PYROCLOR

FOR TRANSFORMERS

Monsanto

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INTRODUCTION

Pyroclor is the transformer askarel made by Monsanto. (Askarels are non-flammable insulating liquids which, if decomposed by an electric arc, evolve only non-explosive gaseous mixtures). Monsanto has been producing askarels in the U.S. since 1932, and in the U.K. since 1951 under the name Pyroclor.

This booklet describes the characteristics of askarels, particularly how they differ from mineral oil, and gives information on the design and operation of askarel transformers. This information is based on facts gathered by Monsanto from the knowledge and experience of transformer manufacturers and users over three decades.

Advantages of Pyroclor Transformers For siting indoors, Pyroclor transformers have considerable advantages over other types of transformer.

1 Pyroclor transformers provide the cheapest way of obtaining a fireproof installation. The use of fire fighting equipment, fire walls, and pebble drains is unnecessary.

2 Pyroclor transformers are particularly suitable in many applications where fire risk is great and space is limited, such as near furnaces, and, as in the United States and on the Continent, in coal mines.

3 Pyroclor transformers can be used in dusty and dirty atmospheres without extra protection or frequent outages for maintenance.

4 Pyroclor transformers can be used in installations where overvoltages due to lightening or switching surges are prevalent.

5 Pyroclor transformers are quiet in operation.

6 Since Pyroclor transformers can be installed at the load centre, expensive low voltage cable runs are reduced and voltage regulation is improved.

7 The stability of Pyroclor means that it can last at least as long as 30 years even if overloads cause the rated temperature to be exceeded.

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8 Pyroclor transformer installations permit the fire insurance premiums to be reduced in some countries.

9 Pyroclor transformers can operate at voltages as high as 120 kV.

Application of Pyroclor Transformers Pyroclor transformers have been used in a very wide range of applications and recent examples include installations in steel works, glass factories, public buildings, stores, and offices. The tendency now for buildings to be taller favours the positioning of sub-stations on the top storeys of buildings, and in a recent example Pyroclor transformers were installed on the 42nd floor of a building in Montreal.

The mining industry employs askarel transformers in America and in France, and elsewhere they have been installed at the load centre in mine winding gear, which is situated over the mine shaft itself.

Askarel transformers are also widely used on electrified railways. On some U.S. railways, where askarel transformers have been used satisfactorily since 1933, the transformers are located below the floor on the Multiple-unit cars. Underground railways in a number of cities have also installed askarel transformers in their distribution system.

Other recommended applications include electric furnaces, infra-red ovens, oil refineries and ships.

Monsanto itself has some 10 Pyroclor transformers installed at its various plants. These have so far given satisfactory service for various periods up to 6 years.

Properly designed and installed askarel transformers will give trouble-free service for a minimum of 30 years. Since their introduction in 1932, the manufacturers report finding the overall failure rate to be less than 0.5 per cent for all units under test and service conditions. The Edison Electrical Institute's report on their member utilities publishes the failure rate for askarel transformers as 0.13 per hundred banks per year. Even the rare reports of failure are invariably found to be due to improper sealing, which allows moisture to enter.

Askarel transformers working at 120 kV have been made, but most work in the region of 11 kV. Units are in service with ratings up to 30 MVA, although since they are normally employed only indoors, the majority are found in the range between 50 KVA and 1.5 MVA.

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PROPERTIES

Pyroclor was developed for normal operation under class A conditions. An alternative askarel, Pyroclor ETR, has been developed for operation under class B conditions.

The most important properties of Pyroclor and Pyroclor ETR are shown in the table.

Composition Pyroclor is composed of 40% trichlorobenzene and 60% hexachlorodiphenyl by weight, with 0.125% of gas scavenger. Pyroclor ETR is entirely tetrachlorodiphenyl with the same concentration of gas scavenger.

Typical properties of Pyroclor and Pyroclor ETR

(These values do not constitute a specification)

Property	Pyroclor	Pyroclor ETR
Description	Liquid which, at room temperature, may contain crystals	Clear, pale straw coloured, viscous liquid
Viscosity at 60°C (cS)	2.9	5.8
Pour Point (°C)	—32 or lower	—7
Relative Density at 15.5/15.5°C	1.564	1.461
Coefficient of expansion/deg C	0.0007	0.00070
Specific Heat at 75°C (J/g deg C)	1.3	1.16
Thermal Conductivity at 75°C (W/m deg C)	0.107	0.1003
Evaporation loss (per cent)	2.5 (6 h at 100°C)	0.07 (2 h at 125°C)
Fire Point	None	None
Refractive index n_D^{25}	1.6148	1.6295
Inorganic chlorides (ppm)	0.1 max.	0.1 max.
Acid number (mg KOH/g)	0.01 max.	0.01 max.
Water content (ppm)	30 max	30 max.
Dielectric Strength at 20°C by B.S. 148:1969 (kV)	40 min.	40 min.
DC Resistivity at 100°C and 500V/mm after 1 minute electrification (Ω cm)	1.0×10^{13} min.	1.0×10^{11} min.
Loss tangent at 100°C and 50 c/s	0.03 max.	0.03 max.
Permittivity at 100°C and 50 c/s	3.9	4.6

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Physical properties *Viscosity* The ratio of trichlorobenzene to hexachlorodiphenyl in Pyroclor has been selected to match the viscosity-temperature characteristic of mineral oil. Figure 1 illustrates the similarity.

Solubility of Water Figure 2 shows that water is slightly more soluble in clean Pyroclor than in mineral oil, but there is very little change in the solubility between new and used Pyroclor, as can be seen from the graph.

Vapour Pressure The variation of the vapour pressure of Pyroclor and Pyroclor ETR with temperature is shown in Figure 3.

Air Absorption The amount of gas dissolved in a liquid may be expressed as a Bunsen coefficient, that is, the volume of gas at NTP dissolved in unit volume of a liquid at a partial pressure of 760 torr. The Bunsen coefficients for the solution of air in Pyroclor and Pyroclor ETR are shown in Figure 4.

Chemical properties The chemical inertness of Pyroclor is outstanding and in particular it has excellent fire resistance, thermal stability and resistance to oxidation and hydrolysis.

Fire Resistance Although Pyroclor will be shown to have a flash point when examined by the usual laboratory tests, this flash burns with a 'cold' flame and no fire is carried back to the liquid phase, therefore there is no corresponding fire point. The autogenous ignition temperature of Pyroclor has been measured by dropping small quantities of the liquid on to the floor of a ceramic lined muffle furnace. The liquid did not take fire until the surface was a dull red heat, approximately 700°C. Once the liquid, however, leaves such a hot surface it ceases to burn and it is therefore impossible to convey fire by moving streams of liquid. The laboratory of the National Board of Underwriters (U.S.A.) have carried out stringent tests on the fire resistance of this type of liquid and have concluded that it is essentially non-flammable.

Thermal Stability and Effect of Arcing Pyroclor undergoes no thermal decomposition whatsoever at temperatures below 175°C. If Pyroclor is raised above this temperature by, for example, local over-heating or transient arcing, small quantities of hydrogen chloride are produced. The gas scavenger, absorbs this hydrogen chloride and prevents attack on the iron core or the cellulosic insulation.

If a major internal fault occurs in a Pyroclor transformer which results in a sustained arc below the Pyroclor surface, then the high temperature of the arc will decompose the Pyroclor. The main de-

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composition products are carbon and hydrogen chloride. Hydrogen chloride is non-flammable and will not form explosive mixtures with air, but is an unpleasant and irritating gas to breathe. However, it is easily detected in the atmosphere and exposure to low concentrations would produce no lasting ill-effects. Since it is very readily soluble in water, it is likely to be removed rapidly from the atmosphere under most normal circumstances. Hydrogen chloride does not quench the arc that produces it, and consequently the circuit breakers should be capable of interrupting the probable fault current. For the same reason, Pyroclor is unsuitable for switchgear. The amount of gas that is produced by an arc in Pyroclor will vary according to the circumstances, but a figure quoted is 135 cm^3 per kWs.

Laboratory tests and practical experience have shown that phosgene and chlorine are not formed as decomposition products of askarel.

Resistance to Oxidation Pyroclor has exceptionally good resistance to attack by oxygen. When subjected to a bomb test at 140°C in oxygen at a pressure of 250 psig. (17 kg/cm^2) there was no evidence of oxidation as judged by development of acidity or the formation of sludge. Hot mineral oil in the presence of oxygen undergoes a series of complex chemical reactions, producing by stages, peroxides, acids, water and other condensation products which eventually form a sludge.

Stability to Hydrolysis Pyroclor is resistant to attack by water, although water will dissolve in Pyroclor and the presence of this mixture will naturally affect the electrical properties. In an experiment, Pyroclor was refluxed with water and oxygen was passed through the mixture and at the end of the experiment no free chlorides were generated, even after extending the time over a considerable period. A further experiment was conducted whereby the liquid was sealed in a glass capsule with water and heated for many hours at 150°C, and once again no chloride formation could be detected.

Dielectric properties Although a transformer liquid is principally a coolant, it must also act as an insulation in and between the windings of the transformer, and the dielectric properties are therefore of great importance.

Dielectric Strength The dielectric strength of Pyroclor is equal to the best quality mineral oil and has the dielectric qualities required for the voltage stresses encountered in transformers over the entire temperature range of operation. Figure 5 shows the variation of the dielectric strength of Pyroclor (measured according to B.S.148:1959) with temperature.

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At low temperatures the gas scavenger has a tendency to crystallise and exhaustive tests have shown that even with samples of Pyroclor containing large quantities of suspended crystals, the dielectric strength of the liquid is not affected and there is no alignment of the crystals between the electrodes.

Permittivity The permittivity of Pyroclor is much closer to the permittivity of cellulose and this leads to a greater uniformity of stress in impregnated press board. The variation in the permittivity of Pyroclor at 50 c/s is shown in Figure 6.

Loss Tangent The variation of the loss tangent at 50 c/s of new Pyroclor with temperature is shown in Figure 7. Satisfactory Pyroclor in a transformer may be expected to have considerably higher loss tangent than new material, in the range 0.2 to 0.8 at 100°C.

D.C. Resistivity The variation of the d.c. resistivity of new Pyroclor with temperature is shown in Figure 8. These readings were made one minute after the application of a stress of 500 V/mm. Satisfactory Pyroclor sampled from a transformer may have a d.c. resistivity as low as $2.5 \times 10^{10} \Omega$ cm. at 100°C.

D.C, Resistivity of Pyroclor is thus seen to be much lower than that of mineral oil by comparison. This inevitably leads to lower insulation resistance on finished transformers filled with Pyroclor than on their counterparts filled with oil. This is, however, quite normal and is an accepted characteristic of Pyroclor transformers.

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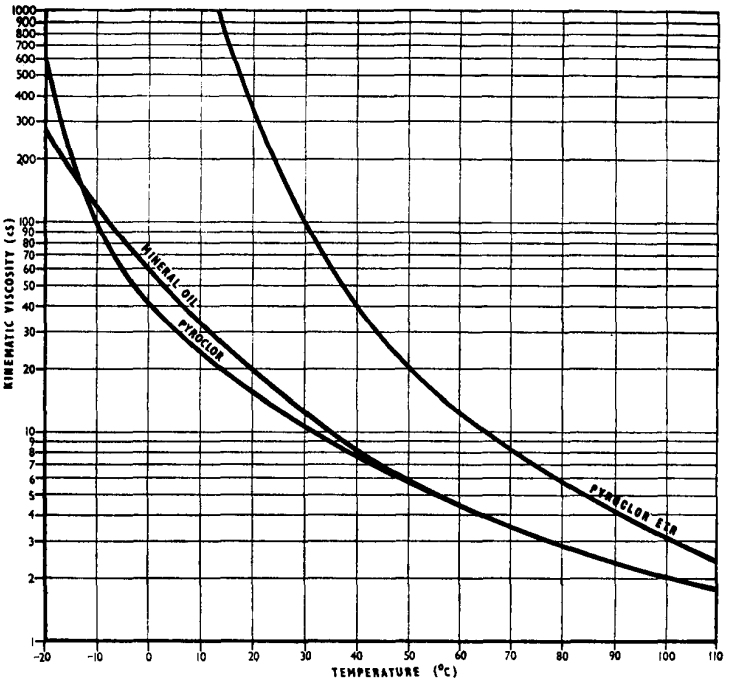

Figure 1 The viscosity-temperature characteristics of Pyrocior, Pyrocior ETR and mineral oil.

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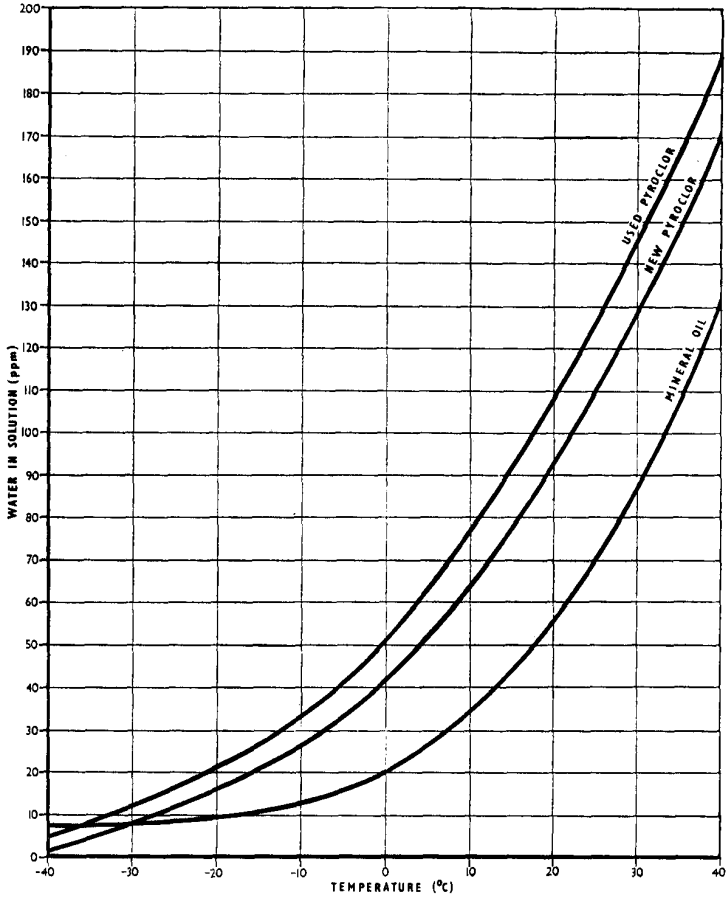

Figure 2 The solubility of water in Pyroclor and new mineral oil.

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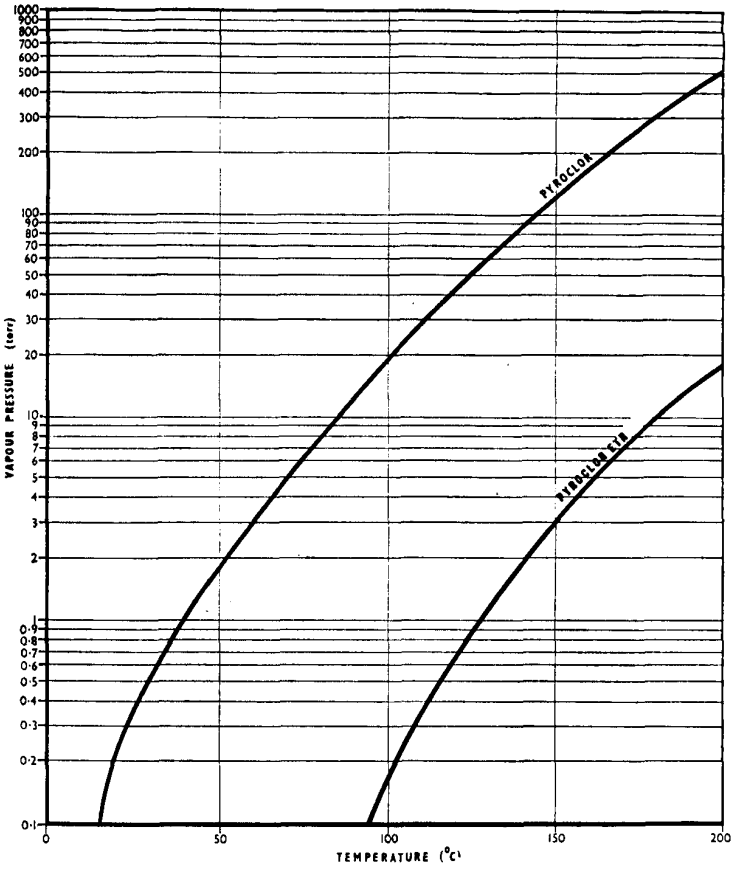

Figure 3 The variation of the vapour pressure with temperature of Pyrocior and Pyrocior ETR.

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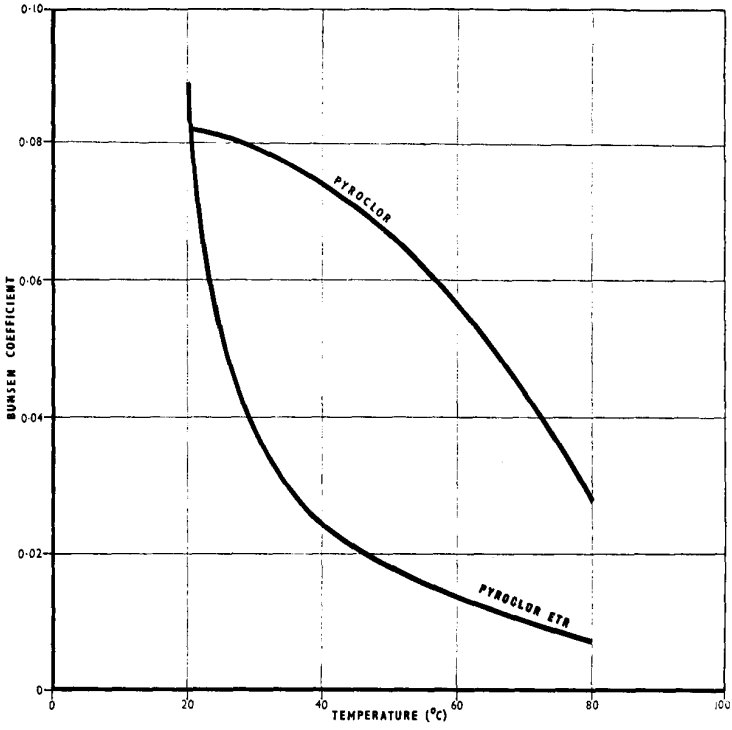

Figure 4 The air absorption of Pyrocior and Pyrocior ETR.

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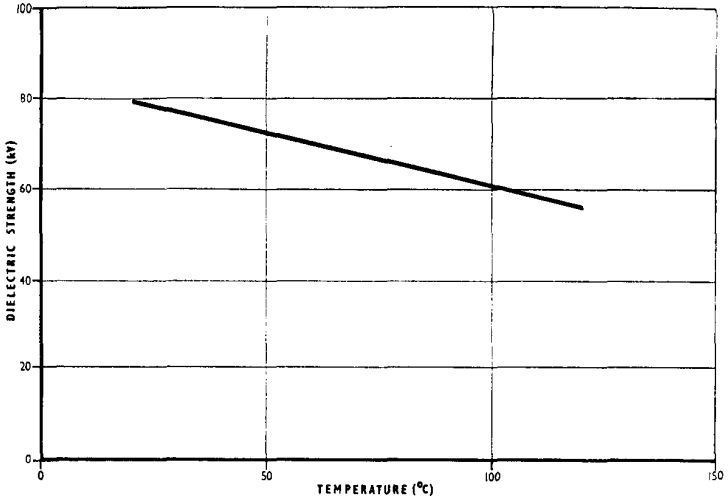

Figure 5 The variation of the dielectric strength of Pyrocler with temperature.

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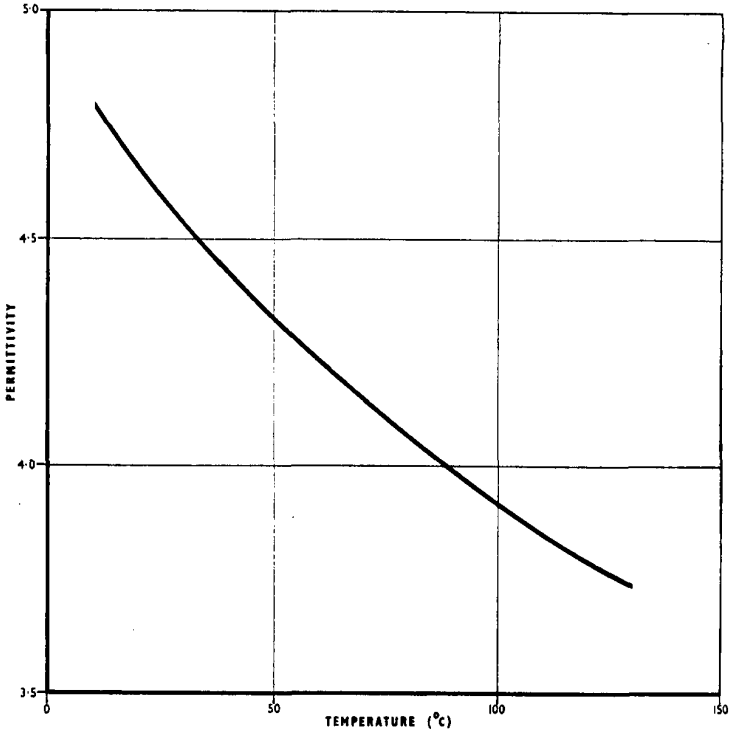

Figure 6 The variation of the permittivity of Pyrocior with temperature..

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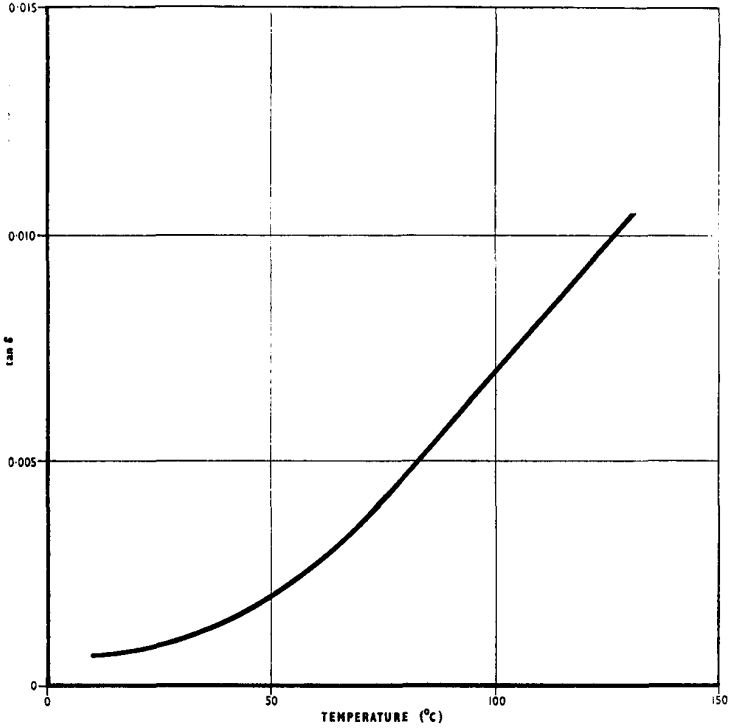

Figure 7 The variation of the loss tangent of new Pyrocior with temperature.

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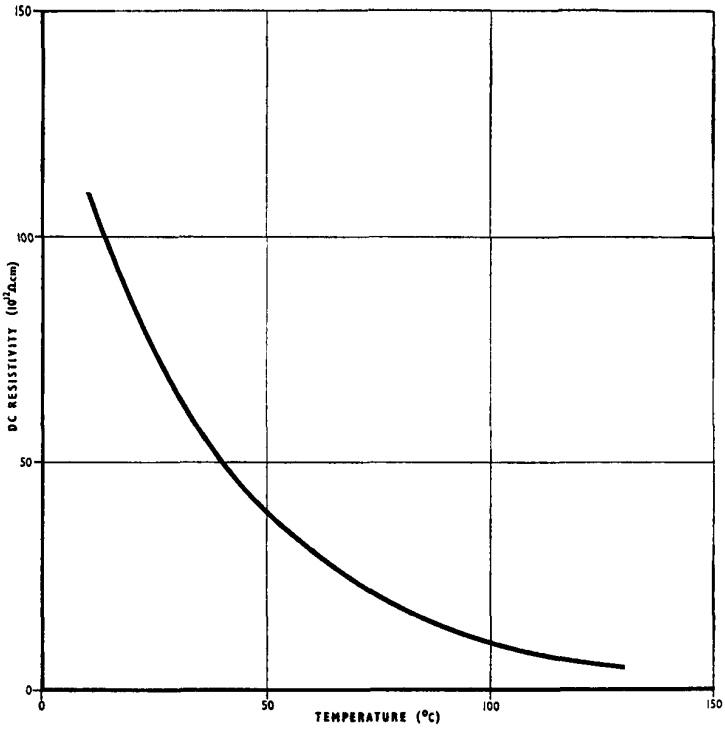

Figure 8 The variation of the d.c. resistivity of new Pyrocior with temperature.

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DESIGN OF PYROCLOR TRANSFORMERS

Compatibility of materials Since Pyroclor is a mixture of chlorinated hydrocarbons, it is a plasticizer for a variety of resins and plastics normally used in the construction of mineral oil transformers. If any of these materials are polar, they ionise to a greater extent in Pyroclor than in mineral oil because of the greater permittivity of Pyroclor and so increase the dielectric losses more. For these reasons special attention must be given to the selection of materials which will be suitable for use with Pyroclor.

Pyroclor is a more searching liquid than mineral oil, so we do not recommend that the oil filling of existing transformers be replaced by Pyroclor as this would be very likely to cause extensive leaking and, in many cases, a breakdown due to the attack on insulating materials.

A very large number of materials has been examined for their suitability for use with Pyroclor, and lists of tested materials are available. Further information can be obtained from Monsanto.

Reduction in volume For successful transformer design using Pyroclor it is desirable to keep the liquid volume to a minimum because it is more costly than oil. Even without radical re-design, useful economies can be made by rounding the corners of the tank or by using tanks with cruciform shape. Considerable economy can be made by filling dead space with wood or even glass marbles. The wood, however, must be of low resin content and must be thoroughly dried. In addition, cooling tubes having oval or star-shaped cross-sections can be used to cut the volume.

Sealed transformers Transformers using Pyroclor are normally hermetically sealed, since as Pyroclor transformers do not require any maintenance, possible ingress of moisture is eliminated. Welded tank designs have become popular with Pyroclor transformers. Another special feature with hermetically sealed Pyroclor transformers is the so-called 'top hat' type of construction with an air or nitrogen filled space

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which is used to allow for expansion of the fluid. The sealing is frequently so arranged that the gas is under a slight negative pressure when cold. With hermetically sealed units it is customary to make provision for a rupturable relief diaphragm which can be vented to the outside atmosphere.

Unsealed transformers Pyroclor transformers fitted with breathers are also made. The breather should be fitted with a silica gel moisture trap to prevent ingress of moisture with expansion and contraction following heat cycles of the transformer. The conservator is recommended with breather designs, since at maximum operating temperatures the trichlorobenzene present has a relatively high vapour pressure and the conservator will prevent losses by evaporation. An alternative is to fit the breather on to the end of a section of vertical tube which will act as an air condenser for the Pyroclor vapour. If a Bucholz relay is fitted, it should be suitable for use with Pyroclor.

Tap changer Since Pyroclor is unsuitable for switchgear, on-load tap changing below the liquid surface is not adopted. It is usual to incorporate some form of interlock to prevent this.

Terminals Because water floats on the surface of Pyroclor, the terminal connections should preferably be brought through the side walls of the tank, below the surface. If connections have to pass through the liquid surface, they should be encased in suitable sleeving to prevent the possibility of a flashover arising from surface moisture.

Tank and lifting lugs Since Pyroclor is nearly twice as dense as mineral oil, these items must be sufficiently robust.

FILLING PYROCLOR TRANSFORMERS

Pyroclor as received, either in drums or in bulk, is ready for filling the transformer directly. Care should be taken to carry out the filling as quickly as possible indoors, and days when the humidity is high should be avoided. If the drums have been exposed to low tem-

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peratures, the gas scavenger may have crystallised, but this will re-dissolve when the temperature of the transformer rises, so it is only necessary to agitate the drums to ensure that the crystals are washed into the tank. Alternatively, the crystals may be re-dissolved by pre-heating the drums to approximately 50°C.

Vacuum impregnation of transformer windings can be carried out with Pyroclor, but unless precautions are taken the volatile trichlorobenzene is likely to escape. This can be avoided by using a trap in the vacuum line or alternatively the viscosity of the Pyroclor can be brought back to normal after the impregnation process by adding fresh trichlorobenzene.

A table for converting volumes to weights is given in the Appendix.

MAINTENANCE

Sealed transformers A properly designed sealed Pyroclor transformer requires no maintenance.

Unsealed transformers Pyroclor and oil are two different chemical substances and the condition of Pyroclor should be judged only on the basis of dielectric strength, appearance and water content. High loss tangent and low d.c. resistivity in used Pyroclor is to be expected; these values are not an indication of chemical or electrical breakdown.

New Pyroclor has a minimum dielectric strength of 40 kV at 25°C, and a maximum moisture content of 30 ppm. If the dielectric strength decreases significantly this indicates moisture pick-up, arcing or both. When the dielectric strength has fallen below 40 kV, an analysis for water is necessary. If water is found in excess of 100 ppm, its source should be located and corrections made.

When the moisture content approaches 125 ppm (saturation level) the dielectric strength of Pyroclor drops below the value required for efficient insulating. The moisture content should not be allowed to rise over 70 ppm; it should be held as near as possible to 30 ppm. Maintaining a low moisture level will ensure high dielectric strength and top operating efficiency.

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The colour of used Pyroclor is a useful guide to its condition. In a properly designed transformer the Pyroclor retains its original pale straw colour throughout its life. A blue, green, or red cast shows that extraction from the other internal materials is occurring, but this is not necessarily a hazard unless the dielectric strength also falls, or this phenomenon is accompanied by leakage. If the Pyroclor is dark brown or black, and if black particles of carbon are seen and the dielectric strength is low, then arcing has been occurring and immediate action must be taken. The development of turbidity indicates contamination from water, insulation particles, metallic dust, or dirt. Care must be taken, however, to distinguish this from the precipitation of the scavenger that occurs at low temperatures. High dielectric strength indicates that any turbidity present is not water, and that the insulating efficiency of the Pyroclor is still excellent.

Mineral oil is soluble in Pyroclor and any contamination of the Pyroclor by oil will reduce its fire resistance. A maximum hydrocarbon content of 2% by volume can be tolerated, however, but it is recommended that Pyroclor transformers should never be topped up with mineral oil.

Dissolved water can be removed from Pyroclor with a filter press. Before use, the filter paper should be dried in an oven at 110°C for 3 to 4 hours. The Pyroclor is preferably circulated hot, 55 to 60°C, through the filter. If water is present as a separate phase, it should be first removed by separation.

When connecting a filtration plant to a transformer, the dirty Pyroclor should be drawn off from near the top of the tank, pumped through the plant, and then returned to the transformer through the bottom drain valve.

If arcing has occurred, as shown by the presence of carbon, it is often possible to restore the electrical properties of the Pyroclor by treatment with activated alumina. Peter Spence Alumina A 200 is recommended for this purpose. It should be activated by heating to 100°C for two hours and then added to the Pyroclor in the proportion of 0.06% by weight. (A volume to weight conversion table is given in the appendix.) The mixture is stirred for 2.5 hours at 50 to 60°C and then filtered through either a filter press, an edge filter, or a filter with a built-up bed. Only the latter is likely to remove colloidal carbon.

After treatment the unreacted gas scavenger content of the Pyroclor should be tested by the method of ASTM D1701 - 59T. If necessary, additional gas scavenger should be added to restore the original content.

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TOXICITY AND HANDLING PRECAUTIONS

Askarels made by Monsanto have been used for over 30 years without causing any toxic effects, but they must be handled with care.

These precautions should be observed:

1 Avoid skin contact. Protect the hands, preferably by oil-resistant gloves or, for short contact, by using a barrier cream.

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

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

4 If askarel 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 askarel vapours will not cause any ill-effects, but prolonged exposure to a high vapour concentration should be avoided.

Neglect of these precautions may cause acne and may lead to liver damage.

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APPENDIX

Packaging Pyroclor is, at present, packaged in steel drums containing 600lb. (272 kg) by weight, or 38.3 UKgal (174 litres) at 15.5°C by volume. Pyroclor ETR is similarly packaged, but these drums contain a volume of 41.0 UKgal (186 litres) at 15.5°C.

Volume to weight conversion tables

Pyroclor These tables are based on the density of Pyroclor at 15.5°C:

15.67 lb/UKgal 1.563 kg/litre

Weight in pounds

UKgal	0	20	40	60	80
0	—	313	627	940	1254
100	1567	1880	2193	2507	2821
200	3134	3447	3761	4074	4388
300	4701	5014	5328	5641	5955
400	6268	6581	6895	7208	7522
500	7535	8148	8462	8775	9089
600	9402	9715	10029	10342	10656
700	10969	11282	11596	11909	12223
800	12536	12849	13163	13476	13790
900	14103	14416	14730	15043	15357

Weight in kilogrammes

Litres	0	100	200	300	400
0	—	156	313	469	625
1000	1563	1719	1876	2032	2188
2000	3126	3282	3439	3595	3751
3000	4689	4845	5002	5158	5314
4000	6252	6408	6565	6721	6877

Litres	500	600	700	800	900
0	782	938	1094	1250	1407
1000	2345	2501	2657	2813	2970
2000	3908	4064	4220	4376	4533
3000	5471	5627	5783	5939	6096
4000	7034	7190	7346	7502	7659

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Pyroclor ETR These tables are based on the density of Pyroclor ETR at 15.5°C:

14.63 lb/UKgal 1.460 kg/litre

Weight in pounds

UKgal	0	20	40	60	80
0	—	293	585	878	1170
100	1463	1756	2048	2341	2633
200	9226	3219	3511	3804	4096
300	4389	4682	4974	5267	5559
400	5852	6145	6437	6730	7022
500	7315	7608	7900	8193	8485
600	8778	9071	9363	9656	9948
700	10241	10534	10826	11119	11411
800	11704	11997	12289	12582	12874
900	13167	13460	13752	14045	14337

Weight in kilogrammes

Litres	0	100	200	300	400
0	—	146	292	438	584
1000	1460	1606	1752	1898	2044
2000	2920	3066	3212	3358	3504
3000	4380	4526	4672	4818	4964
4000	5840	5986	6132	6278	6424
Litres	**500**	**600**	**700**	**800**	**900**
0	730	876	1022	1168	1314
1000	2190	2336	2482	2628	2774
2000	3650	3796	3942	4088	4234
3000	5110	5256	5402	5548	5694
4000	6570	6716	6862	7008	7154

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

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.

Forms No. 11-3 (E) M-E (11/68)-2
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