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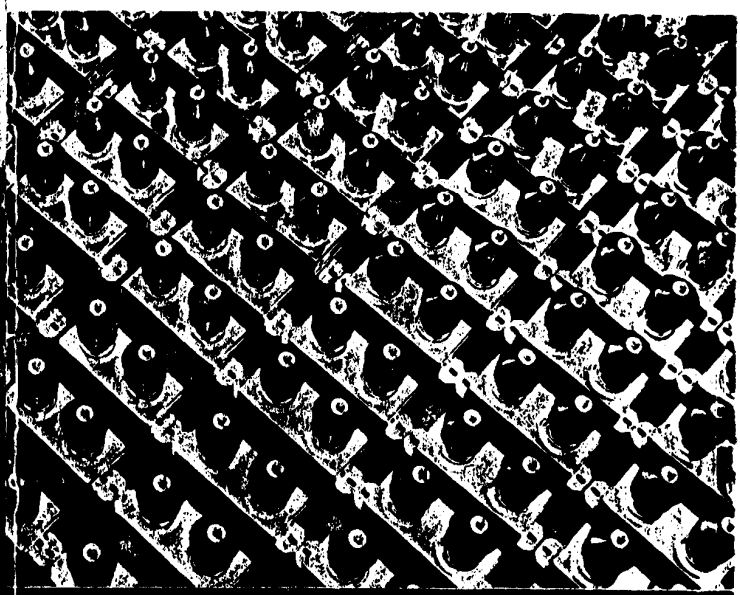

AROCLOR FOR CAPACITORS

MONS 078556

AROCLOR

Aroclor is a registered trade mark

MONS 078557

FOR CAPACITORS*

Monsanto

REG.

MONSANTO HOUSE · 10-18 VICTORIA STREET · LONDON SW1

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INTRODUCTION

The Arochlor* dielectrics are a range of chlorinated diphenyls produced by Monsanto for the manufacture of impregnated paper capacitors. These products are generically known as 'askarels', that is, synthetic fire resistant insulating liquids which, if decomposed by an electric arc, evolve only non-explosive gaseous mixtures.

The Arochlor liquids were first used in the United States in 1931 and to-day they are extensively used in the capacitor industry throughout the world. Monsanto has been producing Arochlor at its Newport plant since 1951.

There are three grades of Arochlor, identified by their code numbers: *Arochlor 1242* (Commercially known as Trichlorodiphenyl) the most economically attractive, is essential for outdoor capacitors in a low temperature environment, but is the most difficult to handle in production.

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

Arochlor 1254 (Commercially known as Pentachlorodiphenyl) is the easiest to handle in production and is sometimes chosen for capacitors to operate in exceptionally hot environments, but does not gain the maximum economic advantage.

Advantages of using Arochlor Reduced size capacitors are possible for a given rating; fluorescent lighting units are a particular application in which this is utilised.

Reduced raw material cost arising from the smaller quantity of paper and foil needed in manufacture.

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Reduced labour content because of the fewer windings required.
Increased through-put from a given plant capacity with existing labour force.

Higher stress operation of capacitors is possible because of a more uniform permittivity in the capacitor.

Longer life capacitors are produced because of the high stability and resistance to oxidation of Aroclor.

Small fire hazard because Aroclor is fire-resistant.

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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
Relative Density at 20/20°C	1 385	1 456	1 549
Pour Point (°C)	-19	-7	+ 10
Viscosity at 90°C (cS)	9 5	5 2	10 2
Coefficient of expansion °C	0 00076	0 00074	0 00069
Specific heat at 75°C (J/g °C)	1 24	1 16	1 08
Thermal conductivity at 75°C (W/m °C)	0 1038	0 1003	0 0976
Evaporation loss (%) (2 h at 125°C)	0 12	0 07	0 00
Flash Point (°C) ASTM D93/62	154 (min)	154 (min)	204 (min)
Fire Point	None	None	None
Refractive Index n_D^{25}	1 6240	1 6295	1 6370
Inorganic chlorides (ppm)	0 1 (max)	0 1 (max)	0 1 (max)
Acid number (mgKOH/g)	0 01 (max)	0 01 (max)	0 01 (max)
Water content (ppm)	35 (max)	35 (max)	35 (max)
Permittivity at 20°C and 50 c/s	5 97	5 38	5 04
Permittivity at 100°C and 50 c/s	4 83	4 67	4 26
Loss tangent at 100°C and 50 c/s	0 018	0 015	0 010
D.C. resistivity at 100°C and 500 V/mm after 1 min. electrification (TΩ cm)	8 0	7 0	8 0
Dielectric strength at 20°C (kV) (B.S. 148:1968)	50 (min)	60 (min)	70 (min)

Composition Aroclor is made by the chlorination of diphenyl 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 Aroclor contains a range of chlorodiphenyls with differing numbers of hydrogen atoms substituted by chlorine, and in each of these chlorodiphenyls 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 tempera-

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ture and become less as the temperature is raised. As previously explained, Aroclor 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 viscosities increase smoothly but sharply as the temperature is reduced. Aroclor 1242 has the lowest pour point of all three grades.

Vapour Pressure It can be seen that Aroclor 1242 has the greatest vapour pressure at a given temperature and Aroclor 1254 the least, and this needs to be considered when deciding the temperature of Aroclor during degasification and impregnation. The vapour pressure of Aroclor varies with absolute temperature according to the usual logarithmic law. The variation of the vapour pressures of the Aroclor dielectrics with temperature is shown in Figure 2.

Chemical properties The chemical inertness of Aroclor is outstanding. The liquids are not oxidised 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/cm²), 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 is manufactured to a rigid specification ensuring a low initial 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 temperatures of 100°C.

Aroclor 1242 is slightly sensitive to ultra-violet light, which can result in the formation of traces of ionic contaminants. The other grades are relatively unaffected by exposure to light.

Aroclor 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.

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 is higher than that of mineral oil, which accounts for the size reduction

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and increase in stress that is possible. Stresses of 15 to 17 V/μm are common with Arocior and higher values are reported.

Since chlorinated diphenyls are polar compounds, their permittivities are highly temperature-dependent. This is illustrated in the upper part of Figure 4, which shows the variation with temperature of the permittivity of each of the three grades of Arocior. These readings were taken at a frequency of 60 c/s and an electric stress of 1 V/μm.

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 Arocior, being lowest for Arocior 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 Arocior, being greatest for Arocior 1242 and least for Arocior 1254. With Arocior 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.

Although the permittivity of Arocior 1242 is of a high order, continued research on these products has revealed the possibility of obtaining even higher permittivities with this class of material. It is likely therefore, that the final word has not been written on this subject and that improved products will become available in this field in the course of the next few years.

Loss Tangent The loss tangent, or power factor, of Arocior is also highly temperature dependent. This is illustrated in the lower part of Figure 4, which shows how the loss tangents plotted here on a logarithmic scale of each of the three grades of Arocior vary with temperature.

The curve for each grade of Arocior 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 Arocior. The temperature at which the peak occurs is about 19° below the pour point.

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The loss tangent of Arocior is greater than that of fresh mineral oil, but by selection of a paper of lower density the loss tangent of the impregnated capacitor can be minimised without sacrificing the economic advantages. Furthermore, the internal temperature does not rise beyond acceptable values.

D.C. Resistivity The values quoted in the table are typical for Arocior as produced, but they can be improved by vacuum dehydration and values of 20 to 50 T Ω cm at 100°C are common. The values for Arocior 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 variation of the d.c. resistivity of the 3 grades of Arocior with temperature is shown in Figure 5.

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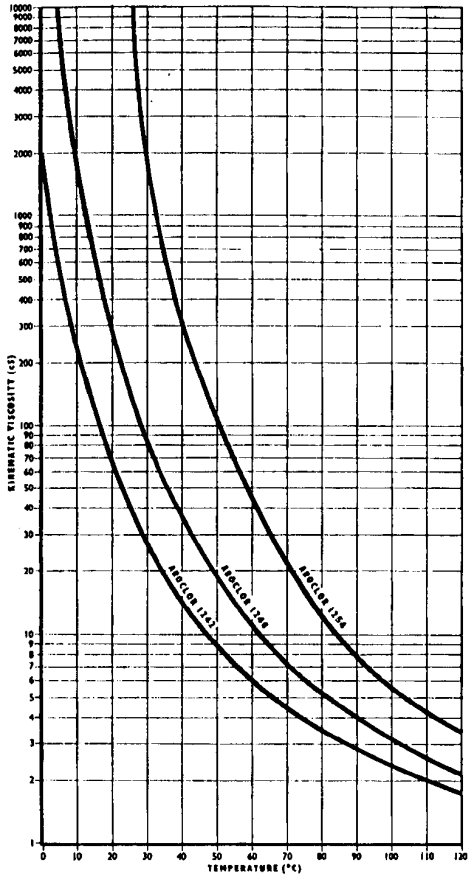

Figure 1 The viscosity-temperature characteristics of the Aroclor dielectrics

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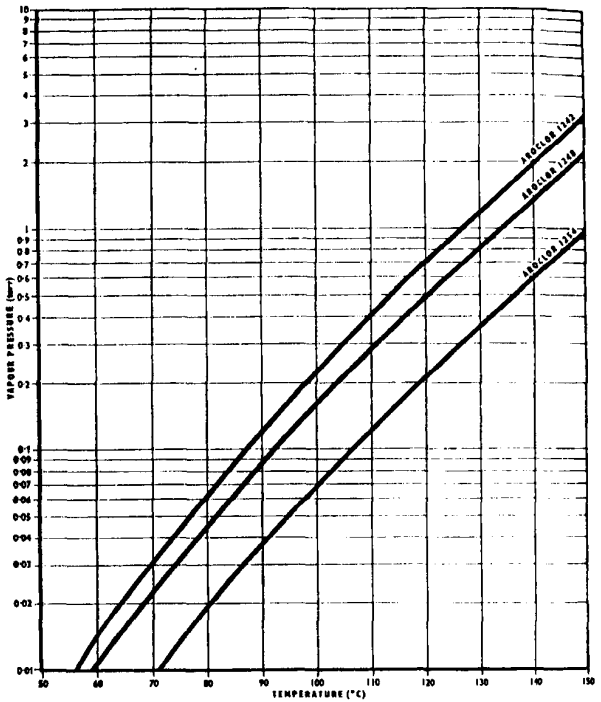

Figure 2 The variation of the vapour pressure of the Arocior dielectrics with temperature

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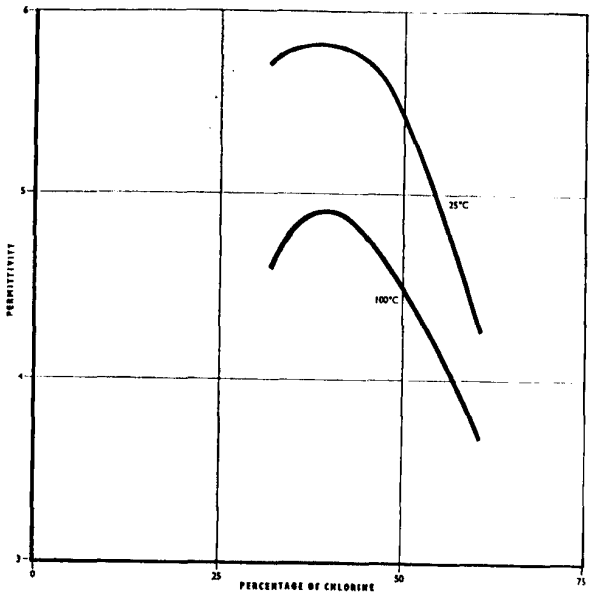

Figure 3 The variation of permittivity with chlorine content

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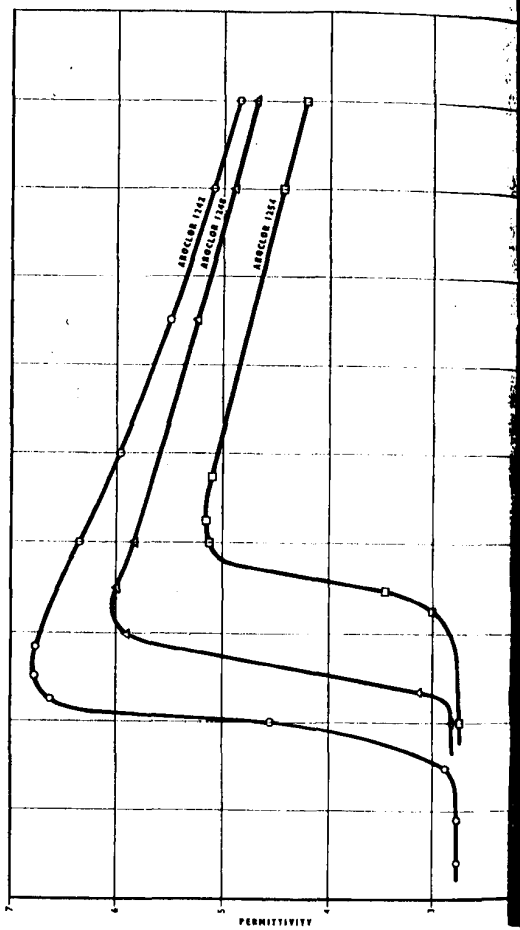

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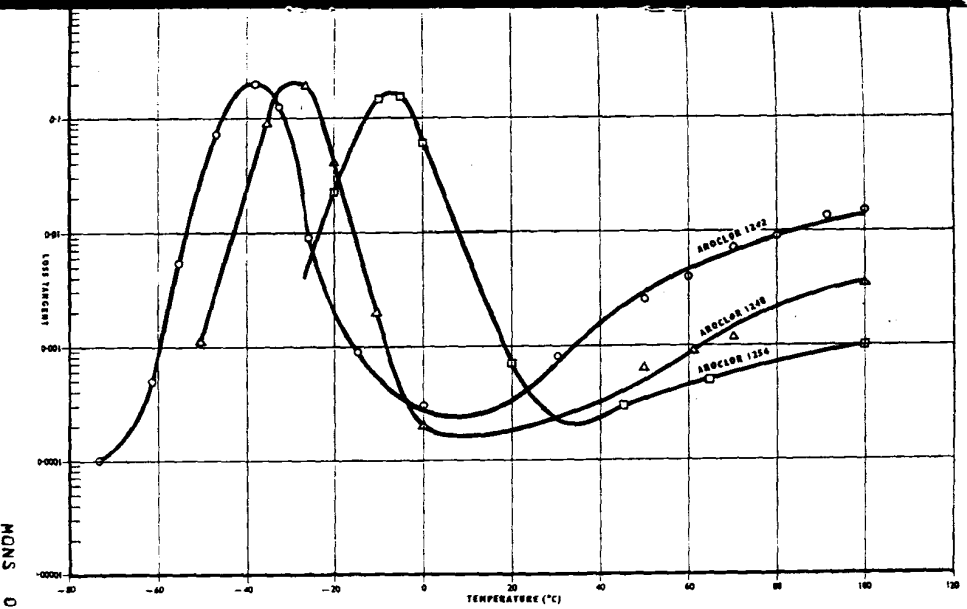

Figure 4 The variation of the permittivity and dielectric loss angle of Aroclor with temperature

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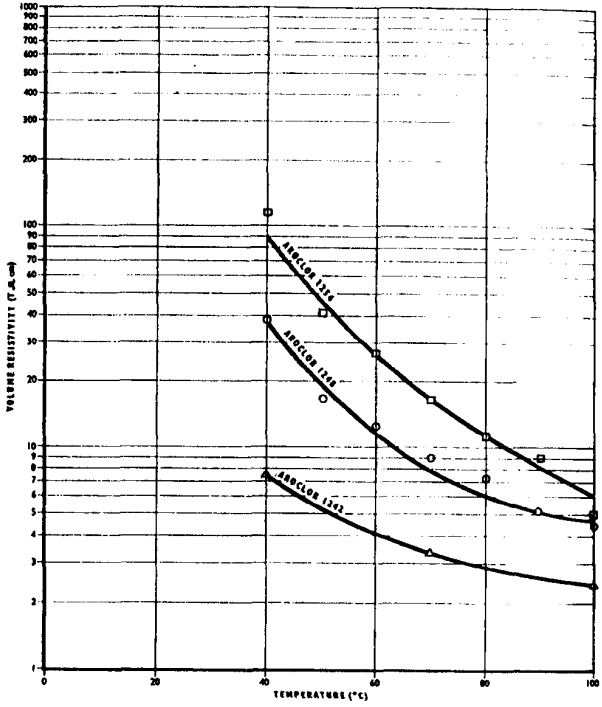

Figure 5 The variation of the DC resistivity of the Aroclor dielectrics with temperature

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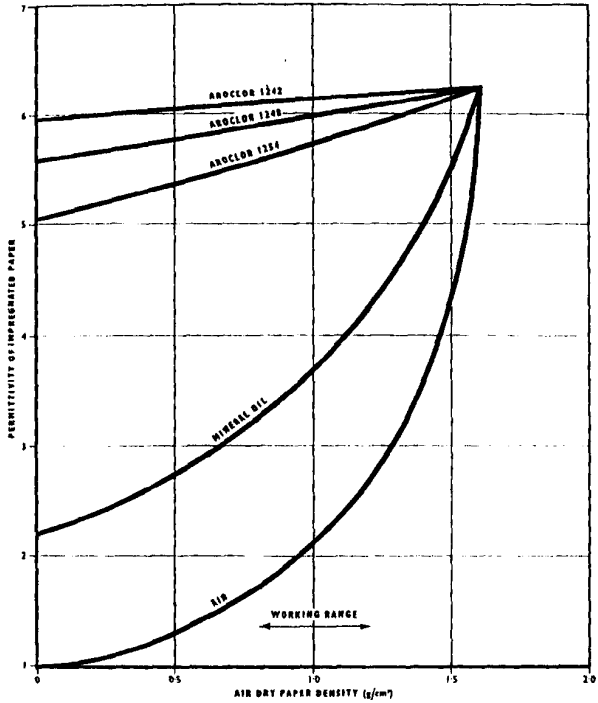

Figure 8 The permittivity of paper impregnated with Aroclor

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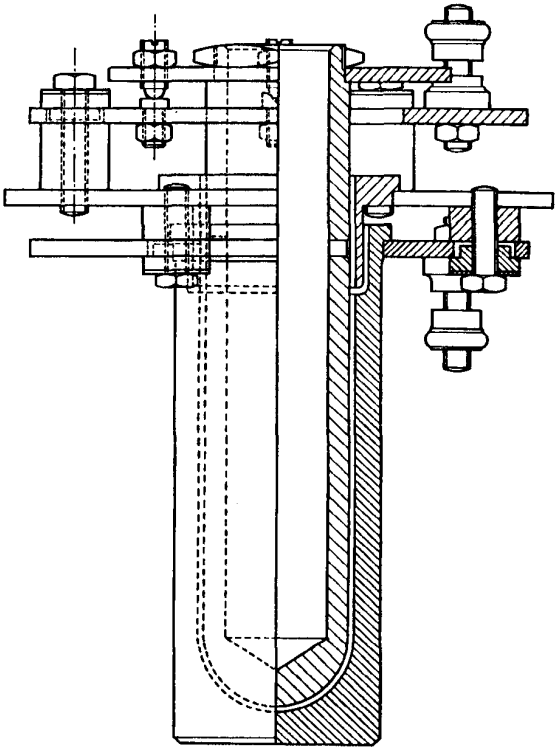

Figure 7 The Monsanto dielectric test cell

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CONSTRUCTION

CONSTRUCTION OF AROCLOR CAPACITORS

Paper Kraft paper is strongly recommended since it has nearly 5 times the acid neutralising properties of 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 6 for the 3 grades of Aroclor 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.

It is advantageous to use low density paper since it has been shown both theoretically and practically that such paper gives 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 and have developed suitable grades for use with it.

Assembly of capacitors It cannot be emphasised too strongly that every material that comes into contact with Aroclor must be carefully checked for compatibility. Aroclor is a good solvent for many thermoplastics 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.

The windings should be sealed with a suitable adhesive such as gum arabic or Gloy. 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 should be employed. Opaque bushings must be used because of the slight light sensitivity of some grades of Aroclor, particularly Aroclor 1242.

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PRODUCTION

PRODUCTION OF AROCLOR CAPACITORS

Although the production of Aroclor 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, no special cleaning is necessary, although it is advisable to rinse the plant first with Aroclor which is subsequently discarded. It must be noted at this point and always borne in mind that Aroclor has a very considerable detergent effect. That is to say that since the density is nearly twice that of oil, any dirt existing in the system will be washed out due to the greater density effect of the Aroclor.

Earth treatment The main difference between Aroclor and oil capacitor impregnation plant is the earth treatment section. Aroclor, as received in drums, is suitable for filling into capacitors after vacuum treatment but it is generally advisable to have an earth treating facility available to treat any Aroclor which could become contaminated during the process cycle. For example if capacitors are filled by a flooding technique, then Aroclor which is unused and which is returned to the system will be found to be slightly contaminated and earth treatment is advised. For this to be fully appreciated, it must be realised 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.

The earth treatment can be carried out in two principal ways. In the first place the earth is contained in a column and the liquid is circulated until the contamination is removed.

Alternatively, activated earth is added to the liquid in a container and it is stirred to ensure intimate mixing and then the earth is filtered through a normal paper filter. In both cases either Fullers' Earth or activated alumina may be used and each must be thoroughly dried. It has been found by experience in laboratory tests that the earth may be pacified by heating to excessive temperatures, and the optimum treatment is about 150°C for 6 hours. The activated

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material is then added to the Aroclor to be treated at a level of .2% - 2% by weight. The use of freshly activated earth gives a controlled high quality of material from the treatment stage. However, there still exists the problem of separating the earth 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 strongly 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 unpumpable. 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. Aroclor capacitors may be vacuum impregnated by a manifold technique in which the liquid is piped individually to each capacitor can and this is perhaps more suitable for the larger power factor correction capacitors. 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 as this process is carried out under vacuum the losses will be greater with a liquid which is more volatile.

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

Toxicity precautions and the handling of Aroclor is dealt with in a separate section but workers handling the liquid, or capacitors coated with it, are advised to wear rubber gloves or use barrier cream.

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PERFORMANCE

PERFORMANCE OF AROCLOR CAPACITORS

A.C. capacitors at low ambient temperatures

If a capacitor is continuously energised 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 energised in ambient temperatures down to -60°C, and it was found that such capacitors satisfactorily survived whilst installed outdoors during the winter 1962-3.

If, however, a capacitor is subjected to a low temperature environment first and then energised 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

For operation at still lower temperatures a blend of Aroclor 1254 and trichlorobenzene has been used.

D.C. capacitors

Aroclor 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 stabilisers in the Aroclor to overcome the slight electrochemical degradation which tends to take place. Generally the effect is proportional to the quantity of stabiliser used and up to 1 per cent of anthraquinone, or 1,8 dichloroanthraquinone, and 2 per cent of azobenzene have been used.

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TOXICITY

TOXICITY AND HANDLING PRECAUTIONS

Aroclor made by Monsanto has been used for over 33 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 must be handled in a closed or confined area provide exhaust ventilation or wear an approved respirator.

4 If Aroclor 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 vapour will not cause any ill effect, but prolonged exposure to a high vapour concentration should be avoided.
If these precautions are neglected acne may develop and excessive exposure may cause liver damage.

APPENDIX A

LABORATORY MEASUREMENTS ON AROCLOR

The Monsanto dielectric test cell

There are many test cells available for measuring the electric properties of liquid dielectrics, but since most of these were designed for use with mineral oil, Monsanto has designed a test cell especially for use with Aroclor. This design of cell is used in our laboratories and is available for sale to customers. It is essentially a three terminal cell with cylindrical stainless steel electrodes separated by a 1 mm gap. Figure 7 shows details of the construction of this cell.

The procedure for cleaning and filling the cell

Great care must be taken to ensure careful cleaning for Aroclor measurements with this or any other cell. The Monsanto cell is designed for easy cleaning and accurate assembly.

The Monsanto cell is first cleaned by a series of thorough washings as follows:

1 A wash with benzene
2 A thorough washing with detergent and hot tap water
3 Repeated rinsing with hot tap water
4 6 rinses in distilled water
5 2 rinses in analytical grade acetone

During the wash with the powder detergent a soft hair brush is used and all parts of the electrodes are thoroughly brushed. The cell is then dried in an air oven at 130°C for 30 minutes. Finally it is rinsed twice with the Aroclor to be measured before filling a third time, when the electrical measurements are taken.

Measurements

The temperature at which the electrical properties are made is measured by a thermometer resting in the central well of the cell. For routine tests a temperature of 100°C is used.

Permittivity and loss tangent are measured first with a transformer bridge at a stress of 1 V/μm and at mains frequency of 50 c/s. D.C. resistivity is then measured with an electronic megohmeter one minute after the application of a stress of 0·5 V/μm. If repeated readings of d.c. resistivity are performed on the same quantity of Aroclor in the cell, a gradual increase is noted. It is therefore recommended that if a repeat measurement of resistivity is required, the cell be emptied, thoroughly cleaned, and then refilled.

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Process control measurements For operating an impregnation plant, it is convenient to be able to measure the electrical properties of the Arocior without the necessity of taking samples, and a cell can be incorporated in the system e.g. in a flow line. It should be arranged that there is a turbulent flow of Arocior 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 Arocior 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 50 ml of Arocior. 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 Arocior 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 colour change of the Arocior is noted.

Results The Arocior in which the sample has been immersed must not experience a decrease in resistivity below 1·0 terohm cm.
Information on materials which have been tested is available on request.

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Technical Service

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

Front cover illustration by courtesy of

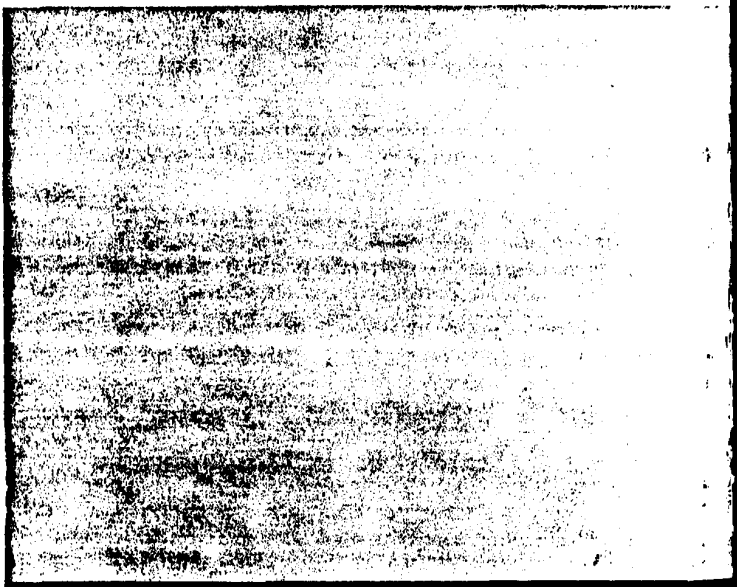
Industria Condensatori
Applicazioni Elettroelettroniche
Milano

Every effort has been made to ensure that the information in this publication is reliable, but as the conditions under which it may be applied are beyond our control, we cannot accept responsibility for any results of its use.

Forme No. F.B. 674-[illegible]
Published by Monsanto Chemicals Limited.

Printed in England by Oxley Press Ltd., Nottingham
TECHNICAL SERVICE BULLETIN G6/2
Reprinted March [illegible]
This edition supersedes all previous editions

MONS 078581



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