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Demonstration project for the on-site remediation of polluted manufactured gas plant sites
by three innovative technologies

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Executive Summary

Three technologies for on-site remediation of soil polluted by manufactured gas plant activities have been demonstrated at the MGP site of Lier. The field demonstration was preceded by a detailed site investigation and extensive laboratory scale treatability studies.

Soil with low PAH concentrations was treated with biopiles with five conditions, including a control, bio-augmentation with PAH degrading bacteria, chemical-biological treatment, white-rot fungi and a combination of bacteria and white-rot fungi. None of these technologies was effective for removal of PAH during the field demo. Results of laboratory-scale treatment were superior to those in the field but were also inadequate. Limited bioavailability of the PAH is believed to be the cause.

Soil washing was effective for removing PAH and cyanides from the sand fraction of soil contaminated with higher contamination levels. The coarse gravel fraction which was isolated from the soil wash plant was still significantly contaminated. Results in lab scale tests were comparable to those achieved in the field. Soil with high PAH contamination levels was treated with the Clean Soil Process (coal agglomeration) on a lab-scale. The process was effective for one out of two soils.

1. Pollution at manufactured gas plant sites

Polluted Manufactured Gas Plant sites (MGP) are widespread in the industrial world. They produced gas that was used for lighting and heating purposes from the second half of the nineteenth century through the 1950s. The raw material was usually coal (dry distillation of bituminous coal, although in some instances oil was used too. The raw gas was purified on site prior to storage in gas holders.

The following process residuals were obtained and usually stored or dumped on the side or in the surroundings:
- coal tar, stored in tar pits
- ash, clinker, coke and lamplblack
- cyanide purifier materials (based on iron oxide and lime)
- ammonia liquor
- spent gasoil.

Typical pollutants which are found in MGP soils and groundwater are aromatic hydrocarbons (BTEX), polyaromatic hydrocarbons (PAH), cyanides, thiocyanate, phenols, heterocyclic compounds, ammonia, sulfate and sulfides and sometimes heavy metals (Hayes et al., Eds, 1996).
2. Remediation technologies for MGP sites

Thus far these sites have been remediated mainly through isolation, or by excavation followed by off-site disposal or thermal treatment (Schmidt, M., 1995). Isolation requires costly long term monitoring and treatment of groundwater for containment of polluted groundwater (usually required during decades). Landfilling of excavated materials only shifts the problem and consumes scarce landfill capacity. Thermal desorption is very effective to remove PAH and cyanides, but it is costly and thermal treatment capacity is not widely available. In general, those approaches are expensive and there is a need for adequate and cheaper alternatives.

Bioremediation has been widely used as a low cost technology for cleanup of soils which are contaminated with mineral oil. Bioremediation of soil contaminated with PAH has proved difficult because high molecular weight PAH (especially 5- and 6-ring PAH) are difficult to degrade biologically. This is ascribed to their low bioavailability (low water solubility) or inherent recalcitrance. Nevertheless, often success is claimed when using technologies which promote bio-availability of PAH or which circumvent these problems (Sprenger, C. et al., 1994). Inoculation with specialized bacteria that have hydrophobic properties may be helpful, as well as with white-rot fungi that may degrade PAH with extracellular enzymes (Munnecke D.M. et al., 1995). Another approach is the chemical cleavage of high-MW-PAH as a pretreatment for a biological degradation of the ring fission products (Srivastava, V.J. et al., 1994). These approaches may be useful for treating soils with relatively small degrees of contamination. Free cyanide is susceptible to biodegradation, although complex iron cyanides are known to be difficult to be degraded biologically. However, the latter are considered to be far less toxic than free cyanide.

Soil washing is a process which is suitable for treating sandy soils with a wide range of organic as well as inorganic pollutants. The sand fraction is separated from the soil by screening and density separation and it is cleansed by consecutive physical and chemical treatment steps. The pollutants are usually concentrated in a relatively small organic fraction and a fine particulate sludge fraction which are both disposed of (landfilling or incineration). A typical process scheme is shown in enclosure 1.

Soil with a very high level of pollution by coal tar may be difficult to treat. Landfilling is not possible due to the high organics content. Incineration is very expensive. Thermal desorption is limited by a maximal content of organics in the soil (1-2% at most to avoid explosion danger). Such a soil may be cleansed with the Clean Soil Process (CSP), a modified soil washing process which uses heat and coal to mobilize and absorb the tar components. A typical process diagram is shown in enclosure 2. Pollutants which are associated with coal tar can be transferred from soil to coal particles, to which they are preferentially sorbed by tumbling and abrasive effects in a washing drum in which temperature and soil/water ratio are controlled (Szymocha, K. et al., 1995). The tar/coal agglomerates which are formed are removed through sieving, separation by density and froth flotation. They can be used for co-combustion in coal-fired power plants or cement kilns.
3. Project scope and objectives

In this project, three innovative technologies for ex-situ and on-site treatment of polluted MGP soils have been demonstrated and evaluated for technical and economical feasibility. These are the Clean Soil Process (CSP), soil washing and bioremediation in biopiles. Target pollutants were PAH, but the effects of treatment on cyanide were evaluated as well.

The technologies were demonstrated at the site of the abandoned MGP in Lier, Belgium. They were applied according to the degree of soil contamination. Pollution at the site has been characterised extensively. Parts of the site have been selected for treatment with one of the above techniques, following excavation and chemical analysis.

A part (70 tons) of the soil with low pollution levels (20 < PAH < 100 mg/kg DS) has been treated by on-site bioremediation, of which several conditions were tested (control, inoculation with PAH degrading bacteria, inoculation with PAH degrading fungi and chemical-biological treatment).

A part (50 tons) of the moderately polluted soil (100 < PAH < 1000 mg/kg DS) has been treated by soil washing with an on-site installation.

A part (50 tons) of the most polluted soil (PAH > 1000 mg/kg DS) will be treated with the Clean Soil Process. Pollutants are transferred from soil particles to coal particles to which PAH are preferentially. The coal agglomerates containing the PAHs removed from the soil can be combusted in conventional coal fired power plants.

The project involved the following parties: VITO (Mol, Belgium), Jan De Nul- Envisan nv (Aalst, Belgium), OVAM, the city of Lier (Belgium). For certain tasks, a collaboration was set up with Thermo Design Engineering (TDE, Edmonton, Alberta), Intech 180 (Salt Lake City, UT) and Aeres GmbH, Berlin.

4. Techniques implemented and results achieved

Site investigation, excavation and soil preparation

In a first phase, pollution of the soil at the site has been characterized extensively. This nearly doubled the size of the contaminated area when compared to an earlier site investigation. This illustrates the fact that MGP sites are very difficult to characterize, due to the very heterogeneous and complex nature of the pollution. Additional hot-spots were identified which were caused by two tar pits, gas purifier installations as well as by two additional gas holders. Pollution was found to extend beyond the MGP-site, along a former small river which crossed the site. A lot of demolition debris was found in many areas of the site, as well as sintered coal and pure tar.

The soil for the field demonstration was excavated and sieved at 40 mm. The natural soil consisted mainly of clay containing sand. Approximately 10% of the material was discarded as oversize rubble (mainly demolition debris).
Bioremediation in biopiles

Preliminary treatability tests in the laboratory

The soil that was used had total cyanide of 100 mg/kg; free cyanide: 1.5 mg/kg; PAH (16-USEPA): 424 mg/kg. The bulk of the total PAH concentration was from high molecular weight PAHs (2-rings: 0.9 %; 3-rings: 13.2 %; 4-rings: 49.5 %; 5-rings: 21.3 %; 6-rings: 10.7 %). The screening tests were based on slurry biodegradation tests or microcosm tests. Slurry biodegradation tests used 50 gdm soil and 200 ml of distilled water or an aqueous solution containing various additives. The flasks were shaken for aeration during 6 to 12 weeks. Microcosm tests used aerated soil, with soil moisture adjusted to 60% of water retaining capacity.

In comparison to abiotic or live controls, there was no significant effect for adding inorganic nutrients (nitrogen and phosphate), or commercial nutrient formulations such as Inipol EAP22 (Elf Atochem) or Biocrack (Henkel AG).

The effect of adding four different commercial detergent formulations was tested as well (nonionic and mixtures of non-ionic and anionic detergents). None of these had a significant effect on pollutant end concentrations.

Bio-augmentation with bacteria which were isolated from contaminated soils on selective PAH-media (Mycobacteria and Spingomonas sp., added at application rates of 10E7 and 10E8 per gram soil) did promote limited biodegradation of PAH (30 % removal), while no effect was observed on total cyanide levels.

A combination of chemical and biological treatment, in which the soil was at first treated with Fenton’s reagent (iron sulphate with hydrogen peroxide), followed by inoculation with PAH-degrading bacteria, did enhance biodegradation to a limited extent, i.e. 38 % removal of total PAH and 15% removal of total cyanide.

Bio-augmentation with white-rot fungus was evaluated with microcosm tests. Autoclaved fungus was used as a control. With two different qualities of Pleurotus ostreatus spawn (old cultivated spawn and uncultivated substrate), approximately 50% reduction in total PAH but no change in cyanide levels was observed for live as well as autoclaved fungus, as compared to a live control without fungus. It is concluded that the reduction in PAH-levels with Pleurotus o. was not caused by biodegradation, but rather by immobilization of PAH to the organic spawn.

In a microcosm experiment which was performed by Intech180 (Salt Lake City, UT), three species of pelletized white-rot fungi were evaluated at two application rates (10 and 20%), with and without addition of a detergent. Species tested were Pleurotus ostreatus, Irpex lacteus and Phanerochaete sordida, in addition to Pleurotus o. spawn. While significant decreases in the concentrations of PAHs were observed in almost all of the treatments, there was a wide variation in treatment effectiveness. The most effective treatment employed I. lacteus without surfactant amendment, for which a 38% decrease in PAH concentration was observed after 8 weeks. Results with Pleurotus o. spawn were similar, i.e. a 33,1% decrease in PAH concentration.
In an attempt to find out whether the lack of biodegradation of PAH was caused by inhibition of bacteria by soil toxicity, a slurry biodegradation test was set up in which the effect of MGP-soil on glucose degradation was evaluated. Glucose was added to garden soil, to MGP-soil and to a 1:1 mixture of garden and MPG-soil. The respiration rates during the first four weeks were high and very similar for all three conditions. Over a longer period, the respiration for glucose amended garden soil and the glucose amended mixture of garden and MGP soil were twice the rate of glucose amended MGP-soil, which was still significantly higher than the respiration of MGP-soil without glucose added. Thus, the MGP-soil did not significantly inhibit the respiration activity of soil bacteria. Soil toxicity was also checked with a biosensor technique. Biosensor response to the soil was only marginally affected by the MGP-soil as compared to a control garden soil.

In general, PAH degradation activity was absent in soil slurry tests with soils from three different locations from the site. None of the conditions tested allowed for a complete or sufficient biodegradation of PAH and cyanides. Respiration was observed for all conditions except for dead controls, although it was limited for most conditions and moderate to strong when an inoculum of bacteria or fungi was used. Based on these findings we conclude that the lack of significant biodegradation is probably not due to soil toxicity, but rather to the limited bioavailability of the PAH which may be present in weathered tar droplets.

Pilot Scale demonstration of bioremediation

At first, three aerated biopiles were set up which contained 20 tons of soil each (see enclosure 3). Half of biopile 1 consisted of unamended soil, the other half was amended with inorganic nutrients (nitrogen and phosphorus). The soil of biopile 2 was amended with inorganic nutrients and bacterial inoculum. The inoculum consisted of two types of *Sphingomonas* sp, applied at 3x10E6 cells/g soil. Three quarts of biopile 2 consisted of soil amended with a liquid inoculum, the other quart consisted of soil amended with an inoculum grown on sand of the MGP-site. The soil of the third biopile was at first treated with Fenton’s reagent and it was subsequently amended with inorganic nutrients, water and with the same liquid bacterial inoculum as biopile 2.

None of the treatments had a significant effect on concentrations of PAH and cyanide over a period of 500 days. Biodegradation did not occur, contrary to the limited biodegradation that was observed in laboratory treatability tests with bacterial inoculation or chemical-biological treatment. Two weeks after inoculation of the soil, bacteria that can grow on PAH as only carbon source were found in significant numbers in biopiles 2B and 3, and only marginally in biopile 2A. Three months later, bacteria capable of growing on PAH-media were only detectable at diminished numbers in Biopiles 2B and 3, which conditions also had higher counts on rich growth medium than conditions 1A, 1B and 2A.
The two conditions with fungal inoculation were not demonstrated on a large scale because of contamination problems which occurred during the production of fungal pellets. Because of this, the biopile treatment was repeated on a smaller scale with soil in aerated bigbags (1.5 tons of soil each; see enclosure 3). The following conditions were used (all soil supplemented with water and nutrients):

- control (BB1),
- with bacterial inoculum (BB2),
- with Fentons’ reagent and bacterial inoculum (BB3),
- with fungal inoculum (BB4) and
- with bacterial and fungal inoculum (BB5).

The bacterial inoculum consisted of three Mycobacteria sp. and two Spingomonas sp, applied at 10E7 cells/g. Fungal inoculum (Pleurotus o. mushroom substrate) was added at 10% (v/v).

Similar to the larger scale biopiles, no significant biodegradation of PAH nor cyanides was observed in any of the conditions after 300 days (BB1-3) or 120 days (BB4-5). Three weeks after inoculation, bacteria capable of growing on PAH-media were below detection limit (<10E2/g) in the control (BB1) and were found (10E3/g) in inoculated conditions (BB2 and BB3). After 16 weeks, the control had marginal counts of PAH-degraders (10E2/g), while PAH degraders in BB2 and 3 were 10E3-10E4/g. For the conditions with fungal inoculum, lower numbers of PAH-degrading bacteria were found following inoculation. Competition with fungal substrate may be an explanation. The survival of inoculated bacteria in the soil could specifically be demonstrated five weeks after inoculation by PCR-analysis with genus-specific primers.

**Soil Washing for moderately polluted soil**

**Laboratory Scale Treatability tests**

Laboratory scale studies were used to evaluate the effects of chemical additives, such as detergents, dispersants, fenton’s reagent and alkaline treatment. The use of detergents (3 tested by Aeres GmbH, Berlin), dispersants (6 tested) and cosolvents (1 tested) in a first washing step prior to flotation did not provide a net additional effect compared to soil washing without these additives. Therefore they were not used on a pilot scale.

Treatment efficiencies for PAH-removal on lab-scale were very similar to those that were found later on a pilot scale. On a lab-scale, chemical treatment during the attrition step and prior to froth flotation was necessary to achieve adequate removal of cyanide: 45 % removal without versus 80 % removal with chemical treatment. Oxidation with Fenton’s reagent or alkaline treatment produced similar results. Cyanide removal proved easier on the pilot scale, where no specific chemical oxidants or alkaline treatment were required.
Pilot Scale Demonstration of Soil Washing

Six different lots of moderately polluted soil (30 ppm < PAH < 800 ppm; 50 tons in total, have been treated with a mobile soil washing plant with a capacity of 1.5 tons/h. Several process configurations, two different foamers and three collectors for the flotation step were tested over 14 test runs.

The process included the following steps (see enclosure 4):
- washing of the soil in a rotating drum at 50% ds,
- wet screening at 4 mm to remove the coarse fraction,
- two step hydrocyclone treatment with intermediate attrition scrubbing to remove the sludge fraction (silt, clay and fine particulate organics),
- a coal spiral to remove organic particulate matter,
- sieving at 0.3 mm (to remove coal and sintered materials from the sand fraction),
- chemical conditioning in a stirred tank and two-chamber froth flotation;
- dewatering of the cleansed sand with a screw classifier.
- The process water was treated by polymer flocculation, followed by sludge sedimentation in a lamella separator; it was recycled in the process.
- The sludge from the lamella separator was dewatered with a filter press.

With optimal conditions, over 98% of total PAH and over 93% of total cyanides have been removed from the sand fraction of the soil. The average removal of PAH for 14 test runs was 92%, the average removal of cyanide was 85%. The coarse fraction (3-40 mm) was significant (approximately 10 tons) and contained a lot of sintered coal. In general, it was enriched in PAH when compared to the untreated soil. Cyanide was not particularly enriched in this fraction. The fraction with grain size between 3 and 0.3 mm, which was removed after cycloning, consisted mainly of sintered coal. For some lots of soil, its PAH content was lower than for the untreated soil. However, for other lots of soil, its PAH content was higher than that of the feed material.

Clean Soil Process (CSP) for very polluted soil

Laboratory Scale tests

Laboratory scale treatability tests demonstrated the method’s effectiveness for soil from one location, which was found below one gas holder and which was not very weathered. This sample had an initial tar content of 14,300 ppm and a PAH(16) content of 1173 ppm. For this soil, 98% removal of tar from the sand fraction was achieved. CSP was not so successful for a very weathered soil from another location (initial tar content of 33100 ppm; initial PAH(10) content of 2790 ppm). For this sample, only 88% removal of tar from the sand fraction was obtained, with still had too high residual PAH levels.
Pilot Scale Demonstration of the CSP

Because the Canadian partner Thermo Design Engineering has withdrawn its active involvement, which implied providing and operating its CSP-pilot plant at the location in Lier, this part of the demonstration project has not been executed yet. Vito is looking for an alternative partner with whom its own pilot scale soil washing plant can be transformed for the CSP-process in a safe manner. Approximately 50 tons of the most polluted soil (PAH > 1000 mg/kgds, containing residual tar) are scheduled to be treated with this process.

5. Environmental Impact

Bioremediation has the potential for having the lowest environmental impact. When successful, 100% of the soil can be reused. Some MGP soils may contain significant amounts of volatile pollutants, such as naftalene, BTEX, hydrogen sulfide and hydrogen cyanide. One has to take measures to avoid emissions to the atmosphere which may arise during soil aeration. This can be achieved with biofilters or activated carbon filters. Only a limited amount of additives, such as fertilizers, bacteria or fungi, are required. The fungi are available from mushroom farms and pose no environmental danger. The bacteria that are used for inoculation were isolated from natural environments. They have hydrophobic properties and are unlikely to spread significantly from the biopiles to the surrounding environment.

Soil washing and CSP both use process water which can be recycled in the process to a limited extent. The processes are net consumers of water, as part of the process water is removed by the residual sludge fraction which is relatively wet (approx. 40% ds). In general, the water content of the fractions which are produced is higher than the water content of the process input. The water which is recycled requires treatment for which chemicals are needed, such as coagulants and flocculants. Some process water may have to be purged if treatment efficiency is inadequate. The use of coal in the CSP is claimed to have the advantage of producing a cleaner process water which requires less treatment.

During the washing process, volatile pollutants can be liberated, especially during screening and froth flotation. Special measures may be required to contain these emissions. These measures will be more difficult (costly) to implement than in the case of bioremediation.

Soil washing and CSP generate residual fractions, such as a sludge fraction (fines from hydrocycloning, flotation foam) and an organic fraction (e.g. coal residues) which can be highly contaminated and which must be disposed of by landfilling, incineration or co-combustion. In the case of CSP, an organic fraction with high caloric value is produced (coal loaded with tar) which may be used for co-combustion in cement kilns or electrical power plants.
Soil washing and CSP require considerable amounts of energy for mechanical equipment. In the case of CSP, additional energy is required to heat the process water for the first washing step (equivalent to the mass of soil treated) to 70-80 °C. A part of this energy can be recovered when the tar loaded coal is combusted at a later stage.

All three on-site technologies involve soil excavation and screening. During these operations, volatile pollutants may be liberated in the atmosphere. Care should be taken to minimize these emissions, e.g. by keeping the excavation area minimal at each moment, by applying surface covering foams or slurries to supress volatilization or by working under a tent for excavation of hot spots.

6. Economic and Environmental Cost/Benefit Analysis

Bioremediation is the remedial option with the lowest treatment cost. It also has the lowest environmental impact (secondary emissions, use of natural resources). These include a limited use of fertilizers and irrigation water, besides energy for aeration by a blower or by soil tilling equipment. However, because of its limited effectiveness for pollutants which are found in MGP soils, it can only applied to a limited extent, depending on local regulations for cleanup target values and initial concentrations of pollutants in the soil.

Soil Washing is a technology with average treatment cost which is widely available. It uses more natural resources than bioremediation (energy, chemicals for treatment of process water). It also leaves a highly contaminated residual fraction (up to 25% of sludge, consisting of soil fines and organic matter) which requires landflling or combustion. It may fill a niche to treat soils with average pollutant levels which cannot be treated biologically and which may be cheaper to treat by soil washing than by thermal treatment. Soil washing is likely to be more easily permitted for on-site treatment than thermal desorption, which requires extensive treatment of process air.

The CSP process is an innovative technology, with only one commercial plant in operation in Canada. It has higher capital and treatment costs than conventional soil washing because certain process equipment may be used for a limited throughput and because of the high energy costs which are associated with heating process water. The success of this method may also depend on the willingness of power plants or cement kilns to combust the tar/coal fraction which is generated in the process and at which price they will do this. Because of the higher costs, CSP is reserved to soils with a very high tar content, for which there is currently no alternative but combustion, which is prohibitively expensive. Thermal desorption may not be applicable for these soils because their caloric value is too high. Landflling may not be an option because the organic content is too high.
7. Potential for Transferability of the Results

The results obtained in this project may be transferred to a large number of MGP sites in Europe where coal was used as a raw material for the production of gas.

For bioremediation, the methods effectiveness for PAH removal will depend to a large extent on the PAH composition profile and bioavailability. When high molecular weight compounds are predominant, such as in the case of this project, bioremediation is not likely to be successful. This may be the case in highly weathered soils. Some soils may be less weathered, e.g. soils from greater depths, which may contain higher proportions of low molecular weight PAH. For these soils, bioremediation may be a viable option. In a number of cases however, bioremediation potential may be limited by other factors such as soil toxicity or a low pH which can be due to the high sulphur content which is typical for many MGP soils.

The results for the soil washing process are likely to be transferable to a large number of sites. The process that was used in this project is typical for a great number of commercial soil wash plants in Europe. Moreover, six different lots of soil which were excavated from different locations across the site gave similar cleanup efficiencies. An important factor which may limit the applicability is soil texture. Soil washing is limited to soils which contain a large fraction of material that can be re-used (sand and gravel; > 70% m/m). Initial pollutant levels and cleanup targets will determine the methods applicability to a greater extent than for thermal desorption. Preliminary soil treatability tests are advised.

The results for the CSP process are likely to be transferable to a large number of MGP-sites. The results which can be achieved with the technology appear to be determined by the quality of the tar which is found in the soil, which may vary according to the degree of weathering and perhaps also according to gas manufacturing process conditions which determine the quality of the tar. Soil texture is another factor that has to be considered in a similar way as soil washing. Treatability tests are advised to evaluate the methods effectiveness in advance.

8. Implications for employment

There are direct and indirect implications for employment.

Direct implications are related to the remediation activities of polluted sites. These are slightly higher for more intensive techniques such as soil washing or the Clean soil process. Typically, a soil washing plant or CSP-plant will employ two full-time operators for treating approximately 30 tons of soil per hour. Bioremediation may require periodic tilling of the soil for aeration by one operator (typically once a week to once a month during twelve months).

Indirect implications for employment are likely to be much more important. They arise from new uses of currently abandoned “brownfield” land which is usually located in urban areas with relatively high land value and significant potential for new industrial development.
9. Dissemination activities

These included the following:
- a videotape was made during the project activities (in Dutch or English language)
- information leaflet about the project for distribution to interested parties (Dutch)
- information meeting for the community surrounding the gasworks of Lier
- information meeting for Belgian authorities (City of Lier, OVAM, BIM, Regional Ministry of Environment of the Federal Region of Brussels)
- site visits for problem holders (such as Electrabel) and interested parties
- coverage of the project on local radio (Radio Mol) and on local TV (TV Brabant)
- poster presentations at soil remediation conferences: Battelle Meeting in Monterey, CA (2000); UNO-Conference at Paris (March 2001)
- Several articles in technical and non-technical Belgian journals or magazines.

10. References

Enclosure 1: Typical process diagram for soil washing

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GRONDWASPROCES

Polluted soil → SCREEN → Clean oversize → Process water
                ↓                        ↓
       HYDROCYCLONE        ATTIRITION SCRUB
                ↓                        ↓
       COAL SPIRAL         Organic fraction
                ↓                        ↓
       HYDROCYCLONE        sludge
                ↓                        ↓
       FLATIONATION        Concentrate
                ↓                        ↓
       DEWATERING          Residue disposal
                ↓                        ↓
       DEWATERING          Clean sand for re-use
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WATER treatment

dirty water
Enclosure 2: Basic flow sheet for the Clean Soil Process
Enclosure 3: Bioremediation on a pilot scale - photographs

Figure 1: Set-up with bigbags for bioremediation at the MGP-site of Lier

In the front, three bigbags can be seen (BB1-3).
In the background the activated carbon filter (right), air blower (middle) and drainage water tank (right) that were also used for the biopile treatment can be seen.

Figure 2: Bioremediation with 3 biopiles at the MGP-site of Lier
Enclosure 4: Soil Washing Pilot Demonstration - photographs

Pilot scale soil washing plant

Clean sand produced by the soil wash process

Coal-rich residual stream from the soil wash process