Monsanto

FROM (NAME & LOCATION) D. Wood-St. Louis-B2SD

DATE October 12, 1976

SUBJECT CALL REPORT
G. E. Pittsfield

DEPARTMENT

TO FILE

Date of Call: October 8, 1976

For G. E.: R. Osthoff
R. Tuggey
W. Fessler

For Monsanto: D. Wood

Phase-Out:

Accepted Monsanto plan as fitting well with their timetable. They still have product in inventory and do not expect to order any more Pyranol A13B1 before phase-out.

They are not sure exactly how they will serve Penn Central Workshop yet. Tuggey will check and respond.

G.E. are supporting program to persuade government not to retrofit. See attached paper for IEEE presentation.

Silicone is now adopted as first choice for power/rail-car transformers. In small power, they will try to sell more oil units.

They still have problem in talking to customers about TCB top up. They see possible hazard, but cannot be too open about this in light of Capacitor Division decision to use DOP/TCB. Most of Hudson Falls $1M research settlement will be spent on TCB toxicity testing.

D. Wood

/dwb

PROBLEMS ASSOCIATED WITH THE RETROFILLING OF ASKAREL TRANSFORMERS

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Pittsfield, Mass.

ABSTRACT

A program involving exploratory and analytical studies of the concept of retrofilling askarel insulated transformers with polydimethylsiloxanes (silicone oil) has generated concerns regarding the practicality and economic feasibility of this concept. This paper identifies and discusses technical and economic problems associated with the retrofilling concept.

INTRODUCTION

Environmentalists have made considerable progress towards achieving their goal of a total ban on polychlorinated biphenyls, (PCB's), a key constituent of askarels. The chemical is specifically identified in the Toxic Substances Control Act of 1976. The sole U. S. producer of askarels has announced it will phase out production as soon as substitutes suitable for use in transformers and capacitors are available. Several companies have announced the availability of transformers with silicone oil for applications that formerly required askarel insulated transformers. These new transformers are not simply askarel units with a substitute fluid. They are units designed around the unique properties of silicone oil.[1]

In view of these developments many people have raised the question of the desirability of draining existing askarel insulated transformers and refilling them with silicone. This question is primarily directed at reducing the probability of accidental spills of askarels from transformers and the associated environmental problems.

Consideration must also be given to the effect on transformer reliability, load capability, and maintenance after the substitution has been made. Furthermore, in view of the extremely stringent limits set by the Environmental Protection Agency for reportable spill levels, the practicality of reducing PCB content of transformers to the point where spills of the substitute liquid would be exempt should be considered.

A program to study the technical and economic aspects of the retrofill concept has been conducted under the direction of the authors. The program involved both exploratory tests and analytical studies. Early in the program, it became apparent that there are many problems associated with the concept. This paper discusses these problems and the data that led to their identification. Methods to overcome these problems were considered and will also be discussed in the text.

SELECTION OF SILICONE AS RETROFILL FLUID

Evidence has accumulated in recent years to support the position that silicones are the forerunners among askarel substitutes.[2,3] Several groups of researchers have arrived independently at the conclusion that polydimethylsiloxane of 50 cs viscosity has many of the characteristics needed for transformer use.[4,5,6] It has a low order of toxicity (immeasurably low in fact) and even after years of use in non-electrical applications, at present there is no evidence that silicones pose a threat to the environment or to health.[7] It combines a high flash point (280-300°C) and a low pour point (-50°C). Life tests in transformers have shown that silicone oil meets the aging requirements for transformer use. Tests simulating electrical failure in transformer tanks have demonstrated that silicone does not continue to burn and does not spread fire to nearby combustible materials. Silicone liquid is being successfully used in railroad car transformers in Japan. Transformer designs using silicone liquid are in their final stages of development, prototype models have been built and tested and production of units for commercial service has begun. Silicone has become the liquid against which the performance of any other askarel substitutes should be measured and was the liquid chosen for our retrofill studies.

IMMISCIBILITIES OF SILICONE FLUID WITH ASKARELS AND ATTENDANT PROBLEMS

In its simplest concept, the retrofilling of askarel transformers with silicone fluid would involve the following steps:

1) Draining of askarel.

2) Flushing of transformer with silicone or other fluid to remove askarel retained by unit (paper, pressboard, etc.).

3) Final fill with silicone fluid.

The amount of the askarel that remains in the porous structures such as paper, pressboard, wood, etc., and the manner in which it partitions between the solid insulation system and the silicone fluid is of major importance. By way of example, a transformer spill immediately after retrofill would release less PCB into the environment than the same spill three years later. This dynamic change in the partitioning could also have an adverse affect on the electrical breakdown characteristics if immiscibilities occurred internal to the insulation structure when the electric stress is high. Immiscibilities could result in discrete two phase liquid regions and the silicone-rich phase by virtue of its low dielectric constant would be subjected to a larger voltage stress relative to the askarel-rich phase. Recent data show that the 60 Hz breakdown strength of silicone fluid in paper is less than askarel and hence the stage is potentially set for dielectric breakdown during the operation of a retrofilled unit. Equilibration times between silicone and askarel would also be adversely affected if two phases are formed internal to the insulation structure. In the latter case the askarel concentration gradient and hence the mass transport rate would be reduced because of the limited solubility within the insulation and core structure.

With the above facts in mind the following tasks were undertaken:

Task 1: Determine the solubility relationships in the ternary system Silicone-Polychlorbiphenyl-Trichlorobenzene. The main objective was to determine whether or not miscibility gaps occurred in the ternary system.

Task 2: Determine the time dependence for askarel removal from model structures (paper and wood) by flushing with silicone (SF-97) and 10C oil. 10C oil would be considered as a flushing medium only and not for final fill.

Task 3: With the data from Task 2 as background, develop a methodology that could be used as a guide for predicting the times required to remove given amounts of askarel from typical components, systems, and transformers. The model would also allow for estimating the times required for flushing to a predetermined askarel level as well as predicting repartitioning of the remaining askarel between the insulation system and the retrofill liquid.

Task 4: Assess effect on transformer reliability and capability.

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SOLUBILITIES IN THE TERNARY SYSTEM, SILICONE-TCB-PCB AT 25°C AND 100°C

The 25°C and 100°C isotherms of the system were determined by the cloud point method. By way of example a beaker containing a known weight of silicone fluid (SF-97) was thermostatted and to this was added, with stirring, Aroclor 1254 (PCB) until the cloud point was reached. The cloud point is the point that saturation has occurred. From the known weight of each component the solubility could be calculated (e.g. silicone will dissolve 12 % by weight of Aroclor 1254 at 100°C). The reverse procedure i.e. the addition of silicone to PCB revealed less than 0.5% silicone dissolved at the cloud point. The same procedures were used using askarel of two different compositions. In one case the askarel consisted of a binary mixture of PCB and Trichlorobenzene while the second composition consisted of a ternary mixture. The addition of these compositions to silicone and the reverse i.e. silicone additions to these compositions allowed construction of the phase diagrams seen in Figure 1 and Figure 2.

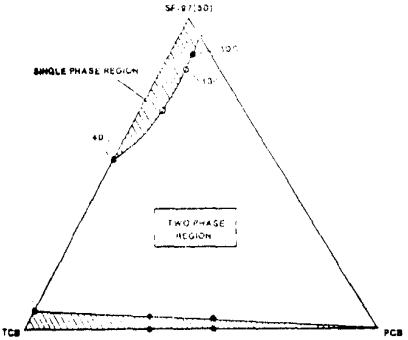

FIGURE 1. ASKAREL SILICONE SOLUBILITY AT 25°C

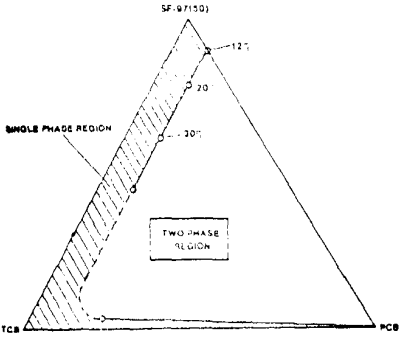

FIGURE 2. ASKAREL SILICONE SOLUBILITY AT 100°C

Inspection of Figures 1 and 2 reveals that miscibilities do occur in the system silicone-TCB-PCB. Since combinations of the three components that results in an overall composition falling in the region designated as two phases will result in a silicone-rich phase and a PCB-TCB rich phase.

That a two phase region can occur within the insulation structure can be seen from an examination of Figures 1 and 2. If we have a structure like pressboard initially impregnated with askarel (60% PCB-40% TCB) *and equilibrate it in a container* of silicone fluid the following changes must occur. As the askarel diffuses out of the impregnated structure into the silicone, the overall composition of the silicone will follow on a straight line from 100% SF-97 to 100% askarel. No immiscibility will occur unless the volume of silicone is small. One observes from an examination of Figures 1 and 2 that at room temperature that the silicone can hold up to 10% by weight of askarel before saturation is reached. It is apparent that the amount of retained askarel in the insulation structure will not saturate the bulk silicone fluid. However, as the silicone penetrates the insulation system the overall composition must change along the line askarel to SF-97 of Figure 1. The askarel cannot dissolve more than 0.5% weight of silicone and as the overall composition traverses the two phase region immiscibilities will occur. Not only will the compositions of the two phases change (one phase will *always be silicone rich relative to the others) but also relative amounts* of the two phases changes.

The solubility determinations have been compiled in tabular form for ready reference in Table I.

TABLE I

*Solubilities of Askarels in Silicone (SF-97)**
% Wt.

	25°C	100°C
Aroclor 1254	-	12
Askarel 60 PCB / 40 TCB	10	20
Askarel 40 PCB / 60 TCB	13	30

* Solubilities of silicone (SF97) in askarels at 25°C and 100°C are all less than 0.5% by wt.

THE REMOVAL OF ASKAREL FROM MODEL STRUCTURES

The objective of this work was to determine the removal rate of askarel from model structures and then by using the data to predict removal rates for various geometries of pressboard and paper used in transformers.

The mass transport of askarel from an impregnated structure into a bulk fluid like silicone can be represented by the following equation:

$$\text{Rate of askarel Removal} = D_S \frac{\Delta C}{\Delta X}$$

where D_S is the diffusivity and $\frac{\Delta C}{\Delta X}$ is the concentration gradient of the askarel.

Model structures were fabricated by winding 5 mil (.013 cm) kraft paper on a 6" (15.24 cm) long wooden dowel which had a diameter of .75" (1.9 cm). A continuous convolute wind was made until a .625" (1.6 cm) build of paper was obtained. By blocking off the extremities of the impregnated structure radial studies could be made and by wrapping a layer of aluminum foil over the outer paper layer axial studies could be made. A schematic of the test procedure can be seen in Figure 3. The

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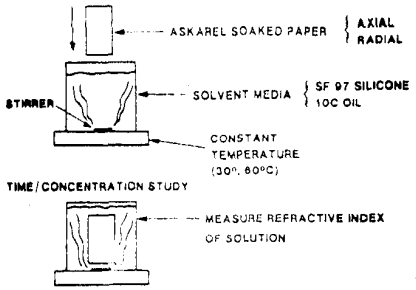

FIGURE 3. EXPERIMENT

model structure impregnated with askarel was immersed in the contained fluid (silicone-10C oil) held at constant temperature (30°C, 60°C). The buildup of askarel in the bulk fluid was monitored as a function of time for both radial and axial directions. Typical data can be seen in Figures 4 and 5. These data can be exploited as a function of $t^{1/2}$

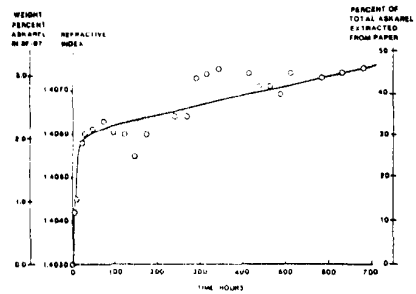

FIGURE 4. AXIAL DIFFUSION OF ASKAREL INTO SF-97 AT 60°C

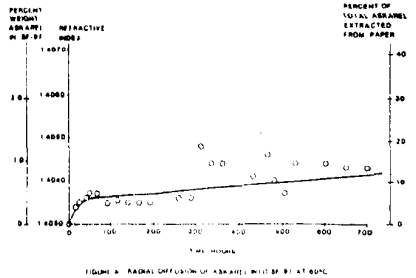

FIGURE 5. RADIAL DIFFUSION OF ASKAREL INTO SF-97 AT 60°C

in which c, see the slopes are directly related to the diffusion coefficients (D_S). Using this technique the values of D_S as a function of temperature can be seen in Figure 6.

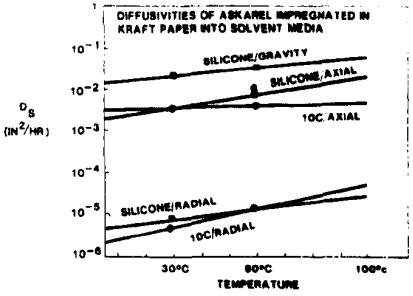

FIGURE 6 CONCENTRATION VERSUS TIME DATA ESTIMATED DIFFUSIVITIES

It should be noted that:

1) All diffusivities increase with temperature and therefore higher temperatures favor the mass transport.

2) Radial diffusivities are comparable for both oil and silicone.

3) Axial diffusivities are comparable for both oil and silicone.

4) Axial diffusivities are much larger than radial diffusivities.

Although the diffusivities for oil and silicone are similar one must not assume that the mass transport rates are similar.

In Figure 7 is shown a sketch of the concentration profile of askarel within a paper structure undergoing leaching in silicone fluid. Within the paper structure two phases exist. At the center of the structure there exists the askarel-rich phase comprised of 99.9% askarel. Within this region exists a small concentration gradient of silicone and for all practical purposes this is pure askarel. The second phase (silicone-rich phase) is comprised of askarel at concentrations of 10% (saturation level) at room temperature. The interphase region between the two immiscible phases is a moving boundary that moves deeper and deeper into the structure, as askarel is removed as a function of time. In order for diffusion to occur, a concentration gradient must exist within the silicone-rich phase. However, at no point in time using silicone will the concentration gradient be as large as that for two completely miscible fluids such as askarel and 10C oil. For this reason, even though the diffusivities, D_S, are equal, 10C oil will remove more askarel and at faster rate than will silicone because of the larger concentration driving force.

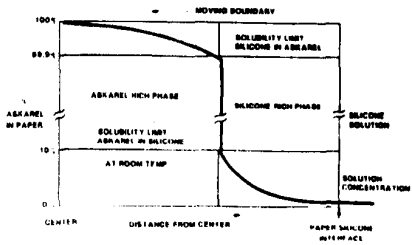

FIGURE 7 ASKAREL CONCENTRATION PROFILE WITHIN COMPOSITE USING SILICONE AS A FLUSHING FLUID

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TIME REQUIREMENTS FOR ASKAREL REMOVAL FROM TRANSFORMER COMPONENTS

Once the diffusion coefficients were determined from the model structure studies, it was possible to construct a series of curves like Figure 8. Here we see the time in hours required to remove predetermined amounts of askarel from kraft paper into 10C oil. By way of example a 10" (25.4 cm) length of kraft paper impregnated with askarel will require approximately 1600 hours to immersion in 10C oil before 50% of the askarel would be removed in the axial direction. Figure 9 shows the same type of plot for radial diffusion. Once again, the larger the diffusion path the longer the time to reach a predetermined askarel content.

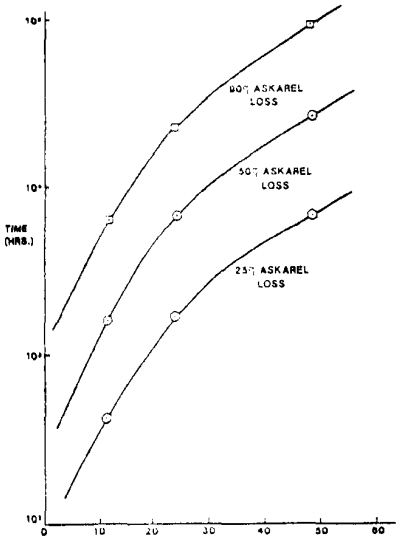

FIGURE 8 TIME REQUIRED TO LOSE ASKAREL TO 10C OIL VERSUS AXIAL LENGTH (KRAFT PAPER, 30°C)

For predicting time requirements for transformers each component was considered separately. Using Figures 8 and 9 the following procedure was used for each component:

1) Estimate axial length.

2) From Figure 8 obtain time, t_{axial} for loss level in question.

3) Estimate average radial thickness.

4) From Figure 9 obtain time, t_{radial} for same level as step 2.

5) Time = t

$$t = \frac{1}{\frac{1}{t_{axial}} + \frac{1}{t_{radial}}}$$

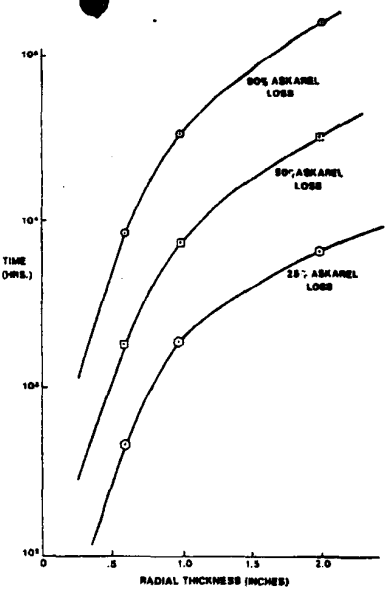

FIGURE 9 TIME REQUIRED TO LOSE ASKAREL TO 10C OIL VERSUS RADIAL THICKNESS (KRAFT PAPER, 30°C)

Using the above approach a precipitation transformer was analyzed mathematically to determine the rate of askarel removal at various temperatures and with silicone and 10C oil. The results can be seen in Figure 10. The precipitation unit would contain approximately 78 lbs. (172 Kg) of askarel after draining. Gravity affects leads to an initial rapid loss and then tapers off and diffusion takes over. It should be noted that even with 10C oil when the mass transport is not affected by phase separation the diffusional loss of askarel is slow. After flushing *the unit for 3 weeks with 10C oil at 90°C the mathematical model* predicts that 23 lbs. (50.7 Kg) of askarel will remain within the insulation structures. This level is well above the reportable spill levels of 1 lb. (2.2 Kg) of PCB anticipated to be the level below which a spill need not be of concern.

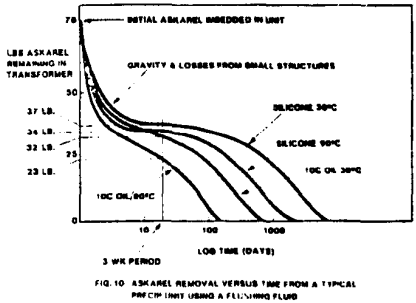

FIG. 10 ASKAREL REMOVAL VERSUS TIME FROM A TYPICAL PRECIPITANT USING A FLUSHING FLUID

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The same type of analysis was done on a number of transformer designs using silicone fluid as the flushing medium at 90°C. In each case the analysis indicated unacceptable levels of residual askarel after several hours of flushing.

Obviously, if one were willing to flush long enough the amount of residual PCB's could be reduced to an acceptable level. However, the time and expense of such flushing and the subsequent disposal of the large quantity of contaminated flushing fluid make such a course economically unattractive.

ASSESS EFFECT ON TRANSFORMER RELIABILITY AND CAPABILITY

Electrical tests on models and components indicated that askarel transformers that were retrofilled with silicone would have reduced dielectric integrity. The reduction is due to the following factors:

1) Substantially lower positive impulse strength, particularly in creep, could cause problems in transformers where the designer did not provide for this weakness.

2) Increased electrical stress at the interface of the two stage liquid region if all the askarel isn't flushed out of the transformer.

3) Silicone has a higher coefficient of expansion than askarel which increases the probability of transformer "breathing" through pressure vacuum bleeders, pressure relief devices, or aged gaskets on older units. Introduction of moisture during such breathing increases the risk of electrical failure for a retrofilled unit.

4) Lower bare electrode strength of silicone in a uniform field could cause problems at tap changers, terminal boards, bushing connections, or other bare electrode locations in some transformers designed for askarel.

5) The selection of 50 cs viscosity silicone as the preferred transformer insulating and cooling medium represented a compromise between fire resistance and cooling liquid efficiency. Tests on a variety of transformers filled with silicone resulted in temperature rises of 5-25°C higher than reached when the units were tested with askarel fluid. Thus the insulation life of some transformers may be reduced if the unit isn't operated at reduced load.

In addition to the risk of lower dielectric strength and premature failure, our work uncovered other potential problems. For instance, silicone has poor lubricity that requires different design considerations for tap changers, pumps, etc., that must operate under the liquid to prevent galling, seizure, and failure. Furthermore, some of the gasket materials in askarel filled units are not compatible with silicones and must be changed out if retrofilling with silicones is to be accomplished.

As indicated earlier, transformers designed for askarel but retrofilled with silicone were found to operate as much as 25°C higher temperature than when filled with askarel. This higher temperature coupled with the fact that silicone has approximately 1.5 times the coefficient of thermal expansion of askarel results in increased liquid volume at full load. This increased volume of liquid could cause problems with sealed tank liquid preservation system on some transformers.

CONCLUSIONS

1) While transformers specifically designed around the characteristics of silicone fluid appear to be a logical successor to askarel filled units, the two fluids are not one-to-one substitutes in existing transformers. Reliability and load capacity of an askarel transformer retrofilled with silicone will be decreased.

2) It is economically impractical to remove all the PCB's in an askarel transformer to the point where no environmental problems exist via the drain and flush method.

ACKNOWLEDGMENTS

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