Dr. R. H. Munch

CIGRE STUDY COMMITTEE NO. 15

Working Group SC 15/WG 02

"Askarels"

Minutes of Meeting held at KEMA in Arnhem, Holland, on 2 June 1971

PRESENT:

| | |
|---|---|
| Mlle. B. Bouvier | France |
| Mr. P.L. Boyer | Switzerland |
| Mr. C.A. Bozzini | Belgium |
| Mr. C.R. Coleman | UK (Secretary) |
| Dr. T.W. Dakin | USA |
| Mme. B. Fallou | France |
| Mr. R. Fournie | France |
| Mr. G.A. Gertsch | Switzerland |
| Mr. G. Groslambert | Belgium |
| Mr. P. Jay | France |
| Dr. E. Knust | Germany |
| Mr. Z. Krasucki | UK |
| Prof. T. Leardini | Italy |
| Mr. A. Matsuoka | Japan |
| Mr. G. Martin-Vallas | France |
| Dr. R. Muller | Germany |
| Mr. H.O. Nerf | Sweden |
| Mr. A. Rein | Norway |
| Mr. E.H. Reynolds | UK (Chairman) |
| Mr. J. Schober | Switzerland |
| Mr. E. Serena | Italy |
| Mr. N. Shito | Japan |
| Dr. R. Syderius | Netherlands |
| Mr. K. Tangen | Norway |
| Mr. Trubacher | USSR |
| Dr. J. Vermeer | Netherlands |
| Mr. L.T.G. Virsberg | Sweden |
| Dr. R. Wilputte | Belgium |

The Chairman opened the meeting and welcomed the delegates.

The Chairman requested that he be notified of any corrections to the membership list which he had circulated.

Titles and official reference numbers of documents circulated to delegates are listed in the Appendix to these Minutes.

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Reference: 15-71 (WG-02)
Reynolds-1.

# CIGRE

## WORKING GROUP SC. 15/WG-02

## REPLACEMENT OF AROCLOR AS A CAPACITOR IMPREGNANT

### 1.0 INTRODUCTION

There have been several occasions in the past, when a search was made for Askarel substitutes. The reasons were varied - a belief that Askarels were insufficiently stable, high cost, poor performance in energy storage capacitors and their toxicity. Recent signs that Askarels have found their way into the environment and the stricter controls over pollution have prompted a renewed search for substitutes. This report summarizes the findings of past work in BICC and suggests new liquids for investigation.

### 2.0 LIQUIDS INVESTIGATED

Certain amines and some polyglycols were examined for a.c. applications, while work on both natural and synthetic esters was done in connection with energy storage capacitors. Fluorocarbons were studied by a member of the staff seconded to Birmingham University. More recently, an ester, a silicone fluid and liquid paraffin have been used to impregnate plastic film capacitors, some of them with vacuum metallized electrodes in place of solid aluminium foils.

### 2.1 Polyglycols

These had permittivities in the range 9 to 12 and it is not surprising that the difficulties in obtaining low conductivity were formidable. The best result obtained by vacuum distillation of triethylene glycol dimethyl ether, of permittivity 9.0, was a conductivity of $3.10^{-8}$ $(\mathrm{ohm.cm})^{-1}$. Rather better values resulted from purification of certain commercial polyglycols in a column of active alumina. A condensate of methoxy polyethylene glycol 350 with di-isocyanate was treated in this way and gave a conductivity of $5.10^{-11}$ $(\mathrm{ohm.cm})^{-1}$ in spite of a K as high as 12.

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When small paper windings were impregnated with this liquid, a tan $\delta$ of 0.23 was measured at 50 Hz, a value much greater than expected from the parameters of the paper and liquid separately. It was ascertained that the polyglycol leached impurities out of the paper, so increasing its conductivity.

2.2 Amines

Although the amines investigated did not have such high permittivities, the highest value being 5.4, similar difficulties of purification were encountered. Diethyl aniline was purified by first distilling it and then passing it down an alumina column. A conductivity of $2.10^{-12}$ $(\text{ohm.cm})^{-1}$ was achieved. On impregnating a paper winding, however, the tan $\delta$ value was again of the order of 0.2. An amine with lower permittivity (4.5) ethyl benzyl aniline gave a lower conductivity ($4.10^{-13}$ $(\text{ohm.cm})^{-1}$) and impregnated capacitors showed a tan $\delta$ of 0.010. The loss tangent, however, increased with applied stress.

2.3 Fluoro-dielectrics

Most of the work concerned the preparation of compounds with a permittivity between 5 and 7, the aim being a liquid with greater stability than Askarel. The most promising compound was trifluoromethyl diphenyl, whose loss tangent could be effectively reduced by treatment with alumina. The work was, however, discontinued at a rather early stage. The cost of fluoro compounds is bound to remain several times that of chlorinated compounds.

2.4 Natural Esters

Castor oil has been used very successfully in energy storage capacitors, where resistance to partial discharges is a prime requirement. Its use at 50 Hz stresses is normally prohibited by excessive losses and therefore it is not known how it would perform in a.c. power capacitors.

The only other natural ester, which has been tried in energy storage capacitors, is Tung oil. Its performance, in terms of the number of capacitor discharges from a given stress before failure, was decidedly inferior to castor oil.

2.5 Synthetic Esters

Both di-octyl phthalate (strictly, di-ethyl hexyl phthalate) and di-octyl sebacate were compared with castor oil in energy storage capacitors. The former emerged well, giving a very similar performance, while the latter gave considerably shorter lives. The conductivity of these liquids was reduced to about the same level as that of castor oil, i.e. about $10^{-13}$ (ohm.cm)$^{-1}$, which is adequate for energy storage but not for a.c. capacitors.

Di-iso-octyl phthalate was purified to a higher degree, using active alumina, such that its conductivity and loss tangent at 100°C fell within the specification for capacitor Askarel. It was found, however, that paper capacitors impregnated with this liquid had rather high losses at elevated temperature, even at working stress. An accelerated life-test on a.c. duty ended in premature failures, compared with Askarel capacitors, probably because of the high dielectric losses.

DiOP was also used to impregnate metallized polypropylene film capacitors. These performed well for many thousands of hours, but the stress used at the time this work was done would now be regarded as rather modest (about 30 MV/m).

Di-nonyl sebacate was purified sufficiently to lead to acceptable loss tangents in polypropylene film capacitors impregnated with this liquid. The capacitors were put in accelerated a.c. life-test, but did not perform well.

### 2.6 Silicone Fluid and Liquid Paraffin

Both these liquids have been used with polypropylene film capacitors, but their performance was inferior to that of Askarel. The use of silicone in a metallized film capacitor was more successful, although, again, the stress used was modest.

## 3.0 SPECIFICATION FOR AN IMPREGNANT

It is not difficult to enumerate the desirable properties, in addition to non-toxicity, of a potential impregnant. Even though both paper and film capacitors are involved, and though it might be thought difficult to use the same impregnant for a.c. and for energy storage capacitors, there is no conflict here.

The permittivity should be between 5 and 7. In paper capacitors a high K is desirable to make full use of the permittivity of the cellulose, while in film capacitors the reason lies in the stress in the liquid being lower for a high K. ERA work has shown that this tends to lead to a higher discharge inception stress. Values beyond 7 or 8 are bound to entail great difficulties in achieving and maintaining high purity as exemplified by the reference to the work on polyglycols.

The conductivity must obviously be low enough to avoid an appreciable contribution to the capacitor losses, even at elevated temperature. This requirement is more severe in paper capacitors, because of the larger volume fraction occupied by liquid, in addition to complications introduced by residual "impurities" in the paper (or film). Even though these solid dielectric components have been purified so as to be free of substances that contaminate Askarel, they may contain other substances that will dissolve in other impregnants with possibly very different solvent properties.

The liquid must withstand the effects of internal discharges without generating too much gas or breaking down into highly corrosive products, although additives may, of course, exist to render such products innocuous.

The viscosity must be low enough to allow impregnation and re-impregnation after temperature excursions. The vapour pressure must be low enough to avoid excessive distillation during processing.

The following is a list of the desirable attributes of an impregnant:

| | |
|---|---|
| Permittivity | 5 - 7 |
| Low loss tangent | $\not>$ 0.005 at 90°C. |
| Gas absorbing | |
| Decomposition products due to discharges harmless or easily rendered so by an additive. | |
| Thermally stable (in vacuo) up to 150°C. | |
| Pour point | less than -20°C |
| Boiling point | greater than 250°C. |
| Vapour pressure at 20°C less than about 1 $N/m^2$. | |
| Swelling of polypropylene at 60°C less than 10% (vol). | |

## 4.0 POSSIBLE CANDIDATES

It would be an impossible task to list all the liquids which satisfy the more easily ascertained of the above requirements, i.e. permittivity, melting and boiling points. Nevertheless, a survey of liquids with suitable permittivities listed in the 1951 NBS

"Table of Dielectric Constants of Pure Liquids" and in the annual digests of literature on dielectrics (NAS-NRC) between 1956 and 1968 has been made. The range was narrowed down by ruling out halogenated compounds as potentially toxic, amines as having been explored previously, alcohols as being too hygroscopic, and phenols as probably too conducting. This left a large number of esters, a ketone and polypropylene oxide.

The well known rule that straight-chain hydrocarbons tend to be gas-evolving, while aromatic compounds tend to be gas-absorbing, helped to eliminate sebacates, succinates, etc. as well as polypropylene oxide. A few liquids were also ruled out because of high cost.

The following table shows the liquids remaining:

| Liquid | K | M. Pt. °C | B. Pt. °C |
|---|---|---|---|
| Benzyl acetate | 5.1 | - 51 | 215 |
| Ethyl phenyl acetate | 5.2 | - 31 | 232 |
| Glycerol triacetate | 7.1 | < - 40 | 260 |
| Ethyl benzoate | 6.0 | - 34 | 213 |
| Benzyl benzoate | 4.9 | 18.5 | 324 |
| Iso-amyl benzoate | 5.0 | | 262 |
| n-butyl benzoate | 5.1 | - 22 | 242 |
| o-hydroxy-2 naphthyl benzoate | 6.0 | | |
| o-hydroxy-phenyl benzoate | 6.7 | | |
| di-n-butyl phthalate | 6.4 | < - 10 | 340 |
| di-iso-octyl phthalate | 5.1 | - 46 | 386 |
| benzyl propionate | 5.8 | | 220 |
| iso-amyl salicylate | 5.4 | | 276 |
| n-heptadecanone | 5.4 | 48? | 320 |

Most of these liquids would have no special virtue for the present application; their appearance in the dielectric constant tables was simply due to someone having carried out an academic study. The task of selecting the best liquids for practical trials from this table may be prolonged and unrewarding.

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