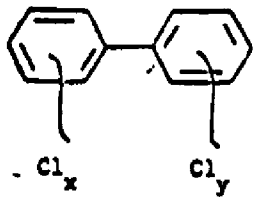
THE NEED FOR CONTINUED USE OF CHLORINATED
BIPHENYLS AS ELECTRICAL INSULATING LIQUIDS

Why are Polychlorinated Biphenyls (PCBs) needed?

The principle use of PCB fluid in the electrical industry is in transformers and capacitors (both large and small) as an insulator and coolant. At the present time there is only one domestic manufacturer of this fluid - Monsanto Chemical Company, calling its product Aroclor. Westinghouse uses the tradename Inerteen and General Electric uses the name Pyranol. Throughout the transformer and capacitor industries it is generically known as an Askarel fluid. Whatever the name, this family of insulants is characterized by stability - high flash points and even higher combustion temperatures essential to safe operation.

PCB's, Aroclors, are essential as dielectric fluids for capacitors and transformers. They have been used for about forty years. They possess a unique combination of physical and chemical properties which allow these devices to operate at high voltages and high power levels, for long periods of time, under extremely varying conditions, and with reliability and safety.

A brief description of the Aroclors is warranted to explain their usefulness as an electrical insulator. An Aroclor consists of a mixture of variously chlorinated biphenyls, according to the formula:



x + y = 1, 2, 3, 4, 5, or 6
(some 7, 8, 9, 10)

with isomers of each chlorination level. All the bonds in these molecules are covalent. They are particularly strong, being aromatic carbon-carbon, carbon-hydrogen, and carbon-chlorine bonds. Table 1 lists some of the compositions of liquid chlorinated biphenyls.

Table 1

Composition of Different Liquid Chlorinated Biphenyls

Components - given as % -	Monsanto Aroclors							
	1221	1232	MCS 1043	1242	MCS 1016	1248	1254	1260
Chlorine	21	32	32	42	42	48	54	60
Biphenyl	14.8		.04	.02	.02			
Mono-chlorobiphenyl	56.5		22.2	.72	.93			
Di-chlorobiphenyl	26.9	~55	74.4	15.6	19.4			
Tri-chlorobiphenyl	1.42		3.3	54.5	64.5			
Tetra-chlorobiphenyl	.05			22.5	15.0	~55		
Penta-chlorobiphenyl				6.7*	.16*		60	
Hexa-chlorobiphenyl								70

*Includes higher than penta-chlorinated isomers.

Because of their bond covalency and strengths, Aroclors have a high degree of thermal stability and chemical inertness, and they do not undergo ionic dissociation. These properties give to Aroclors, with respect to their use in electrical power devices:

(1) high voltage capability
(2) good insulating quality (very low electrical conductivity)
(3) high thermal stability, and
(4) compatibility with various solid dielectric and metallic components of capacitors and transformers.

The chlorine atoms of Aroclors are specifically beneficial in three ways, because they give:

(5) a relatively high dielectric constant, ϵ'_r = 4.0-5.8 which is particularly useful for capacitors.
(6) good corona properties (since most of the products of corona discharge are chlorinated and are readily absorbed by the dielectric, or reacted with relatively little inert gas that remains as bubbles and sustains corona - so they may be subjected to sporadic overvoltages.
(7) the property non-flammability, which occurs at 42% chlorination and above (Aroclor 1242 or MCS 1016, average x + y = 3); thereby the devices with which they are used will not support combustion. (won't support combustion by itself)

Aroclors to 62% chlorination are liquids because of their mixed molecular composition, the isolated individual isomers being crystalline with relatively high melting points. This effect, to prevent crystallization (an effect which would cause loss of electric strength), extends to low temperatures, where they go gradually into a glassy state. Therefore, they

(8) are effective over a broad temperature range, from as low as -60° C to 150° C. (where their vapor pressures are still relatively low).

No other insulating fluid is known that equals the Aroclors, with respect to all these eight properties. It is especially

difficult, or impossible, to find another fluid that is non-flammable, having even just adequate thermal and electrical characteristics for power capacitors and transformers. A replacement for Aroclor is almost bound to present a fire hazard as can be seen from Table 2 (Underwriter Laboratory Flammability Rating) and Table 3 (Alternative Insulating Fluids).

Table 2

Underwriter Laboratory Flammability Rating

Fluid	Flammability Rating
Ether	100
Gasoline	90-100
Ethyl Alcohol	60- 70
Kerosene (100° F.P.)	30- 40
Paraffin Oil	10- 20
Aroclor 1242 and 1016	2- 3

As for capacitors, the most practical substitute for PCB presently known is mineral oil. Use of mineral oil impregnated kraft paper capacitors was pioneered by Westinghouse from 1924-1932.

Introduction of PCBs in capacitors in 1934 resulted in drastic reduction in fire and explosion hazards and greatly increased safety to operating and maintenance personnel as well as the public. Size and cost were reduced commensurately. Further advancement resulted from the introduction of polypropylene film-paper-PCB capacitors in 1967.

Reverting to an oil-paper dielectric system would increase the average capacitor volume (size) by approximately 600%, the weight by 500% and the cost by approximately 400%. At the present levels of demand for capacitor kvac, there would be a shortage of electrical grade papers and a shortage of capacitor factory facilities further tending to increase the cost to the utility, and ultimately to the consumer.

Table 3

Alternate Insulating Fluids

Some Significant Properties of Certain Candidate Insulating Fluids to Replace Aroclor 1242

Fluid	Dielectric Constant, ϵ'_r, at 100° C	Cleveland Open Cup Flammability Flash Point - °C - Fire Point		Density	Cost, ¢/lb
Aroclor 1242	5.5	194	333	1.38	18
Aroclor PCB 1016	4.9	191	319	1.36	19
Aroclor PCB 1043 (lower chlorinated diphenyl)	4.8	160	244	1.28	22
Wemco C Oil (Mineral Oil	2.1	145	150	.9	3

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Use of oil impregnated paper for capacitors has been largely abandoned throughout the world, in favor of one or the other of the PCB systems. The only significant manufacturer in the world is Japan. Even during the recent most unfavorable balance of trade with Japan, this product was never considered for export to the U.S. because of its cost (200-400% more) and because of the flammable rating of the impregnant.

ADVERSE EFFECTS OF POLYCHLORINATED BIPHENYLS

Chlorinated biphenyls, PCBs, during the past two years have been included among possible polluters of the ecology, in association with DDT's. This has raised the question about their continued use in the electrical industry, where they have been serving as insulating fluids for capacitors and transformers for almost forty years.

Chlorinated biphenyls were first identified in the environment along with DDT's and the controls on the levels set by the FDA are "Action Levels", which are the same as for DDT. They are not levels for which PCBs have shown to be harmful to mammals. See Table 4 for "Action Levels".

Table 4

Generally Permitted "Action" Levels of PCBs (same as those issued for DDT)

Medium	Parts per Million PCB Permitted
Water	.5
Butter fat	5.0
Milk	.2*
Fish	5.0
Eggs	.5

*for 4% butter fat.

Tests by Monsanto and others of chlorinated biphenyls, PCBs, in the environment have shown a concentration of higher chlorinated compounds and a reduced or no presence of compounds with three chlorines or less.

Chlorinated biphenyls are considered about 1/10 as toxic as DDT for mammals. White rats fed up to 100 ppm of PCBs in their food steadily over a period of 24 months were healthy (See Table 5 for accumulative level). Dogs fed up to 100 ppm of the PCBs over 24 months showed a slowed weight gain with the higher chlorinated compounds, but not with

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the Aroclor 1242 (See Table 6 for accumulative level). There were no deaths. The higher chlorinated compounds accumulated in their fatty tissue to an equilibrium level.

Chlorinated biphenyls are reported to affect the egg shell and hatchability of some birds. Other breeds of birds have not shown any effects. Birds are more susceptible to the lower chlorinated compounds, di and tri chlorinated. Three ppm of PCB in chicken feed affects the hatchability of Leghorn chickens, but not some other breeds of chicken.

One incident of ingestion of PCBs by humans has been reported from Japan. In this case, a rice oil with 2000 ppm of PCBs was consumed by 1000 people. Severe cases of chloracne, nausea, headaches, and weakness were experienced. Some babies of these people were born with brown pigmented skin, but the pigmentation later disappeared. There were no deaths. It is suspected that the PCB involved contained a chlorinated dibenzofurane, a toxic impurity found in some European chlorinated diphenyls.

Artificially controlled studies of biodegradation using a semi-continuous activated sludge test, SCAS, and also single bacteria culture tests have shown that the lower chlorinated compounds are biodegraded, but the rate of biodegradation decreases as the percent chlorination increases, and is very low for pentachloro compounds and higher (See Table 7 for results of these tests). Monsanto scientists state that they do not know the correlation of these artificial biodegradation tests to environmental conditions.

Chlorinated biphenyls appear to diffuse very slowly through soil.

Monsanto feels that their new grade of chlorinated biphenyl, MCS 1016, is biodegradable, since it contains only 0.16% of penta and higher chlorinated biphenyls. They recommend its use over 1242, which contains 6.7% penta-chlorobiphenyl, for capacitors or wherever the waste material is not strictly controlled.

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TABLE 5

"Storage" of Chlorinated Biphenyls in Albino Rats, After 24 Months' Exposure in Feed

Note: Concentration in lipid became approximately constant at about 6-12 months; except for Aroclor 1254 and 1260 exposures at higher concentrations, noted by *, where it tended to increase continuously with time, and the liver to brain weight ratio increased.

Aroclor - in Feed at	Concentration in Lipid, ppm. 1	10	100	ppm in feed
1242	10	70	200	
1254	50	200	1,500*	
1260	?	?	5,000-10,000*	

TABLE 6

"Storage" of Chlorinated Biphenyls in Dogs, After 2 Months' Exposure in Feed

Aroclor - in Feed at	Concentration in Lipid, ppm. 1	10	100	ppm in feed
1242	3	5	6	
1254	6	18	109*	
1260	13	86*	579*	

* reduced weight gain, increase in liver to brain weight ratio

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Table 7

Biodegradability of Different Chlorinated Biphenyls

- Semi Continuous Activated Sludge Test, 2 x 10^8 cells/cc - (observations after preconditioning sludge to Aroclor tested)

Aroclor	% Chlorine	% Disappearance in 48 hrs
Mono-chlorobiphenyl	18.5	100
1221	21	88
MCS 1043	30	55
MCS 1016	41	35*
1242	42	25
Distillate of MCS 1016	51	15
1254		15
DDT		<10
Linear Alkyl Sulfonate-Standard		100

* Noted concentrating of 4-, 5-, and 6- chlorinated isomers

- Single Cultures, C-2 and C-3, with specific isomers (Europe) - Both cultures have approximately the same effect.

Chlorinated Biphenyl	Time for 50% Disappearance
di and tri	~20 days
tetra	~30 days

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Where are we today?

In the past twelve years 611 million pounds of Aroclors have been used by U.S. industry in their products (See Table 8 for details). 231 million pounds have been used in products that may be classified as open systems, i.e. paint formulations, plasticizers, hydraulic fluids, and semi-closed systems such as heat exchangers. During this same period of time the electrical industry used 380 million pounds of the Aroclors in closed systems which are essentially capacitors and transformers. In the electrical industry the Aroclors are confined to equipment where the containers are sealed and the system is considered to have a "closed" cycle.

An estimate of the total Aroclor used in the U.S. in closed system electrical usage since 1934 is about 690 million pounds. The closed systems can be broken into two categories estimated at 440 million pounds for capacitors and 250 million pounds for transformers. Most of this 690 million pounds is still in use in closed systems today. Some of this amount has escaped into the environment, and this will be analyzed a little later, but the major impact on the environment has been through open system usage, or semi-closed system usage (heat exchangers).

The ratio of usage in open systems to usage in closed systems over the past twelve years was 61%. Using a conservative ratio of 30% for the earlier years, 1934-1950, would add approximately 53 million pounds in open systems prior to 1950 or a total to date in open systems of 324 million pounds maximum compared to 690 million pounds in closed electrical systems.

Calculations show that the amount of Aroclor that has possibly escaped from the closed electrical systems is small. Based upon worst case failure modes and failure rates a maximum of .025% or 110,000 lbs. from

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capacitor failures and a maximum of .040% or 101,250 lbs. from transformer failures could have been introduced into the environment since 1934. This amount when compared to total introduced by open systems is very small $\frac{211,250}{324,000,000}$ or 0.06%.

Looking at the most recent electrical usage figures (Reference Table 7) and projecting ahead, the maximum amount of leakage that could be expected from continuing use of Aroclors in closed electrical systems would be 0.02% or 9,000 lbs. per year assuming no increase in precautions, handling, procedures, etc. This amount when compared to what is already in the environment is very small $\frac{9,000}{324,211,250}$ or .003%.

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Table 8

Monsanto Production and Sales of Aroclors for 1960-1971, with Breakdown Showing Electrical Usage (from CNI News, December 6, 1971)

Figures in short tons	U.S. Production	Domestic Sales: Insulating Liquids[a]	Domestic Sales: Others[b]	Exports
1960	20,786	12,444	5,163	1827
1961	20,333	11,108	7,661	2076
1962	20,986	11,683	7,339	1809
1963	22,367	11,448	7,618	1824
1964	25,417	13,769	8,666	2048
1965	30,240	16,203	9,695	2117
1966	32,925	18,897	10,642	3426
1967	37,655	20,387	10,846	4062
1968	41,427	20,568	11,990	5312
1969	38,194	18,564	15,034	5312
1970	42,527	20,268	16,263	6826
1971[c]	20,236	14,417	4,401	4938

[a] For closed electrical systems - transformers and capacitors.

[b] Includes heat-transfer systems, hydraulics/lubricants, and plasticizers.

[c] Estimated.

Source: Monsanto

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Existing Controls

Monsanto has already taken the following actions:

(a) Stopped sales to "open" users (paint formulators, plasticizers, hydraulic fluid manufacturers, etc.)

(b) Stopped sales for use in heat exchangers - particularly food processors.

(c) Alerted all recipient manufacturers to exercise care in use of fluids.

(d) Provided for waste fluids incineration.

(e) Modified capacitor fluids, eliminating the more highly chlorinated and environmentally more objectionable fractions.

All of these actions have greatly improved the control of PCBs to prevent future environmental damage by eliminating future open system usage which has provided over 99% of PCBs introduced into the environment.

The electrical industry is aware and has been alerted to the environmentally hazardous nature of PCBs. The industry in general exercises high standards of control as it incorporates the fluid into its capacitors and transformers. Safe Practice Procedures for use and handling of PCBs have been in use for many years. The recent (1966) knowledge of PCBs being possible environmental hazards has resulted in warnings and special instructions to customers and handling personnel about the hazardous nature of PCBs. In addition, when sealed systems containing PCB must be opened and drained for repairs, the instructions call for collection of all waste liquid PCB and contaminated materials for special destructive incineration.

Recommendations

Although the electrical industry has recognized and is implementing control systems to decrease the amount of PCBs entering the environment from its handling and use, it supports federal legislation designed to protect the environment. The industry is working with ANSI and other standard organizations to prepare high standards for the use, handling, and disposal of PCBs, however, it is vitally concerned that PCBs not be pre-emptorily banned from manufacture and use in closed electrical systems, since it is felt that the public can be adequately protected without such action, and there are other hazards, particularly fire, associated with known substitute material.

ANSI C-107 committee on the use and disposal of PCBs in electrical equipment is working on a plan to control PCBs. The development of this plan in conjunction with Federal legislation and regulation of the manufacture, use, and disposal of PCBs should bring the PCB situation to a point where regulated electrical industry usage can represent no more threat to the environment than that for numerous other necessary and beneficial materials likewise requiring precautions in use, distribution, and disposal.

E.R. Boquist
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