Monsanto Dielectric Fluids: Aroclors, Pyroclor

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MONS 079883

Aroclor Dielectrics

What are Aroclors?

Aroclor dielectrics are members of a group of synthetic insulating fluids known as 'askarels', which, by definition, are fire-resistant and incapable, when decomposed by an electric arc, of evolving explosive gases or of forming explosive mixtures with air. Most askarels are chlorinated diphenyls or blends thereof with other chlorinated organic fluids. The Monsanto range of askarels includes Pyroclor, RD.*7051 *and the Aroclor series of dielectrics. Capacitor and transformer manufacturers often apply their own trade names to the askarel fluids.*

Aroclor

Aroclors are a series of chlorinated polyphenyls manufactured by Monsanto Chemicals Limited. Each member is identified by a reference number, the last two digits of which indicate the percentage of chlorine in the molecule. Thus Aroclors 1242 *and* 1254 *contain* 42% *and* 54% *by weight of chlorine respectively.*
Each Aroclor is a mixture of isomers of a chemical compound; the fluids therefore do not have sharp points of crystallisation but thicken when cooled below their pour points.
Aroclor dielectrics are highly refined by distillation and by special treatment to remove impurities. Manufacture to rigid specification ensures high resistivity and low power factor.

Pyroclor

Pyroclor is a fire-resistant fluid based on a blend of Aroclor 1260 *and highly-purified trichlorobenzene and has been specially developed as an alternative fluid to mineral oil for use in transformers.*

Fluid RD.7601

*Fluid RD.*7051 *is a fire-resistant fluid based on Aroclor* 1248 *and is suitable for operating at higher temperatures than Pyroclor or mineral oil. The Aroclor and Pyroclor dielectrics are fire-resistant and will not produce explosive gases or explosive mixtures with air when heated or brought into contact with an electric arc.*

* AROCLOR is a Registered Trade Mark.

Contents

1 Introduction

The following properties of the Aroclors have attracted the interest of the electrical industry by reason of their:

1 Excellent electrical properties

2 Fire-resistance

3 Chemical inertness

The Aroclors, on account of their superior properties, are gradually replacing mineral oil as the traditional dielectric fluid, and have made possible a considerable improvement in the design of electrical equipment.

Mineral oil dielectric fluids have two serious limitations:
1 Oil is inflammable and its vapour or decomposition products can form explosive mixtures with air.
2 Under continuous electric or thermal stress in the presence of air, degradation occurs which seriously reduces the electrical and physical properties of the oil.

Aroclor dielectrics, in addition to being fire-resistant, do not react with water or air, nor do they affect recommended materials of construction. Furthermore, their permittivities and breakdown-strengths are superior to those of mineral oil. Aroclor dielectrics may be used in suitably designed equipment for many years without purification or replacement.

Although initially more expensive than mineral oil, Aroclors are often more economic in the long run when the lower cost of installation and prolonged service life are taken into consideration. In *Capacitors*, Aroclor dielectrics permit considerable savings to be made in size, weight and cost for a given capacity rating. In *Transformers*, Aroclor dielectrics are used when mineral oil would introduce a fire-hazard or where minimum maintenance is especially important. This latter consideration will also affect the choice between askarel-filled and air-cooled equipment.

Aroclor dielectrics manufactured by Monsanto Chemical Company, U.S.A, have been in use in many parts of the world for more than 20 years and have been available from U.K manufacture since 1951.

The first part of this booklet deals with the general properties of Aroclor dielectrics. Detailed consideration of two important applications for Aroclor dielectrics—capacitor impregnation and transformer cooling—then follows. Other applications—such as in rectifiers, induction regulators, cable impregnation, and potting and jointbox compounds—are briefly considered.

Laboratory demonstration indicating the fire-resistant properties of Pyroclor.
The asbestos cord on the left is impregnated with Pyroclor, whilst that on the right is impregnated with a conventional coolant.
The Pyroclor specimen did not burn after the application of a bunsen flame.

2 Properties of Aroclor Dielectrics

Table 1 Properties of Aroclor Dielectrics (Typical Values)

	Units	*Aroclor* 1242	*Aroclor* 1248	*Aroclor* 1254	Pyroclor*	*RD* 7051
Description		CLEAR, PRACTICALLY COLOURLESS LIQUID				
Pour Point	°C	−18	−9	+10	−32	The properties of RD 7051 are similar to those of Aroclor 1248
Viscosity	cks.	8.0 (55° C)	5.4 (80° C)	6.5 (100° C)	2.5 (80° C)	
Specific Gravity @ 100° C		1.31	1.38	1.47	1.48	
Specific Gravity @ 20° C		1.38	1.46	1.55	1.56	
Specific Heat @ 20–100° C	Cal/gm°C	0.28	0.27	0.26	0.26	
Index of Refraction @ 25° C	Deine	1.624	1.630	1.637	1.615	
Evaporation Loss (*a*) According to DIN (2 hrs @ 125° C)	%	0.12	0.07	0.03	2.5 (6H, 100° C)	
(*b*) According to BS.148:51	%	0.4 (max)	0.3 (max)	0.1 (max)	0.6 (max)	
Fire Point		None	None	None	None	
Acid Number	mg/KOH/gm	<0.01	<0.01	<0.01	<0.01	
Inorganic Chlorides	p.p.m.	<0.1	<0.1	<0.1	<0.1	
Permittivity (50–1000 cycles) @ 100° C		4.8	4.6	4.2	ca.4	
Power Factor @ 100° C and 50 c/s	%	<4.0	<3.0	<1.5	<3.0	
Resistivity @ 100° C and 200 v/mm, 1 min.	ohm. cm.	$>1\times10^{11}$	$>1\times10^{11}$	$>1\times10^{12}$	$>1\times10^{11}$	
Dielectric Strength (*a*) According to Verein Deutscher Elektrotechniker Specification 0370, 2.5 mm gap	kV/cm.	>200	>200	>200	>200	
(*b*) According to BS.148:51 4 mm gap	kV	>40	>40	>40	>40	

* Pyroclor and RD.7051 may contain crystals at room temperature, but these crystals should dissolve if the liquid is warmed to 60° C (140° F)

Pyroclor boils at approximately 210° C (410° F), the boiling point of trichlorobenzene

Specific gravity

The Aroclor dielectrics are heavier than water or mineral oil, and this should be taken into account in designing electrical equipment. It should also be remembered that any moisture finding its way into Aroclor filled equipment will float on the fluid. Conductors brought out through the liquid surface should be encased in suitable sleeving (glass, porcelain, or bakelised paper) to prevent the possibility of flashover arising from surface moisture.

Viscosity and pour point

The temperature/viscosity curves for the Aroclor dielectrics and a typical transformer mineral oil are shown in Fig. 1. The viscosities and pour points of the individual Aroclors largely determine their operating temperature ranges. Aroclor 1254, for example, is widely used in capacitors for steady or intermittent operation in ambient temperatures down to about $-20°$ C ($-4°$ F). Where capacitors may be exposed to lower temperatures, Aroclor 1242 or a blend of Aroclors with a liquid such as trichlorobenzene is recommended.

As will be seen from Fig. 1, Pyroclor was designed to match fairly closely the viscosity/temperature curve of conventional transformer oil. Fluid RD.7051 is suggested, however, for transformers which are designed for a fluid temperature rise substantially greater than 55° C (130° F).

Specific heat and thermal conductivity

The specific heats of the Aroclors 1242, 1248, and 1254 are shown in Fig. 2 and their thermal conductivities in Table 2 below. The specific heat of Pyroclor can be taken as 0.25 cals/gm/°C (0.25 B.Th.U./lb/°F) for all practical purposes over a fairly wide temperature range.

Table 2 Thermal conductivity of Aroclor Dielectrics at 40° C (104° F)

Product	*K.cals/sec cm °C*	*or B.Th.U./hr ft °F*
Aroclor 1242	0.095	0.0713
Aroclor 1248 and RD.7051	0.090	0.0682
Aroclor 1254	0.087	0.0652
Pyroclor	0.083	0.0623

Vapour pressure

Figs. 3a and 3b illustrate the variation of vapour pressures of the various fluids with temperature.

Cooling efficiency

The cooling efficiency of Pyroclor is comparable with that of mineral oil.

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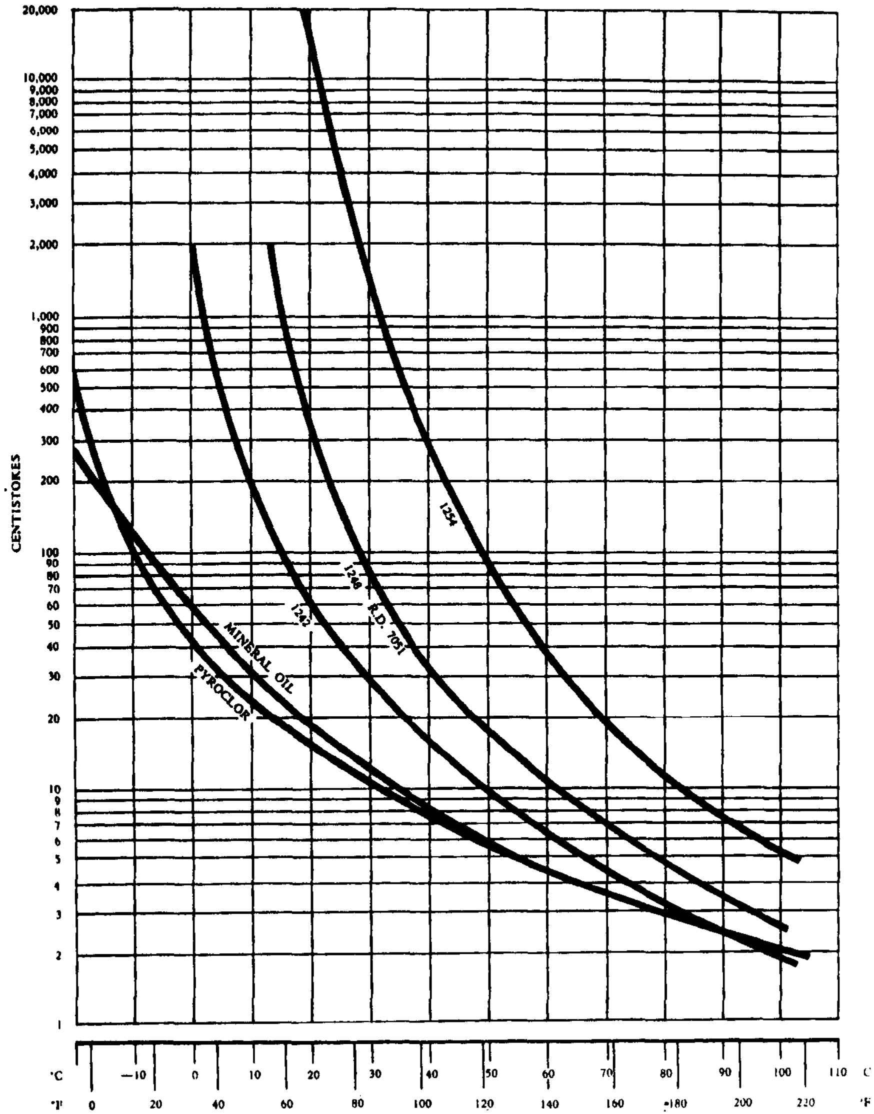
Fig. 1 Kinematic viscosities



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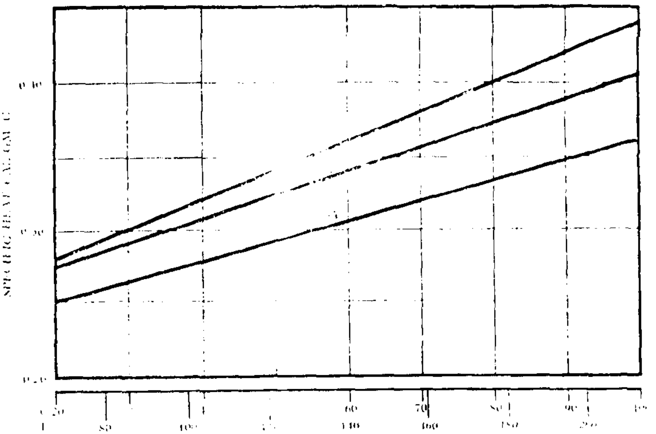


Fig. 2 Specific heats of Aroclors as a function of temperature

CHEMICAL PROPERTIES

The chemical inertness of the Aroclors is outstanding. The fluids 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 (284° F) in oxygen at a pressure of 250 lb per square inch (12 kg/sq. cm), there is 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 or sludging.

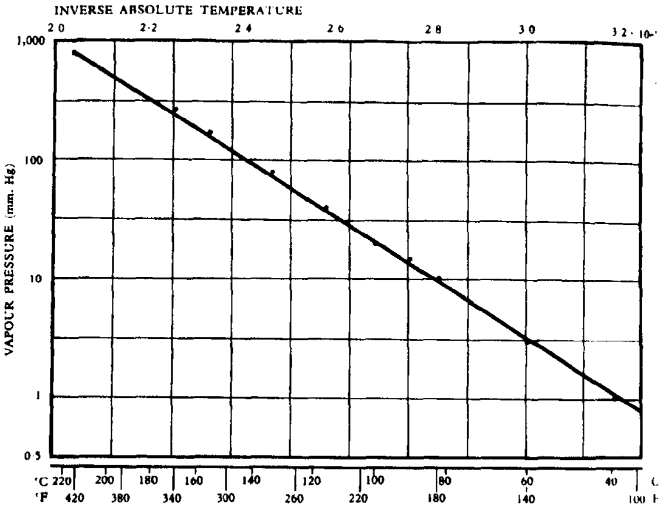
Acidity and free chlorides

Aroclor dielectrics are 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 fluids are heated for prolonged periods in the presence of air and moisture at temperatures of 100° C (212° F).

Light sensitivity

As a general rule, Aroclor dielectrics are unaffected by exposure to light but the lower chlorinated members of the series, such as Aroclor 1242, are slightly sensitive to ultra-violet light, which can result in the formation of traces of ionic contaminants. Opaque bushings are therefore recommended for capacitors impregnated with Aroclor 1242.

Fig. 3a Vapour pressure of Pyroclor as a function of temperature



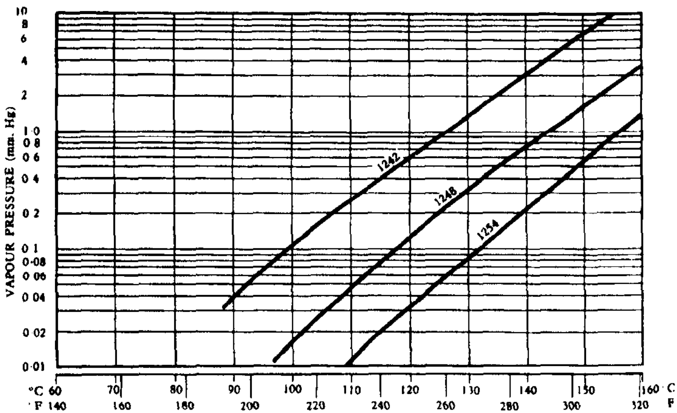


Fig. 3b Vapour pressures of Aroclors as a function of temperature

Thermal breakdown

Aroclor dielectrics undergo no decomposition at temperatures up to 175° C (365° F). At much higher temperatures or when subjected to power arcs, the principal decomposition products of the fluids are carbon and hydrogen chloride.

Table 3 gives an analysis of the decomposition products formed by subjecting a typical transformer oil, Pyroclor, and Aroclor 1254, to an electric arc. The samples used for the test had not been de-gassed.

Table 3 Decomposition products by electric arc

Mineral oil		*Aroclor 1254*		*Pyroclor*	
Hydrogen	60%	Hydrogen	0%	Hydrogen	0%
Carbon Monoxide	3	Carbon Monoxide	0–0.3	Carbon Monoxide	0.25
Carbon Dioxide	0	Carbon Dioxide	0–0.3	Carbon Dioxide	0
Unsaturated hydrocarbons	16	Unsaturated hydrocarbons	0	Unsaturated hydrocarbons	0.50
Saturated hydrocarbons	10	Saturated hydrocarbons	0	Saturated hydrocarbons	0
Oxygen	2	Chlorine	0	Oxygen	0.25
Nitrogen	9	Hydrogen Chloride	99–100	Nitrogen	2.0
				Hydrogen Chloride	97.0

It is evident that the gaseous mixture formed by the mineral oil would yield highly explosive mixtures with air. On the other hand, not only do the askarel fluids produce a smaller quantity of gas than mineral oil, but the gases evolved are non-inflammable.

Laboratory tests and practical experience with transformers have shown that phosgene, chlorine, carbon monoxide or hydrocarbons are not formed as decomposition products of the Aroclors. Hydrogen chloride, which is non-inflammable and easily detected by its sharp odour, is the only gas produced.

Solubility of gases

The Bunsen coefficient is defined as the number of cubic centimetres of a gas at N.T.P dissolved in one cubic centimetre of the fluid at a partial pressure of 760 mm of mercury. The coefficients for Aroclor 1248 and Pyroclor are shown in Fig. 4. The gas absorption of askarels obeys Henry's Law over a range of several atmospheres, i.e, the volume dissolved is proportional to the pressure, but since the gases themselves obey Boyle's Law, it follows that the volume of gas, measured at the equilibrium pressure of the gas-liquid system will be a constant. This volume of gas when related to one cubic centimetre of fluid will, therefore, be numerically equal to the Bunsen coefficient. The following expression applies therefore:

$$\frac{P_o}{P_i} = 1 + RB$$

Where P_o is calculated pressure without absorption
P_i is the equilibrium pressure
R is the liquid volume/gas space ratio
B is the Bunsen coefficient

Thus, in the case of a transformer filled with Pyroclor such that at maximum operating temperature of, say, 80° C (176° F), the air-fluid ratio is 1:5 with an internal pressure of 5 lb per sq in., then the amount of air dissolved in the fluid would correspond to a reduction of pressure from a theoretical value of 5.8 lb per sq in. without any absorption to the practical value of 5 lb per sq in.

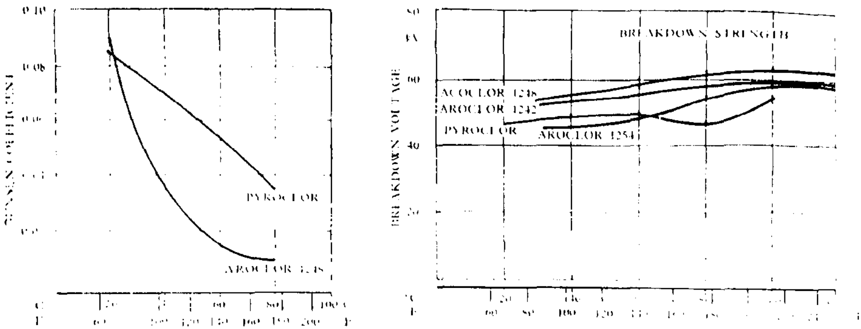


Fig.4 Air absorption

Fig.5 Breakdown strength

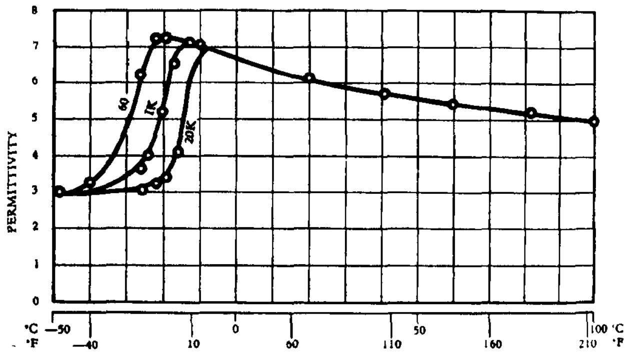
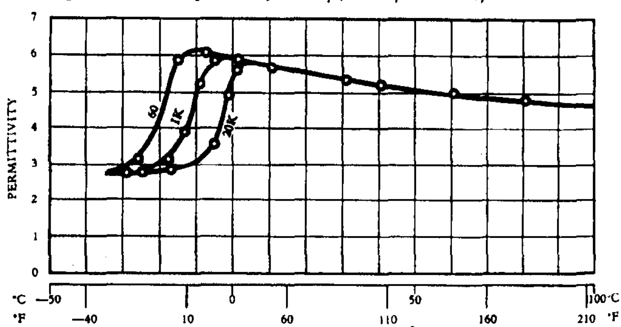


Fig.6 Aroclor 1242 permittivity at 60 c/s, 1000 c/s and 20 kc/s

Fig.7 Aroclor 1248 permittivity at 60 c/s, 1000 c/s and 20 kc/s



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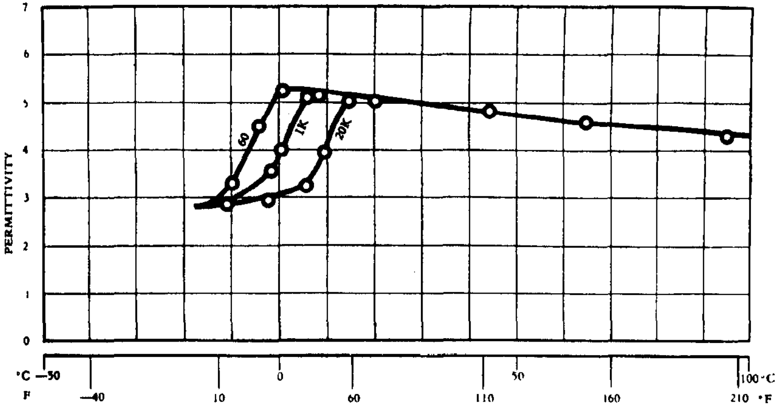
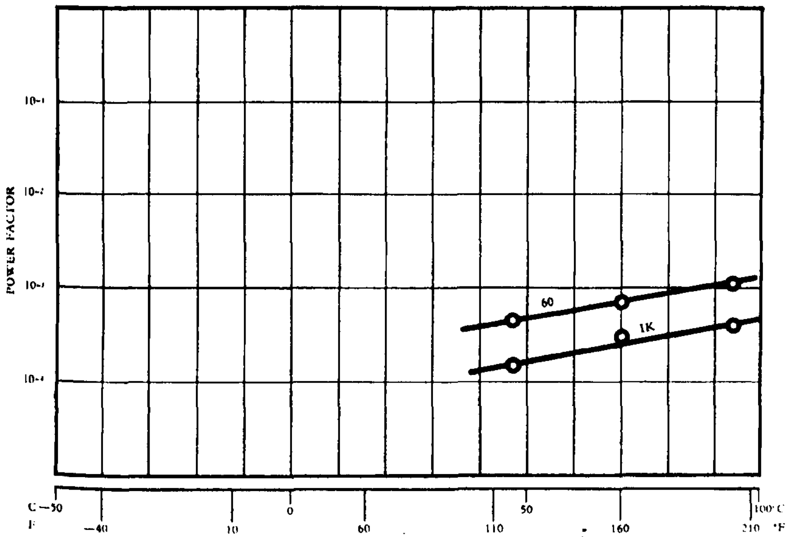


Fig.8 Aroclor 1254 permittivity at 60 c/s, 1000 c/s and 20 kc/s

Fig.9 Capacitor oil power factor at 60 c/s and 1000 c/s



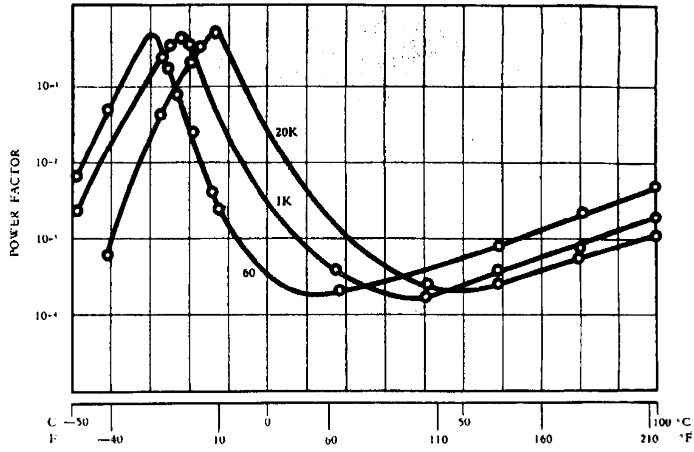


Fig.10 Aroclor 1242 power factor at 60 c/s, 1000 c/s and 20 kc/s

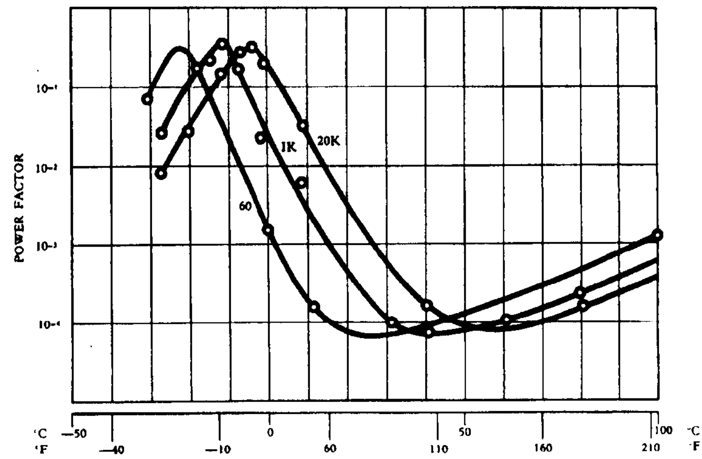


Fig.11 Aroclor 1248 power factor at 60 c/s, 1000 c/s and 20 kc/s

Breakdown strength

The breakdown strengths over a range of temperature of typical samples of Aroclors and Pyroclor are shown in Fig. 5. These measurements were carried out using two electrodes of ½ in. diameter (BS. 148 : 51) with a spacing of 2 mm. These values are at least as good as those obtained with a good mineral oil.

Permittivity

The permittivities of the Aroclors over a range of temperature for various frequencies are shown in Figs. 6, 7, and 8. They were measured by a Schering bridge, the sample being contained in a stainless steel test cell. It is apparent that this property is dependent on both frequency and temperature, but its value is greater than that of mineral oil (2.2–2.3) for those conditions that are usually encountered with impregnated paper capacitors.

Permittivity is less important in the case of transformer fluids and, therefore, a graph for Pyroclor has not been included. At −30° C (−22° F), Pyroclor has a permittivity of about 5 falling to about 3.9 at 100° C (212° F). On account of its relatively high permittivity, however, it is advantageous to design transformers so that facing electrodes should be in the vertical plane wherever possible.

Power factor

The power factors of the Aroclors are shown in Figs. 10, 11, and 12. These values were measured over a range of temperature at various frequencies and are higher than those obtained for mineral oil, particularly for certain combinations of frequency and temperature. Although a low power factor is desirable in capacitors, it will be shown later that the higher power factors of the Aroclor impregnants are not a serious disadvantage.

Fig. 12 Aroclor 1254 power factor at 60 c/s, 1000 c/s and 20 kc/s

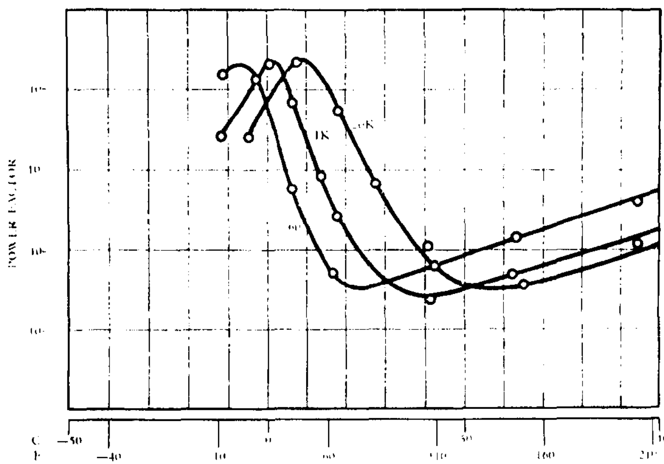
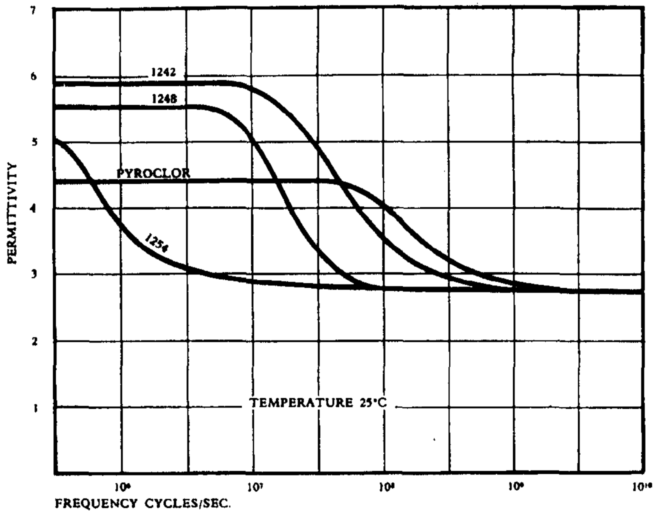


Fig. 13 Permittivity at radio frequencies



Permittivity at radio frequencies

The permittivities of the Aroclors and Pyroclor are plotted in Fig. 13 as a function of frequency at 25° C (77° F). Over an appreciable range, the permittivity of the Aroclors is higher than that of mineral oil.

Tan δ at radio frequencies

Fig. 14 shows the values of tan δ of the Aroclors and Pyroclor over a frequency range at a temperature of 25° C (77° F). These values are higher than are encountered with mineral oil. Tan δ is related to power factor by the relation:

$$\text{power factor} = \frac{\tan \delta}{\sqrt{1 + \tan^2 \delta}}$$

Volume resistivity

The high volume resistivity of the Aroclors and Pyroclor is achieved by rigid purification and control procedures. If the fluids should become contaminated, as for instance by careless handling, then the high electrical properties of the fluids can only be restored by suitable filtration treatment through Fuller's Earth. Typical results of volume resistivity measurements on production samples of Aroclor 1248 and Aroclor 1254 over a temperature range are shown in Fig. 15. Measurements were carried out with a field of 200 volts/mm in a stainless steel test cell, the actual reading being made after one minute's electrification.

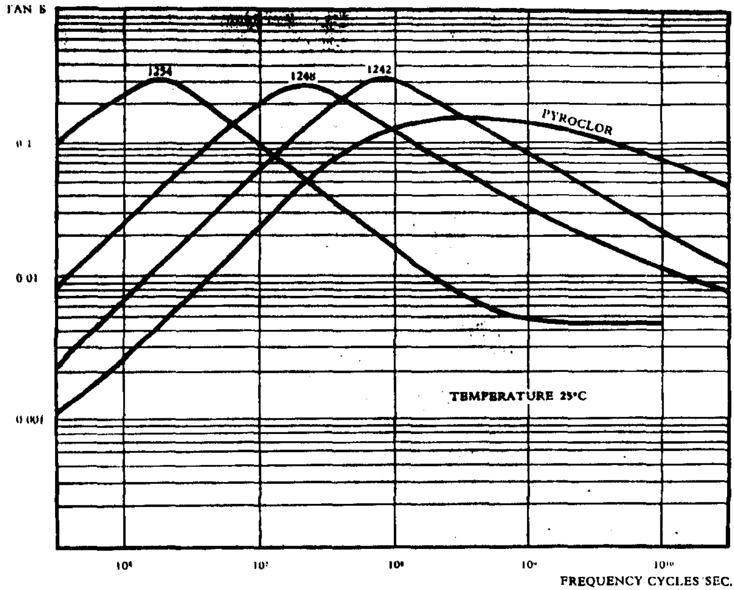
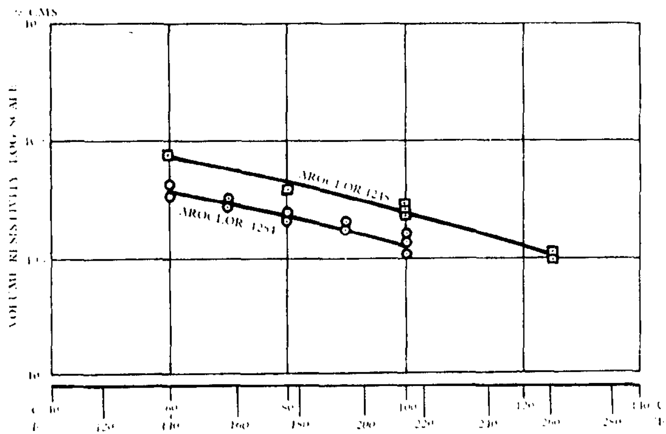


Fig.14 Tan δ at radio frequencies

Fig.15 Typical values of volume resistivity



3 Applications of Aroclor Dielectrics

CAPACITORS

It was recognised early in the development of paper-and-foil capacitors, that improvements could be achieved by filling the air spaces in the paper with a material having a permittivity equal to that of the paper itself. Although mineral oil and petroleum jelly have been used for many years, their permittivities are still low compared with the cellulose of the paper and it is only with the development of the askarels that further improvements have been achieved.

Chlorinated diphenyls were first used commercially for capacitor impregnation in the early 1930's. Since then the chlorinated diphenyl capacitor has become increasingly popular in Europe, particularly in France, Italy, and Germany and the trend towards their use continues. Power factor correction capacitors with chlorinated diphenyl impregnants are now in use throughout the world. In the U.S, for example, it is reported that over 20 million kVArs of power factor correction capacity, using askarel impregnants, have been installed. Also, it is said that more than 60 million small capacitors are in service in fluorescent light ballast, capacitor-start motors, and electronic equipment.

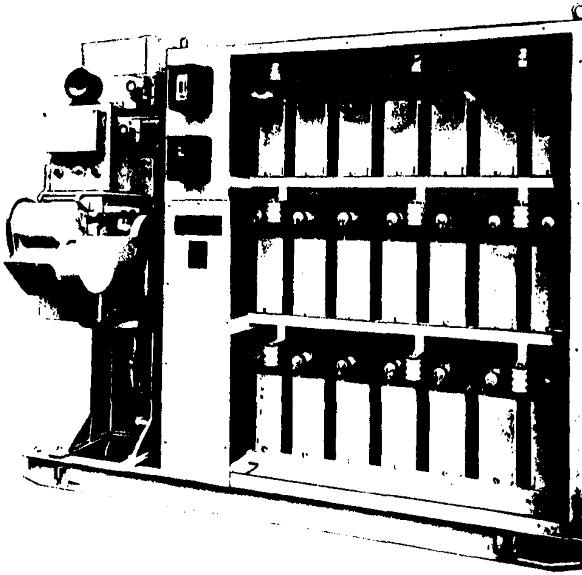
Chlorinated diphenyl impregnants have enabled considerable advances to be made in capacitor design for industrial power factor correction, and have led to the 15-kVAr and 25-kVAr unit capacitors now in use at voltages from 440 up to 13,800 volts.

Aroclor Dielectrics and mineral oil as Capacitor impregnants

Permittivity

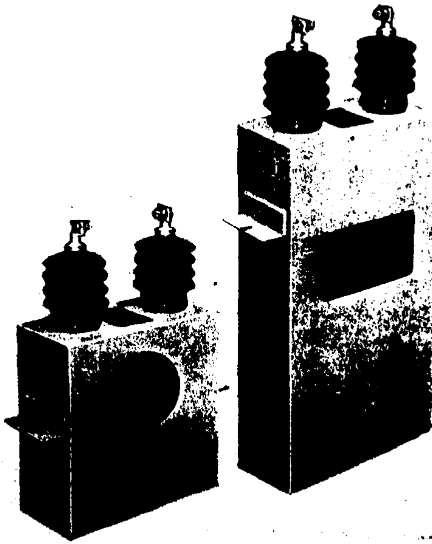
As is shown in Figs. 6, 7, and 8, the permittivities of Aroclor dielectrics, at temperatures above their pour points, are much higher than that of mineral oil. By proper selection of Aroclor dielectrics or by blending them with a suitable fluid, such as trichlorobenzene, fluids can be produced having very low pour points but still having the same high permittivity of chlorinated diphenyl.

Capacitor tissue may be considered to be a fibrous mat, the fibres of which have a permittivity approaching that of pure cellulose, i.e, about 6.6. In the impregnation process the air in the interstices between the fibres is replaced by a suitable dielectric fluid. If the permittivity of the impregnant corresponds exactly to that of the cellulose fibres of the tissue, then the total volume of the dielectric could be reduced to a minimum and the stress gradient would be uniform. The high permittivity of Aroclor dielectrics enables advantage to be taken of this fact and, in consequence, reductions in volume of as much as 40% compared with the equivalent mineral oil capacitor, have been achieved.



A three-phase capacitor bank rated at 400 kVAr at 2.3 kV assembled from indoor type Aroclor impregnated high-voltage capacitor units.

Photograph by courtesy of Dubilier Condenser Co (1925) Ltd.



High-voltage outdoor capacitor units rated at 20 kVAr at 8 kV, 50 c/s, showing relative size.
Right is a mineral oil impregnated unit, while left is one impregnated with Aroclor.

Photograph by courtesy of Dubilier Condenser Co (1925) Ltd.

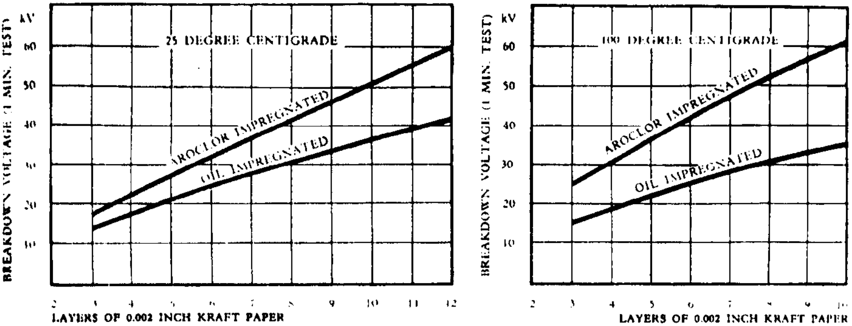


Fig. 16 Breakdown voltage of Aroclor and mineral oil impregnated Kraft paper

Dielectric strength

A comparison is made in Fig. 16 between the dielectric strengths of 0.003 in. Kraft paper impregnated with pentachlordiphenyl (Aroclor 1254) and the same paper impregnated with mineral oil. The higher breakdown strength of the Aroclor impregnated paper permits the use of higher working stresses in capacitors. The higher dielectric strength of Aroclors and the more uniform stress distribution achieved by the use of Aroclor-impregnated tissue, allow Aroclor capacitors to be operated at considerably higher stress gradients than mineral oil impregnated capacitors.

Power factor

The relationship between power factor and temperature is shown in Figs. 9, 10, 11, and 12 for the Aroclors 1242, 1248, and 1254 and for mineral oil. The presence of minute amounts of ionic impurity accounts for the fact that the Aroclors have higher power factors than mineral oil over the whole temperature range. The power factor of an Aroclor-impregnated capacitor is, however, lower than would be expected as these ionic impurities are held by the paper and, hence, are prevented from contributing to the power factor of the unit.

A further factor to be taken into consideration regarding the power factor of an impregnated capacitor is the influence of the density of the paper used. Thus, although the power factor of Aroclor-impregnated paper is higher than that of the same paper impregnated with mineral oil due to the higher permittivity of the Aroclor, a paper of lower density can be used with Aroclor than would be used with mineral oil. This will offset the permittivity effect and result in a capacitor of lower power factor (see Fig. 17). The use of lower density paper will also reduce the resultant permittivity of the impregnated unit but the magnitude of the reduction is very much lower than would result if the same paper were used with mineral oil (Fig. 18).

The power loss of an Aroclor-impregnated capacitor is somewhat higher than that of its mineral oil-filled equivalent but the increase is acceptable. Values of the order of 0.3% are typical.

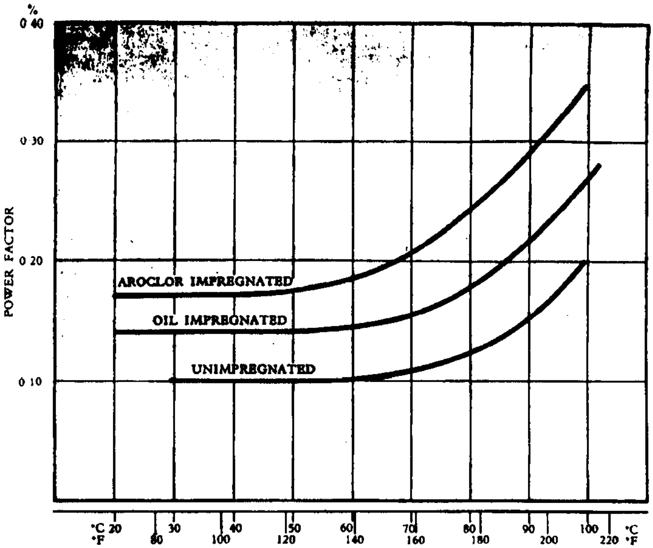
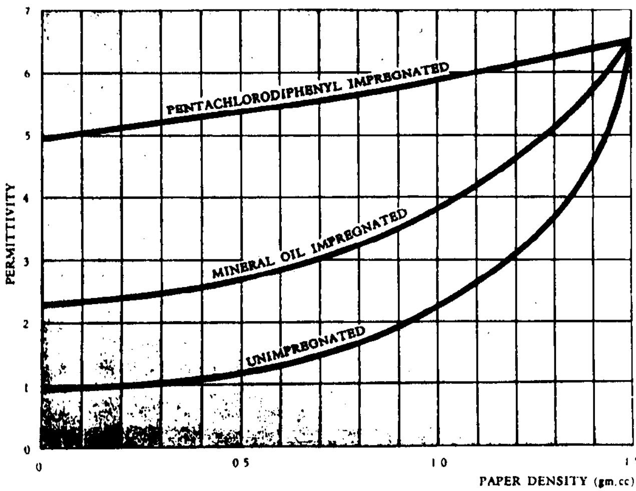


Fig. 17 Power factor of impregnated and non-impregnated paper

Fig. 18 Effects of paper density on the permittivity of impregnated paper at 20° C



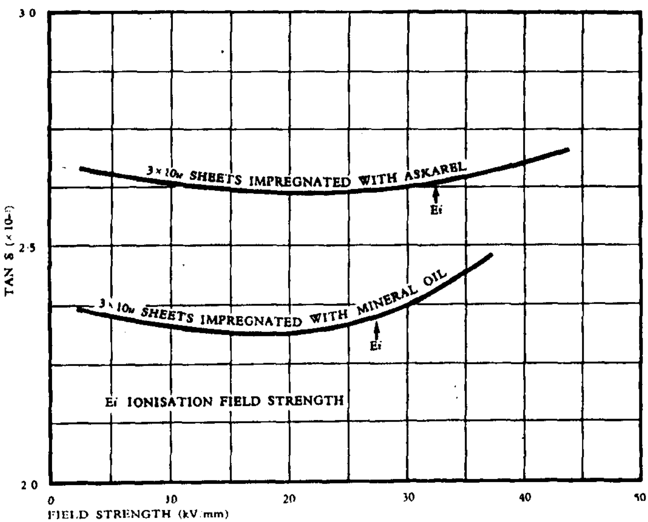
Stability

It will be seen from Fig. 19 that both Aroclor-impregnated and mineral oil-impregnated tissues show a fairly sudden increase in power factor at a certain level of electric stress due to minor breakdowns in the impregnant. This level of stress, the "inception discharge voltage", is higher for Aroclor than for mineral oil. Early failure will result if the dielectric operates at above this stress, but it is clear that the value for Aroclor is much higher than for mineral oil. Below this critical level, a small amount of degradation still occurs, but this is less with Aroclor than with mineral oil. This degradation is reflected in a fall in inception discharge voltage and it has been found in life tests under constant stress that, although the inception discharge voltage decreases during life, it drops far more slowly with Aroclor than with mineral oil. Under surge conditions, Aroclor-impregnated tissues of the thickness encountered in capacitors have a breakdown strength at least equal to that of similar tissues impregnated with mineral oil.

Fire resistance

The Aroclors will neither cause electrical fires nor contribute to fires from other sources.

Fig. 19 Power factor against ionisation field strength of impregnated papers



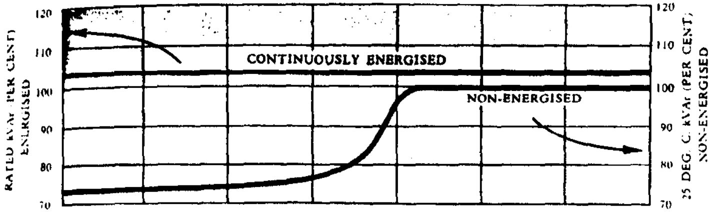
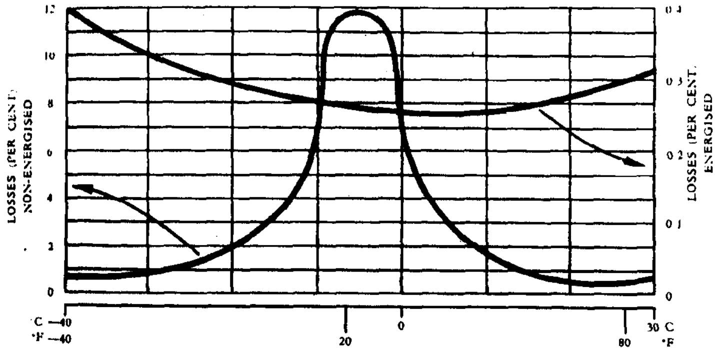


Fig. 20
Fig. 21 } Behaviour of a chlorinated diphenyl capacitor at various temperatures on and off load



Performance of ...-impregnated Capacitors

Intermittent operation in cold weather

A capacitor impregnated with Aroclor 1254 put on circuit at temperatures below the pour point of the fluid would have only about 75% of its rated capacity and its power factor would be high. If, however, the temperature at which the unit were put on load were not below about −20° C (−4° F) the capacitor would safely reach its full capacitance value in a few seconds due to the heating associated with the relatively high power factor. Under continuous operating conditions, an equilibrium will be reached between the internal and ambient temperatures, thereby ensuring that the capacitor operates at its rated capacity with minimum losses. (See Figs. 20 and 21.)

At lower temperatures contraction of the frozen dielectric may lead to fissuring which could result in flashover and rapid destruction of the capacitor. Under such conditions, it is preferable to use an Aroclor with a very much lower pour point such as Aroclor 1242 or to use a blend of Aroclor 1254 and trichlorobenzene.

High temperature operation

Since the total volume of the capacitor is reduced if chlorinated diphenyl is used as the impregnant instead of mineral oil, it follows that the total surface area of the capacitor is smaller. Heat dissipation would therefore be less efficient and the internal temperature of the capacitor would be higher. The use of low density capacitor tissues, however, lowers internal losses and hence reduces the internal temperature of the capacitor. On the other hand, Aroclor capacitors give longer life and better performance at higher temperatures than mineral units. Twenty-five kVAr units have been working for many years in such locations as the Arizona and Libyan deserts, where the ambient temperatures are about 40° C (104° F). Under such conditions the maximum temperature in the centre of the windings is in the region of 80° C (176° F).

Service life

Aroclor-impregnated capacitors used for power-factor correction, although normally operating under higher voltage-gradients than oil-impregnated capacitors, have given fully comparable service life. This is not surprising in view of the excellent chemical and thermal stability of the Aroclor dielectric.

Not only is the ionisation inception voltage higher for Aroclor than for oil, but the differential is increased during long periods of electrical stress particularly at higher temperatures, and this favours longer service life.

D.C. Capacitors

Several years ago it was observed that the service life of chlorinated diphenyl-impregnated capacitors under continued D.C. voltage stress was reduced as the working-temperature was raised above 40° C (104° F). It was found, however, that certain stabilisers could be added to the chlorinated diphenyl to counteract the slight degradation occurring at these high operating temperatures. Typical stabilisers are anthraquinone, azobenzene and certain of their derivatives. Accelerated life tests of Aroclor 1254 capacitors with and without stabilisers are shown in Figs. 22a and 22b. Capacitors impregnated with stabilised Aroclor have a service life under D.C. operation comparable with that for oil-impregnated capacitors.

Cost

Substantial reduction in cost of capacitor manufacture is possible through the use of Aroclor dielectric impregnants due to savings in paper, aluminium foil, and containers. Furthermore, production rate can be increased since the higher permittivity means more kilovars per impregnation batch.

Manufacture of Aroclor-impregnated Capacitors

The impregnant in capacitors is under much higher electrical stress than the insulating fluids in other apparatus. Consequently, precautions must be taken to ensure that the impregnant should have the highest possible resistivity and the lowest possible power factor. Most manufacturers dehydrate and filter the dielectric fluid and carry out impregnation under carefully controlled conditions in order to avoid contamination.

Capacitor Aroclor should never be exposed to the atmosphere except when being transferred to storage, or when an impregnator is opened after a batch of capacitors has been impregnated. The Aroclor which is returned to storage should be dehydrated and filtered through Fuller's Earth before re-use. Procedures for

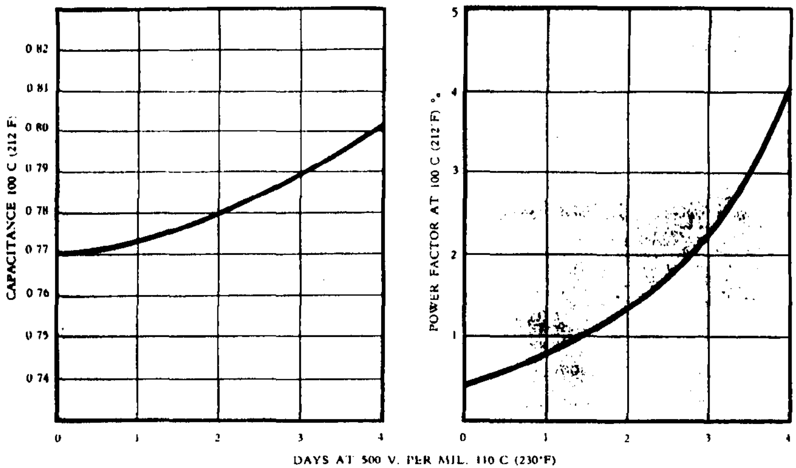
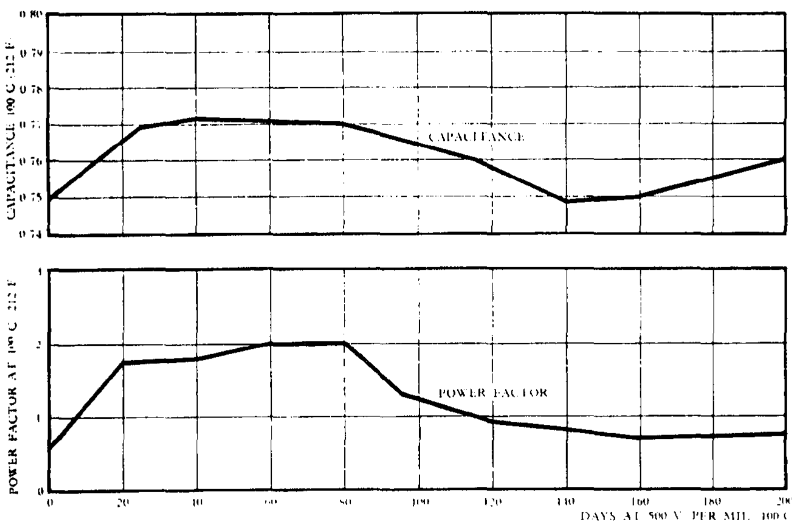


Fig. 22a Showing the rapid electrical deterioration which occurs when an askarel treated capacitor is operated on D.C. voltage at high temperature

Fig. 22b Electrical deterioration of the askarel treated capacitor illustrated in Fig. 22a is eliminated if anthraquinone be dissolved in the askarel impregnant. One half per cent anthraquinone is dissolved in the askarel impregnant of the capacitors here illustrated



dehydrating capacitor Aroclor are, in general, similar to those followed for mineral oil. It is somewhat easier to de-gas Aroclor than mineral oil under vacuum because, firstly, less frothing occurs, and, secondly, Aroclor releases the last traces of air more easily than oil. Dehydration of Aroclor 1254 is usually carried out at a temperature not above 120° C (248° F) and at a vacuum of 1 mm Hg or less depending on the temperature.

Impregnation temperatures up to 130° C (266° F) are used with Aroclor 1254; 75° C (167° F) with Aroclor 1242. It is advantageous to dry the capacitor windings before impregnation at as hard a vacuum as possible. Impregnation cycles from 12 hours to 48 hours are usual. Aroclor capacitors are sealed either with casings full of warm fluid or with a dry air or inert gas space above the fluid to allow for expansion.

Care should be exercised in selection of materials to be used in Aroclor-impregnated capacitors. Kraft tissue is strongly recommended because it has been found to give the best service life. Copper lead-in tabs should be tinned. Fluxless solders are preferred, but if fluxes are necessary, they should be used sparingly and care should be taken to remove residual traces before impregnation. Trichloroethylene vapour degreasing plant is suitable for this purpose.

Bushings and gaskets which are likely to be in contact with the fluid may be made from silicone elastomers, most grades being suitable. Although internal fuses have been used in some Aroclor-impregnated capacitors, their use is not generally recommended for multi-plate types.

Aroclor 1254 is usually selected for operation throughout the normal ambient temperature range. Aroclor 1242 is suggested for use at lower temperatures down to about −40° C (−40° F), or alternatively, and at still lower temperatures, mixtures of Aroclor with low pour point fire-resistant solvents of suitable electrical quality may be used.

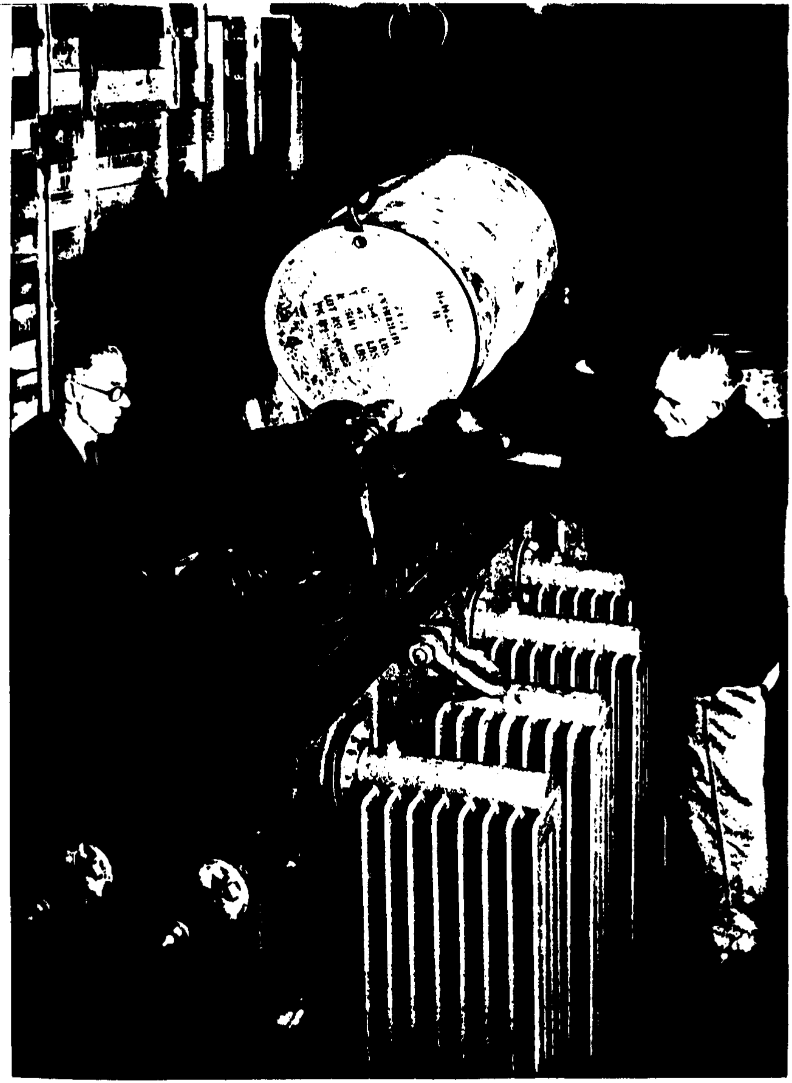
TRANSFORMERS

A deliberate search for insulating fluids possessing the excellent insulating properties of freshly purified mineral oil coupled with higher stability in service and a high measure of fire resistance resulted in the development of askarels as transformer coolants.

The inflammability of mineral oil and, more important, the danger of explosion from decomposition products arising when mineral oil is subjected to arcing, necessitate the installation of numerous safety devices and the observance of safety regulations, sometimes enforced by law, to protect premises where oil-filled electrical equipment is installed.

When oil-filled transformers are installed outdoors they can be isolated and the consequences of explosion and fire are minimised; when installed indoors, however, fireproof vaults, oil run-off drains, pebble pits, and chemical firefighting equipment may be necessary. In some installations, the associated buildings and equipment may be very expensive and inconvenient to install, occupying valuable space and adding very appreciably to the cost of installing the transformer.

A second disadvantage of mineral oil is its sensitivity to heat, particularly in the presence of air or moisture. A series of chemical reactions gradually occurs in warm transformer oil, leading by degrees to formation of peroxides, organic acids, and complex long-chain hydrocarbons. The complex hydrocarbons eventually produce



One of fifteen transformers, designed to operate in conjunction with a 500 KW mercury arc rectifier for underground service in mines, being charged with Pyroclor.

Photograph by courtesy of Hackbridge & Hewittic Electric Company Limited.

a sludge which raises the viscosity of the fluid and, in severe cases, deposits a coating on the windings of the transformer severely reducing the transfer of heat to the coolant. It has been reported that the rate of sludge formation doubles approximately for each 7–10° C (10–14° F) temperature rise in the region of 80° C (144° F).

The formation of peroxides and acidic by-products increases the sensitivity of the oil to moisture. Water-in-oil emulsions may result from the emulsifying action of the metallic soaps produced by the attack of these acidic products on the metals present in the transformer. Under such conditions the dielectric strength of the fluid falls to very low values.

These deficiencies of mineral oil are well recognised and attempts have been made to retard deterioration by the addition of oxidation inhibitors or by sealing under a nitrogen atmosphere.

Transformer askarels, on the other hand, are fire resistant and do not deteriorate chemically, a fact that has been borne out by service records extending over a period of 15 years and more.

When to use Pyroclor transformers

Three types of industrial transformers are manufactured, mineral oil-filled, askarel-filled, and air-cooled.

Most transformers are mineral oil-filled because they are usually the least expensive to construct. In those locations where an oil-filled transformer would have to be enclosed in a safety-vault, the overall installation cost may exceed the cost either of an askarel-filled transformer, or of an air-cooled transformer, both of which would provide the required safety without the addition of vaults.

Both askarel-filled and air-cooled transformers have their own advantages, depending largely on the particular circumstances of a given installation. The initial cost and subsequent maintenance of air-cooled units will vary greatly according to their location and rating. The askarel unit usually provides the more economic alternative in dusty, damp and corrosive atmospheres because of the difficulty of sealing and providing adequate cooling for a dry-type transformer. The space requirements for askarel and air-cooled transformers are about the same, except when voltages upwards of 3.3 kV are considered. For these higher voltages askarel-filled units often show a size advantage. The impulse rating of askarel transformers is very much better than that for air-cooled units. The air-cooled transformer must rely upon clearances in air for its insulation. The dimensions, and resultant cost, of an air-cooled transformer designed to operate at the impulse levels of a liquid-filled transformer would be considerably greater than those of its askarel-filled counterpart. This high cost is usually not considered justifiable.

Air-cooled transformers are likely to be lighter in weight than askarel units though this is rarely a consideration; they are, however, noisier in operation. A comparison of the sound levels of typical liquid-cooled and air-cooled transformers made in the United States gave the following figures:

Transformer sound levels

kVA Rating	*Liquid Filled*	*"Dry" Type*
200–300	56 db	66 db
301–500	58 db	68 db
501–700	60 db	70 db
701–1000	62 db	72 db

Pyroclor-filled Ferranti transformer, left, installed adjacent to conventional rectifier-transformer installation at Monsanto's Newport Works.

Unit sub-stations

The absence of fire-risk with the askarel transformer has brought about economies through a new trend in indoor electrical distribution involving the so-called "unit sub-station". This system feeds power at a voltage higher than utilisation levels, which is stepped-down by means of transformers sited at the centres of load. By carrying power through industrial plants at high voltage to the actual load centres, considerable savings result from the reduced cable requirements; LT cable costs are lowered; less copper is used, and voltage drop is reduced with corresponding improvement in the performance of equipment. The cost of the secondary and power centre distribution transformers is more than offset by the savings resulting from the elimination of long, costly low-tension runs inside the plant.

Operating temperatures

With the development of solid insulating materials capable of withstanding temperatures up to about 200° C (360° F) attention has turned to the possibility of operating electrical equipment at higher temperatures. Theoretically, both the air-cooled transformer and the askarel-filled transformer can be operated at much higher temperatures than are possible with oil-filled equipment.

Although Pyroclor was designed for operation at temperatures normally encountered with mineral oil, it can be operated safely at higher temperatures for extended periods in transformers under high overload conditions. Other Aroclor-based fluids, such as RD.7051, are recommended for normal on-load operation with top fluid temperatures above 100° C (212° F). By the use of liquid-cooled transformers operating at higher temperatures, smaller, and perhaps ultimately cheaper, units may be designed with reductions in iron, copper, and the coolant itself. A detailed examination of materials and equipment suitable for use at these higher temperatures is being carried out and further information will be given on request.

Applications of Pyroclor transformers

In current practice, the power rating of askarel transformers is in the range 50 kVA–2000 kVA, although units are in service at ratings up to about 30,000 kVA. Large units installed outdoors are generally mineral-oil filled. Pyroclor transformers are especially recommended for basement sub-stations, or for unit sub-stations located near load-centres. They are also recommended for use in electric locomotives, mines, theatres, department stores, hospitals, blocks of flats, for rooftop installation, electric furnaces, infra-red ovens, oil refineries, ships and, in general, in any area which may be considered "difficult" because of dirt, dampness, fire-hazard or where the elimination of otherwise essential fire precautions would lead to economy.

Cost considerations for Pyroclor transformers

Pyroclor is appreciably more expensive than mineral oil on a volume basis, and the price of Pyroclor transformers is likely to be 20–30% higher than that of mineral-oil filled counterparts. On the other hand, the installed cost or total cost amortised over the expected life of the equipment may work out to be less with Pyroclor.

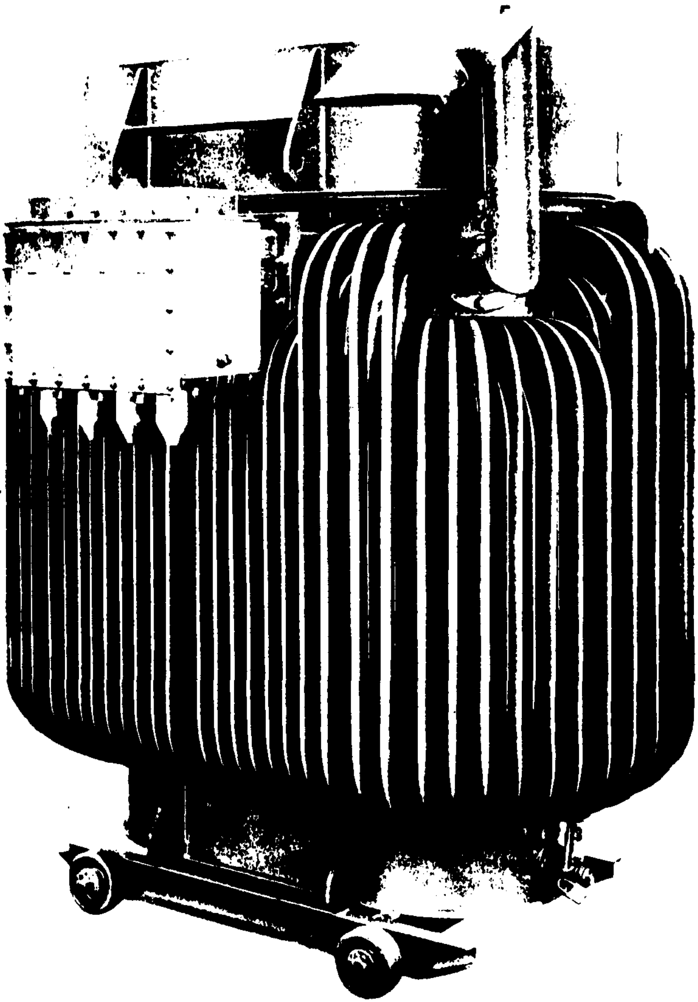
A typical example of this difference in installation costs is afforded by the experience of a manufacturer who installed a Pyroclor transformer and an oil transformer of equivalent rating in different areas of a paper mill to perform the same type of service. The total installed cost of the oil-filled unit worked out to be 22% more than the total cost of the Pyroclor-filled unit, largely owing to the fire-protection requirements for the oil-filled unit. The use of Pyroclor transformers allows the following economies to be made:

Space, associated buildings, etc.

Pyroclor transformers, as they are free from fire risk, do not require provision of vaults, anti-fire arches, oil-drains, sumps, or fire-fighting equipment.

Installation

Savings in feeder-cable costs may be achieved by placing Pyroclor transformers at the centre of electrical loads. To cite a hypothetical case, a saving of nearly 1 ton of



A 600 kVA, 3-phase, 50 cycle, ground mounting transformer
with a voltage ratio of 11,000/415 volts.
This Pyroclor-filled transformer was ordered for
installation in the Royal Palace at Baghdad.

Photograph by courtesy of The English Electric Company Limited.

Pyroclor-filled transformers built by South Wales Switchgear Ltd, for Krangede Aktiebolag, Stockholm.
Photograph by courtesy of South Wales Switchgear Ltd.

Pyroclor-filled transformers. Two 250 kVA transformers in foreground, and 300 kVA, 3-phase, 50 cycle, transformers in background.
Photograph by courtesy of Metropolitan-Vickers Electrical Co Ltd.

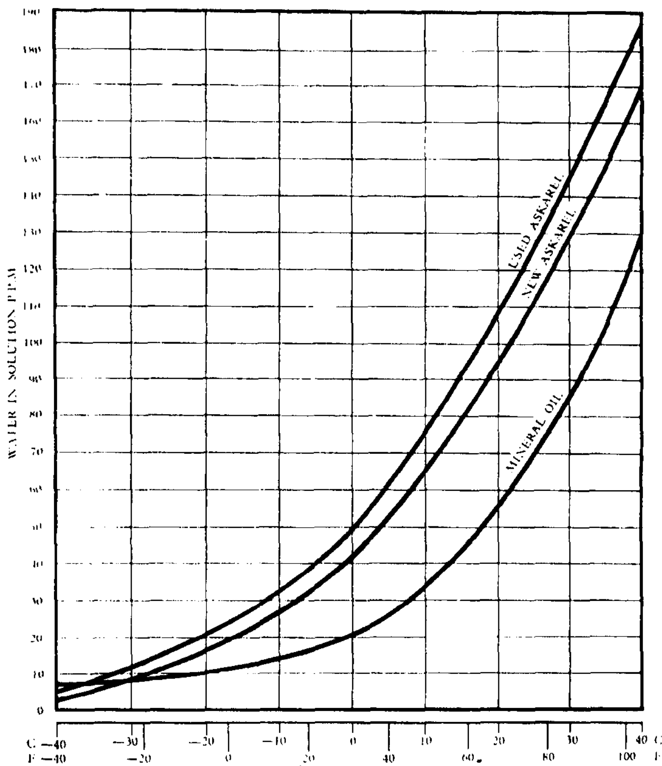
copper may be made in feeder-cable by reducing by 400 feet the distance from the low-voltage side to the service point of a three-phase transformer of 1000 kVA, 13,500/380 volts. In some installations it is also possible to realise significant economies in switchgear through the use of Pyroclor transformers.

Service

Economies during service may be manifest in several ways:

1 Pyroclor transformers require considerably less maintenance than oil-filled or air-cooled equipment.
2 Pyroclor transformers have much greater overload tolerance.
3 Insurance premiums are reduced in some countries when transformers filled with a fire-resistant liquid are used.

Fig. 23 Solubility of water in askarel and in new mineral insulating oil



Performance of Pyroclor

Dielectric strength—effect of moisture

The dielectric strength of Pyroclor at power frequencies is about 20% higher than that of fresh mineral oil, the differential usually increasing during service. The dielectric strength of Pyroclor, as of mineral oil, may be lowered either by the presence of fibres or by moisture. Moisture should, therefore, be avoided in Pyroclor-filled transformers, although the effects of moisture are rather different from those in oil.

The solubilities of water in new and used mineral transformer oil and in new and used transformer askarel are shown in Fig. 23.

It is interesting to note that although the initial solubility of water in askarel is higher than in mineral oil, it does not increase significantly during service. On the other hand, one of the well-known problems with mineral oil is the increase in moisture solubility after the oil has been in service, and the fact that the presence of dissolved moisture contributes to further degradation of the oil. Absorption of water in mineral oil considerably reduces the resistance of the oil to chemical changes through oxidation. Absorption of moisture, however, does not affect the chemical resistance of Pyroclor.

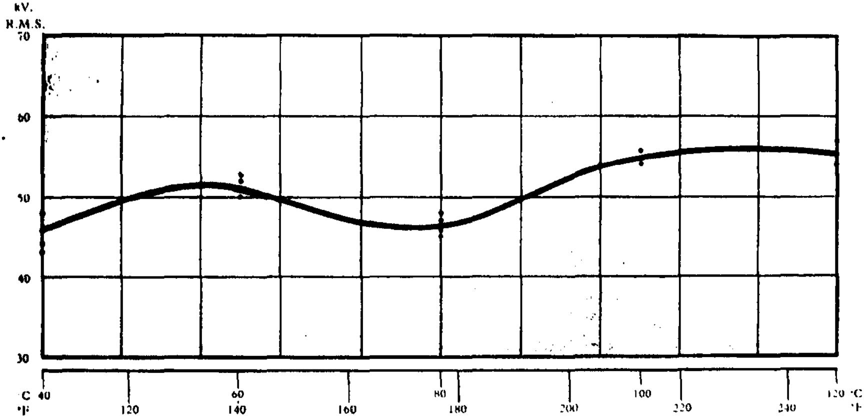


Fig. 24 Breakdown voltage as a function of temperature
(1" sphere electrodes—2 mm. gap)

Moisture will float on Pyroclor and will not, therefore, tend to be carried down into the windings. If leads are taken through the liquid surface, however, they should be suitably encased in porcelain, or other material, to prevent flashover.

Dissolved moisture may be removed from Pyroclor by standard Fuller's Earth treatment, or other dehydration techniques.

Oxidation and sludging

Mineral oil, heated in the presence of air or moisture, will oxidise and deteriorate; no such deterioration occurs with Aroclor dielectrics. The comparative effect on dielectric strength of heating Pyroclor and transformer oil in air is shown in Fig. 24.

Corrosion

Pyroclor has a low free acid value (see Table 1, p. 6) and, consequently, is non-corrosive. Furthermore, askarel transformer fluids, after service for 15 years, have shown only negligible acidity change. It has been reported that even these minor changes have been attributed to traces of the solid insulation or varnish dissolving in the askarel. In one test the original askarel had a neutralisation value of zero which rose to only 0.03 mg KOH/gm after 15 years of service.

Pyroclor contains 0.125% of tetraphenyl tin which absorbs any hydrogen chloride which might be liberated if the fluid is subjected to corona discharge or occasional "spitting", and which in the presence of moisture would corrode the metals and weaken the cellulosic materials used in the construction of the transformer.

Contamination with mineral oil

Mineral oil is soluble in Pyroclor, and any contamination of the Pyroclor by oil will reduce its fire resistance. The Underwriters Laboratory in the United States permits a maximum hydrocarbon contamination of askarel of 2% by volume. Pyroclor transformers should never be "topped-up" with mineral oil.

Design and construction of Pyroclor-filled transformers

Sealed and open types

Pyroclor-filled transformers of both the sealed and open types are in common use. The sealed type is, however, preferred since by preventing contamination from outside sources, the full benefit of the high stability of Pyroclor is gained giving years of maintenance-free operation. The breathers on open type transformers should be fitted with moisture-absorbing driers, which must be maintained in an efficient condition.

Sealed units are designed with a 15–20% free space which is filled with dry air or nitrogen. Generally, the tank is sealed whilst the Pyroclor is warm so that the transformer is under a slight negative pressure when cold. The internal pressure at normal operating temperatures is thus correspondingly reduced.

Rupture discs

Arcing within the transformer can cause a considerable increase in pressure due to the formation of hydrogen chloride and hence confined spaces in which breather type transformers are installed must be well ventilated. Alternatively, vent pipes to the outside atmosphere should be fitted to the transformer and be at least equal in diameter to the relief diaphragm. The vent pipes on outdoor installations should be fitted with self-closing check valves to prevent ingress of moisture to the transformer interior should the relief diaphragm break.

Gas absorbers

In some installations, gas absorbers containing soda lime are fitted after the relief diaphragms to absorb any hydrogen chloride released as the result of a short circuit and bursting of the relief diaphragm. The modern tendency, however, is not to fit absorbers.

Pyroclor-filled transformers manufactured by The Electric Construction Co Ltd, installed at the Milk Arch sub-station below Waterloo Station.

Photograph by courtesy of British Railways (Southern Region).

Tank and fittings

Careful design of the transformer tank reduces the volume of fluid required and hence compensates for the relatively high cost of Pyroclor. Reductions of up to 40% have been achieved by shaping the tank to the coils, filling dead spaces with inert material, and using specially shaped tubes (star or oval) giving maximum cooling-surface to volume ratio.

Tap-changers

On-load tap-changers, if used with Pyroclor-filled transformers, should not operate under the surface of the fluid. They are usually installed in a separate air-box attached to the main transformer tank or inside the tank above the fluid level.

Materials of construction

Impregnating varnishes and coatings used in Pyroclor-filled transformers must be tested for resistance to the fluid. Tank coatings are unnecessary as Pyroclor itself acts as a corrosion inhibitor if filled into a bright steel tank. However, if it is considered desirable to paint the inside of the tank, recommended primers and paints are available and details will be supplied on request.

Pyroclor softens natural rubber and many of the available synthetic materials. Seals and gaskets should be made from nitrile rubber, and should be designed to present minimum surface area to the fluid.

Pine, maple, poplar, hornbeam, and beechwood, if thoroughly dried and heated to free them from natural oils, are suitable for use with Pyroclor. Varnished, oil-treated or paraffin-treated woods of any kind should not be used.

Maintenance

Properly designed Pyroclor transformers require very little maintenance during service life. Examination of the Pyroclor after many years' service in sealed units constructed of recommended materials has shown it to be in practically as good condition as when the transformer was originally filled.

Pyroclor, if contaminated with dirt or moisture or by absorption of ionic or resinous impurities from materials of construction within the transformer, can be purified by filtration techniques similar to those employed for oil using Fuller's Earth or activated alumina. Activated alumina is preferable because it is less likely to remove the tetraphenyl tin. Detailed suggestions for treating and filtering Pyroclor with activated earth or alumina may be obtained on request.

OTHER ELECTRICAL EQUIPMENT

Pyroclor is used in transformers not only on account of its dielectric qualities, but also because it has good heat exchange properties. There are many other types of electrical equipment which also require a highly inert heat exchange medium. For example, heavy-load resistors and rectifiers have been successfully cooled by Aroclor 1248 and induction voltage regulators have been filled with Aroclor or Pyroclor. In this last application, on-load switching should not be carried out under the surface as Aroclor is not as efficient an arc-suppressive fluid as mineral oil, and hence fluid degradation and burning of contacts will occur. Owing to this lower arc-suppressive efficiency, askarels cannot be used in place of oil in switch-gear.

The thermal properties of the filling for temperature-sensitive elements of equipment such as thermostats is also of prime importance. The relatively high coefficient of expansion of the Aroclors, coupled with fire resistance and stability, renders them ideally suitable as thermal-responsive fluids.

The dielectric properties of the solids and fluids used in cable and junction boxes are also of great importance. Although at high voltages the high permittivity of Aroclor would lead to high power-dissipation from conductor to earth, with low voltages and heavy currents the power dissipated in this way would be negligible compared with that due to resistance heating of the conductor. Aroclor impregnants may be used, therefore, in cables carrying heavy currents at relatively low voltages where fire resistance is important.

The lower members of the Aroclor range are not suitable for joint-box filling owing to their fluidity. However, the more highly chlorinated, resinous, compounds such as Aroclors 1260, 1262, and 4465, have good insulating properties, and are also extremely water-repellent. They are, therefore, very useful for this application. Aroclors 1242 or 1248 may be used in fluid-filled bushings.

4 Compatibility of Aroclor Dielectrics with other engineering materials

It cannot be emphasised too strongly that any materials to be used with Aroclor dielectrics must be very carefully selected if the electrical properties of the Aroclor fluids are to be fully utilised. Most inorganic materials used in transformers are unaffected by Aroclors, but many organic materials are either dissolved or swollen by them. Some composite materials commonly used in the electrical industry, however, may impair the electrical qualities of the Aroclors, although their own physical characteristics are not appreciably affected. Monsanto has tested many such materials and can recommend a selection which will be suitable for use with askarel fluids.

Materials should be examined for resistance to Aroclors by immersing samples in the fluid at 100° C (212° F) for two days, and then comparing the electrical properties of the fluid and the physical properties of the sample before and after immersion. The following general recommendations may be given:

Inorganic materials Glass, asbestos, magnesite and porcelain are satisfactory provided they are dry and free from ionizable impurities.

Metals Aroclor dielectrics are non-corrosive to those metals commonly used in electrical equipment, e.g, steel, aluminium, silver, tin and zinc. Exposed copper is satisfactory in Pyroclor-filled transformers but copper for use in Aroclor-impregnated capacitors should be tinned.

Plastics and resins In general, fully cured thermosetting plastic materials are suitable for use with Aroclor dielectrics; most of the thermoplastic materials are unsuitable. Plastics which can be used with Aroclors include phenol-formaldehyde (Bakelite, most grades), melamine-formaldehyde and resorcinol-formaldehyde resins, polyesters, polyurethanes, epoxy-resins, silicones, Terylene, cellulose tri-acetate sheet and nylon. Polyvinyl chloride, most alkyd resins, polystyrene, acrylics and polyethylene are unsuitable. Materials based on thermosetting resins should always be checked for compatibility with the fluids with which they will come into contact. An extra curing treatment (a few hours' heating at 100–120° C (212–248° F) in an air oven) often greatly improves the resistance to attack by Aroclor dielectrics of a material which should be suitable in all other respects.

Protective coatings Baked coatings are generally satisfactory; air-dried coatings are usually not suitable. If varnishes and paints must be used in the interior and coils of equipment filled with Aroclor dielectric, they must be tested for adequate resistance to the fluid. The fluids themselves function as corrosion inhibitors.

Elastomers Of the synthetic elastomers, silicone and isocyanate rubbers are most satisfactory; certain other elastomers, e.g, nitrile rubber, may be used provided the area of contact is very limited.

Cellulose Cellulose itself is not affected by Aroclor dielectrics, and most woods, paper, and cotton are satisfactory. Materials likely to produce fibres easily should be avoided. Woods having a high resin content should be stove-dried before use. Cork is satisfactory.

Oil and grease Aroclor dielectrics are miscible with mineral oil, and once thus contaminated can be purified only with great difficulty. Aroclor for capacitor manufacture must never be contaminated with mineral oil. In Pyroclor-filled transformers, slight mineral oil contamination of the fluid is not harmful, but if the fire-resistant properties of the Pyroclor are to be retained, the mineral oil content should never exceed 2% w/w (see page 40).

Mineral-based greases should not be used on cocks and valves in process lines handling Aroclor dielectrics.

Adhesives and fluxes In general, adhesives based on thermoplastic resins or on animal glues should be avoided. Adhesives based on starch or certain natural gums (such as gum arabic or shellac) are permissible. Fluxless solders are preferred, but if fluxes are essential, they should be of the resinous type and any residual flux left on the joint should be carefully removed with suitable solvents (see page 26).

From the detailed account given above, it is evident that conductors and the majority of the common structural materials used in the electrical industry are satisfactory for use with Aroclor dielectrics. If there is any doubt as to the suitability of a particular material, the user is invited to consult Monsanto Chemicals Limited.

5 Handling of Aroclor Dielectrics

Toxicity

Aroclor dielectrics are not particularly difficult fluids to handle. They should, nevertheless, be handled with care since prolonged contact can lead to absorption of the fluid through the skin. Such exposure may produce a type of acne and lead ultimately to liver damage. The hands should therefore be protected by gloves or by a barrier cream. Workers should be instructed to wash with soap and water after handling Aroclors and they should be encouraged to maintain a high standard of personal hygiene.

The vapour pressures of the Aroclor dielectrics are low, and no problem from Aroclor vapours should be encountered at ordinary temperatures. The vapours of hot Aroclors should be avoided, and for this reason capacitor-impregnation plants should be well ventilated. The same precautions should be taken with Pyroclor which has a somewhat higher vapour pressure on account of its trichlorobenzene content.

It should be emphasised that the standards of cleanliness demanded are also those required to protect the fluid from contamination. Aroclor dielectrics should be kept in closed containers, away from atmospheric moisture and dust, to prevent the access of impurities which would seriously impair electrical characteristics.

Transfer and storage

Aroclor dielectrics are shipped in galvanised drums or special road tankers. These should not be opened until the fluid is to be used or transferred to permanent storage. The Aroclor dielectrics should be slightly warmer than the surrounding air when they are transferred to storage vessels and the transfer should not, if possible, be made in wet weather. Containers, pipes, metal hoses, and pumps used for handling or transferring Aroclor dielectrics must be completely free from oil, grease, or other foreign materials. Such equipment should, if possible, be kept exclusively for use with these fluids or, if this is not possible, the containers and transfer system must be washed with Aroclor dielectric before transfer of the main portion of the fluid. Although mild steel storage tanks are suitable for Pyroclor and have also been successfully used for capacitor Aroclors, storage and impregnation vessels of stainless steel, zinc/tin, aluminium, or galvanised steel are to be preferred. Aroclor 1254 is usually stored at a temperature of between 60–80° C (140–176° F) and Aroclor 1242 at not over 70° C (158° F). Storage tanks should preferably be sealed from the atmosphere to prevent entry of moisture. If, however, the tank is connected to the atmosphere, it should be fitted with a silica gel drier which should be kept in fresh condition. Stirrers are not necessary in storage tanks, but circulating pumps should be provided. Pump inlet connections should be made as short as practicable and maximum use should be made of gravity feed due to the high specific gravity of Aroclor.

Testing Since these fluids are to be used in electrical applications, electrical tests are the only means of checking quality. For capacitor dielectrics, breakdown strength, permittivity, power factor, and volume resistivity are the important criteria. For transformer fluids, breakdown strength is most important although volume resistivity also gives an indication of quality.

The greatest precautions to avoid contamination are essential. Sampling should be carried out with carefully cleaned and dried apparatus, as described in ASTM D.923–49. After sampling, the fluid should be stored in tinted glass bottles and tested as soon as possible. The stopper of the bottle should be of glass, fully cured thermosetting resin or polyethylene, and covered with clean tin-foil. A small quantity of the fluid should be allowed to pour over the lip of the bottle to clean off any dust or other impurity before a sample is taken for tests.

It is usual to test for volume resistivity, permittivity, and power factor in the same test-cell. Suitable cells have been described in the ASTM handbook and elsewhere. Great care must be exercised in cleaning the cell before use and it is emphasised *that cleaning techniques adequate for testing mineral oil are not sufficiently rigorous for fluids such as the Aroclors, having higher permittivities.*

The cell should be taken apart and the electrodes rinsed with hot and then cold trichlorobenzene. They should then be washed twice with methanol, and then twice with tap water, followed by a 10-minute soak in hot 10% trisodium phosphate solution. Finally, they should be thoroughly washed with tap water, assembled, washed at least twice with distilled water, and dried in a clean air-oven at 120° C (248° F) for two hours.

If the cell is left for much longer than two hours, ionic contamination will occur, which will affect the measurements. The cell must not be touched by hand during, or after, the final washing.

When a test-cell is reserved for testing Aroclor and Pyroclor, washing the cell with hot trichlorobenzene or benzene and drying before use is sufficient. The cell should be stored under one of these solvents.

The first, and preferably the second, filling of the cell should be discarded.

A.C. tests must be carried out before the volume resistivity measurement at high D.C. voltage is taken, since the latter test is likely to produce long-term polarisation effects in the fluid which can lead to errors in subsequent tests. Permittivity and power factor can be measured by any reliable bridge technique. The tests are carried out at 100° C, maintained at plus or minus 1° C by a thermostatically controlled oil-bath or air-oven. A test frequency of 50 cycles/sec is preferred to a higher frequency since the power factor at this frequency is a much more sensitive criterion of dielectric purity than at higher frequencies. Volume resistivity measurements are made at 100° C by applying a stress of 200 volts D.C. per mm. It will be found that more polarisation occurs with Aroclor and Pyroclor than with mineral oil, as evidenced by a greater increase of resistivity. It is therefore necessary to measure resistivity after one minute's electrification as a standard test. Any standard method of measurement may be employed in the laboratory (galvanometer, etc) but in the plant or warehouse an industrial megohmeter is quite suitable.

Breakdown-strength is measured by the method of BS.148:51. Cleanliness of apparatus in this test is not so vital, and it is sufficient to clean the electrodes with dry calendered tissue. The first filling of the cell should be discarded. It will be observed that the Aroclor dielectrics form more carbon on breakdown than mineral oil.

Tests of both the low-voltage and high-voltage measurements should be repeated if possible, particularly in the case of breakdown voltage.

Earth treatment and filtration

Although the electrical properties of each batch of Aroclor dielectric are checked before it leaves the factory, they should be re-checked by the customer before use. In general, the filtration and dehydration procedures used with mineral oil are also applicable to Pyroclor and to capacitor-grade Aroclors. It is recommended that Aroclor for capacitors should be given a Fuller's Earth or activated alumina treatment immediately before use to guarantee that the electrical properties of the fluid passing to the impregnator are as high as possible.

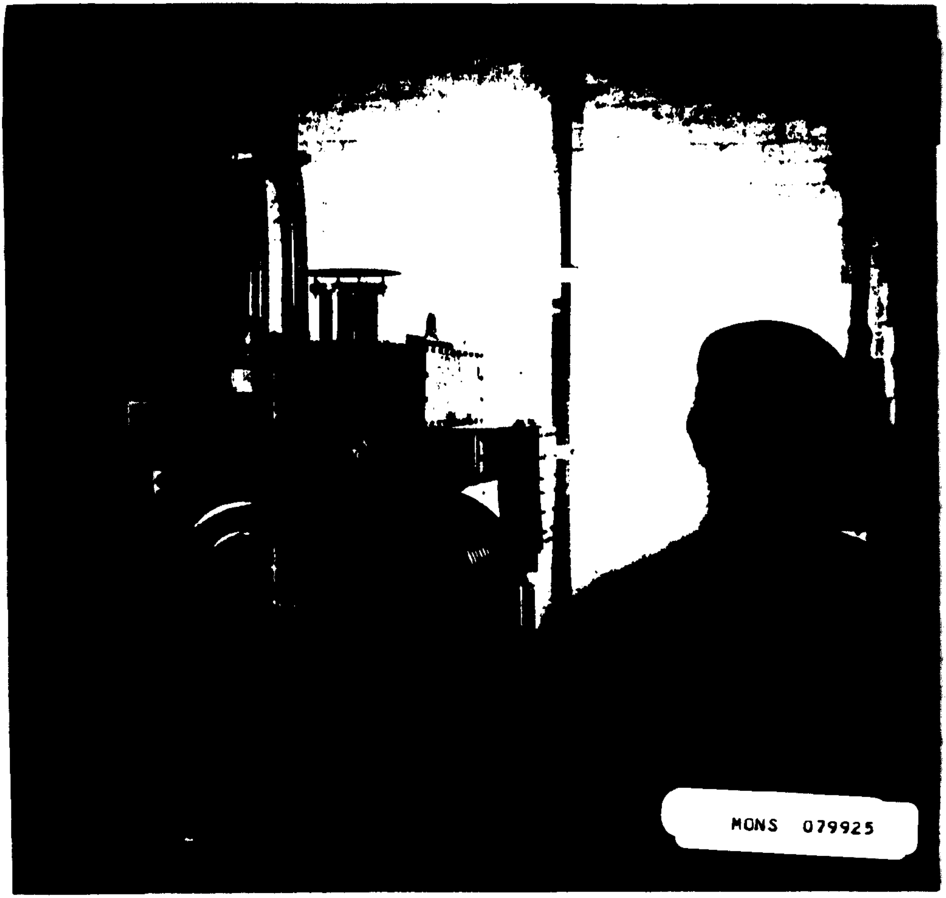
The precise method employed for filtration is not critical, but it is important that the Fuller's Earth be thoroughly dry before use, and that adequate time be allowed for the Aroclor dielectric to mix with the earth before filtration. The earth should be heated in shallow pans in an oven between 200° C and 400° C (390° F and 750° F) for 2–12 hours, depending on the temperature. Up to 1% by weight of earth should be added to the Aroclor and the mixture slowly stirred or re-circulated at 70–80° C (158–176° F) (not over 70° C (158° F) for Aroclor 1242) for about 4 hours before filtration.

The treatment is repeated if tests indicate that the desired electrical properties have not been obtained.

Monsanto Chemicals Ltd is always ready to provide additional information on the use of the materials indicated in this booklet and to assist manufacturers in the solution of particular problems arising from their application.

Suggestions made in this booklet are based on conclusions reached after extensive laboratory investigation. They are published in the belief that they will be of value, but in view of the variations in conditions under which they may be applied, we cannot accept responsibility for loss or accident which may result from their use or application.

Pyroclor-filled 250 kVA transformer.
Photograph by courtesy of The Bowater Paper Corporation Limited.



6 Bibliography

The following list of references covers most of the published work on the subject of Askarels

Fire Resistance

American Society of Testing Materials, Pt. IIIB, p. 606 (1946)

Askarels are defined as insulating fluids which are both non-inflammable and incapable of evolving explosive gaseous mixtures when decomposed by the electric arc.

"Liquid Dielectrics and Cooling Media" *Miscellaneous Hazards 2581*, Sept. 29, 1934. Underwriters Laboratories Inc.

An investigation into the fire-resistance of askarels. A flashpoint was observed, but there was no fire-point.

"Liquid Dielectrics and Cooling Media" Admixed with small amounts of Transformer Oil. *Miscellaneous Hazards 2581*, Feb. 18, 1937. Underwriters Laboratories Inc.

An investigation of the effect of small quantities of mineral oil as impurity in askarel. It is shown that at 5% concentration fire-resistance is reduced, but that at 2% and below there is no effect whatsoever.

N.B.F.U. Pamphlet No. 70, 1951, National Electric Code

Standard of the National Board of Fire Underwriters for Electric Wiring and Apparatus. Article 450, "Transformers", § 4522.

"Askarel-Insulated Transformers Installed Indoors. Askarel-insulated transformers rated in excess of 25 kVA shall be furnished with a pressure-relief vent. If installed in a poorly ventilated place they shall be furnished with a means for absorbing any gases generated by arcing inside the case, or the pressure-relief vent shall be connected to a chimney or flue which will carry such gases outside the building. Askarel-insulated transformers rated at more than 15,000 volts shall be installed in a vault."

General

F. M. CLARK, *Electrical World* **100**, 373 (1932)

The range of physical characteristics which can be achieved with chlorinated aromatic hydrocarbons is outlined. The high degree of control possible in manufacture is emphasised and the rapid demulsifying properties of this class of fluid is mentioned. The solvent action of the fluids is also examined.

P. D. WILMOT AND N. G. H. THOMAS, *The Engineer*, March 15, 1957 and March 22, 1957

The first paper reviews the physical, chemical and electrical properties of Pyroclor (transformer askarel) in relation to its function as a fire-resistant cooling fluid for transformers.

The second paper proceeds to a study of the design and application of Pyroclor-filled transformers and demonstrates how their use makes possible considerable savings in other equipment. A review of compatible insulating and constructional materials is included and illustrations of typical installations are given.

J. G. FORD, *Electrical Engineering* **67**, 1066 (1945)

This paper deals with transformer coolants in general, a section being devoted to askarels. The behaviour of water in askarels is discussed. The higher power-factor of askarel is mentioned, with the comment that this property does not affect breakdown strength to any great degree. Reconditioning by means of filter presses and activated earths or clays is mentioned: after such treatment neutralisation number should be less than 0.05, and 60 cycles power-factor less than 1% at 20 C.

A. VON HIPPEL, *Dielectric Materials and their Applications*, Wiley (1955)

This is a general text-book on insulation. Several notes are given on the stability of transformer askarels (Pyranol). A description of askarel transformer design is given, and tables at the end of the book give the specific inductive capacities and power-factor over a frequency range.

F. M. CLARK, *Journal of Industrial and Engineering Chemistry* 29, 689 (1937)

The electrical applications of chlorinated hydrocarbons are surveyed. A quantitative investigation is given of the gases evolved in arcing chlorinated dielectrics. Pyroclor is shown to evolve only hydrogen chloride gas. Viscosity/temperature and dielectric strength/ASTM-electrode spacing plots are drawn. Results of stability tests on chlorinated hydrocarbon fluids are given.

F. M. CLARK, *Electrical Engineering (Transactions of the American Institution of Electrical Engineers)* 56, 671 (1937)

The dielectric strength of askarel under various conditions is examined. A description is given of an experiment in which both mineral oil and askarel were allowed to breathe freely to the atmosphere in the presence of sunlight. Sludge eventually formed in the mineral oil and breakdown strength dropped. No deterioration whatsoever, even in breakdown strength, occurred with askarel. Water was observed as a separate phase in both fluids at the end of the experiment. In a further experiment askarel was mixed with water and the mixture was refluxed for nearly 200 days in the presence of air and in the presence of aluminium. There was only a very slight fall in the breakdown strength of the askarel, and examination of the aluminium showed that no chloride had developed. A graph is plotted, from which it is clear that the breakdown strength of askarel is superior to that of mineral oil over a wide range of ASTM electrode spacings. The two curves diverge as the voltage increases. Temperature/breakdown strength plots are given. Graphs of breakdown strength against thickness of insulation for impregnated paper are also given at different temperatures. Corona inception voltages for various thicknesses of impregnated paper are reported. In all cases askarel shows higher values than oil.

F. M. CLARK, *Transactions of the American Institution of Electrical Engineers* 59, 434 (1940)

The effect of water on mineral oil and askarel (Pyranol) is examined. The solubility of water in askarel is shown to be higher than in mineral oil, but there is hardly any increase with service. In equilibrium with moist air, askarel also absorbs more water. Under breakdown strength test conditions breakdown strength/temperature curves at various water contents show that askarel is superior to mineral oil at the higher water content level at lower temperatures. However, for 1 minute B.D.S. tests at power frequencies and at room temperature Pyranol is better than oil over the entire range of water contents. The effect of water absorption on cellulose insulation and on power factor and resistivity is also discussed. Modifications to a blotter press are described.

F. M. CLARK, *American Society for Testing Materials.* Symposium on Insulating Oils. Special Technical Publication No. 95 (1949)

The electrical applications of chlorinated hydrocarbons are surveyed and the non-sludging properties of the fluids are emphasised. Solubility of water in transformer askarel is graphed as a function of temperature, and the effect of passage of water-contaminated liquid through a paper filter-press is shown graphically. The fire-resistance of chlorinated hydrocarbon dielectric is discussed, and the effect of scavengers as a means of absorbing dissolved hydrogen chloride is closely examined. The author takes the view that with askarel only chloride concentration and dielectric strength are important, power factor not being of any significance. However, the addition of aluminium hydroxide to reduce the power factor of the fluid whilst in the tank is described. There follows a considerable amount of interesting discussion.

B. G. CHILDS AND A. W. STANNETT, *Proceedings of the Institution of Electrical Engineers*, Vol. 100, Pt. IIA, No. 3 (1953)

An investigation of the effect of hydrochloric acid liberated by arcing transformer askarel on the tensile strength of paper used for insulating transformers (*a*) in the presence, and (*b*) in the absence of tetraphenyl tin scavenger. Whilst a considerable fall in tensile strength of the paper occurred when no scavenger was present, the paper which had been exposed to askarel containing tetraphenyl tin showed no significant change. Comparative physical data on transformer askarel and a typical Class B.30 oil are included in the paper, and further references are made to askarels in the discussion, ibid page 94.

T. W. DAKIN AND C. N. WORKS, *American Institution of Electrical Engineers.* Technical Paper 52, 228 (1952)

Impulse breakdown tests on askarel are reported. The impulse breakdown strength in asymmetric fields of impregnated pressboard is shown to be lower with askarel than with mineral oil, despite the fact that the 60 cycles B.D.S. is considerably greater with askarel. It is shown that this effect is connected with the chlorine atoms of the molecule. Several graphs of breakdown/electrode spacing and number of cycles applied are given.

G. M. L. SOMMERMAN, C. J. BUTE AND E. L. C. LARSON, *American Institution of Electrical Engineers.* Technical Paper 54, 69 (1954)

A photographic technique to measure ionisation in mineral oil and askarels is detailed. Disc electrodes between which were placed impregnated pressboard and dry photographic paper were immersed in the liquid under test. Above a threshold voltage, Lichtenberg figures occurred in the thin film of liquid under the rounded electrode edge. With mineral oil the figures were independent of voltage polarity and evenly distributed, whilst with askarel the figures depended markedly on voltage polarity and were more localised. The chlorine atoms of the askarel were shown to affect the liquid ionisation process and the puncture voltage of askarel in impregnated pressboard. Chopped wave tests showed that the ionised particles originating near the cathode travelled much faster in askarel than in mineral oil.

C. W. LEWIS, *Journal of Industrial and Engineering Chemistry* **46**, 366 (1954)

The mode of action of tetraphenyl tin as a scavenger is investigated. The rate of change of concentration of hydrogen chloride in askarel containing tetraphenyl tin was examined using a solometric method. The reaction rate indicated that a bimolecular process occurred, and it is suggested that triphenyl tin chloride and benzene, or diphenyl tin dichloride and benzene are formed. Ethylene oxide—also known as a scavenger—was also examined.

Transformer Design and Applications

L. CANTALUPI, *Elettrificazione* **2**, No. 12, p. 14 (Dec., 1951)

Askarel transformer design in Italy is discussed. The electrical and thermal stabilities of chlorinated hydrocarbons are considered. The actual places where such transformers were used in Italy at the time of writing are mentioned and the general considerations affecting the choice of such units are examined. Materials suitable for use with askarel are listed: the author considers that any copper used should be passivated with cellulose covering. Methods for allowing for expansion of the fluid with temperature rise are mentioned.

H. R. TURNER AND W. T. MCLACHLAN, *General Electric Review* **101**, 726 (1933)

Askarel (Pyranol) transformers are described. The savings involved in installation costs of Pyranol transformers are mentioned. Single-phase units have been built with a 35% reduction in dielectric volume. 500 kVA 27,000/216 Y-volt secondary network units of much smaller dimensions than the equivalent oil units are described, in which height was reduced from 88½ inches to 60 inches, length from 106½ inches to 102 inches, and width increased by 4 inches, resulting in 50% reduction in fluid volume. The high-voltage cables were connected by plugs instead of junction boxes, thereby making the connections more accessible. The grounding switch earthed the feeder cables at the transformer terminal by plugs and sockets controlled from outside: an electrical interlock prevented switching when the unit was energised. An interlock prevented the movement of the ratio adjuster unless transformer was grounded, and also prevented switching on unless the adjuster was in one of the tap positions.

L. H. BURNHAM AND S. T. MAUNDER, *General Electric Review* **42**, 236 (1939)

Several types of askarel (Pyranol) transformer are described and the saving of total installation cost is stressed. The use of star-section circulating pipes to reduce fluid volume is mentioned. It is stated that a diaphragm and pipe for venting in the event of arcing failure should be at least 6 inches in diameter. A self-closing check should be fitted outside the vent-pipe to prevent ingress of moisture in the event that the diaphragm is broken. Forced-air cooling of pipes may be employed, but water-cooling may also be used. The Pyranol itself may be pre-circulated through air-blast cooled pipes, as has been done for railway traction units. On-load tap-changing has been effected by mounting the contactors in an air-box.

Types of transformers illustrated and described above:

1. 4000 kVA 11,431—to 2300/4000 Y-volt 60-cycle single-phase with gas-absorber.

2. 2500 kVA 6900—to 460-volt 60-cycle three-phase.

3. 2000 kVA 26,000—to 575-volt 60-cycle three-phase with vent-pipe.

4. 5000 kVA/6667 kVA 33,000—to 2400/4160 Y-volt with load-ratio-control equipment (contactors in an air-box) and fans for forced-air operations on overloads.

5. 4850 kVA 11,000—to 1408-volt 25-cycle with forced Pyranol circulation and air-blast cooling and with air expansion-chamber (for main-line locomotive).

6. 12,000 kVA 44,000 Y—to 200-volt three-phase 60-cycle water-cooled with expansion-chamber—for furnace application.

7. 625 kVA 11,000-volt 25-cycle air-blast cooled (for multiple-unit cars).

8. 1370 kVA 11,000-volt 25-cycle forced-air cooling (for railway traction).

British Thomson-Houston Activities **16**, 115 (1940)

A description is given of a transformer filled with askarel. Economy in the quantity of fluid was effected by compact design. The tank was hermetically sealed and equipped with a bursting-disc and vent. The sampling-valve was at the top of the tank, so that if water were present this would be detected.

General Electric Review, p. 30 (Jan., 1938)

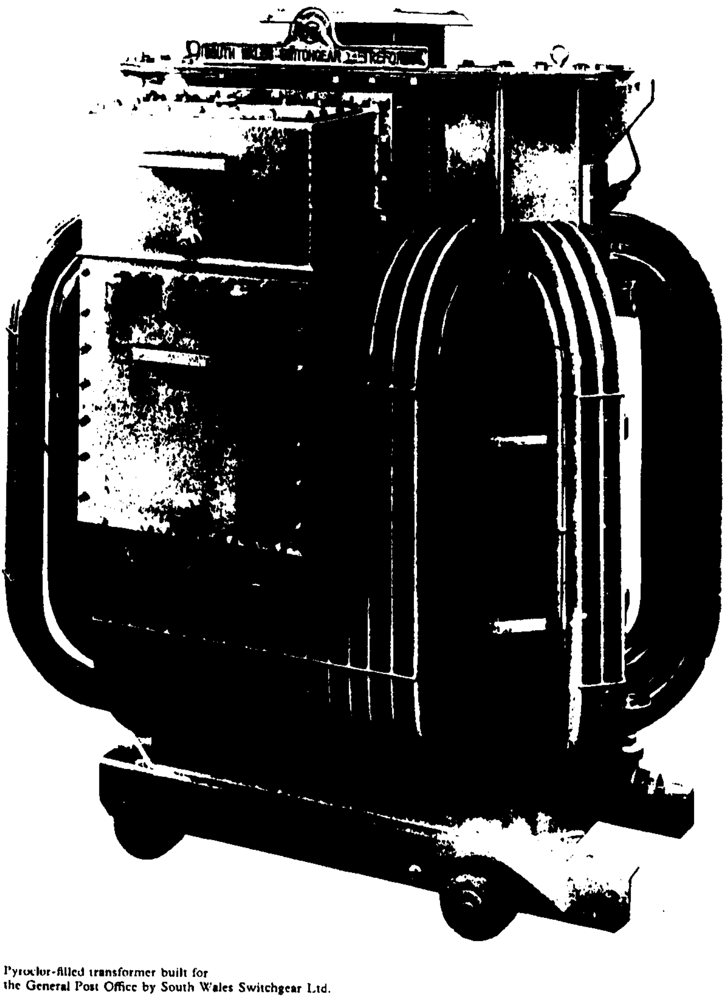
A note on the use of askarel in railway traction transformers. Small units are cooled by thermo-syphon action from the transformer to an air-blast cooler; forced circulation with turbulent flow is employed in larger units.

General Electric Review, p. 44 (Jan., 1934)

A general description is given about the development of askarel transformers in the U.S.A. It is pointed out that total installation costs are cheaper in many cases with askarel than with mineral oil.

L. H. BURNHAM, *Railway Electrical Engineer* **29**, 160 (1938)

Askarel transformers used on railway traction are described. The problems arising in using air-cooled units in this application are discussed and several types of Askarel transformer employed on American locomotives are described.



Pyroclor-filled transformer built for
the General Post Office by South Wales Switchgear Ltd.

Photograph by courtesy of South Wales Switchgear Ltd.

Designed by John Denison-Hunt FSIA

Printed by Benham and Company Limited
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