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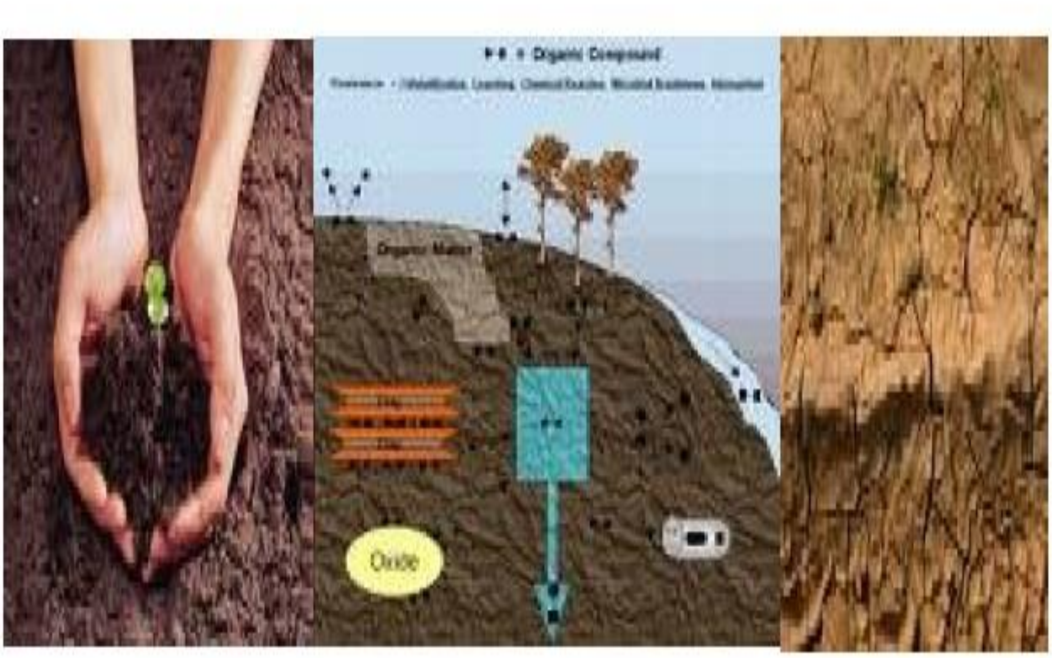
SOIL POLLUTION



CHAPTER THIRTEEN

PLANNING AND REALISATION OF SOIL REMEDIATION

For Post graduate Students 2020\2021
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Introduction:

A successful remediation plan has to be based on the information gained during the preliminary diagnostic works, which are done before taking the decision to start a remediation project. The following checklist should be worked out and carefully studied before starting with the actual design of the technical work.

1- What are the types and chemical nature of the pollutants determined at the site؟

–Organics

–Inorganic substances

2- What are the dimensions and scale of pollution?

–Is the pollution localized؟

–Is it of the dispersed type؟

–How urgent is the remediation plan؟

3- What is the risk level?

–Low risk level

–Medium level

–High risk level

4- Which technical measures are thought to be most suitable for carrying out this project?

–In place (in situ)

–Ex situ? And if yes, should the soil be transported to a special facility? Should the remediation be carried out in a prepared bed system, or in a tank؟

5- Are there any financial restrictions on choosing the technical method of remediation?

6- Which method is technically suitable and financially fitting in the economic framework of the project?

1. Categories of Pollutants

A pollutant can in fact be any environmentally harmful substance that is accidentally or on purpose transported to the soil. Yet, for the sake of planning, a common, rather simplified classification, enables the selection of the suitable remediation method. The following checklist helps limit into a few categories the uncountable substances that may pollute the soil, having similar chemical and physical properties, and in most cases، having comparable degrees of response to a given remediation process.

- Are the pollutants in the present case chemically characterized and identified? If yes، are they solids, or leachates؟
- Are they organics or non-organics? If organic, are they aliphatics or aromatics? If aromatics are they halogenated؟
    - How high/low are their molecular weights? (from the tables)
    - Are they volatile or of low volatility?
    - Are they (for organics) polar or non-polar? What is their degree of solubility (high, low)؟
    - Is there any information about their biodegradability?
    - If inorganic, of which category are they: metals, metal cations, waste–acids/alkalis?
    - Are they easily oxidisable compounds? Are there any inorganic cyanides?

The careful utilization of this checklist, as we will see later, is a very important step on the right way to select the appropriate method of remediation. Other factors, such as the scale of pollution and financial restrictions, may impose a revision of the decisions taken at this stage.

1.2 Scale of Pollution

Results of sampling and chemical investigation supply enough information about the spatial dimensions of the pollution case which is supposed to be treated. Pollution cases may be, according to their spatial dimensions, classified into the following two main types:

1. Localized pollution cases. These are cases resulting from spill accidents, where materials spilled are known and the risk is at a minimum when quick measures are taken.

In these cases, remediation is mostly carried out in situ. Material safety data sheets supply information on the pollutant or the hazardous material forming the spill, so that immediate actions can be taken.

2. Diffused pollution cases. Pollutants entering the soil will try to spread in both horizontal and vertical directions, whereby the dimensions of transport and diffusion will depend upon the saturation of the soil and upon its hydraulic and lithological character. When pollutants reach the groundwater, its further transport will, as it was said before, depend upon the lithological character of the aquifer.

1.3 Risk Level

Risk levels of contaminants should be determined according to the information collected on the chemical and physical properties of the potentially toxic material and its degree of dispersion in the area of investigation. Information on bioavailability and mobility of the material may indicate a low risk level, if the toxic material is in an immobile form or a non-bio-available form with no impact on the environmental conditions. However, continuous monitoring is important in such cases, where no immediate risk exists, yet possible problems are expected on change of the chemical or physical conditions. In cases where immediate risk exists, such as after spill accidents or the discovery of old toxic deposits resulting from old landfills, or military or industrial sites، measures for remediation should be started or carried out within a short time.

2- Remediation Technologies

According to the scale of pollution, the risk level and the financial and time constraints on the remediation project, treatment of the soil may take place immediately in place (in situ), or the soil may be transported to special facilities where remediation may be carried out in special reactors or vessels, which are specially designed for this purpose (in tank method). An example of this process is the washing of heavily polluted soils in special tanks. The polluted soil may also be transported and spread on a surface prepared to prevent the spread of contamination in lateral and vertical directions. Beds arranged in this way form the so-called prepared beds, upon which the remediation process will take place. This method is especially suitable for soils contaminated by oil products. Generally speaking, however, four classes of remediation technologies are known. These are:

Chemical and physical methods

Biological methods

Fixation methods (also storing and immobilization)

Thermal destruction methods

Figure 13.1 shows the main types of remediation technologies in a schematic way.

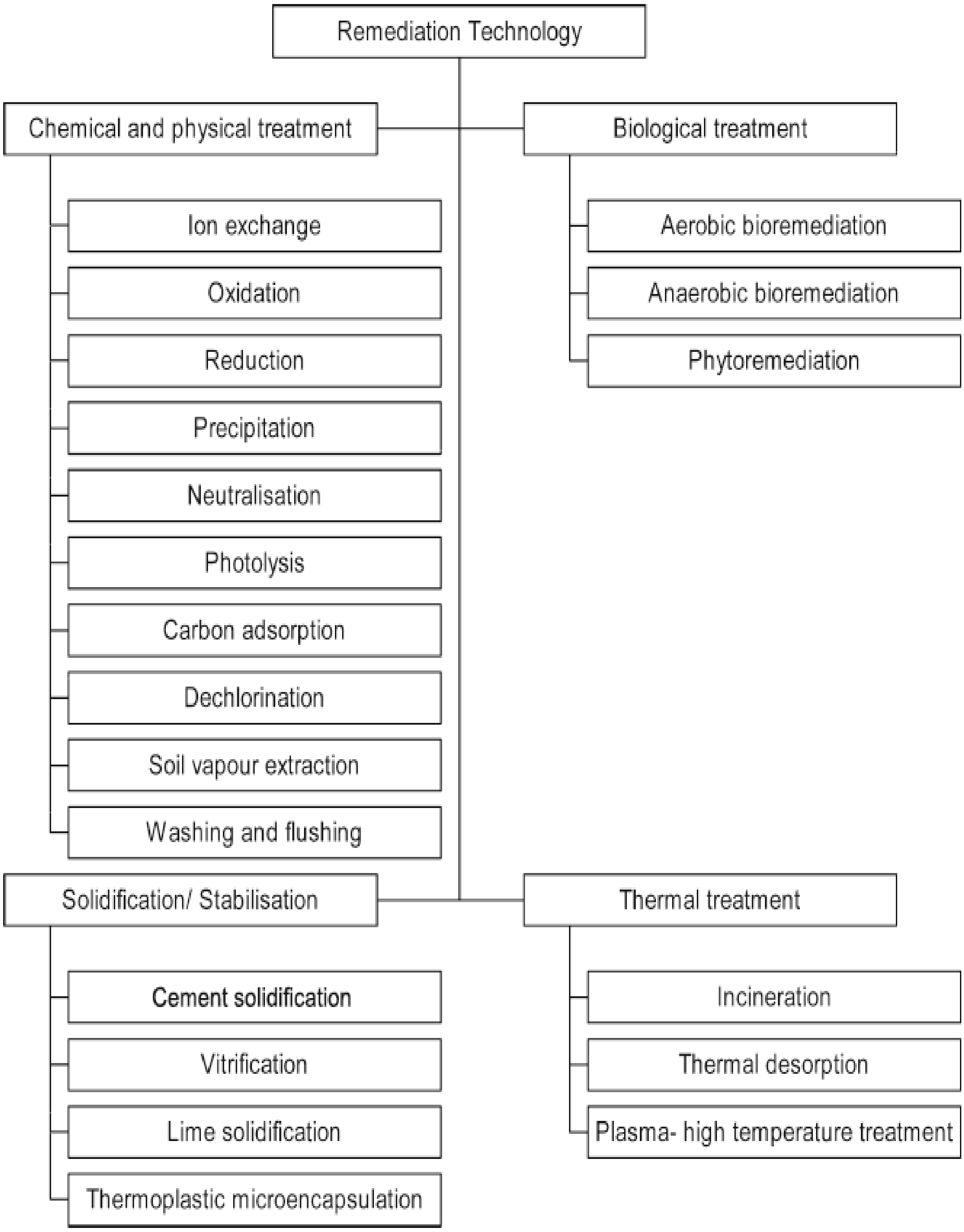


Fig. 13.1 Common remediation technologies

Some of the above-mentioned methods may require specific technical installations (tanks and prepared beds), others may be suitable for use in place (in situ), while others may be suitable for all three operational modes of remediation. Table 13.1 roughly shows the specific mode, or modes, suitable for each of the above-mentioned techniques. From the table, one can clearly see that technologies like vacuum extraction and soil flushing are mainly done in situ, while all bioremediation methods are suitable for all operational modes. This fact plays a role in the financial planning of the remediation project and should be taken into account. The main decisive role, however، is played by the effectiveness of the method to the type of pollution encountered. In the following, each of the above-mentioned technologies will be shortly described.

Table 13.1 The different operational modes with their corresponding remediation techniques based on Boulding (1995)

Operational mode(s)	Suitable remediation technique
In situ	Soil vacuum extraction (SVE), soil flushing
In situ or in prepared beds	Carbon adsorption, ion exchange
In situ or in tank	Thermal stripping, dechlorination, cement solidification, vitrification, lime solidification, thermoplastic microencapsulation
All (in situ, in tank or in bed)	Neutralisation, oxidation, bioremediation (all methods)
In prepared bed	Photolysis
In prepared bed or in tank	Precipitation, reduction, carbon adsorption, ion exchange
In tank	Pyrolysis, infrared, rotary kiln, fluidised bed, soil washing

2.1. Chemical and Physical Remedial Techniques

The aim of all chemical and physical methods of remediation is to change the chemical environment in a way that prevents the transport of toxic substances to other elements of the soil system; examples here can be given by transport to plants, to groundwater، or to soil organisms. Such preventive measures may include decreasing mobility، or change of chemical constitution Chemical and physical methods of remediation include the following.

2.1.1. Oxidation

Oxidation is a common, highly effective remediation technology for soils contaminated by toxic organic chemicals and cyanides. Oxidizing agents used in this technology include a wide range of substances, among which the most common are hydrogen peroxide, ozone and potassium permanganate.

2.1.2. Ion Exchange, Chelation and Precipitation

Soil components with high CEC values are capable of binding positively charged organic chemicals and metals in a way that makes them chemically immobile and thus reduces the risk imposed by them on the soil environment. The addition of soil conditioners، such as synthetic resins, zeolites or clays, may help increase the CEC characteristics of the soil and thus enhance the binding of positively charged contaminants on the negative functional groups of the soil matter.

Newly developed resins are now used for sites contaminated with complex materials، such as toxic metals combined with organic matter or even radioactive contaminants. Such multipurpose resins are capable of carrying out the process in one step. An example may be given by the resin developed with the help of the American Department of Defence (DoD), which depends on polymers derived from naturally occurring humic acids (Sanjay et al. 2006).

According to the authors, this resin is effective in cleaning sites contaminated with various types of pollutants, especially when the aquifers are contaminated with NAPLs. The treatment material is put within permeable reactive barriers (PRB) constructed to intercept the path of the contaminated groundwater plume.

2.1.3. Photolysis

Photolytic degradation technology depends upon degrading the organic contaminants with ultraviolet radiation. This may be carried out using artificial UV light or just by exposing the soil to sunlight, which may be sufficient for degrading shallow soil contaminants. The process can be carried out in situ or in prepared beds. However, deeply contaminated soils must be excavated and transported to special facilities, where the process is carried out in special tanks. A combination of photolytic degradation and bioremediation may be achieved by adding microorganisms and nutrients to the soil after the photolytic treatment.

Photolytic treatment using UV technologies is a very effective method, due to the fact that UV rays actually destroy the contaminants leaving no residue. UV photons are used in this technology to break the chemical bonds in volatile organic substances (VOCs), such as trichlorethylene (TCE), toluene, benzene, etc.

2.1.4. Adsorption on Granulated Active Carbon (GAC)

This technology depends upon the tendency of most organic compounds to adsorb on the surface of activated carbon. Adsorption tendency increases with the molecular weight boiling point of the organic material. Thus we find that the technology of adsorption on granular activated carbon (GAC) is best suited for volatile organic compounds، hydrocarbons of high molecular weights, halogenated volatile organic compounds (VOC) and their halogenated forms, as well as some explosives and pesticides.

Remediation through adsorption on activated carbon is a method that can be carried out in the liquid phase (as in treatment of groundwater), or in the gas phase (as in treating off-gases from soil vapour extraction remediation methods). As a matter of fact, one of the earliest applications of this method was the use of GAC in adsorbing military gases by gas masks in the First World War.

Adsorption on activated carbon is a process carried out ex situ in special tanks or in prepared beds. It is principally used to treat toxic gases, solvents and organically based odours. However, impregnation of activated carbon with additional chemicals may be helpful in controlling some inorganic contaminants such as hydrogen sulphide، mercury or radon.

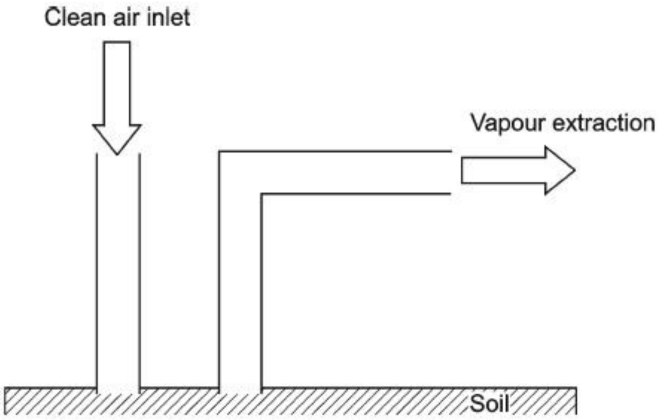
2.1.5. Soil Vapour Extraction (SVE)

Soil vapour extraction is a popular technology for the remediation of soils. It is a relatively simple process to remove volatile and easily evaporated organic contaminants within the vadose zone, i.e. contaminants persisting or accumulated above the groundwater table. The technical process of this technology involves injecting clean air into the unsaturated zone to effect a separation of organic vapours from the soil solution، by partitioning these vapours between the soil solution and the soil air. The vapours joining the soil air are then removed via vacuum extraction wells. Figure 13.2 shows a schematic view of an SVE arrangement.

Needless to say, the effectiveness of soil vapour extraction will depend principally on the degree of water saturation in the treated soil, as well as on the physical and chemical properties of the extracted contaminant, such as vapour pressure and volatility. Vapour extracted by this method may be further treated by carbon adsorption or any other suitable method that may help to dispose of the toxic gases collected.

To enhance the extraction in this technology, heated air or steam may be injected into the soil. Reports on the use of steam at sites of defunct gas stations show high efficiency performance at a reasonably low cost. Adding an air sparing system to the technical installations of SVE makes this technology also suitable for removing contaminants from the saturated zone.

Fig. 13.2 A schematic diagram to explain the technical arrangements required for soil vapour extraction (SVE)



2.1.6. Soil Washing

In this technique, polluted soil is scrubbed by water through mechanical agitation to remove the hazardous contaminants or reduce their volume. It makes use of the selective binding of contaminants to fine material (silt and clay) rather than to coarse soil material (sand and gravel). Adding chemical additives or surfactants to the water may enhance this process. After separating the two soil fractions, fine material carrying the major part of contaminants is further treated by other methods of remediation to get rid of the separated contaminants (see Fig. 13.3), while the coarse material, if cleaned up, may be returned to the plot.

Soil washing belongs to the category of volume reduction techniques in which the contaminants are concentrated in a relatively small mass of material. It is used to treat soils contaminated by a wide range of pollutants, ranging from metals to oil products and pesticides.

2.1.7. Soil Flushing

Soil flushing is a remediation method used for in situ treatment of inorganic and organic contaminants. Known sometimes as the cosolvent flushing method, this technique depends upon

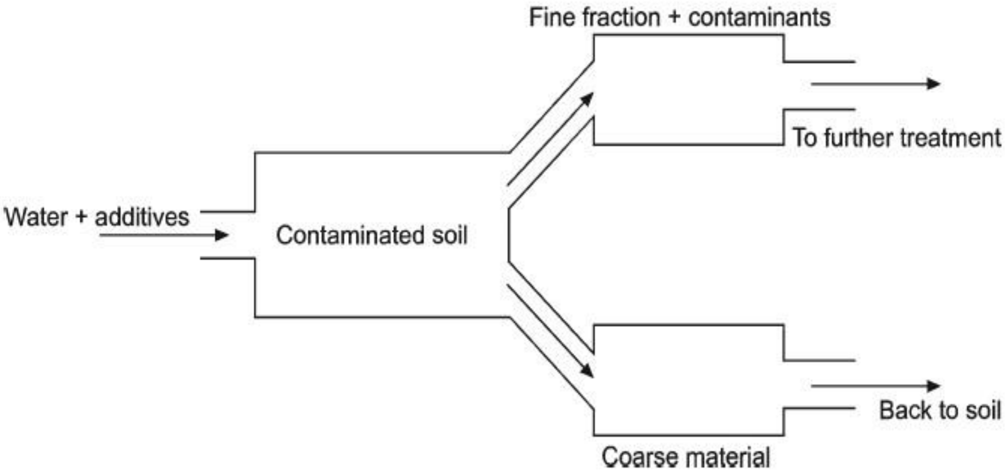


Fig. 13.3 Schematic diagram showing the different steps in soil washing

injecting a solvent mixture, such as water and alcohol or surfactants، into the vadose or saturated zone. The leachate, i.e. the solvent with leached contaminants، is drawn from recovery wells to be treated above ground or disposed of. The flushing technique is mainly used to treat soils contaminated by inorganics, including radioactive contaminants. It may also be used to treat VOCs, SVOCs, pesticides and fuel remnants. It must, however, be mentioned that flushing may not be effective for soils with low permeability. Also, the costs for above-ground treatment of the leachates may raise the financial burden of the remediation project. Figure 13.4 is a diagrammatic illustration of the process.

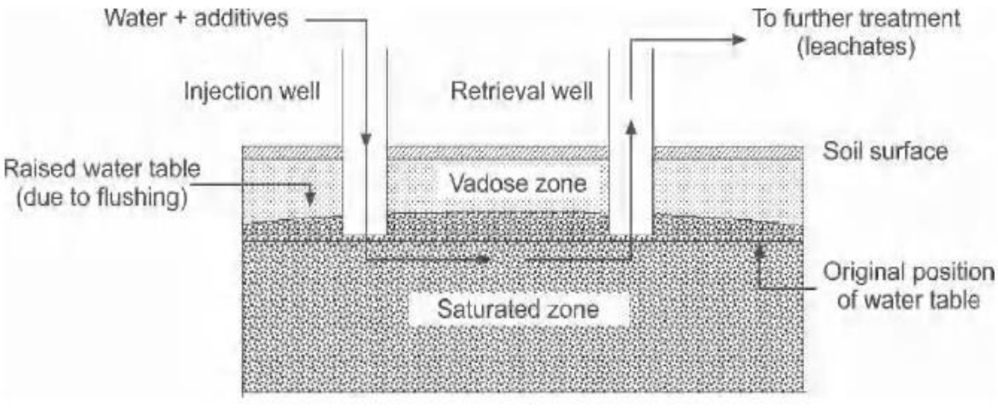


Fig. 13.4 Diagrammatic illustration of soil flushing techniques

2.2.Biological Treatment (Bioremediation)

Biological treatment of contaminated soils is a remedial technique making use of naturally occurring microorganisms in the soil, which are capable of degrading toxic materials while carrying out their daily biological activities. Examples of such organisms include bacteria and yeast. As explained before, some bacteria are capable of digesting a wide range of organic contaminants that are otherwise very difficult to separate or degrade by any of the known technical methods.

Bioremediation is an easy and effective method resulting in the changing of organic contaminants, such as fuels or other oil products, into carbon dioxide and water. However، the time required for complete remediation will depend upon whether the process is carried out in situ, or in special facilities where excavated soil material is transported. Ex situ technologies are normally faster and more effective than in situ processes.

2.2.1. In Situ Bioremediation Techniques

In situ bioremediation techniques are mainly used to treat non-halogenated semivolatile organics, such as diesel fuel and heavy oils, beside other materials that are susceptible to metabolism by microorganisms. This technique, sometimes known as aerobic bioremediation, is accomplished by introducing oxygen and nutrients to the soil in order to enhance biodegradation of the contaminants. Two technical methods are used to create the suitable life conditions for the microorganisms. These are:

1. Bioventing. In this method, atmospheric air is injected through special wells into the soil above the water table, i.e. in the vadose zone, to supply the oxygen required for the microorganisms.

2. Peroxide injection. Here, oxygen is introduced in a liquid form through injection of hydrogen peroxide into the soil. However, this method is only applied to sites where the groundwater is already contaminated, so as to avoid unknown consequences resulting from the contamination of the groundwater by this chemical in areas of limited pollution.

2.2.2.Ex Situ Bio-Remedial Methods

Ex situ bio-remedial methods, i.e. those methods carried out away from the pollution site, are normally faster than the in situ methods. They are applicable for a wider range of contaminants, yet they are more expensive and may, in some cases, need pre-treatment as well as post treatment measures, in order to achieve the optimum effectiveness.

According to whether the treatment takes place in special tanks or in prepared beds, ex situ bioremediation consists of two main technologies: slurry phase treatment and solid phase remediation.

1. Slurry phase treatment. In this technology, the polluted soil is excavated and transported to special facilities where it is mixed with water in special tanks (bio reactors). Oxygen and nutrients are later added, and the so formed mixture is thoroughlymixed to form a thin slur. Temperature, nutrients and oxygen concentrations are controlled so that the organisms may have the best conditions in which to sustain their bioactivities, leading to the degradation of the pollutants.

2. Solid phase treatment. Here the polluted soil is treated above the ground in prepared beds. Despite the benefit of being less expensive than the slurry bed treatment, it is not so effective and needs more time and space to prepare the beds.

Figure 13.5 shows in a schematic way the most common processes in biological treatment of polluted soils and the relations that connect them.

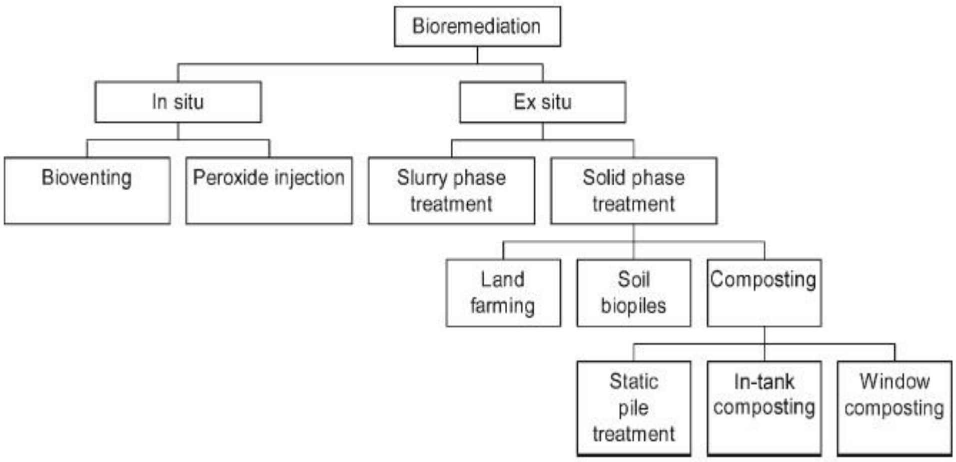


Fig. 13.5 A schematic diagram showing the different technologies of bioremediation

2.3. Solidification/Stabilization Methods

This is a group of technologies aimed at immobilizing or stabilizing contaminants in the soil and to prevent them from entering the environment, either by enclosing them into a solid mass or converting them to the least soluble, mobile or toxic form. Various technologies are known that secure safe performance of these processes. The following are the most successful among them:

Bitumen-based solidification. In this technology, the contaminated material is embedded in molten bitumen and left to cool and solidify. The contaminants thus encapsulated in the molten bituminous mass are changed to an immobile form that cannot enter the environment.

Encapsulation in thermoplastic materials. Thermoplastic materials (e.g. modified sulphur cement) are molten and mixed with the contaminated material in specialtanks and vigorously mixed to form a homogenous slurry fluid. After cooling, the resulting solid may safely be disposed of.

Polyethylene extrusion. The contaminated soil is mixed with polyethylene binders heated and then left to cool. The resulting solid may be disposed of, or used in other ways

Pozzolan/Portland cement. Pozzolanic-based materials (e.g. fly ash, kiln dust, pumice) are mixed with the contaminated matter in presence of water and alkali additives. In this environment, heavy metals may precipitate out of the slurry. The restmass solidifies enclosing the remaining organic contaminants.

Vitrification. In this process the contaminated soil is encapsulated into a monolithic mass of glass. Vitrification may be carried out in situ or ex situ. In situ vitrification is performed by introducing graphite electrodes into the soil and heating them electrically with powerful generators to temperatures between 1 600–1 800 °C. At these temperatures the soil melts and forms a glass block. Upon cooling, organic contaminants are pyrolysed and reduced to gases during the melting process, while heavy metals remain enclosed in the stabilised glass mass. This method has also been successfully used in treating soils contaminated by radioactive materials.

Vitrification may also be done in special appliances where contaminated soil would be molten in presence of borosilicate and soda lime to form a solid glass block.

2.4. Thermal Treatment

Volatilisation and destruction of contaminants by thermal treatment is a very effective technique. It is achieved by heating the contaminated soil in kilns to temperatures between 400 and 700 °C, followed by further treatment of the kiln off-gas at higher temperatures (800–1 200 °C) to secure total oxidation of the organic volatile matter. Thermal treatment includes various technologies, the most important of which are:

Incineration. In this technology, contaminants are combusted at high temperatures (970-1200 °C). It is particularly effective for halogenated and other refractory organic pollutants. Properly operated incinerators may be of very high destruction and removal efficiency (DRE), reaching to as much as 99.9999%, which is normally required for PCBs and dioxins.

Thermal desorption. This is the process by which organic contaminants are volatilised under controlled conditions by heating the contaminated soil to temperatures up to 600 °C. Under these conditions, contaminants of low boiling points vaporize to be afterwards collected and further treated. Other than incineration, this technology aims to physically separate the contaminants from the soil (Fig. 13.7).

Plasma high-temperature metals recovery. At high temperatures (plasma activated) metal fumes are purged, and then later recovered and recycled. This is suitable for soil as well as for groundwater.

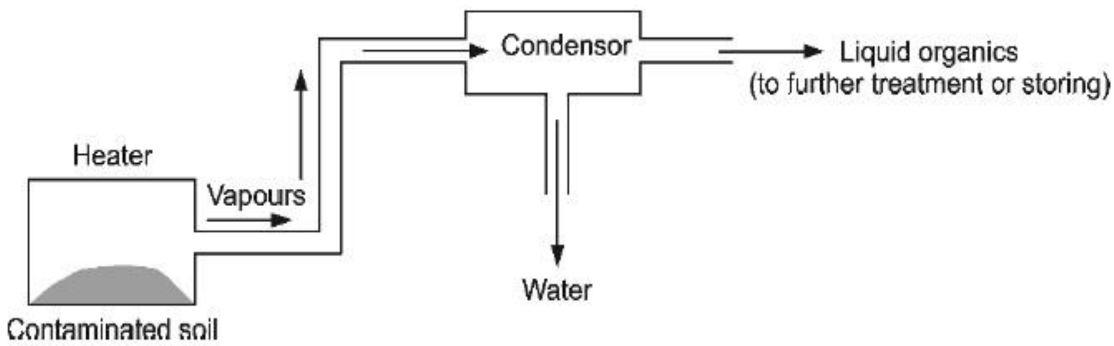


Fig. 13.7 Schematic diagram of a thermal desorption system