AROCLOR* DIELECTRIC FLUIDS FOR CAPACITORS

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MONS 073260

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INTRODUCTION

The Aroclor* dielectric fluids are a range of chlorinated biphenyls produced by Monsanto for the manufacture of liquid filled capacitors. These products are generically known as 'askarels', synthetic fire resistant insulating liquids which, if decomposed by an electric arc, evolve only non-explosive gaseous mixtures.

The Aroclor liquids were first used in the United States in 1931 and today they are extensively used in the capacitor industry throughout the world.

There are three grades of Aroclor fluids in common use for capacitors as indicated below:

Aroclor 1242 (Commercially known as Trichlorobiphenyl) the most economically attractive, is essential for outdoor capacitors in a low temperature environment, but is more difficult to handle in production.

Aroclor 1248 (Commercially known as Tetrachlorobiphenyl) is a compromise between the economic advantages of 1242 and the ease of handling of 1254.

Aroclor 1254 (Commercially known as Pentachlorobiphenyl) is the easiest to handle in production but does not gain the maximum economic advantage.

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Advantages of Using Aroclor Fluids.

- Reduced size capacitors are possible for a given rating; fluorescent lighting units are a particular application in which this is utilized.
- Reduced raw material cost arising from the smaller quantity of paper and foil needed in manufacture.
- Reduced labor content because of the fewer windings required. Increased through-put from a given plant capacity with existing labor force.
- Higher stress operation of capacitors is possible because of a more uniform permittivity (Dielectric Constant) in the capacitor.
- Longer life capacitors are produced because of the high stability and resistance to oxidation of Aroclor fluid.
- Small fire hazard because Aroclor fluid is fire-resistant.

PROPERTIES

Values for the most important properties of the Aroclor® dielectrics are given in the Table.

Typical Properties of the Aroclor Dielectrics. (These values do not constitute a specification)

Property	Aroclor 1242	Aroclor 1248	Aroclor 1254
Visc. at 37.8°C. (ASTM D88-56)	82-92 sec.Saybolt Univ.		
Visc. at 54.4°C. (ASTM D88)		73-80 sec.Saybolt Univ.	
Visc. at 98.9°C. (ASTM D88-56)			44-48 sec.Saybolt Univ.
Sp. Gr. at 25/15.5°C. (ASTM D1810)	1.381 - 1.392		
Sp. Gr. at 65/15.5°C. (ASTM D287)		1.404 - 1.414	
Sp. Gr. at 65/15.5°C. (ASTM D1810)			1.495 - 1.505
Color, APHA	50 max.	100 max.	50 max.
Condition	Clear	Clear	Clear
Acidity, mg. KOH/g. (ASTM D974,D664)	0.01 max.	0.01 max.	0.01 max.
Pour Point, °C. (ASTM D97-57)	-14 or lower	-7	7 - 12
Refractive Index at 25°C. (ASTM D1807)	1.6240 - 1.6260		1.6370 - 1.6390
Refractive Index at 20°C.		1.630 - 1.631	
Inorganic Chlorides (ASTM D1821)	0.05 ppm. max.		0.05 ppm. max.
Distillation Range (ASTM D-20)		343 - 373°C.	
Distillation Range (ASTM D-20-56)			
°C. Corrected for stem and barometric pressure			
10%	325 min.		366 - 378°C.
50%			371 - 383°C.
90%	360 max.		378 - 394°C.
Water Content (ASTM D1533-60)	35 ppm. max	35 ppm. max	35 ppm. max.
Resistivity, 100°C., 500 v. D.C. at 0.1" gap. (ASTM D1169)	500×10^9 ohm-cm.,min.	500×10^9 ohm-cm.,min.	500×10^9 ohm-cm., min.
Dielectric Constant, 100°C. at 1000 cycles (ASTM D924-49)	4.7 to 4.9	4.6	4.15 to 4.35
Dielectric Strength (ASTM D877-49) at 25°C. KV min.*	35	35	35
Flash Point, Cleve open cup (ASTM D92-57)*	170° to 200° C.		
Flash Point, (C.O.C.)*		193°C.	
Burn Point (ASTM D92)			Higher than 350° C.
Fire Point*	None to boiling point		
Sulfates (ASTM D117-31)*	None		None
Fixed Chlorine Content (Carius)*	43 + 0.5%	47.5 - 48.5%	55 + 0.5%
Evaporation at 100°C. for 6 hrs.*	0.4% max.		0.4% max.
Specific Heat at 25°C. *	0.29	0.27	0.26
Hydrolyzable Chlorine Compounds (ASTM D1820-61) ppm. chlorides max.	0.5		1.0
Thermal Stability (ASTM D1936) chlorides	0.4 ppm. max.		0.5 ppm. max.
Coefficient of Thermal Expansion * (ASTM D1903)	0.00068 cc./cc./°C.		0.00066 cc./cc./°C.

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* Not determined unless by special request.

NOTE: To compare properties obtained by different laboratories, exactly the same test methods and techniques must be used. Different test methods or techniques will produce varying results.

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Composition

Aroclor fluid is made by the chlorination of biphenyl to predetermined chlorine contents which are indicated as a percentage by the last two digits in the code number e.g. Aroclor 1248 contains 48% chlorine by weight. Each grade of Aroclor fluid contains a range of chlorobiphenyls with differing numbers of hydrogen atoms substituted by chlorine, and in each of these chlorobiphenyls there is abundant isomerism.

Physical Properties

Viscosity. The Viscosity-temperature characteristics of the Aroclor liquids are shown in Figure 1. It can be seen that Aroclor 1254 is the most viscous at all temperatures and Aroclor 1242 the least. The differences between the three grades are greatest at lower temperature and become less as the temperature is raised. As previously explained, Aroclor fluid consists of a number of homologues and consequently each grade does not have a sharply defined melting point, but remains liquid over a wide temperature range. Instead, their viscosites increase smoothly but sharply as the temperature is reduced. Aroclor 1242 has the lowest pour point of all three grades.

Vapor Pressure. It can be seen that Aroclor 1242 has the greatest vapor pressure at a given temperature and Aroclor 1254 the least. This fact should be considered in determining the fluid temperature during degasification and impregnation. The vapor pressure varies with absolute temperature according to the usual logarithmic law. The variation of the vapor pressures of the Aroclor

dielectrics with temperature is shown in Figure 2.

Chemical Properties

The chemical inertness of Aroclor fluid is outstanding. The liquids are not oxidized by exposure to air or oxygen even under extreme conditions of temperature and pressure, nor do they react with moisture. When subjected to a bomb test at 140°C in oxygen at a pressure of 250 p.s.i.g. (17 kg/cm^2), there was no evidence of oxidation as judged by development of acidity or formation of sludge. They can withstand many years of service in electrical equipment at high temperatures without oxidation.

Aroclor fluid is manufactured to a rigid specification ensuring a low value for free acidity and free chlorides. Tests have shown that these low values are maintained even when the liquids are heated for prolonged periods in the presence of air and moisture at elevated temperatures.

Aroclor fluid is slightly sensitive to ultra-violet light, which can result in the formation of traces of ionic contaminants.

Aroclor fluid undergoes no decomposition at temperatures up to 175°C. At much higher temperatures, or when subjected to arcs, the principal decomposition products are carbon and hydrogen chloride.

Laboratory tests and practical experience have shown that phosgene, chlorine, or hydrocarbons are not formed as decomposition products of Aroclor fluid.

Electrical Properties

The laboratory methods used to measure the electrical properties of the Aroclor dielectrics are described in Appendix A.

Permittivity (Dielectric 'constant')

The permittivity of Aroclor fluid is higher than that of mineral oil, which accounts for the size reduction and increase in stress that is possible. Stresses of 15 to 17 V/um are common; and higher values are reported.

Since chlorinated biphenyls are polar compounds, their permittivities are temperature-dependent. This is illustrated in Figure 4, which shows the variation with temperature of the permittivity of each of the three grades of Aroclor fluid. These readings were taken at a frequency of 50 c/s and an electric stress of 1V/um.

At the lowest temperatures, all three grades have a permittivity of about 2.8, since, because of the very high viscosity, there is no contribution from dipole orientation polarizability. As the temperature is increased, the permittivity begins to increase when the viscosity becomes sufficiently reduced to allow the molecular dipoles to orientate themselves in the alternating electric field. The temperature at which this increase in permittivity begins is dependent upon both the grade of Aroclor fluid (being lowest for Aroclor 1242), and the frequency of the applied field.

As the temperature is further increased, the permittivity passes through a maximum, and then decreases. This decrease in permittivity with increase of temperature is due mainly to the disturbance

of the alignment of the dipoles by thermal agitation. The maximum permittivities attained vary with the grade of Aroclor fluid, being greatest for Aroclor 1242 and least for Aroclor 1254. With Aroclor 1242 the permittivity of this series reaches a maximum, and a further reduction in chlorine content causes a reduction in permittivity, as shown in Figure 3.

Loss Tangent. The loss tangent, or power factor, of Aroclor fluid is highly temperature dependent. This is illustrated in Figure 5, which shows how the loss tangent (plotted here on a logarithmic scale) of each of the three grades vary with temperature.

The curve for each grade consists of a peak due to absorption associated with the transition in permittivity, followed by a region where the loss tangent steadily increases with temperature. In this latter region, the loss tangent follows the increase in fluidity with increasing temperature and is highly dependent upon the purity of the fluid. The temperature at which the peak occurs is about 19° below the pour point.

D. C. Resistivity. The values quoted in the table are typical for Aroclor fluid as produced; but they can be improved by vacuum dehydration or treatment with suitable grades of absorbent such as fuller's earth or activated alumina. Values of 20 to 50 TΩ cm at 100°C are common. The values for Aroclor 1242 and 1248 are lower than 1254 because a given amount of contamination reduces the d.c. resistivity more with a liquid of lower viscosity and higher permittivity.

The approximate variation of the d.c. resistivity of the 3 grades of Aroclor fluid with temperature is shown in Figure 6.

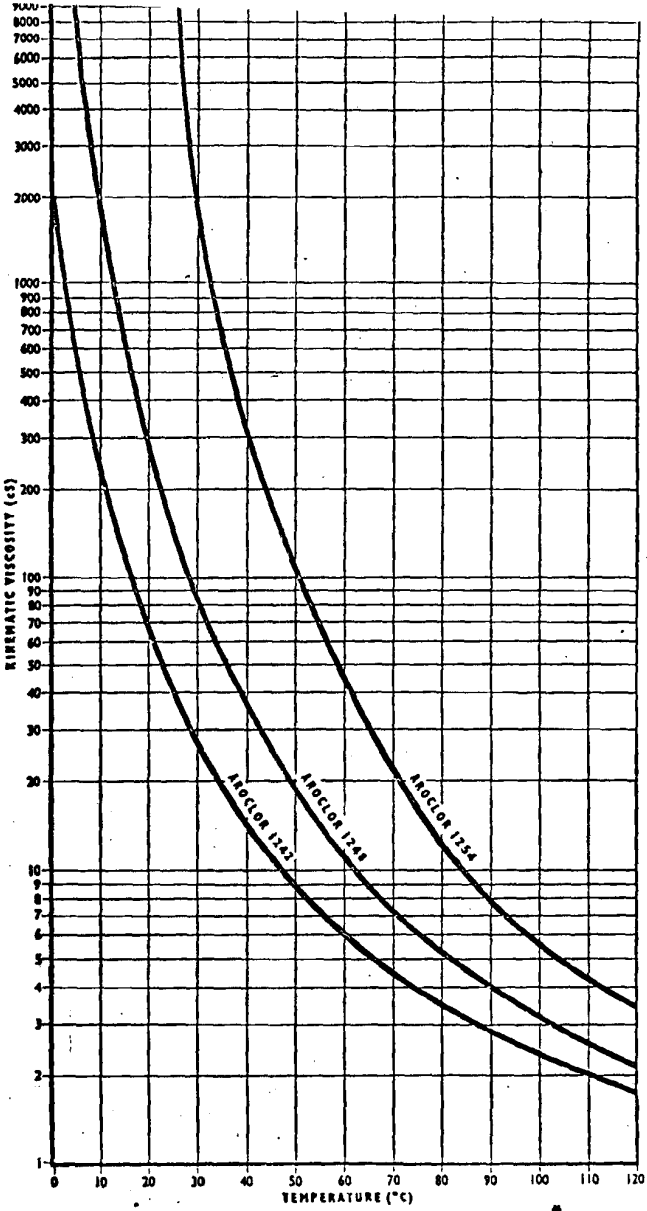

Figure 1 The viscosity-temperature characteristics of the Aroclor* dielectrics

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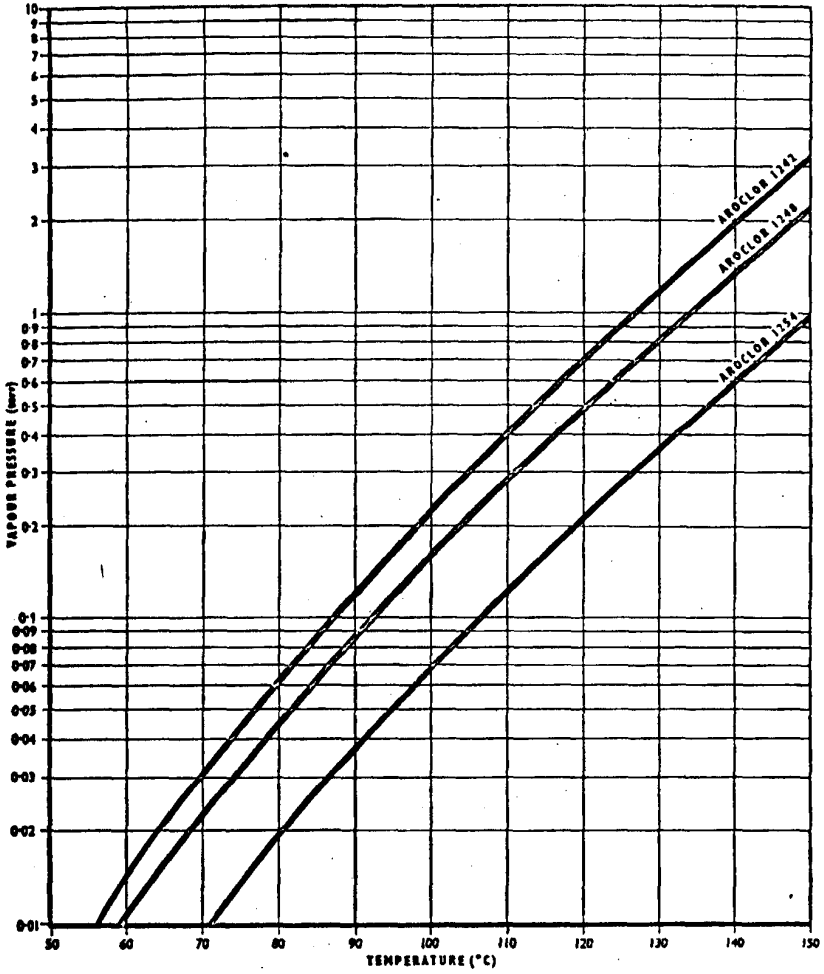

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Figure 2 The variation of the vapour pressure of the Aroclor* dielectrics with temperature

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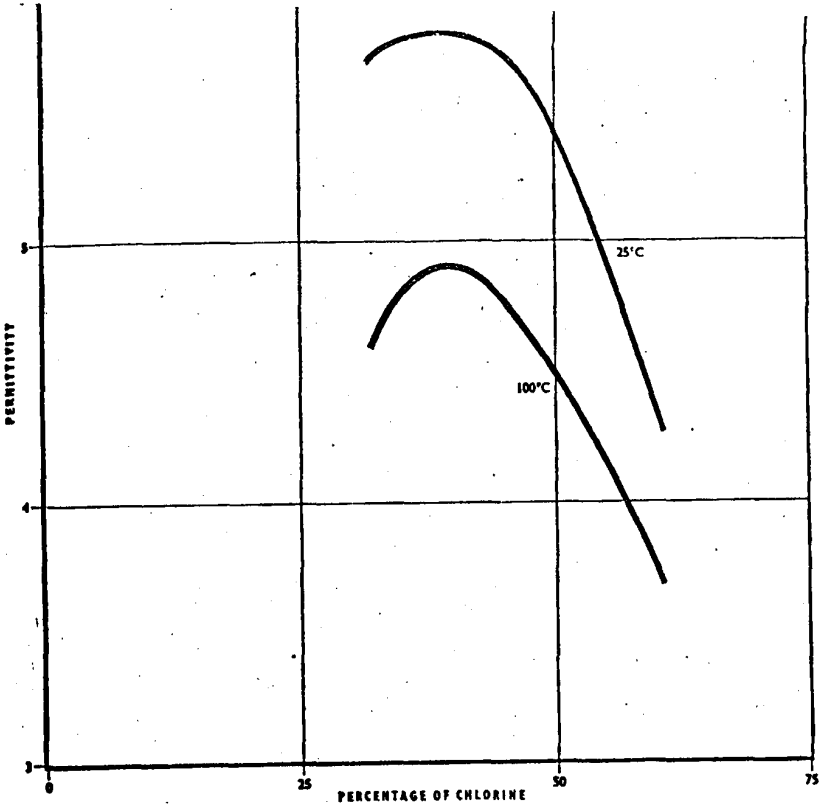

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Figure 3 The variation of permittivity with chlorine content

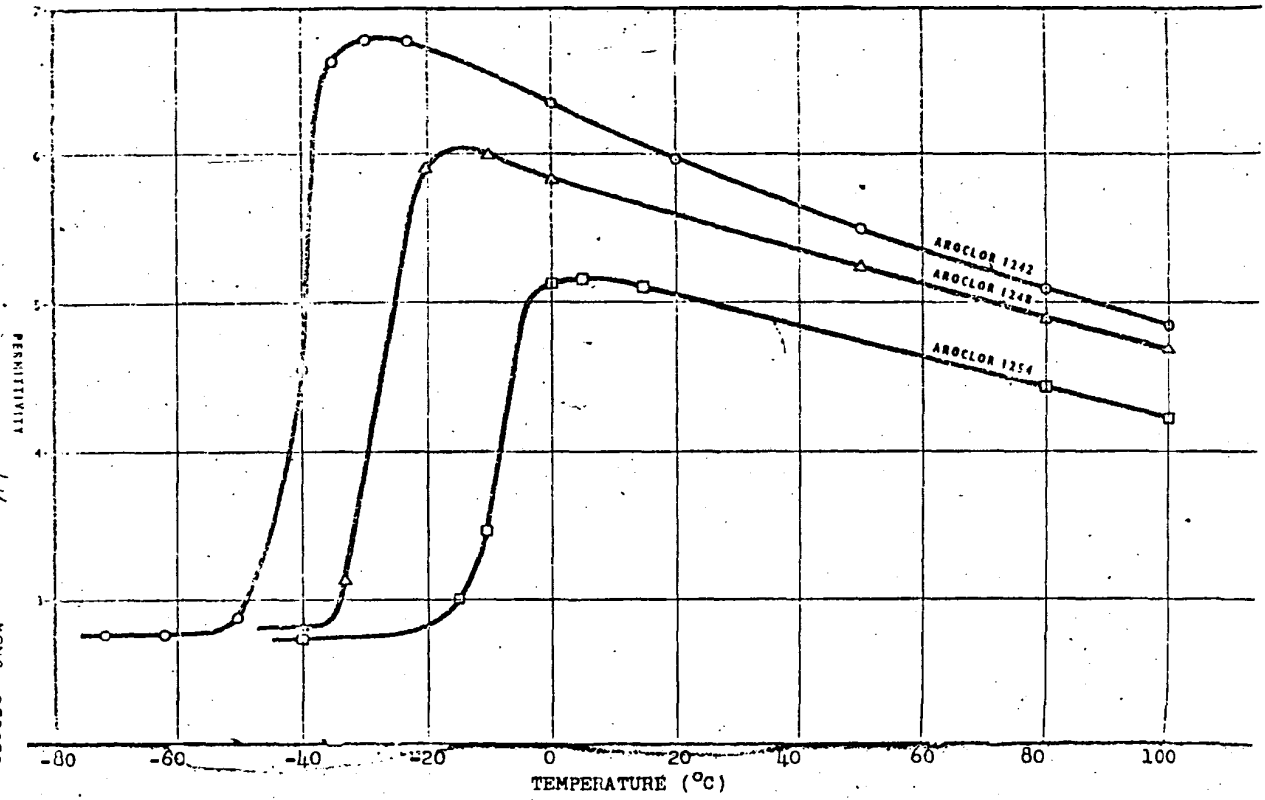

Figure 4 The approximate variation of permittivity of Aroclor* fluids with temperature

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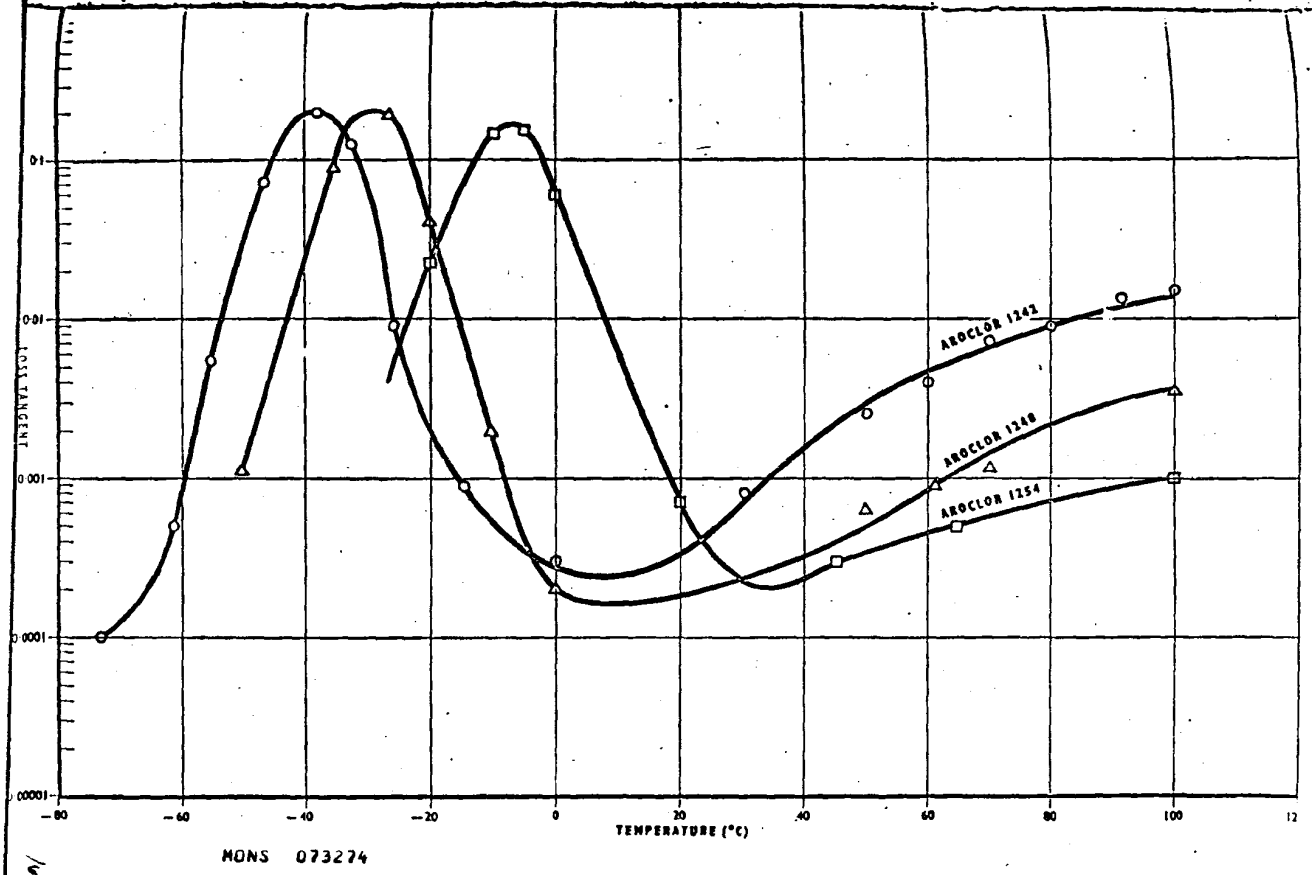

Figure 5 The approximate variation of the dielectric loss angle of Aroclor* fluids with temperature

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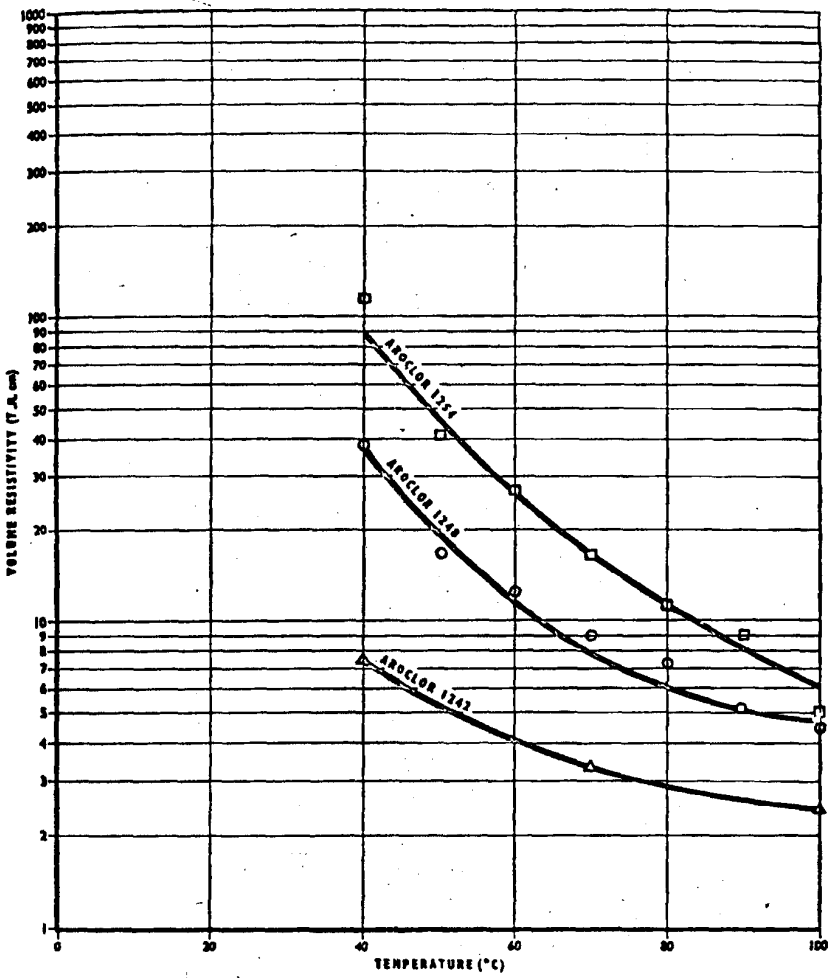

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Figure 6 The approximate variation of the DC resistivity of the Aroclor* dielectrics with temperature

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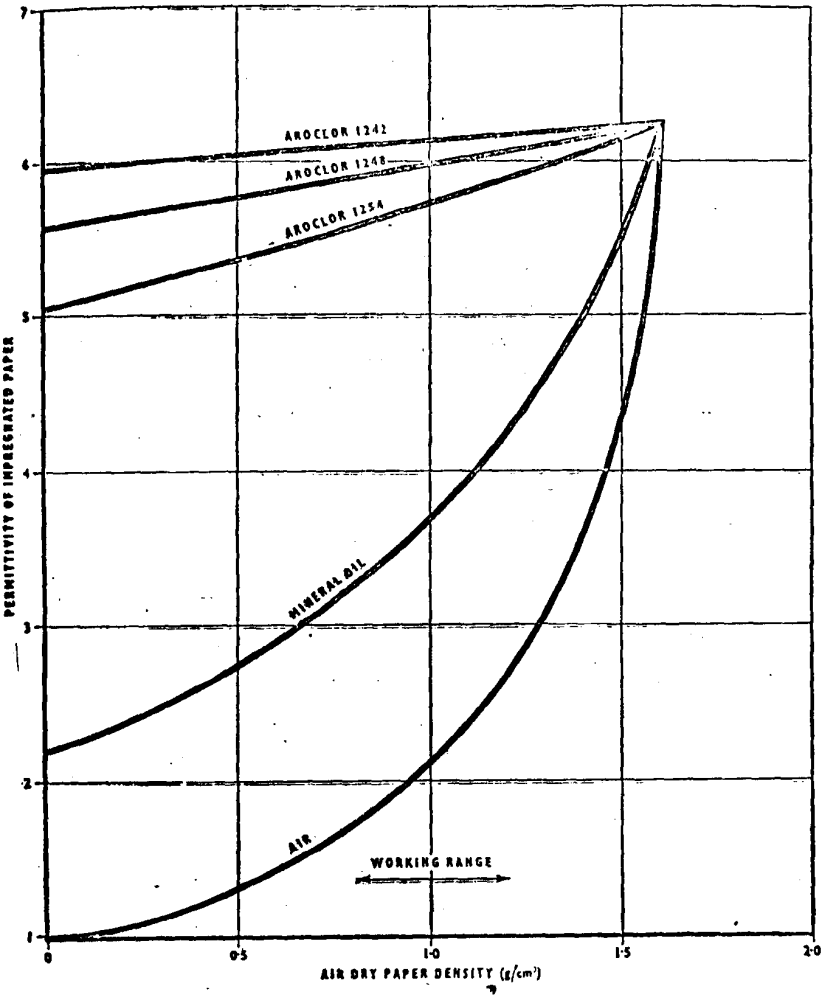

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Figure 7 The permittivity of paper impregnated with Aroclor* fluids
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CONSTRUCTION

Construction of Aroclor Fluid Capacitors

Paper

Kraft paper is used because of its purity and its nearly five fold capability of acid neutralization over rag tissue.

The permittivity of impregnated paper depends upon the density of the paper as well as the permittivity of the impregnant. This relationship is shown in Figure 7 for the 3 grades of Aroclor fluid and for mineral oil, the values being calculated at a temperature of 20°C. Since paper impregnated with Aroclor 1242 has the highest permittivity, the least area of windings is needed to obtain a given value of capacitance and the greatest economy is obtained.

Low density paper has been shown both theoretically and practically to give the least dielectric loss in a capacitor. This effect arises from the distribution of electrical stress between the cellulose fibres and the impregnant and is in addition to, and independent of, any losses in the impregnant itself.

Most manufacturers of capacitor tissue are familiar with Aroclor fluids and have developed suitable grades for use with them.

Assembly of Capacitors

It cannot be emphasized too strongly that every material that comes into contact with Aroclor fluid must be carefully checked for compatibility. Aroclor is a good solvent for many thermo-

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plastics and elastomers and the resulting solution has a high dielectric loss tangent. Materials which must be considered include the major insulation, the lead-through insulators, any means of sealing the container and the residues from the manufacturing process e.g. fluxes left after soldering.

Connection tags if of copper should be tinned, otherwise stainless steel can be used. Soldering should be kept to a minimum and where possible the special cored solders which have been developed by manufacturers for use with Aroclor fluid should be employed. Opaque bushings must be used because of the slight light sensitivity of some grades of Aroclor fluid, particularly Aroclor 1242.

PRODUCTION

Production of Capacitors

Although the production of Aroclor fluid impregnated capacitors is generally similar to that of oil impregnated units, and similar plant may be used, there are several differences in detail and these are described in the following sections.

If an oil plant is to be changed to Aroclor fluid, resistant gasket seals must be installed and the equipment thoroughly cleaned and flushed with Aroclor fluid (which is subsequently discarded).

Purification (Absorbent Treatment)

The main difference between a chlorinated biphenyl and an oil capacitor impregnation plant is the purification section. It should have the capability of degassing and treating the fluid with absorbent material to remove contamination. If capacitors are filled by a flooding technique, then Aroclor fluid which is unused and returned to the system will be found to be slightly contaminated. This fluid must be purified by treatment with a suitable absorbent such as fuller's earth or activated alumina. For this to be fully appreciated, it must be realized that the Aroclor liquids are more susceptible to contamination than their mineral oil counterpart. Because of their higher solvent action and higher permittivity, the contamination level which would be acceptable in mineral oil and which is commonly encountered in an impregnation plant will be unacceptable for Aroclor fluid. The absorbent treatment can be carried out in two principal ways. In the first place the absorbent

is contained in a column and the liquid is circulated until the contamination is removed. Alternatively, activated absorbent is added to the liquid in a container and it is stirred to ensure intimate mixing and then the earth is filtered through oven dried paper filter. In both cases either fuller's earth or alumina may be used and each must be activated. It has been found by experience in laboratory tests that the earth may be over activated and the optimum temperature is about 200°C. for 6 hours. If this is then added in quantities to the material to be treated, it is ensured that the fresh activated earth is used each time and the treatment may be more easily controlled in this way in the mixing technique. However, there still exists the problem of separating the absorbent and here the column technique has a considerable advantage, since circulation through the column does not necessitate further filtration. This method has the disadvantage that the column gradually becomes less active during its life and there is not always the same degree of control over the treatment process.

Impregnation

It is customary to store the capacitor liquid in a large tank the size of which depends on whether the material is delivered in drums or tankers. It is recommended that these storage tanks be lagged and heated since at low temperatures difficulty would be encountered in pumping the Aroclor 1254 and in certain extremes of temperature even Aroclor 1242 can become umpumpable. After transfer from the storage tank the liquid is first earth treated and mixed with any unused liquid drawn back from the capacitor

impregnation tank, if applicable. The treated liquid is then subjected to vacuum drying and de-gassing in exactly the same way as with mineral oil and after this process it is passed to the final storage vessel where it is held before being passed to the impregnation section. Large capacitors may be vacuum impregnated by a manifold technique in which the liquid is piped individually to each capacitor can. Alternatively, they may be filled by a flooding technique which is more applicable to the smaller fluorescent lighting capacitors. Here the capacitors can be loaded in wire cages and completely immersed in the liquid in the same way as with mineral oil. For the actual impregnation cycle the following temperatures are recommended:

Aroclor 1242	70- 80°C
Aroclor 1248/1254	90-100°C

The lower impregnation temperatures are recommended for Aroclor 1242 since it will be sufficiently thin at these temperatures.

After the impregnation cycle has been completed the vessel should be cooled to below 50°C before being opened. This is to avoid the unpleasant fumes of Aroclor vapor escaping into the work-shop. The capacitors should then be sealed as quickly as possible at the proper temperature and degreased before final painting and testing.

Toxicity precautions and the handling of Aroclor fluids is dealt with in a separate section but workers handling the liquid, or

capacitors coated with it, are advised to wear gloves or use barrier cream.

PERFORMANCE

A.C. capacitors at low ambient temperatures.

If a capacitor is continuously energized before and whilst subjected to a low temperature environment it operates satisfactorily because the heat produced in the dielectric balances the heat lost from the case. A self-compensating process exists such that if the temperature of the dielectric falls the losses increase, and more heat is generated to establish a new equilibrium. Tests have shown that a capacitor impregnated with Aroclor 1254 can operate continuously energized in ambient temperatures down to -60°C.

~~survived whilst installed outdoors during the winter 1962-3.~~

If, however, a capacitor is subjected to a low temperature environment first and then energized it may be damaged by discharges occurring in voids formed by the contraction of the dielectric before it has time to heat up sufficiently. Cases when this might occur are in street lighting capacitors during winter, or capacitors installed in a plant that has been shut down during winter holiday periods. For this reason, the following minimum ambient temperatures are suggested for the 3 grades:

Aroclor 1254 - 7°C
Aroclor 1248 -28°C
Aroclor 1242 -45°C

D.C. Capacitors

Aroclor fluid is also used in d.c. capacitors but it has been found that at the high stresses used the service life of the capacitor tends to be reduced if the working temperature is raised above 40°C. This can be overcome by using stabilizers in the Aroclor fluid to overcome the slight electrochemical degradation which tends to take place. Generally the effect is proportional to the quantity of stabilizer used and up to 1 per cent of anthraquinone or 2-ethyl anthraquinone and 2 per cent of azobenzene have been used.

TOXICITY

Toxicity and Handling Precautions

Aroclor fluid made by Monsanto has been used for over 35 years without causing any toxic effects, but it must be handled with care.

These precautions should be observed:

1. Avoid skin contact. Protect the hands, preferably by oil-resistant gloves.

2. If skin contact should occur, wash off with soap and water.

3. If hot Aroclor fluid must be handled in a closed or confined area provide exhaust ventilation or wear an approved respirator.

4. If Aroclor fluid gets in the eyes, flush with large amounts of water. In the event that irritation persists refer the patient to a Physician.

5. Infrequent exposure to Aroclor vapor will not cause any ill effect, but prolonged exposure to a high vapor concentration should be avoided.

If these precautions are neglected acne may develop and excessive exposure may cause liver damage.

APPENDIX A

Laboratory Measurements of Aroclor Fluids

Monsanto's test methods are based on the ASTM Standards and procedures. However, for electrical testing many techniques may be used. Therefore, understanding and interpretation may be required to correlate different results obtained under various testing conditions.

Monsanto will work with you in comparing the various techniques for measuring electrical properties.

Process Control Measurements

In operating an impregnation plant, it is convenient to be able to measure the electrical properties of the Aroclor fluid without the necessity of taking samples. A cell installed in a flow line is useful for this purpose. It should be arranged that there is a turbulent flow of Aroclor fluid through the gap between the electrodes except when a measurement is being taken so that adequate cleaning of the electrode surfaces occurs. To obtain the same value of d.c. resistivity with a plant cell and with a laboratory cell it is necessary for the Aroclor fluid to be (1) stationary whilst the measurement is made, (2) subjected to the electric field for one minute, and (3) at the same temperature.

APPENDIX B

Compatibility Testing Method

Procedure

If the material is available in a laminar form or is a surface coating a piece 25 mm square is cut from a sheet. Other materials are selected so that the sample taken is present at the same concentration as in the finished article. The sample is put into a glass jar that has previously been cleaned and dried in the following sequence:

1. Wash in benzene
2. Wash with hot water and detergent
3. Six rinses with distilled water
4. Rinse twice with analytical grade acetone
5. Dry in an oven at 130°C for 1 hour

To this jar, and to a similar one without a specimen within it, are added 150 ml of Aroclor fluid. The jars are then closed with ground glass lids and aged in an oven at 100°C for 7 days.

After ageing, the jars are removed from the oven and the electrical properties of the Aroclor fluid in both the specimen jar and the control jar are measured at 100°C according to the method described in Appendix A. The specimens are examined for swelling or other signs of deterioration, and any color change of the Aroclor fluid is noted.

Results

The Aroclor fluid in which the sample has been immersed must not experience a decrease in resistivity below 1 terohm-cm at 100°C. Information on materials which have been tested is available on request.

Technical Service

The technical service staff of Monsanto is always ready to provide additional information on the use of the materials described in this report, and to assist manufacturers in the solution of particular problems ensuing from their application.

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