Remediating PCB Wastes Using Microorganisms

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The Railway Technical Research Institute (RTRI) is developing a process for remediating PCB-contaminated wastes by using irradiation with ultraviolet light (UV) and degradation by microorganisms. The process is intended primarily to treat waste oil contaminated with PCBs from high-voltage transformers and condensers. It degrades the PCBs using naturally occurring microorganisms. Basic laboratory tests have been completed and the process is being tested at a pilot plant. This article outlines the basis of the method, which is very different from conventional incineration or other chemical processes.

What are PCBs?

Storage of PCBs

Polychlorinated biphenyls (PCBs) are synthetic chemical compounds. Because of their excellent insulation performance, nonflammability, low volatility, and good stability, etc., they were used worldwide, mainly as electrical insulators and heating media.

By the early 1970s, about 1 million tonnes of PCBs had been produced. However, when the decline in the population of the White-Tailed Sea Eagle was linked with high tissue levels of PCBs, it was realized that PCBs are harmful, perhaps acting as so-called hormone disrupters. Subsequent investigations have shown that PCBs have widely contaminated the earth. After the infamous 1968 Kanemi Oil Poisoning Incident in Japan in which 14,000 people were injured and more than 100 were killed by cooking oil contaminated with PCBs, production of PCBs was banned and their use was limited. However, since there was no suitable method for safe disposal of waste PCBs, they have been stored untreated (see information box) for the past 25 years. A Ministry of Health and Welfare investigation into storage of waste PCBs conducted in 1992, showed that about 7% of equipment on the official list of electrical devices and equipment using PCBs is missing, prompting the realization that stored waste PCBs need to be disposed of properly and promptly.

The only method of treating waste PCBs approved by the Japanese government is high-temperature incineration. However, this method runs the danger of generating dioxin, which is even more toxic than PCBs. Public resistance to incineration makes it virtually impossible to use.

Alternative Solutions

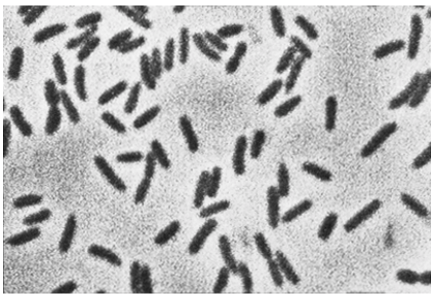
Several chemical treatments that can be applied to oils contaminated with low concentrations of PCBs are being developed and evaluated. They include the alkali catalyst method, solvent extraction method, and supercritical water oxidation method.

Degradation by microorganisms

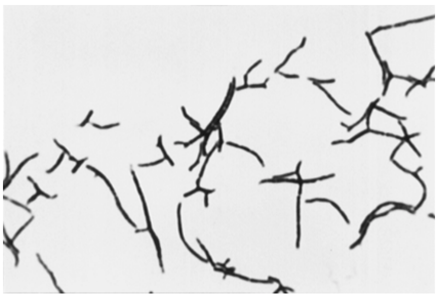
PCBs are so stable that they hardly degrade naturally. However, in an oxygen-free environment (such as the bottom of a deep lake), PCBs are dechlorinated by anaerobic microorganisms (microorganisms that can grow in the absence of oxygen). In environments containing oxygen, PCBs with a low number of chlorine atoms are degraded by some microorganisms. Therefore, it was believed possible to remediate PCB-contaminated wastes using microorganisms.

The first step was to isolate microorganisms that can degrade chlorine-free biphenyl. Then their ability to degrade PCBs was examined. Microorganisms that degrade biphenyl are relatively common, but most can only degrade biphenyl or PCBs with a small number of chlorine atoms. Repeated selection was used to obtain microorganisms with a high ability to degrade PCBs leading to the choice of *Comamonas testosteroni* TK102 and *Rhodococcus opacus* TSP203.

When PCBs are broken down, the end-products are water, carbon dioxide, and chlorine. The reaction is catalyzed by enzymes with an exceptionally high degree of specificity and there is no fear of producing harmful materials such as dioxin. Using microorganisms to break down PCBs is very effective for PCB homologues with a small number of chlorine atoms, but mixed PCBs consisting mainly of pentachlorobiphenyls, which were used in high-voltage transformers and condensers, are not broken down easily. To treat these PCBs using microorganisms, pretreatment is needed to reduce the number of chlorine atoms.



Comamonas testosteroni (TK102) (RTRI)



Rhodococcus opacus (TSP203) (RTRI)

Dechlorination by UV irradiation

Although PCBs can be dechlorinated by various chemical treatments, use of chemicals adversely affects microorganisms and sometimes produces harmful by-products. In addition, chemicals and equipment increase the treatment cost. We finally selected irradiation with UV light as the best dechlorination method. In this method, the PCBs are dissolved in a solvent, such as hexane or alkaline alcohol solution, and then irradiated with UV to cause dechlorination. A low-pressure mercury lamp typically used for microbial sterilization can be used. The reaction occurs at normal temperature and pressure. After the reaction, the solvent can be recovered by distillation.

The reaction has no adverse effect on microorganisms but as it proceeds, the dechlorinated PCBs build up, gradually reducing the reaction efficiency. Consequently, the PCBs cannot be dechlorinated completely by UV irradiation alone. However, the number of chlorine atoms can be reduced to such an extent that the microorganisms can degrade the PCBs.

Test-tube Degradation of Sample PCB

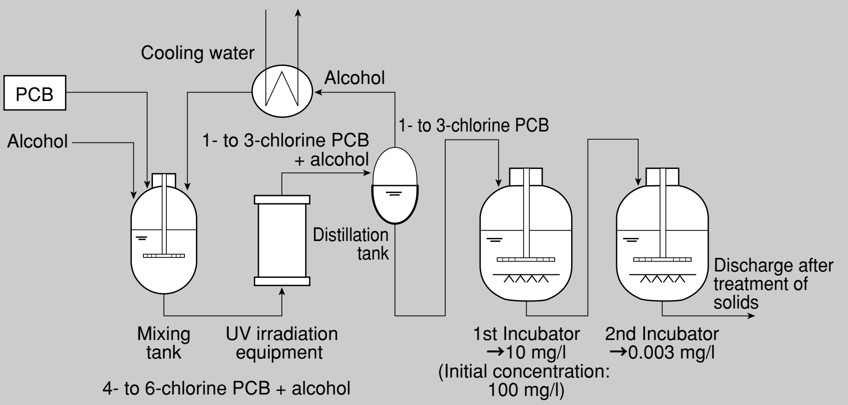
A sample PCB that had been dechlorinated by irradiation with UV light was degraded by *Comamonas testosteroni* TK102. TK102 can degrade PCBs with 3 or fewer chlorine atoms and can grow in a medium containing 4000 to 5000 ppm of PCBs. As a result, the dechlorinated PCB was completely degraded by TK102, demonstrating that a combination of UV irradiation and microbial degradation can effectively treat PCBs.

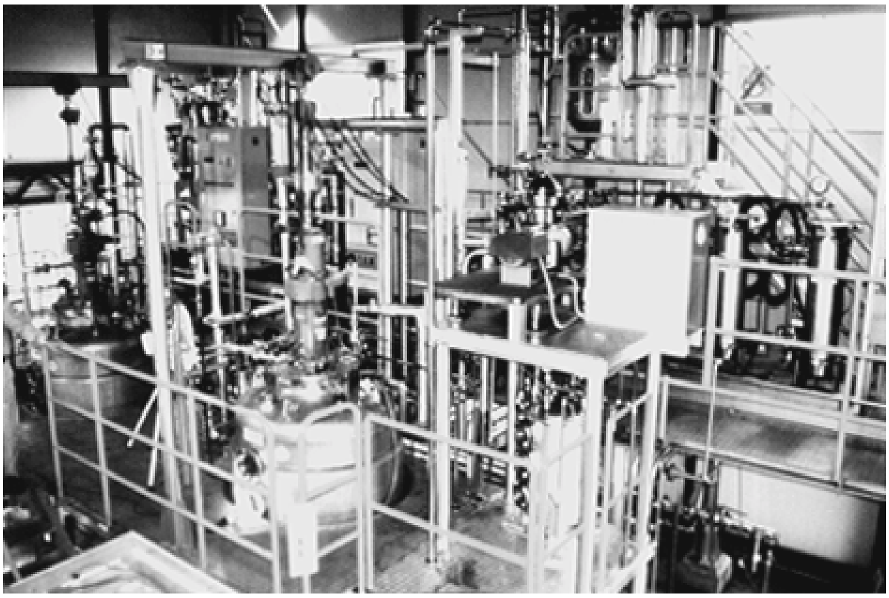
Scaling up

Following this success, the test was scaled up to small- and medium-sized incubators of 10 and 90 liters.

In Japan, the level of PCBs in waste water may not legally exceed 0.003 ppm, which is much stricter than the US level of 2 ppm. To meet this very strict standard, we decided to use a two-stage process in which two types of microorganisms with different properties were used. The first stage used *Comamonas testosteroni* TK102, while the second stage used *Rhodococcus opacus* TSP203. Although TSP203 is very good at degrading PCBs, it cannot grow when the concentration is higher than about 10 ppm. In contrast, TK102 can reduce the initial PCB concentration from 100 ppm to 10 ppm or less in about 2 days. Both these advantages were put to use by treating the PCBs first with TK102 and then with TSP203. Even without UV irradiation, this two-stage process reduced the level of PCBs consisting mainly of trichlorobiphenyls to less than 0.003 ppm in about 10 days.

Figure 1 Pilot Plant Concept, and Installation (below)

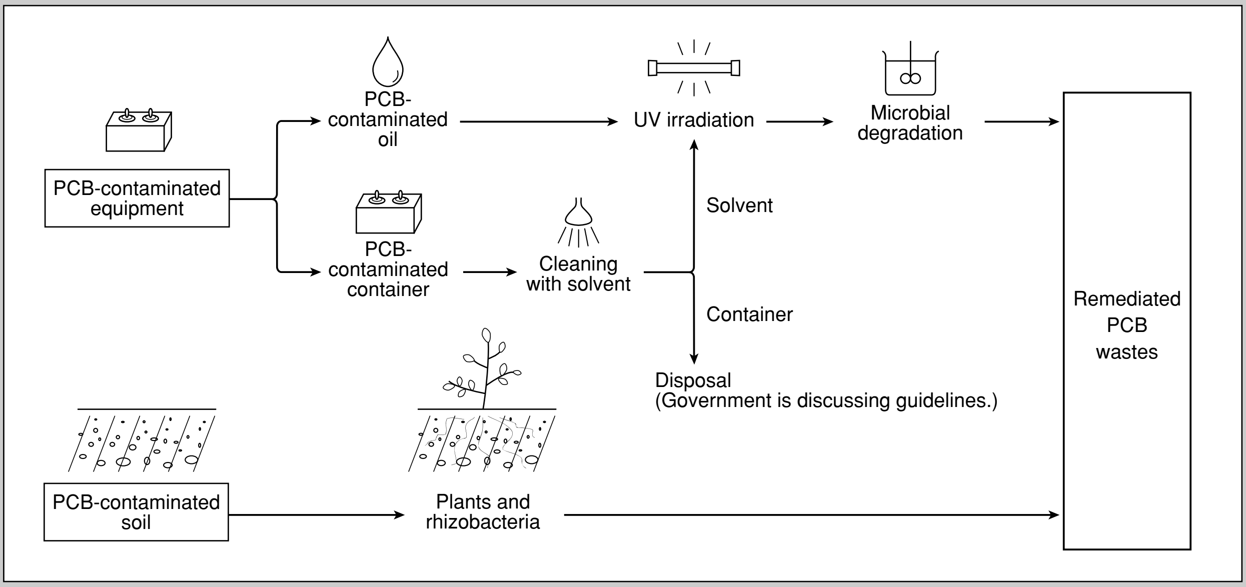




Pilot Plant Demonstration

Based on these test results, we decided to perform a demonstration test using a pilot plant consisting of UV irradiation equipment and two large incubators with a total capacity of 1000 liters (Fig. 1). After the PCBs are mixed with alcohol in the mixing tank, the mixture is fed to the UV irradiation equipment. The dechlorinated mixture is vacuum-distilled in the distillation tank to recover the alcohol. The

Figure 2 Microbial Remediation of PCB Wastes



condensed PCBs are degraded to 10 ppm or less by TK102 in the first incubator, and are then fed to the second incubator where they are completely degraded by TSP203. The pilot plant is closed with an active carbon filter fitted at each opening to the air. The waste from the incubators is held in a storage tank.

Using this pilot plant, we confirmed that PCBs could be degraded to levels of less than 0.001 ppm in about 10 days. At present, we are attempting to increase the rate of degradation from about 10 days to 5 days by improving the microorganism degradation efficiency and the UV irradiation conditions. In addition, the system is being improved in terms of recycling because it is effective in reducing the volume of waste water and increasing the treatment efficiency.

Effective Treatment of Other Contaminants

In remediating PCB-contaminated wastes, it is necessary to treat both PCB-contaminated oils and PCB-contaminated containers and soil, etc. The flow of PCB treatment is shown in Fig. 2. A PCB-contaminated container is first cleaned with solvent and then disposed of. The contaminated solvent is then remediated by our process. To treat PCB-contaminated soil, we have started work on genetic engineering of plants and rhizobacteria with PCB-degrading genes from microorganisms.

Studies on degradation of PCBs using microorganisms have been in progress worldwide for more than 25 years. They include isolation and genetic improvement of new PCB-degrading microorganisms, and development of pre-treatments for promoting degradation of PCBs by microorganisms. Our PCB treatment combining UV irradiation and microbial degradation is the closest to practical application and may well be applicable to other pollutants. ■

Acknowledgement

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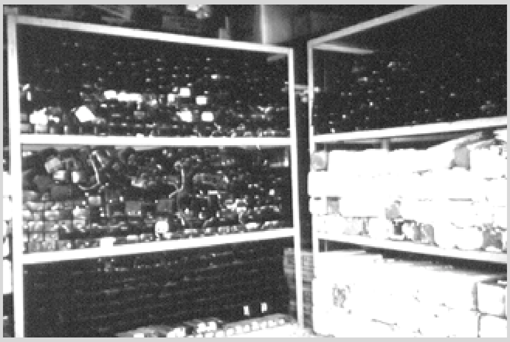
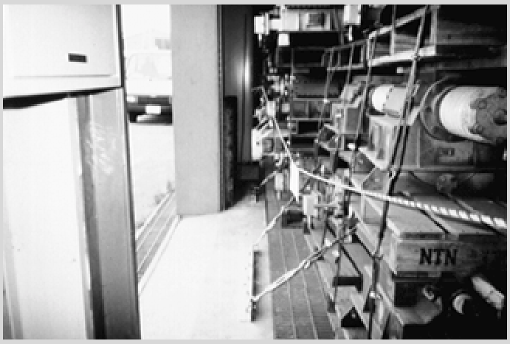
Storing PCB Wastes in Japan

(Photos: JR East)

Japan has strict regulations governing the storage of PCB-contaminated equipment. These photographs show JR East's storage facilities at Oi, Koriyama, and Ofuna. Facilities storing PCBs must be marked and must be secured by locked doors at all times. The facility manager must also be indicated.



The storage methods vary according to the type of item; contaminated oil is stored in drums, while small parts from used equipment are stored in racks.



Large equipment, such as transformers, is stored on floor pallets, and is secured by cables to prevent toppling over in an earthquake.

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