CL:AIRE

CSB 7

(February 2008)

case study bulletin

CL:AIRE case study bulletins provide a source of information on the characterisation and remediation of specific sites in the UK. This case study bulletin describes the application of soil washing on contaminated materials at The Avenue near Chesterfield.

Remediation Trial at The Avenue Using Soil Washing

1. INTRODUCTION

This bulletin describes a CL:AIRE Technology Demonstration Project (TDP11) in which contaminated material from The Avenue site in Chesterfield, Derbyshire was treated at pilot-scale using soil washing.

The pilot demonstration project was carried out at The Avenue by DEC NV using plant-scale equipment provided by the Belgian company VITO laboratories. The plant is a small-scale replica of the fixed, static plant that DEC operates in Belgium.

The main objectives of the trial were to evaluate:

- the feasibility of using soil washing to (i) remove contaminants from the soil, and (ii) maximise the amount of treated material which could be recycled on the site as construction backfill.
- the costs of large-scale soil washing on this site.

This pilot-scale trial was one of a number of demonstration trials being carried out on The Avenue site, which had the overall aim of developing an appropriate remediation and redevelopment strategy. The trial was funded by the national regeneration agency, English Partnerships, through the National Coalfields Programme's £104.5M remediation project for The Avenue site, being delivered by East Midlands Development Agency (emda).

2. BACKGROUND TO SOIL WASHING

Soil washing is an *ex situ* water-based, volume reduction process in which organic and inorganic contaminants are physically separated, and/or chemically extracted from the soil. The bulk fraction that remains after removal of the majority of the contaminants can then be recycled on the site as construction in-fill material. As a separation process, soil washing does not destroy the contaminants but, rather, separates them so that only a small proportion of the original soil requires disposal as hazardous waste, or needs to be treated further.

Compared to "dig and dump", soil washing can be cheaper because treatment costs can be more than off-set by reduced transport and landfill costs. Further information on the background of soil washing can be found in CL:AIRE TDP2 Report, "Remediation of Basford Gasworks using Soil Washing" and in Technical Bulletin TB13, "Understanding Soil Washing".

3. BACKGROUND TO THE SITE

The Avenue Coking Plant and Chemical Works were constructed in the 1950s and operated until 1992. Prior to this, the site had been host to a colliery, lime and iron works, and also included a former licensed tip and contaminated lagoons. During operation, 18 million tonnes of smokeless domestic fuel was produced along with a number of by-products. Subsequently, extensive land and groundwater contamination has been discovered associated with tar lagoons, waste tips, site soils, tanks, sumps and redundant pipework. The contaminants generally comprise coal tars, lime sludge, acids, phenols, polycyclic aromatic hydrocarbons (PAH), volatile organic compounds (VOC), spent oxide (commonly known as Blue Billy), ammoniacal substances, heavy metals and asbestos. The site was considered by the Environment Agency to be a polluter of controlled waters including the adjacent River Rother.

Figure 1: General layout of the soil washing plant.

The site was transferred to English Partnerships' National Coalfields Programme in 1996, and to emda as English Partnerships' delivery agent in April 1999. Jacobs (formerly Jacobs Babtie) was commissioned by emda as principal consultants in the remediation and redevelopment of the 98 hectare site. Jacobs identified a number of contaminated materials on the site and managed a series of technology demonstrations projects aimed at evaluating their potential application to the remediation of the site. The soil washing trial in this Bulletin in one of these demonstration projects.

Materials from two areas of the site were chosen for this trial and these were:

- The former waste tip, containing a mixture of materials with a range of organic and inorganic contaminants such as PAH and cyanides; and
- the plant area, contaminated mainly by organic materials such as phenols, petroleum hydrocarbons and aromatic hydrocarbons.

Further site details are provided in CL:AIRE TDP6 Report, "Biopile Field Demonstration at the Avenue Coking Works".

4. LABORATORY-SCALE TREATABILITY TESTS

Prior to the pilot-scale trials on the site, a series of laboratory-scale treatability tests were carried out by DEC NV in Belgium in order to characterise the contaminated materials. These were followed by preliminary bench-scale washing tests on small representative samples to identify optimum conditions for the pilot test.

The main conclusions from these tests were:

- The contaminants were distributed throughout all fractions of the materials tested (i.e. the clay, silt, sand and gravel fractions;
- The gravel fraction was the major fraction of all the materials tested;
- The organic contaminants are probably associated with coal and pitch particles, both in the sand and gravel fractions;

- A drum washer would be required to disaggregate the material and to abrade surface coatings from gravel fractions;
- The coal and pitch sand and gravel sized particles could be separated by specific gravity-based processes. These processes would involve a mineral jig for the gravel-sized fractions; and a spiral concentrator and upstream classifier for the sand-sized fractions;
- Fine sand and silt sized coal and pitch particles could be separated from relatively "clean" material in this fraction using froth flotation;
- The finest fractions of the material could be separated using a spiral classifier and hydrocyclones.

5. THE PILOT TRIAL

The pilot-scale trial was carried out in November 2001 over a one week period. Figure 1 shows the general layout of the plant and Table 1 provides a description of the modules used (Figure 2 shows a selection of these modules).

The plant was of modular design and had a capacity of between 0.5 - 1.2 tonnes per hour. It was erected inside a temporary treatment building (which had been previously used for the bioremediation trial (TDP6 Report). The concrete floor of the building was lined with a 0.2 mm polyethylene liner to contain any spills. Tanks containing 30 m^3 of water provided buffering capacity for the washing operations.

The trial was carried out on 20 tonnes of material from the waste tip and 10 tonnes of material from the plant area which had been pre-screened to 75 mm.

Composite samples were taken at the following points in the process each test day and sent for chemical analysis:

- Soil input stage (feed hopper)
- Contaminated gravel output
- Washed gravel from gravel jig
- Residue from gravel jig
- Sand fraction after spiral classifier
- Sand fraction after scrubber
- Sand fraction after density spiral
- Coal tailings from density spiral
- Sand fraction after flotation
- Residue separated by flotation
- Decanted fines
- Sludge after dewatering in filter press
- Filtrate from filter press
- Process water after treatment

Table 1. Description of each module of the soil washing pilot plant.

No.	Module	Process Description
1	• Feed hopper with built-in grizzly screen (80 mm apertures) • Electromagnet • Weighing cell and conveyor belt with speed control	• removes coarse debris > 80 mm • removes iron based debris • controls the feed rate to the process
2	• Water sprayed vibratory screen (2 mm apertures) • Solids conditioning buffer tank with an automated solids content indicator	• disaggregates the soil and removes the oversize fraction (2 < 80 mm) • controls water additions to the <2 mm fraction so that the resulting slurry can be easily pumped and so the materials within the slurry can be readily segregated. In general, the water:solids ratio is 4:1.
3	• Hydrocyclone or stubcyclone (used separately or in series with screw classifier, Module 4) with an adjustable d95-cutpoint of between 30 µm and 60 µm.	• segregates the <2 mm material into a discharge product containing mostly sand-sized material and one containing silt and clay. In addition, hydrocycloning also removes a significant proportion of water from the sand-sized discharge product. This partial dewatering to 60-70% water by weight improves the efficiency of the downstream attrition scrubbing process (Module 5). Note: the silt and clay fractions, which contain significant amounts of the contaminants, are subsequently dewatered using a combination of settling in a conical thickener, fine screening using a sieve bend, and filtration using a filter press.
4	• Spiral (or screw) classifier (used separately or in series with cyclone, Module 3).	As an alternative, or in combination with Module 3. Compared to hydrocyclones alone, the spiral classifier removes more organic material. In addition, the gentler action of the spiral classifier limits the potential for emulsifying any free-phase oils.
5	• Two-cell attrition scrubber (2x4kW).	• by abrasion, removes those contaminants occurring as coatings on the sand-sized material. In the scrubber, chemical agents can be added to help the process (e.g. surfactants, acid, complexing agents).
6	• Spiral concentrator: single spiral with 3 turns and with 3-way product splitter.	• uses differences in specific gravity (SG) to segregate: - a low SG product which contains most of the contaminants (organic, light minerals, coal, oil, tar etc); - a heavier SG product, which if "clean" is dewatered as a final product, alternatively, if still above the clean-up target, is further processed by froth flotation (Module 9); - a "middlings" product which is either repassed through the spiral concentrator, or treated using downstream froth flotation to remove the contaminants.
7	• Sieve bend (500 µm screen with cutpoint of 250 µm).	• as part of a staged dewatering process, removes the >250 µm material from the light fraction from the spiral concentrator (Module 6).
8	• Secondary cyclone (3" stubcyclone or hydrocyclone), overflow to clarifier, underflow to flotation conditioner Module 9.	• removes the abraded contaminated material released from attrition scrubbing the sand-sized material (Module 5).
9	• Conditioner tanks to froth flotation.	• where a chemical agent ("collector") is added to enhance the hydrophobicity of the coal and light material as a precursor to froth flotation.
10	• Froth flotation units.	• removes the contaminated coal and low SG material from the relatively "clean" components.
11	• Clarifier tanks for flotation concentrate.	• settles the solids in the flotation concentrate using coagulating and flocculating reagents.
12	• Dewatering cyclone.	• reduces the water content of the clean sand slurry to about 60% solids (by weight) prior to final dewatering with the vibratory screen (Module 13).
13	• Vibratory dewatering screen (500 µm)	• reduces the water content of the clean sand slurry to about 75% solids (by weight).
14	• Process water buffer tanks with additional emergency buffer tanks.	• collects all process water and adds clean "top up" water to maintain water levels throughout the process.
15	• Separated gravel (at Module 2) can be further washed by a drum gravel washer or a jig.	• the gravel washer removes the coatings and the jig removes low SG contaminated fractions such as plastics.
16	• Lab-scale filter press, capacity 52 litres.	• dewaters the thickened fines sludge in a mobile filter press.

Note: In addition, a container for electrical supply and switch boards, data loggers and instrument displays, PC with Labview and chemical dosing and storage units. The container is provided with all necessary follow up instrumentation, sampling equipment, and operator infrastructure.

The samples were analysed for loss on ignition (LOI), dry matter, pH, total petroleum hydrocarbons (TPH), total and speciated polycyclic aromatic hydrocarbons (PAHs), benzene, toluene, ethylbenzene and xylenes (BTEX), phenols, cyanides and heavy metals. The samples were mainly analysed by ALcontrol Netherlands, with three duplicate samples analysed by ALcontrol Geochem in Chester, and TES Bretby for quality assurance purposes.

Ambient air monitoring was also carried out during the treatment. All ambient and personal air monitoring results carried out during the trial were below applicable Health and Safety Executive exposure limits.

6. RESULTS FROM THE TRIAL

6.1 Waste Tip Material

The results of the trial indicated that different parts of the soil washing system had varying rates of efficiency in contaminant removal. Table 2 provides the data for chemical analysis and materials mass balance for the waste tip material.

Table 2. Material mass balance and chemical analysis of treated waste tip material. Results are expressed as mg/kg unless otherwise stated. Shaded columns indicate "cleaned" material. nd - no data.

Parameter	Waste Tip Feedstock	Washed Gravel After Jig	Coal Residue From Jig	Sand Fraction After Density Spiral	Coal From Density Spiral	Sand Wash Residue
Material mass balance (% dry matter fraction of input)		40	34	7	14	5
LOI (%)	12.87	3.40	12.70	9.20	17.15	nd
Total PAH	11692	405	33836	3675	14492	nd
Benzo(a)pyrene	323	30	500	190	325	nd
TPH	693	150	530	405	755	nd
BTEX	26	1	41	10	25	nd
Phenols	13	3	43	6	5	nd
Cyanide	1467	700	1200	2050	2250	nd

The results of chemical testing of the waste tip feedstock indicated that PAHs and cyanides were the main contaminants of concern, with an average concentration of 11692 mg/kg and 1467 mg/kg respectively. The PAHs were mostly 2 and 3 ring compounds.

During treatment, approximately 75% of the material was >2mm. Subsequent treatment of this gravel-sized fraction with the mineral jig removed 97% of the PAH contamination to a low density product which consisted mainly of coal and pitch particles. The remaining higher density product was substantially depleted in PAH (405 mg/kg and specifically 30 mg/kg for benzo(a)pyrene) compared to both the original waste tip feed, and the total gravel fraction (Table 2).

Further scrubbing of the contaminant-depleted higher density product in the drum scrubber resulted in very little improvement in reducing the concentrations of any of the contaminants.

For size fraction <2 mm, the spiral concentrator and froth flotation removed approximately 38% PAH (data not shown).

A materials mass balance of washed waste tip material indicated that approximately 75% is gravel-sized, approximately 21% is sand sized and approximately 5% ends up as the sludge fraction. Approximately half of it (up to 47% of input) was described as potentially recyclable as gravel which could be suitable for reuse in certain areas on site. The gravel is described as a mixture of shale, slag and natural gravels. The residue of the gravel washing consisted of clinker and coal particles, intermixed with wood, plastic and rubble. The residue had a high calorific value and could be potentially marketable as a secondary fuel.

The "cleaned" sand was a relatively small proportion of the waste tip material (7%). Although depleted in PAH relative to the waste tip feedstock, this was still considered too high (3675 mg/kg) to be suitable for use as a recyclable waste. The "cleaned" sand was black in colour, and its high loss on ignition value indicates the presence of residual clinker and coal. Further washing of this sand may improve the quality, but probably not to acceptable limits.

6.2 Plant Area Material

For the plant area material (Table 3), the main contaminant of concern was PAH. As with the waste tip feedstock, the plant area material is dominated by a particle distribution which is mostly gravel-sized.

Segregation of materials >2 mm, followed by mineral jigging produced a contaminant-depleted product which 76% by weight of the total plant area material.

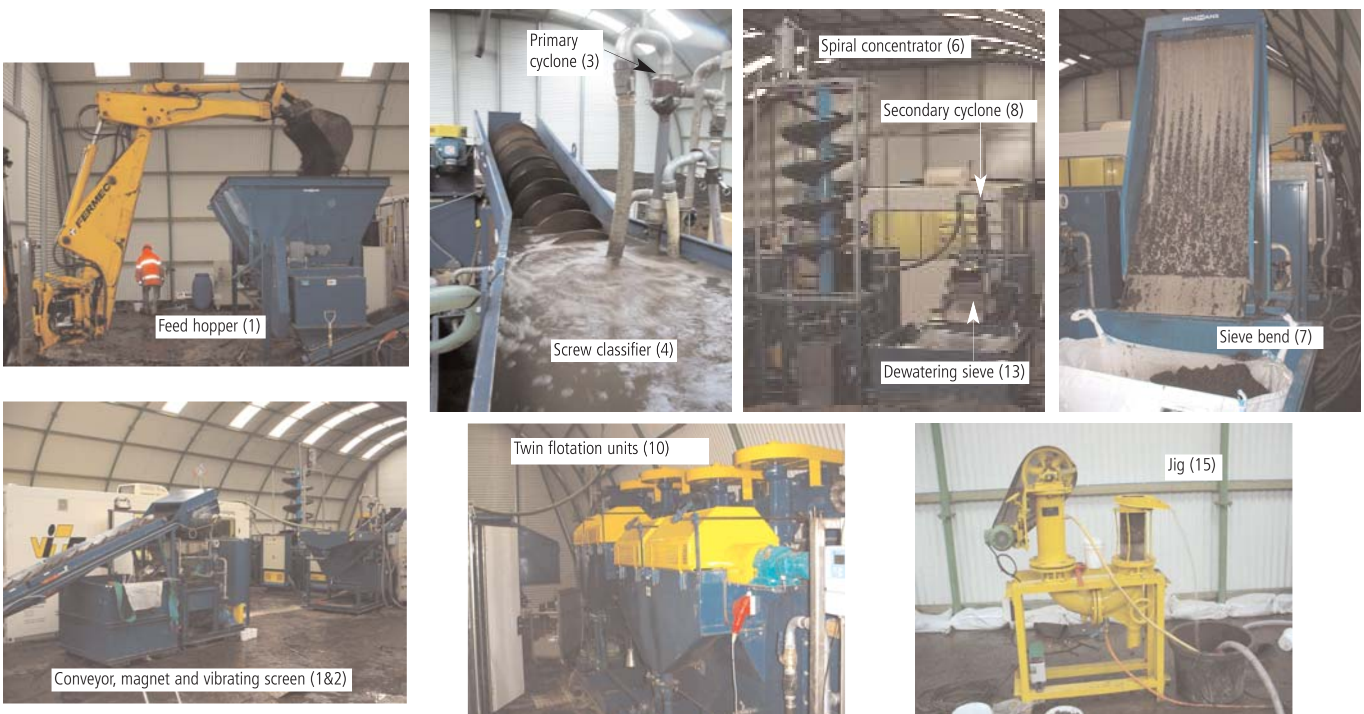

Figure 2. Photographs of a selection of modules in the soil washing process. The numbers correspond to the modules in Table 1.

Table 3. Material mass balance and chemical analysis of treated plant area material. Results are expressed as mg/kg unless otherwise stated. Shaded columns indicate "cleaned" material. nd - no data.

Parameter	Plant Area Feedstock	Washed Gravel After Jig	Coal Residue From Jig	Sand Fraction After Density Spiral	Coal From Density Spiral	Sand Wash Residue
Material mass balance (% dry matter fraction of input)		76	10	8	2	4
LOI (%)	9.80	1.40	13.60	4.25	18.15	nd
Total PAH	9841	1420	23017	2668	14133	nd
Benzo(a)pyrene	565	57	1600	150	735	nd
TPH	520	87	820	210	625	nd
BTEX	17	2	59	8	59	nd
Phenols	8	1	32	1	5	nd
Cyanide	175	14	95	250	295	nd

The resulting residual PAH concentration was approximately 1400 mg/kg (57 mg/kg benzo(a)pyrene), and this material is unlikely to be suitable for reuse in surface soils but could be recycled for use in the subsurface. It may be possible to reduce this concentration by further optimisation of the jig.

For the sand-sized fractions the highest concentrations of contaminants were recorded in the low density spiral product. The highest efficiency was reached by the density spirals, which reduced the total PAH concentrations by approximately 73% to 2668 mg/kg.

A materials mass balance of the plant area material indicated a higher amount of potentially recyclable contaminant-depleted gravel than from the waste tip material (76% of input). The gravel is described as ballast, slags and natural gravel. Only approximately 8% sand was recovered, which was of a poor quality. The residue from the sand washing formed approximately 4% of the input.

6.3 Potential Use of Residues

Washing of waste tip and plant area material resulted in residues such as the coal-clinker residue from the jig and coal residue from the sand washing. These residues had calorific values between 13 and 21 MJ/kg. This suggests a possible reuse as a minor fuel. The waste tip has the highest calorific value due to its wood and coal content. This is very promising as coarse coal forms approximately one third of the screened waste tip soil that was treated. However, due to variability of material in the waste tip, the overall proportion may be significantly different.

Another important residue, although limited to approximately 5% of both materials, is the sludge cake. As the calorific value is low (5 MJ/kg), it is not suitable for co-incineration. However, as landfill regulations prevent the disposal of sludge, it could easily be dewatered to a hard filter cake with about 70% dry matter, prior to disposal.

As expected, the process water and water from sludge dewatering showed elevated concentrations of cyanides and PAHs which required further treatment.

7. FULL-SCALE CONSIDERATIONS

One of the main objectives of the trial was to assess the potential of a full-scale soil washing plant, based on the operation of the pilot-scale version.

7.1 Capacity

The plant used for the trial had a capacity of up to 1.2 tonnes/hour, whilst it is noted that full-scale plants have a capacity in the order of 50-100 tonnes/hour. The full-scale capacity depends on material and equipment characteristics and would depend on treatment volumes.

7.2 Costs

The costs for a full-scale soil washing treatment of these soils were estimated at £20-£25/tonne. These costs exclude fixed costs such as mobilisation, and costs for off-site disposal of residues such as the filter cake, plastics and wood.

7.3 Limitations or Potential Difficulties

One difficulty encountered in the trial involved the separation of fine coal and clinker particles in the sand size fraction. It may be possible to improve on this part of the treatment further, but the material will still remain largely contaminated. It may be possible for this material to be incorporated into another treatment process.

7.4 Environmental Impact

At full-scale, the process requires large volumes of water. Some water is taken up by the washed materials and additional water frequently needs to be added. During soil washing, despite the dilution of process water by the additions of "clean" water, treatment may be required before any discharges to trade waste drainage systems can be made. In addition, to minimise the environmental impact associated with spills, an effective containment system will be required.

8. CONCLUSIONS

It is estimated that soil washing could produce a contaminant-depleted product from the waste tip material which meets the site-specific waste recycling requirements. This material represents 40% by proportion of the original material. A further 7% might also be recyclable if further modifications are made to improve the treatment efficiency.

Approximately 76% of the plant area soil may be able to be recycled as gravel with some minor improvements to reduce the PAH concentrations still further. As with the waste tip material, the 8% sand fraction is of lower quality. The 12% coal residue may be useful as secondary fuel whereas 4% of the fine residue could be treated by another remediation technology and reused on site, or disposed of.

Coal and clinker together form the other half of the waste tip, and are potentially recyclable as secondary fuel, e.g. for blending with high quality coal. This is obviously dependent on a market for the material at the time of treatment. Therefore only 5% of the waste tip is unusable residue, and this can be subjected to an alternative treatment technology and reused on site or dewatered for safe disposal if necessary.

It was suggested that the oversized fraction of the waste tip could be treated, after some pre-screening and crushing. This may help to further reduce the volume of waste materials present.

The costs for full-scale soil washing of these soils will be between £20-25/tonne, excluding fixed costs and disposal of residues.

Acknowledgements

This bulletin was prepared by CL:AIRE staff from information provided by DEC NV and Jacobs. CL:AIRE would like to thank Jonathan Smithson and Anke O'Donnell of Jacobs, and Mike Pearl of UKAEA, who reviewed this bulletin. This trial was funded by English Partnerships through the National Coalfields programme's £104.5M remediation project for the Avenue Site.

For further information on soil washing contact Guy Pomphrey at DEC NV on:
Tel: 01342 323000; Email: pomphrey.guy@decukltd.com; or by visiting the website at http://decukltd.co.uk

Details on the Avenue Coking Works can be found at www.theavenueproject.co.uk

This document is printed on Era Silk recycled paper (FSC certified TT-COC-2109) using vegetable-based inks.