

Soil Remediation Techniques

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Tim Stewart

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1. Introduction

Detrimental human activities have had a major impact on the world's environment over the last two hundred years, and more so in recent years, polluting land, air and water. Soils were allowed to absorb many pollutants as industries went unchecked and discharged their waste products directly onto and into the ground.

Governments around the world gradually recognised the fact that their activities, and the activities of licenced and non-licenced companies, were polluting the land and its soils, through industrial processes and through extracting materials such as Iron Ore, Oil, and Coal from the earth.

Having recognised the problems being caused, many countries introduced laws to remedy the soil contamination problems. For example the United Kingdom Government introduced the *Pollution Prevention and Control Act (1999)*. and the Chinese Government introduced the *Soil and Groundwater Pollution Remediation Act General Principles (2003)*. The European Union is slowly moving towards creating a standard for soil remediation for all its member states. However, in the meantime, a lot of European countries have adopted the 'Dutch Standard' for soils.

The Dutch Standard (VROM, 2000) indicates the allowable amounts of contaminants permitted in the soil before intervention and remediation action needs to be implemented. For example, 'The Standards' cover Metals (lead, mercury, arsenic and others), other inorganic substances (chloride, cyanide and others), aromatic compounds (benzene, phenol and others), polycyclic aromatic hydrocarbons [PAH] (anthracene and others), chlorinated hydrocarbons (dichloromethane, dioxin and others), pesticides (DDT and others) and additional substances (asbestos and others).

In many soil remediation situations, there may normally be a reason to use two or more soil remediation treatment techniques to tackle the soil pollution problem. This may be due to the fact that the soil is contaminated by two or more different pollutants, for example a heavy metal and a hydrocarbon. Subsequently, two or more soil remediation techniques may be required because there are different compositions of the soil at a particular site, or different layer types in the soil, or the position of the aquifer in the soil may determine multiple soil remediation techniques. For example, a case study undertaken by Lageman and Godschalk, (2007) analyses the success of a combined technique of soil heating (by introducing electrodes into the ground), and soil vapour extraction.

There are three general categories for soil remediation techniques. They are biological remediation, chemical remediation and Physical (Engineering) remediation. However many of the remediation techniques fall into two or more of the categories, for example, Sparging, is a Physical (engineering) remediation process when air is pumped into the soil, and it is known as 'Air Sparging'. On the other hand, when you pump nutrients into the soil it is known as Bio Sparging, and falls into the two categories of Physical and Biological Remediation.

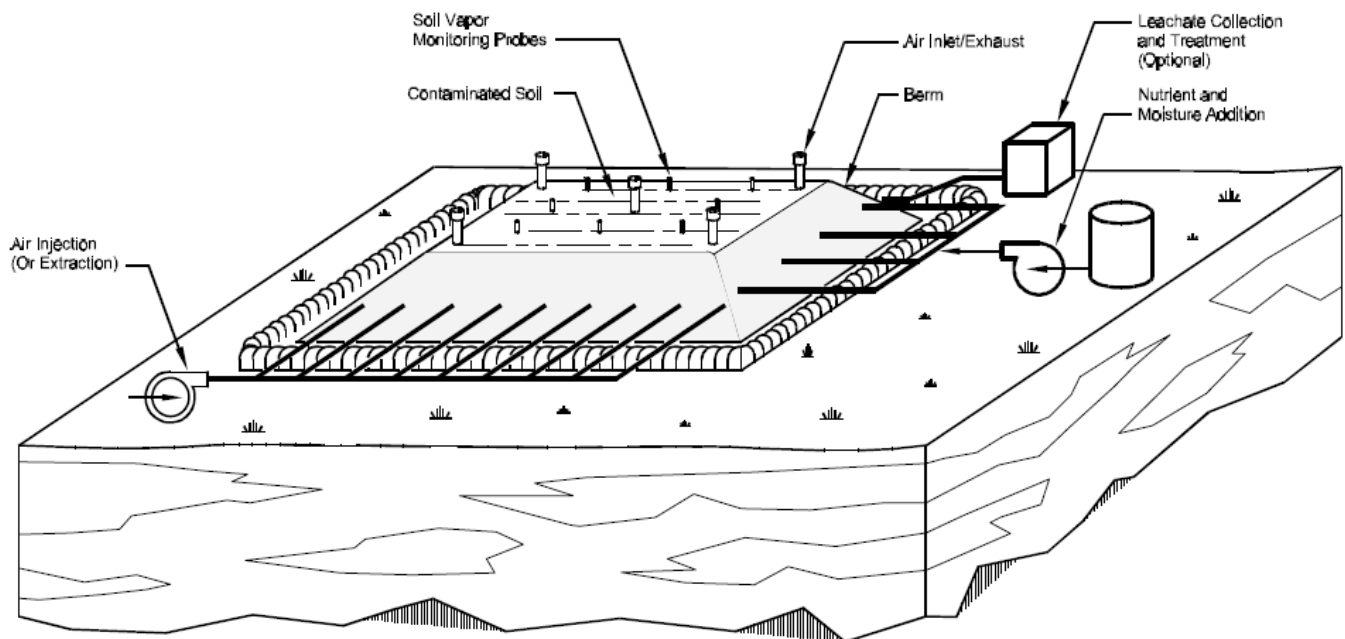
With this in mind, this report is not going to split the different procedures into the three categories; instead it is going to deal with the soil remediation techniques individually.

2. Soil Remediation Techniques

2.1. Bio-piles

Bio-piling is mainly an ex-situ (off site) soil remediation technique, although it can be accomplished on site. According to Wu (2009 p2) it is especially good for removing petroleum hydrocarbons from contaminated sites. The United States Environmental Protection Agency agrees with this when they say Bio-piles are used to reduce concentrations of petroleum constituents in excavated soils (USEPA. 2016. Bio-Pile pIV-1). This is achieved by heaping the soil up in one area, and allowing it to act as a 'compost heap'. The heat that is generated within the soil pile helps to remove the contaminants. To speed up the process of decontamination of the soil - air, moisture, nutrients and minerals can all be introduced into the bio-pile. Depending on what types of vapours are given off the bio-pile will depend whether they are captured and treated or just vented off to the atmosphere.

Typical Biopile System



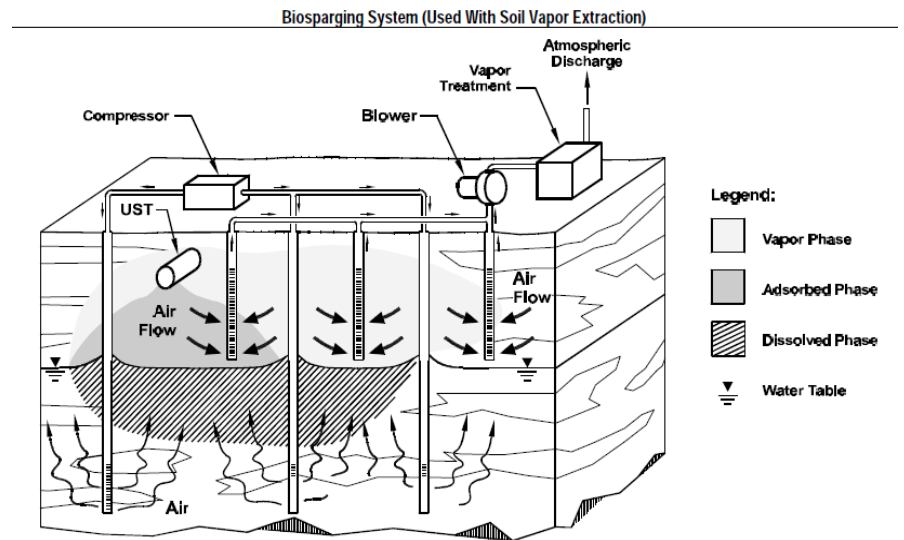
Schematic diagram of a typical Bio-Pile system (USEPA. 2016. Bio-Pile. pIV-2)

2.2. Air-Sparging and Bio-Sparging

Air-Sparging is the process of injecting air (or oxygen) into the saturated zone of contaminated soil. The air causes organic components in the water to vapourise (volatilise) and rise up through the soil for capture and treatment. Bio-Sparging is the process of injecting air (or oxygen) with the addition of nutrients into the saturated zone of contaminated soil. The nutrients enhance the breakdown of organic components. The United States Environmental Protection Agency states that “*Bio-Sparging is most often used at sites with mid-weight petroleum products (e.g. diesel fuel, jet fuel)*” (USEPA. 2016. Bio-Sparging. pVIII-1). Bio-Sparging is an in situ process.

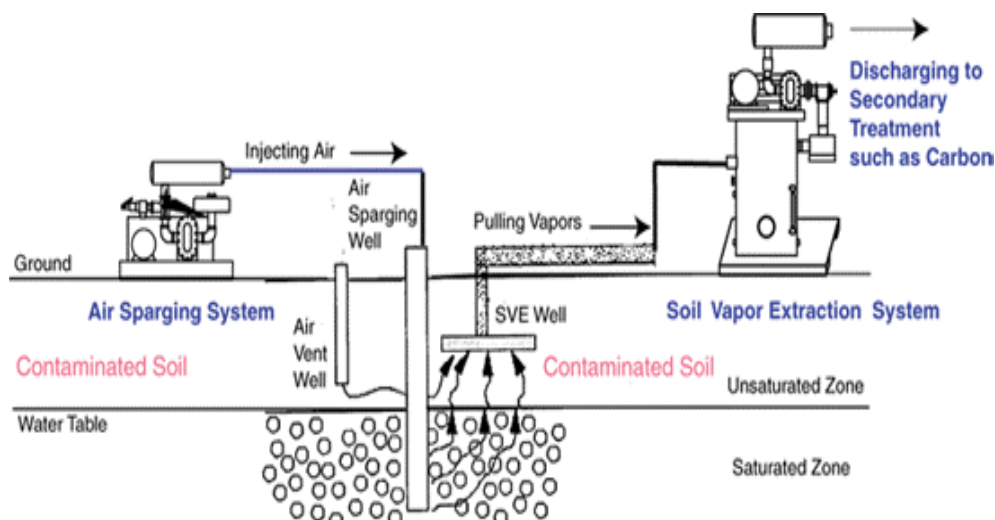
Schematic diagram of the Bio-Sparging process (USEPA. 2016. Bio-Sparging. pVIII-2)

(UST=Underground Storage Tank)



2.3. Soil Vapour Extraction Also Known As Soil Vacuum Extraction (SVE)

This process is usually used in conjunction with Air Sparging or Bio Sparging is an in-situ process and according to Kirtland and Aelion, (2000 p368) Soil Vapour Extraction (SVE) is a process where volatile organic chemicals, which are attached to particles of the soil, are stripped away and are extracted via a vacuum. This removal takes place in the unsaturated zone of the soil. Pollutant vapours rise through the soil medium and are assisted in their journey by a vacuum system on the surface. The contaminated vapour is collected and processed. Clean air is then vented to the atmosphere and the removed contaminants are safely disposed of. In their case study, Kirtland and Aelion, (2000, p367) mention that a pulsed method of operation removes more contaminants than a continuous method. They also state that the pulse method is more cost effective because it uses less energy.

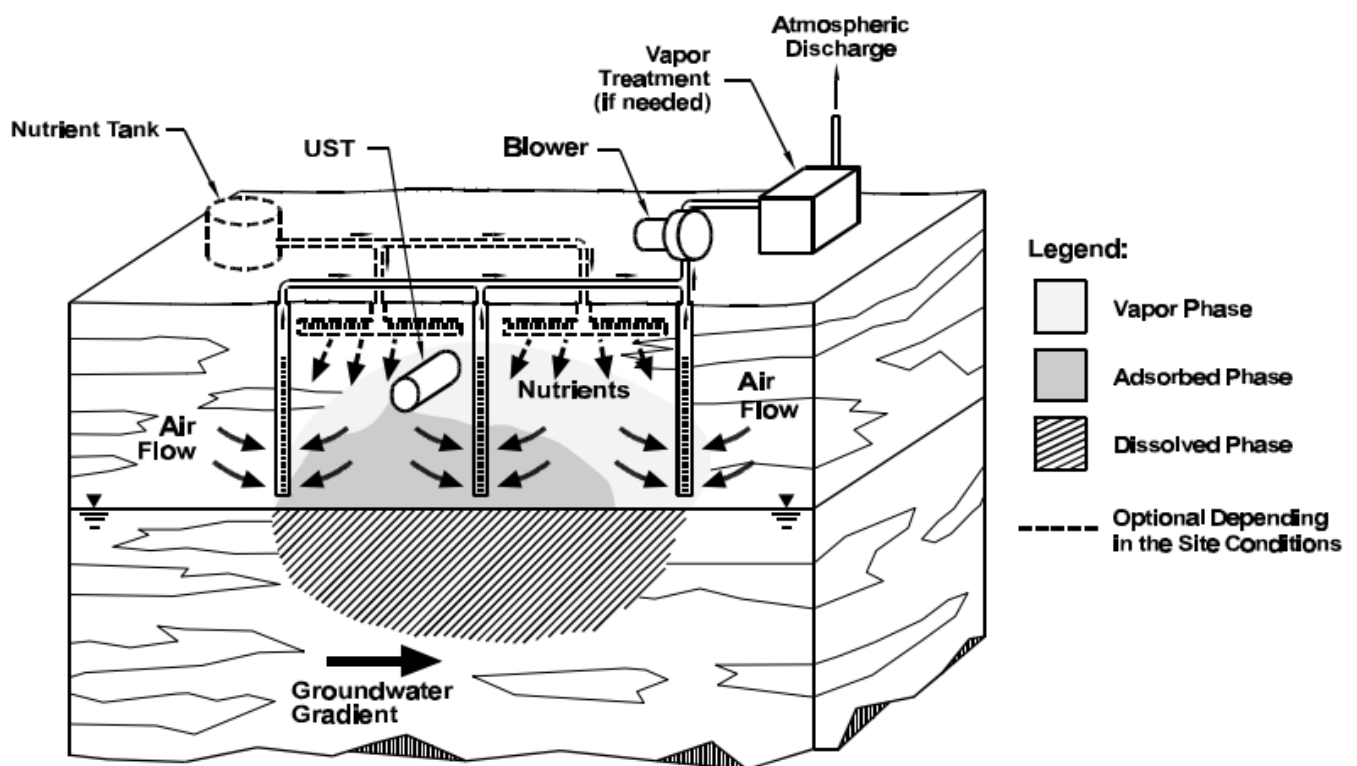


Schematic diagram of Soil Vapour Extraction in conjunction with Air Sparging (Wordpress, 2017 website)

2.4. Bioventing

Bioventing is the process of injecting air, oxygen or nutrients into the unsaturated zone of contaminated soil. The unsaturated zone is called the VADOSE zone. As stated by Khan, Husain and Hejazi, (2004. p103) *"Bioventing is most successful on mid-weight petroleum products like diesel"*. Bioventing is an 'in situ' process and according to Hamberg (2009 p8) the system uses low air pressure to encourage the degrading process of hydrocarbons by micro-organisms. He also states that the system is constructed to avoid air emissions and has been proven effective for the removal of volatile organic compounds (VOCs) and semi volatile organic compounds (SVOCs).

Typical Bioventing System Using Vapor Extraction



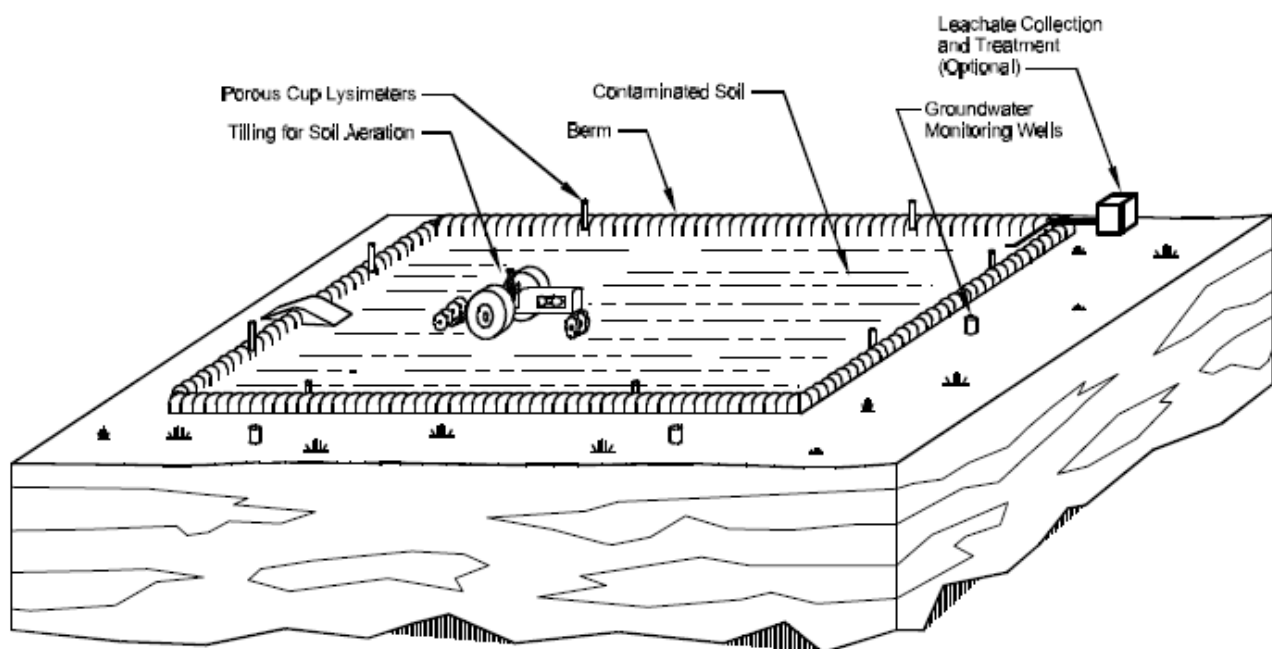
Schematic diagram of the Bio-venting process (USEPA. 2016. Bio-Venting. pVIII-2)

(UST=Underground Storage Tank)

2.5. Land-Farming

The United States Environmental Protection Agency describe Land-Farming as a soil remediation technique whereby contaminated soil is excavated and spread over the ground in thin layers. Air, nutrients, moisture and minerals are then introduced to the soil which stimulates aerobic activity which in turn helps to speed up the process of contaminant removal (USEPA. 2016. Land-Farming pV-1). Hamberg (2009 p30) goes on to say that lightweight petroleum products (petrol) naturally volatilise (cause to pass off in a vapour) in the thin layer of contaminated soil, and disperse into the atmosphere or are captured and treated. However, heavier hydrocarbons within the soil need to be treated with nutrients, bacteria's, air or oxygen injection and possibly lime, to help remediate the soil. Khan, Husain and Hejazi (2004 p97) concur with both USEPA and Hamberg when they say that the contaminated soil is spread thinly on the ground and that the soil is aeriated, plus nutrients, minerals and water are added to stimulate aerobic microbial activity within the soils to break down the contaminants.

Typical Landfarming Operation



Schematic diagram of the Land-farming process (USEPA. 2016. Land-Farming. pV-2)

2.6. Bio-slurry / Bio-reactor system

This remediation technique requires the soil to be excavated and treated ex situ (off site) in Bio-reactors. Within these reactors the contaminated soil is mixed with water, bacteria and nutrients. The solution is constantly agitated to be kept in a slurry condition. This greatly reduces the soil's remediation time. Depending on the remedial process undertaken, the Bio-slurry can then be disposed of, or stored as compost, or, in some cases used as fertilizer. De Groot, Lennart and Bogdanski (2013 p-iv) mention in the review paper the fact that bio-slurry has a beneficial outcome when spread on fields growing fruit, vegetables and grains. However, they go on to say that more studies need to be conducted.

2.7. Phytoremediation (Plants)

"Phytoremediation uses the ability of plants to adsorb, degrade, volatilise or accumulate contaminants in soil, sediments, surface or ground water" (Hamberg, 2009 p17). There are six different processes to Phytoremediation. Ghosh and Singh (cited in Hamberg, 2009 p18) describe these six different processes in the table below. Kachenko (2008 p-iii) describes hyper-accumulator plants and indicates that these types of plants can collect large amounts of heavy metals.

Phytoremediation processes (Ghosh and Singh; 2005).

<i>Phytostabilization</i>	Enzymes and proteins in the rhizosphere or in root cell membranes immobilize contaminants by binding them to the root surface, root cells or nearby soil preventing migration to more sensitive parts.
<i>Phytodegradation</i>	Uptake of organic compounds for transformation or degradation, products are stored in plant tissue, bond to plant lignin, degraded partially or completely.
<i>Phytoaccumulation</i>	Refers to the ability for plant to uptake, relocate, accumulate mainly inorganic contaminants from soil to the roots or leaves.
<i>Phytovolatilization</i>	Root uptake, transport and transpiration above ground of mainly organic compounds. Some metals are subject for volatilization.
<i>Rhizodegradation</i>	Degradation or transformation of organic contaminants by the activity in the rhizosphere derived from root exudes like enzymes and proteins. Degradation means volume reduction and increased pore space which enhances water and oxygen transport.
<i>Evo-transpiration</i>	Combined effort of plant evaporation from leaves and other parts located above ground and transpiration where water is a byproduct of plant activity. A willow tree could transpire 19 000 liters/day.

Table of Phytoremediation processes (Hamberg, 2009 p18. Reproducing the table by Ghosh and Singh 2005)

Phytoremediation is a technique deemed to be environmentally friendly, low effort and cost effective Dada et al (2015 p611). Research carried out by Xu et al. (2014 p48) mentions that Phytoremediation can also be used as the final treatment technique following on from other remediation treatments.

2.8. Microbial remediation also known as Myco-remediation (Fungi)

This is a soil remediation processing technique using fungi. Fungi (including mushrooms) have been found to help in the decontamination process of soils contaminated with heavy metals (Dada et al 2015 p612). The fungi act on the heavy metals by the processes of oxidation and absorption. (Su, Jiang and Zhang, 2014. p34. Citing Siegel et al (1986)) *“found that fungi could secrete amino acids, organic acids and other metabolites to dissolve heavy metals and the mineral containing heavy metals”*.

2.9. Vermi-remediation (Maggots and Earthworms)

Certain animals that live in the soil can break down heavy metals, for example maggots and earthworms (Su, Jiang and Zhang, 2014 p34). This soil remediation process is referred to as Vermi-remediation. (Dada et al (2015 p612) states *“Vermi-remediation is the use of earthworms to clean up contaminants from the soil environment”*. They then go on to mention that earthworms are best used for soils contaminated by heavy metals, although they can be used for other soil contaminants like hydrocarbons.



Image of worms used in Vermi soil remediation (Vermi-Remediation Pty Ltd, 2017) website

2.10. Chemical remediation.

The use of chemicals to remedy soil pollutants can be carried out both in situ (on site) or ex situ (off site). The general idea is to introduce oxygenating chemicals into the contaminated soil to cause the contaminants to decompose. Hamby (1996) mentions that there are many ways of introducing chemicals into the soil for remediation purposes! Chemicals can be sprayed, or the ground can be surface flooded with a chemical solution. Insoluble chemicals can be spread, filled, force injected or placed in a low permeable capsule for slow seepage. However, Hamby (1996) emphasises that the most widely used method of introducing chemicals into the soil is by 'tilling' the soil, and that special equipment can 'till' the soil down to a depth of five feet.



Image of chemical soil remediation (EESI Contracting, 2017) website

2.11. Encapsulation (Capping, barriers, containment)

According to the UK based company Soilutions Ltd (2017b) The introduction of a 'Capping Layer' is the most common way of encapsulation a contaminated soil. The 'Capping Layer' is constructed over the top of the contaminated soil. First to be laid down is clay mat, followed by various membranes which combat any future digging and prevents gas from escaping. Aggregates are then compacted on top of the membranes followed by a soil layer.



Image of a 'capping layer' (Soilutions Ltd, 2017a)

Other methods of encapsulation soil contaminants are Permeable reactive barriers (PRB). These can be used in conjunction with other techniques. The barriers are usually formed by digging a trench around the contaminated soil and filling it with either a sorbent material (e.g. coal, peat, carbon) to absorb the contaminants leaching from the soil, or a biological material (e.g. nutrients and bacteria) which degrades the contaminant when it reaches the trench, or a precipitation material (e.g. limestone) which turns heavy metal contaminants into solids for easy removal (Hamberg, 2009 p22). Another method of a PRB is the 'funnel and gate', where 'cut off walls' (e.g. sheet piling, or jet grouting barriers) funnels the contaminants towards a 'gate' which is filled with either biological, precipitation or sorbent material (Guerin *et al.*, 2002 p15).

Jet grouting can be used as a barrier technique to prevent leachates within a contaminated soil from seeping into non-contaminated areas. These grout barriers can be sited within most soil types. A similar technique can be used to install a horizontal grout barrier underneath the contaminated soil by utilising a horizontal drilling method.

2.12. Stabilization and Solidification (Vitrification and Cementing)

Vitrification is a process where the soil and contaminant is heated up to such a temperature that it is 'producing a pool of molten soil' (Lowery et al 1994 p2). Organic contaminants are destroyed by Pyrolysis (Hamby, 1996 p13). Inorganic contaminants, like heavy metals, are immobilised by being turned into a glass structure (Glassification). The temperatures that are reached are between 1600°C and 2000°C (Khan, Husain and Hejazi, 2004 p100).

Ex-situ (off-site) vitrification is a process where silica is added to a hazardous waste produce (e.g. nuclear waste) and then heated until the mixture melts into a glass liquid. This liquid is then poured into stainless steel canisters and allowed to cool. Once cooled the glass that is formed traps and stabilises the hazardous waste within itself. The canisters are then stored in a safe environment (Hanford Vit Plant, 2017).

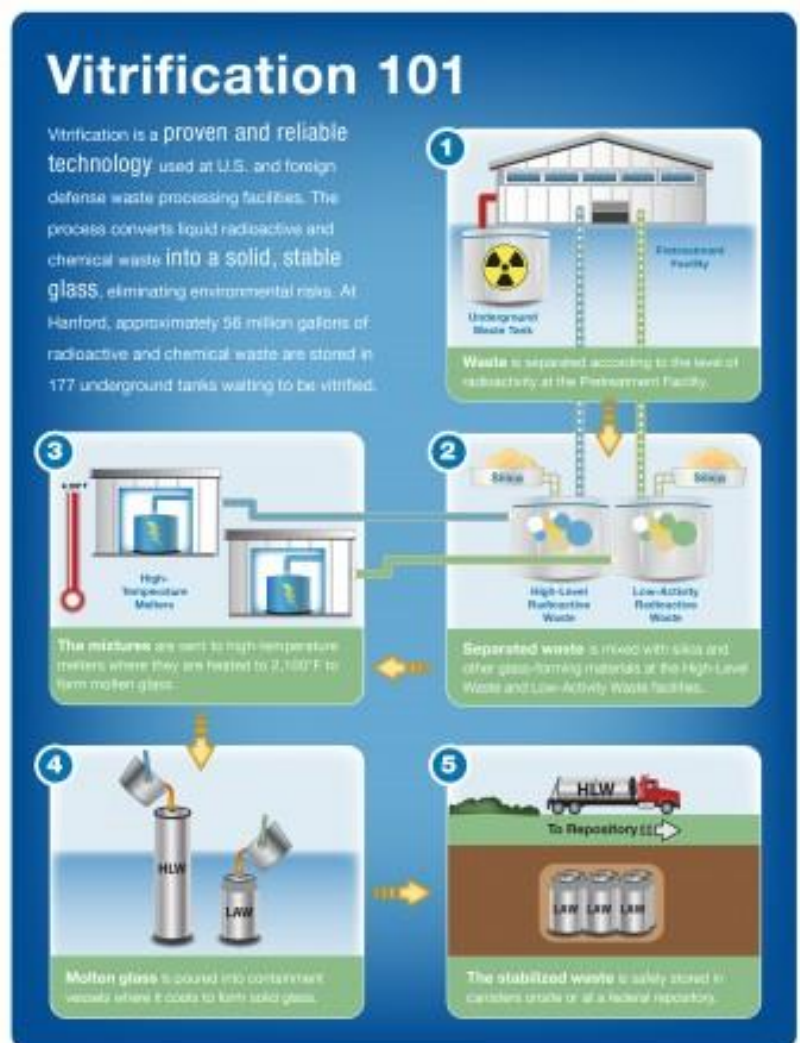


Image of vitrification process (Hanford Vit Plant, 2017) Website

UK based company Dunton Environmental Ltd, (2017) has developed a cement formula which they claim 'significantly enhances the stabilisation of heavy metal and phytotoxic contaminates within soils matrix'. They go on to say that this treatment reduced the leachate from the soil by up to 90%.

2.13. Electro-kinetic (AKA Electro-remediation)

There are three Electro-Kinetic phenomena that develop when treating and removing contaminants in soil. They are Electro-osmosis, Electro-migration and Electro-phoresis (Vane and Zang, 1997 p2). Electrodes are placed into the contaminated soil and an electrical field is generated. Within this electric field different soil contaminants develop either a positive charge or a negative charge (e.g. heavy metals usually develop a positive charge). Positive charges contaminants will flow towards the negatively charged cathode electrode and negatively charged contaminants will flow towards the positively charged anode electrode. The anodes can be made from steel and the cathode can be made from aluminium (He, F. Gao, J. Pierce, E. Strong, P. Wang, H. Liang, 2015 p8130)

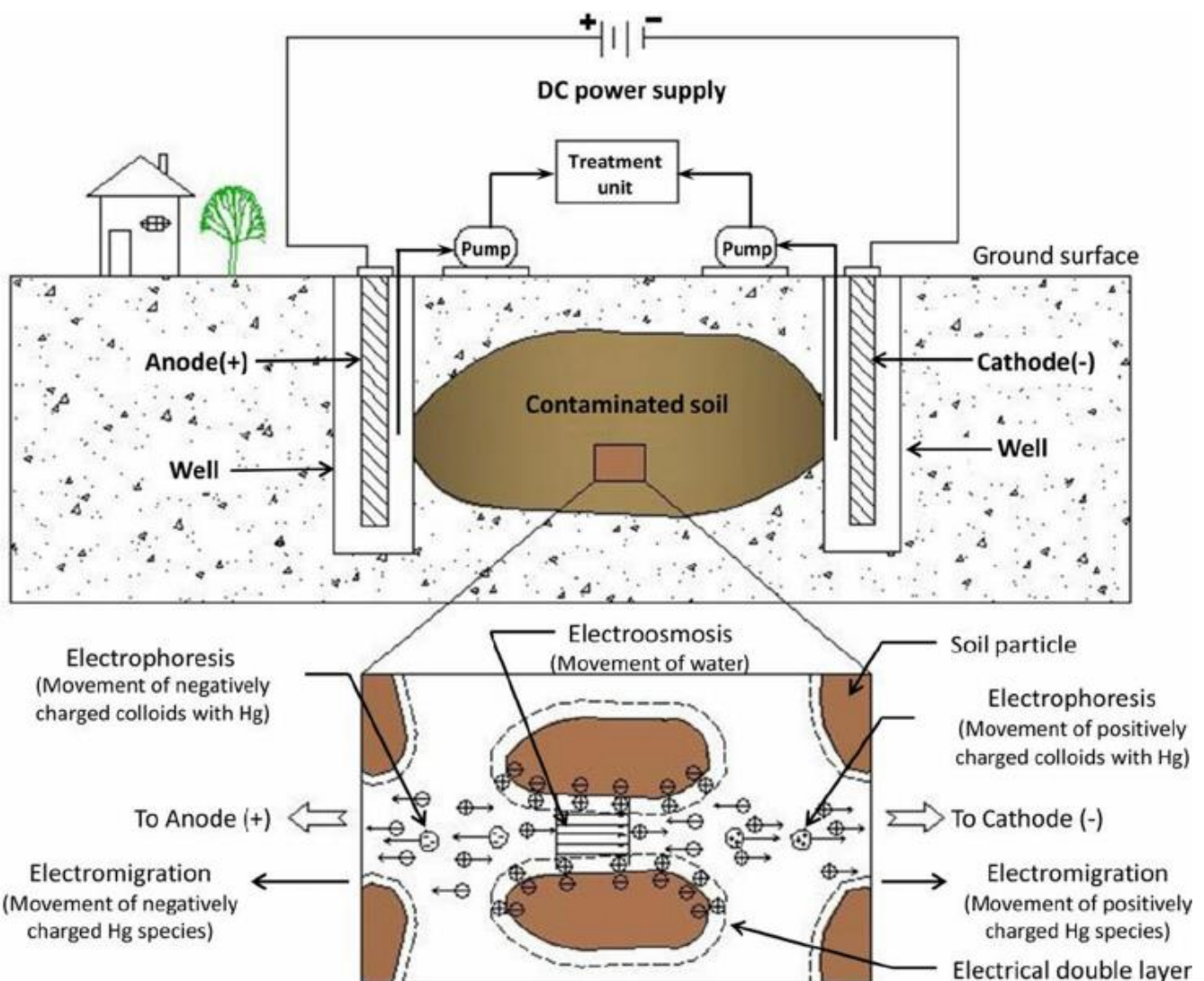
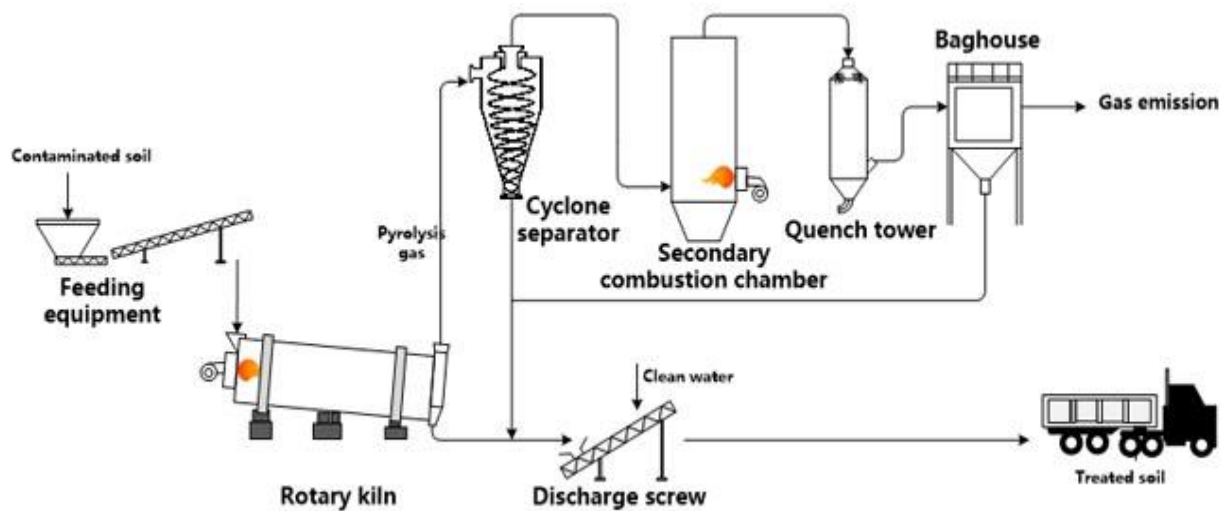


Diagram of electro-kinetic remediation (He, F. Gao, J. Pierce, E. Strong, P. Wang, H. Liang, 2015 p8130)

2.14. Incineration

Hamby (1996 p10) talks about the following incineration processes for contaminated soils! Rotary kiln, infrared furnaces, liquid injection, plasma arc, fluidized bed, and the multiple hearth. He goes on to say that these different incineration techniques can remediate liquids, solids and sludge. The incinerators work at temperatures of between 850°C and 1200°C.

The most versatile of these incinerators is the rotary kiln and can burn many hazardous solids liquids and slurries.



Schematic diagram of rotary kiln incineration (Jereh Group, 2017) Website

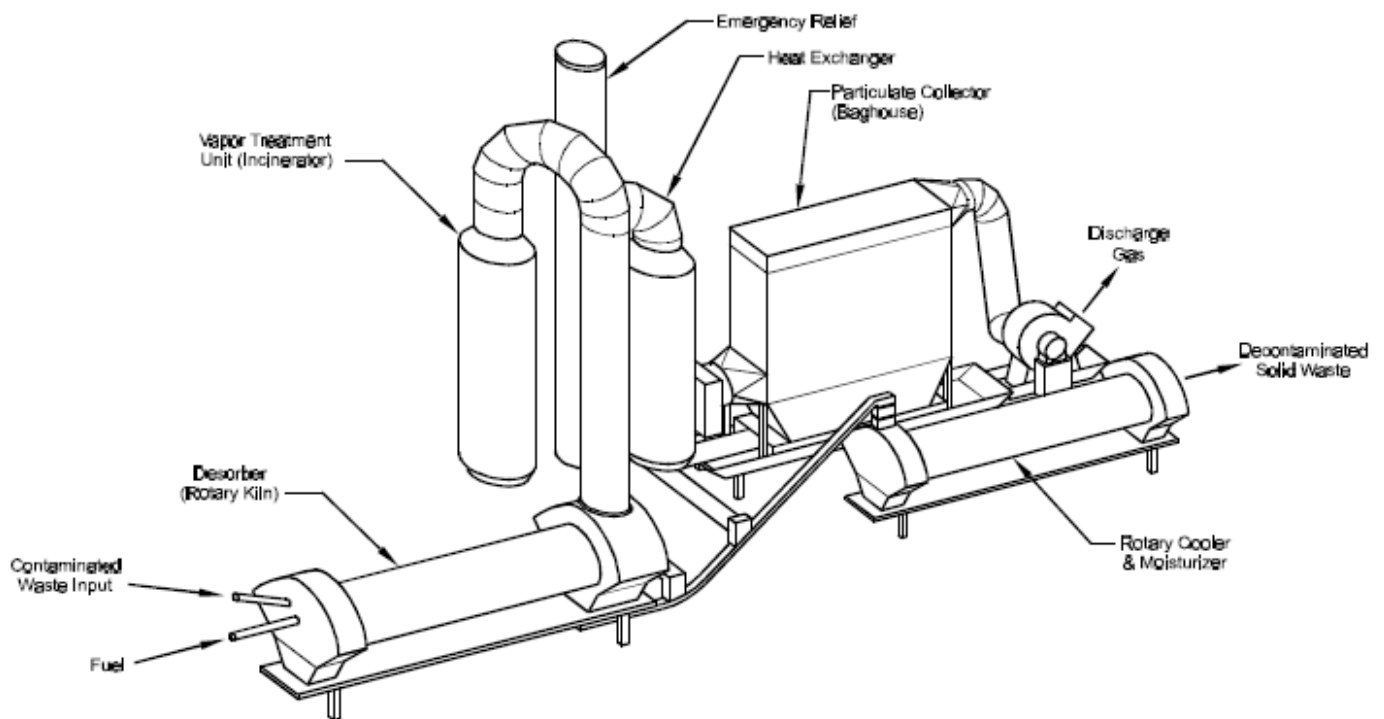
2.15. Thermal Desorption

Khan, Husain and Hejazi, (2004 p101) mention that

‘there is some confusion about the difference between thermal desorption and incineration: thermal desorption does not aim to destroy the organic but rather to change the form to a more treatable one, while incineration aims to destroy the contaminant’

In thermal desorption technology, soil is heated to a sufficient temperature through direct or indirect heating exchange in order to enable the organic pollutant to be volatile or isolated from the contaminated medium (Tan *et al.* 2015 p771, citing Gao *et al.* 2012). Thermal desorption is a very good process for many types of pollutants. Furthermore, contaminated soil that has undergone thermal desorption can then be reused.

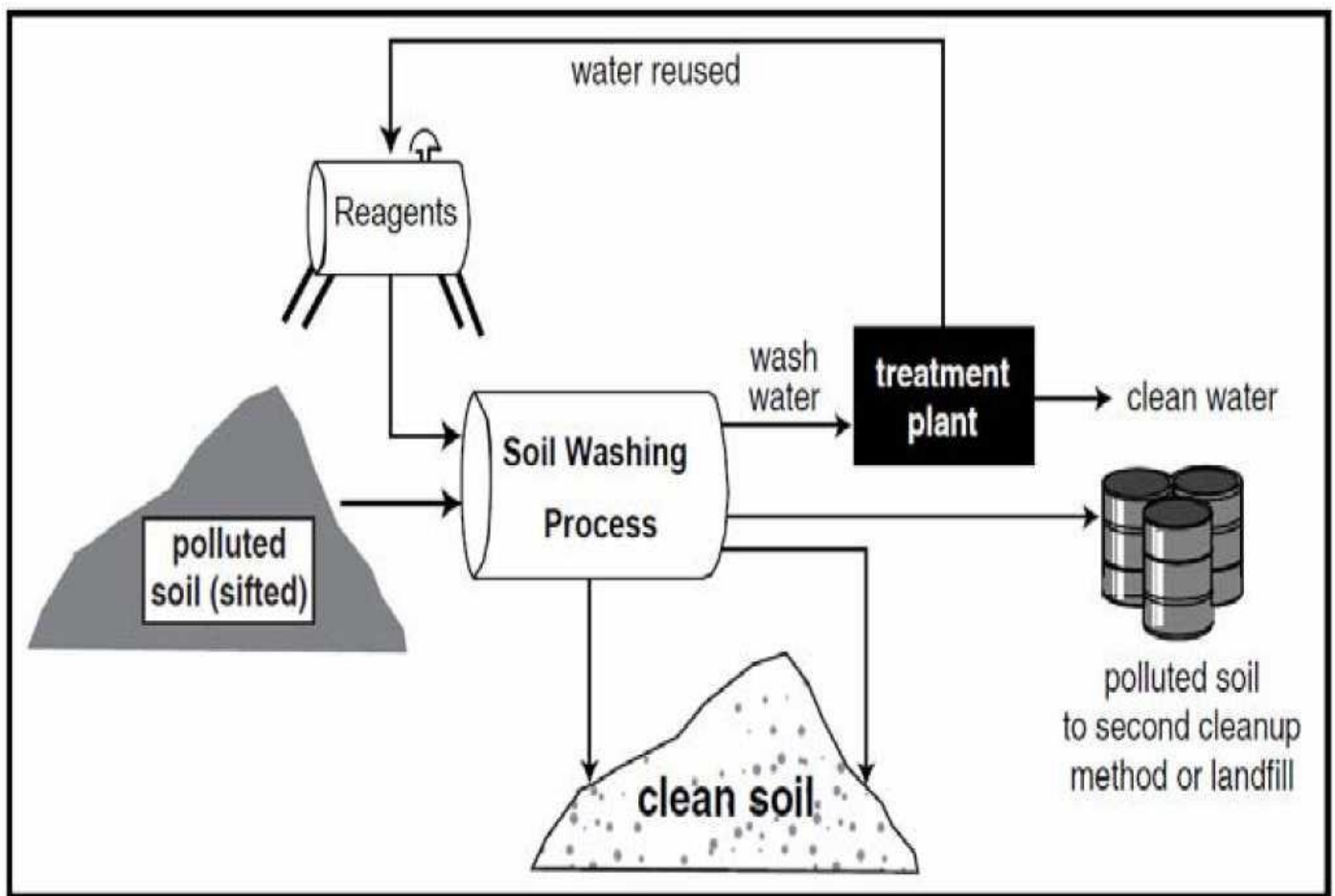
Parallel Flow (Co-Current) Rotary Low-Temperature Thermal Desorption System



Schematic diagram of Thermal Desorption (USEPA. 2016. pVI-2)

2.16. Soil Washing

This is the process of mixing contaminated soils with a washing solution and agitated to remove the pollutants. Im *et al.* (2015 p254) states that the washing solutions usually involve strong acids like hydrochloric and phosphoric acids. Lau *et al.* (2014 p164) mentions that other 'solvents can be used, including 1-pentanol, n-hexane, toluene, dichloromethane and benzene'. However, in the case study by Kim *et al.*, (2013 p8417), they mention the detrimental effects the soil remediation chemicals have on the environment and proceed to conclude that it might be prudent to "eliminate processes which might negate the overall impact of such environmental clean-up procedures" (Kim *et al.*, 2013, p8424).



Schematic diagram of soil washing (Dadrasnia, A. Shahsavari , N. Emenike, 2013 p75)

3. Discussion

This study does not introduce any new techniques or point out any failings in existing practices. It intends to gather together all the present techniques to allow a better understanding for someone new to the subject of soil remediation.

There are many types of soil remediation processed. Several soil remediation techniques only tackle specific soil pollutants and most techniques work best when administered alongside one or more of the other methods.

However, there is an argument for the development of new techniques due to the fact that some existing techniques actually destroy the soils along with the contaminants or changes its consistency. This should be prevented as all soils should be returned to their original sites in good condition minus the contaminants.

The remediation methods that simple barrier off the contaminated soils should only be used as a temporary solution until more permanent solutions are put in place. On no account should barriers be the final solution.

4. Conclusion

The development of environmental technology with regards to soil remediation has been progressing steadily. Government and Organisations have become aware of its importance for the future health of our soils which in turn leads to the future health of us as human being.

If we pollute our soils we will have contaminated flora and fauna. The pollutants which they absorb and ingest will eventually be passed along the food chain to us. Furthermore, we all can become sick through direct contact with contaminated soils.

This has been one of the reasons for swift development of soil remediation technologies. However, there is still a long way to go and everybody (Governments, Companies and individuals) must take responsibility for their own actions and to actively participate in prevention and remediation techniques.

Future generations should not be burdened with our incompetence of the past, and our lack of ability to correctly look after this planet of ours.

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