20 November 1975

Session V:

ECONOMICS AND SUBSTITUTES

Warren Muir, Ph.D.*
Session Chairman

*Senior Staff Member for Environmental Health, Council on Environmental Quality, Washington, D.C.

MONS 070030

INTRODUCTORY REMARKS

Warren Muir, Ph.D.

I guess we have all had an opportunity to hear about health and ecological impact and other aspects of PCB's in the last day and a half. The history of PCB's, as I am sure most of you are aware, is several years old. By 1971 and 1972 there was sufficient concern over their potential environmental effects that a Federal task force was created under the sponsorship of the Council on Environmental Quality and the Federal Council for Science and Technology, which looked into the situation and made a variety of recommendations.

In addition, at that time the Monsanto Chemical Company developed a restricted sales policy with regard to uses of PCB's, and also shortly thereafter, the Organization for Economic Cooperation and Development had an international agreement with regard to uses of PCB.

All of these actions were directed in one fashion or another toward inappropriate uses of the chemical. Yet, as of this date, there is no Federal authority to control the use of these chemicals, despite 5 years of consideration of toxic substances control legislation.

This particular session of the conference deals with economics and substitutes; we will have a presentation or a brief description of two economic case studies that have been done on PCB's, and then several speakers will discuss the substitutability or nonsubstitutability for uses of PCB's.

In dealing with environmental problems such as PCB's and a variety of other chemicals, I am sure you are aware that there is a great deal of scientific uncertainty with regard to particular health or ecological impacts. For example, there is a certain amount of uncertainty as to whether or not something is carcinogenic or whether it can bioaccumulate.

There typically appears to be, however, a much greater uncertainty about the economic implications or the economic impacts of any action that might be taken to mitigate the suspected problems. Much of this arises from uncertainty, about substitutes and also about the inability to predict the actual individual or corporate responses that would be made under a given type of regulatory action or other type of mitigating action. Thus in my view, there is much greater economic uncertainty in many of these issues than there is scientific uncertainty.

Also, irrespective of all the uncertainties, we know that the further along in the chemical marketing and development process, the longer it has been manufactured, and the larger the market, generally the greater the health and environmental effects of the particular chemicals and the greater the economic impact there is of mitigating action, to the extent that they are necessary.

Thus, if we are to deal with problems such as PCB's, we must change our approach toward environmental chemical problems; we must get out of a reactive posture. We must undertake the task of identifying potential hazardous chemicals early in the development process. By so doing, health and ecological problems can be avoided before they develop. And, by so doing, the economic dislocation and impacts from any potential regulatory action will be eliminated or minimized to the benefit of all.

MONS 070031

PCB's IN CAPACITOR APPLICATIONS

Richard L. Rollins*

Abstract

Alternating current (AC) capacitors have used a grade of polychlorinated biphenyls (PCB's) since the 1930's. Long life, high reliability and a high degree of flame retardancy are imparted to the capacitors by these fluids.

The latter characteristic is very important in applications where high exposure to the general population exists such as in fluorescent lights and television sets. The main disadvantage with the fluid is its long persistence in nature. When the capacitor industry became aware of the environmental problem, it generated guidelines for handling and disposal of the material, then voluntarily imposed these restrictions upon itself. Now of the 70,000 pounds per day processed, only 7 pounds are being discharged into plant water effluents. Liquid waste materials are sent to proper incineration facilities and solid waste materials are placed in sanitary landfills to prevent escape into the environment. For 4 years the industry has been using a significantly more biodegradable grade of Aroclor identified as 1016 by Monsanto. In that time, Aroclor 1016 has not been identified as a PCB commonly found in the environment. Non-PCB materials are continuing to be evaluated, but there are not dielectric fluids available today which can be considered an acceptable substitute for PCB's in the broad range of AC capacitors.

On behalf of the electronic industrial association and the manufacturers of PCB capacitors, I appreciate this opportunity to present our point of view. I will discuss PCB capacitors, the industry's response to the environmental problem, and possible alternative candidates to PCB's.

Manufacturers of AC capacitors have used PCB's since the early 1930's, and have used them almost exclusively since World War II. They are presently used, for example, in capacitors for fluorescent lighting, air conditioners, and television sets. These capacitors are in the plant where you work, in the home, and in public gathering facilities. They are therefore near you a high percentage of the time. Manufacturers are very cognizant of their responsiblities in providing a capacitor that will operate satisfactorily in these applications for providing long life and high reliability at a reasonable cost.

*Vice President for Engineering, Jard Corporation, Bennington, Vermont.

The consequence of these requirements in a competitive marketplace is that the products and their components are constantly being reevaluated to increase life, increase reliability, decrease size, and decrease cost. The capacitor manufacturer indeed daily sees pressures for improvements. It is, therefore, an obvious question to ask why are PCB's still used after 40 years during which the best capacitor research and development scientists in the United States were constantly seeking substitutes.

One of the reasons lies in the nonflammability of the PCB material. Because of applications, such as lighting, where personnel and equipment safety are paramount, capacitors must be manufactured since they not only fail infrequently but also fail safely. In applications such as the World Trade Center in New York, where 250,000 fluorescent lights are installed, it is obvious that high reliability and a nonflammable capacitor characteristic are mandatory.

A capacitor which fails violently and contains a flammable fluid could create a serious problem, especially in densely populated buildings, giving visions of a towering inferno. The Consumer Products Safety Commission, as an example, has shown considerable concern over television set fires and has requested Underwriters' Laboratories to develop standards for safety for television set receivers.

A second reason lies in the reliability of the product as it is known today. Presently, the capacitors our companies manufacture have a survival rate per year greater than 99.9888 percent. The requirement that more than 95 percent of our capacitors must survive after 13 years of normal application conditions must also be met.

The test time and the amount of test necessary to guarantee the above reliability is mind boggling to say the least. Many thousands of units and millions of unit hours at or referred to application conditions are required to satisfy our statisticians that any change in product will conform to these present day standards.

Even with the large amount of previous testing and history on the PCB-containing capacitor, there have been many instances which despite all controls in existence cause consumer concern due to extreme failure rates. That is at a rate greater than 10 percent.

The first occurred in 1957, when a variation in the quality of the PCB fluid, as synthesized, resulted in a highly unstable capacitor. Standard analytical tests in use at the time did not detect the quality difference. The result was a large number of capacitors failing in a very short period of application life.

MONS 070032

The consequence was the requirement by the customer that the capacitor manufacturer not only provide compensation for the cost of the capacitor, but the cost of the equipment which contained the capacitor, plus the labor charge for placing the equipment in the installation. The total replacement cost the manufacturer 100 times the original price of the capacitor.

The second instance of numerous failures occurred 6 years later, this time involving the capacitors of most manufacturers. In this circumstance reduced-size capacitors were tested and approved by industry-accepted accelerated life testing and a new size was shipped to customers.

Approximately 1 year later, up to 15 percent of these capacitors began failing in some applications. A subsequent modification in the accelerated-life testing based upon findings in the field failure analyses now provides proper screening to eliminate the chance of such a problem occurring. Therefore the AC capacitor industry now does very extensive evaluations before releasing new designs or using new materials.

The capacitor industry became aware that PCB's were possible environmental problems in 1970. Soon thereafter, in 1971, a committee was formed under the sponsorship of the American National Standards Institute, ANSI, to develop standard industry guidelines for the handling and disposal of capacitor grade PCB's. An interim standard was published as an official standard proposal by the National Electric Manufacturers Association, NEMA, in January 1973. And a final document, C107.1 1974, was published in January 1974.

Briefly, properly planned housekeeping, considerations for employee safety, and scrap disposal procedures were detailed. Today, to the best of my knowledge, all manufacturers of PCB capacitors in the United States have applied these guidelines for the handling and disposal of PCB's.

The success of the manufacturer's control in handling practices is apparent from the fact that of the approximately 70,000 pounds per day used, less than .01 percent or 7 pounds per day is discharged into the water effluents of the plants. The ANSI guidelines also recommended that the capacitor companies change from Aroclor 1242 to a PCB with less toxic effects which Monsanto identified as Aroclor 1016.

Here it must be pointed out that various grades of PCB's cannot, as so often is assumed, be classified as having the same chemical, physical, or biological characteristics. For instance, in "A Comparative Study of Two Chlorinated Biphenyl Mixtures . . .," by Goldstein et al., significant differences were shown to exist in the biological effects of Aroclor 1242 and 1016 on equal doses of the two mixtures. Aroclor 1016 also reduces by greater than 94 percent those higher homologs existing in Aroclor 1242 which were the most persistent in nature. With these benefits, and without sacrificing the capacitor characteristics, all capacitor manufacturers began using the new material by 1972, despite the fact that it was 50 percent more expensive.

After 4 years of use by the capacitor industries, Aroclor 1016 has not been identified as a PCB that is commonly found in the environment. Nor should it be suspected that 1016 would be commonly found, because the industry is exercising control over waste disposal from its capacitors, so that there is little or no opportunity for leaking PCB's.

Our industry believes it is much more important to reduce the environmental problems and to allow continued use of the capacitor-grade PCB than to be concerned with the material cost increase and immediately turn to a substitute which is not thoroughly evaluated and may be flammable.

Alternates have been considered ever since the original introduction of PCB's. The substitutes must be not only a satisfactory dielectric fluid providing acceptable life, reliability, and safety, but in addition must not cause environmental problems. Our experience with PCB's has demonstrated that some material will escape into the environment through processing and handling. Therefore, alternate fluids must be evaluated on this basis. The effects on man and his environment must be determined before the product is introduced. It would be a very serious error to replace capacitor-grade PCB's with a fluid which eventually becomes a greater threat to man.

Further PCB modification which would provide even less toxicity and persistence in nature but still maintain good dielectric properties and good nonflammability would seem to be one alternative to Aroclor 1016. Our companies respectfully urge Monsanto to pursue this possibility.

Non-PCB alternatives are now being offered and suggested. Some are new and some have been available for many years. The industry's position on these is as follows.

Mineral oil is a flammable fluid which was replaced by PCB's in the 1930's. Capacitors using it are 50 to 100 percent larger, much less reliable, and much less safe than those using PCB's. The substitution of mineral oil necessitates redesign of equipment to utilize the larger capacitor, an increase in the capacitor manufacture facility, and will result in increased use of basic materials which are presently in short supply.

Modified synthetic hydrocarbon oils have been developed which while flammable would allow capacitors to approximate today's size. Samples have been dis-

MONS 070033

tributed for testing, but the material is not commercially available.

Phthalate ester, also a flammable fluid and also with biodegradability problems, has been used in certain restricted applications where conditions of limited temperatures exist. The unknown factors of reliability and safety in the broad consumer use areas such as lighting now prevent its use. Evaluations, however, are continuing.

Substituted aromatic compounds are possible candidates, and one has been proposed that has less fire resistance than PCB's; it is suggested to be a good dielectric fluid but only for high-voltage power factor correction. This, to our estimation, represents only 17 percent of the PCB used in closed systems, and leaves completely unanswered an alternative or alternatives for the remaining 83 percent of the applications. Some material has been produced but the fluid has not been made commercially available. In fact, our companies are having trouble obtaining samples from the manufacturer. When samples become available, the time-consuming testing can begin. It has been estimated that 3 years are required before final commercial use after initial testing of a change in capacitor fluids.

Also proposed for limited applications is the use of a plastic film replacing the kraft paper dielectric in the AC capacitor. Although evaluations with the highest quality film have been underway for more than 2 years using the current processing techniques, the reliability of the product is only 1/20th of that of present capacitors in most applications. Significant additional testing is required to determine if the cause of poor reliability is totally inherent or if improvements can be made by modifications in capacitor design.

In summary, there are no commercially available fluids which today can be considered a totally acceptable substitute for PCB's in the broad range of AC capacitors, nor are there substitute dielectric systems which would satisfy the requirements of reliability and safety in most applications.

I would like to reiterate that our companies have shown responsiveness to the environmental problems of PCB's by the following actions.

1. Working as a group with government and consumers in providing guidelines for proper handling and disposal of capacitor- and transformer-grade PCB's.
2. Reducing discharge levels of PCB's in a 16-capacitor plant. Further reductions are now being planned.
3. Converting to a more expensive grade of PCB's which is less persistent and has less toxic effects.

Finally significant differences do exist between Aroclor 1016, which capacitor manufacturers are now using, and material which is predominantly being found in the environment. Our industry believes that all concerned should be aware of the differences.

We respectfully urge this awareness in environmental studies and in drafting of regulations.

MONS 070034

THE ECONOMIC IMPACT OF A BAN ON POLYCHLORINATED BIPHENYLS

Duncan MacArthur* and Stephen F. Nagyt

Abstract

The study described below assessed the effects of a hypothetical total ban on PCB's. In order to compile a realistic scenario, the proposed Toxic Substances Control Act was used as a model. A complete phaseout was estimated to take 76 months, and would involve publication of rules, testing, hearings, halting of imports and manufacturing of PCB's, and depletion of stocks of PCB-containing products.

Mineral oil was assumed to be the primary substitute for PCB's, since a major technological breakthrough in the development of alternate fluids is unlikely in the near future.

Minimum estimates are given for the one-time and annual capital expenditures by industry of a ban on PCB's, and for the primary and secondary impact costs. Intangible issues, such as the effect of a PCB ban on public safety, are also discussed.

In the course of our work with private and public clients, we have examined polychlorinated biphenyls, PCB's, in a number of areas, ranging from product design to economic impact. The work to be discussed here was completed in 1975 as part of a study to examine the effects of the proposed Toxic Substances Controls Act, as illustrated by Senate Bill S776 (20 Feb. 75).

We selected as an example a case study to completely ban an existing product following the procedures outlined in the proposed bill. We use the case study for following reasons. It provides an example of the complete analysis required to assess the impact of a ban; it illustrates the direct and secondary impact on industry; and it enables us to estimate the economic consequences of a ban on one specific product. In our study, we also highlighted the unquantifiable factors.

In our methodology, and again this was done in the early part of the year, we assume all the steps in the proposed Toxic Substance Control Act as illustrated by Senate Bill S776 are taken. The end result of this is a total ban on PCB manufacture and use. We selected PCB's for illustrative purposes only. Our discussion was not intended to reflect on the actual health or environmental aspects of the example product.

*Associate Research Director, Foster D. Snell, Inc., Division of Booz, Allen, & Hamilton, Inc., New York, New York.

†Research Director, Foster D. Snell, Inc., Division of Booz, Allen, & Hamilton, Inc., New York, New York.

The scenario for banning the product is estimated to require about 76 months for complete phaseout of product use. Thirty-eight months were estimated for publications of the rules, testing, hearings, and so forth. The key element in this period is the 24-month period that we estimated would be required for testing. The key element in months 39 through 76 is phasing out the sale of some manufactured goods, particularly appliances. We also assumed that no legal action would be taken by industry until publication of the final ban on substances occurring after the 38 months of testing and hearings.

A possibility in the scenario of the second 38 months is that industry requests a judicial review but complies with the review. We estimated the judicial review takes 2 years and results in a complete product ban. In the second 38-month period the following types of activity would go on: documentation for control purposes; monitoring of shipments; limitation of stockpiling of PCB products; refining methods to prevent PCB's from entering the environment, such as controlled use and control proposal; stopping the production and import of PCB's or equipment containing PCB's, and finally banning the manufacture and sale of PCB-containing products.

In the analysis of our PCB's we have tried to consider the complete life cycle of the product. PCB's are produced by one manufacturer in the United States—the trade name is Aroclor—and about 40.5 million pounds were produced in 1974. The sale of PCB's is currently restricted to electrical use and casting waxes. In the past they were used as transfer fluids from heat exchangers, hydraulic fluids, and so forth. However, as you know, to avoid potential adverse environmental impact, Monsanto restricted domestic and export sales in 1972 to electric installation equipment applications in which the product is enclosed in a relatively well-maintained container throughout its use. Monsanto and others offer PCB disposal service.

We found that PCB applications are characterized by their long-term utilization with the majority controlled by utilities. Transformers, for example, were reported to last 20 to 30 years, and capacitors to last 7 to 10 years.

The number of transformer manufacturers vary; anywhere from 2 to 10 have produced PCB-containing transformers. Primary use is as nonflammable electric insulating oil. Previous estimates report approximately 5,000 transformers were produced per year with an aver-

MONS 070035

age PCB amount of about 5,000 pounds per transformer. Value of shipments (1974 data) is estimated at $35 to $45 million.

The number of people using capacitors varies. Estimates range from 16 up to 50 capacitor manufacturers. There are approximately 90 to 100 million units per year produced with a value about $105 to $147 million. There are primarily two types: large utility capacitors, using about 9 to 13 million pounds of PCB's per year, and small industrial capacitors, using about 17 million pounds per year.

In the case of casting wax, there is only one manufacturer in the United States. RCB's represent 30 percent of the components of the wax. The annual usage is about half a million pounds. Primarily, it is imported. We also found another indirect importation of PCB's—in capacitors in electrical equipment.

The primary transformer users are utilities; others include manufacturers of and users of electrically powered rail equipment, furnace equipment, and electrostatic precipitators. About 85 percent of PCB transformers are used as network transformers by the utilities, and we estimate that approximately 90 percent of the transformer uses are controlled by the utilities, either through ownership or service contracts.

With respect to the capacitor users, electric utilities use large capacitors and manufacturers and consumers of goods use small capacitors. Electric utilities use them primarily for power factor correction, and smaller units are used for starting and other uses such as fluorescent lighting. We estimate that about 2 to 3 percent of large capacitors are consumed as replacements and about 5 to 10 percent of the small capacitors were consumed as replacements.

With respect to the casting wax, approximately 98 percent of that is now recycled and the people in the business maintain that the remaining 2 percent that is left in the mold is destroyed when the mold is prepared at high temperatures.

The final step is disposal. Monsanto and others have specialized incincerator facilities for PCB liquids, primarily for large uses such as transformers and capacitors used by utilities.

The ban of PCB's was estimated to result in a one-time cost of $13.7 million. There would be additional expenditures of $110 million annually. The ban would also affect regulatory codes, public safety, and other intangible areas, and, as always, the net result would be an increase in consumer costs.

The primary impact, which is on the manufacturer and users, is estimated at $8.8 billion for one-time costs and approximately $16 million for annual costs. Key elements in this, surprisingly enough, were "red tape" required by Senate Bill S776. There are also disposal costs, plant rebuild costs, and salary costs.

Secondary impact on users of PCB's, PCB-containing products or services, and disposal organizations is estimated at $4.9 billion for one-time costs and $93 billion for annual costs. Elements of secondary impacts are primarily new plant rebuilds for increasing the capacitor output of the United States, disposal, and the increased cost of substitutes.

The annual costs reflect the forecasted increased costs of electrical equipment manufacture and use, including replacements of existing equipment. Since the lifetime of large transformers and capacitors is 20 to 30 years, the additional annual cost, over $110 million, was forecast for the same period.

In the proposed 38-month time period, industry representatives indicated that for primary and secondary transformer use, there would essentially be a shift to mineral oil as a replacement for PCB's, since the environment and performance characteristics of other substitutes are not thoroughly researched. Major technological breakthroughs, such as development of substitute fluids, were not forecast.

We did use minimum cost estimates. The cost of replacing a PCB transformer, for example—not necessarily the transformer but the vault which is surrounded by the building—has been estimated as varying anywhere from $5,000 to $50,000. We used a figure of about $10,000, which we consider low and very conservative.

The economic impact of changing the regulatory codes cannot be accurately quantified without a detailed survey. However, the impact of the changeover for those localities with regulations was estimated not to cause major dislocation in building activities. We do know that many cities permit only nonflammable, essentially PCB, electrical equipment to be installed in tall buildings; however, others do permit non-PCB transformers with a vault.

intangible issues include public safety, which would be impacted by a ban on PCB's. Analysis would require a detailed analysis of the tradeoffs between the benefits of the product versus the benefits of the ban. Electrically driven trains use PCB transformers and it has been reported that the flammable liquid in the transformer would be a potential hazard. Uses of other transformers in rail cars, if possible, would require redesign and overhaul of existing equipment. Use of large quantities—over 20 gallons of liquid—in buildings would present a potential danger even in walls. Insurance underwriters have reportedly studied the problem but nothing has been presented as a request to change rates.

Other intangible areas are in replacements for all types of equipment. Dry transformers, for example, are

MONS 070036

reported to have a low reliability. There are also specific areas, such as replacement capacitors for compact equipment in which the capacitors cannot be replaced with a non-PCB-containing unit similar in size and characteristics, forcing either salvage or scrappage of the equipment.

In assessing all these costs, we forecasted pass-through to the consumer.

MONS 070037

THE USE OF DOW CORNING® Q2-1090 DIELECTRIC LIQUID IN POWER TRANSFORMERS

Richard H. Montgomery*

Abstract

Dow Corning has developed Q2-1090 Dielectric Liquid to replace askarels in transformers. Five years of laboratory and field testing have shown it to be both efficient and safe. It is now being sold in commercial quantities both for new transformers and for retrofilling old transformers. With some redesign, competitive entries, and further restrictions on PCB use anticipated, it is expected to have favorable economics. A 3- to 5-year phase-in to completely commercially qualify the liquid in all applications is planned.

Thank you for the opportunity to come here today to represent the silicone industry, which in the United States consists of the Dow Corning Corporation, the General Electric Corporation, Union Carbide, and Stauffer Chemical. The global silicone industry is now 5 years into a program to qualify dielectric fluid replacements in both transformers and capacitors. The Japanese silicone industry and Dow Corning Corporation have led this effort to date. As a result of this extremely large effort by the industry, I am very pleased today to make two major announcements.

First, the technology to commercially manufacture a capacitor dielectric fluid with superior dielectric properties is being developed. This material appears to withstand any of the high electrical stresses the material would normally be used for in the industry. We plan to make this product commercially available during 1976. At its present state of development, we know of no environmental problems with this particular product. No chemistry would indicate there should be any. But this will be continually studied, as have other products from the silicone industry.

Second, Dow Corning now has commercial production available to manufacture silicone transformer liquids in sufficient capacity to handle the global transformer market, and that is a very large investment. So let me now turn in some detail to the transformer industry and the role silicones can play.

We must remember that today three environmentally safe transformer systems are available to replace transformers filled with PCB liquids. Gas-cooled, air-cooled dry types, and liquid-silicone-filled transformers will meet almost every need where PCB-containing transformer fluids are used.

The silicone industry has produced insulating materials for transformers for 25 years. The industry's newest material, a silicone transformer liquid, is now in use in Japan as a direct replacement for PCB-containing transformer oils. In the United States, extensive field testing has been under way for 4 years and at the present time this material is being examined for inclusion in the U.S. National Electrical Code.

Now, to underscore Dow Corning's personal assurance in the safety, the efficacy, and the efficiency of this liquid, Dow Corning has notified its vendors that we will be specifying silicone-filled transformers for all the new transformers in our production plants around the world. Our existing askarel transformers, in which we have a very heavy investment, are being phased out rapidly through a silicone retrofit program. Over 6 transformers have been installed new or retrofitted in the past year, and this program will accelerate in the spring. It is, of course, not possible in Michigan during the winter months to drain the PCB's satisfactorily and replace these materials with a silicone fluid.

The material that we are talking about is known today as Q2-1090 dielectric liquid. Basically, Q2-1090 transformer liquid is a dimethyl silicone that has been specially formulated and qualified for use in electrical applications. The technical feasibility of using the silicone in transformers has been shown in over 20 years of experience in military transformers, in several years of use on the Japanese National Railway, and in a number of power transformers in the Midland, Michigan, area; several other areas around the United States will also test silicone transformers in the next few months.

In addition to these actual applications, which today are well known and have worked out nicely, support for the use of a silicone dielectric fluid in power transformers is contained in over 30 years of accumulated data on dielectric properties and compatibility with the common materials of transformer construction.

The present concern for fire, explosion, health, and environmental hazards are all strong reasons for an evolutionary approach to using silicones and qualifying them in this application for all major power transformer uses over the next few years.

The silicone liquids of this type are much less

*New Product Market Manager, Fluids and Lubricants Marketing, Dow Corning Corporation, Midland, Michigan.

MONS 070038

flammable than typical mineral oils. They actually have a higher flash point than many PCB-containing transformer fluids. Although they will burn, they have an extremely low heat of combustion, extremely high flash points and firepoints, and they have been shown in catastrophic testing to be self-extinguishing. They appear to offer a level of fire safety greatly superior to mineral oils.

The silicone that we are now recommending, a dimethyl silicone, has been evaluated by Underwriters Laboratory, and has received an extremely low flammability classification number. In Japan and the United States, transformer cases containing PCB's, silicones, and mineral oil were subjected to catastrophic failure testing. In both tests, all liquids exploded. Most important, following this test, only the mineral oil continued to burn. Both the polychlorinated biphenyl materials and the silicone fluid self-extinguished. Normally, in a test of this type you would fuse the circuit cutout. The fault in the silicone fluid self-cleared, thereby extinguishing the arc. With the other materials, the backup fuse blew and extinguished the arc.

Following the review of some very extensive data (which is available to all of you by writing to me at Dow Corning, provided you are willing to put in 4 or 5 hours in reading it), the major insurance companies have given their permission to use silicone fluid in indoor transformers. Because it is a new material and since no general policy has been established, the insurers have indicated that they will evaluate each application on an individual basis; this is a conservative approach which we highly applaud.

Dow Corning feels that we should look at a 3- to 5-year evolutionary approach of gradually putting a larger and larger number of transformers into operation. We are offering financial inducements to companies who do this in order to collect a large body of case history data that can be used to convince ourselves and the industry that there are no fatal flaws that have been overlooked. It's an extremely conservative approach.

Silicones are often used in small concentrations in the preparation of certain foods. Any time you eat a jam or jelly or drink a glass of some of that good old Milwaukee beer, you are eating a food-grade dimethyl silicone. And if you have an ulcer and you eat Di-Gel, you are also eating it. They are excellent deflaccuants.

The toxicity of dimethyl silicones to mammals, aquatic life, and plants has been very thoroughly investigated. The extremely low toxicity of silicones has made it difficult to detect any toxic reactions in test subjects. Studies directed toward determining the tendency of silicone to bioconcentrate have been negative. It has not been possible to date to show that any bioaccumulation was occurring.

It has been often stated that silicones are persistent in the environment because they do not biodegrade, under the evidence available at the present time. However, there is considerable evidence that silicones do chemically degrade in the environment. Contact with soil and water causes the liquid to depolymerize to low-molecular-weight species, and known chemistry definitely suggests that these degrade in water or in the atmosphere.

Silicones cost more money than the current liquids being used in transformers, but they are not outrageously expensive. Referring to the entire market of capacitors and transformers, and making some assumptions which would include the shipment of present products such as PCB's to the manufacturer's site, if we include the shipping costs, my estimate is that the industry PCB purchases would be about $19.2 million.

If good engineering practices are followed to reduce the amount of fluid needed, which has never been a design criteria in the major manufacturer's mind, as mineral oil, of course, is cheap, those costs would probably rise with the use of silicone to an industry figure of $25 million.

So the total increased cost to the electrical and electronics market would be about $5.8 million or 29 percent. If we made the assumption that the dielectric fluids cost is 20 percent of the total material cost going into a transformer or capacitor, we are talking about an average cost increase of about 5.8 to 6 percent at the manufacturing level on new equipment.

I feel that this slightly higher initial cost of silicone liquid-filled transformers is more than offset by the cost of monitoring and controlling of PCB-filled transformers over their lifetimes. And with silicone, no known environmental hazards are incurred.

PCB-filled transformers currently in service can be changed over to Q2-1090 transformer liquid without undue problems. I think the work we have done over the past 4 years—some of it in conjunction with Dow Chemical, a lot of it in conjunction with leading transformer manufacturers—shows this.

I think you will be hearing not only from Dow Corning in more detail on this subject. I highly suspect that our worthy competitors, who can manufacture dimethyl silicones to the same specifications once they learn what they are, will go into the market. At that particular time, the law of supply and demand will come into effect. The silicone industry at the present time has *more capacity than it can sell. I anticipate the economics* will be extremely favorable for further consideration of this product in both transformers and capacitors over the next three years.

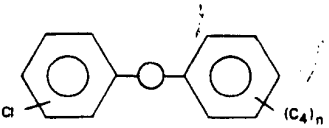
MONS 070039

DOW XFS-4169L: AN ENVIRONMENTALLY ACCEPTABLE CAPACITOR FLUID

Dean Branson, Ph.D.*

Abstract

Dow and McGraw-Edison Companies have developed a new capacitor fluid which is electrically, ecologically, and economically acceptable. Chemically, the new fluid can be described as butylated monochlorodiphenyl oxide.



n = 0, 1, 2, 3

Dow XFS-4169L capacitor fluid

Dow XFS-4169L capacitor fluid performs equal to or better than Aroclor 1016 in power capacitors. This conclusion is based on dielectric losses, discharge inception voltages, capacitor size, fire hazard, reliability, economics, and availability. Dow XFS-4169L capacitor fluid and its components are acceptable in terms of health and environment according to an assessment of biodegradability, bioconcentration in fish, toxicity to animals, and toxicity to fish. Other capacitor manufacturers are currently evaluating XFS-4169L for applicability in their respective companies. Field trails have been started with utility companies across the country.

The contents of this presentation represent 4 years of joint research between Dow and McGraw-Edison Company which has culminated in the development of an environmentally and electrically acceptable capacitor fluid.

When PCB's replaced mineral oils some 40 years ago in power capacitors, this represented another step forward in the electrical industry's continuing effort to provide the public with low-cost electrical power and safer electrical equipment. As a result of the use of PCB's, there has been a downward trend in the cost per kilovar of power factor correction.

In 1971, Monsanto limited the sale of PCB's for dielectric uses where acceptable alternatives were not yet available. Since then, industry has been searching for alternatives which were ecologically, electrically, and economically acceptable.

Today, we want to report to you that Dow and McGraw-Edison have developed a butylated monochlorodiphenyl oxide known as XFS 4169L. It meets all the above criteria and can be used in high-voltage capacitors.

Initially, over 50 fluids representing several chemical families were selected as possible dielectric fluids on the basis of their chemical and physical properties. These fluids were then screened for both electrical performance in miniature capacitors and for potential hazard to the health and the environment in a battery of indicative tests.

The conclusion of these screenings was that the most promising chemical family was the alkylated monochlorodiphenyl oxides.

Electrically, several members of this family performed equal to or better than Aroclor 1016. It was the health and environmental data that demonstrated the significant advantages of the butylated monochlorodiphenyl oxides.

Electrical Performance

The confidence that McGraw-Edison Company has in high-voltage capacitors made with the XFS fluid is based on the following assessment of these six key electrical performances.

1. *Dielectrical losses*. The dielectric losses are as low or slightly lower than for capacitors with a PCB known as Aroclor 1016. This is true for both paper-film and all-film high-voltage power capacitors. This means that the capacitors will operate under normal temperatures and that the operating costs will be minimal. This is one of the same significant advantages that PCB's have relative to mineral oil.
2. *Discharge inception voltages*. Discharge inception voltage is significantly higher than for Aroclor 1016 in both paper-film and all-film capacitors. This means that operating voltages may surge at least 20 to 30 percent higher without resulting in temporary malfunction due to electrical discharges known as corona.
3. *System size*. The size or volume per unit of high-voltage power capacitor correction known as kilovar is

*Capacitor Fluid H.N.E., Project Manager, Health and Environment Research Laboratories, Dow Chemical, Inc., Midland, Michigan.

MONS 070040

the same as for comparative capacitors impregnated with Aroclor 1016. This means that it will not be necessary to redesign capacitors, the capacitor manufacturing, or the application of capacitors.

4. *Fire hazards*. As indicated with PCB's, there is a low risk of explosion and fires from power capacitors impregnated with XFS 4169L. A major problem associated with a failure in a paper-film power capacitor is the decomposition of the paper and to a lesser degree, the film. The resulting pressure of the gases formed is a major cause of tank rupture. After failure, the flammability of the fluid may contribute to a fire only if the paper, the film, and the fluid, are above the ignition or flash temperatures.

Under normal operating conditions, a capacitor will operate between 40° and 80° C. At a time of failure, this temperature will have to exceed the flashpoint of the capacitor fluid before this fluid becomes contributive to the explosiveness or the flammability of the system. In this regard, the flash temperature for the existing dielectric fluids for mineral oil is 154° C; for Aroclor 1016, 186° C; and for XFS 4169L (104)°C. The fire temperature for mineral oil, 167 PCB, is greater than 316° C; for XFL 4169L, it is 199° C. This clearly shows that the flash and fire points are substantially above the operating temperatures.

The National Electric Code allows the installation of the electrical devices without a vault if they contain less than 3 gallons of burnable liquid. The most common size of our capacitor used today is a 200-kilovar unit. These units contain less than 3 gallons of fluid, and are installed predominantly outdoors.

5. *Capacitor reliability*. Power capacitors impregnated with XFS are more reliable than the same type of capacitors impregnated with Aroclor 1016. This conclusion is based on results of comparative evaluations. The following tests have been completed. Three years of accelerated life tests, more than 18 million kilovar hours in full-sized units without failures. Hundreds of sample capacitors operating up to 200 percent of the rated voltages for a wide range of temperatures, minus 60° to plus 125° C.

6. *Economics and availability*. The long-range price of power capacitors impregnated with XFS 4169L will be reasonable. The increased price or expense attributed to the fluid is expected to be less than $20 for a 200-kilovar unit.

Dow has assured the electrical industry that it will have the manufacturing capabilities to produce XFS at a million pounds per year rate during the first quarter of 1976. Should this fluid prove to be acceptable to the industry, Dow is willing to make the commitment to produce the fluid in multimillion pound quantities per year by the end of 1976.

Health and Environmental Assessment

The Dow Chemical Company's assessment of the health and environmental acceptability of XFS 4169L as a dielectric fluid in capacitors is based on the following criteria.

1. *Biodegradability*. The components in XFS 4169L are significantly more biodegradable than the components of Aroclor 1016. With micro-organisms, the rates of formation of radioactive carbon dioxide from radiolabeled components of XFS 4169L are much faster than for 2,5,2' trichloro biphenyl, a major component of Aroclor 1016. The major component in 4169L is 45 times more biodegradable than the representative PCB isomer. This rate of biodegradability is comparable to several nonpersistent industrial chemicals.

2. *Bioconcentration*. The bioconcentration factors in fish of the components of XFS 4169L are low relative to the components of Aroclor 1016. The environmentally significant components in each fluid show a factor 30 times less bioconcentratable in trout muscle for XFS.

3. *Toxicity to animals*. In both acute and 90-day toxicity tests with animals, XFS shows very little toxicity. For example, in rats, a dose of 10 grams per kilogram of XFS 4169L was administered orally and had no observable effect on rats.

The levels of the components of XFS that accumulated in the fat of rats fed the XFS in the diet for 150 days were significantly lower than for the comparable dietary tests with Aroclor 1016. For example, the accumulation in the fat was 22 times less for XFS; the apparent plateau level was achieved in 1 to 2 months compared to 6 to 7 months for the PCB, and the estimated half-life of the rat was 7 days with XFS compared to 60 days for the PCB. This indicates the relatively low degree of toxicity associated with XFS 4169L in animals.

4. *Toxicities to fish*. The XFS material is only moderately toxic to fish compared to capacitor-grade PCB, which is extremely toxic. The concentration of XFS that was toxic to fathead minnows was 15 milligrams per liter compared to 0.76 milligrams per liter of Aroclor 1016, which is a factor of 20 times less toxic to the fathead minnow.

Dow and McGraw-Edison Companies have determined that XFS 4169L is an acceptable alternative to capacitor-grade PCB in high-voltage power capacitors. This is based on the electrical performance and its low potential impact on health and the environment.

Today, McGraw-Edison is proceeding with field trials of capacitors at utility companies across the

MONS 070041

country. Other U.S. manufacturers of power capacitors are currently evaluating XFS for applicability in their respective companies.

The information about XFS in this discussion is only a very brief summary of the toxicological and ecological data which have been generated.

MONS 070042

CHLORINATED BIPHENYL DIELECTRICS— THEIR UTILITY AND POTENTIAL SUBSTITUTES

David Wood*

Abstract

The paper describes the major reasons for the use of chlorinated biphenyl in capacitors and transformers. These lead to establishment of objectives for research into potential substitutes. MCS-1238, a non-PCB capacitor fluid developed by Monsanto, is discussed and areas where further development work is required are indicated. The particular problems associated with definition of "fire resistance" relative to transformer fluids is raised.

I. INTRODUCTION

In 1970, Monsanto voluntarily began its program of terminating sales of chlorinated biphenyls to open applications—those which could result in losses to the environment. By late 1972, this program was fully implemented and Monsanto was selling these products only to manufacturers of sealed electric equipment such as transformers and capacitors.

Major applications affected by our withdrawal were carbonless paper, fire-resistant hydraulic fluids, heat transfer fluids, and plasticizers. Sales for other miscellaneous minor applications were discontinued during the same period. This action resulted in a reduction of some 45 million pounds per year in the use of chlorinated biphenyl in areas where entry to the environment was less controllable.

We decided at that time to continue supply to closed electrical applications because we believed that:

1. Entry of chlorinated biphenyl to the environment was limited and controllable;
2. A more biodegradable, lower chlorinated homolog had been developed which the capacitor industry could use;
3. Withdrawal would have brought to a halt production of equipment essential to the safe and efficient distribution and use of electrical energy because there was no known satisfactory replacement for chlorinated biphenyl dielectrics.

Today we continue to sell chlorinated biphenyl, observing the following policy:

1. We supply only to manufacturers of *sealed* electrical equipment such as capacitors and transformers.
2. We supply lower chlorinated homologs, Aroclor 1016, to the capacitor industry.
3. We offer an incineration service for liquid PCB wastes.
4. We continue to work with ANSI Committee C107 and other bodies to establish appropriate handling and control procedures for equipment containing chlorinated biphenyl.
5. We allocated increased research resources in 1969 to seek and develop effective replacements; this program continues.
6. In seeking possible replacements, we will insure that differences between Aroclor and candidate fluids from our program are widely reviewed in order that the potential impact of any compromises is fully evaluated.

The implementation of these and other programs both by ourselves and electrical equipment manufacturers was prompted by the utility of this dielectric family and the difficulties inherent in developing substitutes to effectively and fully replace it.

II. UTILITY OF CHLORINATED BIPHENYL IN CAPACITORS

1. *Fire Resistance*

The adoption of chlorinated biphenyls in 1929 as capacitor dielectrics stemmed from their superior dielectric properties compared to mineral oil. However, recognition of the fire-resistant character of the fluids influenced system and equipment design and standards over the subsequent 45 years. It is probably true that today many people find it difficult to assess potential capacitor fire hazard purely because Aroclor has been used for 45 years.

Particular examples where fire resistance in a capacitor is of benefit include:

a. fluorescent lighting ballasts,
b. air-conditioner motor capacitors,
c. television capacitors,
d. large power capacitors where high fault currents can cause rupture and ejection of fluid from pole-mounted units close to people and buildings,
e. industrial furnace capacitors.

2. *Stability*

The persistence of chlorinated biphenyl in the environment is associated with the high degree of thermal, chemical, oxidative, and hydrolytic stability which permits capacitor manufacturers to fulfill the exacting reliability requirements that exist today.

*Manager, Product and Marketing Dielectrics, Monsanto Industrial Chemicals Company, St. Louis, Missouri.

MONS 070043

3. *Dielectric Constant/Dielectric Strengths*

These properties are important in determining the size of a capacitor. In a mixed dielectric system, e.g., paper/Aroclor or paper/polypropylene/Aroclor, the dielectric properties of Aroclor permit optimization of stress distribution between the components making up the dielectric layer. This has enabled capacitor manufacturers to reduce paper and film volumes for a given capacitance. I shall discuss under the heading of "potential substitutes" the impact that this could have on:

a. paper/film availability and usage;
b. design of equipment containing capacitors.

III. UTILITY IN TRANSFORMERS

Chlorinated biphenyl transformers represent less than 15 percent of transformers in service. Their use is associated with the need to limit fire hazard in installations.

1. *Railroad Transformers*

Multiple unit cars as used in rapid transit systems have transformers mounted beneath each car. By nature of the type of service, involving high passenger density, safety is essential.

2. *Urban Power Substations* (e.g., Underground Vaults)

These designs need to take into account city center space limitations and also the safety of the public and maintenance crews. Fire-resistant liquid transformers are helpful to all these objectives.

3. *Industrial Load Centers*

Efficient system designs for large, power intensive, manufacturing plants (e.g., automotive assembly, steel production) often incorporate transformers close to the electrical load centers. The use of Aroclor transformers at these centers, in the heart of the plants, or overhead in roof structures, protects both employees and plant.

4. *Transformer/Rectifiers*

Programs to reduce the emission of particulate matter from stack gases, for example in fossil fuel generating plants, include installation of electrostatic precipitators. The transformer/rectifiers energizing the precipitator field must be located close to the electrodes. In many designs, the multiple transformers are located in a penthouse above the precipitator. A fire in the penthouse could lead to shutdown of the precipitator, and thus the generating plant, if pollution control is to be maintained. A fire-resistant fluid is of obvious benefit in this application.

In each of these applications, Aroclor protects the system from:

a. initiation of a transformer fluid fire by an electrical fault beneath the liquid level,
b. electrical breakdown of the fluid causing emission of flammable gases,
c. propagation of fire if the transformer liquid content is involved in an external fire.

IV. POTENTIAL SUBSTITUTES IN CAPACITORS

1. *Research Objectives*

In seeking potential substitutes, our research objectives of necessity involved keeping those properties that gave Aroclor its value. We equally recognized the need that an Aroclor replacement should eliminate environmental concerns. A replacement should ideally operate across the full range of current Aroclor capacitor applications while requiring minimum changes in design of capacitors and equipment utilizing capacitors.

The use of chlorinated biphenyl is worldwide. Monsanto manufactures chlorinated biphenyls both in America and Great Britain. We supply to the capacitor industry of many countries. We sought potential replacement products that could be made available with the consistent quality control applied to Aroclor on a worldwide basis.

We referred earlier to availability of codielectric components in capacitors. A solution requiring substantial changes in availability of polypropylene film (quantity or quality) or a major increase in short-term availability or capacitor paper, we considered unsatisfactory. If in 1974 such increased quantities had been required, they would not have been available. Capacitor production would have fallen short of demand, further jeopardizing efficient power supply.

Our research objectives can be broadly summarized in table 1.

2. *Non-PCB Candidates*

The capacitor industry is currently examining two Monsanto non-PCB (candidate) dielectrics. These contain no chlorinated biphenyl and are not chlorinated products. The two fluids are designated MCS 1238 and MCS 1588. Both of these products are blends of synthetic hydrocarbons with a high dielectric constant additive to give a dielectric constant equivalent to Aroclor 1016. Table 2 lists some of the properties of MCS 1238 and MCS 1588 compared to Aroclor 1016.

MONS 070044

Table 1. *Research objectives in seeking potential substitutes for capacitors*

1.	Match or exceed Aroclor 1016 capability:	
	a. Dielectric constant Dielectric strength	- Usage of other components - Convertability
	b. Stability Power factor	- Reliability
	c. Fire resistance	- Safety
2.	Good environmental compatibility:	
3.	a. Span existing applications	- Complete solution.
	b. Internationally available	- Not solely U.S.A. situation.

Table 2. Some properties of MCS 1238 and MCS 1588 compared to Aroclor 1016

Property	Aroclor 1016	MCS 1238	MCS 1588
DK 25° C	5.9	6.0	6.1
100° C	4.85	5.1	5.1
Corona IV/EV[a]	-	-	-
Hydrolysis stability[a] (neutralization number)	0.00	0.00	0.00
Dissipation factor fluid tan δ 60 Hz. 100° C	0.0025	0.05	0.05
Dissipation factor model paper capacitor at 90° C	0.0032	0.0039	0.0035

[a]See text explanation, section IV 2.

MONS 070045

Corona inception and extinction voltages are more a function of capacitor design than of the liquid itself. Preliminary industry results demonstrate functioning in capacitors equivalent to Aroclor 1016. Further full-scale work is required before final conclusions can be drawn.

Dielectric constants relate closely to those of Aroclor 1016 over the temperature range of capacitor operation. Hydrolysis stability is mentioned because of work carried out on earlier candidates based on esters, which gave concern because of hydrolysis instability. Hydrolysis was assessed by measuring the neutralization number of a sample with 0.5 percent water added, which had been heated for 168 hours at 210° F in a stainless steel bomb along with an aluminum and a mild steel coupon.

3. *Fire Resistance*

Neither MCS 1238 or 1588 is fire resistant. This deficiency versus Aroclor 1016 must be closely considered.

4. *Environmental Considerations*

The environmental/health evaluation of capacitor replacement fluids must be related to:

a. Degradation—If some quantity enters the environment, at what rate and through which mechanism will it degrade?
b. Tissue accumulation
c. Toxicity—Occupational safety
   Environmental compatability

5. *Degradation*

Biodegradation has been studied using a semicontinuous activated sludge technique. Forty-eight-hour exposure of Aroclor 1254, Aroclor 1016, and MCS 1238 dielectric fluids to activated sludge using a semicontinuous procedure resulted in the percent biodegradation rates and 95 percent confidence limits shown in table 3.

For the polychlorinated biphenyl (PCB) materials, the level of chlorination appears to be the most significant factor in their relative biodegradability. The rate of biodegradation decreases as the number of chlorine atoms per biphenyl molecule increases. Chromatograms representing samples after exposure to activated sludge show significant alteration in the Aroclor 1016 isomer distribution, but little for Aroclor 1254. Degradation of the nonhalogenated fluid, MCS 1238, proceeds much more rapidly than for the halogenated PCB fluids with no evidence of resistant components. The methodology for this technique is described in appendix B.

6 *Tissue Accumulation*

Figure 1 depicts the results of rat tissue residue level studies vs. time and compares Aroclor 1242, Aroclor 1016, and MCS 1238. A fraction of the ingested Aroclor 1242 and Aroclor 1016 was stored in rats' lipid reservoirs. However, most of this residue was depleted after the rats had been on the basal laboratory diet for several weeks. During the course of the feeding study, residues of Aroclor 1016 accumulated more slowly and to a significantly lesser extent than those of Aroclor 1242. During the recovery period, these PCB residues decreased to lower values for Aroclor 1016.

The residue concentrations of MCS 1238 quickly reached a stable level well below the concentration in the feed. The residues did not increase with continued exposure. After feeding of the treated chow was ceased, the MCS 1238 residues were rapidly metabolized and/or excreted. The tissue residue accumulation and depuration profile of MCS 1238 shown in figure 1 is markedly different than those of the Aroclor fluids, especially that of Aroclor 1242. Methodology is given in appendix A.

Table 3. Results of biodegradation using a semicontinuous activated sludge technique

Material	48-Hour percent biodegradation	Feed concentration, ppm
Aroclor 1254	15 ± 38	1
Aroclor 1016	33 ± 14	1
MCS 1238	70 ± 10	3

MONS 070046

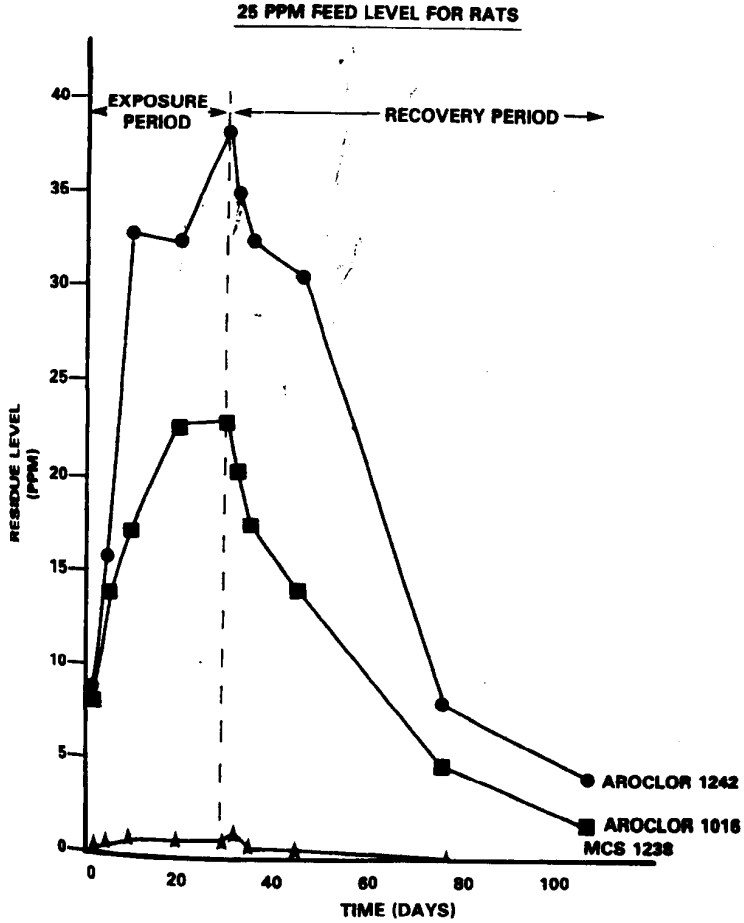


Figure 1. Results of rat tissue residue level studies vs. time, comparing Aroclor 1242, Aroclor 1016 and MCS 1238.

MONS 070047

7. *Toxicity*

Before samples of MCS 1238 could be evaluated in the capacitor industry and within Monsanto, acute toxicity data was gathered:

a. Rat—Acute single oral dose LD_{50}: 3,800 mg/kg.
b. Rabbit—Dermal LD_{50}: 5,000-8,000 mg/kg.
c. *Rabbit—Potential eye irritation:* A slight degree of irritation resulted when 0.1 ml of undiluted MCS 1238 was placed in the conjunctival sac of the rabbit eye. The average maximum score recorded at one and again at 24 hours after treatment was 12.0 on a scale of 110.0. All eyes had regained normal appearance 72 hours after dosing.
d. Rabbit—Potential skin irritation: When undiluted, MCS 1238 was held in continuous 24-hour contact with intact rabbit skin, a moderate degree of irritation resulted. The maximum average score was 3.6 on a scale of 8.0.

Further programs are in process, or scheduled, to study the following:

a. vapor inhalation,
b. *ultimate degradation*,
c. 90-day pilot feeding study,
d. long-term (2-year) feeding studies, and
e. fish tissue residues.

8. *Conclusions*

To summarize Monsanto research activities:

- A large number of single compounds and mixtures have been evaluated in terms of physical property data, environmental compatability, fire resistance, and model capacitor life testing.
- These have led us to conclude that:
  a. Aroclor 1016 may well be sufficiently degradable to remain in controlled use,
  b. MCS 1238 is a potentially acceptable replacement with the qualification that it is not fire resistant.
- Further programs must be completed with MCS 1238 in order to:
  a. deepen our knowledge of its environmental compatibility,
  b. permit complete evaluation by the capacitor industry across their range of applications,
  c. enable utilities, capacitor users, and agencies to evaluate the significance of decreased fire resistance.

As a closing thought to this section, I would like to comment that since 1929 when Aroclor was first developed as a capacitor dielectric, normal commercial pressures have spurred efforts to find superior replacements. The awareness of environmental accumulation of chlorinated biphenyls from other applications added further impetus for more intensive research in the chemical and electrical industries. Aroclor has defied 45 years of search for a superior replacement.

V. SUBSTITUTE TRANSFORMER FLUIDS

Neither Monsanto nor any other company, to our knowledge, has developed a transformer dielectric with equivalent fire resistance to that of Aroclor. The difficulties that we face in common with other workers in this field are twofold:

1. Aroclor has become the reference standard for fire resistance in transformers because it works and has worked for 45 years. To establish standards to guide research effort, there is a need for objective evaluation of the fire hazard associated with the major sectors of transformer use.
2. The chemistry which imparts fire resistance tends also to produce stable molecules. Monsanto seeks replacement products that will provide protection against:
   a. fire from transformer faults under the liquid surface,
   b. fire from secondary ignition of gaseous arc decomposition products,
   c. fire propagation if the transformer is involved in an externally initiated conflagration.

We strive to accomplish this and produce an environmentally compatible product. We have four candidates which are currently being evaluated by the transformer industry. These materials are in a sufficiently early stage of development that it would be premature to give detailed property data at this meeting.

MONS 070048

APPENDIX A

METHODOLOGY FOR FEEDING STUDY

Feeding and Sampling

Rat chow containing 25 ppm Aroclor 1242, Aroclor 1016, or MCB 1238 was prepared by mixing the products into Ralston Purina rat chow. The treated chow was fed ad libitum to adult albino rats for an exposure period of 30 days. Following the 30-day exposure period, all remaining rats were placed on the basal laboratory diet. At predetermined intervals during the exposure and recovery periods, five rats from each exposed set and a control set were sacrificed. Fat tissue was excised for analysis and composited for each group. Samples were quick-frozen and stored in glass containers with aluminum foil-lined caps to minimize risk of contamination.

Isolation

The dielectric fluid residues were isolated from the fat by solvent extraction. A weighed amount of fat was placed in an Erlenmeyer flask and homogenized three times with 25 ml of pesticide-grade hexanes and anhydrous sodium sulfate using an ultrasonic homogenizer. The combined supernatants and washings were filtered through anhydrous sodium sulfate and diluted to 100 ml with hexane.

Lipid Weight Determination

A 5 ml-aliquot of the extract solution was pipetted into a tared 50-ml beaker. After evaporation of the solvent under a stream of nitrogen, the beaker and residue were reweighed to obtain the lipid weight of the aliquot. All residue levels are reported as ppm on a lipid weight basis.

PCB Cleanup And Measurement

Sample cleanup for the extracts containing Aroclor 1242 and Aroclor 1016 residues was accomplished by pipetting an aliquot of the extract onto a 5 percent deactivated alumina column and eluting with 125 ml of hexanes. The column eluate was collected in a Kuderna-Danish evaporative concentrator, a 3-ball Snyder condenser was attached, and the solution was concentrated to 5 ml. The residue levels in the extracts were measured by gas chromatography using an electron capture detector.

Non-PCB Cleanup And Measurement

Sample cleanup for the extracts containing MCS 1238 residues required separation of the residues from the lipid by preparative scale gel permeation chromatography. Following the GPC separation, the extracts were further cleaned up on an alumina column, collected, and concentrated as above. The residue levels in these extracts were measured by gas chromatography using a flame ionization detector.

Calculations

Calibration curves for each product were prepared by plotting detector response (total peak area) versus nanograms of standard injected. Residue levels in the samples were determined by summation of the total area of peaks corresponding to peaks in the standard and use of the appropriate calibration curve. The calculations were done as follows:

$$\text{Residue (ppm)} = \frac{(N)(V_F)}{(V_I)(W)}$$

where N = Amount of product from calibration curve (ng),
V_F = Volume of final concentrate (ml),
V_I = Volume injected (ul),
W = Lipid weight of original sample (g).

APPENDIX B

TECHNIQUE FOR BIODEGRADATION METHOD

Biodegredation Method

Since activated sludge is one of the most important agents for sewage treatment, test procedures evaluating its action are of great importance.

The semicontinuous activated sludge (SCAS) method has been extensively utilized in the development of biodegradable detergents. In our SCAS procedure, patterned after the Soap and Detergents Association's

MONS 070049

standard method (1,2) mixed liquor (activated sludge and supernatant) from a local domestic sewage treatment plant is charged to magnetically stirred glass vessels of 1.5-l capacity. Means for aeration and sampling are provided. The SCAS unit is generally operated using a retention or aeration time cycle of 24 to 72 hours. At the beginning of each cycle, synthetic sewage (300 mg glucose, 200 mg nutrient broth, and 130 mg K_2HPO_4) and the appropriate test material in ethanol solution are added to the mixed liquor (2,500 mg/l suspended solids concentration). Aeration is maintained until the end of the cycle, at which time the sludge is settled and 1 l of supernatant drained. The cycle is then reinitiated by the addition of tap water, synthetic sewage, and test material. Operation of the units can be continued for an indefinite period of time until consistent degradation rates are observed.

Sample Analysis

Biodegradation of the test material was determined during one cycle each week by analyzing 20 to 50 ml mixed liquor samples withdrawn after feeding and at the end of the aeration cycle. The mixed liquor analytical procedure involved extraction with three successive 25-ml portions of hexane, and drying combined extracts with anhydrous sodium sulfate. Extracts were concentrated in a Kuderna-Danish evaporative concentrator equipped with a 3-ball Snyder condenser, and measured by electron capture or flame ionization gas chromatography. Calibration curves for each product were prepared by plotting detector response (total peak area) versus nanograms of standard injected.

The percent biodegradation was calculated from the following equation:

$$\text{percent biodegradation} = (C_o - C_n)/C_o \times 100$$

where C_o and C_n use the initial and final concentration of test material, respectively, on the mixed liquor.

REFERENCES

1. *J. Am. Oil Chem. Soc.*, Vol. 42 (1965), p. 986.
2. *J. Am. Oil Chem. Soc.*, Vol. 46 (1969), p. 432.

MONS 070050

SOME COMMENTS ON ALTERNATIVES TO PCB's

Bruno Rey Coquais*

Abstract

In the transformer industry, the benefit of a non-flammable liquid seems to exceed the risks of pollution by polychlorinated biphenyls; however, to minimize eventual contamination of the environment, it is suggested to use, when possible, a mixture of chlorobenzene and trichlorobiphenyl or even chlorobenzene alone.

For the impregnation of capacitors, most of the substitutes which can be imagined are not very attractive, though they are useful for certain applications; it is proposed to use a mixture of pure dichlorobiphenyls and their alkylated derivatives. This impregnant, named chloralkylene, has dielectric properties very similar to the industrial trichlorobiphenyl.

The tests in progress already show that chloralkylene is easily biodegradable and has a low toxicity. This compound seems to be quite acceptable for the environment and should be a perfect substitute for polychlorinated biphenyls in capacitors.

To begin with, I would insist on the fact that heavy chlorinated biphenyls have been used for a long time in dispersive applications as plasticizers and for other uses. Although these types of applications have been stopped in accordance with the OECD recommendations of the February 14, 1973, it is not surprising to continue to find these persistent, highly chlorinated PCB's everywhere in the environment. It is therefore very difficult to know if the electrical uses of PCB's for transformers and for capacitors have a significant contribution to the pollution of our environment.

TRANSFORMERS

PCB's are used in transformers only when the fire hazard is high (department stores, theatres, movies, skyscrapers, factories); otherwise oilfilled transformers, which are cheaper, are always preferred. We do not think dry-type transformers would be a competitive alternative in spite of the fact that silicone and epoxy belong to the range of products we market. They may be very attractive in some cases, but in addition to certain economical and technical disadvantages, dry transformers do not offer a perfectly safe solution wherever flammable vapors (solvents, oil, gas) may be present accidentally.

We believe a nonflammable dielectric liquid is absolutely necessary to prevent the risk of fire in transformers. In table 1 we have listed the different possible solutions. In the United States, at this time, transformers are filled with Inerteen 70-30, which is based on pentachlorobiphenyl, or with Inerteen 100-42. To minimize the pollution risk, a mixture of trichlorobiphenyl and chlorobenzene or even the chlorobenzene alone could be used in spite of some technological problems.

In any case, the systematic recovery of used PCB's will further limit pollution hazards; our company Prodelec has organized this practice throughout France since 1968, as soon as this pollution problem became known. This systematic recovery has now been enforced in France by the French law of July 8, 1975, on PCB's.

CAPACITORS

For capacitor impregnation, we have examined various possible solutions. We think that the performances of such compounds as silicone; sulfone or synthetic oil (alkylbenzene, polybutene); phthalate; and sebacate—which we are indeed selling ourselves for certain applications—are not really satisfactory enough for generalized or widespread use.

In our opinion, a substitute to PCB's should be characterized by:

- High permittivity;
- Nonflammability, at least not sustaining combustion;
- Compatibility with polypropylene film;
- Being a permanent liquid with no crystallization until -25°;
- Good thermal and electric subfield stability;
- Regarding its effect on the environment, being fairly easily biodegradable, to eliminate the risk of accumulation, and by having low toxicity.

To get a good and nonflammable dielectric fluid means in practice that the compound must be a chlorinated aromatic hydrocarbon. We have studied, for instance, new structures, as shown in figure 1. With chlorobiphenyl oxide, we are afraid of the risk of metabolization in highly toxic dioxins and we feel that products of the family of the chlorobiphenylethane are technically and environmentally much more promising. Actually, introducing a totally new compound would require a long and expensive testing program and it seems better to take advantage of the huge amount of knowledge gathered about PCB's and to see how it may be possible to improve the present situation.

* Development Manager, Prodelec, S.A., 25 Quai Paul Doumer, Courbevoie, France.

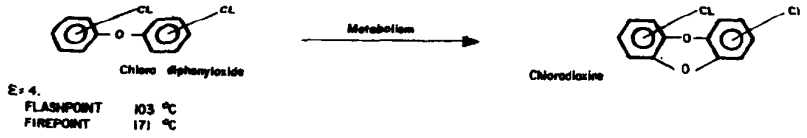
MONS 070051

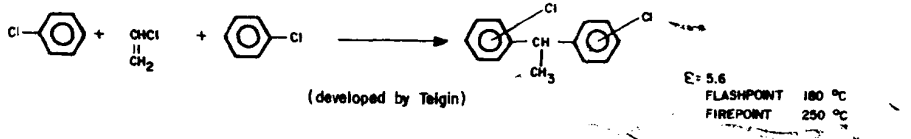
Table 1. Possible solutions for dielectric liquid

IEC type	Chloro-biphenyl	Chloro-benzene	Pour Point (°C)	Viscosity Cst at 20° C	ε at 20° C	Hydrogen index[a]	Askarels for transformer
T_1	60% hexa	40% tri	<-33	21	4.5	<0 excess Cl	Pyralene T_1 Pyroclor
T_2	45% hexa	55% tri and tetra	<-40	11	5	<0 excess Cl	
T_4	70% penta	30% tri	<-30	20	5	0	Inerteen 70-30 Pyralene T_4
	45% penta	55% tri and tetra	<-40	10		<0 excess Cl	Pyralene T_2
T_3	100% tri		<-18	65	6	16	Pyralene T_3 Inerteen 100-42
	60% tri	40% tri	<-50	7	6	10	Pyralene 1460
	40% tri	60% tri and tetra	<-20			4	
		100% tri and tetra	Chrystallize -9		6	<0 excess Cl	

[a] Hydrogen index = $\frac{\text{No. hydrogen - No. chlorine}}{\text{Molecular weight}}$.

MONS 070052





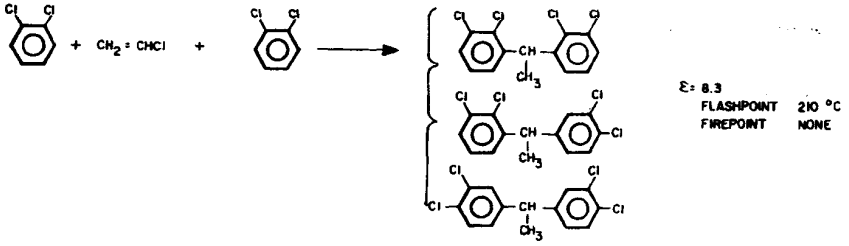


Figure 1. New structures for nonflammable dielectric fluids.

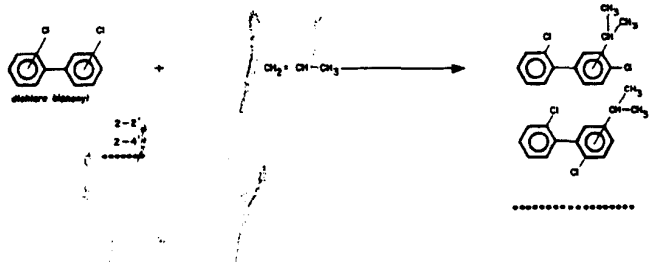


Figure 2. Structure of chloralkylene.

Table 2. Composition of various impregnants

Composition, percent	Chloralkylene 12	Pyralene 3010 (trichloro-biphenyl)	Pyralene 1500	Pyralene 2000
Biphenyl	0	0	0	1.6
Monochlorobiphenyl	0	0	0.5	18.4
Dichlorobiphenyl	20	11.4	37.5	44.0
Trichlorobiphenyl	0	57.1	40.0	23.4
Tetrachlorobiphenyl	0	29.4	20.5	11.7
Pentachlorobiphenyl	0	2.2	1.5	0.9
Alkylchlorobiphenyl isomers	80	-	-	-
Chlorine content, percent	25.8	42.	38.5	33.5

MONS 070054

Table 3. Comparison of chloralkylene to commercial trichlorobiphenyls

Characteristics	Chloralkylene 12	Pyralene 3010 (trichlorodiphenyl)
Specific gravity at 20° C	1.163	1.391
100° C	1.097	1.319
Coefficient of expansion	7.5×10^{-4}	6.8×10^{-4}
Viscosity Cst. at 20° C	135	65
100° C	3.2	2.3
Pour point (ASTM D 97)	-25° C	-23° C
Firepoint (Cleveland)	258° C	none until boiling
Permitivity at 20° C	6.00	5.93
100° C	4.86	4.80
Resistivity 100° C - 500 V - 1 mn	$>3000 \times 10^9$	$>3000 \times 10^9$
Dissipation factor +g6 100° C - 50 cps	<0.02	<0.02

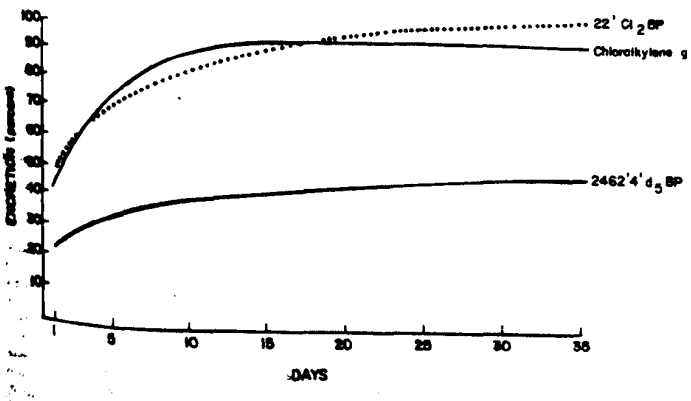


Figure 3. Excretion by rats, with diet of 2 ppm/day for 5 weeks.

MONS 070055

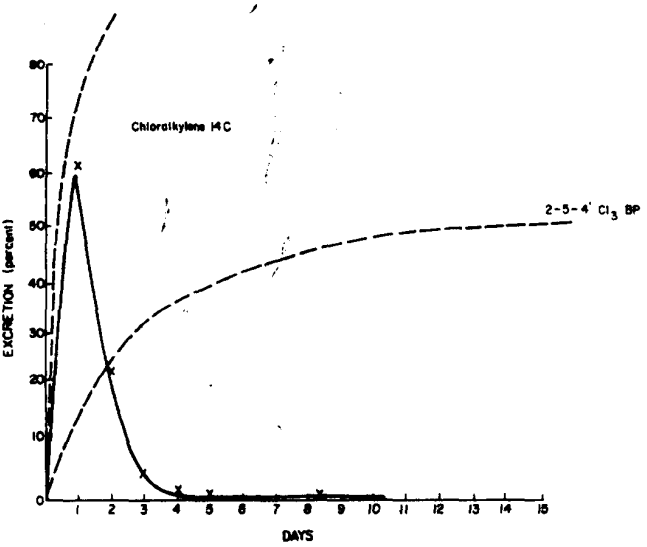


Figure 4. Excretion by rhesus monkey; single oral dose 1 mg/kg.

The studies carried on, in particular by Prof. Korte and Dr. Klein in Germany, seem to prove the easy biodegradability of PCB's when they have a very low chlorine content; therefore, pure mono- or dichlorobiphenyls could be quite acceptable for the environment.

As an impregnant consisting only of mono- and dichlorobiphenyls would crystallize at room temperature, it is necessary to produce a more complicated mixture to get a permanent liquid at all temperatures. We have therefore developed a product named "chloralkylene," obtained by addition of an alkyl chain, actually an isopropyl group, on a mixture of nearly pure dichlorobiphenyl isomers (figure 2).

As shown on table 2, chloralkylene contains no penta- nor tetrachlorobiphenyl and the trichlorobiphenyl content can be extremely low. Technically, for its dielectric and physical properties, the chloralkylene is a perfect substitute to the commercial trichlorobiphenyls (Pyralene 3010, Arochlor 1016), as shown in table 3 and as checked by some major capacitor manufacturers here and abroad.

To assess its impact on the environment, we have given chloralkylene to the Institute for Ecological Chemistry in Bonn, Germany, Prof. Korte. This institute is engaged in an extensive investigation on "PCB's in the Environment." We therefore hope to have next spring the final results on the fate of chloralkylene in comparison with PCB isomers.

Tests on environmental acceptability are actually being carried out with chloralkylene based on 2-4' dichlorobiphenyl labeled with 14c. The tests consist of a study of the balance of the excretion, the storage, and the metabolism in rats and in monkeys (figures 3 and 4); the monkey studies are being completed at the Institute of Experimental Pathology and Toxicology, Albany Medical College, Albany, New York. These tests also examine the fate of chloralkylene in a soil plant ecosystem and in an aquatic ecosystem, as well as its behavior under atmospheric conditions, upon waste composting, and in sewage treatments. The results so far obtained prove that

MONS 070056

chloralkylene does not accumulate, is metabolized quickly, and behaves generally like the dichlorobiphenyls isomers themselves.

Chloralkylene is two times less toxic than trichlorobiphenyl when one compares the acute toxicity values. At this time, there is no real reason to consider PCB's dangerous for the labor manufacturing capacitors, if the necessary precautions are taken. We think that with an easily biodegradable compound such as chloralkylene, long-term effects due to accumulation along the food chain do not need to be feared.

The chloralkylene price is presently twice that of the currently commercially available polychlorobiphenyls, which would result in an increase of the capacitor costs of about 5/10 percent. However, by substituting mineral oil or other substitutes with less outstanding characteristics, the increase of the cost of capacitors would be much higher. We hope to improve its economy and are quite confident that chloralkylene could thus be an excellent substitute for trichlorobiphenyls.

MONS 070057

PCB's AND THEIR SUBSTITUTES – A BRIEF LOOK AT SOME EXAMPLES OF PAST TRADEOFFS

Dale Hattis, Ph.D., and Albert Murray, Ph.D.*

Abstract

Some aspects are described of a study of the economic, health, legal, and other impacts of the past voluntary restriction on PCB sales. Examples illustrate the importance of examining the effects of substitute technologies in assessing regulatory policy by showing the potential for surprises in this regard. In the PCB case, substitutes may be producing both unanticipated economic benefits and unappreciated health and safety risks.

I am Dale Hattis of the Center for Policy Alternatives at M.I.T. My colleague at the center, Dr. Albert Murray, who was originally scheduled to speak here—and who would be the most appropriate speaker on this subject—was unfortunately taken ill about a week and a half ago and he is now still recuperating in the hospital. What I have done in his place for presentation today is to extract some particular examples of tradeoffs from Al's work on PCB's, which illustrate some occasionally surprising features of the technological changes that arise out of environmental/health concerns.

For context, I would like to say that our project, sponsored by the Council on Environmental Quality and EPA, and under the direction of Dr. Nicholas A. Ashford, has for the past year been exploring ways to analyze the economic, environmental health, legal, and other impacts of regulatory decisions related to environmental chemicals. In this exploration, we are now in the process of completing eight experiments in the analysis of the impacts of particular regulatory actions, primarily drawn from the past 5 years of history. The first of our eight experiments, though not strictly resulting from a mandatory governmental action, was the restriction a few years ago of the sale of PCB's for particular uses. Because our case studies are experiments to explore the practical use of methods, and because the resources we could devote to each case were relatively small, we could not perform as comprehensive an elucidation of effects as we would have wished. Nevertheless, we do think that our analyses have revealed important types of questions, similar to those referred to yesterday by Mr. Train, which are difficult to deal with in the single chemical reactive context of most current regulatory authorities.

My initial two examples of such questions on PCB's illustrate the fact that it is sometimes difficult to be sure that technological changes introduced with the intent of reducing environmental health risks accomplish their purpose on balance, when the risks of substitute practices are considered. Sometimes there appear to be legitimate reasons for concern that particular changes—especially in the absence of continuing regulatory followup—might create environmental health hazards as dangerous or more dangerous than the ones that are eliminated.

As a first example, the substitutes for PCB's in some large heat exchangers and in some special hydraulic fluids for high-fire-risk uses are flammable at elevated temperatures. Concern for the lack of fire protection previously provided by PCB's in these situations has reportedly caused a substantial increase, as much as a doubling in some cases, in fire insurance rates on some industrial facilities employing high-temperature heat exchangers. In our case study, Al Murray estimated the total increase in premiums at possibly in the tens of millions of dollars annually. This, of course, reflects mainly property damage and not the human cost. However, if our information on the increased premiums is correct, and if the apparent perception of the insurance companies is correct as to the size of the added chance of catastrophic fires, then we must consider that such events would be likely to be accompanied by appreciable human casualties. The rise in insurance rates, of course, may not reflect an actual change in risk, and in that case the increased insurance cost is simply a transfer payment to the benefit of the insurance companies, but the matter seems to deserve further exploration with the aid of hard statistics on actual fire-risk experience. If the data confirm that appreciable human impact may be expected to occur, alternative means for reducing this risk might be productively evaluated.

Another, although probably less important, example of potential risk of substitute technology arises in the case of the former use of PCB's as a dye-solvent for carbonless carbon paper. It may be recalled that at some frequency PCB's from this source found their way into recycled paperboard products for food contact use, and this was a source of concern for the FDA. Now the PCB's formerly used for this purpose have been replaced, but unfortunately it is not public information what exactly has replaced them. The barrier of trade secrecy

*Research Associates, Center for Policy Alternatives, Massachusetts Institute of Technology, Cambridge, Massachusetts.

MONS 070058

In this instance, as in many others, can frustrate attempts to assess the difference in environmental health risk produced by the change in technology.

Two other examples illustrate the potential for a different category of surprises—those in the economic area.

Formerly, PCB's costing on the order of 25 cents per pound were used in many paints and coatings, sometimes as a major ingredient. In this application PCB's were a chemically stable blender and conferred resistance to fire, impacts, water, and weathering. Our inquiries with paint manufacturers indicate that chlorinated paraffins now perform essentially all the technical functions of PCB's at about half the former cost. Our industry informants mention some increased problems in a few of their products with lowered stability to dechlorination—causing occasional discoloration, and loss of weathering resistance—but over the great bulk of their product lines, the industry perception appears to be that the change has been economically beneficial. PCB's had evidently become established as paint additives before the availability and advantages of the chlorinated paraffins became widely appreciated. Later, when approximate technical equality and lower prices might have tempted paint manufacturers to substitute, the usual inertial resistance to any change appears to have missed this opportunity to be generally neglected. The real world and the economists' ideal one occasionally behave differently.

Another example of a surprise (at least to us) in the economic area is the potential importance of even small adverse impacts on sport fishing. A U.S. Department of Interior survey (ref. 1) indicates that in 1970 a total of about 700 million person-days and five billion dollars were spent in pursuit of this pastime — mainly in fresh water. The five billion dollars must, of course, be considered an underestimate of the actual "value" of that activity to people. If PCB's had continued to be used as they were in the past, we might speculate that additional concern of people about residues (such as that now publicly in evidence), or possibly some declines in fish populations might have led to small fractional declines in participation or enjoyment of fishing by some portion of the population. If this were to occur, the loss of value to society of even less than a fraction of a percent of national sport fishing activities might be appraised at tens of millions of dollars annually—depending on the "value" realized by former fishers in substitute recreational activities.

The importance of examining subtle and uncertain effects, including the effects of substitute technologies, is illustrated by such occasional insights into their potential magnitude.

REFERENCES

1. Fish and Wildlife Service, Bureau of Sport Fisheries, U.S. Dept. Interior, "National Survey of Fishing and Hunting," Resource Publication 95, GPO, Washington, D.C., 1972.

MONS 070059

ENJ-2065—AN ELECTRICAL INSULATING FLUID

E. J. Inchalik, Ph.D.*

Abstract

The need for an electrical insulating fluid whose use would avoid the adverse toxicological and ecological effects associated with polychlorinated biphenyls prompted a study of organic esters as possible substitutes. The study culminated in the identification of diisononyl phthalate (ENJ-2065) as a dielectric fluid of potential interest to the capacitor industry. ENJ-2065 has been made available to that industry and it is now being used in some commercial capacitors.

In late 1970, a study was begun at Exxon Research and Engineering Company by Drs. A. J. Rutkowski and E. O. Forster to develop an electrical insulating fluid whose use would avoid the adverse toxicological and ecological effects associated with polychlorinated biphenyls. This study culminated in the identification of diisononyl phthalate (ENJ-2065) as a dielectric fluid of potential interest to the capacitor industry. Exxon Chemical Company U.S.A. has made ENJ-2065 available to the industry for its evaluation and it is now being used in some commercial capacitors.

In the preliminary phases of this study, the dielectric properties of a significant number of mono- and dibasic acid esters were determined in order to obtain a general understanding of the interrelation between molecular structure and dielectric properties. From these data it was concluded that major attention ought to be directed at the esters of phthalic acid. The phthalates that we tested all had dielectric constants of 4-6, close enough to the desired level for fluids for the widely used paper-based capacitors to justify further evaluation. The optimum dielectric constant for these capacitor fluids is one which closely matches the dielectric constant of the paper. A close match reduces electric field inhomogeneities, increases dielectric strength and lifetime, and decreases capacitor size. Other important property criteria for a paper dielectric fluid include a low dissipation factor, to reduce energy loss and destructive heat buildup; a high dielectric strength, to reduce capacitor size and improve service life by permitting short-term exposure of the fluid to abnormally high stresses without breakdown; a low gassing tendency, to avoid production of gases that could lead to pressure buildup in sealed units; stability at elevated temperatures, to prevent capacitor breakdown and stabilize performance; low viscosity, to allow for easier impregnation and filling of capacitors and elimination of air pockets; a low order of toxicity; and compatibility with the environment.

Consideration of these factors as well as availability and cost resulted in narrowing the choice of potential candidates to those shown in table 1. From this list, diisononyl phthalate (ENJ-2065) was selected as the most promising for additional study. ENJ-2065 was chosen on the basis that it has (1) a higher dielectric constant than the phthalates of higher molecular weight, (2) an advantage in its loss characteristics relative to the lower molecular weight dihexyl and dioctyl phthalates, (3) a relatively high flash point of 430° F, (4) a more highly branched molecular structure than dihexyl and dioctyl phthalates with the potential for improved hydrolytic stability and (5) a good balance of other physical and electrical properties. ENJ-2065 is manufactured in the United States by Exxon Chemical Company U.S.A. from phthalic anhydride and a mixture of branched isomeric alcohols in which C_9 alcohols predominate.

Electrical insulating fluids have to remain essentially unchanged chemically when subjected to temperature cycles. Once having chosen ENJ-2065 for further evaluation, it was desirable to know what effect certain contaminants might have on its stability, how these contaminants might be removed, and what additives, if any, might be useful in enhancing its stability.

The effects of small amounts of two potential contaminants, alcohol and water, on conductivity of ENJ-2065 are shown in tables 2 and 3. The results show that alcohol levels of less then about 1,000 ppm and water levels of less than about 100 ppm can probably be tolerated without affecting performance seriously. To remove small quantities of these impurities as well as any acids or catalyst residues from the production of ENJ-2065, we found percolation through a packed column of activated Attapulgus clay to be effective, but we did not carry out extensive studies to optimize a purification system. It is our feeling that systems now being used in the industry for purification of PCB's prior to use in capacitors, or slight modifications of them, will prove to be satisfactory for ENJ-2065.

Although the most widely used capacitors today are of the all-paper type, newer types based on polypropylene film and paper or on all-polypropylene film are growing in importance. With capacitors of this type, the dielectric constant of the fluid is less important.

*Research Associate, Chemical Intermediates Technology Division of Exxon Chemical Company, Linden, New Jersey.

MONS 070060

Table 1. Electrical and physical properties of phthalate esters

Phthalate Ester	Dihexyl	Di-2-ethylhexyl	Diisooctyl	ENJ-2065	Diisodecyl	Ditridecyl
Dielectric constant	5.64	5.33	4.97	4.66	4.45	4.08
Tan delta	--	0.14	0.30	0.05	0.02	0.01
AC conductivity, 10^{-11} (ohm-cm)$^{-1}$	9.0	2.1	1.3	0.29	0.20	0.04
Breakdown voltage (KV/0.1 in.)	--	28	27	30	36	29
Boiling point--mid @ 5 mmHg, °C	210	230	235	252	256	286
Pour point, °C	-33	-50	-45	-48	-50	-37
Viscosity, cps., 20° C	50	81	83	95	110	230
Flashpoint, COC, °F	380	425	430	430	452	470
Firepoint, COC, °F	420	475	485	495	515	555

MONS 070061

Table 2. Effect of residual alcohol on conductivity of ENJ-2065

Temperature cycle (1,000 V, 60 Hz)	Conductivity $(10^{-12}$ ohm-cm$)^{-1}$ Wt. percent alcohol added		
	0	0.01	0.1
25° C	0.78	1.97	1.98
90° C	40	65	320
25° C	3	4	12

Table 3. Effect of residual water on conductivity of ENJ-2065

Temperature cycle (1,000 V, 60 Hz)	Conductivity $(10^{-12}$ ohm-cm$)^{-1}$ Wt. percent water added			
	0	0.001	0.01	0.1
25° C	0.78	2.7	3.7	135
90° C	40	165	>400	>400
25° C	3	10	25	70

Table 4. Weight gain of PP film in contact with dielectric fluid

Fluid	Run number		
	1	2	3
ENJ-2065	11.0	10.9	13.8
Arochlor 1242	18.8	18.2	22.8

MONS 070062

impregnation of the polypropylene film with the fluid, however, is of great importance and prompted a brief study, summarized on table 4. These data show that ENJ-2065 swells polypropylene capacitor-grade films satisfactorily, as measured by the film weight gain after 2 days at 60° C, so that film impregnation should not be a serious problem. The next generation of capacitors may well be based on metallized polypropylene film. Polychlorinated biphenyls cannot be used for this type of capacitor since they generate hydrogen chloride, which can lead to premature breakdown.

In summary, we believe that ENJ-2065 has a balance of properties such that it will find a niche in the capacitor fluid field.

MONS 070063

GENERAL DISCUSSION OF SESSION V

CHAIRMAN MUIR: All right. I see that we have reached our scheduled departure hour. I think it's only fair to entertain a few questions from the audience and given the diversity, I would request that people raise a question from the floor and then address their questions to the individual they would like an answer from.

MR. BEN KININGHAM (Illinois Lung Association, Springfield, Illinois): I do not have any particular gentleman on the panel to address. I just want to refer to the breakdown of the film, If anyone could elaborate on how that comes about, and if so, is there any research that is being carried on now in development of films that would be any more stable.

MR. RICHARD ROLLINS (Jard Corporation, Bennington, Vermont): Are you talking about a biological breakdown?

MR. KININGHAM: Biological or chemical or both breakdowns.

MR. ROLLINS: It is a reduction type atmosphere in the capacitor so it does not see the oxygen that would normally be considered. The basic problem is not one of the degradation as much as it is an inherent characteristic of not being able to survive voltage levels or stresses in an AC application.

MR. KININGHAM: Would it be feasible to develop an alternative program?

MR. ROLLINS: The organic type films have been used or have been attempted to be used in AC capacitors. The basic problem is one of corona exception and corona distinction voltages, and this is inherently low and goes down to initiation of points 250 to 275 volts and the extinction voltage is extremely low. The meaning of the corona is that the capacitor slowly deteriorates by this ionic device which is the definition of corona. The interpretations of corona I am not going to get into today because every capacitor designer has his own opinion, but every capacitor designer is completely aware of what the corona problems can do. So essentially what we are saying is that organic films have the basic problem of not being able to withstand high AC voltages, especially in the dry system.

On an impregnated system, the circumstances are still there, so you are not really changing the circumstances a great deal in all polypropylene film or any organic film when you impregnate it.

VOICE: I have a question for Dave Wood. We heard a number of things about environmental factors. How about a still lower chlorinated material than 1016 that might be a more desirable material? I believe Monsanto has passed a given developmental material such as 1043, which is a lower chlorinated material.

MR. DAVID WOOD (Monsanto Industrial Chemicals Company, St. Louis, Missouri): We have done considerable work with MCS 1043, but at the present time commercialization of such a product must hang in the balance pending further conclusions being drawn about the true significance in the differences observed between the trichlorinated materials and bichlorinated materials. Aroclor 1016 was itself a reduction in materials from the Aroclor 1042 widely used by the industry.

In order to carry through development of the dichlorinated material, I think we need some approvals from the community that they recognize a movement in that direction as one that should be taken.

So yes, some data are already available. Acceleration or stopping of that program depends largely, on some of the things that we hope will come out of this conference this week.

MS. NANCY STROUP (Environmental Defense Foundation, Washington, D.C.): I apologize for the open-handedness of my question, but I hope that the panel members will respond as concisely as possible.

One of the speakers mentioned that his concern was that we not jump from the frying pan into the fire, and I am sure it's the concern of everyone at this meeting. To that end I would like to know when the four or five compounds that are now being developed to replace PCB's will be tested for the health and safety of these compounds, including carcinogenic, immunogenic, and teratogenic tests before your marketing. And whether this information will be available for independent review.

DR. MUIR: Essentially, as I already outlined in my talk, we developed a date for the work and the work is going forward and we recognize the biphenyl problem and that replacing the product inevitably is going to have to satisfy the most thorough and rigorous testing.

DR. DEAN BRANSON (Dow Chemical, Inc., Midland, Michigan): In the case of methosilicones additional data will be published very shortly and will be publicly available. I think this is most in the minds of all manufacturers when they consider substitutes

MONS 070064

for the material which is dielectrically one of the best ever developed. This will seem to solve the problem when it comes out.

DR. E. J. INCHALIK (Exxon Chemical Company, Linden, New Jersey): A great deal of information is already available. You may recall in 1972 a program sponsored by the National Foundation of Health Sciences and one subject made by Dr. Tapper, what he observed at comparison of PCB and mercury, it was like an ideology searching for a disease, and that's a quote.

The recent study by Dr. Hartung of the University of Michigan has concluded that no problems attributable to polyesters have been noted due to the constant low level exposure of the general population, and that occupationally, only mild skin irritation has been observed at high exposures. But he did point out that ecological work should be continued. And I might add that Dr. Tapper suggested the same.

To help answer these questions, particularly related to these items, a research grant has been made by the University of Missouri to the Manufacturing Chemists Association, and they are starting tests. I think we can hope within the next year or so results will be coming from this study obviously available to all which will help answer these questions.

MR. DUNCAN MacARUTHUR (Booze Allen and Hamilton, Inc., New York, New York): Well, some of the things that you have asked for are in progress and when these things are available, they will also be made available to the general public.

MR. DAVID C. MORRIS (Weyerhauser Company, Tacoma, Washington): You stated, sir, that a cost of $4.9 million would be necessary for I guess you would call them secondary market users like my company, to replace our PCB with some substitute.

Did I understand you correctly, Mr. MacArthur?

MR. MacARTHUR: Yes.

MR. MOSS: Just for my own sake, I just believe in it very strongly, the cost alone is estimated at $2 million and we are right in the midst of investing. And I think somewhere along the line the investing might not take into account the factors that we initially have to face. I would guess it's at least 50 times over.

CHAIRMAN MUIR: Yes, sir.

VOICE: There are three experimental items coming on the market. Will someone label these transformers--

MR. ROLLINS: Well, I'm not too sure, but there have been requests that major capacitors manufacturers now conform by labeling all capacitors that have greater than I believe 5 pounds of Aroclor--I may be wrong, but on small capacitors, the basic problem is the label gets hidden because this is placed into another piece of equipment.

MR. STEVE NUMUS (Environmental Protection Agency): I have a question for Richard Montgomery regarding the use of silicone which was approved by Underwriters Lab for indoor use. Do you know the reasons why it was approved for indoor use and why it was not approved for outdoor use?

And secondly, can somebody give me an idea of the percent of transformers in the United States used for outdoor purposes as opposed to indoor purposes?

MR. RICHARD H. MONTGOMERY (Dow Corning Corporation, Midland, Michigan): First of all, Underwriters Laboratory does not approve of any particular material for any given use--once you exceed 600 volts in a transformer, Underwriter's Laboratories has no certification. The only certification received from Underwriters' Laboratories is as to the fire hazard of your particular material on a scale which ranges from 0 to 100, with the burnability of water as 0, and gasoline as 100. Therefore, Underwriter's Laboratory does not approve silicone material for indoor use.

In respect to the use of dielectric fluids in transformers, the electric code for outdoor uses does not specify nonflammable material. It does in subsection 450, paragraph 23 approve the use for the indoors. These are the only materials approved for use.

MR. NUMUS: I want to know the percentage as opposed to indoor use.

MR. MONTGOMERY: Well, my research seems to indicate 85 to 90 percent of the transformers sold in the United States are currently outdoor applications, and the other 10 to 15 percent are indoor applications, for safety is of paramount importance.

MR. WOOD: Essentially the figure that he is using is pretty accurate. Very large power transformers are filled with mineral oil because, if they're out in the field, there is not a substantial hazard, they can be screened out. In the medium voltage range the use of askarel is something under 15 percent of the transformers used in that medium voltage area.

MR. CLIFFORD H. TUTTLE (Aerovox Industries, Inc., New Bedford, Massachusetts): I really have two questions--another alternative mentioned up there, the capacitor for getting the high voltage can consume 20 to 50 million pounds a year. How long

MONS 070065

would it take fluid to be available in that type of quantity; 1 year, 2 years, 3 years, or what? I don't want to pressure you, I just want to determine.

The second question is a third of that market is lighting, fluorescence. If you have an application at 100° C, are any of these fluids or alternatives capable of operating at that temperature without breaking?

MR. MONTGOMERY: Let me answer your second question first. The answer is yes. The answer to the first question is we do have the productive capabilities capable to handle that market. It could be accomplished very quickly. It would probably be faster than the industry takes to evaluate and qualify new material.

MR. WOOD: In terms of Monsanto, alternatives could be made available on a production basis in calendar year 1976, in relationship to the stability of these materials at 100° in the HIB and the fluorescent lighting capacitors, these are test sequences which are going on under our test programs. And the results will be forthcoming. We are in a period now of collective work. We are not ready to go tomorrow.

MONS 070066