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1982 Review of Substitutes for Polychlorinated Biphenyls in Transformers

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1982 REVIEW OF SUBSTITUTES FOR POLYCHLORINATED BIPHENYLS IN TRANSFORMERS

Commercial Chemicals Branch
Environmental Protection Service
Environment Canada

EPS 3-EP-84-1E
March 1984

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ABSTRACT

This report presents an up-to-date review of PCB substitutes for use in transformers. Included are silicones, aliphatic hydrocarbons, tetrachloroethylene, chlorinated benzene blends, and pentaerythritol ester blends.

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1 INTRODUCTION

The primary purpose of this report is to present an up-to-date review of substitutes for Askarel Transformers. Askarel is a generic name for fire-resistant liquid dielectrics consisting of polychlorinated biphenyls (PCBs), usually blended with chlorinated benzenes.

Transformers which contain PCBs as a result of adventitious contamination, but were not designed to contain PCBs, are outside the scope of this review. Therefore, the name Askarel Transformer will be used throughout the report to include only those transformers that were designed for use with askarel.

Askarel Transformers were manufactured on the North American continent for a period of 45 years, between 1932 and 1977. They are used principally in those locations where fire resistance is considered to be an important factor. Thus, they are installed usually inside or close to buildings, where mineral oil transformers are not acceptable because of fire hazard. Askarels have performed extremely well as transformer dielectrics and coolants. Unfortunately, polychlorinated biphenyls were found to be environmentally unacceptable because they are persistent, nonbiodegradable, toxic substances, suspected of carcinogenicity.

Therefore, the use of new askarel in electrical equipment has been banned in Canada by regulations under the Environmental Contaminants Act. The existing Askarel Transformers are allowed to continue in service because:

- probability of PCB escape from a closed system such as an Askarel Transformer is very small,
- PCB disposal facilities in Canada are not yet in place, and
- PCBs contained in an energized Askarel Transformer are under much better supervision than PCBs in storage.

For new installations, however, where fire resistance is essential, and for replacement of Askarel Transformers at their "end of life", suitable substitutes for Askarel Transformers must be found.

The alternatives may be divided into three categories:

- use of dry-type transformers,
- provision of fire-resistant vaults for transformers filled with flammable mineral oil, and

- use of transformers filled with fire-resistant fluids, comparable in performance to askarel, but environmentally acceptable.

The use of askarel for new transformers and as a make-up fluid for existing transformers has been banned for several years. There are, however many fluids offered as substitutes for askarel. A comprehensive study of these fluids has been made and the results are presented in Section 2 of this report. The impacts of the Chlorobiphenyl Regulations on the maintenance of existing Askarel Transformers and on the new transformer installations are discussed in Section 3; retrofilling of Askarel Transformers with substitute fluids is discussed in Section 4.

2 CLASSIFICATION AND ASSESSMENT OF FIRE-RESISTANT TRANSFORMER FLUIDS

2.1 General

An ideal transformer fluid should meet all the functional, environmental and economical requirements listed below.

Functional Requirements

- High dielectric strength (greater than 30 kV by ASTM D877).
- Low rate of in-service degradation (sludge formation, moisture pick-up, oxidation and/or acid formation) and long in-service life.
- High resistance to breakdown due to internal arcing.
- Compatibility with materials of construction normally used in transformers (e.g., steel, iron, copper, insulation gasket material).
- Good thermal conductivity, high specific heat and low viscosity over the entire range of operating temperatures to optimize heat transfer capabilities.
- Low pour point (less than -30°C) to enable cold startup without localized overheating.
- Low vapour pressure even at the upper limit of the operating temperature (150°C) to minimize pressure fluctuations in casing and to avoid vapour losses.
- Specific gravity either below or above that of water or ice over the entire range of operating temperatures so that any free water (or ice) remains either at the bottom or on top of the bulk dielectric fluid.
- Low thermal coefficient of expansion to avoid significant fluctuations in equipment fluid operating levels.

Environmental Requirements

- High fire point (greater than 300°C) and high auto-ignition temperature for safety in operation and to qualify for classifications as "non-propagating fluid" by the Canadian Electrical Code and as "less-flammable fluid" by the insurers.
- Low rate of heat release to minimize damage in the event of fire.
- Absence of toxic products of decomposition or combustion for environmental safety in the event of a fire.
- Biodegradable or innocuous when released to the environment.
- Persistence, chronic toxicity and bioaccumulative properties of the chemical in people and the natural environment should be at a minimum.

- Acute toxicity and irritating characteristics to all biota must be at a very low level.
- Waste management aspects of spilled material and final disposal of the material should not create problems.
- Material should not be carcinogenic, teratogenic or mutagenic.
- By-products of combustion or biological degradation should not create secondary concerns along the lines developed above.

Economic Requirements

- Easily manufactured and readily available at a reasonable cost.
- Secure supply for many years.

The following sections relate the properties of specific substitute fluids to these criteria. These substitutes include silicones, aliphatic hydrocarbons, tetrachloroethylene, chlorobenzenes and a pentaerythritol ester blend. Table 1, found at the end of this section (p. 12), compares the relevant physical and chemical properties of these substitutes.

2.2 Silicones

2.2.1 General. Silicones are high-volume industrial chemicals that have found broad usage - antifoams, paper and textile coatings, brake fluids, heat transfer fluids, cosmetic and personal care products, etc. Silicones, such as polydimethylsiloxanes $(CH_3)_3SiO$ $(CH_3)_2SiO$ $_nSi(CH_3)_3$, have been considered as an alternative to askarel because of their fire-resistant and heat transfer properties. Two such fluids are offered as transformer fluids:

- Dow Corning* 561
  Dow Corning Canada Inc.
  6747 Campobello Road
  Mississauga, Ontario
  L5N 2M1

  General Electric SF97 (50)
  Canadian General Electric Company Limited
  720 Caledonia Road
  Toronto, Ontario
  M6B 3X7

Silicone fluid viscosity can be tailor-made for whatever viscosity is required. The dielectric strength is comparable to that offered by askarels. Their low volatility and resistance to thermal oxidation provide good dielectric strength for extended periods of time at high temperatures.

During arcing conditions, bridging of silica occurs between the electrodes. If a fire results, it will produce CH_4, CO_2, silica and water.

Silicone fluids are compatible with most common materials of construction used in electrical apparatus. These fluids may cause stress cracking with certain plastics and rubber-like products.

2.2.3 **Fire and Environmental Considerations.** These fluids can be burned but will self-extinguish when the source of ignition is removed. When involved in a fire, methane, carbon dioxide, silica and water are formed. A potential hazard of inhalation of finely divided silica warrants use of personal breathing protection during fighting of fires involving silicone.

Silicone may cause slight temporary irritation to the eyes and mucous membranes but will not be absorbed through the skin. The silicone fluids have been found to be biologically inert; therefore, accumulation in the environment may pose a problem.

When in contact with soil, silicones will decompose by nonbiological processes (clay, catalyzed hydrolysis). The volatile products (cyclic siloxanes) will enter the atmosphere where, under the influence of moisture, oxygen and ultraviolet light, they will begin to degrade to SiO_2, H_2O and CO_2. The appearance of cyclic siloxanes is a potential problem because they are absorbed by humans.

Disposal of waste silicone is best accomplished by mixing the fluid with scrap solvent and then incinerating it. Precipitators should be present to remove particulate SiO_2. Spills on water can be contained by booms or dykes, concentrated by a surface-active chemical agent and removed with vacuum systems. Dry cement powder and baked diatomaceous earth are examples of absorbent materials which are used on land spills. Spent absorbent can then be disposed of in the manner described previously.

2.3 Aliphatic Hydrocarbons

2.3.1 **General.** These fluids are made up of high-molecular-weight branched-chain aliphatic molecules. They are either extracted from natural sources or are produced synthetically. Synthetic aliphatic hydrocarbons (poly-α-olefins) are blends of synthetic polymeric hydrocarbons while the natural aliphatic hydrocarbon is made with highly refined petroleum oil with a high paraffin content. These two fluids have similar chemical compositions, and their characteristics, as an alternative to askarel, are similar to one another. Only the term "aliphatic hydrocarbons" will be used throughout the following.

The following companies offer aliphatic hydrocarbons as a transformer filling fluid:

- RTEmp Fluid (Natural)
  RTE Corporation
  1900 East North Street
  Waukesha, Wisconsin
  USA 53186

- Gulf FR (Synthetic)
  Gulf Oil Chemicals Company
  Olefins and Derivatives Division
  P.O. Box 3766
  Houston, Texas
  USA 77253

- Mepsol (Synthetic and Natural)
  McGraw-Edison Company
  Thomas A. Edison Technical Center
  11131 Adams Road
  P.O. Box 100
  Franksville, Wisconsin
  USA 53126

RTEmp fluid and Gulf FR have been used extensively as a replacement fluid in transformers. Mepsol is a new product which, to date, has had limited consumer use.

These fluids possess low flammability, low specific gravity and high viscosity properties. Additive packages give the fluid blends improved oxidation stability and enhance other physical and chemical properties of the fluid.

2.3.2 Functional Considerations. Aliphatic hydrocarbons are up to 10-20 times more viscous than askarel or typical transformer oils. Some manufacturers claim this to be an advantage since, with a <u>properly designed transformer</u> under overload conditions (high temperature), the aliphatic hydrocarbons can still become less viscous with increasing temperature in a range that is most critical for heat dissipation. It is claimed that with viscosities below 5×10^{-6} m^2/s there is little to be gained for heat dissipation by further decrease in the viscosity. Askarel reaches this point at 50°C; RTEmp typically reaches this viscosity only at temperatures above 155°C.

The dielectric strength and thermal coefficient of expansion are comparable to that offered by askarels. Advantageously, these fluids do not suffer the loss of dielectric strength at temperatures below 0°C that is associated with cold start failure.

The poly-α-olefins exhibit a lower pour point than askarels, which makes their use more versatile at lower temperatures. In spite of the fact that RTEmp fluid clouds over a broad temperature range, starting at -10°C, it does not exhibit dielectric discontinuity often associated with this clouding phenomenon. During arcing conditions, small amounts of carbon and acetylene are produced but are not considered a serious problem. If poly-α-olefins reach a decomposition stage, hydrogen, methane and carbon monoxide may be released.

Aliphatic hydrocarbons may be used for retrofilling purposes. The liquids are miscible with askarels or other transformer fluids and compatible with most seals and materials used in electrical equipment construction. RTEmp fluid may be used as a make-up fluid for Askarel Transformers for up to 40 per cent by volume. This 40 percent constraint has been set to avoid the point at which the density versus temperature curve of the blended fluid might cross the ice-water density versus temperature curve.

2.3.3 **Fire and Environmental Considerations.** Aliphatic hydrocarbons have met the Factory Mutual requirements and are considered as low flammability fluids. If the liquids become involved in a fire, aliphatic fragments, carbon dioxide and carbon monoxide may be formed.

In the occupational environment, the care and handling precautions taken for conventional transformer oil should be exercised to control exposure to aliphatic hydrocarbons. These liquids may exert slight irritation to the eyes, skin and mucous membranes. Maximum exposure levels in the workplace have been recommended - TLV® 5 mg/m^3 for oil mists.

Spills of these liquids should be contained, absorbed with clay, sawdust or other industrial sorbents, and scooped into steel drums with covers for recovery or disposal. Disposal of waste aliphatic hydrocarbons can be accomplished by incineration under controlled conditions.

2.4 Tetrachloroethylene

2.4.1 **General.** Tetrachloroethylene, C_2Cl_4, is a high volume industrial chemical that is used extensively in the dry cleaning industry. Tetrachloroethylene has been considered as an alternative to askarel because it is considered nonflammable and has an advantageously low viscosity. Two companies offer tetrachloroethylene as a transformer fluid:

- WECOSOL™
  Westinghouse Electric Corporation
  Small Power Transformer Division
  South Boston, Virginia
  USA 24592

- Perclene TG®
  Diamond Shamrock Corporation, 1981
  Electro Chemicals Division
  351 Phelps Court
  Irving, Texas
  USA 75061

These products are supplied as highly purified liquids so that the chemical properties are those of tetrachlorethylene. The Westinghouse fluid, WECOSOL™, is supplied with an additive package at low concentration and an irridescent dye that acts as a leak detector.

2.4.2 Functional Considerations. Tetrachloroethylene is an order of magnitude less viscous than typical transformer oils. This improves heat rejection characteristics. The high density also contributes to thermal benefits of the fluid although the specific heat is lower than askarel and most other fluids.

The dielectric strength is comparable to that of askarels. The results of the electric arcing tests showed no explosive gas formation although small amounts of Cl_2 and HCl are routinely detected along with CO_2 and CO.

Since tetrachloroethylene is a small molecule, there are no problems with sludging.

Both manufacturers warn of compatibility problems. Retrofilling with tetrachloroethylene is not recommended because of gasket compatibility problems encountered with askarel. Immiscibility of tetrachloroethylene with askarel, silicones and other fluids also suggests that it not be used in conjunction with these materials.

2.4.3 Fire and Environmental Considerations. Both Underwriters' Laboratories and Factory Mutual consider this fluid nonflammable although the latter does not approve of it specifically for transformer application. It can be expected that tetrachlorethylene could become involved in a general fire in which case the formation of hydrogen chloride and phosgene (toxic gas) should be considered likely.

Tetrachloroethylene is on the Environmental Contaminants Act 1982 List of Priority Chemicals. In the occupational environment moderate care has to be exercised to control exposure. Tetrachloroethylene irritates the mucous membranes and has anesthetic effects. Maximum exposure levels in the workplace have been recommended - TLV® 100 ppm and STEL 150 ppm. Care should be exercised in the design and operation of transformers to minimize vapour release particularly because tetrachloroethylene boils below the 150°C operating target set for transformers.

Tetrachloroethylene released to the environment will evaporate quickly from water or soil. Degradation through oxidation in the lower atmosphere is fairly rapid, with only 2-3 percent reaching the stratosphere where ozone destruction could be a problem. Disposal of waste tetrachloroethylene by incineration or the equivalent to completely degrade the low-molecular-weight chlorinated hydrocarbons to inorganic chloride is the safest way to minimize adverse environmental impacts. Spill cleanup with standard industrial absorbents is recommended. Spent absorbent should be allowed to "dry", releasing the tetrachloroethylene to the atmosphere rather than disposing of it in a landfill. Incineration or the equivalent would also be highly acceptable.

2.5 Chlorinated Benzene Blends

2.5.1 General. Chlorinated benzene blends are mixtures of isomers of tri- and tetrachlorobenzenes (TTCBs) that are widely used with PCBs in transformers. The chlorinated benzenes were added for viscosity and pour point control. TTCBs have been used as a topping fluid for Askarel Transformers due to their similar properties and compatability with askarels. Two companies offer chlorinated benzene blends as a transformer fluid:

- Tri-Tetrachlorobenzene Blend
  May and Baker Canada Inc.
  Chemicals Department
  6557 Mississauga Road
  Mississauga, Ontario
  L5N 1A6

- Dielectrol I®
  General Electric Company
  One River Road
  Schenectady, New York
  USA 12345

2.5.2 Functional Considerations. TTCBs are an order of magnitude less viscous than typical transformer oils. This improves heat rejection characteristics. The high density also contributes to thermal benefits of the fluid.

The dielectric strength is comparable to that of askarels. The results of electric arcing of the fluid showed no explosive gas formation, although Cl_2 and HCl have been detected. TTCBs have been used as dilutants blended with transformer askarels due to their miscibility and similar properties. Chlorinated benzenes are powerful solvents and often are not compatible with many gasket materials normally used in electrical equipment.

2.5.3 Fire and Environment Considerations. Although TTCBs are considered non-flammable, they will burn at high temperatures yielding hydrogen chloride as one of the products.

In the occupational environment, moderate care has to be exercised to control exposures. Dielectrol 1, which incorporates TTCBs, is a moderate irritant to eyes, skin and mucous membranes. The maximum exposure level in the workplace has been recommended at 300 mg/m^3 (TLV®).

Chlorobenzenes are on the Environment Canada List of Priority Chemicals awaiting further study and evaluation for possible restrictive regulation. Although they exhibit only moderate acute toxicity, they are persistent in the environment and, with a bioaccumulation factor of about 1000, represent a concern for food chain biomagnification. More detailed information about the environmental and toxicological effects of TTCB blends will be required before they can be considered as acceptable substitutes for PCBs in transformers.

Spill cleanup with standard industrial absorbents is recommended. Spent absorbent may then be reclaimed or disposed of. The liquid could also be absorbed on clay or sawdust and scooped into steel drums with covers.

Incineration is not recommended unless a very high temperature facility with absorption of the effluent gas is available.

2.6 Pentaerythritol Ester Blends

2.6.1 General. Blends of esters of pentaerythritol and fatty acids have been offered as a substitute for askarels. These esters have been considered as an alternative to askarels because of their low flammability and high performance characteristics. The following companies offer Midel 7131, a pentaerythritol ester blend, as a transformer fluid:

- Micanite & Insultators Co. Limited (U.K.)
  Westinghouse Road
  Trafford Park, Manchester
  England M17 1PR

- The D & D Group
  P.O. Box 372
  Smithville, Ontario
  L0R 2A0

2.6.2 Functional Considerations. Midel 7131 is four times more viscous than typical transformer oil. The pour point of the ester is lower than that of askarels, which makes its use more versatile at lower temperatures.

The dielectric strength, thermal conductivity and coefficient of expansion are comparable to that offered by typical transformer oils. No toxic substances or gases are generated during arcing conditions. The ester is compatible with the wide range of materials used in transformers. Due to its compatibility, retrofilling and make-up with Midel does not pose a problem.

2.6.3 **Fire and Environmental Considerations.** This fluid meets the low flammability requirements which permit its use as a substitute fluid in transformers. Recommended handling precautions for petroleum-based fluids should be exercised when handling Midel.

TABLE 1 PHYSICOCHEMICAL AND ENVIRONMENTAL DATA FOR PCB SUBSTITUTES

	Silicones		Aliphatic Hydrocarbons		
	Dow Corning 561	GE SF97(50)	RTEmp	Gulf FR	Mepsol
Molecular Weight	high	high	high	high	high
Boiling Point (°C)	-	-	>430	-	-
Freezing Point (°C)	-55	-	-79**	-80**	-
Specific Gravity @ (°C)	0.96@25	0.96@25	0.877@25	0.861@16	0.872@25
Vapour Density	-	-	-	-	-
Vapour Pressure kPa @ (°C)	-	-	$<1.3\times10^{-3}$	-	-
Solubility (g/L) - in H_2O	-	-	Negligible	-	-
- H_2O in	0.05	0.21	0.035(max)	-	0.009
Interfacial Tension (mN/m)	50.0[1]	45.0[2]	38.0	-	-
Dielectric Constant @ 25°C	2.65	2.7	2.4	2.3	2.2
Dielectric Strength (kV)	35	35	43	44	37
Power Factor @ 25°C (%)	<0.0001	<0.0001	<0.001	0.003	-
Viscosity (m^2/s) @ (°C)	50×10^{-6}@25	50×10^{-6}@25	350×10^{-6}@25	113×10^{-6}@38	410×10^{-6}@2
@ (°C)	16×10^{-6}@100	16×10^{-6}@100	85×10^{-6}@50	12×10^{-6}@99	226×10^{-6}@4
@ (°C)	-	-	16×10^{-6}@100	-	-
Pour Point (°C)	-55	-55	-30	-48	-30
Specific Heat (J/(kg·K)	1530	1530	1925[1]	-	2700[2]
Thermal Coeff. of Expansion ($°C^{-1}$)	9.3×10^{-4}	10.55×10^{-4}	7.5×10^{-4}	-	6.9×10^{-4}
Relative Thermal Conductivity(W/(m·K))	0.15	0.16	0.13[1]	-	0.15[2]
Specific Resistance(Ω·m) @ (°C)	2.3×10^{13} @25[1]	3.8×10^{13} @25[2]	8×10^{10} @25	-	2×10^{12} @23
@ (°C)	9.3×10^{12} @100[1]	4.6×10^{12} @150[2]	-	-	-
Flammability	low	low	low	low	low
Flash Point (°C)	300	300	285	265	278
Fire Point (°C)	350	320	312	310	312
Heat Release Rates (kW/m^2)					
- Convective	53	66	546	364	542
- Radiative	25	20	361	414	411
TLV*† (mg/m^3)	-	-	5 (mist)	5 (mist)	-
STEL†† (ppm)	-	-	-		
Bioaccumulation	none	none	-	-	-
Degradation	non-biodegradable	non-biodegradable	-	-	-
Evaporation from water(half-life)(min)	-	-	-	-	-
Hydrolysis	-	-	-	-	-

* Single column data properties of tetrachloroethylene

** Glass transition

† Threshold Limit Value

†† Short-term Exposure Limit (15 min)

††† Time-weighted Average, 8 h/d, 40-h work week

trachloroethylene		Chlorinated Benzenes		Pentaerythritol Ester Blend	Comment
scosol TM*	Perclene TG**	TTCB Blend	Dielectral 1*	Model 7131	
165.85		-	-	614	
121		210	>204	>400	
-22.4		-	-	-60	
1.62@( )		139@( )	1.37@( )	0.98@15.6	
5.83		-	6	-	
2.65@26.3		-	<0.13	1.3x10^{-8}@( )	
0.15		slight	<1%	0@20°C	
0.11		-	-	0.08	
3.23		37.5	-	-	[1,2] ASTMD-971
:	2.4	5.9	5.9	3.2	ASTMD-924
	40	32	32	60[1]	ASTMD-877;[1] BS148
1	0.3	>0.2	-	<0.001[1]	ASTMD-924 except[1]
5x10^{-6}@25[1]	0.52x10^{-6}@25	1.49x10^{-6}@25	3.45x10^{-6}@25	100x10^{-6}@20	ASTMD-88;[1] ASTMD-80
6x10^{-6}@50	-	0.96x10^{-6}@50[1]	0.82x10^{-6}@100[2]	6x10^{-6}@100	[1,2] ASTMD-80
4x10^{-6}@100	-	0.71x10^{-6}@100	-	-	
	-22	-15(-30 max)	-15(-30 max)	-50	ASTMD-97
0[2]	880	1390	1170	2100	[1,2] ASTMD-2266;[3] ASTMD-276
2x10^{-4}[1]	10.2x10^{-4}	8x10^{-4}	8x10^{-4}	7.5x10^{-4}	ASTMD-1903 except[1]
3[3]	0.13	0.07	-	0.155	[1,2] ASTMD-2713;[3] ASTMD-271
	1.8x10^{11}	1.1x10^{8}	>1x10^{10}	20x10^{12}	[1,2] ASTMD-1169
	.	-	-		[1,2] ASTMD-1169
non-flam[1]		non-flam	non-flam	low[2]	[1,2] Underwriters' Lab.
none		none	none	>257[1]	ASTMD-92;[1] IP 36/63
none		none	none	>310[1]	ASTMD 92;[1] IP 36/63
538[1]		370	370	377	Factory Mutual except[1]
411[2]		238	238	116	Factory Mutual except[1]
100 (ppm)TWA+++[1]		-	300	0	[1] OSHA
150 (15min)			-	-	
-			-	-	
-		-	-	-	
20-27		-	-	-	
none @150°C		-	-	-	

3 IMPACT OF PCB REGULATIONS

3.1 Existing Transformer Installations

PCBs were banned as constituents of transformers manufactured in or imported into Canada after 1 July 1980, when the Amendment to Chlorobiphenyl Regulation No. 1 came into effect. The use of Askarel Transformers manufactured or imported before 1 July 1980 is still permitted; none of the other Chlorobiphenyl Regulations in preparation at the present time would prohibit the continued use of these transformers.

Handling of PCBs as part of normal maintenance and/or repair of Askarel Transformers is permitted but adding new PCB-containing liquids is banned. Therefore, any transformer fluid losses must be made up by non-PCB fluids which are compatible with askarel.

The most obvious choice for a make-up fluid is TTCBs which are already a component part of all transformer askarels. The content of TTCBs in different brands of askarel varies but generally does not exceed 40 percent.

Since the pour point of pure TTCBs is much higher than that of most askarels, there was a concern that the dilution of askarels with TTCBs may be harmful to lightly loaded or de-energized transformers at low ambient temperatures.

Tests performed by M.M. Dillon Limited in March 1979 demonstrated that up to one-third of pure TTCBs can be added safely to transformer askarels which already contain as much as 40 percent of TTCBs in the initial formulation.

The information obtained from three major transformer service companies and confirmed by a large number of transformer users indicates that transformer fluid make-up requirements are far below the safe limits recommended for TTCB make-up. Based on our contacts with a large segment of transformer manufacturers and users, we have formed an opinion that no hardship exists due to the ban on the use of PCBs for the transformer make-up fluid.

Although the most widely used make-up fluid is TTCBs, other fluids such as RTEmp or Mdel 7131 appear to be satisfactory for this purpose. Both liquids have been used for topping up of Askarel Transformers with good results.

3.2 New Transformer Installations

The ban on Askarel Transformers created the problem of finding a suitable substitute for those new transformer applications where a fire-resistant installation is essential.

3.2.1 **Dry-type Transformers.** For some applications, the use of air-cooled dry-type transformers, in lieu of Askarel Transformers, is the most suitable solution. Dry-type transformers can be divided into three general categories, with respect to their construction:

- open ventilated
- epoxy encapsulated, and
- cast coil.

Dry-type transformers are limited in their application with respect to voltage class and capacity.

They are most economical to use as open-case ventilated-type in clean, dry locations when the primary voltage does not exceed 15 kV and the load does not exceed 600 kVA.

They tend to be noisy and have relatively low overload capability and poor basic impulse level. Also, they are physically larger than an equivalent liquid-filled transformer.

Epoxy-sealed and cast coil transformers are not as noisy as the open-case ventilated transformers and are not subject to the same restrictions with respect to ambient conditions. However, they are generally more costly than an equivalent liquid-filled transformer. The cost comparison would depend on the specific voltage and kVA ratings as well as the type of liquid used.

Since dry-type transformers are physically larger than liquid-filled transformers of the same capacity and voltage class, it is more difficult or even impossible, at some locations, to replace an Askarel Transformer with an equivalent dry-type unit, because of space limitations.

3.2.2 **Liquid-filled Transformers.** The criteria for selecting liquid-filled transformers can be grouped into four categories:

I <u>Safety Considerations</u>
Low fire and explosion hazard.

II <u>Functional Requirements</u>
Satisfactory performance under all foreseeable operating conditions such as load fluctuations, and lightning and switching surges.

III Environmental Considerations

Transformer fluid to be non-toxic, non-mutagenic and biodegradable or innocuous if released to the environment. The transformer fluid must be easily disposable with no cause for present or future ecological concerns.

IV Economic Considerations

Reasonable cost of manufacture and low operating costs, i.e., high efficiency under load, low no-load losses and easy maintenance.

Askarel transformers satisfy all safety, functional and economic considerations but fail to meet the environmental requirements.

Transformers filled with mineral oil satisfy all functional, environmental and economic considerations, but fail to meet the safety requirements.

Therefore, there is a need for safe and reliable transformer fluids that would satisfy all four groups of transformer fluid selection criteria.

Table 12 presents a comparative assessment of the five types of fluids that are described in Section 2 of this report:

- Silicones
- Aliphatic Hydrocarbons
- Tetrachloroethylene
- Chlorinated Benzene Blends
- Pentaerythritol Ester Blend

These five types of fire-resistant fluids are all acceptable for indoor use. Askarel is not acceptable for environmental reasons and mineral oil is not acceptable for indoor use unless installed in a fire-proof vault. It must be noted that mineral oil transformers are still very satisfactory and the most economical choice for outdoor installations.

Tetrachloroethylene and TTCB blends are nonflammable and therefore get the highest rating with respect to safety.

Silicones, aliphatic hydrocarbons and blends of pentaerythritol ester are listed by Factory Mutual Research as "Less Flammable Transformer Fluids". The heat release rates, both convective and radiative, published by Factory Mutual Research are significantly lower for silicones than for aliphatic hydrocarbons and pentaerythritol ester blend. Therefore, under the safety criteria in Table 12, silicones are classified as "satisfactory" and the other two types as "acceptable". The heat release rates of the pentaerythritol ester blend are lower than those of aliphatic hydrocarbons, but not nearly as low as those of silicones.

All fluids listed in Table 12 are very satisfactory as far as the functional performance is concerned, when used in a new transformer designed for that specific type of fluid.

Environmentally, there is some concern regarding TTCB blends, and to a lesser degree, tetrachloroethylene. Both fluids are presently approved for uses other than in transformers. Additional studies are needed to further evaluate the environmental risk posed by these two types of fluids.

All fire-resistant transformer fluids are more expensive than mineral oil.

TABLE 2 COMPARATIVE SUMMARY OF TRANSFORMER FLUIDS

	Selection Criteria			
Type of Fluid	Safety	Functional	Environmental	Economic
Silicones	3	4	4	2
Aliphatic Hydrocarbons	2	4	4	3
Tetrachloroethylene	4	4	3	3
Chlorinated Benzene Blends	4	4	2	3
Pentaerythritol Ester Blends	2	4	4	2
Askarel	4	4	1	3*
Mineral Oil	1**	4	4	4

Ratings***

4 - very satisfactory

3 - satisfactory

2 - acceptable

1 - unsatisfactory

* Askarel no longer available.

** When used indoors, without fire-proof vault.

*** Based on judgement of contractor.

4 TRANSFORMER RETROFILLING

Replacement of askarel in a transformer with another fluid, known as transformer retrofilling, has been practiced in the United States since about 1975, a few years after Monsanto discontinued production of askarel. The present level of retrofilling activity in the USA is reported to be in the range of 600 to 800 units per year.

The fluids most frequently used for retrofilling are:

- Mineral Oil (for outdoor or fire-proof vault installations).
- Silicones
- RTEmp
- Midel 7131, recently introduced from the U.K.

Generally, the performance of the retrofilled units has been satisfactory. There is no evidence indicating that the replacement of askarel with another fluid has been directly responsible for a transformer failure. In some cases, it was necessary to derate the transformer capacity by 10-20 percent because of the differences in the viscosity and specific heat between askarel and the replacement fluid.

In spite of the success, the retrofilling activity in the USA has decreased considerably from the peak of activity in 1979. Some of the reasons given for the decrease are:

- bad publicity resulting from accidental PCB spills during retrofilling operations.
- restrictions placed by Factory Mutual Research on the use of retrofilled transformers. Some replacement fluids are not considered equal to askarel with respect to fire hazard.

In Canada, retrofilling has never caught on. A few Askarel Transformers were retrofilled with silicone and one or two with mineral oil during the 1976-1981 period. One Askarel Transformer, at a municipal waterworks plant, was retrofilled with Midel 7131 in April 1982 as an experimental demonstration.

In many cases, it is impractical and environmentally undesirable to retrofill Askarel Transformers as long as there are no PCB disposal facilities readily available. Storage of askarel and PCB-containing flushing fluids generated by retrofilling may present higher environmental and health hazards than the continued use of Askarel Transformers installed in guarded areas with access limited to authorized personnel.

In future, when PCB disposal facilities are available, retrofilling should be considered from some specific installations, as an option to replacement with a new non-PCB unit. Getting rid of askarel would be particularly desirable at such locations as food processing plants and proximity to water bodies, where even a small probability of PCB spill due to a transformer failure is considered to be an unacceptable risk. In some of these locations, replacement of the Askarel Transformer with a new non-PCB unit may be much more difficult and more costly than retrofilling.

When retrofilling is being considered, the following factors must be taken into account:

- The replacement fluid must be compatible with the materials of construction of the transformer being retrofilled.
- The coefficient of thermal expansion of the replacement fluid should be relatively close to that of askarel, to prevent exposure of transformer windings at low temperatures and excessive volume of transformer fluid at high temperatures.
- Heat transfer capability of the replacement fluid must be considered and the acceptability of transformer derating reviewed, if applicable.
- Impact of insurance requirements and all applicable rules and regulations of the local electrical inspection authorities must be checked with respect to the proposed replacement fluid.

5 COMMENTS AND RECOMMENDATIONS

5.1 Maintenance of Askarel Transformers

The ban on the use of PCBs for make-up filling of Askarel Transformers does not seem to create any significant problems for the transformer users. The amounts of make-up fluid required are very small. Most Askarel Transformers do not require any make-up fluid for many years of service. When make-up fluid is required, tri-and tetrachlorobenzenes (TTCBs) appear to be the most suitable and most readily available fluids. TTCBs are fully compatible with askarel, since it is one of the components of askarel. Other fluids successfully used for make-up filling of Askarel Transformers are Midel 7131 and RTEmp.

5.2 Replacement for Askarel Transformers

There is no single "best" solution for the replacement of any Askarel Transformer regardless of the type of duty, ambient conditions and location.

For outdoor use and for underground vaults, mineral oil transformers appear to be the best solution.

For indoor applications, constructing a fire-proof vault in an existing building would, in most cases, be either impractical or prohibitive in cost. Generally, therefore, the replacement of Askarel Transformers in existing buildings would be by other than equipment containing mineral oil. The choice of the right transformer for the right place involves consideration of many factors in addition to cost.

If a dry-type transformer is considered, such factors as noise level, clean air requirements, moisture levels, load fluctuations, lightning protection and physical space available must be taken into account.

If a fire-resistant liquid-filled transformer is considered, the most important factors are:

- heat release ratings (both convective and radiative) of the transformer fluid;
- insurance requirements, related to building construction of adjacent walls and ceiling, and curbs to retain leaks of transformer fluids;
- operating conditions and maintenance requirements.

5.3 New Transformer Installations

Selection of the most suitable transformer for a new installation is much easier than the selection of a replacement transformer. There are usually fewer constraints and therefore more than one acceptable solution. The decision would be based on the selection criteria discussed in Section 3 of this report.

Where fire and explosion safety is the most important consideration, e.g., in case of underground substations in mines, a transformer filled with a nonflammable fluid such as tetrachloroethylene would be the best choice.

In other applications, environmental considerations may dictate the use of transformers filled with one of the fluids classified by Factory Mutual as "less flammable fluid" such as silicones or pentaerythritol ester blend.

Further research and development of better transformer fluids are still in progress and the most ideal replacement fluid for askarel may be yet to come.

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