ABSTRACT

This document presents the findings of a study of available wastewater management and treatment technology for the purpose of determining toxic pollutant effluents concentrations and daily load achievable in three industrial categories: polychlorinated biphenyls (PCBs) manufacturing; capacitor manufacturing; and transformer manufacturing.

All plants in the above categories have PCB discharges to either waterways or sewage treatment plants, under normal operating conditions. All plants have discharges to storm sewers or directly to waterways under heavy rainfall conditions.

Extensive survey of wastewater treatment technologies and cooperative laboratory work with several suppliers of treatment equipment and research facilities has confirmed that carbon adsorption technology is the best current candidate for successful removal of PCBs from the wastewaters. As an alternative uv-ozonation was considered. This technology is still in the research stage; however, it offers potential of complete destruction of PCBs all the way to CO_2, water and HCl.

Another adsorbent technology now in the development stage, AMBERLITE polymeric adsorbents, has demonstrated a PCBs removal efficiency roughly equivalent to carbon during laboratory tests. Further testing is needed with this adsorbent to accurately assess its potentiality.

For scrap oils and burnable solid wastes generated at these plants, high temperature, controlled incineration offers a straightforward method of destruction, whereas scientific landfilling appears to be the best suited mode of disposal for nonburnable contaminated solids.

Zero discharge objectives can be best achieved by eliminating discharge streams and developing recycle systems. All non-contact cooling water would be segregated, cooled, and recycled. All other wastewater streams would be pretreated. The portion of the pretreated water which would be used in the plant would be treated with carbon, while the excess water would be

MONS 070354

incinerated in a specially designed system which would allow for energy recovery.

Supporting data, rationale for the selection of above recommended treatment technologies and associated costs are contained in this report.

MGNS 070355

TABLE OF CONTENTS

	Page
SECTION I - INTRODUCTION	1
1.0 OBJECTIVE OF THIS STUDY	1
2.0 SCOPE OF THIS STUDY	1
2.1 Industry Characterization	2
2.2 Control and Treatment Technologies for PCBs Wastes	2
2.3 Capital and Operating Costs for Selected Treatment Technologies	3
3.0 REPORT CONTENT	3
SECTION II - SUMMARY AND CONCLUSIONS	4
SECTION III - RECOMMENDATIONS	15
SECTION IV - WATER USE AND WASTE CHARACTERIZATION	18
1.0 INTRODUCTION	18
2.0 SPECIFIC WATER USES	18
3.0 INDUSTRY AND PROCESS WASTE CHARACTERIZATION	19
3.1 Manufacturing Process - Polychlorinated Biphenyls (PCBs)	20
3.1.1 Process Description	20
3.1.1.1 PCB Production and Usage	22
3.1.2 Raw Wastes	24
3.1.3 Plant Water Usage	24
3.1.4 Wastewater Treatment and Housekeeping	27
3.1.4.1 Treatment Facility for the Effluent from Sauget Complex	31
3.1.5 Plant Effluents	31
3.2 Askarel Capacitor Manufacturing Industry	32
3.2.1 Askarel Capacitor Manufacturing Plants	34
3.2.1.1 Askarel Handling	36
3.2.1.2 Process Description	37
3.2.1.3 Raw Wastes	42
3.2.1.4 Water Use	42

MONS 070356

TABLE OF CONTENTS (Con't)

Page

SECTION IV (Con't)

3.2.1.5 Wastewater Treatment 46
3.2.1.6 Effluent Composition 52

3.3 Askarel Transformer Manufacturing Industry 52

3.3.1 Transformer Manufacturing Plants 59

3.3.1.1 Askarel Handling 61
3.3.1.2 Process Description 62

3.3.1.2.1 Assembly and Askarel Filling Procedure for the Distribution and Power Transformers. . . . 62

3.3.1.3 Raw Wastes 68
3.3.1.4 Water Use. 69
3.3.1.5 Wastewater Treatment 71
3.3.1.6 Effluent Composition 75

SECTION V - SELECTION OF POLLUTANT PARAMETERS. 79

1.0 INTRODUCTION 79

2.0 SIGNIFICANCE AND RATIONALE FOR SELECTION OF POLLUTANT PARAMETERS 80

2.1 Polychlorinated Biphenyls 80
2.2 Chemical Oxygen Demand (COD) 81
2.3 Fats, Oils and Greases 82
2.4 Suspended Solids 82
2.5 Dissolved Solids 83
2.6 Other Constituents 83

SECTION VI - WASTEWATER TREATMENT TECHNOLOGIES 84

1.0 INTRODUCTION 84

1.1 Similarities and Contrasts Between PCBs Wastes and Control Practices in their Production, and in their Use as Dielectrics 84

1.2 Summary of Waste Management Problem Areas 85

1.2.1 Waste Liquid PCBs and Contaminated Scrap Oil . . 85
1.2.2 PCBs in Wastewaters 86
1.2.3 PCBs Contaminated Solid Wastes 86
1.2.4 Air Emissions of PCBs 87

TABLE OF CONTENTS (Con't)

SECTION VI (Con't)

		Page
1.3	Summary of Current PCBs Waste Control Practices	87
1.3.1	Control of Waste Liquid PCBs and Contaminated Scrap Oils	87
1.3.2	Control of PCBs in Wastewaters	88
1.3.3	Control of Solid Wastes Contaminated with PCBs	89
1.3.4	Control of Air Emissions of PCBs	91
2.0	CANDIDATE PCBs WASTE TREATMENT TECHNOLOGIES CONSIDERED	92
2.1	Treatment of Waste Liquid PCBs and Contaminated Scrap Oils	93
2.1.1	Incineration	93
2.1.2	Sanitary or Scientific Landfill	95
2.2	Treatment of Wastewaters Containing PCBs	95
2.2.1	Carbon Adsorption	95
2.2.1.1	PCBs Adsorption Testing by Carborundum Company	97
2.2.1.2	PCBs Adsorption Testing by ICI-US	98
2.2.1.3	PCBs Adsorption Testing by Calgon Corp.	102
2.2.1.3.1	Adsorption Treatment of the Wastewater	105
2.2.1.3.2	Reactivation of the Granular Carbon	106
2.2.1.3.3	Carbon Treatment	107
2.2.1.3.4	Materials of Construction	107
2.2.1.4	Carbon Regeneration Alternatives - Wet Catalytic Oxidation	108
2.2.1.5	Further Applications Data	109
2.2.2	Ultraviolet-Assisted Ozonation	109
2.2.2.1	Molecular Responses to Ultraviolet Region Energy	111
2.2.2.2	Photodegradation of PCBs	112
2.2.2.3	Experimental Factors in UV-Assisted Ozone Oxidation of PCBs	113
2.2.2.4	Destruction of PCBs and Refractory Organics at Houston Research, Inc.	114
2.2.2.4.1	PCBs Destruction Data	114
2.2.2.4.2	Operating Data Obtained from Refractory Organics Tests	114

MONS 070358

TABLE OF CONTENTS (Con't)

SECTION VI (Con't) Page

2.2.2.5 Destruction of PCBs and Refractory Organics at Westgate Research Corp. . . 116

2.2.2.5.1 PCBs Destruction Data 116

2.2.2.5.2 Pilot Scale Tests of Refractory Organics Decomposition . . . 122

2.2.2.6 Laboratory Test Results from AiResearch Corp. 127

2.2.2.7 Comments on UV-Ozone Tests 127

2.2.3 Non-Carbon Adsorbents for PCBs 127

2.2.3.1 The Amberlite XAD Series of Macroreticular Resins. 128

2.2.3.1.1 PCBs Adsorption Testing 128

2.2.3.1.2 Process Concept for Resin Adsorption of PCBs. 129

2.3 Treatment of PCBs - Contaminated Solid Wastes 130

2.3.1 Incineration 130

2.3.2 Sanitary Landfill 132

2.4 Treatment of Air Emissions 132

2.4.1 Condensation Methods 132

2.4.2 Granular Adsorption Methods 132

2.4.3 Catalytic Oxidation of Organics in Evaporated Effluents. 132

2.5 The Potential for Zero Discharge 133

3.0 RATIONALE AND SELECTIONS OF CURRENTLY RECOMMENDED WASTE TREATMENT METHODS. 134

3.1 Incineration Recommended for Liquid PCBs and Scrap Oils . 134

3.2 Carbon Adsorption and UV-Assisted Ozonation Recommended for PCBs in Wastewater 135

3.3 Incineration and Landfill Recommended for Contaminated Solids. 136

3.4 Dry Carbon Filter Adsorption Recommended for Control of Air Emissions 136

SECTION VII - COST OF TREATMENT AND CONTROL TECHNOLOGIES 138

1.0 SUMMARY 138

1.1 Plant to Plant Cost Variations 140

TABLE OF CONTENTS (Con't)

SECTION VII - Con't

		Page
1.2	Activated Carbon Terminal Treatment System	142
1.3	Costs Based on Volume Flow	143
2.0	COST REFERENCES AND RATIONALE	143
2.1	Interest Costs and Equity Financing Charges	143
2.2	Time Basis for Costs	144
2.3	Useful Service Life	144
2.4	Depreciation	144
2.5	Capital Costs	144
2.6	Annual Capital Costs	144
2.7	Land Costs	144
2.8	Operating Expenses	145
2.9	Rationale for Incineration Costs	145
2.10	Definition of Levels of Treatment	148
2.10.1	Effect of Varying Effluent PCB Concentrations	148
2.10.2	Zero Discharge Definition	149
3.0	PCB WASTEWATER TREATMENT PLANT DESIGN PARAMETERS AND COSTS	150
3.1	Introduction	150
3.2	Pretreatment	154
3.2.1	Equalization and Separation Basin	154
3.2.1.1	Equalization Basin Capital and Operating Cost	156
3.2.1.2	Equalization Basin Costs	156
3.2.2	Multimedia Filtration	156
3.2.2.1	Filtration Costs	160
3.3	Activated Carbon Treatment System for Removal of PCBs From Wastewater	160
3.3.1	Activated Carbon System Design	167
3.3.1.1	Regeneration of Spent Carbon	175
3.3.1.2	Economic Analysis of Carbon Treatment of PCB Contaminated Wastewater	178
3.3.2	UV-Ozonation - Potential Alternative	180
3.3.2.1	Description of System Components and Rationale for Cost Evaluation	180
3.3.2.2	Capital Costs	188
3.3.2.3	Operating Costs	188
3.3.2.4	Total Treatment System Cost for Zero Discharge System	200

MONS 070360

TABLE OF CONTENTS (Con't)

SECTION VII (Con't)

		Page
3.3.2.5	Total Wastewater Treatment Plant Costs Using Activated Carbon or Ultraviolet Light Catalyzed Ozonation	200
3.3.3	Cost of Implementing Carbon Adsorption Treatment for Selected Plants	205
3.3.4	Zero Discharge	212
3.3.4.1	Description of Dry Cooling Tower	212
3.3.4.2	Design Criteria	213
3.3.4.3	Capital Costs	213
3.3.4.4	Operating Costs	213
3.3.4.5	Cost of "Zero Discharge" for Selected Plants	218
3.3.5	Comparison of "Zero Discharge" with Discharge to Surface Waters	218
3.4	Scrap Oil Incineration	222
3.5	Solid Waste Incineration	223
3.6	Total Industry Treatment Costs	224

APPENDIX A - Plant 106's Position Statement on Dow's XFS-4169 Capacitor Dielectric Liquid

APPENDIX B - PCB Adsorption Testing by XAD-4 Resin

APPENDIX C - Description of Macroreticular Resins from Rohn and Haas Co.

APPENDIX D - Non-Carbon Adsorption and Other Research Stage PCB Treatment Technologies

APPENDIX E - Energy Requirement for Various Treatment Options

MONS 070361

SECTION II

SUMMARY AND CONCLUSIONS

The table on the succeeding page gives a quantitative summary of daily PCB waste loads achievable by PCB manufacturer and the two major PCBs users (capacitor and transformer industries). This information was derived from data supplied by these industries and presents estimates of amounts of PCB wastes currently discharged by these industries to the environment via water, land and scrap oil generated and destroyed by these facilities via incineration.

The results of this study are grouped into three broad categories. First, those dealing with industrial characterization, production, use and emissions. The second group contains those giving an overview of available technologies for treatment of various PCB wastes and the third summarizes the costs associated with currently recommended waste treatment methods.

Industrial Characterization

1. The domestic annual production of PCBs in 1974 was 40,466,000 lbs of which approximately 22,000,000 lbs was used by capacitor manufacturers and 12,000,000 lbs was used by transformer industries. The balance reflects inventory changes and about 5,395,000 lbs of export sales.

2. There are a total of 37 PCB user (capacitor and transformer) plants in the U.S. and one PCBs manufacturer. Of the 38 plants, 10 discharge their effluents into the water ways while the remainder discharge PCBs into the sewage treatment plants. All plants in these categories have discharges under heavy rain fall conditions.

3. In addition to air emissions, there are three types of waste materials generated at these plants that require treatment and proper handling in order to minimize the PCB entry into the environment. These are:

TABLE 1

SUMMARY OF WASTE LOADS

	Daily Average		
	PCB Discharge in Waterways or Sewers	Land-Destined PCB Wastes	Scrap Oils to Incineration
PCB Manufacturer	3.06 lbs	301 lbs	1425 lbs
Capacitor Industries	5.86 lbs	4440 lbs	3968 lbs
Transformer Industries	0.17 lbs	Unknown	1750 lbs

(a) waste waters containing trace quantities of PCBs (10 to 500 ppb PCBs)

(b) waste PCBs, scrap oils and small quantities of process water highly contaminated with PCBs

(c) burnable and non-burnable solid materials contaminated with PCBs.

Quantitative estimates of these wastes are given in Table 1.

4. The quantities of land-destined wastes originating at the PCBs and capacitor manufacturing plants were estimated from sparse data supplied by a few plants. Similar information is not available from the transformer industry. These plants normally drum their solid wastes and have incomplete information on the number of drums accumulated annually. Some plants compact their wastes prior to drumming; others drum their wastes without the benefit of compacting. There are no adequate records to quantify these wastes. At some plants, the majority of this waste category, however, exists in an enormous total waste volume and probably at relatively low concentrations of PCBs. Further efforts are needed to adequately define these wastes.

5. As yet, very little is being done to control air emissions. The general assumption is that the vapor pressure of PCBs is so low that there will be essentially no air contamination. A few facilities, however, were reported to be filtering and chilling exhaust air from PCBs impregnation areas.

6. While the emissions of PCBs to water are expected to decrease due to improved pollution abatement of waterborne wastes, the release of PCBs to air and land is expected to increase. The primary source of increasing air emissions is the increase in the load of incineration materials due to proper handling of wastes which were previously discharged into the waterways or sewers. The quantities of land-destined wastes will also increase due to improved housekeeping measures.

7. Since most water used at these facilities is for non-contact cooling purposes, at most plants it is possible to significantly reduce the effluent volume by segregation of wastewaters, recycling and proper housekeeping measures.

8. Most plants have already undertaken PCBs containment programs in order to minimize the entry of PCBs into the environment.

9. There is no commercial scale wastewater treatment for PCBs removal being practiced beyond those of gravity settling of the heavy PCBs layers as a sludge from the bottom of sumps or tanks, and skimming of a contaminated oil-layer from the water surfaces.

10. Wastes in PCBs production and PCB wastes in capacitor and transformer manufacturing differ primarily in that the producer generates some higher boiling, highly chlorinated and polycyclic materials referred as "Montar" that are separated from the Aroclor products and incinerated. Thus the users of PCBs do not receive the higher boiling materials. Aroclor 1016 is the principal PCB used by capacitor industry; at some plants Aroclor 1242 and 1221 are also being used in limited quantities. Mineral oil is the principal coolant oil used by the transformer industry. PCB transformer oils (blends of 60 to 70 percent Aroclor 1254 or 1242 and 40 to 30 percent trichlorobenzene) are used in only 5-10 percent of these plants' manufacturing volume. However, it has been concluded that the characteristics of the waste materials and effluents generated in all these facilities are, in general, similar enough so that the same kinds of treatment technologies can be utilized for purposes of controlling PCB entry into the environment.

11. Most industrial analysis for PCBs in wastewaters are based on grab samples and probably have not been more accurate than about $\pm$ 50% at the one and ten ppb level.

12. Rivers receiving PCBs discharges for a number of years vary greatly in PCBs content with time, apparently depending upon PCB content in storm water runoff and the degree to which bottom sediment is agitated and suspended.

13. Wherever there have been PCB operations in the past, there are probably high concentrations in local waterways bottom sediments.

14. All water streams have greatly lowered PCBs contents:

    (a) when solids are removed
    (b) when dispersed or dissolved oils are removed
    (c) When the stream comes in contact with a wide variety of solid surfaces
    (d) when no surface active agents are present.

15. Over the past 45 years, waste PCBs from transformer and capacitor operations have been used as local road oiling compounds. Sometimes they were discarded in dumps adjacent to manufacturing facilities. These are sources of long term leaching of PCBs into waterways, particularly with storm water runoff.

Overview of Available Technologies for the Treatment of Various PCB Wastes

1. The most advanced treatment technology in use is incineration. The PCBs manufacturer and one user have plant scale incineration capable of destroying PCBs with very high efficiency. There are at least two commercial services (Rollins Environmental Services and Chemtrol Pollution Services) available, with four incinerator locations in the Eastern and Southern U.S., that destroy PCBs.

2. Incineration is primarily applicable to waste PCBs and scrap oils contaminated with PCBs. All installations have the capacity of "burning" some contaminated wastewater but, of course, the proportion of that water to the exothermic oil burning must be kept low.

3. Only one commercial incineration service (Rollins) can routinely handle all kinds of PCBs contaminated transformer and capacitor components, sludges, fuller's earth and other solids, as long as they can be contained in a 47 gallon fiber drum. One PCB user company incinerates transformer internals for purposes of metal recovery.

4. Adequate methodology is available for those plants wishing to control the release of PCBs to the environment. Currently available technologies can be applied to the efficient removal of PCBs from wastes, or their destruction with the other wastes.

5. The PCBs content of wastewaters can be lowered to the 1 ppb level or below by carbon adsorption, macroreticular polymer resins and probably other adsorbents.

6. Carbon adsorption is currently the best available technology for plant scale treatment of PCBs wastewaters. This conclusion is based on laboratory tests with PCBs in water, and on the long background of plant scale use of carbon adsorption for removal of organics from water.

7. UV-ozonation technology is the best demonstrated method, on the laboratory scale, for destruction of PCBs in wastewaters when the streams occur in large volume, on a relatively continuous flow basis and with PCBs at the ppb concentration levels. This technology has the potential for conversion of PCBs to CO_2, H_2O and HCl.

8. Waste liquid PCBs and scrap oils contaminated PCBs are best handled, as a guideline, by high temperature (2000-2400°F) and long residence time (2-3 seconds) incineration. However, because of incinerator design variables, the conditions should be chosen in each case to lead to 99.999% destruction.

9. Incinerators should be equipped with low temperature alarms, and low temperature shut down of PCBs feed. They should have high efficiency water scrubbers to prevent HCl dissemination.

MCNS 070367

10. The best incinerator combination for handling wastes from these industries is a rotary burner fired by a liquid burner, and followed by an afterburner and scrubber system. The rotary burner can be designed to handle a variety of solid materials, and the liquid burner can handle both the oily and water type wastes.

11. Polymeric resins (AMBERLITES) were found in laboratory tests to be approximately as effective as carbon in removing PCBs from water. Further pilot scale testing is needed with this newer (than carbon) technology to accurately assess its potential.

12. Although still in the laboratory stage, catalytic reduction of PCBs offers the possibility of reduction to biphenyl and HCl; and catalytic oxidation offers a potential for destruction of PCBs to CO_2, H_2O and HCl.

13. Reverse osmosis and ultrafiltration appear to offer a long term potential for a more maintenance-free, and lower operational cost method of separation of PCBs from water. Success is dependent upon specialized membrane development now being carried out at several facilities.

14. It is believed that treatment systems employing activated carbon and possibly UV-ozonation could produce effluents which would be at or below the limits of detectability for PCBs with currently available analytical techniques. However, since no full scale systems for the treatment of PCBs are in operation at this time, this possibility cannot be confirmed.

15. Unfortunately, no methodology is presently available which can guarantee "zero discharge" to the environment. "Zero discharge" objectives can be best met now by eliminating discharge streams and developing recycle systems. All streams that are high in pollutants and can't be treated for reuse and the rainwater runoffs should be collected and incinerated.

MONS 070368

Costs Associated with Currently Recommended Waste Treatment Methods

1. The Table on the succeeding page summarizes the estimated maximum capital and annual costs for the treatment of wastes generated in each industry category. As shown
treatment of all contaminated and potentially contaminated wastewaters, the incineration of scrap oils and the incineration of contaminated solid waste generated in the domestic production and utilization of PCBs is $35.50 million and $9.61 million, respectively. The total annual cost given above represents $0.28 per pound of PCB utilized within the U.S., based on 1974 data.

2. Rainwater contribution to the capital and annual wastewater treatment costs was estimated at 15 and 25 percent, respectively. If significant isolation of the contaminated areas can be achieved these costs will be somewhat reduced.

3. The estimation of total maximum costs anticipated for the manufacturer and users of PCBs was facilitated by preparing cost estimates for each plant site visited during the course of this study and then aggregating to the total industry category on the basis of the percentage of the total industry represented by the visited plants.

4. The treatment system includes settling for solids removal, oil skimming, equalization, fine media filtration, terminal PCB treatment, flow measurement and sampling, and discharge to surface receiving waters. All sludges and free floating oils are disposed of through incineration. All backwash waters used in the system are recycled back to the gravity settling basin for treatment. All spent adsorbent is destroyed by incineration (for wastewater flows up to 300 gpm) or regenerated on-site for reuse (for waste flows above 300 gpm).

5. An activated carbon system was selected as the terminal PCB treatment method for purposes of estimating the maximum total costs. A potentially viable alternative to carbon adsorption, UV-ozonation, has less well defined capabilities. Additionally, it is believed that unless the UV-ozonation system can do an equal or better job of destroying PCBs at a lower cost, it will not be selected by these industries.

TABLE 2

MAXIMUM PCB INDUSTRY TREATMENT COSTS

Industry	Capital Cost	Total Annual Cost	Cost Per Pound Produced or Used
PCB Producer	$ 1,600,000	$ 595,000	$0.015
Capacitor Manufacturing	16,600,000	4,200,000	0.190
Transformer Manufacturing	17,300,000	4,815,000	0.401
Total	$35,500,000	$9,610,000	
Total Cost Per Pound of PCB utilized		$ 0.28	
Total Cost Per Pound of PCB discharged to waterways		$ 2896	

MONS 070370

6. A carbon adsorption system will remove PCBs from industrial effluents to a level of one ppb or less. It is impractical to design an activated carbon system to obtain a choice of effluent concentrations. The operating cost savings for operations at various effluent PCB concentrations are expected to be too small to justify designing carbon adsorbers for PCBs removal at higher than one ppb level.

7. The work performed by Houston Research and Westgate Research on UV-ozonation indicates that the final concentration is a function of residence time, and that UV-ozonation systems can be designed to achieve any desired effluent PCB concentration.

8. Preliminary comparisons of the capital costs of the two systems show at least a 100 percent greater cost for the ozone system over the carbon. When pretreatment costs are combined with treatment, the UV-ozonation process is about 10 percent higher than the carbon process.

9. The design and fabrication of incineration equipment is a highly proprietary industry, it is believed that any attempt to estimate the cost of such systems on a rational basis would be fruitless. In addition, it seems quite improbable that the smaller PCB user plants would find it economically justifiable to install and operate such a system for destruction of scrap oils and solid wastes contaminated with PCBs. The alternative to on-site incineration is contract incineration. For purposes of cost estimation and based on the range of prices quoted by service companies, a flat rate of $0.10 per pound has been assumed for all scrap oil and solid wastes even if they are generated by facilities which have an on-site incinerator.

10. Contract incineration of large volume, dilute aqueous streams does not seem to be a feasible alternative due to the logistics and transportation cost. For purposes of achieving "zero discharge", capital costs for on-site incineration systems were developed. In this case, the accuracy of capital cost estimates are not deemed as critical in view of the high operating cost, primarily fuel cost, associated with this system.

MCNS 070371

11. The least cost "zero discharge" system comprises segregation of waters used in the plant and cooling and recycling all non-contact cooling water. All other wastewaters will be routed to a central system for equalization, settling and fine media filtration. The portion of the water to be utilized in the plant will be subjected to terminal treatment with carbons, the excess water will be subject to incineration in a specially designed system which would have the potential of energy recovery.

12. Capital and total annual costs to achieve "zero discharge", based on the system described above, was developed for selected plants. It was concluded that the total annual costs for "zero discharge" was about 2.0 to 12.0 times the cost of the carbon system (close loop cooling water case) when rainwater was included.

13. Rainwater runoff is a direct function of the locations' rainfall and runoff area. The rain runoff area may or may not be dictated by the size of the production facility. This single flow could provide the largest flow variation for all production facilities.

14. For the "zero discharge" system the rainwater contribution to the annual wastewater incineration cost is very high. Comparison of the two "zero discharge" cases [(1) inclusion of rainwater runoff as incinerating material and (2) exclusion of rainwater runoff] indicates the annual cost of the case 1 to be 2 to 42 times the cost of the case 2 for the various plants under study.

15. As a rough approximation, energy requirement for waste incineration is directly proportional to the hydraulic load of the unit. Water incineration is far more energy intensive than scrap oil incineration.

16. Energy requirement of each plant is proportional to the total hydraulic load of the pretreatment and terminal treatment systems.

SECTION III

RECOMMENDATIONS

There are indications within the PCBs manufacturer and PCBs user industries that progress is being made in air and water pollution abatement; however, little is being done to assure that the land-destined wastes are disposed of in an environmentally sound manner. This shortcoming can be attributed to higher costs associated with handling large volumes of wastes further information is needed regarding methods and costs of handling land-destined wastes.

Based on the summary and conclusions cited in Section II, the following recommendations are made:

1. Verification sampling should be conducted under controlled conditions in order to define the levels of PCBs discharged into the environment with higher degree of accuracy.

2. Promulgation and enforcement of regulations for water pollution abatement from stationary sources should be continued. Regulations for non-point sources should be initiated to minimize the entry of PCBs into the environment.

3. The use of more biodegradable PCB (Aroclor 1016) in transformer applications should be encouraged.

4. New regulations should be developed and enforced to ensure that the land-destined wastes from these facilities are disposed of in an environmentally sound manner.

5. Additional data should be developed to adequately characterize solid wastes generated by these three industries and then define methods and costs of handling these wastes.

6. The capability of various incineration facilities should be determined for PCBs destruction on a given doctored feedstock using a predeveloped and specific test plan. Analysis of available data indicated that there are differences of opinions as to optimum temperature level and residence time for PCB incineration.

MONS 070373

7. Waste PCBs liquids and scrap oils contaminated with PCBs should be incinerated in approved facilities. New incineration facilities can be installed in one year.

8. Every effort should be made at each plant to minimize flows. The source of rain runoff contamination should be traced and efforts should be directed to isolate the contaminated areas.

9. Disposable foot coverings and outer garments should be provided at each plant; work clothing should not be allowed to leave the plant other than via solid waste.

10. All spills should be cleaned via rags or floor dry and disposed of in waste drums for incineration. All solid waste should be disposed of in impervious sealed containers.

11. As a housekeeping measure, all sinks in the PCB impregnation and PCBs handling areas should be contained. The wash water from these sinks should be properly treated prior to disposal.

12. Wastewaters containing PCBs should be treated by the standard sanitary procedures of settling the sludges and sediments, removal of suspended solids, and skimming to remove floating oils; all prior to specialized terminal treatment for PCBs.

13. Wastewater pretreated as recommended above should then be treated in carbon adsorption columns for removal of PCBs to the ppb levels or less.

14. Spent carbon should be regenerated in an environmentally sound manner, or sent to approved incineration along with other PCBs wastes.

15. Waste capacitor and transformer components, absorbent solids, adsorbents, soil, cloth, paper, wood and similar solids contaminated by PCBs should be incinerated in a rotary kiln. The exhaust should be fed to an incineration unit for liquid PCBs, equipped with afterburner and scrubber to assure destruction of all PCB vapors. Such facilities can be installed in one year.

MONS 070374

16. Exhaust air from PCB impregnation areas should be filtered through absorbent carbon, with chilling, if necessary, to meet clean air quality standards. This equipment can be installed in one year.

17. Research on the catalytic oxidation of dilute PCB vapors in air streams should be conducted to determine the feasibility of low temperature destruction of PCBs by an energy saving process. This method will take more than three years to develop.

18. Research on UV-ozonation should be continued to achieve the following goals:

    a) determination of optimum conditions for a continuous flow reactor system using actual wastewaters

    b) conduct on-site demonstration tests using portable equipment at a PCB using plant, operating on a wastewater slipstream

    c) design, construct and operate a pilot unit, on actual wastewater, to develop reliable capital and operating cost

    UV-ozonization treatment technology can be fully developed and installed in three years.

19. Pilot scale R&D on reductive dechlorination should be continued to obtain reliable capital and operating costs. This method will probably be available for plant scale application in three years time.

20. Laboratory research on catalytic oxidation as a method of PCBs destruction should be initiated. The feasibility of wet catalytic oxidation using suspended commercial catalysts at elevated temperatures (200°-500°C) and elevated pressures (500 to 1000 psi) should be determined. This method will take more than five years to develop.

- Treatment and housekeeping measures practiced at the facilities and on-going PCB containment programs
- Plant waste effluents found and their composition

3.1 Manufacturing Process - Polychlorinated Biphenyls (PCBs)

3.1.1 Process Description

Monsanto, the sole domestic manufacturer of PCBs, manufactures this chemical in their Sauget, Illinois plant. The basic raw material is biphenyl which is manufactured from pure benzene in another Monsanto plant. The PCB manufacturing operation is conducted in two steps. First, biphenyl is chlorinated with anhydrous chlorine in presence of ferric chloride to produce crude PCBs and then the crude PCBs are distilled to obtain the finished product. A schematic flow diagram of this process is given in Figure 3.1.1-1.

The reaction section consists of 6 reactors (3 batch and 3 cascade). Currently Monsanto manufactures four different types of Aroclors (1242, 1016, 1254 and 1221). For the manufacture of any given product, the chlorinator is charged with proper quantities of biphenyl and catalyst and heated beyond the melting point of biphenyl. The flow of vaporized chlorine is then started and the charge is circulated with a pump. Throughout the chlorination, the temperature is kept above the melting point of the mixture, but below 150°C to avoid excessive sublimation and plugging of the line discharging the hydrogen chloride produced by the chlorination. The reaction pressure is maintained near atmospheric. The degree of chlorination is principally determined by the time of contact with anhydrous chlorine. The contact time varies from 12 to 36 hours for the manufacture of different Aroclor types. The degree of chlorination is measured by the specific gravity of mixture or the ball and ring softening point when the product is viscous.

The vapors from the chlorinator (HCl containing PCBs) are scrubbed with liquid Aroclor and the gaseous HCl is sent to another plant at the Sauget complex for purification. The crude product is held at an elevated temperature and blown with dry air for several hours, after which it is sent to the raw Aroclor storage tank where a few tenths of 1 percent of alkali is stirred

Figure 3.1.1-1A - PREPARATION OF CRUDE CHLORINATED BIPHENYLS - MONSANTO KRUMMRICH PLANT

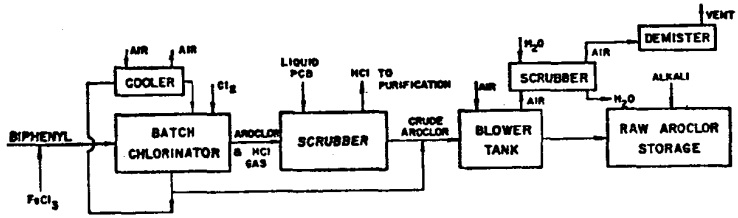
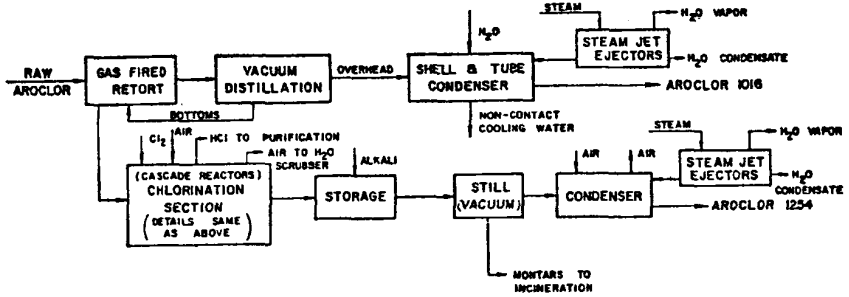


Figure 3.1.1-1B - DISTILLATION OF CRUDE PRODUCTS - MONSANTO KRUMMRICH PLANT



MONS 070377

with the material to react with any remaining hydrogen chloride or ferric chloride. The air from the blower tank is scrubbed with water and vented to the atmosphere through a demister.

The raw Aroclor is subsequently batch distilled under reduced pressure to remove the color, and the traces of hydrogen chloride and ferric chloride. The methods of purification are different for the different types of end products. Raw Aroclor 1254, 1242 and 1221, each are distilled in stills under reduced pressure, achieved via steam jet ejectors; the condensate from the still is the finished product while the bottoms are the Montars which are drummed and sent to incineration.

The distillation section for the 1016 product consists of a gas fired retort and a vacuum distillation tower. The latter is used to allow the separation of the higher chlorinated, less biodegradable compounds from the relatively lower chlorinated and more biodegradable ones. The raw Aroclor (42% chlorinated material) is fed into the reboiler. The vacuum in the tower is maintained at about 100 mg Hg via steam jet ejectors. The steam is partially condensed and the condensate is discharged into the plant discharge sump. The first cut from this tower is recycled back to the retort. At a preset overhead temperature the 1016 product is collected and sent to the product storage. The high boiling residue from the tower is sent to a subsequent chlorination cycle and the resulting raw Aroclor is distilled in a still. The overhead from this still is the finished product. The bottoms from this tower are the Montars, which are sent to incineration.

For special orders, in order to increase electrical resistivity, the Aroclors are stirred, at an elevated temperature, with a few tenths of 1% of well-dried fuller's earth and then filtered through paper.

All Aroclors are stored at 150°F. Steam coils are used on the storage tanks for heating these tanks.

3.1.1.1 PCB Production and Usage

The William G. Krummrich plant at the Sauget complex has an annual design capacity of 48 million pounds chlorobiphenyls. Table 3.1.1.1-1

MONS 070378

TABLE 3.1.1.1-1 PCB MANUFACTURE & SALES

(Thousands of pounds)

	1974	First Quarter 1975
U.S. production	40,466	8,532
Domestic sales	34,406	7,986
U.S. export sales	5,395	1,538
Domestic Sales by PCB Grade		
Aroclor 1221	57	10
Aroclor 1242	6,207	2,201
Aroclor 1254	6,185	2,115
Aroclor 1016	21,955	3,660

Predominant Utilization of Aroclors

Aroclor 1221 & 1016	Capacitor applications
Aroclor 1242 & 1254	Transformer applications

MONS 070379

present data from Monsanto related to production and sales on PCBs for the year 1974 and the First Quarter of 1975. Table 3.1.1.1-2 presents approximate molecular composition of these Aroclors as published by Hutzinger et al (O. Hutzinger, S. Safe and V. Zitko, "Chemistry of PCBs", CRC Press, 1974).

The majority of the PCBs produced in this plant is marketed domestically. At present, almost all Monsanto's PCB production is being used in "closed electric systems" (transformer and capacitor applications).

3.1.2 Raw Wastes

The raw wastes from the manufacturing area consist of the liquor from the scrubber, the condensate from the steam jet ejectors, water used for showers and eye baths, miscellaneous floor wash downs, waste oil collected in drip pans and drums, and montars which are the bottom cut from their stills. The composition and the quantities of the individual waste stream are not monitored. All effluent streams generated in the manufacturing area are directed into the sumps in this area. The waste oil collected in the drip pans and the montars are emptied into 55 gallon drums and sent to incineration.

The raw wastes generated in the incinerator consist of the venturi scrubber liquor and the water phase from the separator sump in the incinerator area. The composition of the combined stream is monitored. However, the composition of the individual streams is not known. Non-product PCB discharges are shown in Figure 3.1.2-1. It has been estimated that this plant generates about 25 lbs. of scrap oil and Montar per ton of PCB produced. Additionally the quantities of material sent to landfill approximates to 5.4 lbs. per ton of PCB produced. Additionally, reports that the plant's PCB contribution to air is under 1 lbs/day.

3.1.3 Plant Water Usage

On the average, the PCB plant uses a maximum of 388,800 gallons of water and a maximum of 360,000 lbs. of steam, daily. Water is used for non-contact cooling purposes in shell and tube condensers, in a water scrubber, for floor washings, for showers and in eye baths. Steam is used in the steam jet

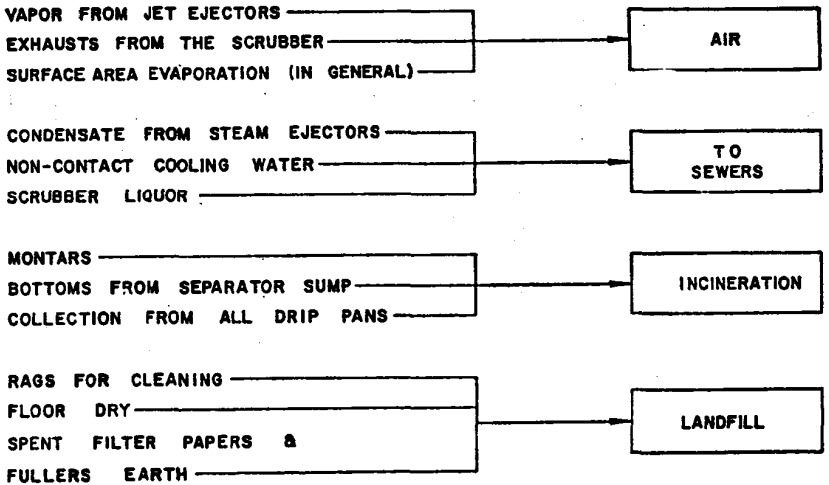
TABLE 3.1.1.1-2

APPROXIMATE MOLECULAR COMPOSITION OF AROCLORS

	Aroclor Type or Grade (percent composition)			
Chlorobiphenyl	1221	1242	1254	1016
$C_{12}H_{10}$	11	<0.1	<0.1	<0.1
$C_{12}H_9Cl$	51	1	<0.1	1
$C_{12}H_8Cl_2$	32	16	0.5	20
$C_{12}H_7Cl_3$	4	49	1	57
$C_{12}H_6Cl_4$	2	25	21	21
$C_{12}H_5Cl_5$	0.5	8	48	1
$C_{12}H_4Cl_6$	ND	1	23	<0.1
$C_{12}H_3Cl_7$	ND	<0.1	6	ND
$C_{12}H_2Cl_8$	ND	ND	ND	ND
$C_{12}H_1Cl_9$	ND	ND	ND	ND
$C_{12}Cl_{10}$	ND	ND	ND	ND

*ND - Denotes non-detectable

Figure 3.1.2-1- NON-PRODUCT PCB DISCHARGES AT MONSANTO'S KRUMMRICH PLANT



MDNS 070382

ejectors and for steam tracing purposes. The plant uses municipal water and purchased steam.

The process water from this facility consists of the liquor from their scrubber and the steam condensates which are discharged in one of the two sumps in the manufacturing area.

Additionally, 273,600 gallons of water are used in the incinerator daily for quenching the hot gases from the fire box. The resulting weak muriatic acid in the quench pot is used in the venturi scrubber and in the packed tower.

The type and quantities of water used and discharged at this plant are summarized below.

Water Balance

. Manufacturing Plant

	Quantities, GPD	
	Used	Discharged
Process Water		
in water scrubber	14,400	14,400
misc. floor wash downs	7,200	7,200
condensate from steam jet ejectors	—	14,400
Non contact cooling water	360,000	360,000
showers, eye bath	7,200	7,200
condensate from steam tracers	—	28,800
Total	388,800	432,000
. Incinerator		
water used for hot gas quenching	273,600	273,600
water phase from the sump	—	14,400
Total	273,600	288,000

3.1.4 Wastewater Treatment and Housekeeping

Monsanto reports significant environmental controls at their Krummrich, Sauget plant. Since 1969, they have invested more than 22 man-years of work and millions of dollars in this program. The in-house goals have reduced the PCB discharges into water to about three pounds per day.

A John Zink designed incinerator was erected at Sauget in 197. to safely dispose of PCBs. A schematic flow diagram of this operation is given in Figure 3.1.4-1. Aroclor is steam atomized and fed into the fire box. Natural gas is used for combustion and the feed is incinerated at temperature above 2200°F at 5 percent excess oxygen with a retention time of 2-3 seconds. The gases are quenched with water and the exhausts from the quench pot are passed through a high-energy venturi scrubber, then through a packed column which is irrigated by the weak muriatic acid originating from the quench pot. Exhausts are then vented to atmosphere through a demister. These exhausts as well as the effluent from the incinerator section are monitored.

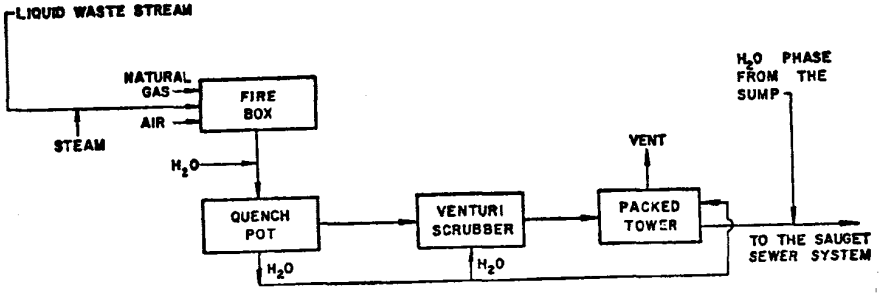
In the incineration area, drainage is directed to trenches and piping which flow into a 10,000 gallon underground concrete basin. The water layer from this basin is pumped continuously, combined with the scrubber liquor, metered, monitored and discharged into the sanitary sewers of the Sauget complex and from there it is sent to the East St. Louis municipal sewers. The organic phase from the sump is periodically pumped into waste storage tanks for incineration.

The incineration unit has a rated design capacity of 10 million pounds per year. However, since the start of its operation this unit has achieved a service factor of about 0.60. Monsanto reports that this incinerator can achieve a maximum of 6 million pounds of capacity annually; the unit is plagued with various mechanical problems.

Monsanto uses their incinerator to process both their own wastes and as a service to other industries. The service charge for incineration is an average of 5¢ per lb. of material, but the cost appears to be increasing.

The incinerator feed is brought into the plant either by truck in 55 gallon sealed drums, by tank trucks or by rail. The drums are opened, picked up by a fork lift and emptied into a concrete pit. The tank truck carrying the waste liquids enters the incinerator area and the liquid waste is then pumped from the truck into the pit. The material in this pit is periodically pumped via a vertical centrifugal pump in one of the four 20,000 gallon, each, incinerator waste feed tanks.

Figure 3.1.4-1-PROCESS FLOW DIAGRAM OF THE JOHN ZINK INCINERATOR. AT MONSANTO'S KRUMMRICH PLANT



MONS 020385

The rail car is brought into a designated area close to the incinerator site. The material from the rail car is normally pumped into a long term, 500,000 gallon storage tank. The material from this tank is pumped into the incinerator feed tanks located on the incinerator pad, when required.

Drainage is provided along the rail tracks. These drains empty into the 10,000 gallon sump located under the incinerator pad.

In the manufacturing area, Monsanto has taken a number of significant steps to prevent loss of PCBs to the environment. Drainage is directed to trenches and piping, and then to one of two concrete 3,000-gallon underground settling basins. This insures PCB containment in case of accidental spill or equipment failure. Relief valve lines and atmospheric vents are routed through catch tanks, or are redirected to settling basins.

When small quantities of PCBs are collected in the settling basins of the manufacturing area they are later pumped into 55 gallon drums, and eventually incinerated. The overflow from these sumps is combined with the non-contact cooling water used at the plant, monitored and then discharged into the Sauget complex's sanitary sewer and from there to the East St. Louis municipal system.

PCBs are packed and shipped in galvanized-steel 55 gallon drums, or in railroad tank cars. All tank cars are top loaded. In the drum filling area spills are cleaned via rags or floor dry and these materials are drummed and sent to landfill located in the town of Sauget.

In the PCB truck or rail car loading area drainage is directed into a small concrete pit. The material accumulated in this pit is periodically pumped into the basins located in the manufacturing area.

Nitrogen blanketing is provided on storage tanks to eliminate any "breathing" of the tanks and resultant PCB escape.

Mist eliminators have been installed in vapor lines to eliminate the possibility of PCBs leaving the manufacturing area through these lines.

Finally, underground sewers have been replaced with above-ground sewers, and repaired or combined with others, so that the effluent from the department can be monitored. In addition, this step will prevent any unknown buildup of PCBs in the sewer systems or any contamination of PCBs into other sewers.

A high housekeeping level is maintained in the plant itself. Housekeeping responsibilities which the operators have assumed are as follows:

- All pumps are checked for leakage on every shift. Drip pans that collect leaks are emptied into scrap PCB drums.
- All leaks are reported and documented so that corrections can be made and settling basins observed.
- "Floor Dry" is used to absorb any PCBs that have spilled or leaked. If it becomes necessary to flush PCBs to the settling basin, a minimum amount of water is used.
- Sampling drums and scrap PCB drums are quickly palletized, labelled and transferred to the incineration area.

3.1.4.1 Treatment Facility for the Effluent from Sauget Complex

The processing and incineration departments' aqueous effluent enters the plant sewer system, and this system discharges into the Sauget Village waste sewer system. The combined streams then flow to the village primary treatment plant. The village treatment plant is under expansion to a secondary chemical treatment plant, scheduled for 1976 completion.

Additionally, evaluations are being conducted to include the village plant discharge in a projected regional biological treatment plant.

3.1.5 Plant Effluents

This plant has no point source discharge from their operation. There is a single discharge from the manufacturing operation (the combined stream of process and non-contact cooling water) to the main sewer system of the Sauget

MONS 070387

complex and there is a second discharge from the incinerator area to the same sewer system. The composition of these streams as reported by Monsanto are as follows:

	Effluent from the Manufacturing Operation	Effluent from the Incineration area
flow rate, gpd	432,000	288,000
PCBs, ppm	0.75	0.15
PCBs, lbs/day	2.70	0.36

It has been reported that these effluents are clear liquids with essentially no suspended solids. The incinerator effluent may contain some amounts of chloride. However, no information is available on the chloride content.

3.2 Askarel Capacitor Manufacturing Industry

Presently 90-95 percent of all capacitors manufactured in the U.S. are of the PCB impregnated type. Two important types of capacitors are phase correctors on power lines and ballast capacitors for fluorescent lighting. Aroclor 1016 is the principal PCB used in this application; at some plants Aroclor 1242 and 1221 are also being used in limited quantities. The principal types of Aroclor impregnated capacitors and their applications are given below.

A. High Voltage Power

Generally AC capacitors are used to improve the power factor of a circuit. Power factor is the ratio of true power in watts to the apparent power as obtained by multiplying the current flowing to the load by the circuit voltage. The power factor correction can be made directly at the load or at utility substations. In the latter case high voltage units will be designed for 4,800 to 13,800 volt service. To the utility engineer the use of capacitors is purely a matter of economics. The main benefits that result from the use of capacitors are:

1. Reduction of losses associated with the delivery of electrical power to the point of use.