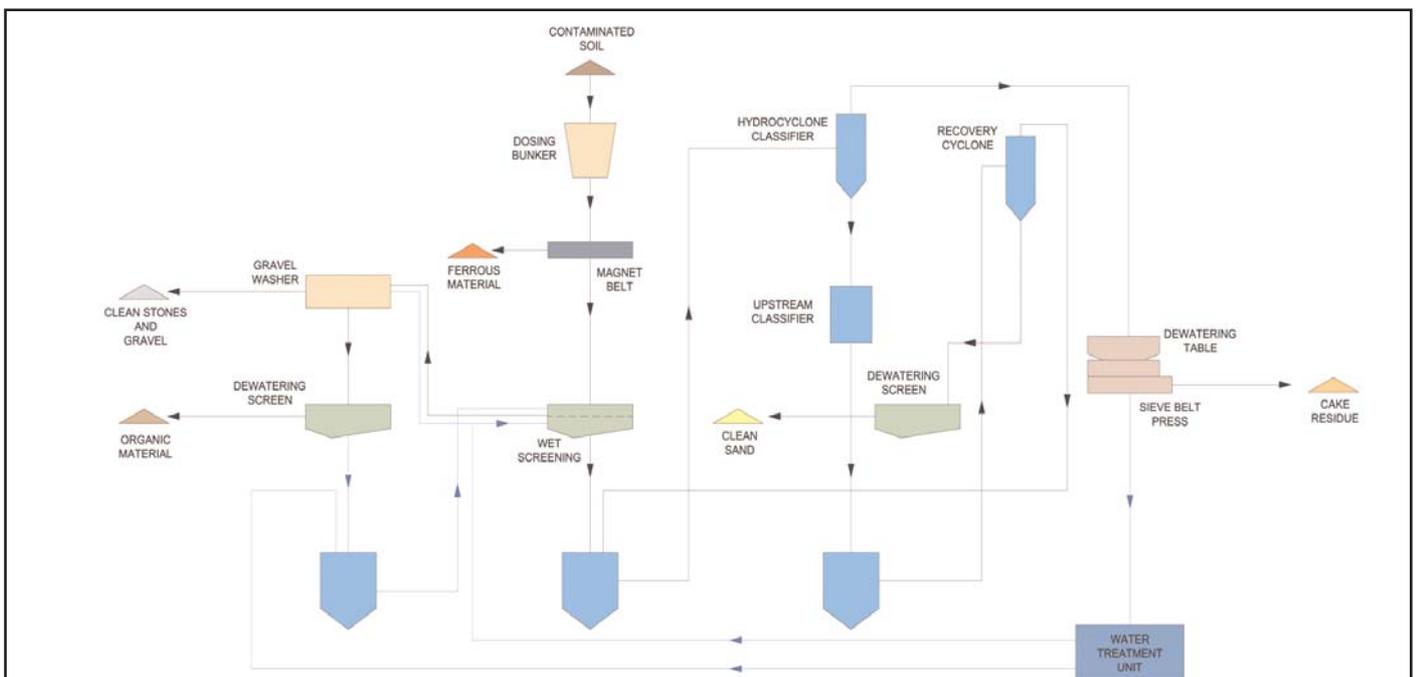
(6) Dewatering of products. The streams with the finest particles normally require the addition of flocculants prior to particle settling and/or removal using a dissolved air flotation water clarification unit. The fine solids are finally dewatered with a filter press or centrifuge;

(7) Process water/leachate treatment using sand filters to remove remaining suspended fines, followed by activated carbon, exchange resins or precipitation to remove dissolved or emulsified contaminants from solution. Cleaned process water can then be reused within the process, and after treatment, disposed of to trade waste;

(8) Treatment and regeneration of the exchange resin or sorption substrate;

(9) Disposal or reuse of the relatively contaminant-free products;

(10) Disposal of the contaminant concentrates as hazardous waste to an appropriate landfill, or further treatment of the concentrates by thermal, biological, chemical, or immobilisation processes. Some practitioners omit some of the stages - this very much depends on the type of contaminant, its relationship to the soil particles, and the type of soil, as explained above. Soil washing processes will potentially treat most types of contamination in all of the soil-contaminant associations illustrated in Figure 2 provided that the contaminated particles have a differential behaviour to the bulk of the particles. Examples of a commercial mobile plant and a treatment centre are shown in Figures 3 and 4.



**Fig.3: Flowsheet of mobile soil washing treatment plant (Courtesy of DEC NV)**

