Partial discharge behaviour of an alternative insulating liquid compared to mineral oil

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Abstract - In times when personal safety and the security of electrical power supply become more and more important, the usage of alternative insulation fluids is demanded in large power transformers. The minimizing of fire loads is another significant reason for new liquids. Different companies are offering such alternative insulation liquids which are already used in distribution transformers. On the other hand there is little experience with those fluids in large power transformers. For the confirmation of the usability of new insulating liquids comparison methods must be tested to find the differences between the alternative insulating fluids and commonly used mineral oil. There are different methods for characterising insulating materials, like AC-Breakdown tests, partial discharge tests, lightning and switching impulse voltage tests, etcetera. Partial discharge behaviour is a distinguishing characteristic of an insulating medium. This paper shows the partial discharge behaviour of alternative insulation liquids such as synthetic and natural esters, compared to commonly used mineral oil. To generate the PD patterns, voltages up to 30kV and inhomogeneous test arrangements were used. A model of an oil/board insulation system was created by using sheets of pressboard.

Keywords-component; Alternative liquids, ester, Transformer, Oil, Partial Discharge

I. INTRODUCTION

During the last 15 years the transmission situation and the demanded performance of the transmission equipment - like transformers and their insulation systems - changed severely [1]. Areas of high population density get more and more overcrowded and the power consumption in such areas is necessitating nonhazardous distribution networks and power transformers. When even large power transformers of several hundred MVA have to be integrated in inhabited tower blocks, especially issues like fire load and environmental effects become more and more important.

Now after a life period of 40 to 60 years many transformers must be replaced or respectively retrofilled in the next five to ten years. After a century of oil use, starting with vegetable oil via PCB's leading to conventional transformer oil, there is the question for a further improvement. The following are available on the market and some of the alternative fluids are already in common use in transformers and reactors at voltage levels up to several tens of kilovolt.

A. *Conventional Transformer Oil*

Mineral oil is made of fossil oil and consists of hydrocarbon compounds of different bonds. There is a difference between paraffinic, naphtenic and aromatic oils (see Fig. 1). In different ratios the components are contained in every oil [2].

naphtenic oil	C_P	42 – 50%
mix oil	C_P	50 – 56 %
paraffinic oil	C_P	56 – 65%
C_P	paraffin bond Carbon	

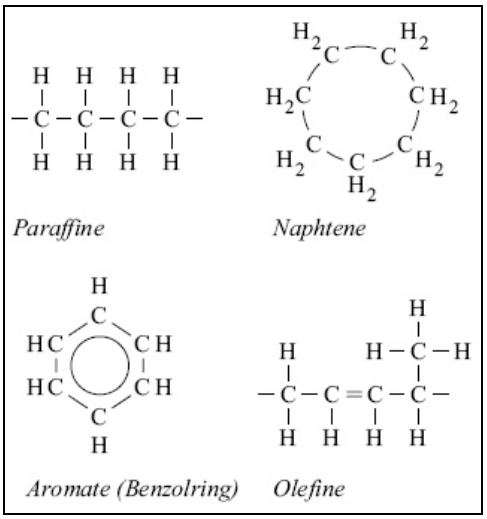

Figure 1. Hydrocarbon compounds in Mineral oil [3].

II. ALTERNATIVE INSULATION FLUIDS

A. *Natural Ester Fluids*

Natural ester fluids appear as 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 low viscosity but they are very unstable in

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oxidation. Fluids with a high percentage of single unsaturated fatty acids have proven as useful.

In Tab. 1 the composition of different vegetable oils is shown [4, 5]. The differing saturation levels of the fatty acid compounds with their different characteristics of the various vegetable oils leads necessarily to a choice between different properties for the insulation liquid. Soybean oil is already in common use.

Vegetable Oil	Saturated Fatty Acids, %	Unsaturated Fatty Acids, %		
		Mono-	Di-	Tri-
Canola oil*	7.9	55.9	22.1	11.1
Corn oil	12.7	24.2	58	0.7
Cottonseed oil	25.8	17.8	51.8	0.2
Peanut oil	13.6	17.8	51.8	0.2
Olive oil	13.2	73.3	7.9	0.6
Safflower oil	8.5	12.1	74.1	0.4
Safflower oil, high oleic	6.1	75.3	14.2	-
Soybean oil	14.2	22.5	51	6.8
Sunflower oil	10.5	19.6	65.7	-
Sunflower oil, high oleic	9.2	80.8	8.4	0.2
*Low erucic acid variety of rapeseed oil; more recently canola oil containing over 75% monounsaturate content has been developed.				

Tab. 1: Typical compositions of vegetable oils [4]

B. Synthetic Ester Fluids

Synthetic esters are made of an acid and an alcohol (Fig. 2). The products differ with their base materials, so the characteristics of the insulation fluids can be modified.

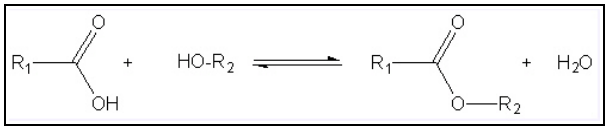

Figure 2. Example of ester synthesis: Synthesis of carbon acid ester: Left Side: acid and alcohol, react onto Ester and Water on the right side [4]

Carbon acid esters are used in transformers, as the Synthetic ester fluid MIDEL 7131 from the M&I company (Fig. 4) or Elantas BecFluid 9902 [6].

The viscosity of synthetic ester fluids is twice as high as the viscosity of mineral oil. Their flash and fire point is higher than the one of mineral oil [6].

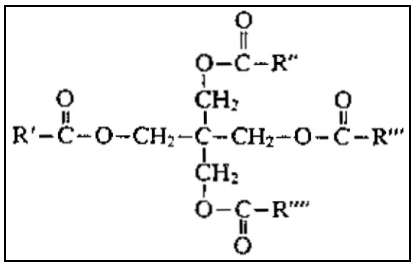

Figure 3. Structure Formula of the synthetic ester MIDEL 7131 [9]

Natural and synthetic Esters are hygroscopic and are able to absorb over 1000ppm of water at room temperature (Fig. 4) and their flash and fire point is about twice as high as the ones of mineral oil.

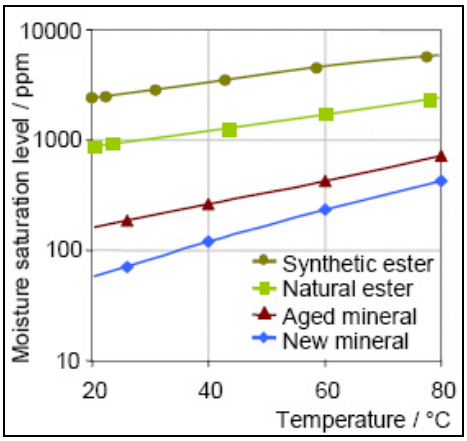

Figure 4. Water saturation values of different types of oils and different temperatures [11]

III. COMPARISON METHODS

The basic functions of transformer oil are insulation and cooling. Therefore liquids of non polar and stabile chemicals are qualified. Furthermore there are other important characteristics like durability, resistance against flashover damages and good compatibility with other materials in the transformer, especially the cellulose. Also the resistance against oxidation and chemical interaction with cellulose in the presence of moisture and temperatures up to 100°C are essential features for a durable insulation system [7]. It is a known fact, that alternative liquids like esters can extend the lifetime of cellulose by decreasing the value of depolimerisation.

The testing of insulation fluids is not just an investigation of the single oil but an investigation of at least an oil-board system. Also the different moisture behaviour of the insulation liquids must be considered. Mineral oil can only solve water in amounts of some 10ppm (at room temperature), natural and synthetic esters can chemically bind water many times over that (Fig. 4) [10].

Common breakdown tests like the IEC 60156 [8] are considered to test the fluid only without attending the coaction

of the insulation liquid and the cellulose. A possible arrangement is shown in Fig. 6. It combines the impregnated cellulose with free oil space in a highly inhomogeneous electric field.

IV. TEST SETUP

As test setup a standard partial discharge setup consisting of a transformer, HV-Divider-Capacitor, coupling capacitor, quadripole and the test vessel (Volume: 17 litres) was used (see fig. 5). The partial discharge signal was analyzed by an ICM System from Power diagnostix. The electrodes were arranged as needle and plate, with a distance of 10mm and 40mm. The Diameter of the plate was 150mm (Border radius 5mm) and there were used tips with a radius of 40µm. Between the electrodes a specimen of pressboard (3mm thick and 190mm in diameter) was placed (see fig.6). Three kinds of liquids were used: Mineral oil, natural Ester and synthetic ester. There were done four series of tests:

- Mineral oil Impregnation and vessel filling
- Synthetic ester Impregnation and vessel filling
- Natural Ester Impregnation and vessel filling
- Synthetic Ester Impregnation and Natural Ester vessel filling

Figure 5. Test arrangement for the partial discharge measurement

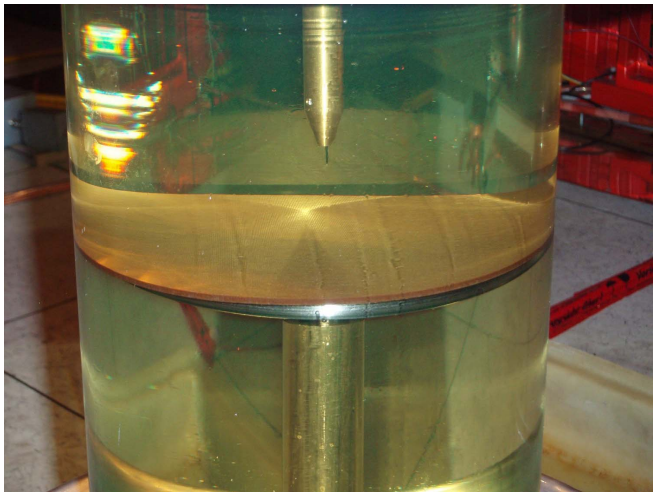

Figure 6. Close-up picture of the electrodes and the pressboard;

V. RESULTS

There is a significant low average PD level at both distances in mineral oil. The average PD in all ester liquids is higher than that. Especially the test series with synthetic ester impregnation and natural ester vessel filling produced the comparatively highest PD. It is also significant, that the PD value of the test series with the synthetic ester is higher then the values of mineral oil but on a lower level then the ones of the natural ester. The results of the partial discharge investigation are shown in figure 7. Both distances and all four test series can be found with their related partial discharge activity.

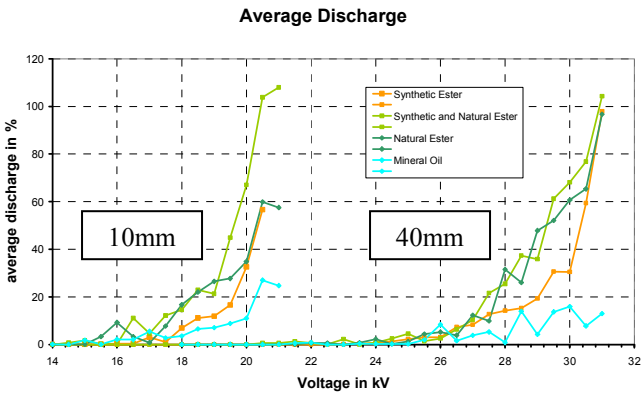

Figure 7. Diagram of the test results. LEFT side: distance 10mm,; RIGHT Side: distance 40mm;

VI. CONCLUSION

The comparison between different insulating liquids requires the collation of many different parameters. This investigation shows, that it must be taken more care of the partial discharge behaviour of used transformers with different types of insulation liquids. The different PD values of esters and mineral oils results on one hand in different values for the permittivity and on the other hand in difficult ways of moisture

exchange between the impregnated pressboard and the surrounding liquid.

The investigations regarding partial discharge measurement of pressboard impregnated with different insulating liquids showed that:

- There are significant differences regarding the average PD levels between the investigated liquids;
- Mineral oil has under highly inhomogeneous field stress the lowest PD levels compared to ester liquids;
- The specimen option with the synthetic ester pressboard impregnation and the natural ester vessel filling produced the highest PD values;

For the future there should be done further investigations with mineral oil-impregnated pressboard and ester-fillings.

ACKNOWLEDGMENT

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