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Mini Review Open Access

Xenobiotic Compounds Present in Soil and Water: A Review on Remediation Strategies

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Abstract

Synthetic chemicals foreign to a particular ecological system and has a biological activity can be called xenobiotic compounds. Xenobiotics include drugs, industrial chemicals, naturally occurring poisons and environmental pollutants. Some microorganisms have the ability of breaking down the xenobiotic compounds partially or entirely. But some xenobiotics are recalcitrant in nature because of various reasons. Some of them cannot be used as substrate by microbes, some cannot transport them due to absence of transporting enzymes and some are in accessible to microbes due to larger structure and insolubility. They can be divided into different groups depending on their chemical composition. Biological and non-biological remediation techniques are the most reliable techniques to degrade these compounds. Bacterial biodegradation used in land filling and composting are most economical methods which uses both the wild type and genetically modified bacterial strains. There are many non-biological techniques which have been grouped under thermal and non-thermal techniques which are suitable for xenobiotic degradation.

Keywords: Xenobiotic; Remediation; Recalcitrant; Bacterial strains

Introduction

Xenobiotic compounds are chemicals which are foreign to the biosphere. Depending on their fate in water and soil xenobiotic compounds may become available to microorganisms [1-5]. Most importantly the dominant means of transformation of these compounds are microorganisms. Polyaromatic hydrocarbons, cyclic biphenyls, nitroaromatic compounds, aliphatic and aromatic halogenated compounds, triazines, azo dyes, organic sulphonic acid and many more have xenobiotic structural features [6-20].

Xenobiotics can exert adverse effects on human health by disrupting or interacting with multiple cellular communication pathways that direct growth, development and normal physiological function [21-40]. These compounds are highly toxic in nature and can affect survival of lower as well as higher eukaryotes. These compounds are persistent and remain in the environment for many years leading to bioaccumulation or biomagnification [41-60]. They also find a way into the food chains and the concentrations of such compounds was found to be high even in organisms that do not come in contact with xenobiotics directly. Certain microbes on continuous exposure to xenobiotics develop the ability to degrade the same as a result of mutations. Mutations resulted in modification of gene of microbes so that the active site of enzymes is modified to show increased affinity to xenobiotics [61-79].

This review gives a brief introduction about the technique, its types with advantages and disadvantages from a detailed list of biological and non-biological techniques.

Biological remediation strategies

There are various biological techniques to use to detoxify or degrade the xenobiotics which are listed in Table 1 and Figures 1-8. Followed by their working diagram.

Non Biological remediation strategies

Thermal strategies (Table 2a and Figures 9-16)

Non thermal strategies (Table 2b and Figures 17-27)

Acknowledgements

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Remediation Techniques	Types	Advantages	Disadvantages	References
Natural attenuation • Uses natural processes to limit the flow of contaminants from chemical spills and also reduces their concentration at contaminated sites.		• Remediation waste is least which has less impact act on the environment; • Can be easily combined with other technologies.	• Ethical issues remain which needs to be correctly perceived by the people. • Costly and complex site characterization.	[34,35]
Phytoremediation Uses plants in combination with microorganisms to remediate the contaminated area.	**Phytoextraction** • Plants remove dangerous elements or compounds from soil or water, most usually heavy metals, metals that have a high density and may be toxic to organisms even at relatively low concentrations.	• Least environmental disturbance. • Solar energy driven technology. • Used on a large range of contaminants. • Cost-effective for large contaminated sites	• Two growing seasons required • Limited to soils less than one meter from the surface and groundwater less than 3 m from the surface • Contaminants may enter the food chain through animals which eat the plants used in these projects	[44,45,73]
	Phytotransformation • It is the breakdown of organic contaminants sequestered by plants via: (1) metabolic processes within the plant; or (2) the effect of compounds, such as enzymes, produced by the plant.			[14,36]
	Phytovolatalisation • Contaminant is taken in by the plant tissue and then volatalised in the environment			[19,79]
	Rhizofiltration • Involves filtering water through a mass of roots to remove toxic substances or excess nutrients.			[18,48]
	Phytostimulation • Involves the stimulation of microbial degradation through the activities of plants in the root zone			[59]
	Phytostabilisation • Root released compounds enhance microbial activity in the rhizosphere			[46]
	Phytoscreening • plants are used as biosensors of subsurface contamination and is a simple, fast, noninvasive and inexpensive method.			[13,63,70]
Biosparging • Air and nutrients are injected into the saturated zone to increase the biological activity of the indigenous microorganisms		• Readily available equipment; • Cost competitive; • In situ technology	• Biochemical and physiological interactions are very complex and needs to be understood • Migration of constituents can lead to toxicity elsewhere.	[57]
Bioventing process injects air into the contaminated media at a rate designed to maximize in situ biodegradation and minimize or eliminate the off-gassing of volatilized contaminants to the atmosphere		• Very economic and easy to install • can be combined with other technologies	• High concentrations can be toxic for microorganisms • Low soil permeability doesn't allows proper implication. • Good for unsaturated zones of soils.	[23,47]
Bioreactors/ Bioslurry • Uses bioreactors and selected bacteria to biodegrade the contaminants.		• Fast degradation • Effective use of inoculants and surfactant	• Soil transport required • Expensive	[77]
Composting • Uses cow manure and mixed vegetable waste to remove the toxicants upto 90% from the contaminated soil.		• Cheap with rapid reaction rate.	• Treatment time more than other techniques • Requires nitrogen supplementation.	[3]
Biopiling • Involves the piling of petroleum-contaminated soils into piles or heaps and then simulating aerobic microbial activity by aeration and the addition of minerals, nutrients, and moisture		• Insitu technology therefore no transportation cost.	• Need to control abiotic loss • Mass transfer problem • Bioavailability limitation	[25,37]

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Land Farming • Bioremediation treatment process that is performed in the upper soil zone or in biotreatment cells.		• Relative simple design and implementation • Short treatment times (six months to two years under optimal conditions).	• Required area is high. • Dust and vapor generation may cause some air pollution.	[29]
Bioslurping • Combines elements of bioventing and vacuum-enhanced pumping to remediate the contaminated site.		• Applied at shallolw as well as deep sites. • Recovers free product, thus speeding remediation	• Low soil permeability hampers remediation. • Soil moisture and oxygen content limits the microbial activities. • Low temperatures slow remediation.	[75]

Table 1: List of biological techniques used in remediation of contaminants with their advantages and disadvantages.

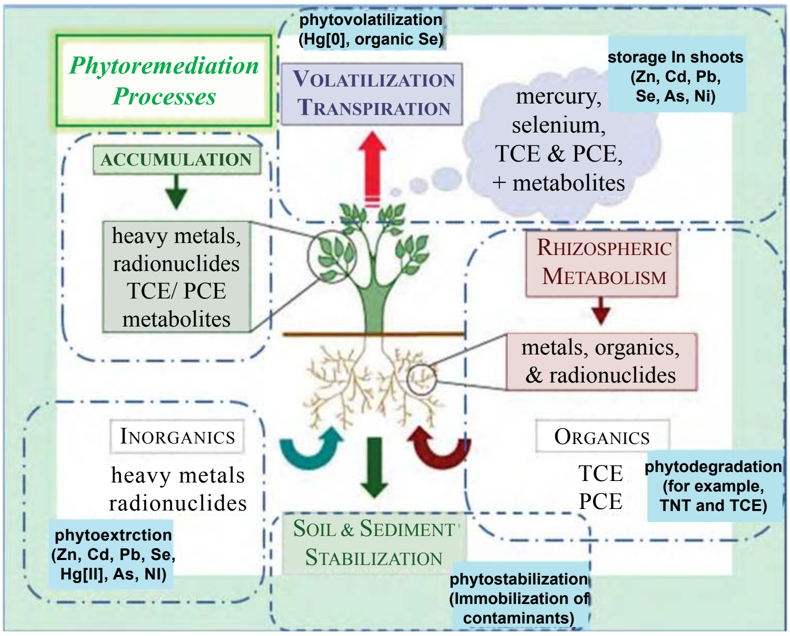

Figure 1: Types of phytoremediation.

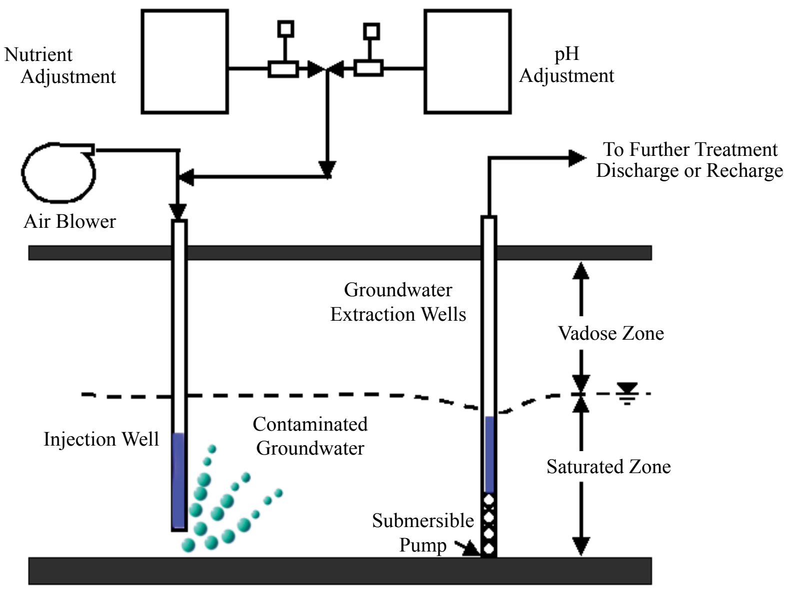

Figure 2: Biosparging.

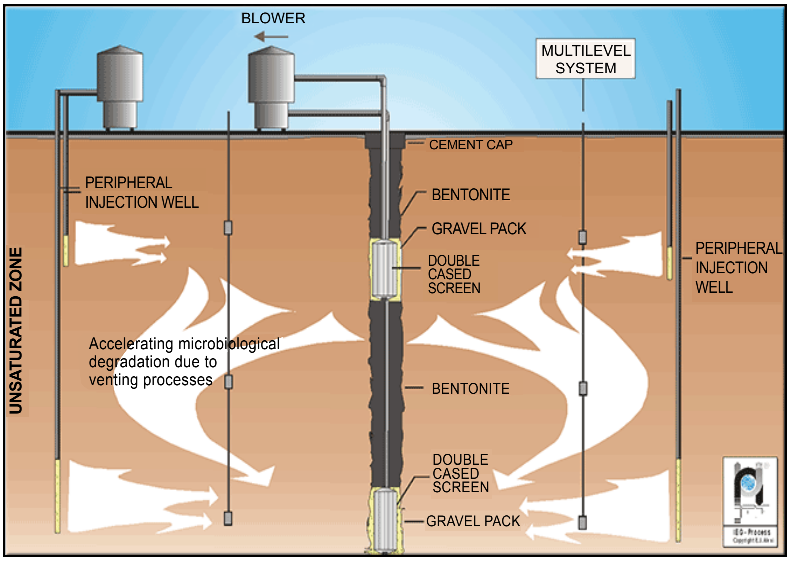

Figure 3: Bioventing.

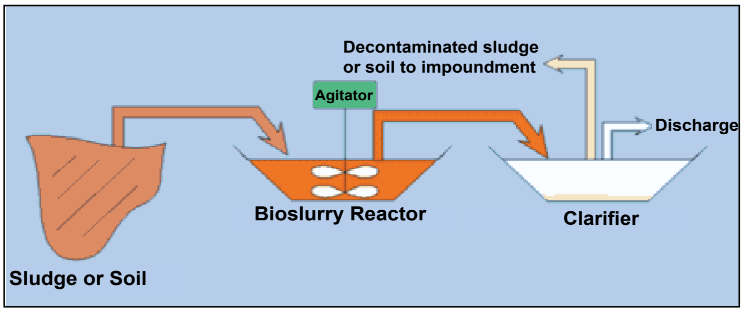

Figure 4: Bioslurry reactors.

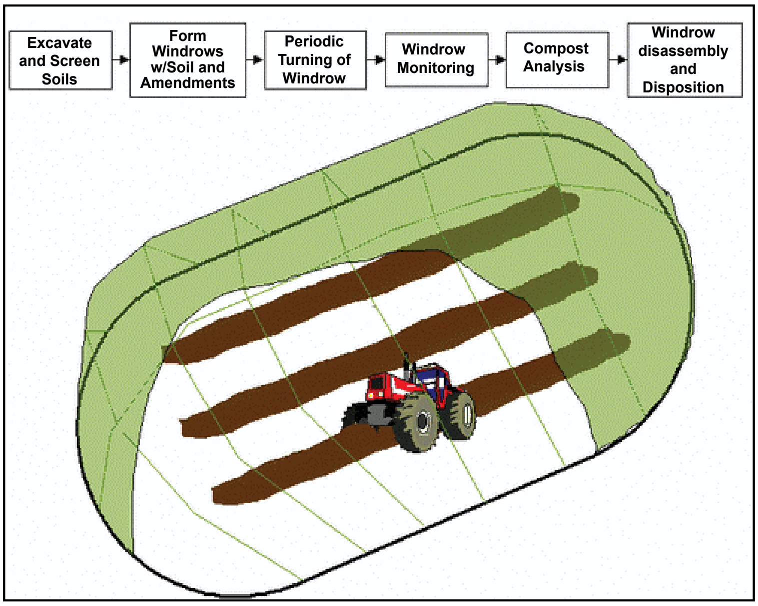

Figure 5: Composting.

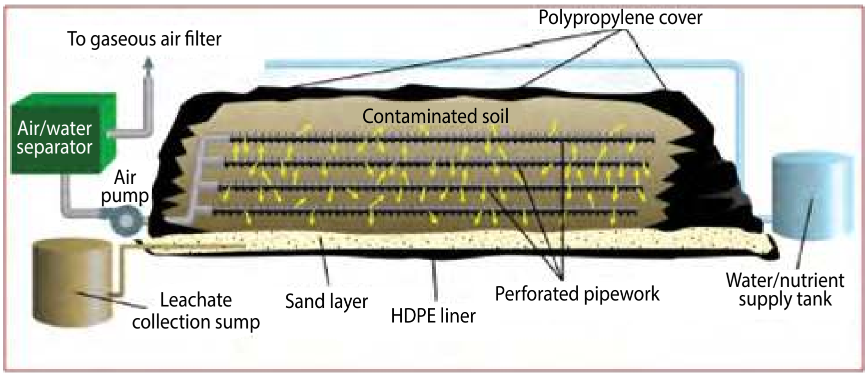

Figure 6: Biopiling.

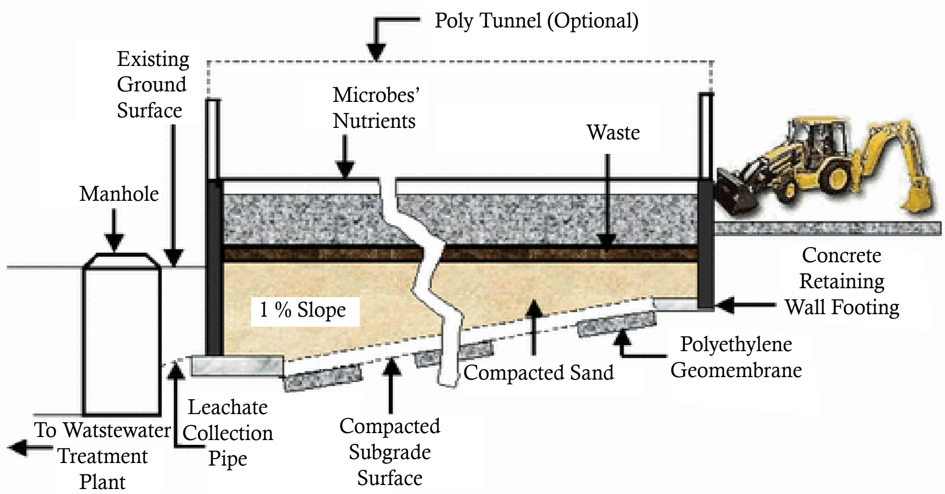

Figure 7: Landfarming.

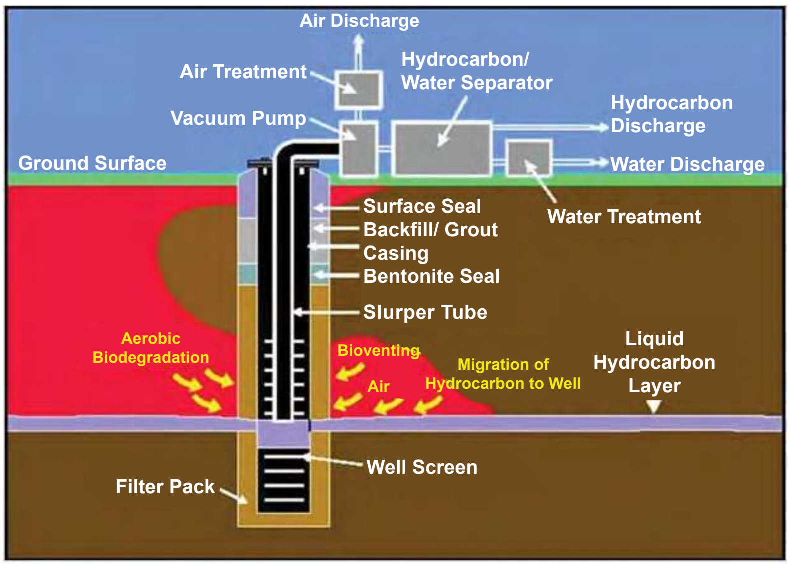

Figure 8: Bioslurping.

Remediation Techniques	Types	Advantages	Disadvantages	References
Thermal treatment (In Situ) • Consists of the following five technologies: electrical resistance heating, steam injection and extraction, conductive heating, radio-frequency heating, and vitrification. With the exception of vitrification, all of these treatment technologies rely on the addition of heat to the soil to increase the removal efficiency of volatile and semivolatile contaminants	**Electrical resistance heating (ERH)** An array of electrodes is used to pass the electrical current through moisture in the soil. As the current flows through the moisture in soil pores, the resistance of the soil produces heat	• Contaminant toxicity as well as its concentration is checked by this technology • Commercially available and widely used.	• Metals are not destroyed and end up in the flue gases or in the ashes. • Rocky soils need to be screened before use.	[7]
	Steam injection and extraction / steam enhanced extraction [SEE]) • Involves injection of steam into injection wells and the removal of contaminants by three methods: Enhanced volatilization, Enhanced mobility and Hydrous pyrolysis oxidation.			[33,61]
	Conductive heating • Uses either an array of vertical heater/ vacuum wells or, when the treatment area is within about six inches of the ground surface, surface heater blankets.			[4]
	Radio-frequency heating (RFH) • A high frequency alternating electric field for in situ heating of soils is used.			[27]
	Thermal Desorption • Contaminated soil is excavated, screened, and heated to release petroleum from the soil			[72]
	In situ vitrification (ISV) • Converts contaminated soil to stable glass and crystalline solids.			[22,69]
Thermal treatment (*Ex Situ*) • Involves the destruction or removal of contaminants through exposure to high temperature in treatment cells, combustion chambers, or other means used to contain the contaminated media during the remediation process	**Hot gas decontamination** The temperature of the contaminated area is raised to 260°C for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants	• Waste is stockpiled Which is easily disposed off later. • Permit reuse or disposal of scrap as nonhazardous material	• Costs of this method are higher than open burning. • Can lead to explosions from improperly demilitarized mines or shells. • Slow rate of decontamination	[33]
	Incineration Uses high temperatures from 870°C to 1200°C to volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes.	• Used to remediate soils contaminated with explosives and hazardous wastes	• Only one off-site incinerator is permitted to burn • Specific materials and feed size required • Bottom ash produced by heavy metals requires stabilization. • Volatile heavy metals, including lead, cadmium, mercury and arsenic can cause air pollution.	[63]
	Open Burn (OB) and Open Detonation (OD) • Uses self-sustained combustion ignited by an external source, such as flame, heat, or a detonation wave (that does not result in a detonation) to destroy explosives or munitions.	• Very effective for many types of explosives, pyrotechnics and propellants	• Minimum distance requirements for safety purposes. • Emissions are difficult to capture for treatment	[68]
	Pyrolysis • Decomposition induced in organic materials by heat in the absence of oxygen.	• Target contaminant groups for pyrolysis are SVOCs and pesticides. • Can treat organic contaminants in soils and oily sludges.	• Specific feed size and materials handling requirements. • Drying of the soil required • Highly abrasive feed sometimes damage the processor unit. • High moisture content increases treatment costs.	[63]

Table 2a: List of non-biological thermal techniques used in remediation of contaminants with their advantages and disadvantages.

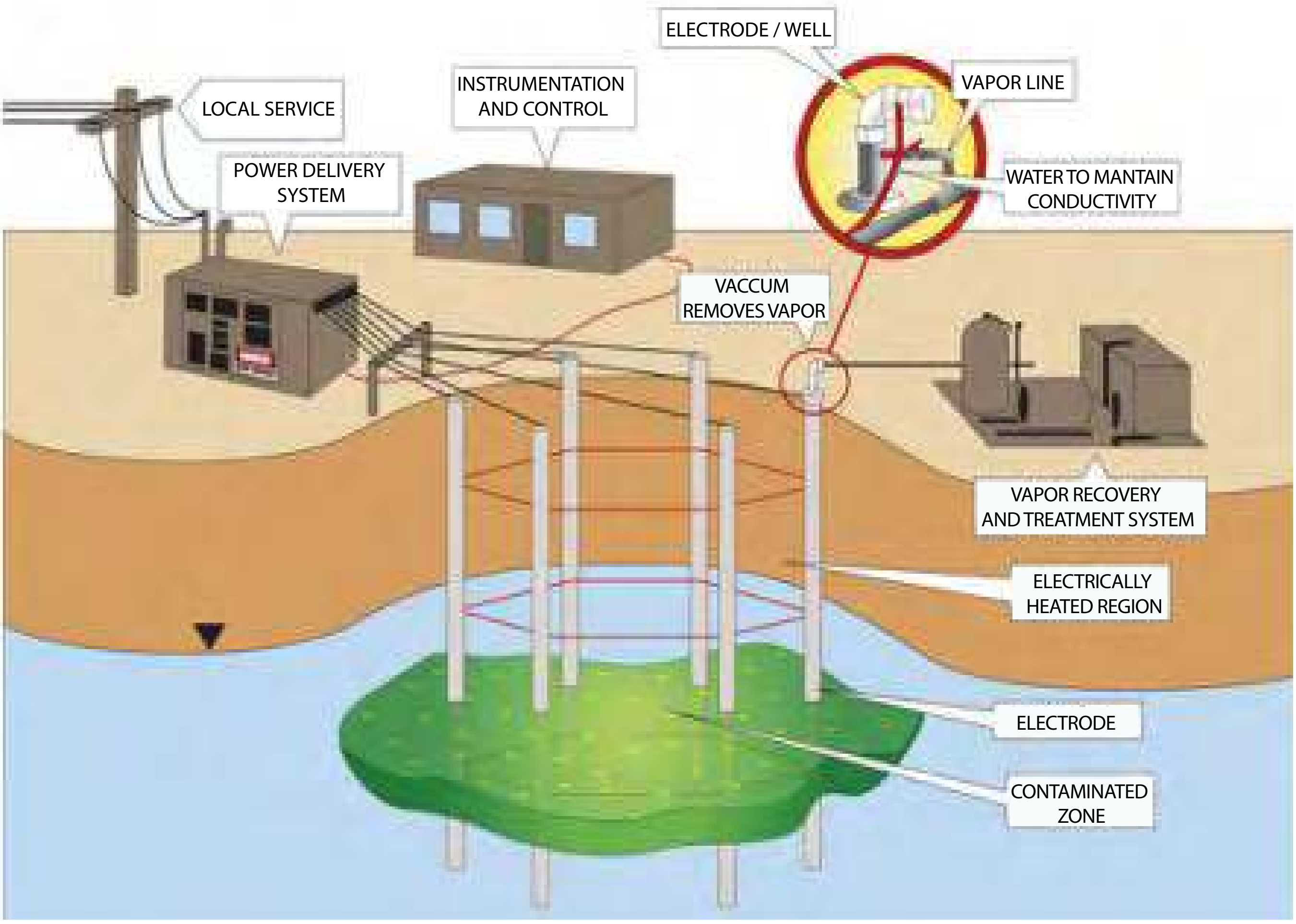

Figure 9: Electrical resistant heating (ERH).

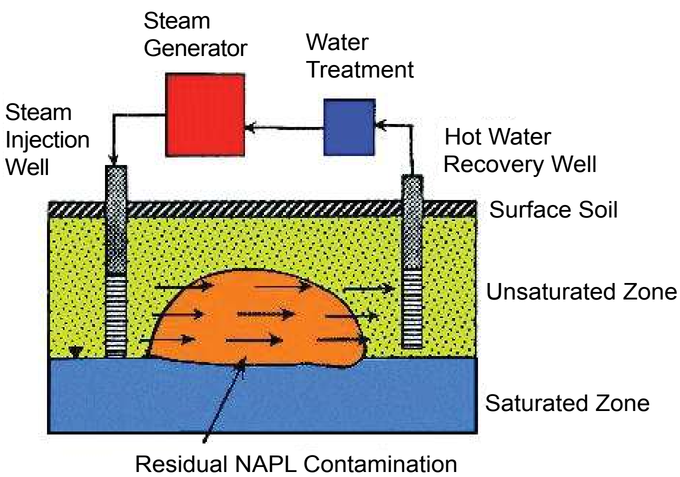

Figure 10: Steam enhanced extraction.

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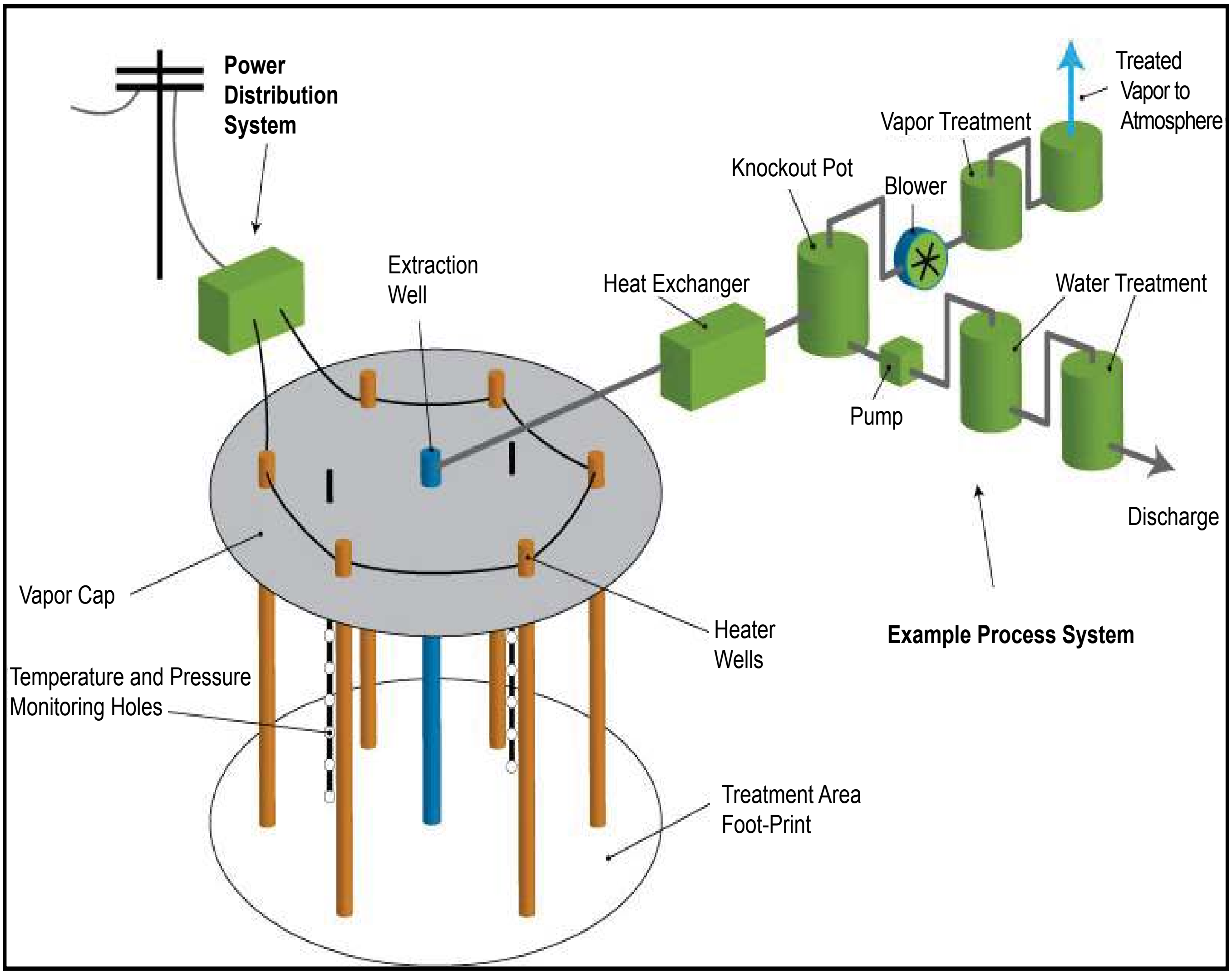

Figure 11: Thermal desorption with conductive heating.

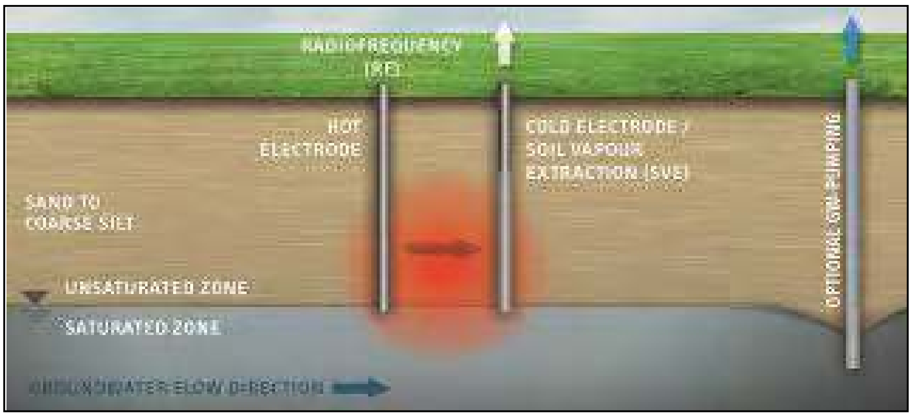

Figure 12: Radio frequency heating.

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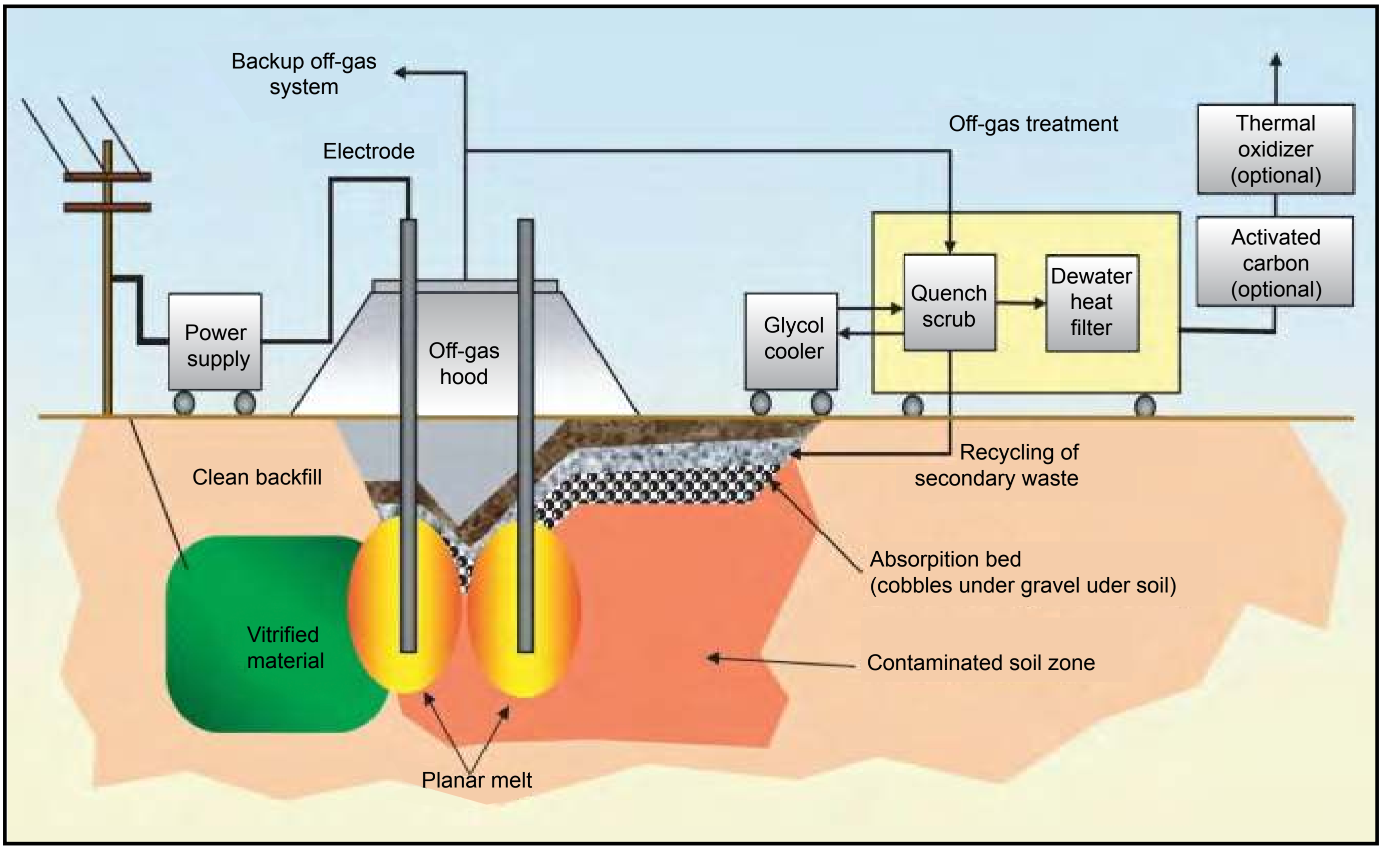

Figure 13: Vitrification.

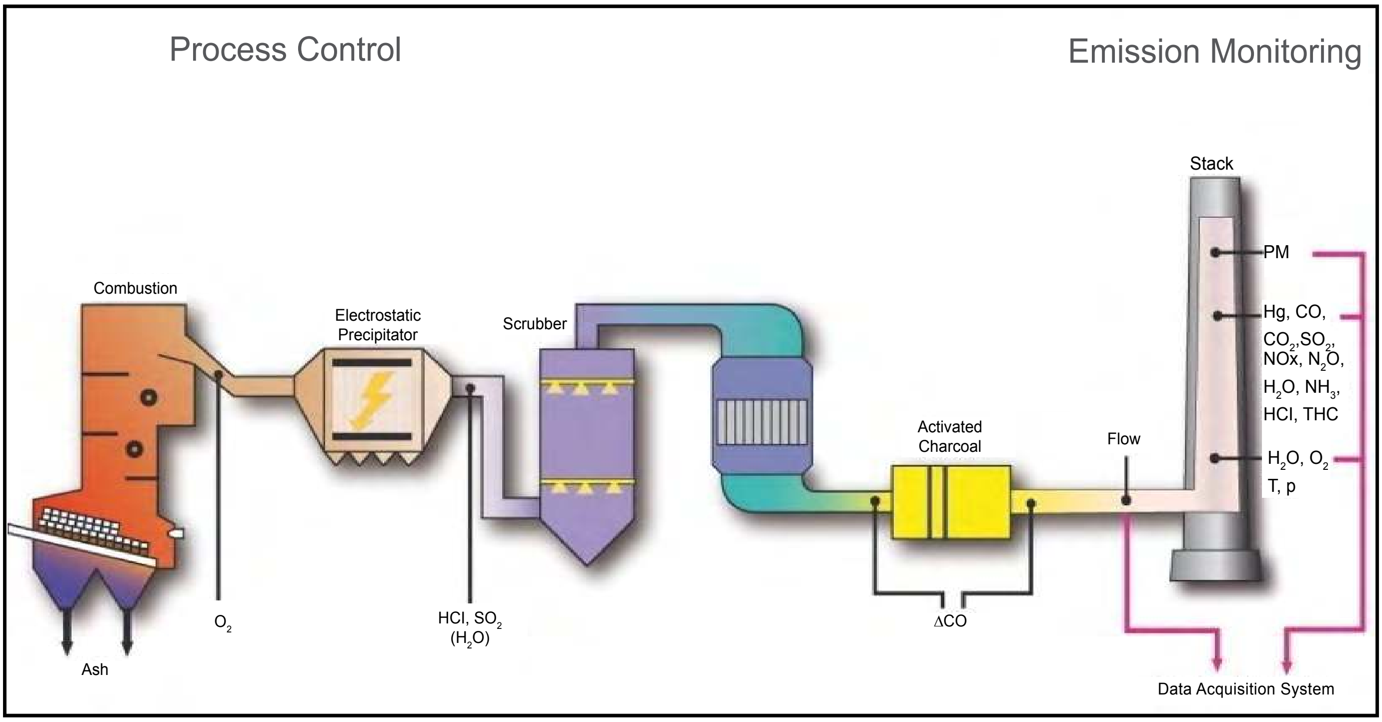

Figure 14: Incineration.

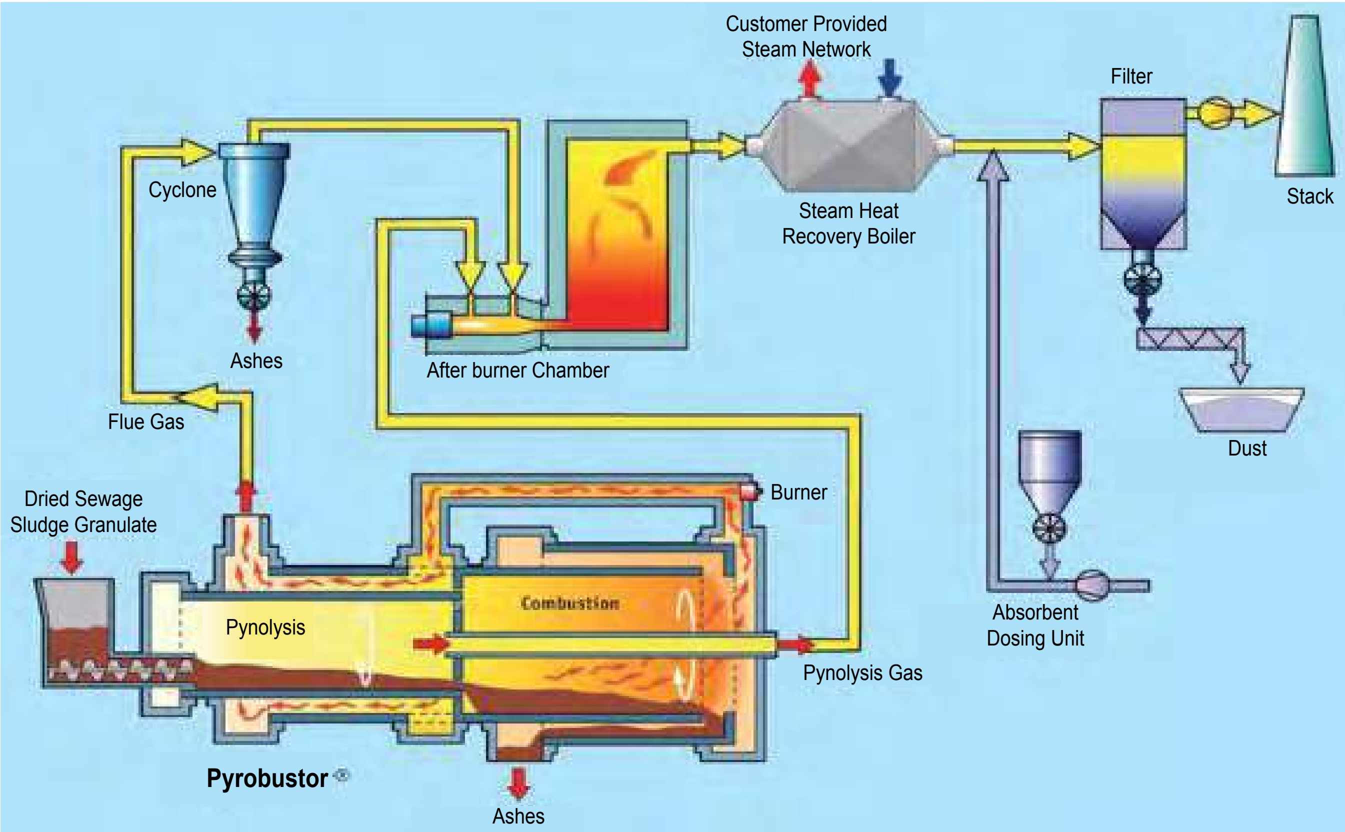

Figure 15: Pyrolysis.

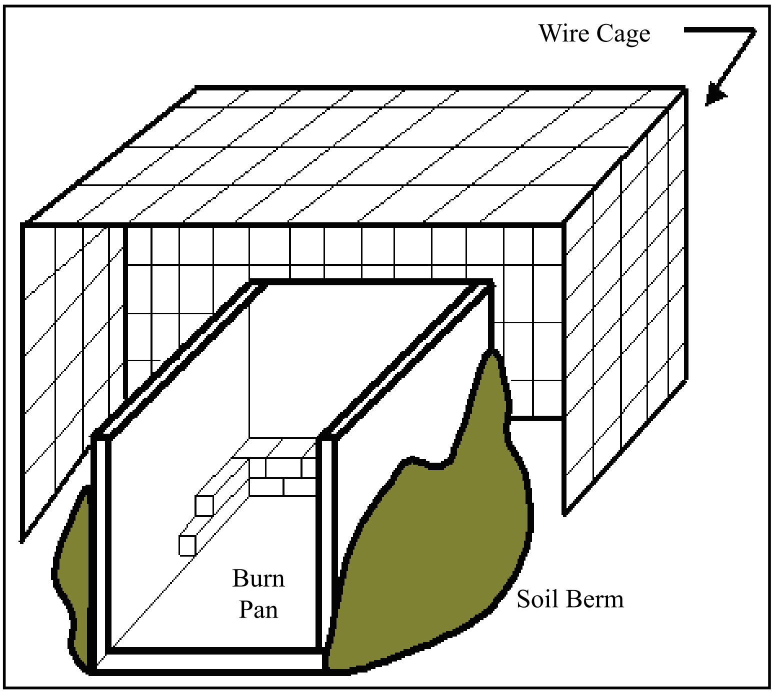

Figure 16: Open dump and open detonation.

Remediation Techniques	Types	Advantages	Disadvantages	References
Soil Vapor Extraction (Soil Venting) • Involves the installation of vertical and/or horizontal wells in the area of soil contamination. Vacuums are then applied through the wells to evaporate the volatile constituents of the contaminated mass which are subsequently withdrawn through an extraction well.		• Very efficient, readily available equipments and easy to install • Requires short treatment times (6-48 months).	• Effectiveness decreases in low soil permeability. • Useful only for the unsaturated zone.	[28,77]
Soil Washing • Uses solvents including water in combination with mechanical processes to scrub soils.		• Effectively reduces the volume of contaminant, therefore, further treatment or disposal is less problematic • Used commercially in large scale.	• Contaminant toxicity is unchanged, although volume is reduced. • Less effective when soil contains a high percentage of silt and clay • After treatment disposal costs are generated.	[17,25]
Soil Flushing • Water is passed through the contaminated soils with a solution that moves the contaminants to an area where they can be removed.		• Useful to all types of soil contaminants and is generally used in conjunction with other remediation technologies. • Reduces the need for excavation, handling, or transportation of hazardous substances.	• Soils with low permeability or heterogeneity are difficult to treat • Long remediation times. • Requires hydraulic control to avoid the movement of contaminants off-site.	[23,41,56]
Encapsulation • Application of low permeability layers of synthetic textiles or clay caps on contaminated areas. Designed to limit the infiltration of precipitation and thus prevent leaching and migration of contaminants away from the site and into the groundwater		• Comprised of the physical isolation and containment of the contaminated material.	• Lithology of soil site controls the efficacy. • The efficiency of encapsulation decreases with time. • Implemented only with shallow contaminated soils.	[2,59]
Stabilization/solidification (S/S) • Relies on the reaction between a binder and soil to stop/prevent or reduce the mobility of contaminants.		• Useful and established remediation technology for contaminated soils in many countries in the world.	• Lack of expertise on technical guidance. • Uncertainty over the durability and rate of contaminant release. • Residual liability associated with immobilized contaminants remaining on-site	[66]
Stable Isotope Probing • A method to identify active microorganisms without the prerequisite of cultivation which has been widely applied in the study of microorganisms involved in the degradation of environmental pollutants.	Polar lipid derived fatty acid-based stable isotope probing (PLFA-SIP)	• Establishes the identity of microorganisms involved in biodegradation.	• Weaknesses of molecular methods (nucleic acid recovery, PCR bias, etc.) and incubation time may result in cross-feeding.	[11]
	DNA-based stable isotope probing (DNA-SIP)			[50]
	RNA-based stable isotope probing (RNA-SIP)			[23,24]
	Fluorescence in situ hybridization and secondary ion mass spectrometry (FISH-SIMS)			[54,55]
	Stable isotope characterization of small-subunit rRNA			[42]
Nanotech Remediation • Uses nanomaterials and nano-products without toxic ingredients to remove toxic chemicals from environment		• Used to stabilize and guard enzymes against mechanical and biotic degradation. Thus increases their half-life and permits recirculation in their use.	• Yet to be exploited commercially	[5,17,18]
Air Striping • Transferring of volatile components of a liquid into an air stream.		• Can achieve better than 95% removal efficacy for a range of organic compounds which are insoluble or slightly soluble in water.	• The presence of solids in wastewaters can foul steam strippers and therefore it is generally advantageous to remove these solids before stripping	[1,6]

Dehalogenation • This technology involves direct chemical stripping of halogen atoms from organics in soils, sediments, and sludges..		• Target compounds are halogenated organics, halogenated SVOCs and pesticides. • Used for soils and sediments contaminated with chlorinated organic compounds, especially PCBs, dioxins and furans.	• High clay and high moisture content increases treatment costs. • Not cost-effective for large waste volumes. • Sometimes diifficult to capture and treat the residuals.	[66]
Electrokinetic Remediation (EKR) • An in situ soil processing technology using electro-chemical and electro-kinetic processes to desorb (separate) and then remove metals and polar organic contaminants from low permeability soils.		• Has small impact on environment (soil removal is not required). • Metals are actually removed from soil unlike stabilization, which leaves the metals in the soil.	• Efficiency reduced by alkaline soils. • Requires soil moisture.	[60,69]
Electrodialytic soil remediation (EDR) • An electrokinetic method used for removal of heavy metals from soil (and particulate waste products) which uses exchange membranes for separating soil and processing solutions.		• Can treat the soil as a stationary wet matrix (*in-situ* or on-site) • Can treat the soil in a suspension (with the possibility for combining EDR with soil washing and only treat the fine fraction with EDR) (On-site).	• Yet to be exploited commercially	[56]
Photo catalytic Degradation • It is the alteration of contaminant by light. Typically, the term refers to the combined action of sunlight and air.		• Complete Mineralization • No waste disposal problem • Low cost	• Limited to surface contaminants	[9,15,72]
Ultraviolet Oxidation • Uses an oxygen-based oxidant (e.g., ozone or hydrogen peroxide) in combination with UV light.		• Chemicals used do not pollute the environment. • Successful with substances such as ferricyanides which cannot be removed by other methods.	• Low turbidity and suspended solids are necessary for good light transmission. • Free radical scavengers may interfere with the reactions.	[11,38]
Precipitation/ Flocculation • Uses non-directed physico-chemical complex cation reaction between dissolved contaminants and charged cellular components (dead biomass).		• Cost-effective	• Yet to be exploited commercially	[50]
Microfiltration • The goal is to separate dispersed oil phase from water using porous membranes.		• Removes dissolved solids effectively.	• Yet to be exploited commercially	[20]
Analytical Biosensors • The biosensors rely on analysis of gene expression typically by creating transcriptional fusions between a promoter of interest and the reporter gene expression serves as a measure of the availability of specific pollutants in complex environments.		• Used for nutrient monitoring • Used for degradation metoblites monitoring	• Bio elements and chemicals used in the biosensors need to be prevented from leaking out of the biosensor over time (serious issue for non-disposable ones	[39,51,52]
Chemical Oxidation • Involves reduction/ oxidation (redox) reactions that chemically convert hazardous contaminants to more stable nonhazardous or less toxic compounds.		• Target treatment group is inorganics. • Also used but less effective for non-halogenated VOCs and SVOCs, fuel hydrocarbons and pesticides.	• Incomplete oxidation may occur depending upon the contaminants and oxidizing agent used • Not cost-effective for high contaminant concentrations. • Presence of oil and grease in the media reduces efficiency.	[8,12,28,30,31]

Table 2b: List of non-biological non thermal techniques used in remediation of contaminants with their advantages and disadvantages.

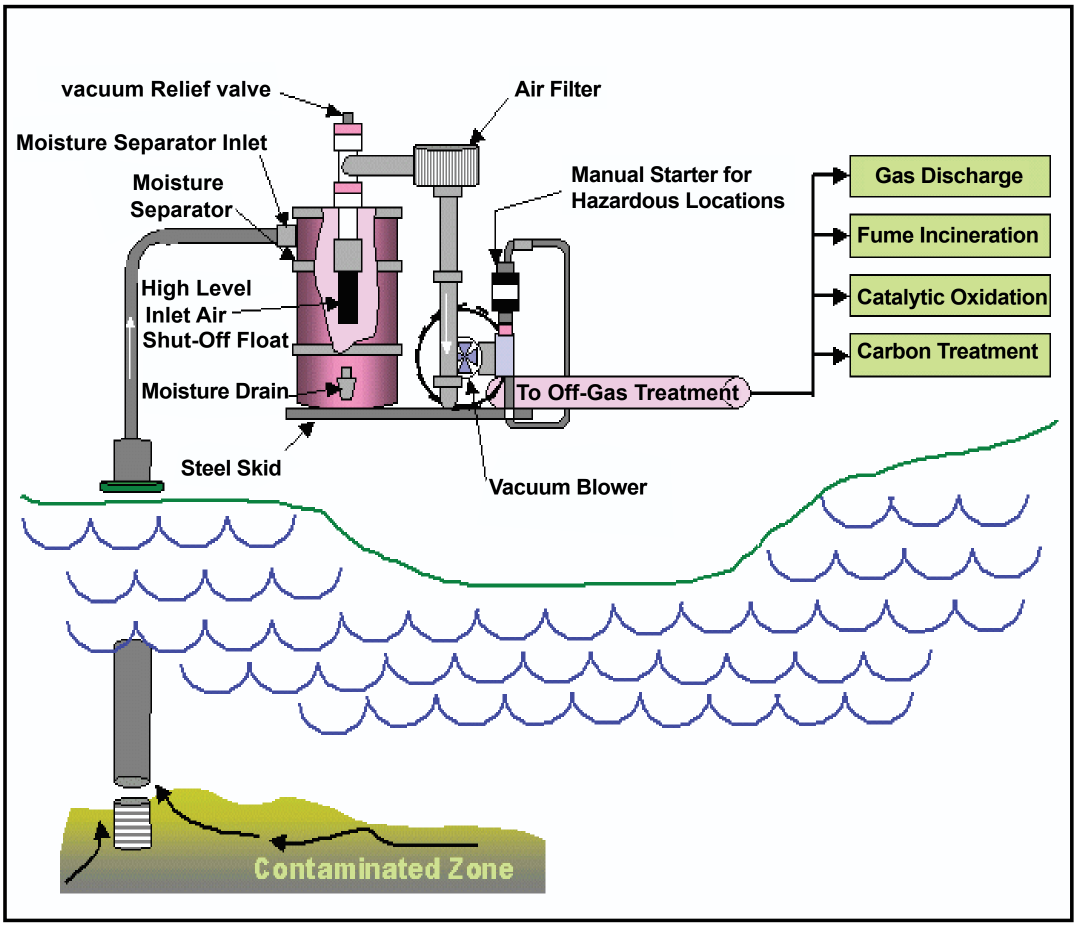

Figure 17: Soil vapor extraction.

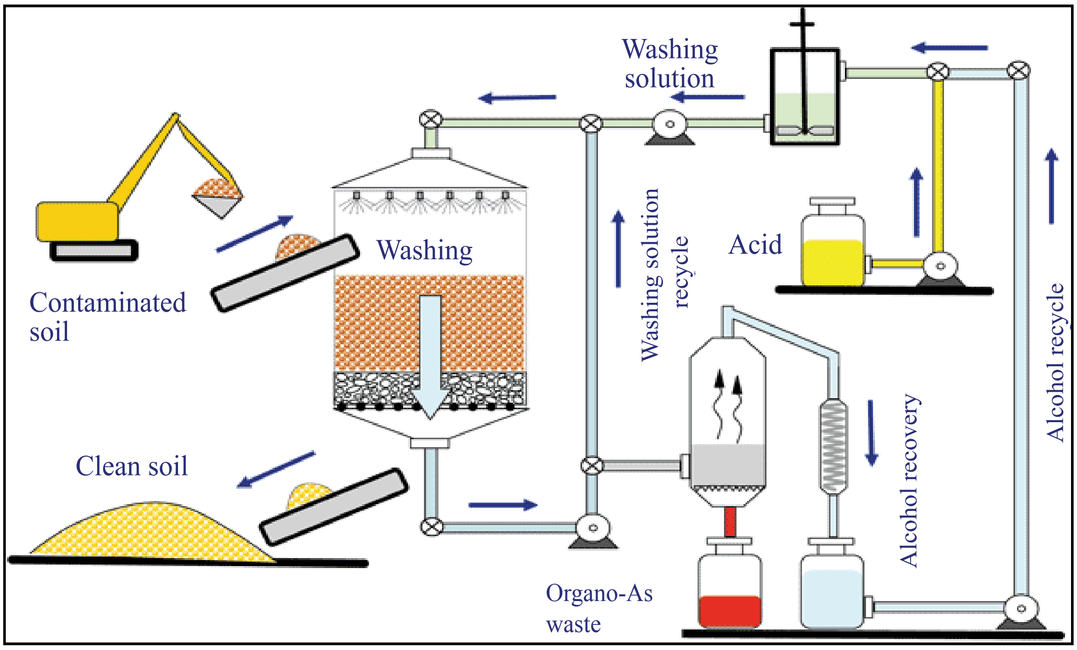

Figure 18: Soil washing.

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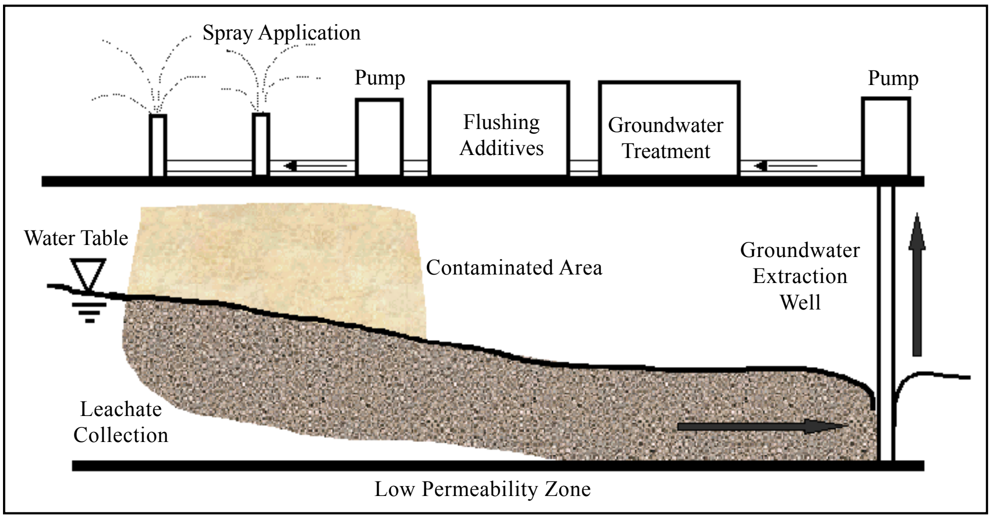

Figure 19: Soil flushing.

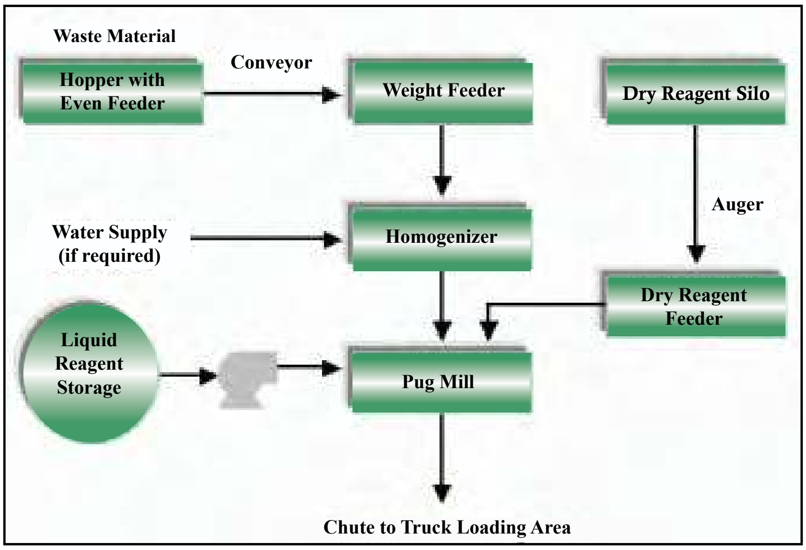

Figure 20: Solidification.

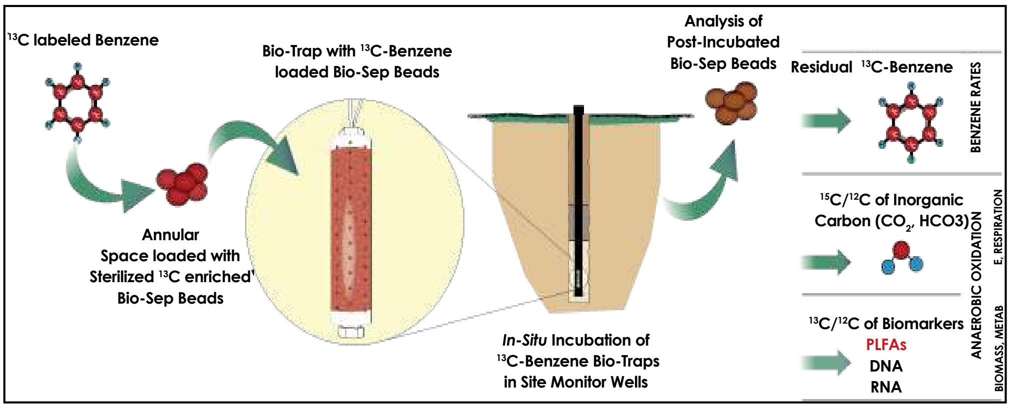

Figure 21: Stable isotope probing.

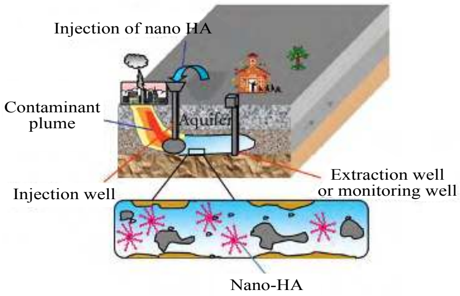

Figure 22: Nanoremediation.

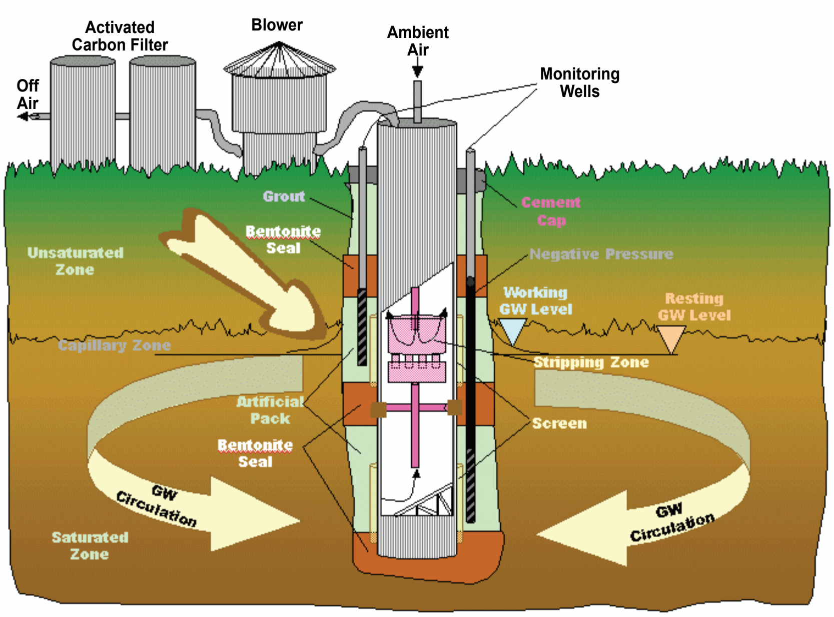

Figure 23: Air stripping.

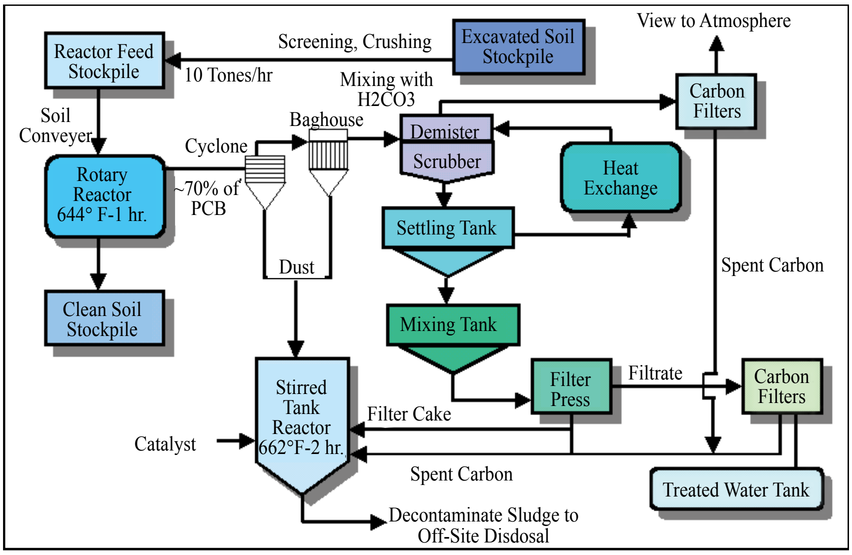

Figure 24: Dehalogenation.

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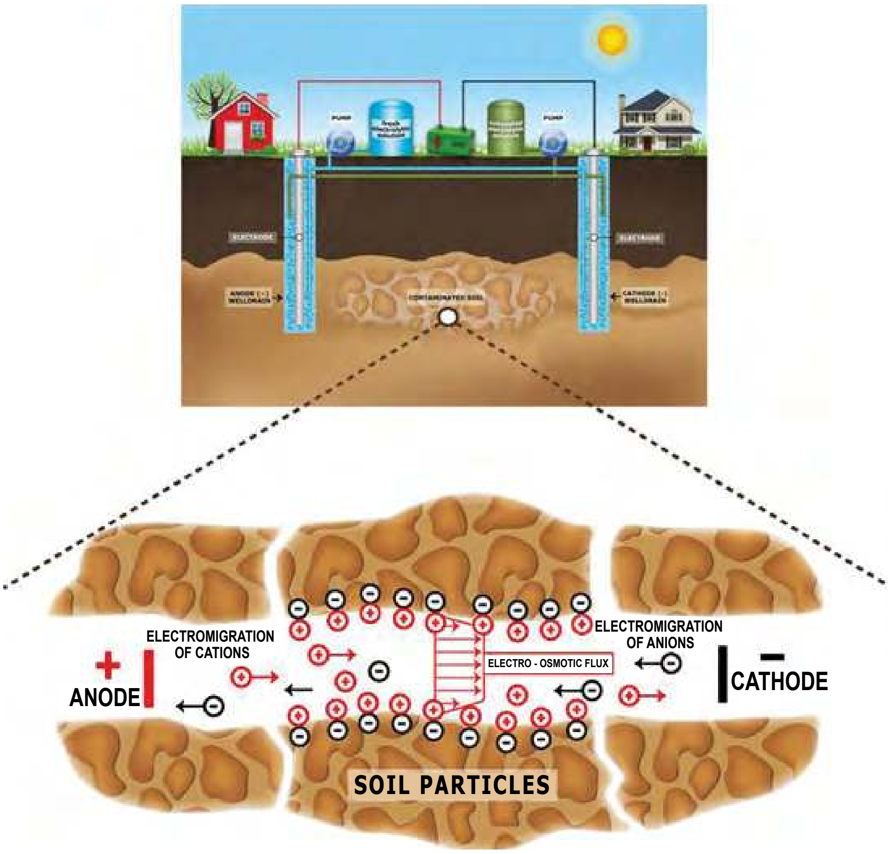

Figure 25: Electrokinetic remediation.

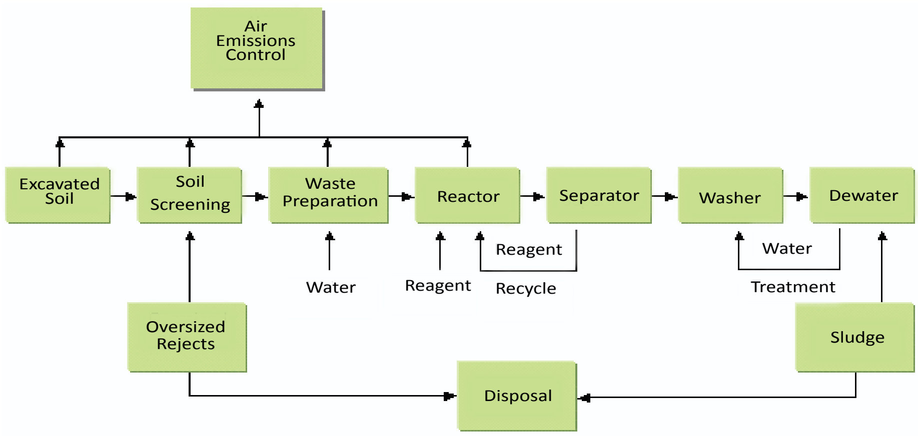

Figure 26: Chemical oxidation.

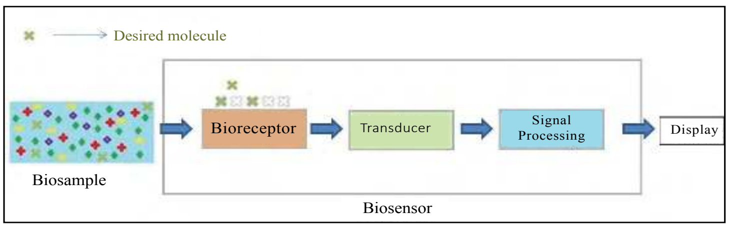

Figure 27: Analytical biosensor.

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