



# Current Status of Research and Development in Soil Remediation Technology

Toru Eto  
Kinya Fujita  
Seiichi Terakura  
Toshiaki Arai  
Mamoru Araoka  
Naoyuki Kamishima

*With the increasing need of protecting the living environment from soil pollution in addition to air and water protection in recent years, the new law for soil pollution control was established in the Ordinary Session of the Diet in 2002. In this report we would like to introduce the outline of the solvent extraction system introduced in 2001 from Terra-Kleen Response Group, Inc., U.S.A. as a technology for purifying the soil contaminated with oils and PCB as well as the outline of the research and development program of Mitsubishi Heavy Industries Ltd. (MHI) on soil remediation technology, focusing mainly on the current status of verification and research in PCB contaminated soil remediation that started in 2001 using the aforesaid technology.*

## 1. Introduction

Soil, as well as water and air, is an important factor of environment, and bears a major role for making the foundation of living things including human being and material circulation. Contamination of soil is likely to affect the health of human beings in various ways through drinking contaminated underground water, taking in crops grown in the contaminated soil and using the contaminated soil directly. Hence, the environmental quality standards for soil were established in 1991 according to the Basic Law for Environment Pollution Control (current the Basic Law on the Environment). In order to protect the health of people and to preserve the living environment, preventive measures against soil pollution and early treatment are essential, but unlike water and air, the soil being a private property, the legislation of purification measures against soil pollution has been lagging behind.

However, with the increasing trend of legislation in Western countries one after another, and with a large number of places in Japan found to have soil contamination through the investigation of the land after the shutdown of factories at the time of redevelopment or resale, the new law for soil pollution control was passed in the Diet on May 22, 2002 under the increasing pressure of social demand. The Law was officially announced on May 29 of the same year. The government and ministerial ordinances specifying the technical standards in detail are expected to be discussed by autumn this year and enforced in January 2003. According to the new law, the owner of the land of the factory specified as the nominated facility by Water Pollution Control Law will be obliged to carry out investigation at the time of shut-

down and to take necessary measures should the soil be found contaminated.

On the other hand, in addition to the legislation, the recent social trends for disclosure of information, the diffusion and permeation of ISO14000 series, and the demands for risk management have brought about independent movements on the part of the enterprises regarding the soil environment. The large enterprises have commenced to carry out investigations and take measures not only at the time of buying or selling the land but also during the time the factory is under operation.

Ever since MHI took upon the task of purifying the VOC (Volatile Organic Compounds) contaminated soil in 1996, it has introduced the purification technology for oil and PCB contaminated soil using solvent extraction system from Terra-Kleen Response Group, Inc., U.S.A. Further, MHI has put into practice the heat treatment technology for the soil contaminated with VOC, oil, and dioxin, etc. using the externally heated kiln through technical collaboration with TechTrade GmbH, German and has started up a full-scale program in soil remediation field with a series of consistent systems from investigation and analysis to countermeasures and environmental monitoring.

## 2. Programs in soil remediation field

Soil remediation aims not at treating the contaminants discharged steadily from the factories such as exhaust gas and water but at removing the contaminants from the soil itself. Hence, unlike the job of selling the purification devices, it is a service job with the purification itself as a commodity. In this business, therefore, the purification measures are taken according to the



Fig. 1 Flow of countermeasure against soil pollution

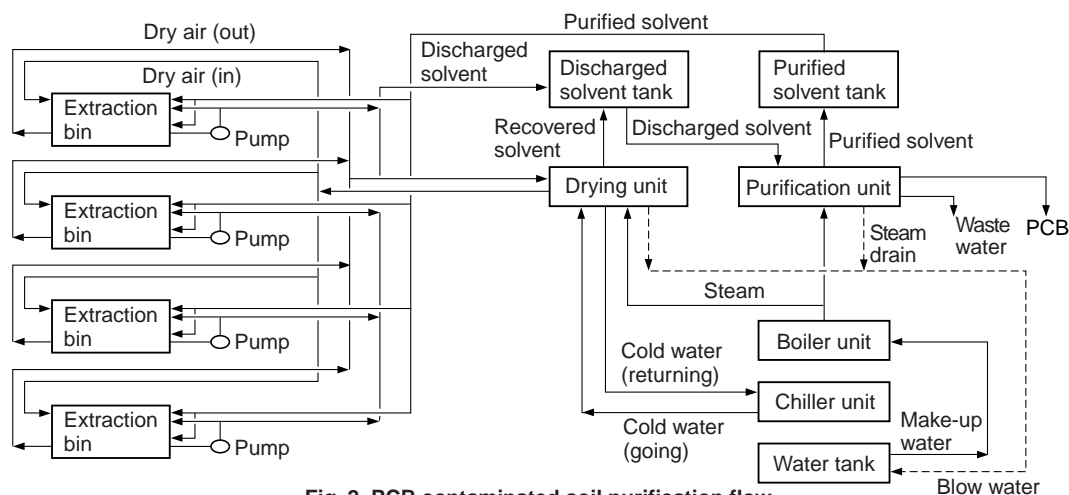


Fig. 2 PCB contaminated soil purification flow

process flow shown in Fig. 1.

(1) Investigation of materials, etc.

The opportunity availed for starting investigation is when the factory specified by law is moved from the present place to a different location or when the ISO14000 series environmental control programs are autonomously carried out. In either case the historical record investigations including investigation of past materials and aural investigation are carried out, in the first place, to identify the contaminants and to estimate the level of contamination.

(2) General survey

Based on the results of the aforesaid material investigation, the sampling and analysis of surface soil are carried out to investigate the actual and general state of contamination.

(3) Detailed investigation

Sampling by boring mainly the contaminated area according to the general survey and analysis of the underground water are carried out to confirm the three-dimensional contamination state for making a contamination map.

(4) Execution of countermeasures against pollution

Countermeasures are taken according to the state of contamination. The new law for soil pollution control scheduled for enforcement in January 2003 calls for such countermeasures as keeping people out of the contaminated area, etc. in addition to the purification of the soil.

MHI has set up a consistent system and organization to cope with the aforesaid countermeasures from (1) to (4). In the field of analysis, for instance, MHI Research and Development Center has so far carried out various environmental analyses and is capable of conducting a high-precision analysis of the contaminants for purification such as dioxin, PCB. Further, the Research and

Development Center has a self-propelled boring machine as a sampling device that drastically shortens the sampling time and enables prompt sampling of soil in the direction of depth. As for the remediation technology, MHI makes use of the technologies for environment control so far developed and commercialized by MHI itself and the technologies introduced from outside to comply with the control standards and to apply to the soil, and puts them successively in practical use.

The main soil remediation technologies owned by MHI are given below.

- (1) Soil Gas Vacuum System: This is a system to excavate the soil contaminated with VOC before evaporating the contaminant using a suction blower and removing through adsorption by activated carbon.
- (2) Ground Water Pumping System: This is a system to pump the ground water contaminated with VOC before leading the water into an activated carbon tower for removal through adsorption.
- (3) Solvent Extraction System: In this system, the contaminants such as oil, PCB, and dioxin are extracted and separated from the soil using the solvent.
- (4) Low-temperature Heating System: In this system, the soil contaminated with VOC, heavy metals with low boiling temperature (mercury, etc.), oil, and dioxin is heated in a kiln at low temperature (300 to 600°C) to separate the contaminants and to purify the soil.
- (5) High-temperature Heating System: In this system, the soil contaminated with high-boiling heavy metals (lead, cadmium, and arsenic, etc.) is heated in a kiln at high temperature (500 to 1000°C) to separate the contaminants and to purify the soil.

This report describes in detail the solvent extraction system used for removing PCB, the treatment of which is drawing attention in recent years.

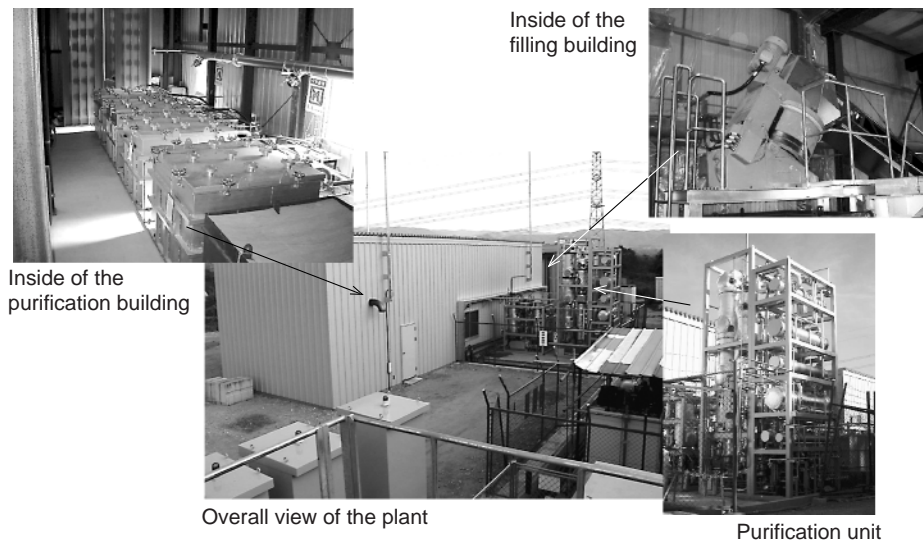


Fig. 3 PCB contaminated soil remediation plant

### 3. Oil and PCB contaminated soil remediation system

#### 3.1 Outline of solvent extraction system

The solvent extraction system is used for safe and steady extraction and separation of the contaminants like oil, PCB, etc. from a large amount of soil. The system flow is given in **Fig. 2** and the arrangement in **Fig. 3**.

This system is composed of three sub-systems: the remediation system for the contaminated soil, the purification system for the solvent extracted and separated from the soil, and the drying system for recovering the solvent from the soil through suction.

The soil remediation system is composed of an extraction bin to charge the contaminated soil, a purified solvent tank to store the purified solvent, and an unpurified solvent tank to store the solvent after purification. The excavated contaminated soil is charged into the extraction bin, where the purified solvent is fed from the purified solvent tank. The contaminated soil is left inside the extraction bin for some time to get it soaked in the solvent before getting the contaminant extracted and separated. After extraction and separation, the solvent is discharged from the extraction bin and stored in the unpurified solvent tank. This process is repeated several times to purify the contaminated soil gradually and steadily until the soil gets purified to a level that it can be recycled and buried back.

The solvent purification system is composed of a filter and a purification unit. The unpurified solvent containing the contaminant is separated into contaminant and solvent, and the purified solvent is then fed into the purified solvent tank for recycling. The extracted contaminant, on the other hand, is condensed and treated separately. In case an on-site destruction of the PCB contaminated soil is required, the solvent purification system can be combined with a separate decomposition unit of extracted PCB.

The soil drying system is composed of a blower, a heating unit, and a condensing unit. The air or vapor heated

in the heating unit is led into the extraction bin to evaporate the solvent left in the extraction bin. The evaporated solvent is then sucked and removed from the extraction bin by the blower to get cooled in the condensing unit before the solvent is recovered. The soil after the treatment can be returned back to the land as the remediated soil.

This system has shown a large number of experiences in U.S.A., an advanced country in the field of soil remediation, and the technology has been authorized by EPA (Environment Protection Agency). The system can be applied to separating the agricultural chemicals and dioxin by selecting the solvent appropriately.

#### 3.2 Features of solvent extraction system

The features of this system are described below in terms of safety and device.

##### (1) Safety

Since the contaminant is separated from the soil at normal temperature and pressure using solvent, the soil itself does not get affected and can be returned back to the land as remediated soil.

Since the solvent used in the treatment is chemically stable, there is no risk of production of non-intentional harmful substances such as dioxin due to thermal or chemical reaction.

Further, because of the closed treatment system, there is no emission of exhaust gas, etc. and so there is no need to worry about the secondary pollution.

Since the used solvent containing the contaminant is purified and recycled, there is hardly any loss of the solvent, and since the harmless solvent is selected for treatment, the soil can be purified safely.

Further, since batch treatment per extraction bin is carried out, the lot control can be made by confirming the purification level per extraction bin.

##### (2) Device

The system, with almost no moving section and less mechanical trouble, is simple and has good cost performance.

Besides, the system can be integrated and put into

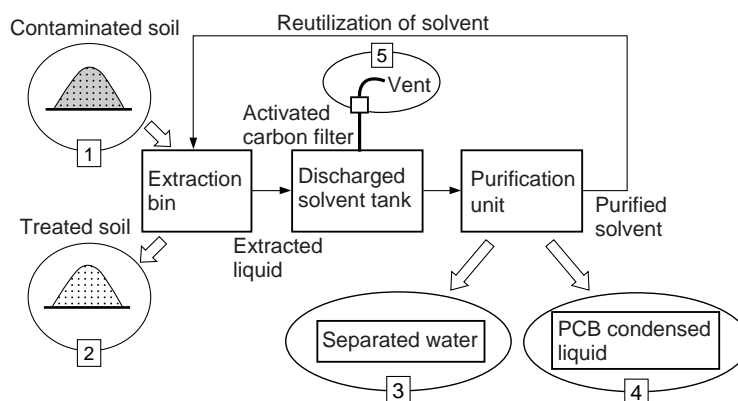


Fig. 4 Rough treatment flow

Table 1 Results of fundamental tests

No.	Item	PCB analysis data	Remark
1	Contaminated soil	PCB content 118 mg/kg	On-site sampling (average concentration)
2	Treated soil	Not detected	Environmental quality standards for soil (not detected) cleared
3	Separated water	Inclusion density 0.0005 to 0.0023 mg/l	Below 0.003 mg/l, the quality standard for discharging the water separated from the contaminated soil
4	PCB condensed liquid	Inclusion density 18wt%	
5	Solvent tank vent	0.05 $\mu$ g/m <sup>3</sup> N	Quality standards for discharge (150 $\mu$ g/m <sup>3</sup> N)

a unit to enable on-site treatment in a polluted site. Particularly in the case of PCB contaminated soil which needs exorbitantly high cost for storage and control, on-site treatment using this system can be used for extracting and separating the contaminant safely and at a low cost.

The extracted PCB can be taken to the Governmental Regional Treatment Center to be established in future according to the Special Measures Law on PCB destruction for final disposal.

### 3.3 Status of verification test of PCB contaminated soil remediation

With the illegal dumping of transformers found in Kita-ku, Kobe-city in May 2001 causing soil contamination due to the leakage of PCB from the dumped transformers, Kobe City government, National Institute for Environmental Studies, and MHI have collectively started research on PCB contaminated soil remediation since October last year, starting with the fundamental tests and on-site purification test (in August 2002). In this report, we would like to present the results of the fundamental tests so far conducted.

Since this is the first time for the study on on-site PCB contaminated soil purification in Japan, we used the laboratory test equipment to analyze the PCB content level of the actually contaminated soil at each emission point in the schematic treatment flow shown in Fig. 4, and conducted fundamental tests to confirm the performance and safety of the system in advance.

The results are given in Table 1 and Fig. 5. As is clear from No. 1 and 2 in Table 1, the purification performance of the actually contaminated soil was verified and the contaminant after purification was found to be well below the environmental quality standards for soil. As shown in Fig. 5, the confirmation of PCB content level in the soil according to the extraction frequency has made it possible to plan for the optimum extraction frequency depending on the contamination level. Further, as shown in No. 3 of Table 1, confirmation was also made of the dried, discharged, and separated water contained in the soil. It was also confirmed that the PCB content in the separated water after purification with activated carbon was below the waste water quality standards for drain. The separated water can thus be sprayed on the soil. As shown in No. 5 in Table 1, it was confirmed

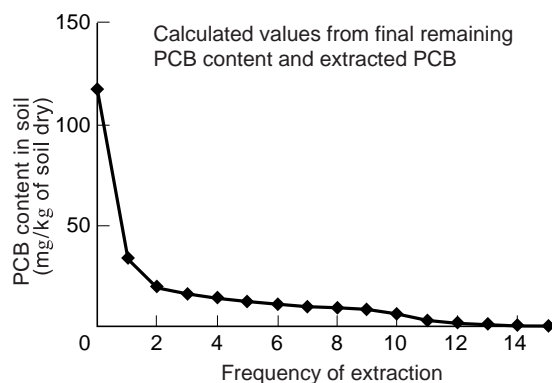


Fig. 5 Results of extraction test

**Table 2 Dioxin treatment record of Terra-Kleen Response Group, Inc.**

Comparison of mean values before and after purification				
Compounds		Before purification	After purification	Purification rate
Unit		pg/g	pg/g	
2, 3, 7, 8 TCDD	(Dioxin)	1	0	
Tetrachlorodibenzodioxin	(Total)	22	2	
Pentachlorodibenzodioxin	(Total)	21	5	
Hexachlorodibenzodioxin	(Total)	119	25	
Heptachlorodibenzodioxin	(Total)	378	134	
Octachlorodibenzodioxin		3503	3468	
2, 3, 7, 8 TCDF	(Dibenzofuran)	1672	9	
Tetrachlorodibenzofuran	(Total)	7808	58	
Pentachlorodibenzofuran	(Total)	5237	91	
Hexachlorodibenzofuran	(Total)	2199	113	
Heptachlorodibenzofuran	(Total)	770	71	
Octachlorodibenzofuran		541	53	
TEQ (Toxicity Equivalent Value)		744	15	98%

Name of project/site: Superfund Site of demolished transformer factory in Carolina, USA

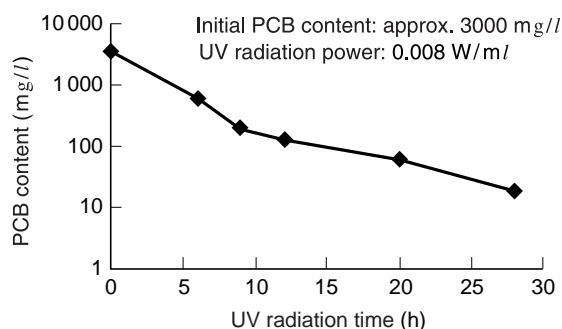
through the high-grade treatment of the tank vent using activated carbon filter that the PCB content in the vent was below the emission standard. These results have proved that the materials discharged from this system cause no secondary pollution, ensuring safe treatment.

Through on-site purification of actually contaminated soil in the future, we are planning to carry out the followings: (1) accumulation of know-how for actual treatment and establishment of safe control standard and (2) establishment of treatment procedures.

#### 4. Future programs

MHI is making study on the development of remediation technologies for soil contaminated with heavy metals and dioxin in addition to the soil contaminated with VOC, oil, PCB, etc.

Compared with the VOC contaminated soil, the soil contaminated with heavy metals is less likely to cause diffusion of contamination, and is at present mostly landfilled to the waste disposal site or is subjected to solidification and insolubilization. However, these treating methods have some problems; the former presses on the capacity of the waste disposal site and the latter limits the future use of the treated site. From these points, a technology to separate heavy metals from the contaminated soil is required. At present, heavy metals are removed from soil mainly through water-washing. In this system water is added to the contaminated soil to make slurry, which is then divided into coarse grains and fine grains using centrifugal separation. This separating technology makes use of the characteristic of heavy metals, namely "the heavy metals show comparatively uneven distribution in fine grains." However, in case of Japan, since the soil has comparatively fine grains, the soil separated with the heavy metals is large in quantity, making it diffi-



**Fig. 6 Result of UV decomposition test of PCB extracted**

cult to reduce the amount of the waste. MHI is currently developing a technology capable of forced separation of heavy metals together with super fine grains from the fine grains of the soil, in order to reduce the amount of waste.

There is an increasing demand for the purification of dioxin contaminated soil surrounding the incinerator after it is dismantled. The aforesaid Terra-Kleen Response Group, Inc. from which we introduced the solvent extraction technology has a experience of dioxin purification in U.S.A. as shown in **Table 2**, and MHI is also making fundamental tests to confirm the effectiveness of the technology.

In the field of treatment, on the other hand, a technology for on-site decomposition of PCB separated from the soil using solvent extraction method is being developed to reduce the amount of the waste. In our fundamental tests in Section 3.3, we have conducted fundamental decomposition tests on extracted and separated PCB using UV (Ultraviolet rays), and have confirmed the validity of the method. The results are given in **Fig. 6**.

Needless to say, the aforesaid contaminants in the soil pollution do not exist independently: in most cases the pollution involves a complex contamination. Therefore, MHI is laying out a plan for a comprehensive systematization of development technology so as to provide optimized technology effective to the contaminant depending on the state of contamination.

#### Kobe Shipyard & Machinery Works



Toru Eto



Kinya Fujita



Seiichi Terakura



Toshiaki Arai

#### Yokohama Dockyard & Machinery Works



Mamoru Araoka

#### Takasago Research & Development Center, Technical Headquarters



Naoyuki Kamishima