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ORGANIC CHEMICALS DIVISION

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LIQUID DIELECTRICS AND AROCLOR

A MARKET SURVEY

John S. Harris
August 15, 1956
O.D. 1134

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INTRODUCTION

The Aroclors were acquired by Monsanto with the Swann Chemical Company in 1935. In our reorganization in November, 1953, they became the responsibility of the Organic Division.

Most of our sales of Aroclor go to the electrical industry in what for most of us is a rather esoteric use: as a dielectric in transformers and capacitors. Up until very recently we held basic manufacturing patents on the Aroclors (or "askarels" as they are called in the electrical industry), and General Electric held the use patents as the result of their early cooperative work with Swann Chemical. Practically all of these patents have now expired.

In reviewing research and development programs some months ago, Messrs. Nason and Lum raised the question of what course of action we should be following on the electrical use of Aroclor and on the dielectric field in general. This report is the result of their assignment to survey the field, the applications, the needs and the problems, and recommend what action we should take.

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SUMMARY AND CONCLUSIONS

We have very few products of which we are the only manufacturer, and the Aroclor family is a prime example. It has had a long and profitable history and last year some 33 million pounds were sold for over $5 million--two-thirds of this for electrical use. Notwithstanding its low price, it gives us a very good return on investment. But with our protective patents gone, and half-a-dozen other chemical manufacturers looking at the Aroclors, we stand a good chance of losing our hold on these products at any time. With the electrical sales alone estimated in 1965 from 30 to 55 million pounds, this would be quite a loss.

The best way to safeguard our exclusive manufacture of Aroclor will be to make patentable improvements on its use in transformers and capacitors. There are several shortcomings in the Aroclors as they now stand, and there are good reasons for believing that a research program stands a reasonable chance of improving these.

In the transformer field, we have some real marketing problems with Aroclor. Between these and the improvements being made in competitive materials, there is a danger of losing an appreciable part of our seven million pound sales--to say nothing of the 14 to 25 million pounds in 1965 if it keeps up its earlier rate of growth for this use.

And the electrical aspects of the Aroclor are just part of the story. With Aroclor moving more and more strongly into a variety of uses ranging from heat exchangers to plasticizers, we may have seen only the beginning of real volume. All any other potential manufacturer needs is a foothold in the business. Since our patents have expired, only meticulous pricing has kept out competitors. If we have to build a new plant--and expansion can't be far off--our investment may force us to raise the price and make the Aroclors much more attractive to potential manufacturers.

Beyond Aroclor there are needs for different liquid (and solid) dielectrics in million-dollar markets. Several of these applications--for example, high temperature dielectrics and sulfones--fit right into programs we now have going for different fields. On the grounds of both "insurance" research on Aroclor and application research for new products, a research program is strongly indicated.

A modest effort in Development on the electrical industry is in order now, to be expanded as new products appear. An increased technical service program in the Sales Department and advertising to transformer customers should pay excellent dividends.

* * *

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RECOMMENDATIONS

The liquid dielectric field is a large one, a multi-million dollar market even excluding petroleum oil as a dielectric which adds another $10 million. The field as a whole is doubling about every ten years. Our activities should be divided between holding on to and strengthening what we have (the Aroclors), and searching for new products for markets we are not yet supplying. Both are very promising fields.

At the moment most of the opportunity lies in the hands of Research, and secondarily, Sales. As soon as more new products are available, Development activities can increase markedly.

Our recommendations on the two areas are as follows:

AROCLOR

The Research Department should institute a program with these preliminary goals:

To determine the cause of temperature instability (well below the decomposition point), and find a means of correcting it.

To characterize the important isomers physically and electrically to determine if lower pour points are possible.

To determine the cause of the poor impulse strength and maximum voltage limit and find a means to correct them.

To find better means of controlling and reducing the power factor.

The Sales Department should:

Increase their technical service facilities, particularly to the major transformer users, and establish relations on a technical level with the major users just as we now have with the transformer manufacturers.

Use advertising and promotion to influence the buyer of transformers toward Aroclor.

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NEW DIELECTRICS

The Research Department, in conjunction with its activities on Aroclor, should screen and synthesize compounds for these applications:

1. Low voltage power capacitors
2. High temperature capacitors
3. A liquid dielectric for Mylar
4. Solid dielectrics
5. A dielectric for metallized paper

The Development Department, though lacking any important new product at the moment, should establish contacts with the major electrical manufacturers. For the time being, the silicate esters and sulfones can serve as starting points as both are of general interest. Several other chemicals, now being handled by different groups that are of interest to the electrical manufacturers, can also be fitted in. Judging from our preliminary calls, the interest shown by this industry in a wide range of organic compounds will quickly swell the number of products involved.

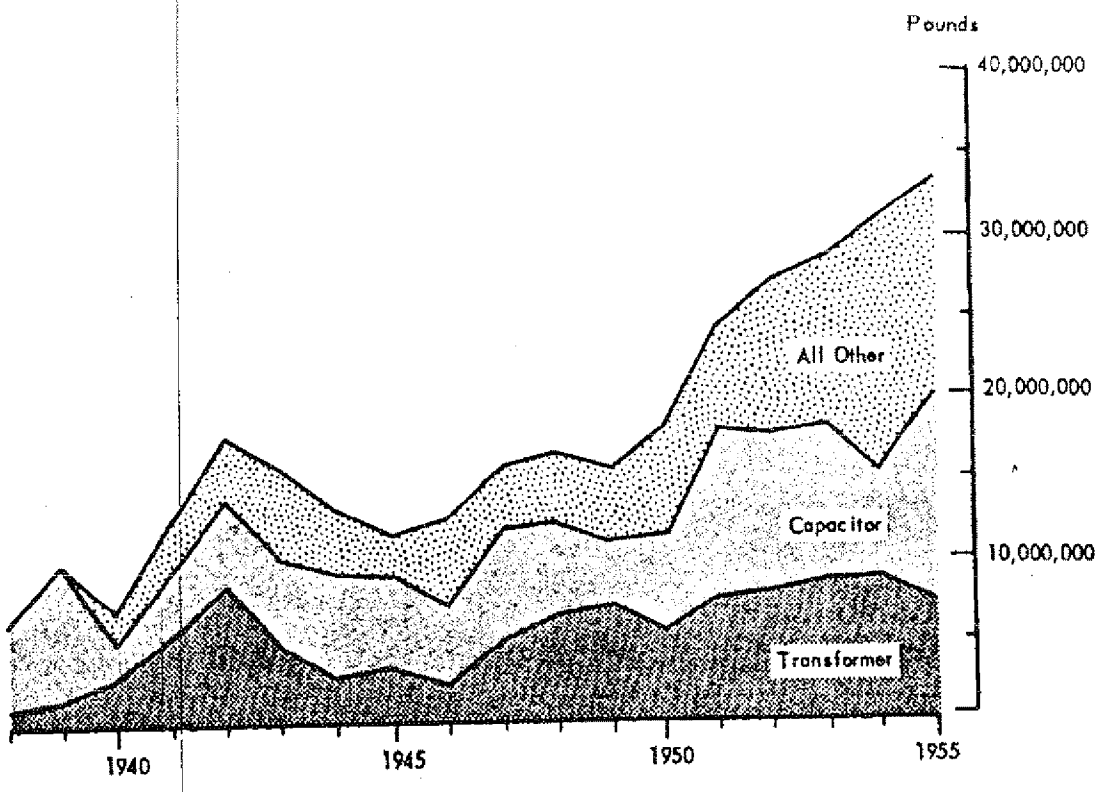
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A final recommendation is that Monsanto acquire a man well versed and recognized in this field of electro-chemistry. A man of the caliber of Thomas D. Callinan of the Naval Research Laboratory would be ideal.

* * * *

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SALES OF AROCLOR



Total: $5,000,000



Heat Exchangers, Hydraulic Fluid, Casting Wax, Wire Insulation, Etc.

Plasticizer

Capacitors

Transformers

1955 SALES VALUE BY APPLICATION:

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PREFACE: DIELECTRICS AND THEIR APPLICATIONS

Except for the very few in the Division who are responsible for the sale and technical servicing of the Aroclors in the electrical industry, this market and its problems are rather foreign to us. Part of the strangeness may come from the fact that it is the electrical characteristics that are important rather than the chemical, and here most of us have had little experience or training. However, oil additives and plasticizers involve more physical than chemical laws, and this suggests that where active programs are underway we have become better acquainted with the industry.

Whatever the cause, it seems desirable to provide a little more background on some of the important technical concepts and applications than is usually necessary in such a survey. Few eyebrows would rise over the mention of a grass-specific herbicide, but more might lift over a discussion of impulse strength and resistivity. These prefatory explanations are particularly important from the point of view of research and development opportunities, but even to appreciate the present marketing problems of Aroclor some understanding of its important electrical characteristics will be helpful. So, on the next page, for those who need it, there is a summary of the basic definitions and concepts that are fundamental to electrical applications.

The use of the Aroclors as electrical fluids grew out of cooperative work between General Electric (Frank Clark) and Swann Chemical (Russell Jenkins) in the early 1930's. The Aroclors were picked originally for capacitors, but several transformer fires about this time gave an impetus to their use in transformers as well. General Electric received the patents on their use electrically--practically all of which have now expired. G. E. gave the generic term "askarel" to Aroclor and its mixtures with chlorinated benzene, and used "Pyranol" as their trade name. Some of the other trade names are: "Inerteen" (Westinghouse); "Chlorextol" (Allis-Chalmers); "Dykanol" (Cornell-Dubilier); "Noflamol" (Wagner Electric); "Elemex" (Line Material); "Askarel" (Maloney Electric). Many different mixtures of the various Aroclors have been made, and some of the more important ones are shown below:

Aroclor 1260: Pyranol 1482.
Aroclor 1260 with 40% trichlorobenzene: Pyranol 1467, 1488; Inerteen PPO, 7336-9; Noflamol.
Aroclor 1260 with 55% tri-tetrachlorobenzene: Pyranol 1470; Chlorextol.
Aroclor 1254: Pyranol 1432, 1476; Inerteen 6935-1; Dykanol A; Elemex Liquid A.
Aroclor 1254 with 25% tetrachlorobenzene: Pyranol 1436, 1481.
Aroclor 1248: Pyranol 1498.
Aroclor 1242: Pyranol 1499; Inerteen 9818-1.

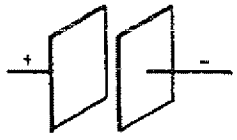
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A THUMB-NAIL REVIEW OF SOME THEORY

(The last time most of us were exposed to the underlying theory of dielectrics and their applications was in college physics and physical chemistry. Assuming that perhaps others will have had as little occasion to recall this knowledge, a short--and simple--summary of some of the definitions and concepts that will be referred to in the report is provided below.)

Dielectric

A dielectric is an insulating material (gas, liquid or solid) when it is used to store electrostatic energy. The same material when it is used to prevent the flow of energy is referred to as insulation. The ability to store electrical energy can be thought of as a strain induced in the molecules of the material subjected to an electrical field. The amount of energy that can be stored will be related to the configuration of the molecule and to a large degree can be accounted for by the dipole moment.



If two plates are oppositely charged, the amount of energy that they can store (the capacitance) depends directly on the area of the plates and the substance between them, and is inversely proportional to the distance between the plates (this may seem strange, but the closer the plates are together, the greater the electrical stress on the dielectric and thus the greater the capacitance.)

Dielectric Constant

In a given capacitor, the minimum energy storage, or capacitance, is provided by a vacuum, and this is taken as unity. Air gives a capacitance 1.0006 times as large and this is referred to as its dielectric constant. Petroleum oil has a dielectric constant of about 2.2, and Aroclor of around 5. Thus, Aroclor in a certain size capacitor can store 4 or 5 times the energy of air or over twice as much as oil. Or, to look at it another way, an Aroclor-filled capacitor can be half the size of an oil-filled capacitor and still do the same job. In capacitors, the higher the dielectric constant, the better (other things being equal); in a transformer it is not very important.

Power Factor

This is one of the more confusing terms as power factor, dissipation factor, loss factor, and loss tangent are all used to describe the same characteristic. However the quantities are numerically equal only at low values. For the purpose of this report, all of the terms can be considered as referring to the loss that occurs in a dielectric when an alternating voltage is applied. Part of the loss can come from leakage of the current through the dielectric and another part from what can be thought of as the friction from rotating molecules. Both show up as heat in the dielectric. A perfect dielectric would return as much energy as was put in to charge it. The difference, the power factor, is the energy lost as heat. The lower it is, the better.

Resistivity

This is simply a measure of the resistance of the dielectric to the passage of direct current. It is measured in ohm-cm. Oil ranges from 10^{13} to 10^{14} ohm-cm, and Aroclor from 10^{12} to 10^{13} at room temperature. The higher, the better.

Dielectric Strength

The ability of a dielectric to prevent a spark or arc when between two electrodes is referred to as its dielectric strength. Many variables enter into the measurement, but using an ASTM test with a gap of 0.1 inches between the electrodes, oil has a dielectric strength of 26 to 30,000 volts and Aroclor, 30 to 35,000 volts. Again, the higher the dielectric strength of a material, the better.

Impulse Strength

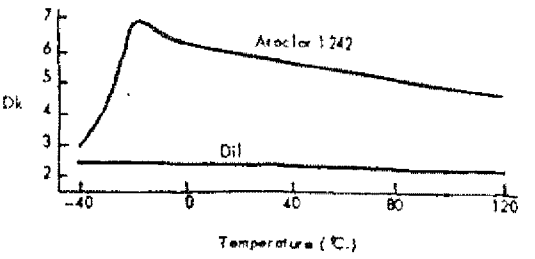
If, instead of applying the test voltage slowly as in the measurement of dielectric strength, it is applied suddenly as a pulse, sometimes quite different results are obtained. This test is intended to approximate the characteristics of a lightning surge, and whereas Aroclor has a higher dielectric strength then oil, it has a lower impulse strength. This is a serious shortcoming of Aroclor in transformer applications.

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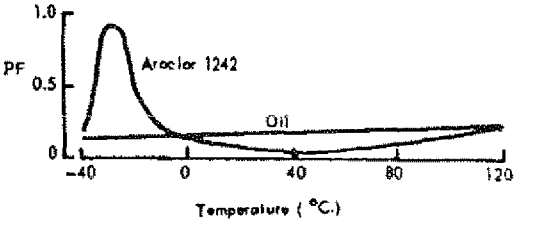
Dielectric Constant vs. Temperature

Ideally a capacitor would maintain the same value of capacitance over its operating temperature range. Since in the capacitor neither area nor distance between the plates varies appreciably, the dielectric constant will be the most important factor over the range of temperatures. If the dielectric constants (Dk) of oil and Aroclor 1242 are plotted against temperature, curves similar to those at the right are obtained. The drop-off in Aroclor is a little below its pour point. This characteristic of Aroclor is another of its important weaknesses.



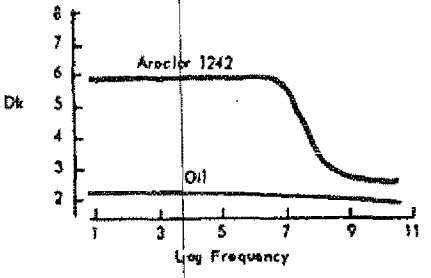
Power Factor vs. Temperature

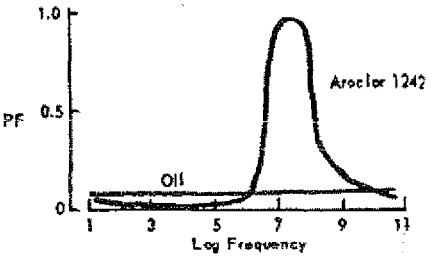
The losses in the dielectric are also influenced by temperature, and the power factor peaks at the same point the dielectric constant drops off--approximately the pour point. A plot of power factor (PF) against temperature for the same liquids gives curves like those to the right. There is one advantage in the loss at low temperatures in Aroclor. When an outdoor capacitor comes on the line and is cold, an appreciable amount of heat is generated and this tends to warm up the liquid and raise the dielectric constant.



Dielectric Constant and Power Factor vs. Frequency

Just as the dielectric constant and power factor vary with temperature, they also vary with the frequency of the applied voltage. This is not important in power equipment since nearly all of this is at 60 cycles. It is important in radio, television, radar, and industrial electronic equipment.



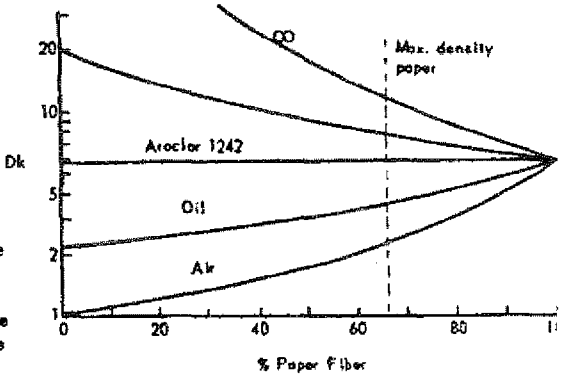


Fortunately the drop in dielectric constant and peak in power factor are all above the 60 cycle range. But they are right in the middle of the frequencies encountered in many other applications.

Dielectric Constant of Paper plus Liquid

Nearly all capacitors are made by winding into rolls sheets of aluminium foil separated by very thin paper. This is then impregnated with the liquid dielectric. The space between the "plates" (the sheets of foil) is actually filled with both paper and liquid. The dielectric constant of the mixture is dependent on the individual dielectrics and is in a sense the average of the two. Actually, the relationship is more complex, but the result is that the higher the dielectric constant of the liquid, the less effect it has on the resultant value of the mixture. This can be seen in the chart where the dielectric constant of various liquids is plotted against the amount (density) of paper present.

Even if a liquid had an infinite dielectric constant, the resultant mixture with paper would have an effective value of only about 12. This limits any practical gain, and leaves decreasing incentive for dielectric constants above, say, 10 to 20. It also illustrates why the capacitor manufacturers are looking so diligently for films with higher dielectric constants to replace paper.



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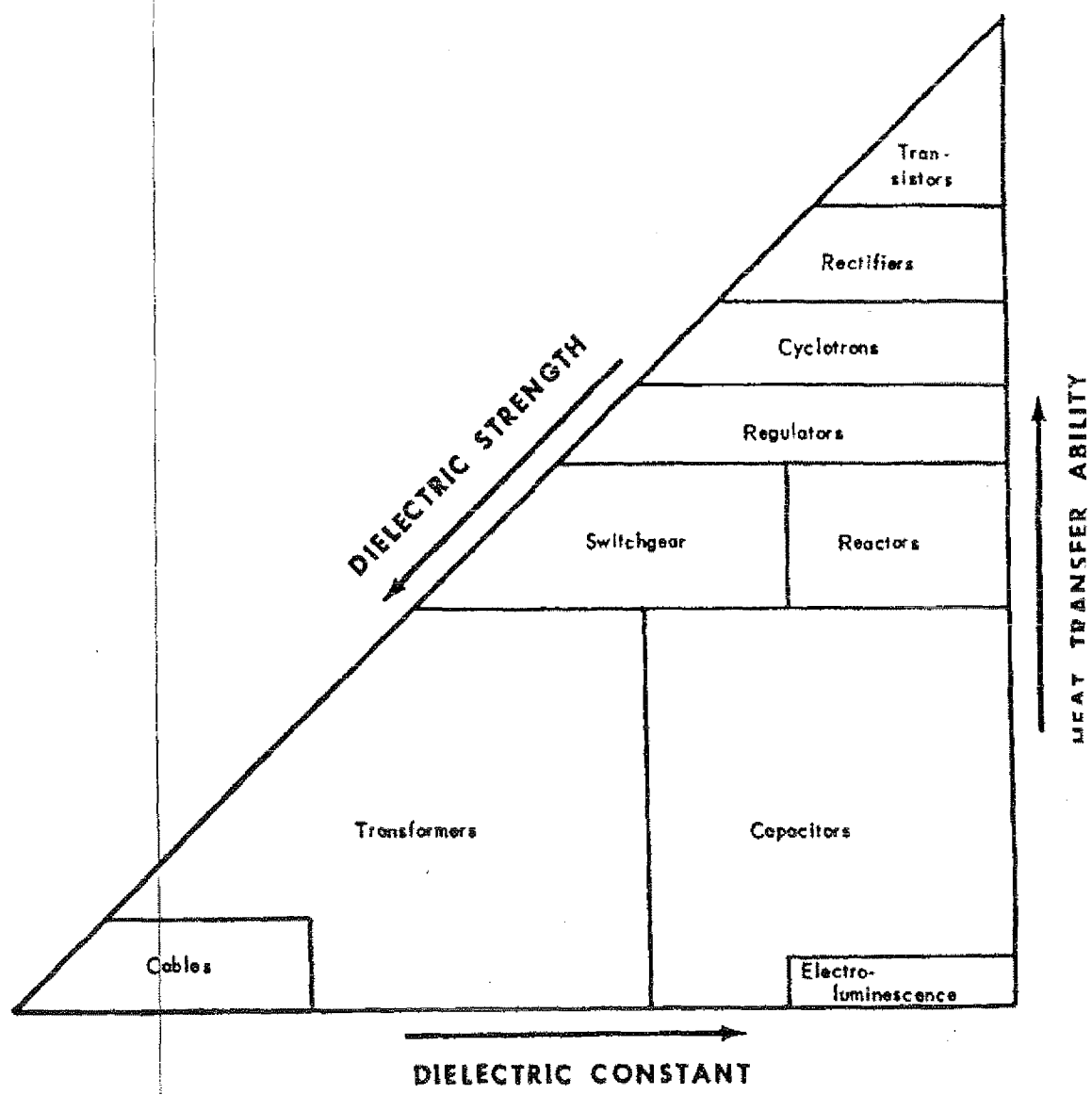
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A liquid dielectric can be used as an insulator, as in a cable; as a dielectric in a capacitor; as a coolant in a transistor; or for a combination of reasons, as in a transformer where the dielectric serves as both insulant and coolant. The most important applications for the Aroclors are in transformers and capacitors, and these will be covered in some detail later. However there are many other important uses for other dielectrics and these are outlined on the next page. Also indicated in pictorial form is the relationship of the application to three major characteristics of the liquid; ability to withstand high voltage, ability to store electricity, and heat transfer quality.

When we developed OS-45 it was as a hydraulic fluid. Yet last year, half that was sold was used as an electronic coolant. We were very fortunate that Raytheon stumbled on OS-45 and developed the dielectric use for it, but the discovery of applications shouldn't be left to chance. One of the prime objectives of this study was to determine just what characteristics are needed in the economically important dielectric applications. With a knowledge of these potential markets and their requirements, we can direct promising products to interested companies without depending on luck, and thus expand our markets in one more large industry.

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APPLICATIONS OF LIQUID DIELECTRICS



(after T.D. Callinan, N.R.L.)

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DIELECTRICS IN CAPACITORS

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I AROCLOR IN CAPACITORS

Any discussion of new products for a given application should begin with the products now in use and their limitations, and the product in largest use today in capacitors is Aroclor. Last year to this market we sold almost 13 million pounds worth a little less than $2 million. Somewhat over half of this went into large capacitors for utility power lines. The remainder of the Aroclor went into ballast capacitors for fluorescent and mercury lighting and into small power factor correction capacitors for air conditioners and similar devices. A small amount went into D.C. capacitors.

The capacitors used by the utilities, and sometimes by industry, are comparatively large, containing several gallons of Aroclor, and can be seen hanging in banks from a good many power and telephone poles. There are two main reasons for using capacitors on power lines: first, to correct for the type of load that many motors and appliances provide. This load, which is mostly inductive, throws out of balance the power demand and may require that the utility company supply considerably more power than the consumer actually uses (and is billed for). A capacitor will bring the power factor back closer to the desired 100%. Thus the 50 Kvar* capacitor which costs the power company $200 is just as effective as adding 50 Kva of generating capacity which would cost some $4,000.

The other major reason to use capacitors on power lines is to maintain the voltage. On a long line the voltage will be higher at the generating end, and the more power that is drawn, the greater the voltage drop at the other end. This can mean that a home that is supposed to receive 230 volts may be only getting 210, and the air conditioner that needs 115 volts to operate properly may actually only have 105. Since this can mean burnt-out motors, the power companies are quite anxious to keep their delivered voltages above reproach. A capacitor close to the load can increase the voltage and tend to regulate it. (In fact, the closer to the load, the better, and, as is discussed later, this presents a good-sized potential market that isn't being tapped yet.)

The smaller capacitors which are used in fluorescent and mercury lamps and on small motors, welders and other industrial appliances, serve much the same purpose as the large power units. Their prime function is to correct the power factor produced by an unbalanced load. There are a number of advantages in providing the correction at the load instead of on the power lines and the utilities have granted lower rates to make it worthwhile for the customer to do so. In addition to power factor correction the capacitor also produces the high voltage necessary to fire the fluorescent lamp, and on a motor it provides the leading power factor necessary to starting.

*(A Kvar, or kilovolt-ampere-reactive, is the amount of capacitance necessary to correct for one Kva of inductive load.)

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A. MARKET SIZE

Out of the 12.7 million pounds of Aroclor sold for capacitor use in 1955 (almost 40% of total Aroclor sales), 6.5 million pounds went into the large power factor correction units, 5.8 million pounds into small ballast and motor capacitors, and the remaining 0.3 million into small D.C. capacitors. On the next page is charted the growth in sales of capacitor Aroclor since 1940.

The rate at which the power companies have accepted capacitors for power factor correction has been constantly increasing. In 1930 they installed only 0.01 Kvar for every kilowatt of new generating capacity. Today the utilities are installing over one-third Kvar for every new kilowatt, and G.E. expects that by 1965 the rate will be at least one-half Kvar per kilowatt. Some utilities, particularly in the South where air conditioning has become prevalent, are installing one Kvar for every kilowatt of new capacity.

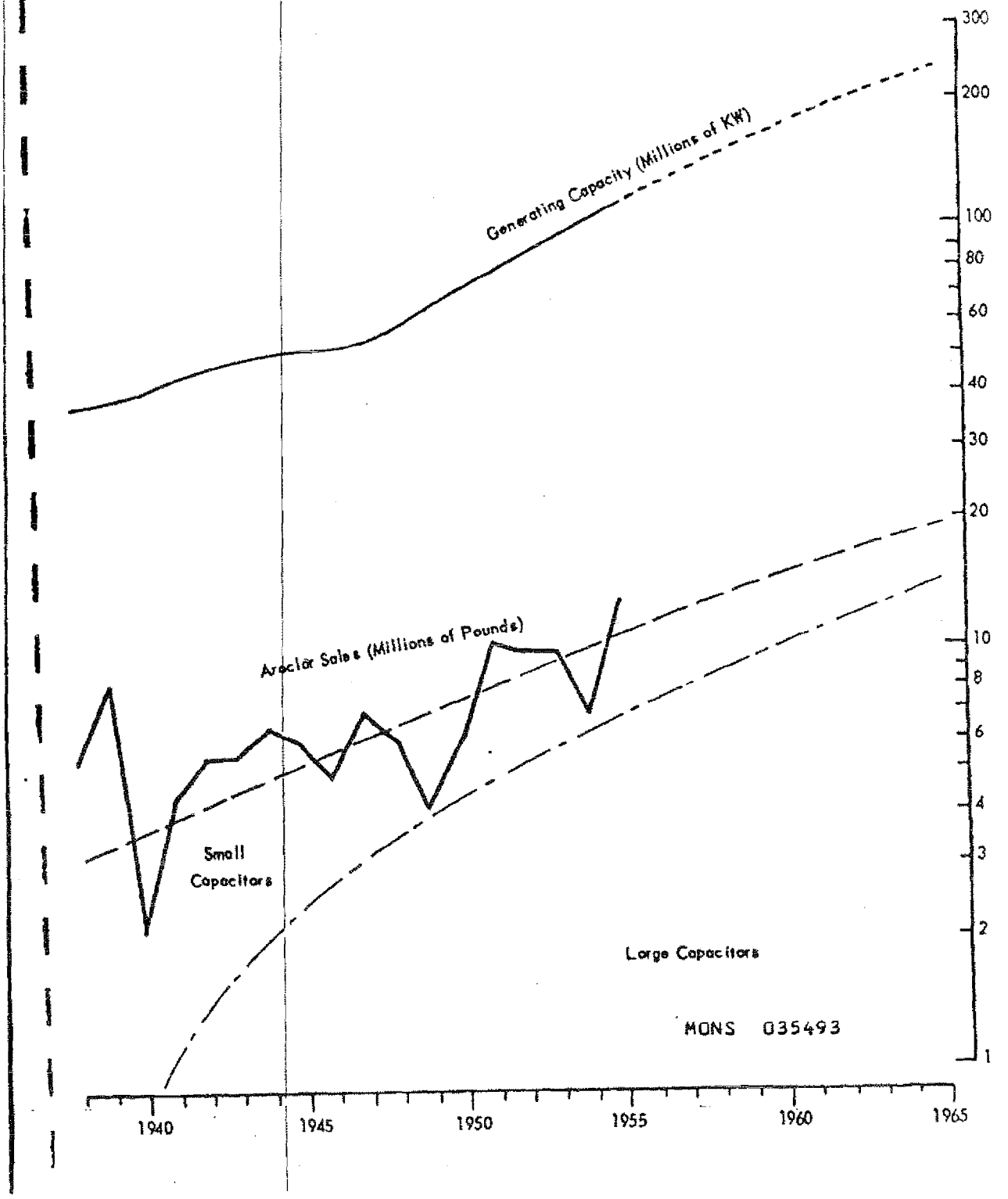
In addition to the market for Aroclor arising from the installation of new equipment, the replacement market should be considered. In the first year or two of use, there is a capacitor failure rate of about 0.1%. After this the number of capacitor failures, as long as they are operated within specifications, is negligible. The first Aroclor capacitors built have now operated about 25 years, and so far there is no indication that they are wearing out. In the last 5 or 10 years, the manufacturers have been building the units closer to design limits--with a lower safety factor--and it may be that their operating life will be shorter. But as of right now, though it will almost certainly come in time, the market for Aroclor in replacement capacitors is nil.

One of the surest growing industries and one on which there are fairly reliable forecasts is the electrical industry. In the chart on the next page the sales of Aroclor for capacitors is compared to the growth of the utility generating capacity, and the trends can be seen to roughly parallel. It appears pretty certain that by 1965 the electrical industry will be consuming 1.5 million gallons of a dielectric for power factor correction. If this is Aroclor it will mean a 20-million-pound annual market.

How much of the capacitor Aroclor sales come from the large power factor units, and how much from the smaller ballast units we have no way of knowing for sure. Some of our customers make both types. However, using the value of power capacitors sold as a guide (as reported by NEMA), the relative importance of each can be estimated. The average sales trend for the two groups of capacitors is shown in the chart and

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SALES OF AROCLOR FOR CAPACITORS



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projected to 1965. Though initially the smaller ballast units accounted for most of our sales, in 1955 sales were about equally divided and by 1965 close to three-quarters of the volume will come from the big capacitors.

If the 1965 market for 1.5 million gallons of liquid dielectric is not supplied by Aroclor, it will be because another product was developed that did not have Aroclor's deficiencies. In the next two sections the advantages and disadvantages of Aroclor in capacitors are compared.

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B. CHARACTERISTICS OF AROCLOR IN CAPACITORS

Until about 1932, all large power capacitors used mineral oil as the dielectric, and up until this time only about 250 Kvar had been installed. The substitution of Aroclor (which cost several times as much as oil) resulted in a capacitor half the size for a given capacitance and the total cost of manufacture was a great deal less. Compared to the units made in 1928, today's capacitor weighs and costs only 20% as much, and last year alone some 4900 Kvar were installed. Much the same advantages have been gained in the ballast capacitors.

Aroclor's prime asset was--and is--a higher dielectric constant. Secondly, though considerably more expensive than oil, as an organic chemical it is very cheap. It is this combination that has held back all other competition for a quarter of a century.

Thirdly, the Aroclors are fire-resistant and remove a constant problem the electrical manufacturers have with the Underwriter's Laboratory where indoor installations are involved. Just how essential this characteristic is is apparently open to debate, as while Westinghouse and Aerovox say that non-flammability is required, G.E. say that they have decided to start playing down this aspect as they may want to go to a flammable dielectric.

There are two other important advantages in capacitor use of Aroclor. The peak in the power factor curve comes just about the bottom of the operating temperature range and this causes a self corrective temperature rise (see page 7). Finally, the peak in power factor vs. frequency is well above the 60 cycle power range.

Certainly there is a strong basis for the remark of Ralph Ruscetta, one of G.E.'s pioneers on Aroclor. After discussing Aroclor's advantages and all the work done in the last 25 years in an effort to find better dielectrics, he stated that they'll "be using Pyranol (Aroclor) or an improved version for the next 20 years". But this has another side, and after listening to a large number of others ticking off Aroclor's shortcomings one can't help but think that if Aroclor is still being used 20 years from now it will have to be an improved version.

C. SHORTCOMINGS OF AROCLOR IN P.F. CORRECTION

The major criticisms of Aroclor in capacitors were four in number and they were heard time and again:

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High temperature (not stable high enough)
Low temperature (dielectric constant drops too soon)
Power factor (too high and too unstable)
Contamination (too sensitive)

One or more of these weaknesses may be inherent--simply the nature of the stuff. But from a number of experts we got a strong indication that they may not be inherent. Since these shortcomings represent opportunities for an improved product and perhaps the re-establishment of a patent position, they are worth looking at as pearls rather than thorns.

High Temperature

Today every large manufacturer has their capacitors operating right up to the ragged edge of the maximum allowable temperature. The outside surface can only radiate so much heat per square inch, and the laws of solid geometry being what they are, the manufacturer can't make the capacitors any bigger or the boxes any smaller without exceeding the maximum temperature on the inside.

Paper is one other limitation in a capacitor and this represents the maximum to which the liquid dielectric has to go. Like most questions, there is no unanimity in industry's answer, but the consensus can be seen:

G.E. Capacitor Dept: "Aroclor-filled capacitors are fine for unlimited periods at 70°C., but at 85°C., they begin to go. Paper has a maximum operating temperature of 90°C. We need to be able to raise the maximum temperature 10 to 15°C., and we think we are going to have to do this very shortly."

G.E. Schenectady: "--the trend is toward higher temperatures, and we are limited by both paper and the liquid."

Line Material Co: "We try to stay below 75°C., hotspot. The paper is good to 96°C., and we feel that Aroclor is the limiting factor."

Sprague Electric: "These (ballast capacitors) are presently limited by the maximum temperature and we would like to be able to go up to 130-150°C. ---paper can be operated into this area."

Pyramid Electric: "For fluorescent lamp ballasts we need a higher temperature limit---."

Westinghouse Lighting Division: "Long range, we feel the trend is away from Aroclor primarily because of its upper temperature limit of 85°C. We want to be able to operate up to 150°C. (with film, not paper)."

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In other words, Aroclor is good to perhaps 75°C. The manufacturers could drive their capacitors another 15° or 20°C. if the Aroclor would stand it, and this is no small gain. Materials like Mylar are being considered at higher cost than paper just to move the upper limit up.

Low Temperature

At the other end of the thermometer, the capacitors for power factor correction and outdoor ballasts need to be able to stand lower temperatures as well. Practically all of the manufacturers have switched now from Aroclor 1254 to Aroclor 1242, and this has given them perhaps another 20°C. lower. But these capacitors are used outside on poles, and in the winter if they are off the line for a time the temperature can go well below Aroclor 1242's pour point. Just exactly what happens in a number of cases when the power is put back on is being debated, but there is no question but that when it does happen the capacitor is all through.

Again, the comments from some of the companies define the need pretty well:

G.E. Capacitor Dept: "We would like better low temperature characteristics and can afford to pay more for a fluid that will go down to -55°C. ---If the Pyranols (Aroclor) cannot be adapted to switch at -20° to -40°F., (-30° to -40°C.) we will have to find a dielectric that can be within the next 5 to 10 years."

G.E. Schenectady: "We need a better low temperature liquid, good to perhaps -45°C.---."

Line Material Co: "We need a higher temperature limit with a pour point of -40°C."

Aerovox: "Aroclor 1242 is still not good enough at low temperatures, perhaps to -15°C., where we actually need -40°C."

It is true that most of the low temperature capacitor failures occur at latitudes above 40° to 42° (Schenectady - Chicago - Portland). This embraces a fair amount of the U.S. market and all of the Canadian, which is becoming important. Further, the capacitor manufacturers say they want to use a single fluid for all units - regardless of destination. This is substantiated by their complete swing from Aroclor 1254 to 1242, even though the latter is more difficult to handle.

In Military applications Mr. Benignus has estimated that there is some 1.5 million pounds of business that Aroclor cannot get (under JANC-25) because of its drop in dielectric constant at low temperatures.

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Power Factor

The power factor in capacitor terminology represents the loss of energy in the capacitor, and it shows up as heat. As far as the actual amount of energy lost compared to the load on the power line is concerned, it is insignificant and wouldn't be missed. It is the heat that is generated in the capacitor that is the serious limitation.

As indicated earlier, the upper temperature limit of Aroclor is already a problem. The temperature rise above air temperature is due to the energy loss. Thus, the lower the power factor, the less the temperature will rise in the capacitor and the less must be dissipated through the walls of the container.

Actually, this appears to be something less of a weakness than those previously mentioned. At the present time, the size of the capacitor couldn't be reduced appreciably even with a lower power factor. However, if an additive were used with the Aroclor to give a higher dielectric constant, as Westinghouse is seriously considering, the power factor will be a definite limitation.

Contamination

This criticism is somewhat like enjoying snow but objecting to the cold. The sensitivity of Aroclor to contamination (which raises the power factor) from practically any source is at least in part the result of its desirably high dielectric constant. However the criticism is wide-spread, and there is one angle that may be of potential interest.

There were always problems with Aroclor 1254, the dielectric chosen in 1932, but Aroclor 1242 is even more sensitive. Techniques of handling and filtration have been worked out so that with proper methods contamination can be fairly well eliminated; but extreme care, and sometimes extended treatment, is necessary.

With the upper temperature limit of Aroclor influenced by the amount of heat generated, the heat generated being the function of the power factor, and the power factor influenced heavily by the contamination, contamination and its control or correction could be a very worthwhile improvement. Such possibilities are discussed in the following section.

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D. OPPORTUNITIES FOR AROCLOR IN CAPACITORS

Monsanto has relatively few chemicals of which we are the only manufacturer. Aroclor is one of these, and it has had a long and profitable life. During most of this time we have had basic manufacturing patents, though the electrical patents were held by G. E. Now all of the important patents have expired.

We know that the capacitor manufacturers would like to have an alternate supplier of Aroclor, and we know that most of the larger chemical companies have looked at Aroclor one or more times with the idea of manufacturing. Westinghouse even gave Carbide and Carbon an order for quantities that would have presumably let them enter production. Solvay has submitted acceptable samples to G. E., and Dow, Diamond Alkali and Tennessee Products are known definitely to have shown interest in manufacturing. In each case it can be assumed that only the low price of Aroclor has kept the competition out--and we can't be sure that it will continue to do so.

Our ability to sell Aroclor at its present price (13.4¢ per pound to the electrical industry and 15.5¢ elsewhere) and still make a good return on investment, is due to the low-cost plants in which Aroclor is made. Very shortly we are going to have to build new facilities to expand our production, and then we will either have to accept a lower return or increase the price. Once the price is up, competition will certainly take a longer look.

This matter goes beyond the electrical business, which consumed 60% of the Aroclor in 1955, and affects all our other markets for Aroclor. If another manufacturer gets a foothold large enough in any one of the markets to justify production, we'll have a bedmate. The most effective means to prevent this, and certainly the most profitable, will be to make a patentable improvement on Aroclor for the electrical industry. With what we can hope will be another 17 years' hold on Aroclor, our pricing can become more flexible and our profits perhaps higher.

Thus, the shortcomings of Aroclor may well be real opportunities and in the following they are regarded in this light.

High Temperature

It seems a strange thing that here is a material that is used in heat exchangers at over 300°C. for long periods without decomposition, and yet the electrical industry says that 85°C. is the top limit. It is true that the amount of decomposition that can be tolerated in a capacitor is

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infinitesimal compared to that in a heat exchanger, yet if sufficient breakdown can occur in a few minutes at 100°C. to be detected, one would certainly expect that a year or two at 300°C. would cause some rather gross changes.

There is a second clue that would point to some hope of improving Aroclor's heat stability. Even ultra violet light will cause enough decomposition of Aroclor 1242 to change its power factor. According to G.E., chlorinated biphenyl should theoretically be an extremely stable molecule, and U.V. should not be expected to produce decomposition. Yet here Aroclor is acting more like a chlorinated aliphatic than a stable biphenyl.

Cornell Dubilier reported a strange phenomenon in testing Aroclor. If they run the dielectric constant first, they get a much better power factor value in the fluid, and reversing the polarity gives even a lower value. They theorize that some contaminant may be "plating out".

All this points to the possibility of there being trace materials present in Aroclor that are much less stable than the bulk of the chemical. If this is true, either removal or control by additives might push the stability up to the point needed by the capacitor manufacturers. Further, the criticisms made of the power factor might be answered at the same time.

Low Temperature

The higher the degree of chlorination of biphenyl, the higher the pour point of the product. Aroclor 1242 replaced 1254 and an appreciable gain was made at the low temperature end. All of the various Aroclor grades are made up of a mixture of isomers, and for the most part we don't know what the electrical and physical properties of the predominant isomers are.

G.E. has decided that this is a worthwhile approach to the matter, and have been doing laboratory work on separation of isomers and determination of characteristics. They have enlisted our aid and have requested samples of any pure isomers we have.

If improvements are to be made and patents to be gained, our control of Aroclor will depend on our being the ones to do it. It might be guessed that the manufacture of a single isomer would be economically out of the question. But, on the other hand, the problem might be solved by the removal of one isomer, or the addition of another, or a change in the conditions of chlorination.

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Power Factor and Contamination

The electrical losses in Aroclor over power frequencies (60 cycles to 400 cycles) is largely due to the presence of contaminants. Successive filtrations reduce the power factor accordingly. Improvement of the power factor could conceivably come from efforts to increase the high temperature stability if this is a matter of trace materials.

Cornell Dubilier reported interesting results in the use of Linde's "molecular sieves" in the removal of trace contaminants from liquid dielectrics. Fuller's earth and other clays have been used routinely to lower the power factor for 25 years and it wouldn't be too surprising if there were improved techniques available by this time. Judging from the widespread difficulties in keeping the power factor down in Aroclor, and the number of questions on better methods, any improvements will be welcomed by our customers.

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II COMPETITIVE DIELECTRICS FOR CAPACITORS

For the purposes of this survey, it does not seem necessary to study comprehensively the other dielectrics that are commercially or potentially available. However, a brief summary may be of assistance in visualizing the capacitor dielectric field as a whole. And in one case, the sulfones, a class of products is involved that is of direct interest to us.

The figures that are given for market size are from a variety of sources, and at best are estimates. They should be considered no more than indicative.

Mineral Oil and Waxes

Long the standard, these natural materials are gradually being replaced by synthetics. They have good electrical characteristics, but a low dielectric constant. They change values relatively little over wide temperature ranges, but are limited above about 125°C. by oxidation. The magnitude of the market for these materials which are used in small capacitors is probably around 2 million pounds and the value perhaps $200,000. Only a very small amount still goes into power factor correction.

Halowax

Halowax, or chlorinated napthalene, is one of the few materials that shows the anomalous behavior of maintaining a high dielectric constant after solidifying. It is used in D. C. capacitors, and light duty A. C. The sales are estimated at 300,000 pounds or $150,000.

Castor Oil

Castor oil has a dielectric constant as high or higher than Aroclor. It is somewhat more subject to electrical losses, oxidation and moisture. It finds use in small electronic capacitors. Yearly sales are estimated at 300,000 pounds or $65,000.

Polyisobutylene

This is a highly viscous polymer that is used to impregnate small capacitors. It has a dielectric constant about that of oil and which is relatively constant over a wide temperature and frequency range.

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Capacitors impregnated with polyisobutylene will meet JANC-25 characteristic E specifications. The annual market has been variously estimated between 150,000 and 600,000 pounds.

Dibutyl Sebacate

For most applications esters are too unstable hydrolytically to be used. However, for very high frequency capacitors that are used in industrial dielectric and induction heating, a liquid is required that maintains a low power factor at these frequencies. Dibutyl sebacate has this property as well as a dielectric constant of 3.6 which is appreciably better than oil. The market is estimated at a maximum of 100,000 pounds or $50,000.

Silicone Fluid

As will be seen, one of the important needs in capacitor dielectrics is for materials that can be used at higher temperatures. This need is so great that the capacitor manufacturers are paying $27.00 a gallon, or $3.20 a pound, for some of the silicones. These are characterized by a somewhat higher dielectric constant (2.76) than oil and very little change over a wide range of temperatures and frequencies. The estimated market is between 85,000 and 170,000 pounds a year or $270,000 to $540,000.

Ethylene Glycol

Strictly speaking, this is not a dielectric, and it is used in capacitors of a different type than are included in this report. Electrolytic capacitors consist of a double roll of aluminum foil immersed in an electrolyte of ethylene glycol, water and certain salts such as borates. The dielectric is formed from the aluminum oxide layer on the foil. The glycol acts as an antifreeze and improves the characteristics of the oxide layer when it is formed. In 1954 about 50 million dollars worth of electrolytic capacitors were produced. The consumption of ethylene glycol is estimated at 7,000,000 pounds for this use, or about $2.8 million.

IN 420

The Federal Telecommunications Laboratory received patents on a phenyl indane (a dimer of alpha-methylstyrene) and its chlorinated derivatives as dielectrics. Monsanto took a license under these patents and prepared development quantities which were submitted to the capacitor manufacturers.

IN 420, the dichloro derivative, was found to have a slightly higher dielectric constant than Aroclor 1254 (5.31 against 4.80) but its major

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advantage was a life on accelerated testing in D.C. capacitors about four times that of Aroclor. Other characteristics were about the same. The estimated selling price in volume was $0.75 a pound (about five times Aroclor's).

In 1954, after a year's development effort, it was concluded that the capacitor companies were not willing to pay anywhere near $0.75 for IN 420, and promotional efforts were concluded. In the course of our survey we received much the same impression. Only one company, Pyramid Electric, would have been willing to buy IN 420 (they still are, but won't pay $2.00 a pound for small quantities). Ralph Ruscetta of G.E. said that IN 420 wasn't worth a tenth of a cent more than Aroclor. Most of the other opinions were somewhere in between.

It would be a mistake to conclude from this that the capacitor manufacturers won't pay more for an improved dielectric than they do for Aroclor. As will be seen, there is a definite break-even point in the cost of capacitor dielectrics. IN 420 at $0.75 a pound is simply above it.

Sulfones

In a patent dated August 13, 1940, General Aniline and Film covered diaryl sulfones, such as dixylyl sulfone, and chlorinated diaryl sulfones as dielectrics. These materials have quite high dielectric constants, ranging from around 10 to 25. General Electric in 1946 patented mixtures of the sulfones in Aroclor; and in 1948, Westinghouse received a patent specifically on phenyl xylyl sulfone and tolyl xylyl sulfone in Aroclor by virtue of their lower pour points. According to the patents, the power factors of the sulfone-Aroclor mixtures are not excessive at low frequencies, and mixture of 50% tolyl xylyl sulfone in Aroclor 1254 has a dielectric constant of about 14.

We have had occasional inquiries for dixylyl and tolyl xylyl sulfone and at one time produced sample quantities of the latter for Westinghouse. We have a patent application on an improved method of preparing tolyl xylyl sulfone. The claims have been allowed, but the patent has not yet issued (Chadwick, St. Louis Case 1337). With our interests in organic sulfones in mind, we explored their status during the survey.

Apparently stabilization has been one of the stumbling blocks, and the power factor tends to increase over a period of use. Another factor has been the unwillingness on the part of the capacitor manufacturing departments to use more than one liquid because of difficulties in segregating equipment.

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However G.E. said that they plan to take another look at the sulfones. Westinghouse's Lighting Division is now having experimental units made up for them at Pittsburgh (with sulfone from G.A.F.), and they plan to put them into life tests. Westinghouse at Pittsburgh has their eye on these, and if they show promise will probably reactivate their interest, too. Dr. Franklin at Diamond Fuze Ordnance predicted that if a stabilizer can be found, the sulfones "would really go".

The prices the electrical industry are talking certainly confirm their willingness to pay more for a higher dielectric constant--a point that will be covered in detail in the next section. Westinghouse said that the sulfones would be economic for them at $1.00 a pound, and Cornell Dubilier said that they could break even paying $3.80 a pound.

Until more is known of the electrical characteristics of the sulfones in actual use, we can't be sure just where they will be used. But with a higher dielectric constant almost universally desired, there is potentially a good-sized market. If the sulfones were used in only 10% of the Aroclor sold for capacitors, at a concentration of 25% and at a price of $1.00 per pound, their sales would be worth over $300,000. It would take an extra 2 million pounds of Aroclor to gross this much.

The Development Department should certainly stay informed of this situation as it progresses, with the aim of evaluating our possible manufacture. Our Research activities on sulfones would fit well into a dielectric screening program as would the problem of stabilization.

Fluorocarbons

There has been considerable research into the electrical use of fluorinated organics. Though liquids can be prepared with very wide liquid limits and very low loss factors, they also have low dielectric constants. Further, their prices--thus far--are extremely high.

Hpwever, there is continuing work in this field and theoretical reasons at least that indicate that fluorocarbons may be of value as capacitor dielectrics. Zissman at the Naval Research Laboratories has prepared fluorinated esters that are said to be "hydrolytically stable". These show no change in electrical characteristics to below -75°C., and are of quite a bit of interest for military applications.

G.E. has apparently been looking into fluoro analogues of Aroclor. They reported these compounds do show improved electrical characteristics, but the economics make them unattractive (for a transformer fluid). G.E.'s Capacitor Division stated they were hiring a man experienced in fluoro chemistry to work in this field. Whether any fluorocarbon will ever achieve large-scale industrial or utility use can be questioned economically.

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but it will be surprising if, with their exceptional physical and electrical characteristics, they are not used in at least specialty applications.

III MARKETS FOR NEW DIELECTRICS IN CAPACITORS

Thus far we have looked only at the markets into which Aroclor is presently going for power factor correction and ballasts. Another major market is the electronics industry, and relatively little Aroclor finds use here. Electronic applications--all of which require numerous capacitors--can be conveniently divided into three types:

Commercial (radio, TV, communications)
Military (radar, missiles, etc.)
Industrial (control, induction heating, etc.)

Though there are no reliable figures on the value of the dielectrics consumed, it is a sizeable market. Over a billion capacitors were manufactured in 1955 and these were worth $200 million. The types that used paper and film were valued at over $100 million, and the dielectrics in which we are interested go into this market.

As something of a guess, 3 to 5 million pounds of dielectrics went into these markets. A good part of it was mineral oil or wax at a few cents per pound, but an appreciable amount of $3.20 a pound, silicones were consumed as well.

In the following section the need for new dielectrics in both power and electronic applications are reviewed. These represent the opportunities for new products and new markets.

A. A REPLACEMENT FOR AROCLOR

There is one subject that invariably comes up in discussing liquid dielectrics, and this is as appropriate a place as any to report it. A wide variety of views were encountered on the odds of finding a replacement for Aroclor--a product that would supplant Aroclor in its major applications.

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As has been noted, Aroclor has several strong advantages. G.E., Westinghouse, Bell Telephone, and others have spent millions of dollars in the search for better dielectrics, so far with little success. An old pro like Ralph Ruscetta may be right when he predicts another 20 years for Aroclor or an improved version.

However there are Aroclor's shortcomings that present an invitation for new products, and there is a less rational, but still valid motive to be considered. G.E.'s Capacitor Department said that they are under considerable internal pressure to get a new impregnant for capacitors. "If there were another dielectric that was no better than Pyranol (Aroclor), Marketing would probably insist on using it". In other words G.E., and the others as well, want a product they can call their own.

The comment is sometimes heard that any new dielectric to be successful will have to be cheaper than Aroclor. With Aroclor selling for 13.4¢ per pound in tankcars, a limit like this can discourage even the most enthusiastic chemist. However, if this were completely true, Aroclor would never have replaced oil at 65¢ a gallon.

Further, dielectrics are used on a volume basis--enough to fill a capacitor can rather than a certain weight. Thus a compound with a specific gravity half that of Aroclor's high value could sell at twice the price per pound and still be equivalent on a use basis.

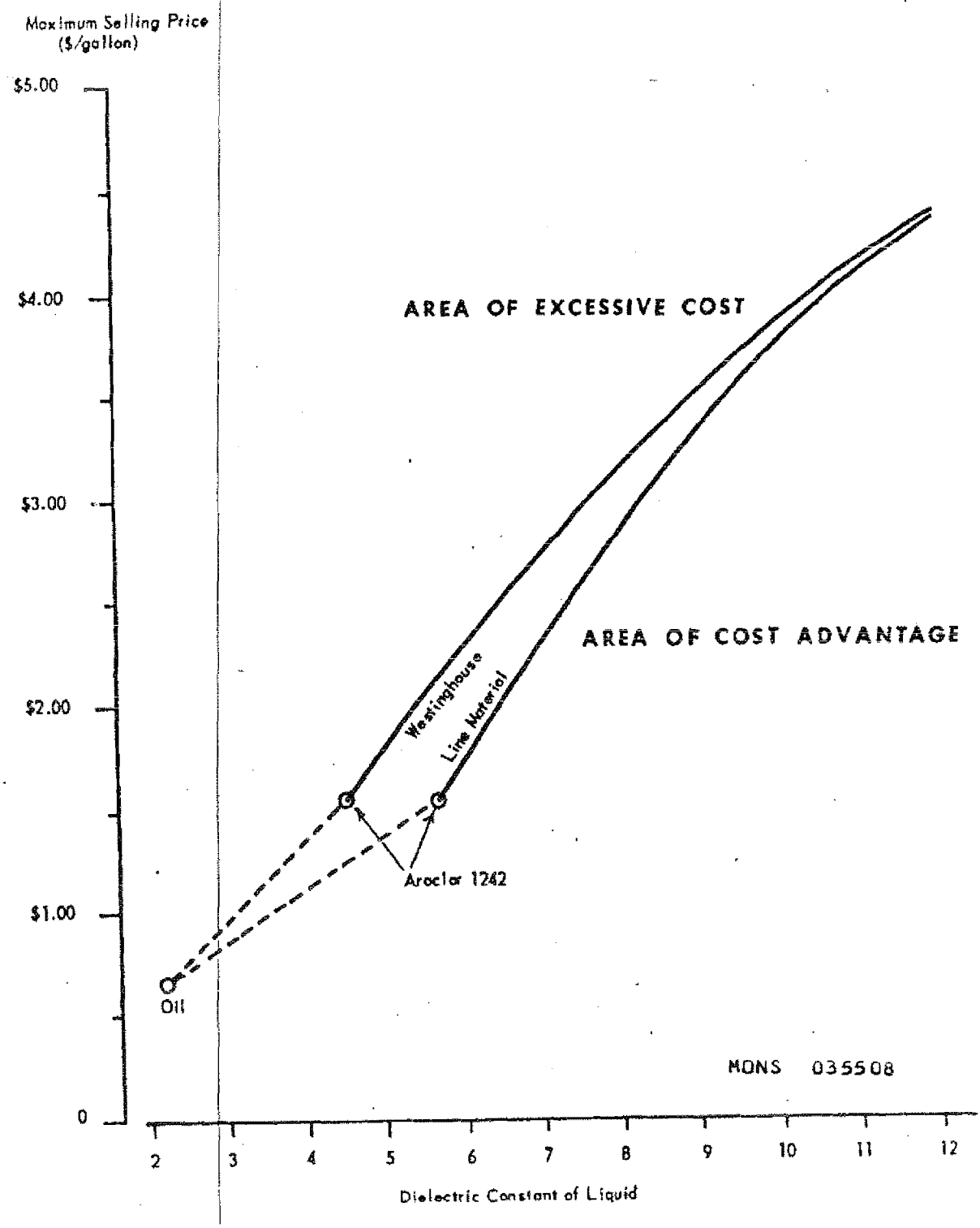
The capacitor business is of course like any other business. They will switch dielectrics when they can make more money with a new one. One of the best ways to reduce the cost of a capacitor is to use a liquid with a higher dielectric constant--the attribute that let Aroclor replace mineral oil. A higher dielectric constant allows the capacitor manufacturer to use not only less liquid, but less paper, foil and container as well (providing the power factor is not excessive). Thus it should be possible to relate the dielectric constant of an improved liquid to the amount of savings it will provide to the manufacturer. This value would represent the maximum that he could afford to pay for the new material.

Using this approach we managed to get two of the major capacitor companies to chart dielectric constant against maximum economic cost to them as based on their own operating and manufacturing data. These break-even curves are shown on the next page. It can be expected that if there is any bias in the figures it is toward a lower cost so that the values shown are probably conservative. Nevertheless, even these rough figures can be of considerable assistance in screening potential dielectrics and in choosing intermediates that can lead to economic products. It might be

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MAXIMUM PRICES FOR LIQUID DIELECTRICS

IN 2400 VOLT, 25 KVAR CAPACITORS



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noted that though the values were arrived at completely independently by Westinghouse and Line Materials, they are remarkably close to each other. They would have been practically identical had not Westinghouse shown an inexplicably low value for the dielectric constant of Aroclor.

It seems a fair conclusion that (a) the capacitor companies have reasons to want a new dielectric; and (b) if it is a better dielectric they will pay more for it. On the other hand the odds against finding a new dielectric that will fill the requirements will be high, as most known compounds have been pretty thoroughly evaluated.

This is the same sort of a situation that we face in agricultural and biological chemicals, and the answer that is valid there may hold for dielectrics, too. This is to select from the thousands of new compounds we make each year for a variety of purposes appropriate chemicals to be screened for electrical characteristics, and in this way uncover leads on new dielectrics. As will be seen in the following sections not only can this be considered "insurance research" to protect our stake in Aroclor, but will provide the application research toward new markets that Aroclor does not serve.

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B. LOW VOLTAGE A.C. CAPACITORS

One of the greatest needs for new dielectrics is in capacitors to go on the low voltage side of power lines, generally at 220 to 440 volts. Not only did the manufacturers like Westinghouse, Line Material and Cornell Dubilier stress this, but so did Detroit Edison as a customer. There are several advantages to putting the capacitor as close to the load as possible, but so far it has been too expensive.

According to Westinghouse, it costs them about 2.5 times as much to build a Kvar for 240 volts as it does for 2400 volts (due mostly to the higher cost of the thinner paper necessary). A liquid with a dielectric constant half again as high as Aroclor would drop their cost to 1.5 times as much as the high voltage units, and the impression was gained that this might be a realistic price in view of the advantages the power companies would receive.

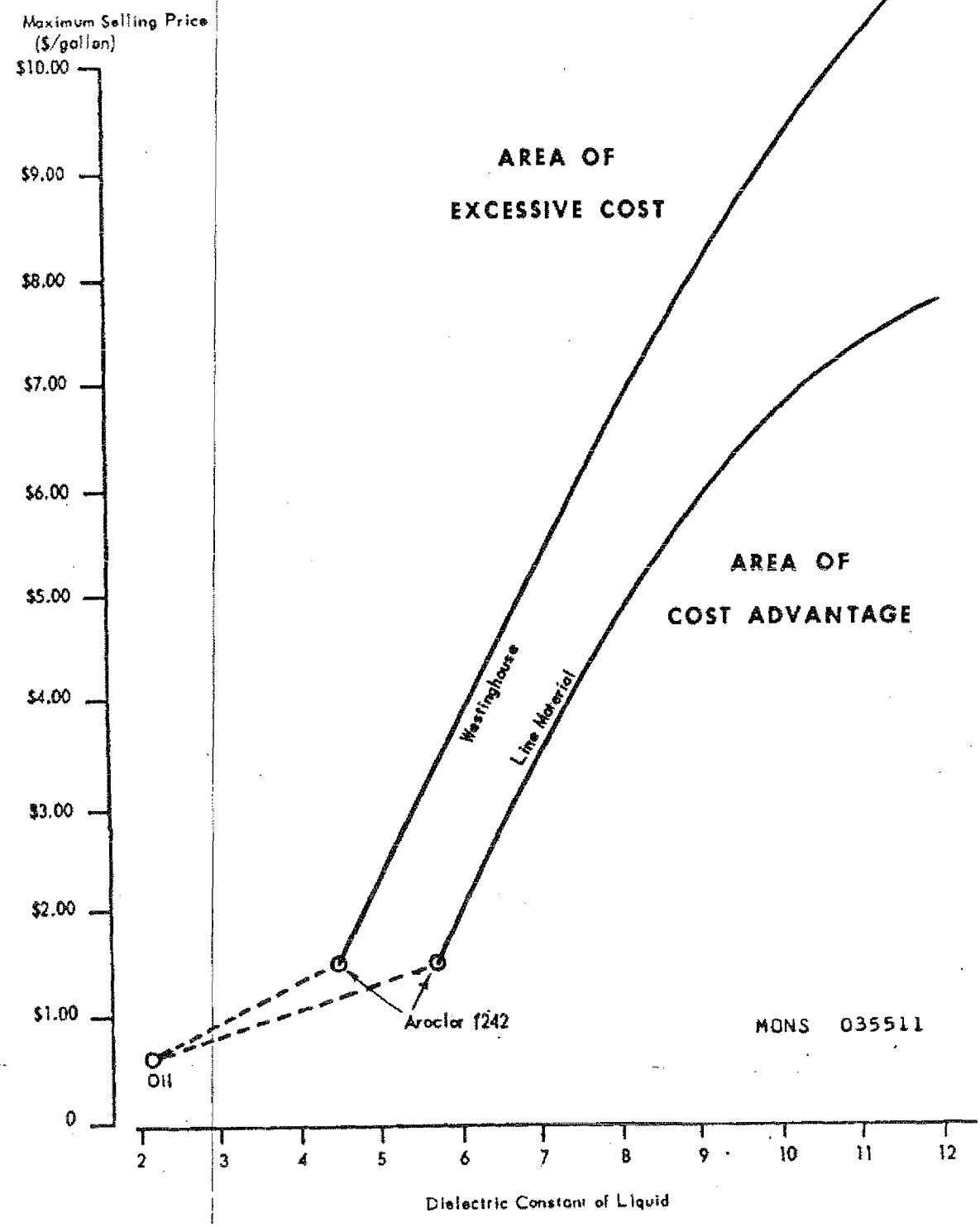
As in the case of a replacement for Aroclor, we probed for some actual figures on what better dielectrics were worth to the manufacturers. The curves we obtained from Westinghouse and Line Materials are shown on the next page. Though the values from the two companies show a greater difference than in 2400 volt capacitors, there is no question of the greater economic advantage in this application. A liquid with twice the dielectric constant of Aroclor could command a price around $0.70 per pound if it had the same specific gravity, or $1.00 a pound if it had a gravity of around one (Aroclor is 13.4¢/lb.).

That the capacitor manufacturers think this is an important market is indicated by the fact that Westinghouse plan to put most of their emphasis on the development and improvement of low voltage capacitors. At present only 10 to 15% of their production is of low voltage units, but this would be a great deal larger if the price were competitive with the bigger units. A portion of this market would probably come out of high voltage Aroclor capacitors, but Westinghouse envision important new markets: for example, putting capacitors on every machine in a plant instead of at the high voltage side of the power center where only the <u>average</u> value of the load is corrected.

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MAXIMUM PRICES FOR LIQUID DIELECTRICS

IN 230 VOLT CAPACITORS



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C. HIGH TEMPERATURE CAPACITORS

In line with practically every other field, there is a drive to operate capacitors at ever increasing temperatures. Much of this impetus comes from the military of course, but even in non-military applications capacitors are being pushed to their upper limits. At the same time, for military use lower temperature specifications are being set. For these applications the capacitor manufacturers will accept quite modest electrical characteristics as long as they can get the right physical ones.

The total market for suitable materials is problematical. Silicone fluid is being used at present at $27.00 a gallon or $3.20 a pound. The estimates of total silicone sales ranged from 10,000 to 20,000 gallons a year for a total value of between $270,000 and $540,000. Obviously, price is no object here.

For jet engine ignition systems Aerovox needs a fluid stable from -65°C. to 200° to 250°C. The dielectric constant would preferably be above 4; the dielectric strength around 30KV; and a power factor of 0.3% or lower. They are now using silicones as is Cornell Dubilier. G.E. envisions a 15,000 gallon per year market for a liquid with a dielectric constant of greater than 2.2 (oil) that will operate at 150°C.

Sprague Electric is interested in a liquid which will be stable (electrically) above 125°C.; has a resistivity of greater than 10^{12} ohm-cm. at 125°C. to 200°C.; 60 cycle power factor of less than 0.5% and 2 to 3% at zero; and a dielectric constant of greater than 2.5. If such a material were priced at $2.00 a pound or less they estimate a total market of as much as 200,000 gallons per year (!).

We have had a little experience with this market already, and without our effort (or even our knowledge for quite some time) OS-45, our silicate ester fluid, has been going into the electronic industry as a dielectric-coolant for air-borne radar. Though its intended use was high temperature hydraulics, last year, as mentioned earlier, half of the total sales of $120,000 went to electronic applications.

And obviously this is an application that fits well into our present programs. With laboratory work underway on functional fluids and high temperature lubricants, we are preparing materials that will have many of the required physical characteristics. These same materials, or modifications, may also possess the necessary electrical properties.

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D. LIQUID DIELECTRICS FOR MYLAR

Mylar, duPont's terephthalate ester, is about the first film that has found extensive use in the electrical industry. Its chief virtues in capacitors are higher temperature stability than paper and lack of moisture absorption. On the other hand it is expensive--several times the cost of paper. DuPont is apparently having trouble maintaining consistent electrical characteristics from batch to batch. It is sensitive to corona discharge, subject to pinholes, and poorly wetted by liquid dielectrics (and herein lies an opportunity).

Nonetheless, Mylar is an improvement and almost all of the manufacturers are using it or are planning to. Bell Telephone plans to replace paper with Mylar throughout its system. Even in power capacitors Westinghouse says that its price is almost competitive with paper in 230 volt capacitors (because of the thinner films possible) but it will have to come down a great deal to go into high voltage power capacitors.

The point that practically everyone using Mylar made was that they need a liquid that will wet Mylar readily to impregnate the capacitors. Mineral oil, even with vacuum impregnation, takes days to find its way between all the layers. Without an impregnant, pinholes and corona discharge quickly start degrading the Mylar.

We asked whether Aroclor could be used and found two opinions, "No", and "We don't know", but very little fact. DuPont state in their Mylar bulletin that Aroclor can be used. Bell Telephone say Aroclor will dissolve Mylar at 150° to 200°C., but they haven't actually tried it as an impregnant. G.E. and Westinghouse at Pittsburgh say Aroclor can't be used, and Westinghouse at Cleveland don't know. But every one of them--and others--want a suitable impregnant. Only Westinghouse would like to have it non-flammable and this only for their power capacitors.

It should not be too difficult for us to determine if Aroclor wets or attacks Mylar, and with our knowledge of surface phenomena, and perhaps a few simple wetting tests, we should be able to tell whether any classes of our chemicals <u>are</u> adaptable. Or, since this must be a matter of some concern to duPont, we may want to work up a cooperative program with their application lab. (The man to contact at duPont in such a case is Mr. R. C. Meyers, Manager, Industrial Sales, Film Department, Wilmington, Delaware.) The market for a satisfactory product will probably not be large at present, but it is growing.

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E. SOLID DIELECTRICS

Throughout all the discussions on capacitor dielectrics thus far we have been talking about liquid dielectrics. We had expected originally to stick to this limitation as it avoids getting involved with the polymeric materials that are used as films or potting compounds, or even, in the case of Epon resins, as impregnants. We still feel that these materials are outside our cognizance, both by reasons of organization and competence.

But a solid doesn't have to be a polymer, and the only thing that separates a liquid from a solid is its melting point--which doesn't have to be below room temperature. And there are some very interesting markets for solid dielectrics.

According to estimates reported by Paul Benignus, about 300,000 pounds of Halowax (chlorinated napthalene) and 150,000 pounds of polyisobutylene will be used in 1956. Both of these are practically solid at room temperature. We have no report on the amount of wax that is used in small capacitors, but it is probable that the majority of the 400 million paper and film capacitors produced last year contained wax. At a conservative figure of 2 pounds of wax per thousand capacitors, a total of perhaps 500,000 pounds of wax was used.

As was illustrated in the thumbnail review of electrical theory, the dielectric constant of most liquids drops radically when the liquid cools to solidification. A few materials perversely refuse to follow this behavior and maintain their dielectric constant in spite of becoming solid. Halowax and polyisobutylene are such compounds.

A few years ago the Bell Telephone Laboratories discovered that lanosterol from sheep's wool had an amazingly high dielectric constant--from 8 to 12. Further it showed this anomalous behavior of maintaining its high value to very low temperatures. In fact the dielectric constant in the solid is much higher than in the liquid.*

Unfortunately, the amount of lanosterol available from sheep's wool is very limited, and its recovery in most cases is not economically feasible even at high prices. The Bell Labs said that a material like this would be used commercially at a dollar a pound and could have extensive use at 50 cents a pound. They might use 10,000 pounds a year or more themselves, and estimated the total market at upwards of a million pounds.

*(A copy of the unpublished paper from Bell Telephone Laboratories is available.)

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Most of the lanosterol molecule is probably electrically inert, and it is at least conceivable that similar but simpler structures could contain the active groups. If so, it might be of interest to consider some of our steroid intermediates and by-products in this light.

But it is quite possible that solids with high dielectric constants can be found in other classes of compounds. Solids, even when they don't have high dielectric constants, have advantages in small capacitors. Tight containers are unnecessary, leakage is no problem and usually the dielectric constant is relatively stable over wide temperature ranges. Aerovox, Astron, Cornell Dubilier, G.E., and Diamond Ordnance are all interested in having better solid dielectrics. Clark at G.E. predicts that eventually even the big power capacitors will use solid instead of liquid dielectrics.

F. DIELECTRICS FOR METALLIZED PAPER

A somewhat similar problem to the dielectric for Mylar is the need for a non-corrosive dielectric in metallized paper capacitors. These units consist of windings of paper which have an aluminum film deposited (by vacuum metallizing) directly on the paper. This allows a smaller capacitor and has the very desirable property of "self-healing". If there is a pinhole or flash-over through the dielectric, the metal and paper are consumed around the fault, and the short is corrected. Unfortunately, if Aroclor is present enough HCl is released to cause progressive deterioration of the entire unit.

A satisfactory dielectric would be either liquid or solid (melting below 125°C.), it should have a dielectric constant greater than oil (2.2), and it should not give off corrosive products when arcing or sparking occur.

Some 3 million metallized capacitors were manufactured in 1955. About 5 pounds of impregnant are required per thousand capacitors which indicates a total market at present of only about 15,000 pounds. This is not enough to justify research, but it may provide another outlet if suitable products are developed for other uses.

G. MILITARY APPLICATIONS

Military requirements take a surprisingly large share of all electronic production. Out of the total manufacturers' sales of electronic

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equipment in 1956, which is estimated at $8.4 billion, $3.8 billion or 45% will be for military purposes.

The needs of the military for improved dielectrics have been covered, at least in part, in previous sections. Essentially they need operability from -65°C. to 200°C., or higher. They want as high a dielectric constant as possible to cut down on size and weight. And they need extreme reliability.

It would have required a great deal of digging to get information on the quantities of dielectrics in different applications, as these matters quickly get obscured by security. Though the totals are included in the 1.1 billion capacitors produced in 1955, we don't know what proportion or what type the military took. Mr. Benignus has estimated that under Specification JANC-25, characteristic E (which Aroclor does not meet because of low-temperature characteristics), there may be 1.5 million pounds of dielectrics used.

We do know that the military can be a prime customer for improved dielectrics. At Diamond Ordnance Fuze Laboratory we were told of the need for a better liquid dielectric, and that a suitable material could command a development price of as much as $25 a pound. The requirements for one type of fuze could run 1.5 million pounds, and in this quantity they could afford $4 to $5 a pound.

It is usually pretty hard to justify very much work for military needs except on a contract basis, and dielectrics would be no exception. However, if improved materials are found, the military could provide the initial justification for production.

H. D.C. CAPACITORS

Most of the applications which have been discussed have involved alternating current capacitors. In power filter circuits direct current capacitors are needed and mineral oil and specially inhibited Aroclor are presently used in these units.

Sprague Electric indicated a need for a dielectric for D.C. that can be used at higher temperatures than Aroclor, say up to 125°C. The dielectric constant should be over 3 and the other electrical characteristics similar to oil. Cornell Dubilier want a dielectric for D.C. capacitors that can be used from -55°C. to 100°C. They need a dielectric constant of 8 to 10, but the power factor can be fairly high--perhaps 2%. They

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estimate the market for such a product at "perhaps 20% of present Aroclor sales". If by this they mean Aroclor sales in small capacitors, the market would be around a million pounds.

I. HIGH FREQUENCY CAPACITORS

One other relatively small application is that of capacitors which are used for high frequencies as in induction and dielectric heating. In this application a liquid which maintains a low power factor and high dielectric constant at very high frequencies is required. Dibutyl sebacate is now being used at $4.50 a gallon. However, the total market is probably less than 100,000 pounds a year, or $50,000.

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DIELECTRICS IN TRANSFORMERS

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I INTRODUCTION TO TRANSFORMERS

Electrical transformers consist essentially of two coils of wire wound on an iron core. They are used most often to "step up" or "step down" the voltage. They range in size from a doorbell transformer to power transformers nearly as large as a house. The smaller transformers, "specialty transformers", do not use appreciable quantities of Aroclor, and in this survey we will consider only the larger transformers which are used to transmit and distribute power.

A generator may typically put out voltage at 11,000 volts (11 Kv). A transformer will step this up to 130 Kv for the long lines into a city, as the losses are lower in high voltage transmission. At the edge of the city a "ring sub-station" transformer drops the voltage back down to 22 Kv and this is carried to distribution sub-stations within the city where a transformer again lowers the voltage to perhaps 4 Kv. Power is carried at this voltage to the pole-mounted transformers that drop the voltage once more to 220 volts for homes or 440 to 660 volts for industries.

These transformers are generally divided into "power transformers" which are rated at 500 to 1,000 Kva (kilovolt-amperes) or above, and "distribution transformers" which are generally smaller than 1,000 Kva. Among the distribution transformers are two special classes: load center transformers and network transformers. If this is regarded as interesting but rather useless information, it should be noted that it is only in these two last classes of transformers that Aroclor finds any appreciable consumption.

A load center transformer is used, for example, in an industrial plant where the power demand is reasonably high. The voltage comes into the plant as high as the power company can supply it, and it is stepped down as close to the point of use as possible. In this way appreciable power losses are avoided. A network transformer is the type that is used below the sidewalk in downtown areas where there are concentrated power demands. It can be quickly seen that in both of these types of installation, fire hazard is an important consideration.

One other series of classification is necessary to understand where and why Aroclor is used and the changes that may seriously affect our Aroclor sales. There are four basic types of construction of transformers: ventilated dry, sealed dry, oil, and Aroclor. The difference lies in the dielectric used to insulate the coils from each other and from the metal case. In the ventilated dry type air is the dielectric; in a sealed dry transformer an inert gas such as nitrogen is used. In the other two classes

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oil or Aroclor is used. In all cases, the dielectric constant is relatively unimportant. The critical electrical properties are dielectric strength, impulse strength and power factor.

Below is a summary of the relative advantages of each method of construction in chart form. The choice of a transformer for any installation will depend on the balance between these and other less important factors. Essentially, oil-filled transformers have the advantages of low price, good electrical characteristics, and low noise. Aroclor-filled transformers are fire-resistant, can be used anywhere, have good electrical characteristics (up to a point) and low noise. Open, ventilated transformers are light in weight. The dry, sealed type can be used anywhere, are fire-resistant and require no maintenance.

TRANSFORMER COMPARISON

	LIQUID FILLED		DRY	
	Oil	Aroclor	Open Ventilated	Sealed
Price	75%	100%	100%	120%
Impulse Strength	100%	100%	50%	50%
Weight	80%	100%	65%	85%
Noise Level	"X"	"X"	"X" + 10db.	"X" + 10db.
Applications:				
Indoor	Vault	OK	OK	OK
Outdoor	OK	OK	NO	OK
Submersible	OK	OK	NO	OK
Fire-Resistant	No	Yes	Yes	Yes
Maintenance	Some	Some	High	Low

On the face of it, it would appear that Aroclor should be at least holding its own in getting new business, but a combination of factors--some valid and some perhaps not--is losing business for us. These influences are covered in some detail in the following.

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II AROCLOR IN TRANSFORMERS

In about 1930, while G.E. was testing Aroclor as a capacitor impregnant, there were several serious fires that started from oil-filled transformers. G.E. tested a formulation of Aroclor and trichlorobenzene for transformer use and by 1932 had introduced it commercially. The only alternative at that time was the dry, ventilated transformer and these had the drawback of requiring clean, dry operating conditions. Had the dry, sealed transformer been available in 1930, it is possible that Aroclor would have never been used, but the sealed transformer had to wait on the development of the silicones and other high temperature insulations before it could be built.

The hazard from fire in a transformer at a power generating station is not large. Sprinkler equipment is usually provided if there are buildings near. Most distribution transformers are in an isolated building or yard, and even pole-mounted transformers are considered relatively safe since they are nearly always some distance from homes and buildings. The primary places that a transformer fire could lead to extensive property damage are in load center installations where the transformer is in the middle of a plant or building, and network transformers that are adjacent to buildings (and pedestrians). It is in these two applications that most of the transformer Aroclor has gone, and is now in some danger of being supplanted by dry, sealed transformers.

There is no argument that Aroclor has served a useful purpose in the past. The question now is whether it has outlived its usefulness, and a good many important people think it has. In the following we will try to cover why many customers are ready to bury transformer Aroclor; why they may, in part, be wrong; and what the possibilities are of rejuvenating this market. It's well worth thinking about, because last year we sold 7 million pounds of Aroclor for transformers, and in ten years this could be more than doubled.

A. MARKET SIZE

In considering the transformer Aroclor market, we are looking at a pretty small part of the business. Most manufacturers estimate that in less than 5% of the installations is fire hazard important. In terms of the liquid used--Aroclor--it is even less. Over 20 million gallons of transformer oil were used last year against a half-million of Aroclor. Probably not more than 1 or 2% of the transformers sold contain Aroclor.

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Power transformers are practically all oil-filled, with only a few dry. Distribution transformers as a whole are estimated at less than 5% Aroclor filled. Using Westinghouse sales as an example, the two types of greatest interest to us are shown below:

	1950	1955
Load Center Transformers:		
Oil	-	15%
Aroclor	-	25%
Dry	-	60%
Network Transformers:		
Oil	50%	60%
Aroclor	50%	35%
Dry	-	5%

Repeated comments that the dry-type transformers are taking Aroclor business were heard. G.E., Westinghouse, Allis Chalmers, Wagner, and Maloney all concurred. Even installed transformers are involved, with Potomac Power replacing 40 Aroclor-filled network transformers with the dry type. Our own Union Electric Company is replacing askarel with oil in the downtown area. Westinghouse indicated that in the last three years they have gotten about twice as much business as G.E. in networks and load centers because they have been pushing dry, ventilated while G.E. has promoted Aroclor-filled transformers.

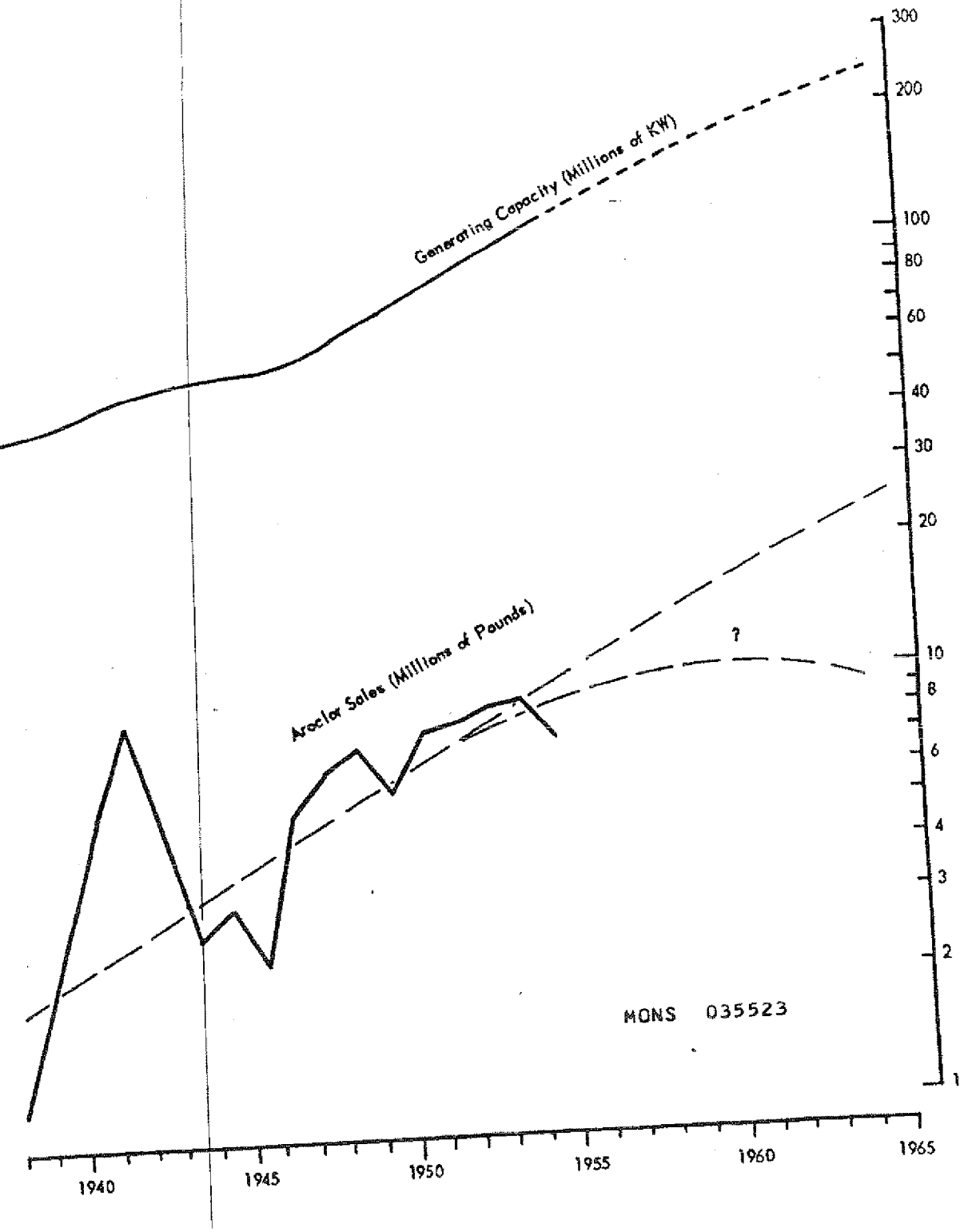
On the next page is charted the sale of Aroclor for transformer use since 1938. The peak in 1942 was caused by the requirements of the U.S. Navy for Aroclor-filled transformers. The downturn which started in 1953 is more noticeable when compared to the sales of load center and network transformers. Based on the first half of 1956, the sales look somewhat better, but they still indicate a levelling off.

Year	Sales of Aroclor (lbs.)	Sales of Load Center Network Transformers ($)
1952	7,890,000	18,000,000
1953	8,600,000	20,500,000
1954	8,660,000	26,000,000
1955	7,140,000	40,900,000
1956 (est.)	9,000,000	--

Also charted on the next page is the generating capacity of the utilities which can be considered the common denominator of the electrical industry. As can be seen, the growth of Aroclor sales has not kept

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SALES OF AROCLOR FOR TRANSFORMERS



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pace in recent years with the growth of the electrical industry. If it were to parallel generating capacity, we should expect to sell around 25 million pounds of Aroclor for transformers in 1965. It looks pretty definite that we won't sell anything like this, but how much we will sell will depend more on the action we take in marketing and technical fields than on the extrapolation of the sales curve.

B. THE PROS AND CONS OF AROCLOR IN TRANSFORMERS

Not since we asked the disinfectant industry for suggestions on new chemicals have we heard so many criticisms of a product. Rightly or not, Aroclor is considered a thorn in the side of every transformer manufacturer and user by both those who have had experience with it and those who haven't. A number of the criticisms are consistent--but they may be consistent for the same reason that a lot of rumors and superstitions are prevalent; nobody bothers to put a stop to them. There is reason to believe that at least some of Aroclor's criticisms are unjustified or made to appear worse than they are. In the following an effort is made to collect and classify the criticisms and, insofar as we are able, to analyze them on objective grounds.

Aroclor's Advantages:

Aroclor's only reason for use in a transformer is, of course, its non-flammability. This is important when the transformer is to be installed indoors. Compared to the dry-type transformers which contain air or an inert gas, Aroclor has the advantages of higher dielectric and impulse strength and lower noise level.

Once this is said, it about covers Aroclor's strong points. Against these must be weighed a rather extensive list of real or imagined faults.

Flammability vs. Explosibility:

Ranking close to the top of Aroclor's handicaps is the feeling that though Aroclor can't burn, it has exploded and released large quantities of HCl, and there isn't much to choose between the two situations. What apparently happens is that there is a short in the transformer which causes an arc. If it is a "stewing short" the pressure build-up is slow and quite a bit of Aroclor can be decomposed. A heavy arc will cause a fast pressure increase and rupture of the tank.

In the early forties, an Aroclor-filled transformer exploded in a public building in Philadelphia apparently as the result of a stewing arc. The

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HCl released caused about as much panic and damage as a fire would have, and reportedly the damage claims and lawsuits were extensive. Union Electric claims to have had several explosions with Aroclor. One, beside Vandervoorts, caused about as much of a mess as a fire would have. Another case was an explosion in a subway that required evacuation of all adjacent people.

As mentioned, several utilities are reported to be going back to oil or over to dry transformers because of this characteristic of Aroclor. General Motors, since the Livonia fire, has been replacing both oil and Aroclor with dry transformers. Potomac Power in Washington, D.C., are replacing 40 Aroclor transformers for this reason.

There is no doubt that this is a serious matter, but there is reason to believe that it is not as bad as it is made out. Everyone knows about the few cases that have occurred, but no one mentioned how seldom it happens, what the odds are against it, and what the average service life is. This is the first example of situations in which good technical relations and sales promotion might help a great deal. And though this won't be covered until a later section, there is no reason why the transformer manufacturers should provide this service.

Price:

The "high price" of Aroclor was nearly always mentioned as one of its major handicaps. The price was considered high as compared to oil, of course. The extra 25% in cost of an Aroclor-filled transformer results from the higher cost of the liquid, the special insulating materials and handling needed.

Yet there were some pretty responsible people at places like Westinghouse and Allis Chalmers that felt a higher price would be justified if some of Aroclor's deficiencies were overcome. The feeling was gained that price is a simple (and popular) thing to complain about, but the real basis for the discontent lay in some of the other factors.

Impulse Strength:

It will be remembered that the impulse strength is the ability of a dielectric to resist a suddenly applied voltage, as in a lightning stroke. A high impulse strength is important in transformers because of the possibility of such power surges.

It is very peculiar that Aroclor, which has a higher dielectric strength than oil, when in the press-board used in transformer construction has a considerably lower impulse strength than oil. Quite a bit of work has been done on trying to find out why this happens and to correct it, so far with little success.

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What this means in terms of transformers is that greater distances between windings and the transformer shell must be provided. Up to about 16 Kv an Aroclor transformer is the same design as an oil, but above this special design is necessary. If Aroclor could be used routinely above 16 Kv. it would be a big advantage over the dry type which have poor impulse strength and have 16 Kv as their upper limit. Further, it would place Aroclor in a much stronger position vis-a-vis sulfur hexafluoride, which may in time be a serious threat.

Another interesting case of everyone "knowing" something, but no one knowing why, turned up here. One of the limitations of Aroclor that almost everyone was sure of was that it can't be used above 69 Kv. This is serious, as the trend in transmission voltages is upward. Duquesne Light even said that they had ordered two 138 Kv transformers from G. E., but that G. E. had never delivered them because of "design problems". Everyone at Maloney Electric were convinced that 69 Kv was the top. None knew where he had heard it, but all were sure that 69 Kv was the biggest G. E. had built.

Then in talking to Clark of G. E., we learned that "there is no inherent reason why Aroclor cannot be operated above 69 Kv". He implied that the early engineering data did not support this limitation and that it was simply a policy that had no reason. Westinghouse claimed the top limit on Aroclor is 100 Kv.

Again, there is no transformer manufacturer who has much of any incentive to determine just what the maximum voltage is, whether it can be improved as some say it can in the light of present-day knowledge, and to correct the industry-held misconception.

Power Factor:

As in the case of capacitors, the power factor of the dielectric is a measure of the amount of energy lost in heat. Similarly in a transformer it has no relationship to the amount of energy being put through the coils.

For years the power factor of oil has been measured, and they have found that this is a good means of determining when the oil should be replaced. A consulting company by the name of Doble Engineering has promoted this method (and their equipment for measuring it) extensively. It isn't too surprising that transformer users apply this same test to Aroclor-- without justification according to Westinghouse.

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Unfortunately, Aroclor because of its higher dielectric constant, is more susceptible to contamination which results in a higher power factor. Almost everyone complained about this and was concerned about it. The only people who weren't were those who knew the most about it.

Duquesne Power said that oil usually runs 2 to 3% power factor, and then said (with almost horror) that sometimes they find Aroclor in transformers with a value of 20 to 30%.

Then we learned from the Transformer Division of Westinghouse that power factor is an "overly-emphaszied" subject. Even at 25 to 50%, the actual loss of energy in the liquid is still less than that lost by the copper and iron in the transformer. It isn't the value of the power factor that is important, but the change in value that may be indicative of things happening, like contamination. G.E. has run life tests on transformers at 15 to 20% power factor that have lasted just as long as at lower values.

This isn't to say that contamination and power factor aren't important in transformers. They are, and they are a particular problem with Aroclor, where everything from rubber hose to water will cause trouble. But when Duquesne writes the service department of Westinghouse reporting concern over the power factor and they get back a letter (which we saw) saying in effect, "Tough, but it's what you have to expect from Aroclor", it seems that there are things that can be done to improve the situation. Wagner Electric thinks that G. E. is primarily responsible for the confusion on power factor, and that they should have cleared it up years ago.

A good part of what might be done falls again into the area of technical relations and sales promotion. In addition, there are some other approaches, such as the possibility of using Doble Engineering as consultants to investigate the true importance of power factor in Aroclor.

Toxicity, Etc.:

There were a number of other complaints about Aroclor. "Toxicity" was one of the major ones, but usually they were referring to the occasional case of dermititis that occurs. The odor and its persistence were criticized as were the difficulties in handling it; they can't use their standard oil equipment. Others couldn't find satisfactory gaskets.

The fact that transformer Aroclor is a mixture of Aroclor 1260 and trichlorobenzene has raised problems in the vacuum impregnation of transformers as the trichlorobenzene tends to distill off. There are possibly other drawbacks to the trichlorobenzene and these are discussed further in the following section on improvements in Aroclor.

The weight of Aroclor is another disadvantage. Not only does Aroclor's high specific gravity make an Aroclor-filled unit the heaviest of any type of construction, but since the dielectric is purchased on a volume basis, it makes it more expensive.

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C. NEEDED IMPROVEMENTS IN AROCLOR

We can safely say that Aroclor does have several shortcomings in transformers. A valid question is what, if anything, can we do to improve it. As will be remembered from the discussion on capacitors, we have a vital stake in making patentable improvements on Aroclor, as this will tend to re-establish our control over the product and decrease the likelihood of competitive manufacturers.

There has been a lot of work done on Aroclor's deficiencies, but it may not be safe to assume in this case that all of even the easy or obvious possibilities have been explored. Most of the men who have worked on it have been best versed in electrical theory, and there is no one that knows Aroclor and its chemistry as well as we do (which actually may not be claiming as much as we would like). We can't graphite any lab experiments here to prove this possibility, but we did ask some of the top experts in the country whether improvements in the important weakness were feasible or even theoretically possible. By and large their answer was yes.

Impulse Strength:

Transformer Aroclor is usually about 60% Aroclor 1260 and 40% trichlorobenzene. Tin tetraphenyl is added as an HCl scavenger. Originally the trichlorobenzene was appreciably cheaper than the Aroclor and this mixture gave about the most economical product with the right characteristics. Today there seems to be a question of whether a straight Aroclor might not be just as cheap.

Trichlorobenzene may be more than just a problem during vacuum impregnation. In a paper published by Dakin and Works of Westinghouse*, they gave the following figures for impulse strength in liquid-impregnated press-board:

Dielectric	Average Impulse Strength (Kv)
Mineral oil	82
Transformer Aroclor	64
Trichlorobenzene	62
Capacitor Aroclor	81

One might be a little inclined to be suspicious of the trichlorobenzene since Aroclor without it is almost as good as oil.

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*Trans. Am. Inst. Elec. Engrs. 71, Pt. 1, 321 (1952)

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Dropping trichlorobenzene and switching Aroclors in the formulation may not be the answer, of course. Dr. Callinan, of the Naval Research Laboratory, gave some convincing evidence that it should be possible to improve the impulse strength by means of additives of a considerably different sort than have been previously tried.

In any event, the problem and the market is important enough for us to make very certain that it isn't soluble by any reasonable amount of work on our part.

Power Factor:

The other major technical objection to Aroclor in transformers was based on power factor. Much of the feelings of customers is exaggerated, and this part of the problem can't be solved at the lab bench. But Aroclor is extremely sensitive to contamination, and transformer manufacturers do have to do everything but stop breathing to avoid excessive power factors when they fill transformers (and it might help if they would).

This problem is identical with the one discussed under capacitors. If a means can be found to make Aroclor less sensitive to thermal and U. V. breakdown, and better methods of removing contamination can be developed, it will be invaluable in both the major Aroclor applications.

D. MARKETING PROBLEMS

As Nanki-Poo said to Yum Yum in Gilbert and Sullivan's Mikado:

"Here's a pretty mess."

If this seems a little strong, note that

item: The utilities that have Aroclor in their transformers don't like it and some are even taking it out.

item: Those that don't have it are afraid of it.

item: The transformer manufacturers have more trouble with Aroclor than with oil, and make less profit on their sales.

item: And we, the only ones who would like to see Aroclor go into transformers, have no contact or influence with those who decide what kind of transformer to buy.

Perhaps it is far more surprising that we sold seven million pounds last year for transformers than is the fact that sales are not keeping up with the electrical industry.

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There are some real problems in the use of Aroclor in transformers, and these have been discussed. There are certain improvements that are (at least theoretically) possible on the technical side such as impulse strength and upper voltage limit, and the possibilities of improving these should certainly be evaluated. In a somewhat different category it seems fairly certain that such characteristics as power factor and explosions have been exaggerated far beyond their true importance. And, finally, even if every criticism they make of Aroclor is true, there are still some ways (legal and ethical) by which we should be able to prolong the sales life and volume of Aroclor in transformers.

By way of background, it may be remembered that up until very recently G. E. held patents on the use of Aroclors in capacitors and transformers and collected a royalty on each pound sold to the other electrical manufacturers. In the transformer field they pioneered Aroclor and up until four years ago provided the know-how and technical service to all users. At that time the service end was turned over to us.

One other fact is important in looking at the marketing problems and that has to do with how transformers are sold. If a utility company decides that they need a transformer, they will specify the type, size and characteristics in an order to a transformer manufacturer. It is seldom that the manufacturer even knows where the transformer will be installed. If an architect designs a shopping center he will specify to the contractor the conformance to local codes and where the transformer will be installed, but the choice of brand and type of transformer will probably be made by the electrical sub-contractor and/or the utility company. Thus the transformer manufacturers are between us and the consumer of Aroclor, and at present we have no contact with any of the people who decide whether or not to use Aroclor.

Our Problem with the Transformer Manufacturers:

The transformer manufacturer, obviously, is in business to sell transformers. He will give preference to selling the one that gives him the greatest profit and requires the least service. His feelings toward air, oil and Aroclor are going to be based upon what the materials do for him and his customers. To a great extent he is going to like whatever his customers like.

A great many customers are convinced that power factor is a big problem with Aroclor, and that packings won't hold, and that it is toxic, and there have been lots of explosions, and so on. In the case mentioned earlier, even though Jim Ford, Manager of Westinghouse's Transformer Division Engineering Department, stated that the emphasis on power factor has been placed there by their customers without justification, their Service Department in Pittsburgh replied to a complaint of Duquesne Light on Aroclor's

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power factor that it was just one of those things you have to expect. And to further confound the situation, Jim Ford went on to say that "in the last ten years complaints (on Aroclor) have been practically nil", and he undoubtedly was being honest. Those in the company that know the answers aren't in contact with those that service the customer, and those that know don't educate those that don't know. Why should they?

The man in Westinghouse who is in charge of the sales of Aroclor-filled transformers (he is equivalent to one of our product managers) stated indirectly that they have little or no incentive to sell this type of transformer. He implied that their profit was less on these units than the other competitive types. If this is true, it would be hard to blame Westinghouse for not going all out to sell Aroclor.

The General Superintendent of Transmission and Distribution of Duquesne Light put the problem very simply: "You people should not depend on Westinghouse or General Electric to sell your fluid for you".

There are at least a couple of ways that we can establish the essential contact with potential customers that the transformer manufacturers appear to have neither the incentive nor the desire to do.

Technical Service and Technical Relations:

The first possibility is that of building up a technical relationship with the consumer through which we can overcome many of the present misconceptions and head off the growth of new ones. At present we do have technical contact with the transformer manufacturers. The number of major electrical utilities is not so large--usually not more than one to a city--but that they could be covered. If we had had such a relationship with Detroit Edison several years ago, we might have changed considerably the outcome of the meeting at which no one reported any direct experience with Aroclor, but some had heard that it was hard to handle and took a lot of care. At that time it was decided that Detroit Edison wasn't going "to get mixed up with Aroclor".

We might not have been able to head off Potomac Power's decision to remove 40 Aroclor-filled transformers, but we could have made sure it was being done for a good reason. Perhaps it's too late to talk Union Electric from converting from Aroclor to oil in downtown St. Louis. The Maintenance Department of Duquesne Light has been trying for five years to get a policy ruling that no more Aroclor-filled transformers will be purchased because of the trouble they have been having with power factor and packings. Three months ago they were successful.

The problem isn't a great deal different than on plasticizers or functional fluids or resins. To keep a customer satisfied requires, among other things, answering his complaints whether they're real or imagined.

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The more difficult the product is to handle and the more different it is from previously used materials, the more help is needed. For a million dollars worth of business we should be able to give a hand now and then to those who have to live with Aroclor in their transformers.

Advertising and Promotion:

Aroclor is used in transformers in these places:

Schools
Hospitals
Factories
Public buildings
Offices
Underground networks
Mines
Railway locomotives
Commuter cars

We have already mentioned that the transformer companies generally have no influence on what type of transformer is purchased (and if they do, no incentive to push Aroclor). Union Electric said that on private jobs it is the architect or consulting engineer who decides on the transformer; in large industrial plants the plant engineers often make the decision. Duquesne Light advises the architect of the type they plan to install. If the customer wants something different, he may be asked to pay the difference.

There are three ways that we can think of to reach the engineers and architects: direct mail, advertising in technical and trade journals, and Sweet's File. Direct mail needs no elaboration here and it will depend on the availability of lists of the right people.

We asked several places in the industry what magazines reached the men who decide on transformers. The two magazines that were nearly always mentioned were Electrical World and Electrical Engineering. The latter is the professional journal of the American Institute of Electrical Engineers.

It might appear at first that there would be resentment on the part of the transformer manufacturers if we were to push Aroclor-filled transformers. The situation is not greatly different than advertising the soft drink manufacturers who use our products, or the plastic molders who use our resins, or the disinfectant manufacturers that buy Santophen 1. And, too, we're on the side of the angels just as we are with Pydraul and Skydrol because we're advertising safety. An advertisement listing Aroclor's virtues (and there are some), the places it is used, and the transformer manufacturers who supply it shouldn't make anybody very mad.

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There is one other place that promotion of Aroclor for transformers may be worthwhile. What we need is some means of making sure that when an architect, or contractor, or engineer reaches for a catalogue of transformers, he will not only find information on Westinghouse, G.E., Maloney, etc., but he will also find out why his transformer should be filled with Aroclor (a point that the manufacturers are quite restrained about). Sweet's File is the only publication of which we know that provides this reference service.

Sweet's Catalog Service puts up in large volumes, catalogues of every conceivable material of construction and piece of equipment from fuse boxes to cooling towers. These are distributed without cost (to the recipient) to several lists of professional and engineering people for whom they provide a constant reference service. Two of these lists may be of interest to us:

Architectural: 17,000 individuals (architects, engineers, and contractors for general building).

Industrial construction: 12,000 individuals (architects, engineers, contractors, and corporation building departments).

The use of a media that would be on hand whenever questions on the choice of a transformer arose could give us the direct line that we need to the man who makes the purchasing decision. If it is of interest, a typical section in Sweet's File runs $1,500 to $4,000, depending on size, colors, etc.

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III NEW DIELECTRICS FOR TRANSFORMERS

At present there are the stirrings of what may become major changes in the transformer dielectric field. Some rather large claims have been made for the new dielectrics, but judging from the comments of the technical people, the public relations departments have provided a good part of the hyperbole. However, the consensus, even among the more conservative, is that there are radical changes coming in transformer design--the estimates of "when" range from 5 to 15 years.

Aroclor was the first liquid other than oil to be used in transformers to any extent. It was picked because it was on hand and it provided the essential characteristic of fire-resistance. It would be surprising indeed if it were the only chemical that can be so used, and if there were not better products yet to be found.

In the following sections are reviewed the two types of materials that are now being used experimentally in transformers: sulfur hexafluoride and the fluorocarbons. Finally, the characteristics needed in an improved liquid dielectric are reviewed. If Aroclor is to be replaced in transformers, we certainly would prefer to be the ones to do it. The task doesn't appear hopeless, and we are well versed in one of the two fields of chemistry that could produce a better product. The other field, fluorochemistry, will probably become of increasing interest to us.

A. SULFUR HEXAFLUORIDE

In September, 1954, General Electric announced the construction of the first two transformers using sulfur hexafluoride (SF_6) as the dielectric. These were to be installed by Consolidated Edison of New York. The new transformers were stated to be lighter, quieter, safer and useable at voltages higher than liquid-filled transformers. Replacement of liquid-filled transformers in many applications was implied.

SF_6 is a very heavy gas that liquifies at -68°C. At atmospheric pressure it has a dielectric strength about twice that of air. At a pressure of three atmospheres (about 45 psi) its dielectric strength is equivalent to that of oil. SF_6 is inert and non-flammable and does not attack metals. It is relatively non-toxic. SF_6 has the very desirable ability of being able to "absorb" electrons and thus quench an arc.

However, SF_6 is not without disadvantages in transformers. A tank to hold a gas at 3 atmospheres must be heavy--so heavy that any weight advantage of the SF_6 would be lost. Further, such tanks come under the

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pressure vessel code which has stringent requirements. Some refer to such a device as a potential bomb, since arcing could cause a pressure rise that would rupture the tank.

Under conditions of arcing, toxic materials are formed which must be absorbed. SF_6 is much less effective as a coolant than oil or Aroclor. Insulating materials are attacked unless absorbents are present. And its maximum operating temperature, according to G.E., is 125°C.

In essence, the SF_6-filled transformer can be considered an improvement on the dry, sealed (nitrogen-filled) transformer. It is already being used at 69,000 volts, Aroclor's upper limit (supposedly), and units for 138,000 volts are being built. It is considered by most as a direct competitor of Aroclor, rather than oil. When we consider that the dry-sealed transformer has already made serious inroads on Aroclor business, the effect of SF_6 will not be a pleasant one from our point of view.

Just how serious the competition from SF_6 is going to be won't be ascertainable for at least two or three years yet. Judging from the comments of the transformer manufacturers, the full impact, if it comes, will be felt in the next five to ten years. Unless we want to manufacture SF_6, our only recourse will be to either improve Aroclor's weaknesses or find a better fluid--or both.

B. FLUOROCARBONS

Westinghouse, typically, has taken a different tack than G.E. They have built a transformer which uses a fluorocarbon to cool the transformer by evaporation from the coils. This also is to be, or has been, installed by Consolidated Edison for testing.

The fluorocarbon is Minnesota Mining's "O-75", a fluorinated ether with the empirical formula $C_8F_{16}O$ which boils at 100°C. at atmospheric pressure. This liquid is pumped up from the bottom of the transformer tank and sprayed over the coils. The chief advantage in such a system is the greatly superior cooling even compared to oil; 5 gallons of the fluorocarbon is equivalent to 500 gallons of oil. The temperature difference between the coils and radiator (condenser) can be held to as little as 1°, while in oil the differential can be as much as 100°C. This attribute provides excellent overload characteristics.

However, a transformer using this form of cooling can be no smaller, as the dimensions are fixed by the dielectric strength of the vapor. Another drawback is the necessity of "preheating" the liquid to get the shell filled with vapors before connecting the transformer to the line when it is cold.

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This type of transformer is even farther away than the SF_6-filled, but Westinghouse thinks of it as an eventual competitor to the oil-filled transformers. It is impossible as yet to tell just what the effect of this development will be, and the future may depend on finding liquids with better characteristics for this use.

C. THE IDEAL TRANSFORMER FLUID

There are definite advantages in liquid-filled transformers, and, barring some miraculous developments, oil is here to stay. Oil's greatest deficiency is flammability, and this will probably remain the chief justification for using any other liquid. Of course, if there were a liquid with greatly improved dielectric strength, impulse strength, and stability over oil, it would be of great interest, but there is no indication that such liquids are likely.

The "ideal" fluid would of course, have all the advantages of oil and be non-flammable and cheaper. But the electrical industry would be quite interested if we had one that didn't have Aroclor's major weaknesses and was even a little more expensive.

The following list is a composite of the comments we received from G.E., Westinghouse, and Allis Chalmers. It is more or less in the order of importance of the characteristic. The ideal transformer fluid would be:

Fire-resistant
Dielectric strength equivalent to oil
Impulse strength equivalent to oil
Non-corrosive or combustible arc gasses
Insensitive to contamination
Stable at 125°C. or higher
Resistant to oxidation and decomposition
Liquid to -40° to -60°C.
Compatible with metals and insulations
Dielectric constant of 4 to 6
Non-toxic and non-irritating
Susceptible to economic refining
Price: $1.50 to $3.00 per gallon

Non-flammability is actually pretty uncommon among organic compounds. Halogenated and phosphorus-based chemicals are the two

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main classes that have this property. There are important drawbacks to chlorinated compounds (and fluorinated, too), chief among them being the production of HCl (or HF) on decomposition. Esters of phosphorus such as tricresyl phosphate, have been tried as transformer fluids and apparently the electrical properties were not too bad. However, the lack of hydrolytic stability was enough to prevent its use.

If, in our continuing synthesis of phosphorus-containing compounds, we find any that appear to have the necessary physical characteristics, they should certainly be checked electrically. There is still a promising field for transformer dielectrics. By 1965 there will probably be close to 50 million gallons of liquid dielectrics used. Even 1% of this is a pretty healthy chemical market.

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OTHER LIQUID DIELECTRIC APPLICATIONS

SWITCHGEAR

VOLTAGE REGULATORS

CABLE

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OTHER LIQUID DIELECTRIC APPLICATIONS

As illustrated in the chart on page 9, there are many applications for liquid dielectrics ranging from cyclotrons to transistors. In the course of this survey we tried to limit our attention to only the major applications--major in the sense of volume of use. Capacitors and transformers certainly qualify as the two largest, but there are others that consume appreciable quantities of liquid. Three of these, switchgear, voltage regulators and cable, could be fitted into the field work without requiring many additional calls and these appeared to be the next largest applications. These three are reported on in the following sections.

It is quite possible that even some of the smaller applications will have attractive possibilities for new chemicals. For example, the field of electroluminescence may suddenly blossom into a tremendous business. If further studies in the field of dielectrics are made, these other applications should be better defined.

SWITCHGEAR

The term "switchgear" refers to the switching and interrupting devices and the associated control equipment in electrical circuits. Automatic switchgear are called "circuit breakers". There are two types of switchgear used, depending on the dielectric: air or gas (SF_6) and oil.

A switch depends upon drawing an arc between two contacts, one of which is movable, and then extinguishing the arc. The largest circuit breakers can interrupt up to 25 million Kva at 330,000 volts in a tenth of a second or less. The dielectrics we are interested in are those that are used to interrupt the arc.

In oil-filled transformers the same liquid is often used for the switchgear which may be housed in the same enclosure. Aroclor cannot be used for the interruption of the load because of the HCl produced. However, it is used to switch no-load voltages (when there is no load on the secondary of the transformer.)

We were unable to get any estimate on the amount of oil used in switchgear. As a rough estimate, if we assume that the requirements for switchgear oil are 5% of transformer needs, around a million gallons of oil would be consumed annually.

In the 1920's there were several fires from switchgear and while in the U.S. designs were changed to make safer operation with oil, in

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Europe they began to use compressed air to quench the arc. Compressed air breakers are now growing in use in this country. They are about 10% more expensive than oil for equivalent capacity.

Sulfur hexafluoride shows considerable promise in this use and is coming in rapidly. Breakers up to a million Kva have been built and there is no apparent limitation as yet. The ability of SF_6 to absorb electrons makes it very effective in quenching.

Fire hazard is not a major consideration in switchgear. Only when the breaker is installed indoors is this important, and here air breakers can be used. An improved fluid would give less carbon (or other conducting material) after arcing and equivalent or more gas generating capacity, as it is the hydrogen and other gasses that assist in breaking the arc.

The requirements of an ideal switchgear fluid would include the following:

Dielectric strength equivalent to oil or higher
Non-corrosive to metals before and after arcing
Non-conductive after arcing
High gas generation on arcing
Power factor less than 1%
Pour point of -50°C.
Stable at 70°C.
Non-flammable

Even though a total market of several million pounds a year is involved this does not appear to be a very promising application. Oil is fairly satisfactory and gas can be used elsewhere. SF_6 seems to be an improvement in the gas-type. Our efforts can probably be spent more profitably elsewhere unless we stumble onto a compound that shows promise of meeting the requirements of a better fluid.

II VOLTAGE REGULATORS

A voltage regulator does just what the name implies, and is a necessary part of many power lines. Most of the manufacturers make what is called a "controlled inductance" regulator. Allis Chalmers, however, makes a load-tap type which controls the voltage by automatic switching between transformer taps.

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They have a real problem in that they need a fire-resistant fluid for this use, but cannot use Aroclor because of the HCl formation. Until they find a non-flammable liquid they will be at a competitive disadvantage. Implied, but not said, was the likelihood, or perhaps occurrence, of fires with their units.

In addition to fire-resistance Allis Chalmers need electrical characteristics similar to oil, but preferably non-sludging and without carbon formation. The market they refer to as "sizeable" but we could get no definite figures. On price, they "could stand at least an askarel price".

In itself this use can't justify much searching, but anything that shows promise for transformers will be worth looking at here. This may be an application that a new fluid could be introduced into very readily, as Allis Chalmers seem to need a non-flammable dielectric badly.

III CABLE

One type of power line which is installed underground consists of a pipe containing three cables. The entire pipe is filled with oil and pressurized with nitrogen to 200 psi to avoid gas bubbles. Voltages as high as 130 Kv are carried with such systems. These underground cables are used to feed power into downtown areas without the use of overhead wires.

There are hundreds of miles of such cable in the U.S. and its use is increasing. Duquesne Light has just installed a few miles of it that required 40,000 gallons of oil to fill. Volumes like this immediately attracted our interest in the application.

However, some rather unusual characteristics are needed in the dielectric fluid. First of all, as low a dielectric constant as possible is desired. In a long run of cable an appreciable amount of capacitance is set up, and the higher the dielectric constant of the liquid, the more energy is stored. In a cable the purpose is to transmit power, not store it. Oil with its very low dielectric constant is ideal.

Equally important is the dielectric strength, as the better it is, the higher the voltage that can be carried. Here, conceivably, would be justification for a new fluid if it were appreciably better than oil. Another characteristic open to improvement is gas formation in electrical fields.

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When a bubble forms there is a concentration of electrical stress across it and corona or arcing can occur. Aliphatic compounds are more subject to gassing than aromatic, but the latter tend to form insoluble polymers which increase the power factor.

The power factor is another important characteristic of a cable oil, since minimum losses are desired. Further, the loss shows up as heat, and this can be difficult to get rid of in a long pipe since the oil is not circulated.

By and large, this application does not look very promising for synthetics. The only entrée would probably be through a greatly increased dielectric strength. The likelihood of finding such a material appears rather slight.

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There are comparatively few texts and articles that cover the field of dielectrics, particularly from a chemical point of view. We did find a few quite helpful publications and these are listed below:

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Power Capacitors, R. E. Marbury, McGraw-Hill, 1949.

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"Electrical Insulation and Dielectrics, 1955", Reprints from Electrical Manufacturing Magazine.

"Plastics and Dielectric Materials". Reprints from Electrical Manufacturing Magazine.

"Liquid Dielectrics", A. H. Sharbaugh and R. W. Crowe. General Electric Review, May, 1954.

"Transformer Insulation Power Factor, What Does It Mean?", by E. C. Wentz. Westinghouse Engineer, November, 1954.

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FIELD CALLS MADE DURING THIS SURVEY*

Aerovox Corporation, New Bedford, Massachusetts (20)
Allis Chalmers, Milwaukee 1, Wisconsin (14)
Allis Chalmers, Transformer Div., Pittsburgh, Pa. (7)
Astron Corporation, East Newark, New Jersey (28)
Bell Telephone Laboratories, Murray Hill, New Jersey (26)
Business and Defense Service Administration, U.S. Department of Commerce, Washington, D. C. (3)
Cornell Dubilier Company, New Bedford, Massachusetts (21)
Cornell Dubilier Company, South Plainfield, New Jersey (27)
Detroit Edison Company, Detroit 26, Michigan (12)
Diamond Ordnance Fuze Laboratory, Washington, D.C. (32)
Duquesne Light Company, Pittsburgh, Pennsylvania (6)
Federal Telecommunications Laboratory, Nutley, New Jersey (22)
General Electric Company, Capacitor Dept., Transformer Division, Hudson Falls, New York (17)
General Electric Company, Transformer Division, Pittsfield, Mass. (4,19)
General Electric Company, Schenectady, New York (15)
General Electric Company, The Knolls Laboratory, Schenectady, N.Y. (16)
Line Material Company, S. Milwaukee, Wisconsin (13)
Meloney Electric Company, St. Louis 20, Missouri (30)
National Electric Mfgrs. Association, New York 17, New York (23)
Naval Research Laboratory, Washington 25, D.C. (31)
Pyramid Electric Company, North Bergen, New Jersey (25)
Radio Electronic & Television Manufacturers Association, Washington, D.C. (2)
Sprague Electric Company, North Adams, Massachusetts (18)
Sweet's Catalog Service, F. W. Dodge Corp., New York 18, New York (24)
Union Electric Company, St. Louis, Missouri (8)
Wagner Electric Company, St. Louis 14, Missouri (29)
Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania (10)
Westinghouse Electric Corporation, Lighting Division, Cleveland 1, Ohio (33)
Westinghouse Electric Corporation, Research Labs., Pittsburgh, Pa. (5)
Westinghouse Electric Corporation, Transformer Division, Sharon Pennsylvania (9, 11)

* (The Diary Reports giving the details of the calls are availeble).

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