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Integrated remediation of brownfield sites using batch and continuous thermal desorption combined with physiochemical processes

S. Nusimovich
Tox Free Solutions Ltd, Australia

Abstract

The use of an integrated approach to manage environmental cleanups, based on the use of thermal desorption and other processes, is ideally suited for the management of brownfield sites. Processing of sludge, sediment, and contaminated soil using continuous indirect thermal desorption based on a vertical retort achieves the desired cleanup levels for contaminants such as organic compounds, pesticides, and PCB. This process when connected to a high-temperature ceramic filtration unit and a full-condensing gas treatment train, in combination with destruction processes such as plasma destruction or recycling processes for organic compounds, offer a range of resources that, when used in an integrated way, can deliver the desired results whilst minimising environmental and health risks and achieving a one stop solution. The effectiveness of this system is supported by data from industrial-scale applications of the processes in the treatment of PCB-contaminated soil and tetrachloroethylene-contaminated material.

1 Introduction

Progress and industrialisation have brought about immense improvements in our quality of life. This development has produced a number of impacts, both negative and positive. Amongst the negative impact of this development, the adverse effects on the environment caused by the release of chemicals are considered to be the most significant. The discharge of contaminated liquids has impacted waterways and aquifers with a variety of chemicals, including both halogenated and non-halogenated organic compounds.

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It is the contamination of soil and groundwater that is considered by experts to be "amongst the most complex and challenging environmental problems faced by many countries" [1]. Soil and groundwater are complex matrices making both the delineation of the extent of the contamination and its removal difficult tasks. The definition of clean up targets is also made extremely difficult by the technical and economic limitations of the available remediation technologies, as well as the complexity of evaluating potential long term health risks, modelling the evolution of contaminants and their breakdown products in the different media, and the use, both present and future, of the affected land.

The search for a portfolio of technologies to address these problems commenced as soon as the first major cases of soil and groundwater pollution were detected. The application of in-situ technologies offered a number of advantages over ex-situ options. However, complete removal or destruction of the pollutants present in the contaminated soil has proven an elusive target. It is the excavation of the contaminated soil and its processing that has proved to be a more efficient operation, that can offer guarantees of performance. Removal of the contaminated soil allows for the specific dimensioning of the problem, the thorough sampling and characterisation of the soil, and, more important, for the processing under controlled conditions and the analysis of all produced streams.

Amongst the technologies used in the remediation of contaminated soils, thermal technologies have found a wide range of application. The use of heat to evaporate, desorb, oxidize, or incinerate compounds were soon seen as processes that could be applied to the treatment of contaminated soil. The separation of compounds from the soil or their destruction using thermal processes has been applied extensively to the remediation of contaminated soil. Amongst these technologies, thermal desorption has been used as a separation process and has evolved since its early uses, in the 1970s.

2 Review of the technology

Thermal desorption is a physiochemical separation process consisting in the direct or indirect heating of a mass of sludge or solids to a certain temperature, either in a batch or a continuous process. Thermal desorption separates the volatile and semi-volatile compounds. Thermal decomposition of the contaminants does not generally take place, although some degree of oxidation or pyrolysis may occur in localised areas [1].

Thermal desorption units may be directly or indirectly fired. In direct systems, heat is transferred by convection, radiation, or from an open flame, to the contaminated material, whilst in indirect systems, heat is transferred by conduction. A number of systems have been developed over time and applied to the decontamination of soil, sediment, and sludge. These systems include rotary dryers, heated screws, thermal blankets, batch desorbers, and hollow disc dryers [2]. Desorption temperatures vary with the system used and the source of heat, with systems classified into low temperature and high temperature processes. Low temperature processes operate at 120-200°C, whilst high temperature desorption processes are designed to operate above 350°C. Given the nature of

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the process, it is suited for the separation of contaminants that are volatile or semi-volatile, with boiling points within the range of operation of the units. Organic compounds, both halogenated and non-halogenated, pesticides, hydrocarbons, polychlorinated biphenyls (PCBs), and polycyclic aromatic compounds have all been separated using these processes. The technology has been successfully used to process large volumes of contaminated materials in the last twenty years, with projects completed in Europe, the U.S., Asia, and Australia.

Treatment of contaminated material from contaminated sites has been the preferred remediation option for Superfund sites in the U.S. since 1982, where the environmental authorities have selected this option over passive measures [3]. Although there has been an increase in the selection of source control measures such as institutional controls, monitoring, and relocation of affected populations, these methods are still a minority. Ex situ technologies, where the contaminated materials are removed and treated, represent the majority of the projects [3]. Outside solidification and off-site incineration, thermal desorption has been the preferred technology in the period 1982-1999, treating a total volume of over one million tonnes. The application of incineration technologies has followed a decreasing trend since 1985, from a high of 38 % of all projects in 1985 to 9 % in 1999 [3].

The performance of the thermal desorption process is dependent on three main parameters: temperature, residence time, and the operating pressure. These three parameters affect the evaporation or desorption of the contaminants from the solid or semi-solid matrix. Root [4] describes the drying process as consisting in three steps. The first step involves the addition of heat to the material until the boiling point of the liquid is reached. The second stage, once the boiling point is reached, involves the evaporation of the liquid at a certain rate. The last stage commences once a critical moisture point is reached, and the drying rate starts to fall. This process, when applied to desorption of a mix of compounds with different boiling points, trapped in a complex heterogeneous matrix, becomes complicated. The rate of heat transfer becomes critical in such a scenario, with agitation providing the necessary force to increase thermal conductivity, and enhancing contact of the particles to heat.

Residence time varies depending both on the characteristics of the product, such as particle size, and the contaminant. This variable, along with temperature, offer the operator the capability to control the outcome of the process. It is important to identify the particular parameters that affect processing of contaminated soils, materials, and sludge. Treatment of these materials presents significant engineering and project management challenges.

Given the heterogeneity of the materials to be processed in remediation projects, engineers are presented with two options: the design of a multi-purpose system that is able to process a wide range of products, or the design of a specific process for a particular product. Temperature control, residence time, and the selection of the gas treatment technology are all affected by the contaminants to be desorbed. The selection of the gas treatment technology and desorption temperature will vary with the compounds targeted for desorption. Careful

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selection of the gas treatment system is important as either total destruction of the pollutants or complete recovery are targets to be attained. Authorisation by the relevant authorities and achieving performance targets depend on the efficiency of this system. Examples of the variability in the application of thermal desorption are presented in Table 1.

Table 1. Application of thermal desorption

Contaminant	**Desorption temperature range**	**Gas treatment technology**
Hydrocarbons	Low-medium	Condensation Thermal oxidation
Chlorinated compounds	Medium	Condensation Carbon adsorption Chemical absorption
PCB	High	Condensation Carbon adsorption Chemical absorption

In most cases, separation of particles from the vapour phase is necessary before other gas treatment technologies are used.

The use of thermal desorption technology in remediation projects requires the consideration of two other important issues: the management of all streams separated by the process, and the siting of the plant and its permitting. The first issue relates to the destination of all the products obtained as a result of the process. Usually, in the case of remediation projects, desorbed soil and a liquid concentrate will be produced. The composition of these streams will obviously vary depending on the feed material and process conditions. These materials will require final disposal or recycling, with the environmental and technical specifications for these operations requiring careful analysis.

The siting of the thermal desorption plant will depend on the magnitude of the project, with the design of a transportable plant to be set up on site as an option to be used in projects requiring the treatment of over 10,000 tonnes. The construction of a central facility to process contaminated materials can be considered when, either the complexity of the plant, or the location of the contaminated sites, makes it an economically viable option.

3 TDPP Technology

Tox Free Solutions Ltd (Australia) developed thermal desorption technology using a novel system based on the use of a vertical retort and a high temperature filter. This was the result of many years of development, and the experience gained from several thermal desorption projects in Australia. The proprietary technology has been used to build a plant, TDPP-III, which was commissioned in January 2002 as a fixed facility to process contaminated soil. Previous plants had been successfully used in desorption of organochlorine pesticides, coal tars, chlorinated compounds, and hydrocarbons. Analysis of the problems posed by contaminated soil identified the preferred criteria used in the selection of a

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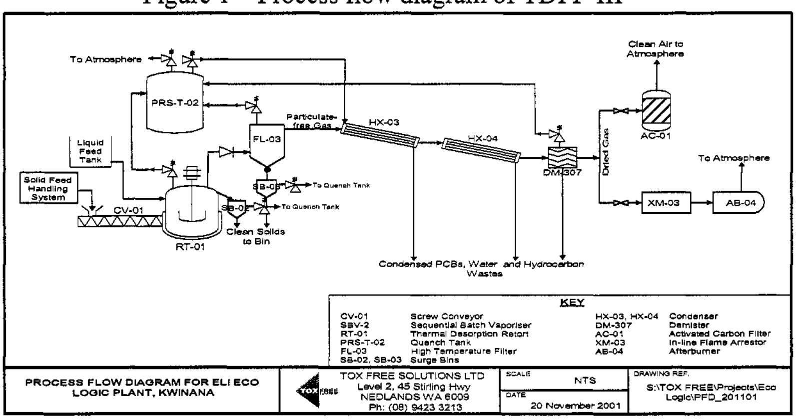
suitable technology for the remediation of contaminated soil. These criteria are presented in Table 2.

Table 2 – Criteria for the selection of remediation technology

Criteria	**Preferred features of the remediation technology**	**Expected results**
Applicability	Wide range of applications for the remediation of contaminants	Potential to process wide range of contaminants
Environmental performance	Minimisation of emissions and discharges Maximisation of recycling Minimisation of environmental risks during operation and in the future	Minimum environmental impact Recovery of products for reuse Complete destruction of contaminants
Economic performance	Cost effectiveness	Good return on investment
Public acceptance	Clean technology Flexibility for siting the plant or process	Public acceptance

Design of TDPP-III followed the criteria of Table 2. The configuration of a high temperature thermal desorption unit was combined with a modular gas treatment system that offered great versatility in the treatment of different contaminants. The design of an indirectly heated closed system, operating under a slight negative pressure, under continuous Nitrogen purging minimised the decomposition of contaminants whilst preventing the formation of hazardous atmospheres and emissions. Recovery of products was maximised through the design of a full condensing system that allowed for the collection of different fractions. The system is presented in Figure 1.

Figure 1 – Process flow diagram of TDPP-III



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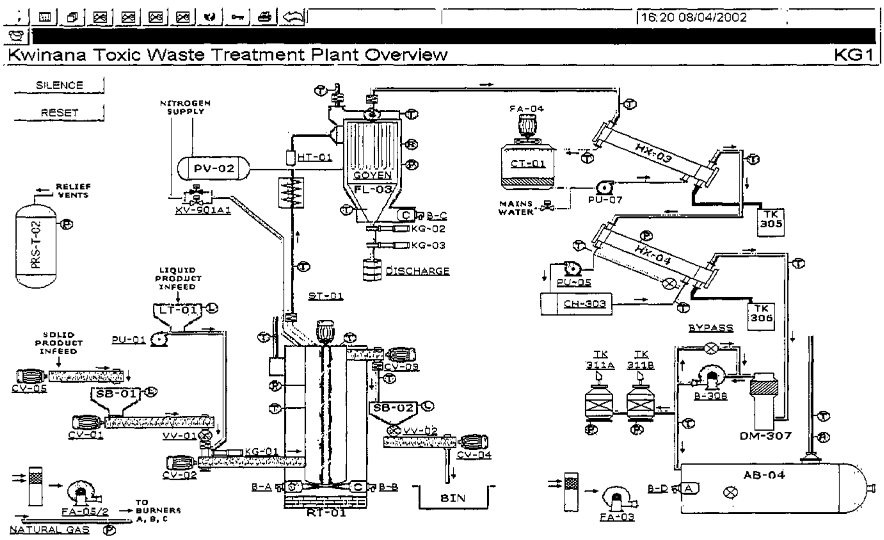
The system consists of a thermal desorption unit which can reach temperatures of 600°C. Thermal desorption takes place in a vertical retort, filled with an inert medium agitated by a helicoidal stirrer. Solid contaminated material is fed using an auger. Vaporised pollutants are filtered thorugh a high temperature heated filter. The particle-free gas then passes through a series of condensers operating at ever-decreasing temperatures. The two condensers separate the majority of VOC and SVOC, that are collected in tanks for recycling or destruction. As the system operates under Nitrogen, the gas exiting the last condenser is mostly this inert gas with traces of compounds that have not been condensed. This gas stream can then be circulated through an activated carbon filter for final polishing or, alternatively, it can be thermally oxidised. The use of the thermal oxidation option is applied when materials are contaminated with hydrocarbons, whilst the full condensing mode with activated carbon is used when materials are contaminated with halogenated compounds. The system includes a secondary containment system to prevent release of materials even in the case of overpressurisation.

The plant has been designed with a high level of instrumentation and control, to be operated through a computer-based logic, whilst registering all process parameters in real time. A typical screen during processing of contaminated soil is shown in Figure 2.

Figure 2. Process control screen of TDPP plant



4 Case Studies

Two processes will illustrate the potential applications of the TDPP thermal desorption process to the remediation of brownfield sites.

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4.1 Thermal desorption of PCB-contaminated soil and debris

Soil and debris from several contaminated sites was treated by thermal desorption using plant TDPP-III. The material was produced during the demolition of concrete slabs and removal of contaminated soil at several power plants, in Western Australia. The areas had been affected by spills and leaks from electrical transformers filled with PCB. The material was also contaminated with petroleum hydrocarbons and was heterogeneous in particle size, characteristics, and moisture content. PCB concentrations were above 50 mg/kg, with various levels of contamination.

Table 3. Concentration of hydrocarbons and PCB in soil

Sample reference	**Concentration of PCB (mg/kg)**	**Concentration of total petroleum hydrocarbons (mg/kg)**
SF-104	3,400	580
SF96	200	580
SF177	160	190
SF181	360	190

The soil was processed by thermal desorption at a temperature of 430-450^{0}C, with the gas treatment train in full condensing mode, and the activated carbon filter AC-1 as the final stage before release of non-condensable gases to atmosphere. A total of 216,512 kg of soil were processed during the first stage of the project, between January 25 2002 and March 14 2002. The plant ran discontinuously, with feed rates of 700 kg/hour, producing 12,800 kg of condensate, composed of PCB, water, and hydrocarbons. The desorbed soil, equivalent to 94 % of the starting material was disposed of at a licensed landfill. In all cases, concentrations in the desorbed soil were below 0.2 mg/kg of PCB and below detection limits for hydrocarbons. The detection limits for hydrocarbons were 0.2 mg/kg for C_{6-9} and C_{10-14}, and 0.4 for C_{15-28} and C_{29-36}, respectively. All collected condensate is to be destroyed by plasma destruction.

An independent party [5] completed sampling and analysis of emissions from the treatment process. These results are summarised in Table 4.

Table 4. Results of the emission monitoring program

Compounds	**Concentration (mg/m^3, 0^0 and 760 mmHg, on a dry basis)**
PAHs	All compounds <0.015
PCBs	All compounds <0.001
Total SVOCs	**< 0.15**
Chloromethane	0.2
Dichloromethane	0.85
Benzene	0.001
Bromomethane	0.01
All other VOCs	<0.003
Total VOCs	**1.1**

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All emissions were well below the limits established by the environmental authorities for the process.

The use of the TDPP plant allowed the operator to offer a system that could manage desorption of both hydrocarbons and PCB in one step, with a reduction of over 94 % in volume that required destruction. Desorption of debris can be achieved by batch desorption or crushing of the material for feeding through the TDPP system.

4.2 Thermal desorption of tetrachloroethylene sludge

Tetrachloroethylene is a common solvent used in dry cleaning and other applications. Numerous sites contaminated with chlorinated solvents require considerable budgets to attempt complex remediation projects. As an indication of the dimensions of the problem, recent pilot work carried out at a site in the U.S., contaminated with tetrachloroethylene, with an affected area of less than 6,500 m^2 put the total remediation figure at $3 million to $25 million [6].

Sludge produced by the dry cleaning industry is currently processed at the TDPP plant by thermal desorption. A study of the process, completed in 2001, tested the use of the thermal desorption unit to attempt the recovery of tetrachloroethylene from the sludge for reuse as solvent. Analysis of samples of the organic phase of the condensate, obtained at retort temperatures of 180^0C and 221^0C, showed consistent levels of tetrachloroethylene in the range of 98 % to 98.7 %. The composition of the organic phase of the condensate is presented in Table 5.

Table 5. Composition of organic phase of condensate samples

Tetrachoroethylene	**98.7 % v/v**
Other chlorinated solvents	**1.2 % v/v**
Hydrocarbons	**<0.1 % v/v**
Hydrochloric acid	**<0.001 % v/v**

The presence of other chlorinated species, absent in the starting material indicate that a certain degree of decomposition of the tetrachloroethylene takes place, as it would be expected under the process conditions.

The final solid product still shows detectable levels of hydrocarbons and polycyclic aromatic hydrocarbons. This is a significant finding, as it shows that contaminants present in the starting material, with boiling points above that of tetrachloroethylene would require a higher processing temperature.

The gas produced during the process was also sampled and analysed. The condenser was shown to have an efficiency of 98.5 % for removal of tetrachloroethylene from the gas stream. Other compounds detected in the gas stream included other chlorinated compounds, ketones, and hydrogen chloride.

This application demonstrates the feasibility of using the process to recover organic compounds with a high efficiency and the potential for reuse, not only of the desorbed soil as clean fill, but also of the liquid fraction.

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5 Potential applications of the technology as an integrated modular system

It is clear from the two cases described in previous sections and the more than 60 Superfund projects completed in the U.S., that thermal desorption continues to offer tremendous potential for remediation of contaminated sites. This is especially so, in the case of brownfield sites, where the level of cleanup achieved by thermal desorption can offer the possibility of reuse of the desorbed soil on site.

The combination of the TDPP technology with a destruction technology and the design of a gas treatment system specified for the control of the target pollutants for a particular project is a cost-effective strategy that provides a fully integrated solution that can be implemented on-site. It is possible to treat the off gas or the condensate using a destruction process directly. An example of such an application is the design of an integrated system, where packaging material is separated to be desorbed in a batch desorber and all condensed liquids are directed to a PLASCON® unit to be destroyed by a plasma arc. This application would be especially suitable for halogenated materials such as PCB, dioxins, and chlorinated pesticides.

The reduction of costs, risks, and environmental impacts by implementing this strategy are significant. The elimination of the need for transporting the separated contaminants to the disposal facility by destroying them on-line reduces risks and costs, whilst the installation of gas treatment equipment specifically designed for control of the target pollutants minimises environmental impacts. The on-site recycling of the processed soil not only eliminates the cost of transport of that material, but it offers a safe alternative that reduces development costs of the brownfield site.

6 Conclusions

The TDPP thermal desorption technology is a high temperature separation process that can treat a wide range of contaminated materials. Its greatest potential derives from the fact that it offers a cost-effective high-performing means to separate contaminants from a complex matrix. The use of the technology for desorption of PCB-contaminated materials and tetrachlorethylene-contaminated sludge are examples of successful industrial-scale applications of the process.

The use of TDPP technology combined with a destruction process as an integrated solution for on-site treatment of contaminated materials results in a cost-effective option to reclaim contaminated soil in brownfield development projects. The engineering of the gas treatment system as a modular system that can be assembled to target specific pollutants minimises environmental impacts and risks. These combined strategies result in the design of an integrated system that can be implemented on-site to maximise recycling of materials and minimise costs and environmental risks.

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