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119. — THE USE OF NONFLAMMABLE LIQUID IMPREGNANTS IN ELECTRICAL CAPACITORS AND TRANSFORMERS

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SUMMARY.

The synthetic, nonflammable insulating liquids are non-oxidizing and possess excellent dielectric stability for use in capacitors and transformers. The gases evolved when these liquids are decomposed by heat or the electric arc are nonflammable and chemically nonexplosive. Their use as impregnants for solid insulations insures a better electrical stress distribution across a heterogeneous insulation than is possible with mineral oil. The high dielectric constant of these impregnants also results in smaller physical size than does the use of mineral

oil when used in capacitors of similar construction. The solvent action of these liquids on other materials of construction may lead to increased dielectric loss which can be eliminated by the use of activated alumina as illustrated. Because of their nonflammable and nonexplosive characteristics, equipment containing these liquids may be installed without the severe restrictions which normally apply to the installation of similar oil filled equipment. This frequently results in an economy in the installation and operation of transformers in which these synthetic liquids are used. Further economies are obtained through the elimination of many of the maintenance problems generally associated with the use of mineral oil.

REPORT

Mineral insulating oil has been the most widely used impregnating liquid for electrical insulation, despite the fact that its use involves difficult problems of refining and protection against dielectric and chemical degradation. Most of these problems arise from the fact that mineral oil is a complex composition whose chemical make-up varies widely from one crude source to another. This variation in chemical composition is reflected in the varying utility of any one refined product for different electrical applications. But overshadowing these difficulties of composition and selection are the difficulties arising from the ease with which mineral insulating oil is oxidized. Resort has been made to mechanical and to chemical means by which the oxidation of the oil may be substantially reduced.

The nonflammable materials, however, possess none of these basic objections found in oil. They are synthetic products, easily subject to quality control regulation and acceptance and made from materials which are widely available. Unlike mineral oil, the nonflammable insulants are not subject to oxidation, and maintenance problems of this type are eliminated. Their marked chemical stability insures freedom from both chemical and dielectric degradation when properly prepared and used in suitably designed electrical equipment. Because of their characteristic properties, these liquid insulating materials have found their greatest engineering applications in electric capacitors and transformers.

CHEMICAL BASIS OF THE NONFLAMMABLE LIQUIDS.

In the United States, the nonflammable insulating liquids are called " Askarels ". In Europe as well as in the United States, these Askarel compositions are also known by various trade names such as Pyranol, Inerteen, Arochlor, Dykanol, Pyralene, Clophen and Nepolin.

Askarel is a class name which is applied in the United States to designate a synthetic nonflammable insulating liquid which when decomposed by the electric arc evolves only nonflammable gaseous mixtures [1]. The chemical basis for this desirable behavior is found in the high reactivity of hydrogen and chlorine [2]. When properly chlorinated so that each molecule contains a chemically equivalent amount of hydrogen and chlorine, decomposition of a true Askarel by heat or the electric arc forms only hydrogen chloride and carbon. To meet the desired chemical and dielectric stability required in electrical applications, commercial Askarels of present usage are the chlorinated derivatives of aromatic hydrocarbons. Most widely used are chlorinated benzene and the chlorinated diphenyls, of which the trichlorbenzene and pentachlor diphenyl are examples. Each of these materials is used as a mixture of its isomers from which its liquidity is derived. For transformer use, these chlorinated products are blended in proportions to give the required viscosity or solidification characteristics [3].

COMMERCIAL NONFLAMMABLE INSULATING LIQUIDS.

A number of nonflammable insulating liquids are in commercial use. These are all compositions comprising chlorinated diphenyl or mixtures of chlorinated diphenyl and chlorinated benzene. Typical properties and uses of the nonflammable liquids are given in table I. The properties listed are average values and are not necessarily representative of any one commercial source of these products.

CAPACITOR APPLICATIONS.

From the dielectric standpoint, the greatest advantage possessed by the nonflammable insulating liquids as capacitor impregnants in place of mineral oil lies in the higher dielectric constant which is possible to be obtained. Figure 1 illustrates the effect of chlori-

TABLE 1.

Typical properties and uses of the nonflammable insulating liquids.

Use	Capacitors	Capacitors	Transformers	Transformers
Condition (25°C)	Clear	Clear	Clear	Clear
Color	Yellow tint	Light yellow	Yellow tint	Yellow tint
Acid value (mg KOH/g)	< 0.01	< 0.01	< 0.01	< 0.01
Free chloride ion	Nil	Nil	Nil	Nil
Sp. gravity (25° C)	1.40–1.45	1.54–1.55	1.5[illegible]–1.5[illegible]	1.55–1.5[illegible]
Fire point (°C)	None	None	None	None
Pour point (°C)	0 to −7	6 to 12	−[illegible] to −[illegible]	−3[illegible] to −[illegible]
Viscosity (37.8°C)	200 (S. S. U.)	3 000 (S. S. U.)	[illegible] (S. S. U.)	[illegible] (S. S. U.)
Viscosity (98.9°C)	40 (S. S. U.)	46 (S. S. U.)	-	[illegible] (S. S. U.)
Viscosity (100°C)	1.2° (E)	1.4° (E)	-	-
Coef. of expansion (25–65°C) (cm³/cm³/°C)	68×10^{-4}	65×10^{-4}	67 × 10^-[illegible]	[illegible] × 10^-[illegible]
Heat conductivity (40°C) (kcal/m/h/°C)	0.091	0.087	0.087	0.087
Refractive index (20°C) (D)	1.623	1.638	1.607	1.61[illegible]
Dielectric strength (20–90°C): (kV/cm) (V. E. D.)	200	200	200	200
V. P. M. (A. S. T. M.)	350	350	350	350
Dielectric constant	5.3 (20°C)	5.0 (20°C)	4.5 (25°C)	[illegible] (25°C)
	4.4 (90°C)	4.2 (90°C)	3.9 (100°C)	[illegible] (100°C)
Specific resistance (90°C) (Ω-cm)	1–5 × 10^[illegible]	1–5 × 10^[illegible]	1–5 × 10^[illegible]	1–5 × 10^[illegible]
Power factor (90°C)	0.015	0.015	0.01–0.05	0.01–0.05

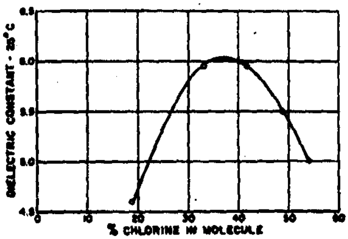

Fig. 1. — The effect of chlorination on the dielectric constant of diphenyl.

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nation on the dielectric constant of the hydrocarbon diphenyl. It will be observed that a dielectric constant about 6 is obtainable

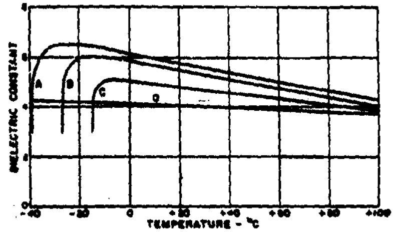

Fig. 2. — The effect of temperature on the dielectric constant of Askarels.

A, trichlor diphenyl; B, tetrachlor diphenyl; C, pentachlor diphenyl; D, blend of chlor diphenyl and chlor benzene.

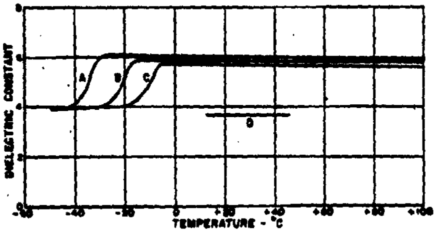

Fig. 3. — The effect of temperature on the dielectric constant of impregnated capacitor paper.

A, trichlor diphenyl impregnated; B, tetrachlor diphenyl impregnated; C, pentachlor diphenyl impregnated; D, mineral oil impregnated.

with the proper degree of chlorination. The use of liquids of such high dielectric constant as compared to mineral oil (dielectric constant 2.2) is reflected in a decrease in the size of the impregnated paper capacitor which may be only about 50-60 % of the size of the oil treated capacitor of similar construction and capacitance.

The dielectric constant of the chlorinated diphenyl, however, decreases rapidly at the point of its solidification. The effect of temperature change on the dielectric constant of typical chlorinated diphenyls of commercial use is illustrated in figure 2. The effect of temperature on the capacitance of capacitors impregnated with typical commercial nonflammable liquid dielectrics is illustrated in figure 3.

The dielectric loss characteristics of the capacitor having a Kraft

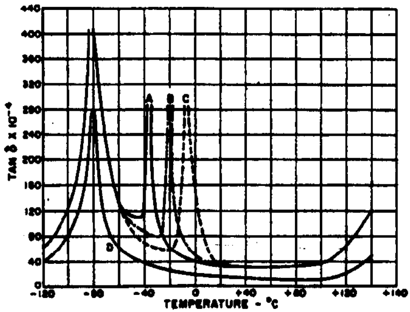

Fig. 4. — The effect of temperature on the dielectric loss of Kraft paper spaced capacitors impregnated with chlorinated diphenyl.
A, trichlor diphenyl; B, tetrachlor diphenyl;
C, pentachlor diphenyl; D, unimpregnated capacitor.

paper dielectric impregnated with each of the commercial nonflammable capacitor liquids are illustrated in figure 4, showing the effect of temperature on tg δ characteristic of the finished capacitor, in comparison to similar data on the dried but unimpregnated paper.

The high dielectric constant of the nonflammable capacitor impregnants insures a further advantage. Because of its closer approach to the dielectric constant of capacitor paper fibre a more evenly distributed dielectric stress results than is obtained with the use of mineral oil. If the dielectric constant of the capacitor paper fibre is accepted as 7, the electric stress applied to the liquid film in the oil impregnated capacitor will be about 1.5 times that absorbed by the liquid film in the chlorinated diphenyl capacitor of similar design. This insures a greater dielectric stability for the chlorinated diphenyl treated capacitor.

With mineral oil treated paper insulation it has been observed that on increasing the voltage, from a low value, internal discharge (ionization) will occur at a certain inception voltage. If that voltage is maintained or exceeded, these discharges will normally build up

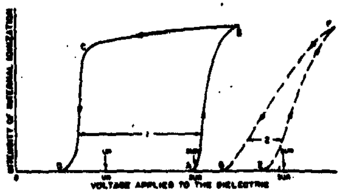

Fig. 5. — Ionization phenomena in paper spaced capacitors impregnated with chlorinated diphenyl and with mineral oil.

1, Ionization in mineral oil treated capacitor.
2. Ionization in chlorinated diphenyl treated capacitor.
U_o Rated voltage for both capacitors.

Inception voltages :

A for mineral oil treated capacitor;
E for chlorinated diphenyl treated capacitor.

Extinction voltages :

D for mineral oil treated capacitor.
G for chlorinated diphenyl treated capacitor.

in magnitude, but if the voltage is reduced, the discharges will persist with much the same intensity until a much lower voltage is reached, after which with some further reduction in voltage, the discharges will stop. This last voltage is known as the " extinction voltage ".

It has been the experience of one of us [5] that the chlorinated diphenyl treated insulation behaves more favorably than the oil treated dielectric with respect to the ionization problem. This is indicated diagrammatically in figure 5. The exact shape of these curves depends on the details of manufacture, such as the efficiency of the drying and the impregnation process, the purity of the insulating liquids, and the type of insulating paper which is used.

As illustrated in figure 5, the difference between the inception and the " extinction " voltages for the chlorinated diphenyl treated capacitor dielectric is much less than for the oil treated dielectric. Where substantial voltage surges are likely to be encountered in commercial service, as for example where the capacitor is connected directly to overhead line networks, this difference in the relation of the extinction voltage to the inception voltage of internal ionization for the mineral oil and the chlorinated diphenyl impregnated capacitor is of practical significance.

TRANSFORMER APPLICATIONS.

An inevitable result of continued progress in modern high voltage installations is the demand that the fire risk accompanying the use of mineral insulating oil be reduced or eliminated altogether. This

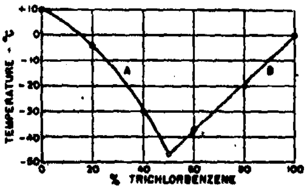

Fig. 6. — The solidification temperature of pentachlor diphenyl as affected by the presence of trichlor benzene.
A, pour point region;
B, crystallisation region.

has led to the production of oil poor and dry type high voltage switchgear and to gas filled transformers and liquid filled transformers utilising the nonflammable insulating liquids. Because the transformer operating requirement for liquid filled transformers necessitates the use of such liquids as coolants as well as insulants, and at temperatures at least as low as — 30° C, the nonflammable insulating liquids for transformer use are synthetic blends of chlorinated benzene and chlorinated diphenyl. Figure 6 illustrates the solidification temperature values of such blends as a function of

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the amount of the chlorinated diphenyl present. Figure 7 illustrates the viscosity-temperature relation of typical nonflammable transformer insulating and cooling liquids in commercial use. The average characteristics of such liquids are included in table I.

Because of their specific advantages, the manufacture and use of the nonflammable, liquid filled transformers is increasing and becoming more widespread. In some areas, however, the purchase of

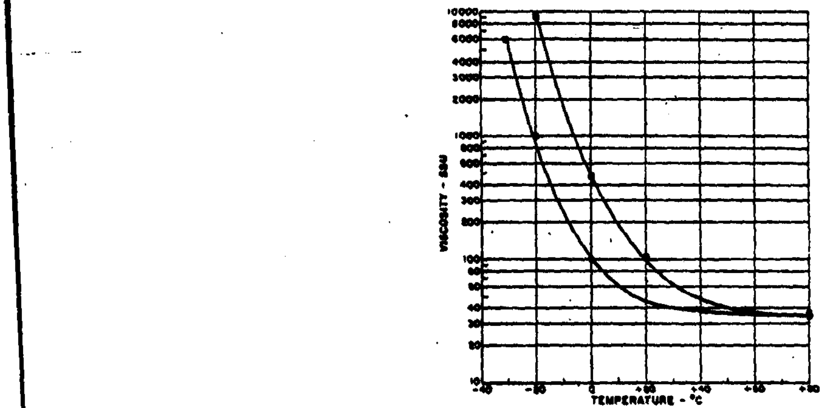

Fig. 7. — The viscosity-temperature relation for typical transformer Askarels.

this type of transformer has been retarded because of its added cost as compared to a similar oil filled unit. The synthetic insulating liquid is heavier and more expensive than mineral transformer oil, but when drawing comparisons, the advantages of the nonflammable liquid filled transformer should not be overlooked. The initial cost of a transformer is frequently not so decisive a factor as the saving in installation costs and the saving in space, material and operating costs.

Economy in installation. — For reasons of safety, enclosed, solidly built and fireproof vaults with proper oil drainage are required for the installation of oil filled transformers. In the United States, the requirements of the National Electric Code of the American Standards Association for oil insulated transformers installed indoors reads as follows [6] :

" Oil insulated transformers shall be installed in a vault constructed as specified in this article except as follows :

" *a. Not over* 112.5 kVA *total capacity.* — The provisions for transformer vaults specified in this article apply except that the vault may be constructed of reinforced concrete not less than 4 inches thick.

" *b. Not over* 600 V. — A vault is not required provided suitable arrangements are made where necessary to prevent a transformer oil fire igniting other materials and the total transformer capacity in one location does not exceed 10 kVA in a section of the building classified as combustible or 75 kVA where the surrounding structure is classified as fire resistant construction. "

The normal vault construction called for by the National Electric Code (American) except as indicated specifies that the " walls and roofs of the vaults shall consist of reinforced concrete not less than 6 inches thick, masonry of brick not less than 8 inches thick, of 12 inch load bearing hollow tile, or 12 inch load bearing hollow concrete building units... " [7].

On the contrary, the requirements of the National Electric Code of the American Standards Association for Askarel insulated transformers installed indoors eliminates the expensive installation requirements except as noted in the following paragraph [8] :

" Askarel-insulated transformers rated in excess of 25 kVA shall be furnished 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 of flue which will carry such gases outside the building. Askarel insulated transformers rated more than 15 000 V shall be installed in a vault. "

For oil insulated transformers installed out-of-doors, the National Electric Code of the American Standards Association carefully specifies the conditions of installation in order to minimize the fire risk [9]. No restrictions of such nature, however, are applied to the Askarel insulated transformer for out-of-doors installations.

Under certain circumstances, therefore, the expensive vault construction can be entirely eliminated by the use of Askarel insulated transformers and the transformer can be installed indoors, even on the factory floor, with only the usual protective guards to prevent contact with the live parts of the transformer.

Economy in operation. — Because of the freedom permitted in the selection of the site for the transformer installation when the nonflammable insulating liquid is used, the transformer can be brought much closer to the point of power consumption, thereby reducing the power losses which are normally incurred due to the longer cable connections which are necessary when mineral oil filled transformers are used. It has been found [10] that for every 1000 m (3 250 feet) saved in the length of low voltage cable there results an added saving of about 0.4 to 0.5 % in the electrical power transmitted.

A further economy in the operation of the nonflammable, liquid filled transformer results from the elimination of the problem of oxidation to which the mineral transformer oil is susceptible. The nonflammable liquid is non-oxidizing and during operation forms no moisture or liquid insoluble products similar to the formation of oil sludge. Sludge deposits on the windings and heat dissipation surfaces of the Askarel filled transformers is therefore impossible. With a properly constructed transformer containing the nonflammable insulating liquid and using the air tight, sealed construction or a properly designed conservator to prevent the entrance of moisture, filtration or complete replacement of the liquid which is generally the practice with mineral oil filled transformers is eliminated.

THE PROBLEM OF ASKAREL CONTAMINATION.

The synthetic, nonflammable liquid dielectrics are characterized by a wider range of solvent action than is mineral oil. The result is that careful attention must be given the selection of other insulating materials and insulating varnishes to prevent their degradation on contact with these liquids and to prevent the liquid from degrading due to the presence of these materials in liquid solution.

In general, it has been found that most of the vegetable oil type varnishes are attacked by the synthetic, nonflammable liquids. Completely cured synthetic resins including the phenolic resins, the polyurethane type resins, the epoxy resins and the cellulose ester resins such as cellulose acetate, are suitable for use in contact with these liquids. Oil or asphalt modifications of these resins frequently increase their susceptibility to attack by the synthetic liquids. The usual cellulosic insulations such as Kraft paper, linen paper and cotton paper and the cords and pressed boards made from such cellulosic pulps are suitable for use with the same degree of acceptance quality control as is normally exercised in their use in mineral oil filled apparatus. Mineral oil is soluble in these nonflammable liquids and its presence may affect the nonflammability of the synthetic liquid and introduce a degree of explosivity in the gases formed by the action of an electric arc. In accordance with the findings of the Underwriters' Laboratory of the National Board of Fire Underwriters (American), the permissible amount of mineral oil in transformer Askarel does not exceed 2 % by volume of the Askarel [11].

The effect of contamination in Askarel filled transformers. — The problem of contamination resulting from the solvent action of the nonflammable liquids on the insulations and structural mate-

Fig. 3. — Showing the use of an activated alumina reconditioner for the removal of impurities during the operation of the Askarel filled transformer (Courtesy of the Prodelec Company).

rials used in the manufacture of such equipment rarely if ever concerns the dielectric strength of the liquid. The effect of contamination, however, may be pronounced when viewed from the standpoint of the dielectric loss. Contaminated liquids of the synthetic, nonflammable type invariably show an increase in dielectric loss, to an extent which is chiefly dependent on the type of material present in liquid

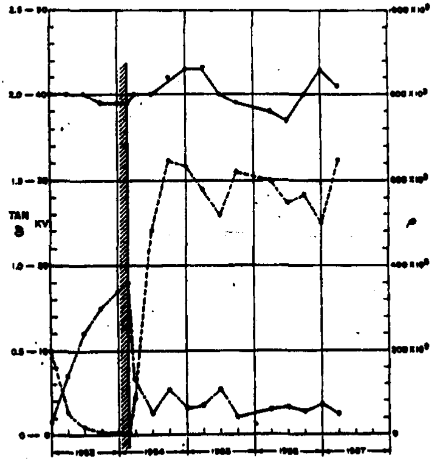

Fig. 9. — The characteristics of Askarel as affected by commercial transformer use [18].
a. Without activated alumina treatment (1953).
b. With activated alumina treatment (1954 et seq.).
———— Dielectric strength.
———— tg δ.
.... Resistivity.

solution. Possible contaminants in transformer manufacture include welding and solder fluxes, varnishes and resins of many types, resin laminated structures and the like. Engineering care must be exercised to prevent the contamination of the insulating liquid beyond that limitation imposed by good engineering practice.

It has been found by experience that despite the careful selection of commercially available materials, a trend toward increased dielectric loss in the liquid of the Askarel filled transformer will occur during the early stages of the operation of the unit in service. This change in dielectric loss has been demonstrated to be of little if any practical significance by the excellent operating record of this type of transformer, but even this trend of change can be eliminated by the use of activated alumina either placed inside of the transformer or in a separate container through which the dielectric liquid is caused to circulate [12], [13]. Its application to the nonflammable liquid filled transformer is illustrated in figure 8 which shows the activated alumina container attached to a 7 500 kVA, 82 500 V power transformer [15]. Figure 9 illustrates both the behavior of the Askarel in the transformer before the circulation through the activated alumina was started and the effect of such circulation during subsequent years of the commercial operation of the transformer

The details of the construction, rating and testing of this transformer are as follows :

Kva capacity	7 500
Voltage rating	82 500 ± 5 %/5 660 V
Insulation tests { High voltage to ground	141 kV
Insulation tests { Low " "	12 kV
Surge test	310 kV
Cooling	Natural cooling through radiators
Conservator	Filled with askarel, air drier
Buchols relay used	-
Askarel used	Pyralene
Weight of askarel	10 400 kg (22 880 lbs)
Ambient temperature of operation	−25°C to +35°C
Service use	Continuous service feeding power to an electrolytic factory
Maximum temperature of askarel	80° C
Activated alumina container	Diameter 560 mm (22 inches), height 1 500 mm (59 inches)
Weight of activated alumina	85 kg (187 lbs)
Circulation of askarel	Thermo siphon
Initial service (without alumina)	January 27, 1953
Circulation through alumina started	March 1, 1954

In figure 9 data are given for the dielectric strength, tg δ and the resistivity of the Pyralene during the life of the transformer to date.

These measurements were made on samples composed of equal amounts of the liquid drawn from the top and the bottom of the transformer. The dielectric strength value was made in accordance with the test requirements specified by the American Society for Testing Materials [16]. The tangent of the angle of dielectric was measured at 100° C under 26.6 V/mm (0.665 v. p. m.) with a frequency of 50 cycles/s. The resistivity was measured at 200 V/mm (5 v. p. m.) after 1 minute of electrification at 100° C.

In addition to the data illustrated in figure 9, additional values were measured for the acidity, color, refractive index, chloride ion content and moisture content of the Askarel. The results obtained in this type of testing indicate (*a*) no loss due to evaporation, (*b*) no decomposition of the chlorinated molecules, and (*c*) no change in the moisture content. The slight increase in liquid acidity (0.004 to 0.015 Mg KOH/g) which was noted during the period of operation before the circulation through the activated alumina was started has been eliminated (present acidity value 0.002) along with the color increase which is now being maintained at a value of 50 (APH).

Contamination in Askarel filled capacitors. — As in mineral oil impregnated capacitors, the presence of moisture in the Askarel impregnated capacitor increases the dielectric loss under A. C. voltage, and decreases the capacitor life. The lowest possible energy losses and the longest capacitor life in practice are therefore only obtained with the lowest residual moisture content which is obtainable only by the use of the most efficient drying processes during the manufacture of the capacitor.

Moisture, however, is only one impurity which may be present in the liquid impregnated capacitor. Any other substance that dissolves in the impregnant and is dissociated thereby into positive and negative ions is liable to have a harmful effect on the dielectric loss of the capacitor. Even the dipolar structure of the insulating paper normally used in capacitor manufacture has been shown by one of us [17] to have a pronounced effect on determining the loss characteristic of both the oil and the Askarel impregnated capacitor at the highest and lowest temperatures of possible application (*fig.* 4). The presence of ionizable contaminants dissolved in the Askarel impregnant of the capacitor, however, may have a more significant effect on the dielectric loss of the capacitor within the normal temperature range of commercial operation.

Probably the most sensitive test for the presence of dissolved impurities which effect the dielectric loss and usability of the Askarel treated capacitor is a test for the variation of the dielectric loss with applied voltage at an elevetad temperature. In a capacitor containing an uncontaminated Askarel impregnant, the losses (tg δ) are substantially constant at all voltages up to the limiting value where internal discharges begin, beyond which the value of tg δ increases. If the Askarel impregnant be contaminated, however, the value of tg δ measured at normal room temperature will show an changing value throughout the entire range of voltages used, below that which produces internal discharge. If this test be repeated with the capacitor heated uniformly to a higher temperature, it will

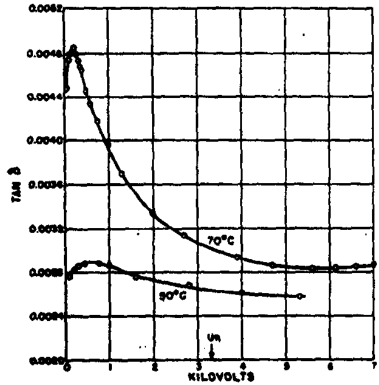

Fig. 10. — The effect of voltage on the dielectric loss characteristic of contaminated Askarel treated capacitors at elevated temperatures [5]. U_n, Rated capacitor voltage.

be found that there will occur a pronounced maximum value of the losses at some intermediate voltage in the test range. Figure 10 illustrates the results obtained at two different temperatures [5]. The actual voltage at which this maximum value occurs is a function not only of the total dielectric thickness but also of the viscosity of the impregnant at the temperature of the test [18]. The curves of figure 10 showing the pronounced maxima in the tg δ — voltage relationships are typical of the contamination of the impregnant. The magnitude of the " hummock " is an indication of the " effectiveness " of the contamination. It has been observed that very small amounts of a harmful material in the Askarel may result in peak values of tg δ 2 or 3 times its normal value at rated voltage.

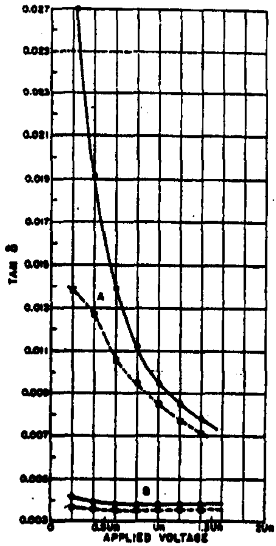

Fig. 11. — Comparing the effect of voltage on the dielectric loss of contaminated and uncontaminated Askarel treated capacitors [5].
A, contaminated capacitors; B, Uncontaminated capacitors.
U_n, Rated capacitor voltage.
.... 50° C; ———— 85° C.

If substantial amounts of contaminant are present, extremely high values of tg δ may be observed as in figure 11. In the capacitor

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tested in figure 11, the Askarel was contaminated with a small quantity of an elastomer recommended for sealing the capacitor can. The peak tg δ value is approximately 0.03 at 85° C, whereas the same type of capacitor when impregnated with the uncontaminated Askarel showed a peak value of only 0.004 [5].

From the illustrations given it might be concluded that the presence of the Askarel contaminant is not of practical and dangerous effect when the capacitor is operated at rated voltage (U_n). Such, however, is not the case. When such contaminated capacitors are operated continuously at their normal rated voltage, the losses soon commence to increase at that voltage stress also. When this occurs, ultimate failure of the dielectric inevitably results because of thermal instability.

THE PAPER SPACER.

In the foregoing discussion it has been implied that the source of the material which may contaminate the Askarel lies in the use of an improperly selected varnish or resin, or in the presence of a foreign material introduced in the gasketing or sealing operations, or by the materials used in soldering or welding, or picked up by the Askarel during factory handling or shipment, or from some other " accidental " source. Contamination of this type is important, but accidental effects of this type are not the only significant sources of trouble. The contamination of the Askarel may arise from the cellulosic insulation itself. Cellulose products are used widely in transformer and capacitor construction in the form of insulating papers, tapes, cloths, cords and pressed boards. It has long been recognized that proper care must be exercised in the selection of the cellulosic insulation used in the construction of oil filled apparatus. The same degree of care must be exercised in the selection of cellulosic insulation for use in Askarel filled equipment. This is especially true in the case of capacitors where increased dielectric loss arising from the use of unsuitable papers or pressed boards may lead to overheating and dielectric breakdown.

The quality control of the insulating papers usually involves chemical tests for the characterization of the paper fiber and the purity of the pulp [19], supplemented by physical and electrical tests to insure the quality of the paper sheet. In many cases, the dielectric loss of the impregnated paper corresponds to the loss in the dried but unimpregnated paper, but experience has shown [20] that with the Askarel impregnated paper this relationship is not always sustained and that higher loss values increasing rapidly with temperature may be exhibited by certain Askarel treated papers.

Examination of the Askarel treated paper is necessary to eliminate the use of " contaminated " paper of this type.

An illustration of the problem presented by differences in three commercial capacitor papers is presented by the test results given

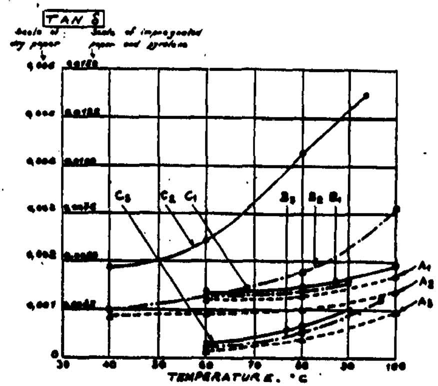

Fig. 12. — The effect of temperature on the losses in capacitor papers [20].
A_1, B_1 and C_1, three different (dried) capacitor papers (density 0.9);
A_2, B_2 and C_2, same papers after Pyralene impregnation;
A_3, B_3 and C_3, Pyralene after treated paper tests;

in figure 12 [20]. In obtaining these results the following procedure was used :

1. The Kraft papers used were from three commercial lots of capacitor paper, each having a specific gravity of 0.9.
2. The papers to be tested were assembled in pads 0.1 mm (0,004") thick.
3. The paper pads were dried at 105° C under a pressure lower than 1 mm for a period of 18 h.
4. The Askarel used was 1476 Pyralene.
5. The Askarel was approved for use on the basis of its resistivity and loss angle values.

6. The Askarel was degassed and introduced in the evacuated impregnation vessel at a temperature of 110° C.

7. The vacuum was broken by means of dried air and the impregnated papers were allowed to stand at atmospheric pressure for 15 h.

8. Electrical measurements were all made in a special cell which also constituted the drying and impregnation chamber. No exposure of the dried paper or the dried and impregnated paper to normal room atmopsheric conditions was permitted.

9. Electrical tests on the Askarel impregnated papers were made with a Schering Bridge at a voltage stress varied up to 5 volts per micron (127 volts per mil) at 60 cycle frequency.

10. Electrical tests on the dried but unimpregnated papers were made at 2 volts per micron (51 volts per mil).

From the data illustrated in figure 12, it will be observed that the dielectric loss in Askarel impregnated capacitor paper may in some instances be much higher than the losses to be anticipated from measurements made on the dried paper before impregnation. Tests on the Askarel made after its use in the impregnation of the paper showed no abnormality which would be indicative of the presence of soluble contamination. These test results are supported by the examination of commercial capacitors in which these papers were used. Capacitors made with paper B and with paper C were each characterized by higher losses after drying and impregnation than would have been expected from the measured losses of the papers before impregnation with the Askarel. The quantity and nature of the constituents in Kraft paper which are the basis for the abnormalities observed are not yet able to be specified by chemical analysis. Measurement of the losses of the Askarel impregnated paper dielectric is an important supplement to the physical, chemical and dielectric tests usually made on the unimpregnated paper.

THE DIELECTRIC STRENGTH UNDER SURGE VOLTAGES.

The power frequency voltage breakdown of the Askarel and the Askarel treated insulation is equal to and in many instances superior to the breakdown of mineral transformer oil and the corresponding oil treated insulation. However, in transformer construction, the surge voltage breakdown of the insulation treated with Askarel is equal to the surge voltage breakdown of insulation treated with mineral oil of like viscosity only when the electrical field is uniformly applied or when small insulation thicknesses are used. For large gap distances or with thick layers of the impregnated insulation tested with surge voltages under conditions which cause a nonuniform distribution of the voltage stress, the surge voltage breakdown of the Askarel and Askarel treated insulation is lower than that of the corresponding oil or oil treated dielectric [23]. As in the case of a gas insulated transformer, the solution of this problem lies in the design of the transformer. Those transformer designs which give the greatest uniformity in the distribution of the applied voltage favor the highest surge voltage breakdown values for the Askarel filled transformer.

THE PROBLEM OF HYDROGEN CHLORIDE.

In the normal operation of the Askarel filled transformer, electrical arcing beneath the surface of the Askarel does not occur. However, during high voltage testing, corona may be formed. *Furthermore*, despite the excellent service record of the Askarel filled transformers over many years, electrical breakdown during the commercial use of the transformer may occur. It is well recognized that an electrical arc will cause the molecular breakdown of mineral oil. It also causes the molecular breakdown of Askarel. In mineral oil, such breakdown results in the formation of carbon sludge and gases such as hydrogen, methane, acetylene, carbon monoxide, and other flammable and toxic volatile materials. In Askarel, breakdown under the electric arc produces carbon and hydrogen chloride gas. The volatile products formed from the decomposition of mineral oil by the electric arc introduce a degree of flammability and explosivity which is absent when the Askarel liquid is decomposed. Hydrogen chloride is neither flammable nor explosive. But hydrogen chloride may be corrosive in the presence of moisture. Experience has shown that a dielectric failure in an oil filled transformer is frequently repairable without serious degradation of the properties of the cellulosic insulation. Experience has also shown that when dielectric breakdown occurs beneath the surface of the liquid in an Askarel filled transformer, the hydrogen chloride formed may attack the cellulosic insulations present. Serious degradation of these insulations may be caused by the slow attack of the hydrogen chloride dissolved in the Askarel liquid. This degradation of the cellulosic insulation can be eliminated by the presence of a " getter " dissolved in the Askarel [21]. A " getter " is defined as a material which when present in the Askarel at the time the insulating liquid is decomposed by the electric arc will react with the hydrogen chloride and eliminate the possibility of its reaction with the insulating and structural parts of the transformer. Such a material has no function in modifying the normal dielectric bevavior of the Askarel under normal operating conditions and becomes effective and of significant protective action only when hydrogen chloride is formed as when an electric arc has caused decomposition of the Askarel. Since the " getter " is present during the normal commercial use of the transformer, it must possess good dielectric properties when dissolved in the Askarel and must not diminish its freedom from fire nor detract from the nonexplosive quality of the arc formed gases. Such a material is tin tetra phenyl [22]. When dissolved in the transformer Askarel to an extent of about 0.15 % by weight, tin tetra phenyl gives adequate protection against the *degradation* of the *structural* and insulating members of the transformer [24].

THE USE OF STABILIZERS.

In the normal use of Askarel in A. C. voltage capacitors and in transformers there is no necessity for the use of a stabilizer of any type. The chemical stability of the Askarel and its freedom from the possibility of oxidation, unlike the behavior of mineral oil, removes any necessity for the use of antioxidants or retarders which have been found desirable in certain types of oil filled transformers.

Under D. C. voltage, however, the life of the Askarel treated capacitor has been extended by the use of a stabilizer [12]. It is believed that when the Askarel treated capacitor paper dielectric is operated under high values of D. C. voltage stress, there is a small but significant degradation of the Askarel which affects the performance of the capacitor in D. C. voltage use. Such a stabilizer is anthraquinone and its chlorinated derivatives.

THE USE OF ASKARELS AT LOW TEMPERATURE.

For the operation of the Askarel capacitor at low temperature in cases where the capacitor is not continuously energized, the use of penta chlor diphenyl has not been found to give a completely satisfactory performance. During periods when the capacitor is off voltage, the impregnant may solidify with resultant mechanical motion and the possibility of void formation within the dielectric structure. In some cases, capacitors impregnated with penta chlor diphenyl have failed electrically when the normal capacitor voltage was reapplied after a period of time at temperatures below — 15° C during which the capacitor was not energized. By the use of trichlor

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diphenyl or mixtures of a selected chlorinated diphenyl and trichlor benzene as the impregnant, Askarel filled capacitors can be switched on and off voltage with impunity at temperatures as low as — 25° C and lower. The characteristics of trichlor diphenyl which are suitable for such applications are given in the data of table II. These properties are average values and do not necessarily represent the properties of any single commercial source of this material.

TABLE II.

The average properties of trichlor diphenyl suitable for use in capacitors subject to low ambient temperatures.

Condition (25°C)	Clear
Color	Practically colorless
Acid value (mg KOH/g)	< 0.01
Free chloride ion	Nil
Specific gravity (25°C)	1.38
Pour point (°C)	−14 to −20°C
Viscosity (37.8°C)	85 (S. S. U.)
Viscosity (98.9°C)	34 (S. S. U.)
Viscosity (100°C)	1.15° (E)
Specific heat (25°C) (cal/g/°C)	0.29
Coef. of expansion (25-65°C)	67×10^{-5}
Heat conductivity (50°C) (kcal/m/h/°C)	0.093
Refractive index (20°C) (D)	1.623
Dielectric strength (20-90°C):	
(kV/cm) (V. D. E.)	200
V. P. M. (A. S. T. M.)	350
Dielectric constant	5.6–5.9 (25° C) 4.7–4.9 (100° C)
Specific resistance (90°C) (Ω-cm)	5×10^{11}
Power factor (90°C)	0.015

THE PROBLEM OF TOXICITY.

The Askarel insulating liquids possess a very low order of toxicity when handled in accordance with normal practice in the manufacture and operation of oil filled capacitors and transformers. As with most materials, however, a degree of toxicity is introduced under certain handling conditions. Continued contact with the liquid Askarel may cause some skin irritation. If the vapors from the hot materials are breathed over a sufficiently long period of time, systemic effects may result. The lower order of volatility of the commercial Askarels as compared with most chlorinated materials in commercial use (chlorinated ethylene) protects against abnormal personnel difficulties. Despite this and especially when the heated Askarels are handled in open containers, good ventilation of the atmosphere should be provided.

Hydrogen chloride, which is formed only when the Askarels are decomposed as by an electrical arc, is a toxic gas. It is to be pointed out, however, that the exceedingly unpleasant and irritating characteristic of hydrogen chloride acts to give adequate warning of its presence even in very small concentrations, thus preventing the dangerous exposure of persons. It is suggested by the Underwriters' Laboratory [11] of the National Board of Fire Underwriters (United States) that " the resulting concentration of hydrochloric acid in air when failure of a transformer or other electrical apparatus containing these products occurs will depend largely upon the conditions. It will constitute a toxic hazard only where the conditions are such as to cause a high concentration of the fumes, as in a closed room ".

In accordance with this finding, the National Electric Code of the American Standards Association as already stated [8], permits the installation of Askarel filled transformers up to 15 000 V rating without the fire vault protection required for oil filled transformers, but the code does require that in poorly ventilated areas, means shall be provided for carrying off the gases evolved in case the transformer should fail electrically.

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