INVESTIGATION ON NATURAL ESTER FLUIDS CONCERNING GASSING AND COMPATIBILITY WITH TRANSFORMER MATERIALS

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Abstract: The environmental and fire requirements on transformer fluids in sensitive applications like urban areas, traction etc. are high. Inflammability, no hazard to water, a ready biodegradation are the main targets, which gives priority to the usage of ester fluids instead of mineral oils. For the user, the maximum flexibility will be provided, if equipment can be filled with the insulating liquid of his own choice. For the transformer design it means automatically that some characteristics like viscosity and density should be similar to these of the mineral oil. A new natural-like ester, which owns similar characteristics like mineral oil, has been investigated in this work. The fact that the chemical structure of this fluid is different from that of other natural ester fluids, means a risk concerning its compatibility with the other materials which are used in transformers like copper enamel, insulation materials, gaskets and so on. In this work the oxidation stability and the influence of the natural ester liquid on different transformer materials was investigated in comparison to that of usual insulating liquids. Furthermore the gassing behaviour of the new ester fluid has been tested and evaluated. Recommendations for characteristics of the oxidation stability of natural esters conclude this investigation.

1 INTRODUCTION

In the last 10 years the interest of the power transmission and distribution industry has grown for the usage of natural ester liquids because of their better biodegradability and high flash point. This advantage is accompanied by some other properties significantly different from these of mineral oil. Natural esters possess intrinsically a higher viscosity and density values which may require a redesign of the transformer cooling.

A new natural-like ester fluid with properties very similar to mineral oil-based transformer liquids has been developed by a French utility. A compatibility investigation with transformer materials, as well as some ageing studies concerning gassing and oxidation stability.have been carried out.

2 CHARACTERISTICS OF THE NEW NATURAL ESTER BASED FLUID

The fluid is a mixture of oleic rapeseed oil and ethyl-hexanolic ester (1:1) plus 0,3% inhibitor di-t-butyl-p-cresol (DBPC). The ethyl-hexanolic ester is produced by the transesterification of the triglycerides of the rapeseed oil with 2-ethyl-1-hexanol. That means that the fatty acid profile of the ester is the same as the original rapeseed oil one. The new ester fluid has a lower viscosity at 40℃ in comparison to others natural esters and this is an advantage concerning the cooling behaviour in the transformer. On the other hand this ester has a much lower flash point (Table 1) than other natural and synthetic esters. Its density is comparable to that of mineral oils. Noticeable is the higher neutralisation value of the new natural ester in the delivery state.

Table 1: Typical properties of the new ester fluid in comparison to synthetic ester and mineral oil at delivery state.

Property	Standard	new natural ester	synthetic ester	mineral oil
Density at 20℃ [KgL^{-1}]	ISO 3675	0.890	0.970	<0.895
Kinemtatic viscosity at 0℃ [mm^2S^{-1}]	ISO 3104	84	-	≈80
Kinemtatic viscosity at 40℃ [mm^2S^{-1}]	ISO 3104	17	28	<12
Kinemtatic viscosity at 100℃ [mm^2S^{-1}]	ISO 3104	4.6	-	≈3
Neutralisation value [mg KOH/g oil]	IEC 62021-1	0.28	<0.03	<0.01
Water content [mg H_2O/kg oil]	IEC 60814	200	50	<40
Breakdown Voltage [kV]	IEC 60156	50	>75	>30
Dissipation factor ($\tan\delta$) at 90℃ [-]	IEC 60247	<0.04	<0.03	<0.005
Flash point [℃]	ISO 2719	175	275	>135
Pour point [℃]	ISO 3016	-28	-60	<-40
Biodegradability	-	readily	readily	slow

3 OXIDATION STABILITY

Between all different insulating liquids for transformers, natural esters such as vegetable oils are the most susceptible to oxidation because of their chemical structure. Natural esters contain C=C double bonds in the fatty acid chains. These double bonds are the main sites for attack by oxygen. The more carbon-carbon double bonds exist in the molecules, the highest is their oxidation susceptibility. That means in terms of oxidation stability, that not all natural esters are the same. A higher grade of saturation of the molecules corresponds to a higher oxidation stability. But on the other side such high saturated natural esters have high pour points and viscosity.. Nevertheless, numerous trial tests have shown that the oxidation stability of natural ester formulations is adequate for use in transformers. The here investigated new natural ester fluid has been examined concerning its oxidation stability by using the Siemens aging procedure. For the Siemens Aging Procedure 37,5 ml air saturated insulating fluid is poured in a 50 ml vial. This guarantees a 3:1ratio of fluid to air. A polished copper strip (surface, approx. 11 cm^2) is put in a vial closed with a silicone cap. The ageing takes place at 150℃ in a oven for 164h, guaranteeing a temperature tolerance of ±2℃. The same aging test has been performed for comparison with a natural and a synthetic ester already in use in transformers. The results are given in Table 2.

Table 2: Results of the Siemens aging procedure in comparison to another natural and synthetic ester.

Property	Standard	Measured value new natural Ester	Measured value natural Ester	Measured value synthetic Ester
Diel. loss factor at 20 ℃ [-]	IEC 60247	0,008	0,004	0,014
Diel. loss factor at 90 ℃ [-]	IEC 60247	0,098	0,062	0,405
Neutralisation value [mg KOH/g oil]	IEC 62021-1	0,40	0,06	0,04

From the results it can be seen, that the loss factor of the new natural ester after this type of ageing is less than e.g. for synthetic ester. As it has been proven in further studies the high neutralisation value does not have a deteriorating effect on the solid insulation. This is a major difference to mineral oils.

Further useful characteristics for the evaluation of the susceptibility of natural esters to oxidation are:

-Iodine value (IV) which is one of the oldest and most common methods to determine the magnitude of unsaturation in animal and vegetable oils and fats, or in fatty esters.

-Peroxide Value: it tends to increase and then decrease upon further oxidation due to formation of secondary oxidation products.

-Viscosity: which in natural esters increases as oxidation progresses. In this respect there is a major difference to mineral oils.

4 GASSING BEHAVIOUR

The new natural ester shows like most vegetable insulating fluids a stray gassing behaviour which is connected with the oxidation stability of the fluid and is influenced by temperature. Transformer materials like copper have an influence on the gassing. This is probably connected to the formation and destruction of peroxides.

Hydrolysis and oxidation reactions on natural esters can have a high impact in the development of carbon oxides. Carbon monoxide is produced by both mineral oils and natural esters mainly through thermal degradation of the insulating liquid itself. Its concentration is strongly dependent on the fluid temperature. In mineral oil insulated transformers carbon dioxide derives mainly from the cellulose insulation. On the other side, natural ester liquids show a carbon dioxide formation through thermal endurance which derives from the insulating liquid itself (Figure 1 and 2).

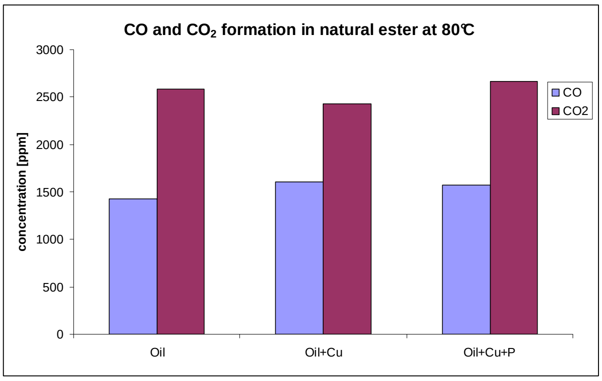

Figure 1: CO and CO_2 development of the natural ester at 80℃ with and without presence of copper (Cu) and Kraft paper (P).

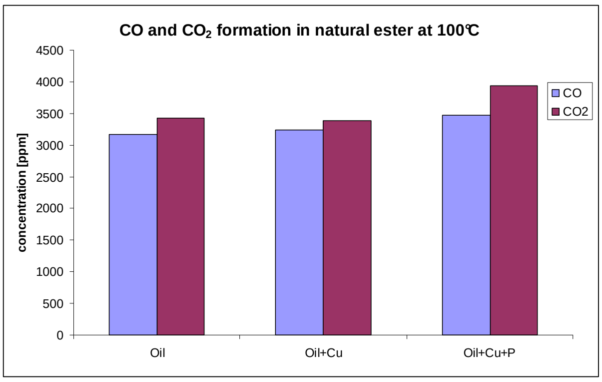

Figure 2: CO and CO_2 development of the natural ester at 100℃ with and without presence of copper (Cu) and Kraft paper (P).

The new natural ester develops in comparison to mineral oil high ethane concentrations. The presence of copper has an inhibitory effect in the formation of ethane, probably because of the interruption of chemical reactions that produce peroxides. Ethane is more likely a product of the oxidation of unsaturated fatty acids and is close related to the oxidation stability of the insulating liquid. Thus ethane can be regarded as a key-gas by the evaluation of the Dissolved-Gas-Analysis of natural ester liquids (Fig. 3).

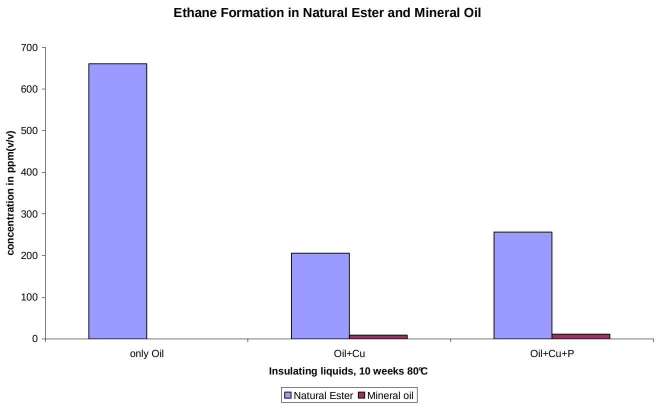

Figure 3: Formation of ethane in natural ester and mineral oil at 80℃ with and without presence of copper (Cu) and Kraft paper (P).

5 COMPATIBILITY WITH TRANSFOMER MATERIALS

New insulating liquids must be investigated, prior their usage in oil filled transformers, concerning their compatibility with other materials which are applied inside the transformer. A compatibility test of the new ester fluid with the following transformer materials has been performed:

-2K epoxide varnish (the gassing behaviour (DGA) as well as the oil properties after storage have been tested and evaluated). The natural ester is compatible with the varnish and suitable for safe operations with this coating.

-Polyamide-imides enameled wires (the thickness of the enamel, the general finish and the breakdown voltage after storage in the ester fluid have been tested and evaluated). The enamelled wires, show after ageing in natural ester acceptable breakdown voltage values.

-NBR and FKM elastomers. properties, like hardness and compression after storage in the ester fluid have been tested and evaluated. Further more the influence of the elastomers on the fluid has also been examined by testing the oil properties prior and after storage.

The test results point out that the usage of NBR gaskets with this natural ester is not possible. A contrario, theFKM elastomer shows after storage in the insulating liquid no influence on its properties and could be applied as a gasket in natural ester immersed transformers. Furthermore there is no change in the FKM characteristics, like hardness and compression, that means that the function as a gasket is also guaranteed in this liquid.

Further materials that are used in transformers like cellulose insulating materials, grain oriented steel, cable clips made of polyamide and polyester tapes have been tested for their compatibility with the natural ester fluid and compared with the values after storage in mineral oil:

The mechanical values after aging of the cellulose insulation materials in the new natural ester are comparable with the values after ageing in mineral oil.

The investigated natural ester has no influence on the insulation coating of grain oriented steel either.

Not all polyamide and polyester materials are compatible with the tested natural ester, therefore they must be selected carefully.

An important value by the construction of transformers is the impregnation of the cellulose insulation. As the viscosity of the natural ester fluid differs from these of other insulating liquids an investigation of its impregnation behaviour was necessary. The impregnation of three different insulating materials, pressboard, laminated board and laminated wood has been tested in comparison to the impregnation with a synthetic ester. The tests have been performed according IEC60641 for pressboard, IEC6073 for laminated wood. The results are given in Table 3.

Table 3: Oil Absorption [%] of different solid insulation materials in natural and synthetic ester.

Solid insulation material	new natural ester	synthetic ester
Pressboard	5,3 %	4,9 %
Laminated board	14,2 %	14,7 %
Laminated Wood	5,4 %	7,3 %

The oil absorption of the natural ester is slightly better to this of the synthetic ester which is already used in transformers.

6 SUMMARY AND OUTLOOK

The growing environmental awareness demands readily biodegradable insulating liquids with a low contamination risk of the ground water. Security concerning the flammability and smoke emission is very important in oil-filled transformers in urban location or in traction application. The investigated new natural ester fluid contains an oxidation inhibitor which guarantees an adequate oxidation stability in applications with restricted oxygen access (hermetically sealed or rubber bag). Like most vegetable insulating oils, the tested natural ester shows a stray gassing behaviour which is connected with the oxidation stability of the fluid. Transformer materials like copper have an influence on the gassing. Most of the studied transformer materials are compatible with the new natural ester, e.g. 2K epoxy varnish, polyamide-imides enamel, cellulose insulating materials. Attention must be paid to material of the gaskets, as well as to some auxiliary materials like fasteners.

After consideration of the material properties the here tested natural ester can be used as an insulating fluid for transformers.

7 REFERENCES

[1] Working Group A2.35: “Experiences in Service with New Insulating Liquids”, CIGRE, Oct. 2010