



Project Summary

Interim Guidelines for the Disposal/Destruction of PCBs and PCB Items by Non-Thermal Methods

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This report summarizes an interim resource and guideline document intended to aid USEPA regional offices in implementing the PCB Regulations (40 CFR 761) with regard to the use of non-thermal methods for the destruction/disposal of PCBs.

The interim report describes and evaluates various alternative chemical, physical, and biological PCB removal and/or destruction technologies, including carbon adsorption, catalytic dehydrochlorination, chlorinolysis, sodium based dechlorination, photolytic and microwave plasma destruction, catalyzed wet-air oxidation, and activated sludge, trickling filter, and special bacterial methods.

Alternative destruction/disposal technologies were evaluated using technical, regulatory, environmental impact, economic, and energy requirements criteria. Because the technologies investigated are at various stages of development (only the sodium based dechlorination processes are now commercially available), data deficiencies exist, and good engineering judgment was used to supplement available quantitative information.

Of the technologies evaluated, many show the potential for greater than 90 percent PCB destruction with minimum environmental impacts and low to moderate economic costs. These technologies are catalytic dehydro-

chlorination, sodium based dechlorination, microwave plasma, and photolytic processes.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Polychlorinated biphenyls (PCBs) are derivatives of the compound biphenyl in which 1 to 10 hydrogen atoms have been replaced with chlorine atoms. PCBs have extremely high chemical and thermal stability, making them quite useful in many commercial applications (e.g., as dielectric fluids in capacitors and transformers; in heat transfer and hydraulic systems, pigments, plasticizers, carbonless copying paper, and electromagnets; and as components of cutting oils).

Their wide use and the lack of recognition of their hazards have led to their wide distribution in the environment (Fuller et al., 1976). Although PCBs have fairly low acute toxicities, some adverse effects have been found in humans, laboratory animals, and other organisms. There is some evidence that PCBs bioaccumulate and may be carcinogenic (Fuller et al., 1976).

Concern over the PCB contamination problem led to a provision in the Toxic Substances Control Act (TSCA) that will require the eventual elimination of the use of PCBs in the U.S. The PCB Regulations, promulgated under TSCA (40 CFR 761), do not require removal of PCBs and PCB items from service earlier than would otherwise be required; but when PCBs and PCB items are removed from service, disposal must be in accordance with the PCB Regulations. Other acts which govern the disposal of PCBs include: the Resource Conservation and Recovery Act, the Clean Water Act, the Clean Air Act, the Occupational Health and Safety Act, and the Marine Protection, Research, and Sanctuaries Act.

Because there is a large amount of PCB in existence that will need disposal, the Electric Power Research Institute projected a shortfall of utility waste PCB disposal capacity (landfill and incinerator) in most EPA regions after January 1, 1980 (EPRI, 1979). In addition, there will be a smaller quantity of waste PCBs from commercial and industrial uses which will require disposal.

The PCB Regulations provide for four general disposal methods:

- Annex I incinerators for PCBs and PCB items having greater than 500 ppm PCB content.
- High efficiency boilers for PCB-contaminated liquids having PCB contents 50 ppm or greater but not greater than 500 ppm.
- Annex II chemical waste landfills for PCB-contaminated liquids (equal to or greater than 50 ppm but not greater than 500 ppm); non-liquid PCBs in the form of contaminated soils, rags, or other debris; and all dredged materials and municipal sewage sludges that contain PCBs.
- Other approved method for PCBs and PCB items that are subject to incineration.

The full report is an interim guidelines document applying solely to the disposal/destruction of PCBs by methods other than incineration in Annex I incinerators or high efficiency boilers, Annex II chemical waste landfills, or as municipal solid waste.

Evaluation Criteria for Non-Thermal PCB Destruction Processes

Since the EPA considers non-thermal PCB destruction processes as alternative

methods to incineration, the basis for evaluation of an alternative (non-thermal) system is its performance relative to a thermal system. As stated in the PCB Regulations, 40 CFR 761.10(e), an alternative system must be demonstrated to "achieve a level of performance equivalent to Annex I incinerators or high efficiency boilers." Before approving any non-thermal destruction process, the Regional Administrator must be able to determine that the alternative system provides "PCB destruction equivalent to" the appropriate thermal method and "will not present an unreasonable risk of injury to health or the environment."

Chapter 2 of the full report describes the development of an evaluation methodology which is not process specific. It involved taking characteristics of any given non-thermal process and comparing them with criteria related to the regulatory, technical, environmental, economic, and energy performance characteristics of thermal processes.

Technical factors which should be included in an evaluation of a non-thermal process are: destruction efficiency, range of PCB concentrations in the waste, ability of the process to handle wastes of varying PCB content, physical form of PCBs the process can handle, restrictions on non-PCB waste constituents, special process requirements, state of the technology, overall facility design and operation, and resource reclamation. Environmental factors which should be included in the overall evaluation are: environmental impacts of the disposal operation itself, environmental impacts of disposal of process wastes, potential impact of accidents and transportation of PCBs to the disposal site, effluent monitoring programs, and closure and post-closure plans. Economic factors considered in the overall evaluation are: capital costs or the cost of facility construction or modification, operating costs, disposal costs, credits for products or by-products, financial requirements related to closure and post-closure monitoring and maintenance, and regulatory costs. Energy factors that should be included in the evaluation are: debits, credits, and resource recovery.

Most of the above regulatory, technical, environmental, economic, and energy factors are discussed for numerous alternative disposal methods in the full report.

Non-Thermal Destruction Methods

The non-thermal destruction processes described in this report are grouped into two broad categories: physicochemical methods and biological methods. Physicochemical methods exploit chemical or physical characteristics of PCB molecules to achieve destruction or detoxification. Biological methods all employ microorganisms which metabolize PCB molecules to less chlorinated PCBs or non-chlorinated compounds.

None of the alternative methods described here or in the full report are at commercial scale, so that only limited data are available. There are, therefore, substantial technical, environmental, economic, and energy information gaps. Some of the methods have not been applied to PCB degradation but offer interesting possibilities. Other methods have been applied to PCBs only in dilute aqueous solution, but are covered because of potential adaptability to PCBs in dilute organic solution (e.g., mineral oil dielectric fluid). Comparison of these alternative methods with thermal methods is necessary, but many of the comparisons are necessarily qualitative.

Destruction efficiencies, for methods that have been so tested, are well below the performance requirements of Annex I incinerators or high efficiency boilers. Currently, none of the alternative methods meet the destruction efficiency requirements of the PCB Regulations. However, destruction efficiency is only one factor that must be considered in the approval process.

Table 1 presents a comparison of technical, environmental, economic, and energy factors associated with thermal (Annex I incinerators and high efficiency boilers) and non-thermal destruction/disposal methods.

Adsorption Processes

Adsorption processes are useful for removing chlorinated hydrocarbons from an aqueous waste stream by contacting it with activated carbon by passing it through a vessel filled with a carbon slurry or granules. Impurities from the aqueous stream are removed by adsorption onto the carbon. Activated carbon has an affinity for organics, and its use for organic contaminant removal from wastewater is common.

In 1976, General Electric's Capacitor Products Department installed a system to eliminate the discharge of PCBs to the

Table 1. Comparison of Thermal and Non-Thermal Disposal/Destruction Methods

<i>Destruction or Conversion Method</i>	<i>Potential for Large Scale Application</i>	<i>Current Status of Technology as Applied to PCB Processing</i>	<i>Destruction Efficiency</i>	<i>Feedstock</i>	<i>PCB Range, ppm</i>	<i>Overall Environmental Impact</i>	<i>Overall Economic Impact</i>
<i>Annex I Incineration</i>	<i>High</i>	<i>1</i>	<i>>99.99%</i>	<i>g,l,s</i>	<i>>50</i>	<i>4,5</i>	<i>8</i>
<i>High Efficiency Boilers</i>	<i>High</i>	<i>1</i>	<i>>99.99%</i>	<i>l</i>	<i><50</i>	<i>4,5</i>	<i>8</i>
<i>Activated Carbon Absorption Processes</i>	<i>High</i>	<i>3</i>	<i>Not applicable</i>	<i>a</i>	<i>Dilute amounts</i>	<i>4,5,10</i>	<i>7,9</i>
<i>Catalytic Dehydrochlorination</i>	<i>Medium</i>	<i>2</i>	<i>99+%</i>	<i>l,g</i>	<i><50</i>	<i>5,11</i>	<i>7,9</i>
<i>Chlorinolysis</i>	<i>Low</i>	<i>3</i>	<i>Low</i>	<i>l</i>	<i>Not applicable</i>	<i>4,5</i>	<i>8,9,12</i>
<i>Goodyear Process</i>	<i>High</i>	<i>3</i>	<i>92%</i>	<i>l</i>	<i><500</i>	<i>4</i>	<i>6,9</i>
<i>Microwave Plasma</i>	<i>Medium</i>	<i>2</i>	<i>95%</i>	<i>l,g</i>	<i>50-500</i>	<i>4,5</i>	<i>7</i>
<i>Ozonation Processes</i>	<i>Medium</i>	<i>3</i>	<i>Not applicable</i>	<i>a</i>	<i>Dilute amounts</i>	<i>5,11</i>	<i>8</i>
<i>Photolytic Processes</i>	<i>Low</i>	<i>2</i>	<i>90-95%</i>	<i>l</i>	<i><50</i>	<i>5,11</i>	<i>7</i>
<i>Sodium-Oxygen-Polyethylene Glycol</i>	<i>Medium</i>	<i>2</i>	<i>95%</i>	<i>l</i>	<i>50-500 and >500</i>	<i>11</i>	<i>7,9,12</i>
<i>Sunohio Process</i>	<i>High</i>	<i>3</i>	<i>99+%</i>	<i>l</i>	<i>50-500 and >500</i>	<i>4</i>	<i>6,9,12</i>
<i>Catalyzed Wet Air Oxidation</i>	<i>Medium</i>	<i>2</i>	<i>99+%</i>	<i>a,l,s</i>	<i>50-500 and >500</i>	<i>3</i>	<i>7</i>
<i>Activated Sludge</i>	<i>Low</i>	<i>3</i>	<i>Not applicable</i>	<i>a</i>	<i>Dilute amounts</i>	<i>11</i>	<i>7</i>
<i>Trickling Filter</i>	<i>Low</i>	<i>3</i>	<i>Not applicable</i>	<i>a</i>	<i>Dilute amounts</i>	<i>11</i>	<i>7</i>
<i>Special Bacterial Methods</i>	<i>Low</i>	<i>3</i>	<i>Not applicable</i>	<i>a</i>	<i>Dilute amounts</i>	<i>11</i>	<i>7</i>

- 1 Method is currently used commercially.
- 2 Proven research method only.
- 3 Limited or no data base.
- 4 Potential controllable method with minimum environmental impact.
- 5 Potential solid residue or wastewater disposal problem.
- 6 Low capital investment and moderate operating costs.
- 7 Moderate capital investment and operating costs.
- 8 Large capital investment and operating costs.
- 9 Resource recovery option.
- 10 Requires recycling or disposal of adsorption medium.
- 11 Potential residual toxicity of by-products.
- 12 Potential return on investment.
- s Solid
- a Aqueous
- g Gas
- l Liquid

investigate alternate treatment systems; i.e., UV-Ozonation and catalytic reduction.

Application of activated carbon adsorption processes is less common to non-aqueous streams. A study (U.S. Air Force, 1976) on using activated carbon to remove the 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) contaminant from Herbicide Orange concluded that, though the process was technically and economically feasible, the technology to dispose of the TCDD contaminated charcoal did not exist. Therefore, Herbicide Orange stocks were successfully incinerated at sea (Ackerman et al., 1978).

From a technical point of view, adsorption processes for removing organic compounds from liquid streams are

Hudson River from its Hudson Falls and Fort Edward manufacturing plants. This adsorption process worked extremely well for dilute aqueous streams contami-

nated with PCBs (Arisman, 1979), but was not very cost effective. High cost and carbon disposal or regeneration requirements caused EPA and GE to

attractive because they offer the possibility of resource recovery; e.g., removal of PCBs from mineral oil dielectric fluids with possible reuse of the mineral oil. However, to be economical, the PCBs must be removed from the adsorbent, so that an adsorption process applied to PCB disposal must be coupled with a second disposal/destruction process to handle PCBs removed from the adsorbent during regeneration of the activated carbon.

Catalytic Dehydrochlorination

Catalytic dehydrochlorination is based on the reaction of polychlorinated hydrocarbons with hydrogen gas under high pressure in the presence of a catalyst (LaPierre et al., 1977). The reasoning behind this reaction is that partially dechlorinated or nonchlorinated compounds could be less toxic and, therefore, could be biodegraded more easily than highly chlorinated compounds. This process has been applied directly to the detoxification of PCBs, but only on the laboratory scale. A study at the Worcester Polytechnic Institute indicates a complete conversion of PCBs into dechlorinated biphenyls (LaPierre et al., 1977).

Catalytic dehydrochlorination should be able to handle a wide range of PCB contaminated material, if they are in the liquid state. Transformers with a PCB concentration of > 500 ppm, as well as PCB capacitors and mineral oil dielectric fluids with PCB contents of 50-500 ppm, should be amenable to treatment by this process.

Potential impacts of the disposal operation, as well as the disposal of process wastes, should be low. According to current studies, a properly designed process should not produce toxic off-gases or contaminated aqueous residues.

Lack of economic data prohibits a cost assessment of a dehydrochlorination conversion facility. Hydrocarbons produced by this process could be used or sold as fuel oil. This economic credit could lower the cost of PCB processing substantially. Qualitatively, capital investment and operating costs appear to be moderate.

Chlorinolysis

Chlorinolysis is an established technology for converting chlorinated hydrocarbons to carbon tetrachloride. This is a vapor-phase reaction in which chlorine is added to the waste material under high pressure and low temperature (or

high temperature and low pressure). A catalyst is not used in this process (S.S.M., 1974). If the waste consists of only carbon and chlorine atoms, the product will be carbon tetrachloride. If the waste contains oxygen or hydrogen, carbonyl chloride and hydrogen chloride are also produced (S.S.M., 1974).

Chlorination as a method of disposing of hazardous wastes was first suggested in 1974. Farbwerke Hoeschst Ag, Frankfurt/Main, Germany, has developed a process in which hydrocarbons and their chlorinated derivatives are completely converted to carbon tetrachloride and hydrogen chloride at pressures up to 24 MPa and temperatures up to 893 K (Krekeler et al., 1975).

Chlorinolysis has not been applied directly to PCB disposal, but a variation of the process may be adaptable. Although the Hoeschst chlorinolysis process can handle chlorinated benzene derivatives on a limited scale only, it may be worthy of evaluation.

The feed must be a liquid, and most impurities must be removed before processing. Chlorinolysis works best on aliphatic compounds.

The destruction efficiency for PCBs should be extremely low in the existing process since aromatic compounds are not processed efficiently. The process works poorly for an aromatic content of greater than 5 percent calculated as benzene.

Potential environmental impacts when considering the construction and operation of a chlorinolysis plant include shipment and handling of the hazardous organochlorine wastes prior to chlorinolysis, control of the potential gas and liquid effluents after conversion, and handling and storage of the final products. Emissions from manufacturing, storage, and transport of polychlorinated aromatics (particularly PCBs) are possible. Accidental spills and leaks of both solid and liquid wastes are the primary sources of emissions. Conventional spill and leak prevention procedures should make the process operationally safe.

The Goodyear Process

The Goodyear Tire and Rubber Company recently developed a process to degrade microquantities (e.g., 120 ppm) of PCBs (Goodyear, 1980). This process involves preparing sodium naphthalide and contacting this reagent with the PCB-containing liquid. The reagent abstracts chlorines from the PCB molecule, and NaCl and non-halogenated poly-

phenyls are formed. The reaction is rapid at room temperature.

The Goodyear process appears well developed on the laboratory scale. The available literature source indicates only that the Goodyear process is technically applicable at this time to handle mixtures of Aroclors (a Monsanto trademark) at 50-500 ppm concentrations.

Undestroyed PCBs remain in the processed heat transfer fluid. This fluid could be recycled or reused directly, so that there is no real environmental impact expected from this process effluent. Overall, the potential environmental impacts of the disposal operation appear to be low although a thorough assessment cannot be made without more test data.

Generally, the Goodyear process appears to be relatively low in cost and may be adaptable to both small and large scale operation. A detailed economic evaluation is needed before this process may be judged economically justifiable. With large scale application product recovery of purified mineral oil may reduce costs significantly.

Microwave Plasma Methods

Lockheed's Palo Alto Research Laboratory (LPARL) has developed a process to destroy PCBs and other hazardous materials by microwave plasma treatment (Oberacker and Lees, 1977). Research started on the bench scale and has been expanded to a unit which can successfully destroy PCBs at the rate of 0.45-2.3 kg/hr. A future goal is to develop a 40-50 kg/hr version.

A 15 kW microwave plasma reactor system capable of destroying 2-11 kg/hr of organic wastes, including PCBs, is now in operation. Laboratory scale experiments have determined that the destruction efficiencies of Aroclor 1242 and 1254 are 99 percent using 4.6 and 4.5 kW microwave power, respectively. The process should be able to destroy PCB concentrations of 50-500 ppm effectively. Further research is needed to determine the maximum concentration of PCBs that can be destroyed with a high destruction efficiency.

Although microwave plasma destruction of PCBs is a controllable method which yields innocuous products, such as CO₂ and H₂O, potentially hazardous products such as CO and organochlorines will also be produced.

An environmental assessment of the microwave plasma disposal operation must consider the shipment and hand-

ling of the PCB material prior to processing, control of the potential gas and liquid effluents after conversion, and the handling, storage, and disposal of final products. Extremely high temperatures and pressures occur throughout the system. Special safety techniques would have to be used to guard against the accidental release of hot, corrosive, or toxic vapors. The use of a caustic scrubber should keep emissions fairly low. Since the effluent streams from a scrubber are mainly liquid, any particulates emitted would be dissolved in the liquid effluent as suspended particles.

Very little information exists on the economics of a microwave plasma process adapted to PCB destruction. Overall, capital costs for a microwave plasma processing facility may be high since useful by-products may not be recoverable. Electrical costs should decrease as microwave power technology advances. Future improvements in basic plasma design should reduce operating costs. Currently, it appears that a large-scale microwave plasma destruction unit will entail moderate capital investment and operating costs.

Ultraviolet-Ozonolysis

Ultraviolet (UV)-ozonolysis is a process that destroys or detoxifies hazardous chemicals in aqueous solution utilizing a combination of ozone and UV irradiation. Fairly simple equipment is required on the laboratory scale: a reaction vessel, an ozone generator, a gas diffuser or sparger, a mixer, and a high pressure mercury vapor lamp (Wilkinson et al., 1978). UV-ozonolysis has proved to be effective in destroying dilute quantities of PCBs in industrial waste water effluents. Experimentation has been on the laboratory level only. Scale-up to pilot plant capacity has not been attempted.

UV-ozonolysis of dilute aqueous streams contaminated at various PCB levels was performed by General Electric's Capacitor Products Department at its Hudson Falls and Fort Edward manufacturing plants (Arisman, 1979). Destruction efficiencies for most experiments were 93 ± 3 percent. PCB concentrations ranged from 30 to 100 ppb in aqueous solution.

The possibility of the formation of reaction products, harmful to aquatic life, must be considered. Residual amounts of halogenated compounds, as well as trace metals, may be contained in the waste effluents. An assessment

of the types of final products that will be produced is necessary. Any auxiliary disposal operations such as adsorption, filtration, or incineration must also be analyzed for possible environmental impact.

Major capital equipment costs will be the reactor, ozone generator and power supply, and the UV irradiation source and power supply. Major operating costs include electrical energy and labor. In general, UV-ozonolysis should be cost competitive with traditional waste water processing facilities.

Photolytic Methods

Photolytic processes are based on the principle that UV radiation activated molecules which may then undergo chemical reaction. Much research has been done on the photodecomposition of various classes of pesticides by using UV radiation (Crosby and Li, 1969; Plimmer, 1970, 1972, 1978; Rosen, 1971; and Mitchell, 1961). The photodecomposition of PCBs is now being studied in the laboratory to determine products formed and the effects of solvents on product formation and rates of reaction (Ruzo et al., 1974).

Currently, very little is known about the photochemical properties of the many PCB isomers. A few studies have shown that the primary reaction at wavelengths > 290 nm is stepwise dechlorination. The actual dechlorination products have rarely been identified (Ruzo et al., 1974). In 1974, a study was carried out to determine the reaction products of PCB photodecomposition in different solvents (Ruzo et al., 1974). It was concluded that if photolysis is to occur, the PCB molecule must absorb light energy above 290 nm or receive energy from another molecule through an energy transfer process. The product may be a complex mixture in which isomerization, substitution, oxidation, or reduction processes have occurred. To date, there have not been any studies of photolysis of PCB-contaminated mineral oils or hydraulic fluids.

Destruction efficiencies as such have not been determined in these laboratory studies. A 90-95 percent yield of dechlorinated PCB in methanol solution has been determined (Ruzo et al., 1974). Methanol substitution products were also found in these experiments.

The photolysis process may be applicable over a wide range of PCB concentrations. The important factor determining the concentration range of the PCBs

is its solubility in the solvent. Research has not been done on an actual PCB-contaminated mineral oil, so that the applicability of this process to PCB disposal/destruction has not been completely validated.

The precise chemical nature of the process wastes needs to be investigated before assumptions about process waste disposal impacts on the environment can be made. Certain chlorinated compounds may exist in the waste streams that could be harmful to the environment. Vapor effluents could contain HCl and photoactive compounds. Aqueous effluents could contain chlorine and components that did not react with the UV radiation.

Factors that will affect overall capital and operating costs for a large scale photolysis processing plant include land availability and cost, types of chemicals and reagents required, labor, monitoring, and application costs. Based on the limited information available, scaled up operating and capital costs appear to be moderate. Possible economic credits could accrue if some of the products are saleable or reusable.

Chemical Degradation with Sodium-Oxygen-Polyethylene Glycol

Reaction of PCBs with sodium-oxygen-polyethylene glycols is based on the fact that sodium metal finely dispersed in certain solvents can serve as a chemical reactant. The reactivity is dictated by the mechanism of decomposition of the PCB molecule. Laboratory experiments have shown that the reacting solution should be composed of polyethylene glycol (avg M.W. = 400, dried over anhydrous Na_2SO_4) and metallic sodium. PCB oil is added to this solution to produce polyhydroxylated biphenyls and hydroxy-benzenes (Pytlewski et al., 1980). This technology exists on the laboratory scale only.

Laboratory studies have indicated an approximate 95 percent conversion of the PCB oil. Precise destruction efficiencies have not been determined. The process appears to be applicable over a wide range of PCB concentrations, particularly in the 50-500 ppm range.

Large amounts of H_2 gas and NaCl will be evolved in this process. The H_2 gas should be drawn off and collected as a source of energy. NaCl disposal should not create any special disposal problems. The recovered H_2 gas could be used as an additional source of energy to melt

the NaCl. The evolution of large amounts of H₂ gas means that the use of open flames, electrical sparking, and electric heating elements must be avoided. The reaction with the sodium metal should be started with heat supplied by steam.

Franklin Research Center engineers made a preliminary cost evaluation for the commercial destruction of PCBs by this process. They determined decomposition cost of almost 70¢/kg of PCBs (Pytlewski et al., 1980). Recovery credits for H₂ gas and the polyhydroxylated biphenyls could bring the cost of the operation low enough to make the process profitable.

The Sunohio Process

Sunohio has developed a process to break down the PCB molecule into its two primary components, biphenyl and chlorine. The chlorines are converted to chlorides, while the biphenyl molecule is converted to polymeric solids. The process is called PCBX, a Sunohio trademark. Full scale stationary and mobile units are now complete. The unit is designed to: (1) heat transformer oil and filter it, removing moisture, acids, and other contaminants; (2) remove and destroy PCBs contained in the transformer oil but not the oil itself, and (3) destroy pure PCBs. The equipment, contained in a large tractor/trailer, is self-contained and either can generate its own power or may be hooked up to an external electric power source. Transformer oils can be removed from fully charged transformers and, after treatment, can be returned to the same transformer in minutes.

The original goal in process development was to remove all PCBs from the treated fluids. Experimental fluids used for laboratory studies have contained as little as 100 ppm and as high as 10,000 ppm PCBs. These fluids after treatment are claimed to have contained 0 to 40 ppm PCBs, respectively. The process appears to be able to handle a wide range of PCB concentrations and types of fluids.

An environmental impact study has not been carried out for the PCBX process. Each generic effluent stream should be analyzed for composition and percent solids. Overall, the potential environmental impact of the disposal operation appears to be very low. Sunohio claims that either very little or no toxic products will be produced.

A cost analysis of the PCBX process is not available. It appears that a major

capital investment is not required since the system is completely portable. It is claimed that transformer oil can be decontaminated for about \$264-\$792 per m³. The theoretical reagent cost is about \$1.10 per kg (Sunohio, 1980). Cost credits may be earned by reusing the decontaminated heat transfer oil instead of discarding it.

Catalytic Wet Air Oxidation

Wet air oxidation is based on the principle that a solution of any organic material can be oxidized by air or oxygen if enough heat and pressure are applied. At temperatures of 433-613 K and pressures of 3.1-17.2 MPa, sewage sludges will be oxidized to alcohols, aldehydes, and acids. At higher temperatures and pressures, the organic material can be oxidized to CO₂ and H₂ (Astro, 1977).

IT Enviroscience (ITE), Inc., recently developed a catalyzed wet air oxidation process for the destruction of PCBs. This process is patented and involves the direct oxidation of PCBs by air or oxygen in an acidic aqueous medium at high temperatures. This process can be used for organic material in aqueous solution, organic liquid residues, and specific types of sludges and solid residues. Special attention was given to PCBs in the development of this process (IT Enviroscience, 1980). This catalyzed wet air oxidation process utilizes a water soluble, single-phase catalyst system. It differs from other processes in that the catalyst is homogeneous, and, unlike uncatalyzed wet air oxidation, heat and pressure requirements are lower. The catalyst itself is used to promote the necessary oxygen transfer.

This technology is new and not completely researched. ITE recently completed feasibility testing and process development studies for the destruction of PCBs. Over 50 tests were made on PCBs by ITE in a 1 liter titanium stirred reactor to define process conditions in the laboratory. Greater than 90 percent of PCBs were repeatedly destroyed by oxidation at 523 K for 2 hours. It is important to note that it is not necessary to achieve 99+ percent destruction of the PCBs since unreacted PCBs will remain in the reactor until destroyed. (This retention of undestroyed PCBs reduces throughput.) The laboratory studies used 5-6 g of Askarel (56 percent PCBs and 44 percent trichlorobenzene) to determine destruction efficiencies. This process may be adaptable over a

wide range of PCB concentrations. Transformer oils with > 500 ppm PCBs might possibly be treated by this process. It is extremely difficult to estimate environmental impacts at this time. It appears that minimal environmental damage would be expected from this PCB disposal operation since the PCBs remain in the reactor until destroyed and since there is no aqueous bottoms product. CO₂, N₂, H₂O vapor, volatile organics, and inorganic solids leave the reactor. The water and condensable organics are retained in the reactor for complete degradation. This step reduces the volume of toxic organic substances that could be contained in the effluent streams. The vent gases are low in volume and could be treated by conventional techniques. Further research is required to develop a detailed environmental assessment of this process.

Economic data for the ITE method are not available. Required information includes: (1) capital costs, (2) operating costs, (3) disposal costs, (4) credits for products or by-products, and (5) regulatory costs. A cost analysis and feasibility study is currently being carried out by ITE to determine the economic viability of this process. Qualitatively, this process seems to be economically feasible if adequate throughput can be attained. Little or no added energy is required, and no auxiliary fuel is consumed. Chemical consumption is low, lowering the cost appreciably.

Biological Methods

Biological disposal methods are all based on the ability of microorganisms to degrade toxic organic compounds, such as PCBs. The major differences between the various methods lie in the means of supporting and contacting the microorganisms with the fluid containing the species to be degraded, means of providing oxygen to the microorganisms, and in pre- and post-treatment.

The literature review indicated that most commercial applications of biological processes are to aqueous streams containing relatively small amounts of organic compounds. Laboratory studies show that pure Aroclor mixtures are degraded and that degradation rates are inversely related to increasing chlorine substitution. Studies (U.S. Air Force, 1976) show that microorganisms could degrade concentrated Herbicide Orange components over a period of years. Commercial land farming is used to degrade oil-contaminated industrial

aqueous wastes. However, PCBs are more refractory than the major Herbicide Orange components and oils. Two biological processes that may be of some interest are activated sludge and trickling filter methods. Both processes are currently used for wastewater treatment.

Activated Sludge Treatment

Activated sludge treatment is classified as an aerobic process because the microbial solution is suspended in a liquid medium containing dissolved oxygen. Complete aerobic treatment without sedimentation is carried out as the wastewater is continuously fed into an aerated tank where microorganisms digest and flocculate the organic waste. The microorganisms (activated sludge) settle from the aerated liquor in a final clarifier and are returned to the aeration tank. The effluent emerges from the final settling tank purified.

Tucker, Litschgi, and Mees (1975) did laboratory testing with a continuous feed activated sludge unit. With a feed rate of 1 mg/48 hrs, they reported an 81 percent degradation of Aroclor 1221, 33 percent degradation of Aroclor 1016, 26 percent degradation of Aroclor 1242, and 15 percent degradation of Aroclor 1254.

Trickling Filter Methods

Trickling filters consist of crushed rock, slag, or stone. These materials provide a surface for biological growth and passages for liquid and air. The primary treated waste flows over the microbial surface. The soluble organic material is metabolized, and the insoluble material is adsorbed onto the media surface (Wilkinson et al., 1978). The biological components are bacteria, fungi, and protozoa. The bottom portions of the filter contain nitrogen fixing bacteria. Trickling filters are classified as low (standard), intermediate, high, or super rate filters based on hydraulic and organic loading rates. Since an aqueous medium is necessary, only dilute dissolvable PCB isomers may readily be contacted with the active microbes.

Neither of the above biological methods can be considered technically applicable to general disposal of PCBs and PCB items. While trace quantities of PCBs could be fed into a commercial scale process and while some degradation would occur, destruction would not be complete, and the amounts fed would be so small as not to aid appreciably the

PCB disposal problem. Further research is warranted, but the research might most profitably be pursued in the following areas: (1) more effective treatment of sewage and wastewater already contaminated by PCBs, (2) treatment of PCB-contaminated dredge spoil, and (3) developing microorganisms effective at degrading PCBs. Because destruction efficiencies of current processes decrease rapidly with increasing chlorine substitution, it is doubtful whether any activated sludge or trickling filter process will be capable of destruction efficiencies equivalent to those of high efficiency boilers or Annex I incinerators.

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The complete report, entitled "Interim Guidelines for the Disposal/ Destruction of PCBs and PCB Items by Non-thermal Methods," (Order No. PB 82-217 498;

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