

## LARGE POWER TRANSFORMERS FOR ALTERNATIVE INSULATING FLUIDS

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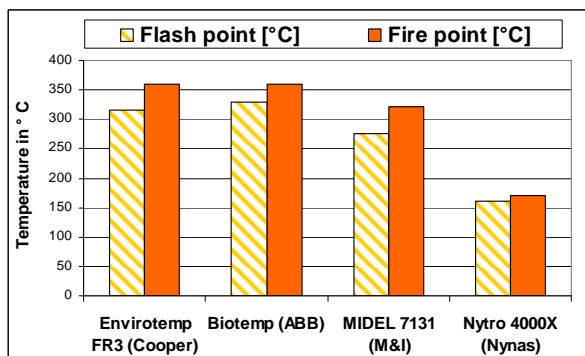
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**Abstract:** In times when personal safety and environmental protection become more and more important, the usage of alternative insulation fluids is demanded in large power transformers. The reduction of pollution risks and fire loads are significant goals for new transformers. Due to their biodegradability and high flash point properties, ester fluids are becoming potential substitutes for mineral oil. Alternative insulation liquids are produced by several companies, and they are frequently used in distribution transformers. To operate power transformers successfully with these alternative insulation liquids a number of issues must be resolved through extensive investigations. Stability of transformer materials and other critical properties have been studied. This paper shows how the alternative insulation liquids can be compared with conventional mineral oil and to each other.

### 1. INTRODUCTION

Over the last 15 years the transmission situation and the demanded performance of transmission equipment – such as transformers and their insulation systems – have changed dramatically [1]. Areas of high population density become more and more overcrowded and the energy consumption in such areas necessitates non-hazardous distribution networks and power transformers. When large power transformers, of several hundred MVA, are to be built into residential tower blocks, terms like fire point and environmental effects become more and more important.

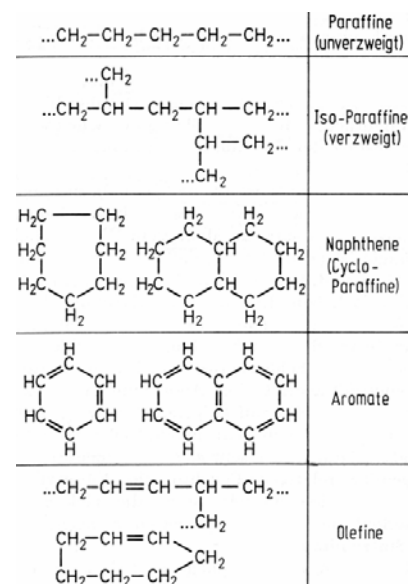


**Figure 1:** Flash and fire points of insulating fluids based on mineral, synthetic and natural ester [2-6]

Mineral oil is made of fossil oil and consists of hydrocarbon compounds with different bonds. There is a difference between paraffinic, naphthenic and aromatic oils (see Figure 2). In varying ratios these components are contained in all mineral oil [7]. Transformer oil has poor biodegradability characteristics and the lower fire point (figure 1).

Silicon fluids specially developed for transformer applications have a high fire point but very limited biodegradability characteristics too. Very poor

lubrication properties and forming jelly-like bridges of silicon-oxide under arcing are further disadvantages.



**Figure 2:** Hydrocarbon compounds in mineral oil [8]

Now, after a service life of 40 to 60 years many transformers will have to be replaced in the next five to ten years. After a century of using conventional transformer oil with very limited biodegradability characteristics, there is a need for further improvement.

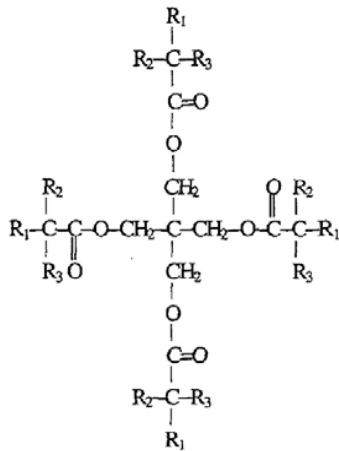
The following types of oils are available and some of the alternative fluids are already in common use at voltage levels up to 40 kV.

## 2. ESTER INSULATING LIQUIDS

### 2.1. Synthetic esters

Synthetic esters are made of acid and alcohol. The products differ in their base materials, so the characteristics of the insulation fluids can be modified. Carbon acid esters (Figure 3) such as Pentaerythrite-

tetra fatty acid ester are used in transformers. They meet the requirements of DIN VDE 0375 and the classification criteria as “not water hazardous” [3, 4].



**Figure 3:** Structure formula of a synthetic ester [9]

The viscosity of synthetic ester fluids is twice as high as the viscosity of mineral oil. Their flash and fire points are higher than that of mineral oil [2-4].

**2.2. Natural ester**

Natural ester fluids are categorized as follows, saturated and single-, double and triple unsaturated fatty acids. Saturated fatty acids are chemically stable but of high viscosity. Triple unsaturated fatty acids have a lower viscosity but they are very unstable in oxidation. To stabilize the ester, it is necessary to add suitable antioxidants. In addition to DBPC, specific antioxidant packages that use complex phenols and amines are used. The addition of antioxidants is limited to below 1% due to its influence on the conductivity level which rises to unacceptable values. Fluids with a high percentage of single unsaturated fatty acids have proven to be suitable. Table 1 shows the composition of various vegetable oils [10, 11]. They are highly biodegradable.

**Table 1:** Typical fatty acid composition of some vegetable oils [10]

Vegetable Oil	Unsaturated Fatty Acids in %			Saturated Fatty Acids in %
	Mono-	Di-	Tri-	
Sunflower oil, high oleic	80.8	8.4	0.2	9.2
Safflower oil, high oleic	75.3	14.2	-	6.1
Olive oil	73.3	7.9	0.6	13.2
Canola oil*	55.9	22.1	11.1	7.9
Corn oil	24.2	58.0	0.7	12.7
Soybean oil	22.5	51.0	6.8	14.2
Sunflower oil	19.6	65.7	-	10.5
Cottonseed oil	17.8	51.8	0.2	25.8
Peanut oil	17.8	51.8	0.2	13.6
Safflower oil	12.1	74.1	0.4	8.5

\*Low erucic acid variety of rapeseed oil; more recently canola oil containing over 75% monounsaturate content has been developed.

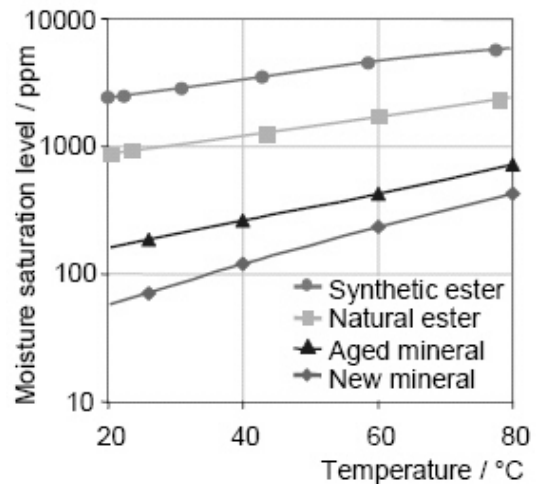
Viscosity of natural esters is about four times higher than the viscosity of mineral oil at room temperature. Their flash and fire points are significantly higher compared to mineral oil [2, 5, 6].

**3. COMPARISON OF ESSENTIAL PROPERTIES**

The basic purpose of transformer oil is insulation and cooling. Liquids of non-polar and stable chemicals are suitable. Furthermore, there are other important characteristics such as resistance to temperature, discharge, flashover and breakdown as well as good compatibility with the other materials in the transformer. Resistance to oxidation and chemical reaction with cellulose in the presence of moisture and temperatures up to 100°C is a particularly essential feature for an enduring insulation system [12].

So the comparison among insulation fluids is not just the testing of the oil itself, but also an investigation of an oil-board system.

The different moisture behavior of the insulation liquids must also be considered for its interaction with the impregnated cellulose. Mineral oil can only absorb water in amounts of some 10's of ppm (at room temperature), natural and synthetic esters can bind water many times over that (Figure 4) [13].



**Figure 4:** Water saturation values of synthetic ester, natural esters, aged and new mineral oil [14]

According to IEC 60156 [15] the common oil breakdown tests only test the fluid. It is also critical to test the coactions of the insulating liquid with cellulose.

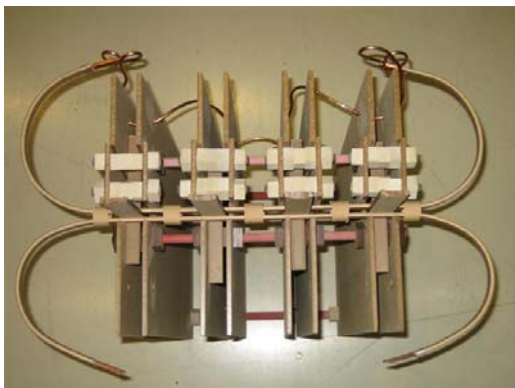
Various tests must be created to realistically represent the arrangement and the actual conditions in power transformers. Various arrangements as shown in Figure 5 to Figure 7 have been tried. They combine impregnated cellulose with free oil space and creepage paths. The electrode shapes and dimensions are similar to transformer components and impose electric field of moderate to considerable inhomogeneity.



**Figure 5:** Test arrangement for an oil/board insulation system with two bare electrodes, the upper electrode is on HV, the lower one is grounded

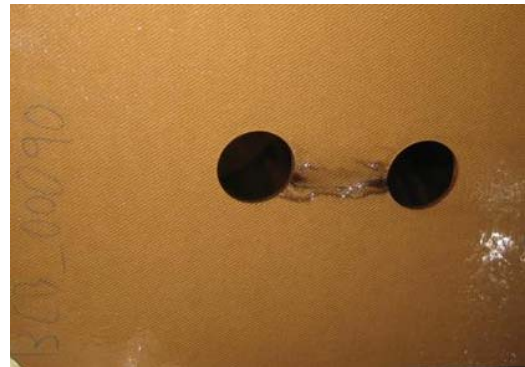


**Figure 6:** Test arrangement for an oil/board insulation system with two insulated electrodes, the upper electrode is on HV, the lower one is grounded



**Figure 7:** Test arrangement for an oil/board insulation system with two insulated electrodes, the lower electrode is on HV, the upper one is grounded

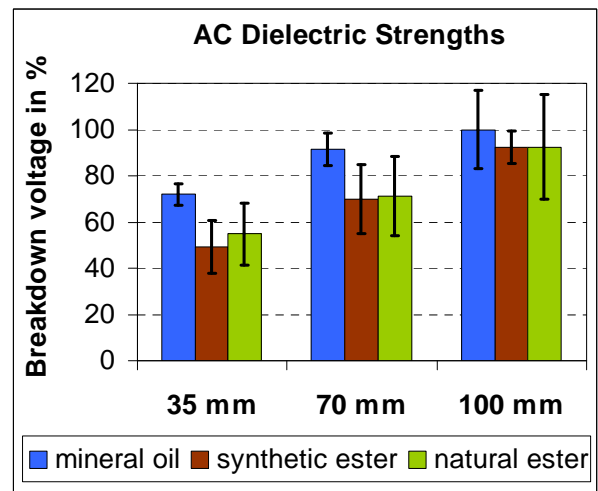
**4. DIELECTRIC TESTS AND PRELIMINARY RESULTS**



**Figure 8:** Creepage traces of the board insulation system with two bare electrodes.



**Figure 9:** Creepage across the spacer edge and punctures on the two paper-wrapped conductors.



**Figure 10:** Breakdown strength with AC 1-min steps, measured on arrangement Figure 5.

Figure 10 shows the dielectric strengths for AC stress. There is a significant difference between the breakdown voltage levels of mineral oil and the ester fluids. For distances 35 mm and 70 mm the dielectric strengths is higher and the standard deviation is lower for mineral oil. The differences become less for 100 mm samples.

The lightning impulse- and switching impulse dielectric strengths of the tested oil/board insulation system shows inconsistent behavior. Depending on the distance the mineral oil or ester impregnated arrangement performs better.

The comparison between different insulating liquids requires the collation of many different parameters. Special attention must be paid to the vastly different moisture capacities of oils and esters.

Investigations are in progress but many more measurements on representative setups have to be done.

We are working toward gathering the required data for practical applications. A large power transformer application can be envisaged, in the near future, after satisfactory clarification of the open issues.

## 5. CONCLUSION

- The AC dielectric strengths of the tested oil/board insulation system impregnated with ester are not as good as those impregnated with mineral oil. The variation using ester was higher than that of mineral oil in almost every case.
- The lightning impulse- and switching impulse dielectric strengths of the tested oil/board insulation system are inconsistent.
- Further analysis is required and new setups are necessary.

## 6. ACKNOWLEDGMENTS

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